Common Language Infrastructure (CLI)
Partitions I to IV

Partition I:  Concepts and Architecture
Partition II:  Metadata Definition and Semantics
Partition III: CIL Instruction Set
Partition IV:  Profiles and Libraries
Common Language Infrastructure (CLI)
Partition I:
Concepts and Architecture
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1 Scope

This ECMA Standard defines the Common Language Infrastructure (CLI) in which applications written in
multiple high level languages may be executed in different system environments without the need to rewrite the
application to take into consideration the unique characteristics of those environments. This ECMA Standard
consists of several sections in order to facilitate understanding various components by describing those
components in their separate sections. These sections are:

Partition I: Architecture
Partition II: Metadata Definition and Semantics
Partition III: CIL Instruction Set
Partition IV: Profiles and Libraries
Partition V: Annexes
Conformance

A system claiming conformance to this ECMA Standard shall implement all the mandatory requirements of this standard, and shall specify the profile (see Partition IV) that it implements. The minimal implementation is the Kernel Profile (see Partition IV). A conforming implementation may also include additional functionality that does not prevent running code written to rely solely on the profile as specified in this standard. For example, it may provide additional classes, new methods on existing classes, or a new interface on a standardized class, but it shall not add methods or properties to interfaces specified in this standard.

A compiler that generates Common Intermediate Language (CIL, see Partition III) and claims conformance to this ECMA Standard shall produce output files in the format specified in this standard and the CIL it generates shall be valid CIL as specified in this standard. Such a compiler may also claim that it generates verifiable code, in which case the CIL it generates shall be verifiable as specified in this standard.
3 References


ISO/IEC 10646 (all parts), Information technology — Universal Multiple-Octet Coded Character Set (UCS).


ISO/IEC 646:1991 Information technology -- ISO 7-bit coded character set for information interchange


**4 Glossary**

For the purpose of this ECMA Standard, the following definitions apply. They are collected here for ease of reference, but the definition is presented in context elsewhere in the specification, as noted. Definitions enclosed in square brackets [ ] were not extracted from the body of the standard.

The remainder of this section and its subsections contain only informative text

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<th>Term</th>
<th>Description</th>
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<td>Abstract</td>
<td>Only an abstract object type is allowed to define method contracts for which the type or the VES does not also provide the implementation. Such method contracts are called abstract methods</td>
</tr>
<tr>
<td>Accessibility of members</td>
<td>A type scopes all of its members, and it also specifies the accessibility rules for its members. Except where noted, accessibility is decided based only on the statically visible type of the member being referenced and the type and assembly that is making the reference. The CTS supports seven different rules for accessibility: Compiler-Controlled; Private; Family; Assembly; Family-and-Assembly; Family-or-Assembly; Public.</td>
</tr>
<tr>
<td>Aggregate data</td>
<td>Data items that have sub-components (arrays, structures, or object instances) but are passed by copying the value. The sub-components can include references to managed memory. Aggregate data is represented using a value type…</td>
</tr>
<tr>
<td>Application domain</td>
<td>A mechanism … to isolate applications running in the same operating system process from one another.</td>
</tr>
<tr>
<td>Array elements</td>
<td>The representation of a value (except for those of built-in types) can be subdivided into sub-values. These sub-values are either named, in which case they are called fields, or they are accessed by an indexing expression, in which case they are called array elements.</td>
</tr>
<tr>
<td>Argument</td>
<td>[Value of an operand to a method call]</td>
</tr>
<tr>
<td>Array types</td>
<td>Types that describe values composed of array elements are array types.</td>
</tr>
<tr>
<td>Assembly</td>
<td>An assembly is a configured set of loadable code modules and other resources that together implement a unit of functionality.</td>
</tr>
<tr>
<td>Assembly scope</td>
<td>Type names are scoped by the assembly that contains the implementation of the type…. The type name is said to be in the assembly scope of the assembly that implements the type.</td>
</tr>
<tr>
<td>Assignment compatibility</td>
<td>Assignment compatibility of a value (described by a type signature) to a location (described by a location signature) is defined as follows: One of the types supported by the exact type of the value is the same as the type in the location signature.</td>
</tr>
<tr>
<td>Attributes</td>
<td>Attributes of types and their members attach descriptive information to their definition.</td>
</tr>
<tr>
<td><strong>Base Class Library</strong></td>
<td>This Library is part of the Kernel Profile. It is a simple runtime library for a modern programming language.</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
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<tr>
<td><strong>Binary operators</strong></td>
<td>Binary operators take two arguments, perform some operation and return a value. They are represented as static methods on the class that defines the type of one of their two operands or the return type.</td>
</tr>
<tr>
<td><strong>Boolean Data Type</strong></td>
<td>A CLI Boolean type occupies one byte in memory. A bit pattern of all zeroes denotes a value of false. A bit pattern with any bit set (analogous to a non-zero integer) denotes a value of true.</td>
</tr>
<tr>
<td><strong>Box</strong></td>
<td>The <strong>box</strong> instruction is a widening (always typesafe) operation that converts a value type instance to <strong>System.Object</strong> by making a copy of the instance and embedding it in a newly allocated object.</td>
</tr>
<tr>
<td><strong>Boxed type</strong></td>
<td>For every Value Type, the CTS defines a corresponding Reference Type called the <strong>boxed type</strong>.</td>
</tr>
<tr>
<td><strong>Boxed value</strong></td>
<td>The representation of a value of a boxed type (a <strong>boxed value</strong>) is a location where a value of the Value Type may be stored.</td>
</tr>
<tr>
<td><strong>Built-in types</strong></td>
<td>..Data types [that] are an integral part of the CTS and are supported directly by the Virtual Execution System (VES).</td>
</tr>
<tr>
<td><strong>By-ref parameters</strong></td>
<td>The <strong>address</strong> of the data is passed from the caller to the callee, and the type of the parameter is therefore a managed or unmanaged pointer.</td>
</tr>
<tr>
<td><strong>By-value parameters</strong></td>
<td>The <strong>value</strong> of an object is passed from the caller to the callee</td>
</tr>
<tr>
<td><strong>Calling Convention</strong></td>
<td>A calling convention specifies how a method expects its arguments to be passed from the caller to the called method.</td>
</tr>
<tr>
<td><strong>Casting</strong></td>
<td>Since a value can be of more than one type, a use of the value needs to clearly identify which of its types is being used. Since values are read from locations that are typed, the type of the value which is used is the type of the location from which the value was read. If a different type is to be used, the value is <strong>cast</strong> to one of its other types.</td>
</tr>
<tr>
<td><strong>CIL</strong></td>
<td>[Common Intermediate Language]</td>
</tr>
<tr>
<td><strong>Class contract</strong></td>
<td>A class contract specifies the representation of the values of the class type. Additionally, a class contract specifies the other contracts that the class type supports, e.g., which interfaces, methods, properties and events shall be implemented.</td>
</tr>
<tr>
<td><strong>Class type</strong></td>
<td>A complete specification of the representation of the values of the class type and all of the contracts (class, interface, method, property, and event) that are</td>
</tr>
</tbody>
</table>
interface, method, property, and event) that are supported by the class type.

<table>
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<th>CLI</th>
<th>At the center of the Common Language Infrastructure (CLI) is a single type system, the Common Type System (CTS), that is shared by compilers, tools, and the CLI itself. It is the model that defines the rules the CLI follows when declaring, using, and managing types.</th>
<th>I 5</th>
<th>Overview of the Common Language Infrastructure</th>
</tr>
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<tr>
<td>CLS (consumer)</td>
<td>The Common Language Specification (CLS) is a set of conventions intended to promote language interoperability.</td>
<td>I 6</td>
<td>Common Language Specification (CLS)</td>
</tr>
<tr>
<td>CLS (extender)</td>
<td>A CLS extender is a language or tool that is designed to allow access to all of the features supplied by CLS-compliant frameworks (libraries), but not necessarily be able to produce them.</td>
<td>I 6</td>
<td>Common Language Specification (CLS)</td>
</tr>
<tr>
<td>CLS (framework)</td>
<td>A library consisting of CLS-compliant code is herein referred to as a “framework”.</td>
<td>I 6</td>
<td>Common Language Specification (CLS)</td>
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<tr>
<td>Code labels</td>
<td>Code labels are followed by a colon (&quot;&quot;:&quot;&quot;) and represent the address of an instruction to be executed</td>
<td>II 5.4</td>
<td>Labels and Lists of Labels</td>
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<td>Coercion</td>
<td>Coercion takes a value of a particular type and a desired type and attempts to create a value of the desired type that has equivalent meaning to the original value.</td>
<td>I 7.3.2</td>
<td>Coercion</td>
</tr>
<tr>
<td>Common Type System (CTS)</td>
<td>[I] The Common Type System (CTS) provides a rich type system that supports the types and operations found in many programming languages.</td>
<td>I 5</td>
<td>Overview of the Common Language Infrastructure</td>
</tr>
<tr>
<td>Compiler-controlled accessibility</td>
<td>Accessible only through use of a definition, not a reference, hence only accessible from within a single compilation unit and under the control of the compiler.</td>
<td>I 7.5.3.2</td>
<td>Accessibility of Members</td>
</tr>
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<td>Compound types</td>
<td>Types that describe values composed of fields are compound types.</td>
<td>I 7.4.1</td>
<td>Fields, Array Elements, and Values</td>
</tr>
<tr>
<td>Computed destinations</td>
<td>The destination of a method call may be either encoded directly in the CIL instruction stream (the call and jmp instructions) or computed (the callvirt, and calli instructions).</td>
<td>I 11.4.1.3</td>
<td>Computed Destinations</td>
</tr>
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<td>Concrete</td>
<td>An object type that is not marked abstract is by definition concrete.</td>
<td>I 7.9.6.2</td>
<td>Concreteness</td>
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<tr>
<td>Conformance</td>
<td>A system claiming conformance to this ECMA Standard shall implement all the mandatory requirements of this Standard.</td>
<td>I 2</td>
<td>Conformance</td>
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<td><strong>Contracts</strong></td>
<td>Contracts are named. They are the shared assumptions on a set of signatures … between all implementers and all users of the contract.</td>
<td>I 7.6</td>
<td>Contracts</td>
</tr>
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<td><strong>Conversion operators</strong></td>
<td>Conversion operators are unary operations that allow conversion from one type to another. The operator method shall be defined as a static method on either the operand or return type.</td>
<td>I 9.3.3</td>
<td>Conversion Operators</td>
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<td><strong>Custom Attributes</strong></td>
<td>Custom attributes add user-defined annotations to the metadata. Custom attributes allow an instance of a type to be stored with any element of the metadata.</td>
<td>II 20</td>
<td>Custom Attributes</td>
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<td><strong>Custom modifiers</strong></td>
<td>Custom modifiers, defined using modreq (“required modifier”) and modopt (“optional modifier”), are similar to custom attributes …except that modifiers are part of a signature rather than attached to a declaration. Each modifier associates a type reference with an item in the signature.</td>
<td>II 7.1.1</td>
<td>modreq and modopt</td>
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<tr>
<td><strong>Data labels</strong></td>
<td>Data labels specify the location of a piece of data</td>
<td>II 5.4</td>
<td>Labels and Lists of Labels</td>
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<td><strong>Delegates</strong></td>
<td>Delegates are the object-oriented equivalent of function pointers. Delegates are created by defining a class that derives from the base type System.Delegate</td>
<td>I 7.9.3</td>
<td>Delegates</td>
</tr>
<tr>
<td><strong>Derived Type</strong></td>
<td>A derived type guarantees support for all of the type contracts of its base type. A type derives directly from its specified base type(s), and indirectly from their base type(s).</td>
<td>I 7.9.8</td>
<td>Type Inheritance</td>
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<tr>
<td><strong>Enums</strong></td>
<td>An enum, short for enumeration, defines a set of symbols that all have the same type.</td>
<td>II 13.3</td>
<td>Enums</td>
</tr>
</tbody>
</table>
| **Equality** | For value types, the equality operator is part of the definition of the exact type. Definitions of equality should obey the following rules:  
  • Equality should be an equivalence operator, as defined above.  
  • Identity should imply equality, as stated earlier.  
  • If either (or both) operand is a boxed value, equality should be computed by first unboxing any boxed operand(s), and then applying the usual rules for equality on the resulting values. | I 7.2.5.2 | Equality |
<p>| <strong>Equality of values</strong> | The values stored in the variables are equal if the sequences of characters are the same. | I 7.2.5 | Identity and Equality of Values |
| <strong>Evaluation stack</strong> | Associated with each method state is an evaluation stack… The evaluation stack is made up of slots that can hold any data type, including an unboxed instance of a | I 11.3.2.1 | The Evaluation Stack |
| Event contract | An event contract is specified with an event definition. There is an extensible set of operations for managing a named event, which includes three standard methods (register interest in an event, revoke interest in an event, fire the event). An event contract specifies method contracts for all of the operations that shall be implemented by any type that supports the event contract. | I 7.6 | Contracts |
| Event definitions | The CTS supports events in precisely the same way that it supports properties… The conventional methods, however, are different and include means for subscribing and unsubscribing to events as well as for firing the event. | I 7.11.4 | Event Definitions |
| Exception handling | Exception handling is supported in the CLI through exception objects and protected blocks of code | I 11.4.2 | Exception Handling |
| Extended Array Library | This Library is not part of any Profile, but can be supplied as part of any CLI implementation. It provides support for non-vector arrays. | IV 5.7 | Extended Array Library |
| Extended Numerics Library | The Extended Numerics Library is not part of any Profile, but can be supplied as part of any CLI implementation. It provides the support for floating-point (System.Float, System.Double) and extended-precision (System.Decimal) data types. | IV 5.6 | Extended Numerics Library |
| Family accessibility | Accessible to referents that support the same type, i.e. an exact type and all of the types that inherit from it | I 7.5.3.2 | Accessibility of Members |
| Family-and-assembly accessibility | Accessible only to referents that qualify for both Family and Assembly access. | I 7.5.3.2 | Accessibility of Members |
| Family-or-assembly accessibility | Accessible only to referents that qualify for either Family or Assembly access. | I 7.5.3.2 | Accessibility of Members |
| Field definitions | Field definitions name and a location signature. | I 7.11.2 | Field Definitions |
| Field inheritance | A derived object type inherits all of the non-static fields of its base object type. | I 7.10.1 | Field Inheritance |
| Fields | Fields are typed memory locations that store the data of a program. | II 15 | Defining and Referencing Fields |
| File Names | A file name is like any other name where ‘.’ is considered a normal constituent character. The specific syntax for file names follows the specifications of the underlying operating system | II 5.8 | File Names |
| Finalizers | A class definition that creates an object type may supply an instance method to be called when an instance of the class is no longer accessible. | I 7.9.6.7 | Finalizers |
| Getter method | By convention, properties define a getter method (for accessing the current value of the property)… | I 7.11.3 | Property Definitions |
| <strong>Global Fields</strong> | In addition to types with static members, many languages have the notion of data and methods that are not part of a type at all. These are referred to as <em>global</em> fields and methods. | II 9.8 | Global Fields and Methods |
| <strong>Global Methods</strong> | In addition to types with static members, many languages have the notion of data and methods that are not part of a type at all. These are referred to as <em>global</em> fields and methods. | II 9.8 | Global Fields and Methods |
| <strong>Global state</strong> | The CLI manages multiple concurrent threads of control … multiple managed heaps, and a shared memory address space. | I 11.3.1 | The Global State |
| <strong>GUID</strong> | [A unique identification string used with remote procedure calls.] | | |
| <strong>hide-by-name</strong> | The introduction of a name in a given type hides all inherited members of the same kind (method or field) with the same name. | II 8.3 | Hiding |
| <strong>hide-by-name-and-sig</strong> | The introduction of a name in a given type hides any inherited member of the same kind but with precisely the same type (for fields) or signature (for methods, properties, and events). | II 8.3 | Hiding |
| <strong>Hiding</strong> | Hiding controls which method names inherited from a base type are available for compile-time name binding. | II 8 | Visibility, Accessibility and Hiding |
| <strong>Homes</strong> | The <em>home</em> of a data value is where it is stored for possible reuse | I 11.1.6.1 | Homes for Values |
| <strong>Identifiers</strong> | Identifiers are used to name entities | II 5.3 | Identifiers |
| <strong>Identity</strong> | The identity operator is defined by the CTS as follows. | I 7.2.5.1 | Identity |
| | • If the values have different exact types, then they are not identical. | | |
| | • Otherwise, if their exact type is a Value Type, then they are identical if and only if the bit sequences of the values are the same, bit by bit. | | |
| | Otherwise, if their exact type is a Reference Type, then they are identical if and only if the locations of the values are the same. | | |
| <strong>Identity of values</strong> | The values of the variables are <em>identical</em> if the locations of the sequences of characters are the same, i.e., there is in fact only one string in memory. | I 7.2.5 | Identity and Equality of Values |
| <strong>Ilasm</strong> | An assembler language for CIL | II 2 | Overview |
| <strong>Inheritance demand</strong> | When attached to a type ..[an inheritance demand] requires that any type that wishes to inherit from this type shall have the specified security permission. When attached to a non-final virtual method it requires that any type that wishes to override this method shall have the specified permission. | I 7.5.3.3 | Security Permissions |
| <strong>Instance Methods</strong> | Instance methods are associated with an instance of a type: within the body of an instance method it is possible | II 14.2 | Static, Instance, and Virtual |</p>
<table>
<thead>
<tr>
<th><strong>Methods</strong></th>
<th><strong>Instruction pointer (IP)</strong></th>
<th>An instruction pointer (IP) points to the next CIL instruction to be executed by the CLI in the present method.</th>
<th>I 11.3.2 Methods</th>
<th><strong>Instruction pointer (IP)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interface contract</strong></td>
<td>An interface definition specifies which other contracts the interface supports, e.g. which interfaces, methods, properties and events shall be implemented.</td>
<td>I 7.6 Contracts</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Interface type definition</strong></td>
<td><strong>Interface contract</strong></td>
<td>An interface type defines an interface type. An interface type is a named group of methods, locations and other contracts that shall be implemented by any object type that supports the interface contract of the same name.</td>
<td>I 7.9.4 Interface Type Definition</td>
<td></td>
</tr>
<tr>
<td><strong>Interface type inheritance</strong></td>
<td>Interface types may inherit from multiple interface types, i.e. an interface contract may list other interface contracts that shall also be supported.</td>
<td>I 7.9.11 Interface Type Inheritance</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Interface types</strong></td>
<td><strong>Interface contract</strong></td>
<td>Interface types describe a subset of the operations and none of the representation, and hence, cannot be an exact type of any value.</td>
<td>I 7.2.3 Classes, Interfaces and Objects</td>
<td></td>
</tr>
<tr>
<td><strong>Interfaces</strong></td>
<td>Interfaces...define a contract that other types may implement.</td>
<td>II 11 Semantics of Interfaces</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Kernel Profile</strong></td>
<td>This profile is the minimal possible conforming implementation of the CLI.</td>
<td>IV 3.1 The Kernel Profile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Labels</strong></td>
<td>Provided as a programming convenience: they represent a number that is encoded in the metadata. The value represented by a label is typically an offset in bytes from the beginning of the current method, although the precise encoding differs depending on where in the logical metadata structure or CIL stream the label occurs.</td>
<td>II 5.4 Labels and Lists of Labels</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Libraries</strong></td>
<td>To a programmer a Library is a self-consistent set of types (classes, interfaces, and value types) that provide a useful set of functionality.</td>
<td>IV 2.1 Libraries</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Local memory pool</strong></td>
<td>The local memory pool is used to allocate objects whose type or size is not known at compile time and which the programmer does not wish to allocate in the managed heap.</td>
<td>I 11.3.2.4 Local Memory Pool</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Local signatures</strong></td>
<td>A local signature specifies the contract on a local variable allocated during the running of a method.</td>
<td>I 7.6.1.3 Local Signatures</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Location signatures</strong></td>
<td>All locations are typed. This means that all locations have a location signature, which defines constraints on the location, its usage, and on the usage of the values stored in the location.</td>
<td>I 7.6.1.2 Location Signatures</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Locations</strong></td>
<td>Values are stored in locations. A location can hold a single value at a time. All locations are typed. The type of the location embodies the requirements that shall be met by values that are stored in the location.</td>
<td>I 7.3 Locations</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Machine state</strong></td>
<td>One of the design goals of the CLI is to hide the details of a method call frame from the CIL code generator. The machine state definitions...reflect these design goals.</td>
<td>I 11.3 Machine State</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The machine state definitions … reflect these design choices, where machine state consists primarily of global state and method state.

<table>
<thead>
<tr>
<th>Managed code</th>
<th>Managed code is simply code that provides enough information to allow the CLI to provide a set of core services, including</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Given an address inside the code for a method, locate the metadata describing the method</td>
</tr>
<tr>
<td></td>
<td>• Walk the stack</td>
</tr>
<tr>
<td></td>
<td>• Handle exceptions</td>
</tr>
<tr>
<td></td>
<td>• Store and retrieve security information</td>
</tr>
</tbody>
</table>

| Managed data | Managed data is data that is allocated and released automatically by the CLI, through a process called garbage collection. Only managed code can access managed data, but programs that are written in managed code can access both managed and unmanaged data. |

<table>
<thead>
<tr>
<th>Managed pointers</th>
<th>[ The O and &amp;] datatype represents an object reference that is managed by the CLI</th>
</tr>
</thead>
</table>

| Managed Pointers | Managed pointers (&) may point to a field of an object, a field of a value type, an element of an array, or the address where an element just past the end of an array would be stored (for pointer indexes into managed arrays). |

| Manifest | An assembly is a set of one or more files deployed as a unit. |

| Marshalling Descriptors | A Marshalling Descriptor is like a signature – it’s a blob of binary data. It describes how a field or parameter (which, as usual, covers the method return, as parameter number 0) should be marshalled when calling to or from unmanaged coded via PInvoke dispatch or IJW (“It Just Works”) thunking. |

| Member | Fields, array elements, and methods are called members of the type. Properties and events are also members of the type. |

| Member inheritance | Only object types may inherit implementations, hence only object types may inherit members |

| Memory store | By “memory store” we mean the regular process memory that the CLI operates within. Conceptually, this store is simply an array of bytes. |

| Metadata | The CLI uses metadata to describe and reference the types defined by the Common Type System. Metadata is stored (“persisted”) in a way that is independent of any particular programming language. Thus, metadata provides a common interchange mechanism for use |
| Metadata Token | This is a 4-byte value, that specifies a row in a metadata table, or a starting byte offset in the User String heap | III 1.9 | Metadata Tokens |
| Method contract | A method contract is specified with a method definition. A method contract is a named operation that specifies the contract between the implementation(s) of the method and the callers of the method. | I 7.6 | Contracts |
| Method contract | A named method describes an operation that may be performed on values of an exact type. | I 7.2.3 | Classes, Interfaces and Objects |
| Method contract | A method contract is specified with a method definition. A method contract is a named operation that specifies the contract between the implementation(s) of the method and the callers of the method. | I 7.6 | Contracts |
| Method definitions | Method definitions are composed of a name, a method signature, and optionally an implementation of the method. | I 7.11.1 | Method Definitions |
| Method inheritance | A derived object type inherits all of the instance and virtual methods of its base object type. It does not inherit constructors or static methods. | I 7.10.2 | Method Inheritance |
| Method Pointers | Variables of type method pointer shall store the address of the entry point to a method with compatible signature. | II 13.5 | Method Pointers |
| Method signatures | Method signatures are composed of  
- a calling convention,  
- a list of zero or more parameter signatures, one for each parameter of the method,  
- and a type signature for the result value if one is produced. | I 7.6.1.5 | Method Signatures |
| Method state | Method state describes the environment within which a method executes. (In conventional compiler terminology, it corresponds to a superset of the information captured in the “invocation stack frame”). | I 11.3.2 | Method State |
| methodInfo handle | This .. holds the signature of the method, the types of its local variables, and data about its exception handlers. | I 11.3.2 | Method State |
| Module | A single file containing executable content | II 6 | Assemblies, Manifests and Modules |
| Name Mangling | … the platform may use name-mangling rules that force the name as it appears to a managed program to differ from the name as seen in the native implementation (this is common, for example, when the native code is generated by a C++ compiler). | II 14.5.2 | Platform Invoke |
| Native Data Types | Some implementations of the CLI will be hosted on top of existing operating systems or runtime platforms that specify data types required to perform certain functions. The metadata allows interaction with these native data types by specifying how the built-in and user-defined types of the CLI are to be marshalled to and from native | II 7.4 | Native Data Types |
### Native size types
The native-size, or generic, types (I, U, O, and &) are a mechanism in the CLI for deferring the choice of a value’s size.

<table>
<thead>
<tr>
<th>Nested type definitions</th>
<th>A nested type definition is identical to a top-level type definition, with one exception: a top-level type has a visibility attribute, while the visibility of a nested type is the same as the visibility of the enclosing type.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nested types</td>
<td>A type (called a nested type) can be a member of an enclosing type.</td>
</tr>
<tr>
<td>Network Library</td>
<td>This Library is part of the Compact Profile. It provides simple networking services including direct access to network ports as well as HTTP support.</td>
</tr>
</tbody>
</table>

#### OOP
[Object Oriented Programming]

#### Object type
The object type describes the physical structure of the instance and the operations that are allowed on it.

#### Object type inheritance
With the sole exception of `System.Object`, which does not inherit from any other object type, all object types shall either explicitly or implicitly declare support for (inherit from) exactly one other object type.

#### Objects
Each object is self-typing, that is, its type is explicitly stored in its representation. It has an identity that distinguishes it from all other objects, and it has slots that store other entities (which may be either objects or values). While the contents of its slots may be changed, the identity of an object never changes.

#### Opaque classes
Some languages provide multi-byte data structures whose contents are manipulated directly by address arithmetic and indirection operations. To support this feature, the CLI allows value types to be created with a specified size but no information about their data members.

#### Overloading
Within a single scope, a given name may refer to any number of methods provided they differ in any of the following: Number of parameters [and] Type of each argument

#### Overriding
Overriding deals with object layout and is applicable only to instance fields and virtual methods. The CTS provides two forms of member overriding, new slot and expect existing slot.

#### Parameter
[Name used within the body of a method to refer to the corresponding argument of the method]

#### Parameter passing
The CLI supports three kinds of parameter passing, all indicated in metadata as part of the signature of the method. Each parameter to a method has its own passing convention (e.g., the first parameter may be passed by-value while all others are passed by-ref).
<table>
<thead>
<tr>
<th>Parameter Signatures</th>
<th><strong>Parameter signatures</strong> define constraints on how an individual value is passed as part of a method invocation.</th>
<th>I</th>
<th>7.6.1.4</th>
<th>Parameter Signatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinned</td>
<td>While a method with a pinned local variable is executing the VES shall not relocate the object to which the local refers.</td>
<td>II</td>
<td>7.1.2</td>
<td>Pinned</td>
</tr>
<tr>
<td>PInvoke</td>
<td>Methods defined in native code may be invoked using the <strong>platform invoke</strong> (also know as PInvoke or p/invoke) functionality of the CLI.</td>
<td>II</td>
<td>14.5.2</td>
<td>Platform Invoke</td>
</tr>
<tr>
<td>Pointer type</td>
<td>A <strong>pointer type</strong> is a compile time description of a value whose representation is a machine address of a location.</td>
<td>I</td>
<td>7.2.1</td>
<td>Value Types and Reference Types</td>
</tr>
<tr>
<td>Pointers</td>
<td>Pointers may contain the address of a field (of an object or value type) or an element of an array.</td>
<td>II</td>
<td>13.4</td>
<td>Pointer Types</td>
</tr>
<tr>
<td>Private accessibility</td>
<td>Accessible only to referents in the implementation of the exact type that defines the member.</td>
<td>I</td>
<td>7.5.3.2</td>
<td>Accessibility of Members</td>
</tr>
<tr>
<td>Profiles</td>
<td>A Profile is simply a set of Libraries, grouped together to form a consistent whole that provides a fixed level of functionality.</td>
<td>IV</td>
<td>2.2</td>
<td>Profiles</td>
</tr>
<tr>
<td>Properties</td>
<td>Properties define named groups of accessor method definitions that implement the named event or property behavior.</td>
<td>I</td>
<td>7.11</td>
<td>Member Definitions</td>
</tr>
<tr>
<td>Property contract</td>
<td>A property contract is specified with a property definition. There is an extensible set of operations for handling a named value, which includes a standard pair for reading the value and changing the value. A property contract specifies method contracts for the subset of these operations that shall be implemented by any type that supports the property contract.</td>
<td>I</td>
<td>7.6</td>
<td>Contracts</td>
</tr>
<tr>
<td>Property definitions</td>
<td>A property definition defines a named value and the methods that access the value. A property definition defines the accessing contracts on that value.</td>
<td>I</td>
<td>7.11.3</td>
<td>Property Definitions</td>
</tr>
<tr>
<td>Public accessibility</td>
<td>Accessible to all referents</td>
<td>I</td>
<td>7.5.3.2</td>
<td>Accessibility of Members</td>
</tr>
<tr>
<td>Qualified name</td>
<td>Consider a compound type <strong>Point</strong> that has a field named <strong>x</strong>. The name “field x” by itself does not uniquely identify the named field, but the <strong>qualified name</strong> “field x in type Point” does.</td>
<td>I</td>
<td>7.5.2</td>
<td>Assemblies and Scoping</td>
</tr>
<tr>
<td>Rank</td>
<td>The <strong>rank</strong> of an array is the number of dimensions.</td>
<td>II</td>
<td>13.2</td>
<td>Arrays</td>
</tr>
<tr>
<td>Reference demand</td>
<td>Any attempt to resolve a reference to the marked item shall have specified security permission.</td>
<td>I</td>
<td>7.5.3.3</td>
<td>Security Permissions</td>
</tr>
<tr>
<td>Reference types</td>
<td>Reference Types describe values that are represented as the location of a sequence of bits. There are three kinds of Reference Types:</td>
<td>I</td>
<td>7.2.1</td>
<td>Value Types and Reference Types</td>
</tr>
<tr>
<td>Reflection Library</td>
<td>This Library is part of the Compact Profile. It provides the ability to examine the structure of types, create instances of types, and invoke methods on types, all</td>
<td>IV</td>
<td>5.4</td>
<td>Reflection Library</td>
</tr>
<tr>
<td><strong>Remoting boundary</strong></td>
<td>A remoting boundary exists if it is not possible to share the identity of an object directly across the boundary. For example, if two objects exist on physically separate machines that do not share a common address space, then a remoting boundary will exist between them.</td>
<td>I</td>
<td>11.5</td>
<td>Proxies and Remoting</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>Return state handle</strong></td>
<td>This handle is used to restore the method state on return from the current method.</td>
<td>I</td>
<td>11.3.2</td>
<td>Method State</td>
</tr>
<tr>
<td><strong>Runtime Infrastructure Library</strong></td>
<td>This Library is part of the Kernel Profile. It provides the services needed by a compiler to target the CLI and the facilities needed to dynamically load types from a stream in the file format.</td>
<td>IV</td>
<td>5.1</td>
<td>Runtime Infrastructure Library</td>
</tr>
<tr>
<td><strong>Scopes</strong></td>
<td>Names are collected into groupings called scopes.</td>
<td>I</td>
<td>7.5.2</td>
<td>Assemblies and Scoping</td>
</tr>
<tr>
<td><strong>Sealed</strong></td>
<td>Specifies that a type shall not have subclasses</td>
<td>II</td>
<td>9.1.4</td>
<td>Inheritance Attributes</td>
</tr>
<tr>
<td><strong>Sealed type</strong></td>
<td>An object type declares it shall not be used as a base type (be inherited from) by declaring that it is a sealed type.</td>
<td>I</td>
<td>7.9.9</td>
<td>Object Type Inheritance</td>
</tr>
<tr>
<td><strong>Security descriptor</strong></td>
<td>This descriptor is not directly accessible to managed code but is used by the CLI security system to record security overrides (assert, permit-only, and deny).</td>
<td>I</td>
<td>11.3.2</td>
<td>Method State</td>
</tr>
<tr>
<td><strong>Security permissions</strong></td>
<td>Access to members is also controlled by security demands that may be attached to an assembly, type, method, property, or event.</td>
<td>I</td>
<td>7.5.3.3</td>
<td>Security Permissions</td>
</tr>
<tr>
<td><strong>Serializable fields</strong></td>
<td>A field that is marked serializable is to be serialized as part of the persistent state of a value of the type.</td>
<td>I</td>
<td>7.11.2</td>
<td>Field Definitions</td>
</tr>
<tr>
<td><strong>Setter method</strong></td>
<td>By convention, properties define …optionally a setter method (for modifying the current value of the property).</td>
<td>I</td>
<td>7.11.3</td>
<td>Property Definitions</td>
</tr>
<tr>
<td><strong>Signatures</strong></td>
<td>Signatures are the part of a contract that can be checked and automatically enforced. Signatures are formed by adding constraints to types and other signatures.</td>
<td>I</td>
<td>7.6.1</td>
<td>Signatures</td>
</tr>
<tr>
<td><strong>Simple labels</strong></td>
<td>A simple label is a special name that represents an address</td>
<td>II</td>
<td>5.4</td>
<td>Labels and Lists of Labels</td>
</tr>
<tr>
<td><strong>Special members</strong></td>
<td>There are three special members, all methods, that can be defined as part of a type: instance constructors, instance finalizers, and type initializers.</td>
<td>II</td>
<td>9.5</td>
<td>Special Members</td>
</tr>
<tr>
<td><strong>Special Types</strong></td>
<td>Special Types are those that are referenced from CIL, but for which no definition is supplied: the VES supplies the definitions automatically based on information available from the reference.</td>
<td>II</td>
<td>13</td>
<td>Semantics of Special Types</td>
</tr>
<tr>
<td><strong>Standard Profiles</strong></td>
<td>There are two Standard Profiles. The smallest conforming implementation of the CLI is the Kernel Profile, while the Compact Profile contains additional features useful for applications targeting a more resource-rich set of devices.</td>
<td>IV</td>
<td>3</td>
<td>The Standard Profiles</td>
</tr>
<tr>
<td>Static fields</td>
<td>Types may declare locations that are associated with the type rather than any particular value of the type. Such locations are <strong>static fields</strong> of the type.</td>
<td>I 7.4.3</td>
<td>Static Fields and Static Methods</td>
<td></td>
</tr>
<tr>
<td>Static methods</td>
<td>…Types may also declare methods that are associated with the type rather than with values of the type. Such methods are <strong>static methods</strong> of the type.</td>
<td>I 7.4.3</td>
<td>Static Fields and Static Methods</td>
<td></td>
</tr>
<tr>
<td>Super Calls</td>
<td>In some cases, it may be desirable to re-use code defined in the base type. E.g., an overriding virtual method may want to call its previous version. This kind of re-use is called a <em>super call</em>, since the overridden method of the base type is called.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This</td>
<td>When they are invoked, instance and virtual methods are passed the value on which this invocation is to operate (known as <strong>this</strong> or a <strong>this pointer</strong>).</td>
<td>I 7.4.2</td>
<td>Methods</td>
<td></td>
</tr>
<tr>
<td>Thunk</td>
<td>A (typically) small piece of code used to provide a transition between two pieces of code where special handling is required</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Try block</td>
<td>In the CLI, a method may define a range of CIL instructions that are said to be <strong>protected</strong>. This is called the <strong>try block</strong>.</td>
<td>II 18</td>
<td>Exception Handling</td>
<td></td>
</tr>
<tr>
<td>Type definers</td>
<td>Type definers construct a new type from existing types.</td>
<td>I 7.9</td>
<td>Type Definers</td>
<td></td>
</tr>
</tbody>
</table>
| Type definition | The **type definition**:
- Defines a name for the type being defined, i.e. the **type name**, and specifies a scope in which that name will be found
- Defines a **member scope** in which the names of the different kinds of members (fields, methods, events, and properties) are bound. The tuple of (member name, member kind, and member signature) is unique within a member scope of a type.
- Implicitly assigns the type to the assembly scope of the assembly that contains the type definition. | I 7.5.2 | Assemblies and Scoping |
<p>| Type inheritance | Inheritance of types is another way of saying that the derived type guarantees support for all of the type contracts of the base type. In addition, the derived type usually provides additional functionality or specialized behavior. | I 7.9.8 | Type Inheritance |
| Type members | Object type definitions include member definitions for all of the members of the type. Briefly, members of a type include fields into which values are stored, methods that may be invoked, properties that are available, and events that may be raised. | I 7.4 | Type Members |
| Type safety | An implementation that lives up to the enforceable part of the contract (the named signatures) is said to be <strong>typesafe</strong>. | I 7.8 | Type Safety and Verification |</p>
<table>
<thead>
<tr>
<th>Topic</th>
<th>Description</th>
<th>Page</th>
<th>Chapter</th>
<th>Section</th>
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<tbody>
<tr>
<td>Type signatures</td>
<td>Type signatures define the constraints on a value and its usage.</td>
<td>I</td>
<td>7.6.1.1</td>
<td>Type Signatures</td>
</tr>
<tr>
<td>Typed reference parameters</td>
<td>A runtime representation of the data type is passed along with the address of the data, and the type of the parameter is therefore one specially supplied for this purpose.</td>
<td>I</td>
<td>11.4.1.5</td>
<td>Parameter Passing</td>
</tr>
<tr>
<td>Types</td>
<td>Types describe values. All places where values are stored, passed, or operated upon have a type, e.g. all variables, parameters, evaluation stack locations, and method results. The type defines the allowable values and the allowable operations supported by the values of the type. All operators and functions have expected types for each of the values accessed or used.</td>
<td>I</td>
<td>7.2</td>
<td>Values and Types</td>
</tr>
<tr>
<td>Unary operators</td>
<td>Unary operators take one argument, perform some operation on it, and return the result. They are represented as static methods on the class that defines the type of their one operand or their return type.</td>
<td>I</td>
<td>9.3.1</td>
<td>Unary Operators</td>
</tr>
<tr>
<td>Unbox</td>
<td>Unbox is a narrowing (runtime exception may be generated) operation that converts a <code>System.Object</code> (whose runtime type is a value type) to a value type instance.</td>
<td>I</td>
<td>11.1.6.2.5</td>
<td>Boxing and Unboxing</td>
</tr>
<tr>
<td>Unmanaged Code</td>
<td>Unmanaged Code</td>
<td>I</td>
<td>7.9.2</td>
<td>Unmanaged Pointer Types</td>
</tr>
<tr>
<td>Unmanaged pointer types</td>
<td>An <strong>unmanaged pointer type</strong> (also known simply as a &quot;pointer type&quot;) is defined by specifying a location signature for the location the pointer references. Any signature of a pointer type includes this location signature.</td>
<td>I</td>
<td>7.9.10</td>
<td>Value Type Inheritance</td>
</tr>
<tr>
<td>Validation</td>
<td>Validation refers to a set of tests that can be performed on any file to check that the file format, metadata, and CIL are self-consistent.</td>
<td>II</td>
<td>3</td>
<td>Validation and Verification</td>
</tr>
<tr>
<td>Value type inheritance</td>
<td>Value Types, in their unboxed form, do not inherit from any type.</td>
<td>I</td>
<td>7.9.10</td>
<td>Value Type inheritance</td>
</tr>
<tr>
<td>Value types</td>
<td>In contrast to classes, value types (see Partition I) are not accessed by using a reference but are stored directly in the location of that type.</td>
<td>II</td>
<td>12</td>
<td>Semantics of Value Types</td>
</tr>
<tr>
<td>Values</td>
<td>The representation of a value (except for those of built-in types) can be subdivided into sub-values. These sub-values are either named, in which case they are called <strong>fields</strong>, or they are accessed by an indexing expression, in which case they are called <strong>array elements</strong>.</td>
<td>I</td>
<td>7.4.1</td>
<td>Fields, Array Elements, and Values</td>
</tr>
<tr>
<td>Vararg Methods</td>
<td>Vararg methods accept a variable number of arguments.</td>
<td>II</td>
<td>14.4.5</td>
<td>Vararg methods</td>
</tr>
<tr>
<td>Variable argument lists</td>
<td>The CLI works in conjunction with the class library to implement methods that accept argument lists of unknown length and type (&quot;varargs methods&quot;).</td>
<td>I</td>
<td>11.3.2.3</td>
<td>Variable Argument Lists</td>
</tr>
<tr>
<td>Topic</td>
<td>Description</td>
<td>Section</td>
<td>Reference</td>
<td>Topic</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------</td>
<td>-----------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Vectors</td>
<td>Vectors are single-dimension arrays with a zero lower bound.</td>
<td>II</td>
<td>13.1</td>
<td>Vectors</td>
</tr>
<tr>
<td>Verifiability</td>
<td>Memory safety is a property that ensures programs running in the same address space are correctly isolated from one another … Thus, it is desirable to test whether programs are memory safe prior to running them. Unfortunately, it is provably impossible to do this with 100% accuracy. Instead, the CLI can test a stronger restriction, called verifiability.</td>
<td>III</td>
<td>1.8</td>
<td>Verifiability</td>
</tr>
<tr>
<td>Verification</td>
<td>Verification refers to a check of both CIL and its related metadata to ensure that the CIL code sequences do not permit any access to memory outside the program’s logical address space.</td>
<td>II</td>
<td>3</td>
<td>Validation and Verification</td>
</tr>
<tr>
<td>Version Number</td>
<td>The version number of the assembly, specified as four 32-bit integers.</td>
<td>II</td>
<td>6.2.1.4</td>
<td>Version Numbers</td>
</tr>
<tr>
<td>Virtual call</td>
<td>A virtual method may be invoked by a special mechanism (a virtual call) that chooses the implementation based on the dynamically detected type of the instance used to make the virtual call rather than the type statically known at compile time.</td>
<td>I</td>
<td>7.4.4</td>
<td>Virtual Methods</td>
</tr>
<tr>
<td>Virtual calling convention</td>
<td>The CIL provides a “virtual calling convention” that is converted by an interpreter or JIT compiler into a native calling convention.</td>
<td>I</td>
<td>11.4.1.4</td>
<td>Virtual Calling Convention</td>
</tr>
<tr>
<td>Virtual execution system</td>
<td>The Virtual Execution System (VES) provides an environment for executing managed code. It provides direct support for a set of built-in data types, defines a hypothetical machine with an associated machine model and state, a set of control flow constructs, and an exception handling model.</td>
<td>I</td>
<td>5</td>
<td>Overview of the Common Language Infrastructure</td>
</tr>
<tr>
<td>Virtual methods</td>
<td>Virtual methods are associated with an instance of a type in much the same way as for instance methods. However, unlike instance methods, it is possible to call a virtual method in such a way that the implementation of the method shall be chosen at runtime by the VES depends upon the type of object used for the this pointer.</td>
<td>II</td>
<td>14.2</td>
<td>Static, Instance, and Virtual Methods</td>
</tr>
<tr>
<td>Visibility</td>
<td>Attached only to top-level types, and there are only two possibilities: visible to types within the same assembly, or visible to types regardless of assembly.</td>
<td>II</td>
<td>8.1</td>
<td>Visibility of Top-Level Types and Accessibility of Nested Types</td>
</tr>
<tr>
<td>Widen</td>
<td>If a type overrides an inherited method, it may widen, but it shall not narrow, the accessibility of that method.</td>
<td>II</td>
<td>9.3.3</td>
<td>Accessibility and Overriding</td>
</tr>
<tr>
<td>XML Library</td>
<td>This Library is part of the Compact Profile. It provides a simple “pull-style” parser for XML. It is designed for resource-constrained devices, yet provides a simple user model.</td>
<td>IV</td>
<td>5.5</td>
<td>XML Library</td>
</tr>
</tbody>
</table>
5 Overview of the Common Language Infrastructure

The Common Language Infrastructure (CLI) provides a specification for executable code and the execution environment (the Virtual Execution System, or VES) in which it runs. Executable code is presented to the VES as modules. A module is a single file containing executable content in the format specified in Partition II.

The remainder of this section and its subsections contain only informative text

At the center of the Common Language Infrastructure (CLI) is a single type system, the Common Type System (CTS), that is shared by compilers, tools, and the CLI itself. It is the model that defines the rules the CLI follows when declaring, using, and managing types. The CTS establishes a framework that enables cross-language integration, type safety, and high performance code execution. This section describes the architecture of CLI by describing the CTS.

The following four areas are covered in this section:

• **The Common Type System.** See Chapter 7. The Common Type System (CTS) provides a rich type system that supports the types and operations found in many programming languages. The Common Type System is intended to support the complete implementation of a wide range of programming languages.

• **Metadata.** See Chapter 8. The CLI uses metadata to describe and reference the types defined by the Common Type System. Metadata is stored (“persisted”) in a way that is independent of any particular programming language. Thus, metadata provides a common interchange mechanism for use between tools that manipulate programs (compilers, debuggers, etc.) as well as between these tools and the Virtual Execution System.

• **The Common Language Specification.** See Chapter 9. The Common Language Specification is an agreement between language designers and framework (class library) designers. It specifies a subset of the CTS Type System and a set of usage conventions. Languages provide their users the greatest ability to access frameworks by implementing at least those parts of the CTS that are part of the CLS. Similarly, frameworks will be most widely used if their publicly exposed aspects (classes, interfaces, methods, fields, etc.) use only types that are part of the CLS and adhere to the CLS conventions.

• **The Virtual Execution System.** See Chapter 11. The Virtual Execution System (VES) implements and enforces the CTS model. The VES is responsible for loading and running programs written for the CLI. It provides the services needed to execute managed code and data, using the metadata to connect separately generated modules together at runtime (late binding).

Together, these aspects of the CLI form a unifying framework for designing, developing, deploying, and executing distributed components and applications. The appropriate subset of the Common Type System is available from each programming language that targets the CLI. Language-based tools communicate with each other and with the Virtual Execution System using metadata to define and reference the types used to construct the application. The Virtual Execution System uses the metadata to create instances of the types as needed and to provide data type information to other parts of the infrastructure (such as remoting services, assembly downloading, security, etc.).

5.1 Relationship to Type Safety

Type safety is usually discussed in terms of what it does, e.g. guaranteeing encapsulation between different objects, or in terms of what it prevents, e.g. memory corruption by writing where one shouldn’t. However, from the point of view of the Common Type System, type safety guarantees that:

• **References are what they say they are** - Every reference is typed and the object or value referenced also has a type, and they are assignment compatible (see Section 7.7).

• **Identities are who they say they are** - There is no way to corrupt or spoof an object, and by implication a user or security domain. The access to an object is through accessible functions and fields. An object may still be designed in such a way that security is compromised. However, a
local analysis of the class, its methods, and the things it uses, as opposed to a global analysis of
all uses of a class, is sufficient to assess the vulnerabilities.

- **Only appropriate operations can be invoked** – The reference type defines the accessible
  functions and fields. This includes limiting visibility based on where the reference is, e.g.
  protected fields only visible in subclasses.

The Common Type System promotes type safety e.g. everything is typed. Type safety can be optionally
enforced. The hard problem is determining if an implementation conforms to a typesafe declaration. Since the
declarations are carried along as metadata with the compiled form of the program, a compiler from the
Common Intermediate Language (CIL) to native code (see Section 7.8) can type-check the implementations.

### 5.2 Relationship to Managed Metadata-driven Execution

Metadata describes code by describing the types that the code defines and the types that it references externally.
The compiler produces the metadata when the code is produced. Enough information is stored in the metadata
to:

- **Manage code execution** – not just load and execute, but also memory management and execution
  state inspection.

- **Administer the code** – Installation, resolution, and other services

- **Reference types in the code** – Importing into other languages and tools as well as scripting and
  automation support.

The Common Type System assumes that the execution environment is metadata-driven. Using metadata allows
the CLI to support:

- **Multiple execution models** - The metadata also allows the execution environment to deal with a
  mixture of interpreted, JITted, native and legacy code and still present uniform services to tools
  like debuggers or profilers, consistent exception handling and unwinding, reliable code access
  security, and efficient memory management.

- **Auto support for services** - Since the metadata is available at execution time, the execution
  environment and the base libraries can automatically supply support for reflection, automation,
  serialization, remote objects, and inter-operability with existing unmanaged native code with little
  or no effort on the part of the programmer.

- **Better optimization** – Using metadata references instead of physical offsets, layouts, and sizes
  allows the CLI to optimize the physical layouts of members and dispatch tables. In addition, this
  allows the generated code to be optimized to match the particular CPU or environment.

- **Reduced binding brittleness** – Using metadata references reduces version-to-version brittleness
  by replacing compile-time object layout with load-time layout and binding by name.

- **Flexible deployment resolution** - Since we can have metadata for both the reference and the
  definition of a type, more robust and flexible deployment and resolution mechanisms are possible.
  Resolution means that by looking in the appropriate set of places it is possible to find the
  implementation that best satisfies these requirements for use in this context. There are five
  elements of information in the foregoing: two items are made available via metadata
  (requirements and context); the others come from application packaging and deployment (where
  to look, how to find an implementation, and how to decide the best match).

### 5.2.1 Managed Code

Managed code is simply code that provides enough information to allow the CLI to provide a set of core
services, including

- Given an address inside the code for a method, locate the metadata describing the method
- Walk the stack
- Handle exceptions
• Store and retrieve security information

This standard specifies a particular instruction set, the Common Intermediate Language (CIL, see Partition III), and a file format (see Partition II) for storing and transmitting managed code.

5.2.2 Managed Data

Managed data is data that is allocated and released automatically by the CLI, through a process called garbage collection.

5.2.3 Summary

The Common Type System is about integration between languages: using another language’s objects as if they were one’s own.

The objective of the CLI is to make it easier to write components and applications from any language. It does this by defining a standard set of types, making all components fully self-describing, and providing a high performance common execution environment. This ensures that all CLI compliant system services and components will be accessible to all CLI aware languages and tools. In addition, this simplifies deployment of components and applications that use them, all in a way that allows compilers and other tools to leverage the high performance execution environment. The Common Type System covers, at a high level, the concepts and interactions that make all of this possible.

The discussion is broken down into four areas:

• Type System – What types are and how to define them.
• Metadata – How types are described and how those descriptions are stored.
• Virtual Execution System – How code is executed and types are instantiated, interact, and die.

End informative text
6 Common Language Specification (CLS)

6.1 Introduction

The Common Language Specification (CLS) is a set of rules intended to promote language interoperability. These rules shall be followed in order to conform to the CLS. They are described in greater detail in subsequent chapters and are summarized in Chapter 10. CLS conformance is a characteristic of types that are generated for execution on a CLI implementation. Such types must conform to the CLI specification, in addition to the CLS rules. These additional rules apply only to types that are visible in assemblies other than those in which they are defined, and to the members (fields, methods, properties, events, and nested types) that are accessible outside the assembly (i.e. those that have an accessibility of public, family, or family-or-assembly).

Note: A library consisting of CLS-compliant code is herein referred to as a “framework”. Compilers that generate code for the CLI may be designed to make use of such libraries, but not to be able to produce or extend such library code. These compilers are referred to as “consumers”. Compilers that are designed to both produce and extend frameworks are referred to as “extenders”. In the description of each CLS rule, additional informative text is provided to assist the reader in understanding the rule’s implication for each of these situations.

6.2 Views of CLS Compliance

This section and its subsections contain only informative text

The CLS is a set of rules that apply to generated assemblies. Because the CLS is designed to support interoperability for libraries and the high-level programming languages used to write them, it is often useful to think of the CLS rules from the perspective of the high-level source code and tools, such as compilers, that are used in the process of generating assemblies. For this reason, informative notes are added to the description of CLS rules to assist the reader in understanding the rule’s implications for several different classes of tools and users. The different viewpoints used in the description are called framework, consumer, and extender and are described here.

6.2.1 CLS Framework

A library consisting of CLS-compliant code is herein referred to as a “framework”. Frameworks (libraries) are designed for use by a wide range of programming languages and tools, including both CLS consumer and extender languages. By adhering to the rules of the CLS, authors of libraries ensure that the libraries will be usable by a larger class of tools than if they chose not to adhere to the CLS rules. The following are some additional guidelines that CLS-compliant frameworks should follow:

- Avoid the use of names commonly used as keywords in programming languages
- Should not expect users of the framework to be able to author nested types
- Should assume that implementations of methods of the same name and signature on different interfaces are independent.
- Should not rely on initialization of value types to be performed automatically based on specified initializer values.

6.2.2 CLS Consumer

A CLS consumer is a language or tool that is designed to allow access to all of the features supplied by CLS-compliant frameworks (libraries), but not necessarily be able to produce them. The following is a partial list of things CLS consumer tools are expected to be able to do:

- Support calling any CLS-compliant method or delegate
- Have a mechanism for calling methods that have names that are keywords in the language
• Support calling distinct methods supported by a type that have the same name and signature, but implement different interfaces
• Create an instance of any CLS-compliant type
• Read and modify any CLS-compliant field
• Access nested types
• Access any CLS-compliant property. This does not require any special support other than the ability to call the getter and setter methods of the property.
• Access any CLS-compliant event. This does not require any special support other than the ability to call methods defined for the event.

The following is a list of things CLS consumer tools need not support:
• Creation of new types or interfaces
• Initialization metadata (see Partition II) on fields and parameters other than static literal fields. Note that consumers may choose to use initialization metadata, but may also safely ignore such metadata on anything other than static literal fields.

6.2.3 CLS Extender

A CLS extender is a language or tool that is designed to allow programmers to both use and extend CLS-compliant frameworks. CLS extenders support a superset of the behavior supported by a CLS consumer, i.e., everything that applies to a CLS consumer also applies to CLS extenders. In addition to the requirements of a consumer, extenders are expected to be able to:
• Define new CLS-compliant types that extend any (non-sealed) CLS-compliant base class
• Have some mechanism for defining types with names that are keywords in the language
• Provide independent implementations for all methods of all interfaces supported by a type. That is, it is not sufficient for an extender to require a single code body to implement all interface methods of the same name and signature.
• Implement any CLS-compliant interface
• Place any CLS-compliant custom attribute on all appropriate elements of metadata

Extenders need not support the following:
• Definition of new CLS-compliant interfaces
• Definition of nested types

The common language specification is designed to be large enough that it is properly expressive and small enough that all languages can reasonably accommodate it.

End informative text

6.3 CLS Compliance

As these rules are introduced in detail, they are described in a common format. For an example, see the first rule below. The first paragraph specifies the rule itself. This is then followed by an informative description of the implications of the rule from the three different viewpoints as described above.

The CLS defines language interoperability rules, which apply only to “externally visible” items. The CLS unit of that language interoperability is the assembly— that is, within a single assembly there are no restrictions as to the programming techniques that are used. Thus, the CLS rules apply only to items that are visible (see clause 7.5.3) outside of their defining assembly and have public, family, or family-or-assembly accessibility (see clause 7.5.3.2).
CLS Rule 1: CLS rules apply only to those parts of a type that are accessible or visible outside of the defining assembly.

Note:

CLS (consumer): no impact.

CLS (extender): when checking CLS compliance at compile time, be sure to apply the rules only to information that will be exposed outside the assembly.

CLS (framework): CLS rules do not apply to internal implementation within an assembly. A type is CLS-compliant if all its publicly accessible parts (those classes, interfaces, methods, fields, properties, and events that are available to code executing in another assembly) either

- have signatures composed only of CLS-compliant types, or
- are specifically marked as not CLS-compliant

Any construct that would make it impossible to rapidly verify code is excluded from the CLS. This allows all CLS-compliant languages to produce verifiable code if they so choose.

6.3.1 Marking Items as CLS-Compliant

The CLS specifies how to mark externally visible parts of an assembly to indicate whether or not they comply with the CLS requirements. This is done using the custom attribute mechanism (see Section 8.7 and Partition II). The class System.CLSCompliantAttribute (see Partition IV) indicates which types and type members are CLS-compliant. It also can be attached to an assembly, to specify the default value for all top-level types it contains.

The constructor for System.CLSCompliantAttribute takes a Boolean argument indicating whether the item with which it is associated is or is not CLS-compliant. This allows any item (assembly, type, or type member) to be explicitly marked as CLS-compliant or not.

The rules for determining CLS compliance are:

- When an assembly does not carry an explicit System.CLSCompliantAttribute, it shall be assumed to carry System.CLSCompliantAttribute(false).
- By default, a type inherits the CLS-compliance attribute of its enclosing type (for nested types) or acquires the value attached to its assembly (for top-level types). It may be marked as either CLS-compliant or not CLS-Compliant by attaching the System.CLSCompliantAttribute attribute.
- By default, other members (methods, fields, properties and events) inherit the CLS-compliance of their type. They may be marked as not CLS-compliant by attaching the attribute System.CLSCompliantAttribute(false).

CLS Rule 2: Members of non-CLS compliant types shall not be marked CLS-compliant.

Note:

CLS (consumer): May ignore any member that is not CLS-compliant using the above rules.

CLS (extender): Should encourage correct labeling of newly authored assemblies, classes, interfaces, and methods. Compile-time enforcement of the CLS rules is strongly encouraged.

CLS (framework): Shall correctly label all publicly exposed members as to their CLS compliance. The rules specified here may be used to minimize the number of markers required (for example, label the entire assembly if all types and members are compliant or if there are only a few exceptions that need to be marked).
Types describe values and specify a contract (see Section 7.6) that all values of that type shall support. Because the CTS supports Object-Oriented Programming (OOP) as well as functional and procedural programming languages, it deals with two kinds of entities: Objects and Values. Values are simple bit patterns for things like integers and floats; each value has a type that describes both the storage that it occupies and the meanings of the bits in its representation, and also the operations that may be performed on that representation. Values are intended for representing the corresponding simple types in programming languages like C, and also for representing non-objects in languages like C++ and Java™.

Objects have rather more to them than do values. Each object is self-typing, that is, its type is explicitly stored in its representation. It has an identity that distinguishes it from all other objects, and it has slots that store other entities (which may be either objects or values). While the contents of its slots may be changed, the identity of an object never changes.

There are several kinds of Objects and Values, as shown in the following diagram.
Figure 1: Type System

Type

Value Types

Floating Point Types

Integer Types

Typed References

Built-in Value Types (special encoding in signature)

Managed (might be in heap)

Unmanaged

Unmanaged

String

Object

Interface

Name Equivalent

Delegates

Bound Value Types

Bound Enums

Structural Equivalent

Arrays

User Defined

Self-Describing

Built-In Reference Types

Pointer

Integer Types

Enums

Name Equivalent

Enum

Built-In Reference Types
7.1 Relationship to Object-Oriented Programming

This section contains only informative text

The term type is often used in the world of value-oriented programming to mean data representation. In the object-oriented world it usually refers to behavior rather than to representation. In the CTS, type is used to mean both of these things: two entities have the same type if and only if they have both compatible representations and behaviors. Thus, in the CTS, if one type is derived from a base type, then instances of the derived type may be substituted for instances of the base type because both the representation and the behavior are compatible.

In the CTS, unlike some OOP languages, two objects that have fundamentally different representations have different types. Some OOP languages use a different notion of type. They consider two objects to have the same type if they respond in the same way to the same set of messages. This notion is captured in the CTS by saying that the objects implement the same interface.

Similarly, some OOP languages (e.g. SmallTalk) consider message passing to be the fundamental model of computation. In the CTS, this corresponds to calling virtual methods (see clause 7.4.4), where the signature of the virtual method serves the role of the message.

The CTS itself does not directly capture the notion of “typeless programming.” That is, there is no way to call a non-static method without knowing the type of the object. Nevertheless, typeless programming can be implemented based on the facilities provided by the reflection package (see Partition IV) if it is implemented.

End informative text

7.2 Values and Types

Types describe values. All places where values are stored, passed, or operated upon have a type, e.g. all variables, parameters, evaluation stack locations, and method results. The type defines the allowable values and the allowable operations supported by the values of the type. All operators and functions have expected types for each of the values accessed or used.

A value can be of more than one type. A value that supports many interfaces is an example of a value that is of more than one type, as is a value that inherits from another.

7.2.1 Value Types and Reference Types

There are two kinds of types: Value Types and Reference Types.

- Value Types - Value Types describe values that are represented as sequences of bits.
- Reference Types – Reference Types describe values that are represented as the location of a sequence of bits. There are four kinds of Reference Types:
  - An object type is a reference type of a self-describing value (see clause 7.2.3). Some object types (e.g. abstract classes) are only a partial description of a value.
  - An interface type is always a partial description of a value, potentially supported by many object types.
  - A pointer type is a compile time description of a value whose representation is a machine address of a location.
  - Built-in types

7.2.2 Built-in Types

The following data types are an integral part of the CTS and are supported directly by the Virtual Execution System (VES). They have special encoding in the persisted metadata:
Table 1: Special Encoding

<table>
<thead>
<tr>
<th>Name in CIL assembler (see Partition II)</th>
<th>CLS Type?</th>
<th>Name in class library (see Partition IV)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bool</td>
<td>Yes</td>
<td>System.Boolean</td>
<td>True/false value</td>
</tr>
<tr>
<td>char</td>
<td>Yes</td>
<td>System.Char</td>
<td>Unicode 16-bit char.</td>
</tr>
<tr>
<td>object</td>
<td>Yes</td>
<td>System.Object</td>
<td>Object or boxed value type</td>
</tr>
<tr>
<td>string</td>
<td>Yes</td>
<td>System.String</td>
<td>Unicode string</td>
</tr>
<tr>
<td>float64</td>
<td>Yes</td>
<td>System.Double</td>
<td>IEC 60559:1989 64-bit float</td>
</tr>
<tr>
<td>int8</td>
<td>No</td>
<td>System.SByte</td>
<td>Signed 8-bit integer</td>
</tr>
<tr>
<td>int16</td>
<td>Yes</td>
<td>System.Int16</td>
<td>Signed 16-bit integer</td>
</tr>
<tr>
<td>int32</td>
<td>Yes</td>
<td>System.Int32</td>
<td>Signed 32-bit integer</td>
</tr>
<tr>
<td>int64</td>
<td>Yes</td>
<td>System.Int64</td>
<td>Signed 64-bit integer</td>
</tr>
<tr>
<td>native int</td>
<td>Yes</td>
<td>System.IntPtr</td>
<td>Signed integer, native size</td>
</tr>
<tr>
<td>native unsigned int</td>
<td>No</td>
<td>System.UIntPtr</td>
<td>Unsigned integer, native size</td>
</tr>
<tr>
<td>typedef</td>
<td>No</td>
<td>System.TypedReference</td>
<td>Pointer plus runtime type</td>
</tr>
<tr>
<td>unsigned int8</td>
<td>Yes</td>
<td>System.Byte</td>
<td>Unsigned 8-bit integer</td>
</tr>
<tr>
<td>unsigned int16</td>
<td>No</td>
<td>System.UInt16</td>
<td>Unsigned 16-bit integer</td>
</tr>
<tr>
<td>unsigned int32</td>
<td>No</td>
<td>System.UInt32</td>
<td>Unsigned 32-bit integer</td>
</tr>
<tr>
<td>unsigned int64</td>
<td>No</td>
<td>System.UInt64</td>
<td>Unsigned 64-bit integer</td>
</tr>
</tbody>
</table>

7.2.3 Classes, Interfaces and Objects

Every value has an exact type that fully describes the value. A type fully describes a value if it completely defines the value’s representation and the operations defined on the value.

For a Value Type, defining the representation entails describing the sequence of bits that make up the value’s representation. For a Reference Type, defining the representation entails describing the location and the sequence of bits that make up the value’s representation.

A method describes an operation that may be performed on values of an exact type. Defining the set of operations allowed on values of an exact type entails specifying named methods for each operation.

Some types are only a partial description, e.g. interface types. Interface types describe a subset of the operations and none of the representation, and hence, cannot be an exact type of any value. Hence, while a value has only one exact type, it may also be a value of many other types as well. Furthermore, since the exact type fully describes the value, it also fully specifies all of the other types that a value of the exact type can have.

While it is true that every value has an exact type, it is not always possible to determine the exact type by inspecting the representation of the value. In particular, it is never possible to determine the exact type of a value of a Value Type. Consider two of the built-in Value Types, 32-bit signed and unsigned integers. While each type is a full specification of their respective values, i.e. an exact type, there is no way to derive that exact type from a value’s particular 32-bit sequence.

For some values, called objects, it is always possible to determine the exact type from the value. Exact types of objects are also called object types. Objects are values of Reference Types, but not all Reference Types describe objects. Consider a value that is a pointer to a 32-bit integer, a kind of Reference Type. There is no way to determine the type of the value by examining the pointer bits, hence it is not an object. Now consider the built-in CTS Reference Type System.String (see Partition IV). The exact type of a value of this type is always...
determinable by examining the value, hence values of type System.String are objects and System.String is an object type.

7.2.4 Boxing and Unboxing of Values

For every Value Type, the CTS defines a corresponding Reference Type called the boxed type. The reverse is not true: Reference Types do not in general have a corresponding Value Type. The representation of a value of a boxed type (a boxed value) is a location where a value of the Value Type may be stored. A boxed type is an object type and a boxed value is an object.

All Value Types have an operation called box. Boxing a value of any Value Type produces its boxed value, i.e. a value of the corresponding boxed type containing a bit copy of the original value. All boxed types have an operation called unbox. Unboxing results in a managed pointer to the bit representation of the value.

Notice that interfaces and inheritance are defined only on Reference types. Thus, while a Value Type definition (see clause 7.9.7) can specify both interfaces that shall be implemented by the Value Type and the class (System.ValueType or System.Enum) from which it inherits, these apply only to boxed values.

CLS Rule 3: The CLS does not include boxed value types.

Note:

In lieu of boxed types, use System.Object, System.ValueType or System.Enum, as appropriate. (See Partition IV)

CLS (consumer): need not import boxed value types.

CLS (extender): need not provide syntax for defining or using boxed value types.

CLS (framework): shall not use boxed value types in their publicly exposed aspects.

7.2.5 Identity and Equality of Values

There are two binary operators defined on all pairs of values, identity and equality, that return a Boolean result. Both of these operators are mathematical equivalence operators, i.e. they are:

- Reflexive - a op a is true.
- Symmetric - a op b is true if and only if b op a is true.
- Transitive - if a op b is true and b op c is true, then a op c is true

In addition, identity always implies equality, but not the reverse, i.e., the equality operator need not be the same as the identity operator as long as two identical values are also equal values.

To understand the difference between these operations, consider three variables whose type is System.String, where the arrow is intended to mean “is a reference to”:

```
A
B
C

Here's some text
Here's some text
```

The values of the variables are identical if the locations of the sequences of characters are the same, i.e., there is in fact only one string in memory. The values stored in the variables are equal if the sequences of characters are the same. Thus, the values of variables A and B are identical, the values of variables A and C as well as B and C are not identical, and the values of all three of A, B, and C are equal.
7.2.5.1 Identity

The identity operator is defined by the CTS as follows.

- If the values have different exact types, then they are not identical.
- Otherwise, if their exact type is a Value Type, then they are identical if and only if the bit sequences of the values are the same, bit by bit.
- Otherwise, if their exact type is a Reference Type, then they are identical if and only if the locations of the values are the same.

Identity is implemented on System.Object via the ReferenceEquals method.

7.2.5.2 Equality

For value types, the equality operator is part of the definition of the exact type. Definitions of equality should obey the following rules:

- Equality should be an equivalence operator, as defined above.
- Identity should imply equality, as stated earlier.
- If either (or both) operand is a boxed value, equality should be computed by
  - first unboxing any boxed operand(s), and then
  - applying the usual rules for equality on the resulting values.

Equality is implemented on System.Object via the Equals method.

Note: Although two floating point NaNs are defined by IEC 60559:1989 to always compare as unequal, the contract for System.Object.Equals, requires that overrides must satisfy the requirements for an equivalence operator. Therefore, System.Double.Equals and System.Single.Equals return True when comparing two NaNs, while the equality operator returns False in that case, as required by the standard.

7.3 Locations

Values are stored in locations. A location can hold a single value at a time. All locations are typed. The type of the location embodies the requirements that shall be met by values that are stored in the location. Examples of locations are local variables and parameters.

More importantly, the type of the location specifies the restrictions on usage of any value that is loaded from the location. For example, a location can hold values of potentially many exact types as long as all of the values are assignment compatible with the type of the location (see below). All values loaded from a location are treated as if they are of the type of the location. Only operations valid for the type of the location may be invoked even if the exact type of the value stored in the location is capable of additional operations.

7.3.1 Assignment Compatible Locations

A value may be stored in a location only if one of the types of the value is assignment compatible with the type of the location. A type is always assignment compatible with itself. Assignment compatibility can often be determined at compile time, in which case there is no need for testing at run time. Assignment compatibility is described in detail in Section 7.7.

7.3.2 Coercion

Sometimes it is desirable to take a value of a type that is not assignment compatible with a location and convert the value to a type that is assignment compatible. This is accomplished through coercion of the value. Coercion takes a value of a particular type and a desired type and attempts to create a value of the desired type that has equivalent meaning to the original value. Coercion can result in representation changes as well as type changes, hence coercion does not necessarily preserve the identity of two objects.

There are two kinds of coercion: widening, which never loses information, and narrowing, in which information may be lost. An example of a widening coercion would be coercing a value that is a 32-bit signed
integer to a value that is a 64-bit signed integer. An example of a narrowing coercion is the reverse: coercing a 64-bit signed integer to a 32-bit signed integer. Programming languages often implement widening coercions as implicit conversions, whereas narrowing coercions usually require an explicit conversion.

Some widening coercion is built directly into the VES operations on the built-in types (see Section 11.1). All other coercion shall be explicitly requested. For the built-in types, the CTS provides operations to perform widening coercions with no runtime checks and narrowing coercions with runtime checks.

7.3.3 Casting

Since a value can be of more than one type, a use of the value needs to clearly identify which of its types is being used. Since values are read from locations that are typed, the type of the value which is used is the type of the location from which the value was read. If a different type is to be used, the value is cast to one of its other types. Casting is usually a compile time operation, but if the compiler cannot statically know that the value is of the target type, a runtime cast check is done. Unlike coercion, a cast never changes the actual type of an object nor does it change the representation. Casting preserves the identity of objects.

For example, a runtime check may be needed when casting a value read from a location that is typed as holding values of a particular interface. Since an interface is an incomplete description of the value, casting that value to be of a different interface type will usually result in a runtime cast check.

7.4 Type Members

As stated above, the type defines the allowable values and the allowable operations supported by the values of the type. If the allowable values of the type have a substructure, that substructure is described via fields or array elements of the type. If there are operations that are part of the type, those operations are described via methods on the type. Fields, array elements, and methods are called members of the type. Properties and events are also members of the type.

7.4.1 Fields, Array Elements, and Values

The representation of a value (except for those of built-in types) can be subdivided into sub-values. These sub-values are either named, in which case they are called fields, or they are accessed by an indexing expression, in which case they are called array elements. Types that describe values composed of array elements are array types. Types that describe values composed of fields are compound types. A value cannot contain both fields and array elements, although a field of a compound type may be an array type and an array element may be a compound type.

Array elements and fields are typed, and these types never change. All of the array elements shall have the same type. Each field of a compound type may have a different type.

7.4.2 Methods

A type may associate operations with the type or with each instance of the type. Such operations are called methods. A method is named, and has a signature (see clause 7.6.1) that specifies the allowable types for all of its arguments and for its return value, if any.

A method that is associated only with the type itself (as opposed to a particular instance of the type) is called a static method (see clause 7.4.3).

A method that is associated with an instance of the type is either an instance method or a virtual method (see clause 7.4.4). When they are invoked, instance and virtual methods are passed the instance on which this invocation is to operate (known as this or a this pointer).

The fundamental difference between an instance method and a virtual method is in how the implementation is located. An instance method is invoked by specifying a class and the instance method within that class. The object passed as this may be null (a special value indicating that no instance is being specified) or an instance of any type that inherits (see clause 7.9.8) from the class that defines the method. A virtual method may also be called in this manner. This occurs, for example, when an implementation of a virtual method wishes to call the implementation supplied by its parent class. The CTS allows this to be null inside the body of a virtual method.
Rationale: Allowing a virtual method to be called with a non-virtual call eliminates the need for a “call super” instruction and allows version changes between virtual and non-virtual methods. It requires CIL generators to insert explicit tests for a null pointer if they don’t want the null this pointer to propagate to called methods.

A virtual or instance method may also be called by a different mechanism, a virtual call. Any type that inherits from a type that defines a virtual method may provide its own implementation of that method (this is known as overriding, see clause 7.10.4). It is the exact type of the object (determined at runtime) that is used to decide which of the implementations to invoke.

7.4.3 Static Fields and Static Methods

Types may declare locations that are associated with the type rather than any particular value of the type. Such locations are static fields of the type. As such, static fields declare a location that is shared by all values of the type. Just like non-static (instance) fields, a static field is typed and that type never changes. Static fields are always restricted to a single application domain basis (see Section 11.5), but they may also be allocated on a per-thread basis.

Similarly, types may also declare methods that are associated with the type rather than with values of the type. Such methods are static methods of the type. Since an invocation of a static method does not have an associated value on which the static method operates, there is no this pointer available within a static method.

7.4.4 Virtual Methods

An object type may declare any of its methods as virtual. Unlike other methods, each exact type that implements the type may provide its own implementation of a virtual method. A virtual method may be invoked through the ordinary method call mechanism that uses the static type, method name, and types of parameters to choose an implementation, in which case the this pointer may be null. In addition, however, a virtual method may be invoked by a special mechanism (a virtual call) that chooses the implementation based on the dynamically detected type of the instance used to make the virtual call rather than the type statically known at compile time. Virtual methods may be marked final (see clause 7.10.2).

7.5 Naming

Names are given to entities of the type system so that they can be referred to by other parts of the type system or by the implementations of the types. Types, fields, methods, properties and events have names. With respect to the type system values, locals, and parameters do not have names. An entity of the type system is given a single name, e.g. there is only one name for a type.

7.5.1 Valid Names

All comparisons are done on a byte-by-byte (i.e. case sensitive, locale-independent, also known as code-point comparison) basis. Where names are used to access built-in VES-supplied functionality (for example, the class initialization method) there is always an accompanying indication on the definition so as not to build in any set of reserved names.

CLS Rule 4: Assemblies shall follow Annex 7 of Technical Report 15 of the Unicode Standard 3.0 (ISBN 0-201-61633-5) governing the set of characters permitted to start and be included in identifiers, available on-line at http://www.unicode.org/unicode/reports/tr15/tr15-18.html. Identifiers shall be in the canonical format defined by Unicode Normalization Form C. For CLS purposes, two identifiers are the same if their lowercase mappings (as specified by the Unicode locale-insensitive, 1-1 lowercase mappings) are the same. That is, for two identifiers to be considered different under the CLS they shall differ in more than simply their case. However, in order to override an inherited definition the CLI requires the precise encoding of the original declaration be used.

Note:

CLS (consumer): need not consume types that violate CLS rule 4, but shall have a mechanism to allow access to named items that use one of its own keywords as the name.

CLS (extender): need not create types that violate CLS rule 4. Shall provide a mechanism for defining new names that obey these rules but are the same as a keyword in the language.
CLS (framework): shall not export types that violate CLS rule 4. Should avoid the use of names that are commonly used as keywords in programming languages (see Partition V, Annex D).

7.5.2 Assemblies and Scoping

Generally, names are not unique. Names are collected into groupings called scopes. Within a scope, a name may refer to multiple entities as long as they are of different kinds (methods, fields, nested types, properties, and events) or have different signatures.

CLS Rule 5: All names introduced in a CLS-compliant scope shall be distinct independent of kind, except where the names are identical and resolved via overloading. That is, while the CTS allows a single type to use the same name for a method and a field, the CLS does not.

CLS Rule 6: Fields and nested types shall be distinct by identifier comparison alone, even though the CTS allows distinct signatures to be distinguished. Methods, properties, and events that have the same name (by identifier comparison) shall differ by more than just the return type, except as specified in CLS Rule 39.

Note:

CLS (consumer): need not consume types that violate these rules after ignoring any members that are marked as not CLS-compliant.

CLS (extender): need not provide syntax for defining types that violate these rules.

CLS (framework): shall not mark types as CLS-compliant if they violate these rules unless they mark sufficient offending items within the type as not CLS-compliant so that the remaining members do not conflict with one another.

A named entity has its name in exactly one scope. Hence, to identify a named entity, both a scope and a name need to be supplied. The scope is said to qualify the name. Types provide a scope for the names in the type; hence types qualify the names in the type. For example, consider a compound type Point that has a field named x. The name "field x" by itself does not uniquely identify the named field, but the qualified name "field x in type Point" does.

Since types are named, the names of types are also grouped into scopes. To fully identify a type, the type name shall be qualified by the scope that includes the type name. Type names are scoped by the assembly that contains the implementation of the type. An assembly is a configured set of loadable code modules and other resources that together implement a unit of functionality. The type name is said to be in the assembly scope of the assembly that implements the type. Assemblies themselves have names that form the basis of the CTS naming hierarchy.

The type definition:

- Defines a name for the type being defined, i.e. the type name, and specifies a scope in which that name will be found
- Defines a member scope in which the names of the different kinds of members (fields, methods, events, and properties) are bound. The tuple of (member name, member kind, and member signature) is unique within a member scope of a type.
- Implicitly assigns the type to the assembly scope of the assembly that contains the type definition.

The CTS supports an enum (also known as an enumeration type), an alternate name for an existing type. For purposes of matching signatures an enum shall not be the same as the underlying type. Instances of an enum, however, shall be assignment compatible with the underlying type and vice versa. That is: no cast (see clause 7.3.3) or coercion (see clause 7.3.2) is required to convert from the enum to the underlying type, nor are they required from the underlying type to the enum. An enum is considerably more restricted than a true type:

- It shall have exactly one instance field, and the type of that field defines the underlying type of the enumeration.
- It shall not have any methods of its own.
- It shall derive from System.Enum (see Partition IV).
• It shall not implement any interfaces of its own.
• It shall not have any properties or events of its own.
• It shall not have any static fields unless they are literal (see clause 7.6.1).

The underlying type shall be a built-in integer type. Enums shall derive from System.Enum, hence they are value types. Like all value types, they shall be sealed (see clause 7.9.9).

CLS Rule 7: The underlying type of an enum shall be a built-in CLS integer type.

CLS Rule 8: There are two distinct kinds of enums, indicated by the presence or absence of the System.FlagsAttribute (see Partition IV) custom attribute. One represents named integer values, the other named bit flags that can be combined to generate an unnamed value. The value of an enum is not limited to the specified values.

CLS Rule 9: Literal static fields (see clause 7.6.1) of an enum shall have the type of the enum itself.

Note:
CLS (consumer): Shall accept definition of enums that follow these rules, but need not distinguish flags from named values.
CLS (extender): Same as consumer. Extender languages are encouraged to allow the authoring of enums, but need not do so.
CLS (framework): shall not expose enums that violate these rules, and shall not assume that enums have only the specified values (even for enums that are named values).

7.5.3 Visibility, Accessibility, and Security

To refer to a named entity in a scope, both the scope and the name in the scope shall be visible (see clause 7.5.3.1). Visibility is determined by the relationship between the entity that contains the reference (the referent) and the entity that contains the name being referenced. Consider the following pseudo-code:

```csharp
class A
{ int32 IntInsideA;
}

class B inherits from A
{ method X(int32, int32) returning Boolean
  { IntInsideA := 15;
  }
}
```

If we consider the reference to the field `IntInsideA` in class `A`:

• We call class `B` the referent because it has a method that refers to that field,
• We call `IntInsideA` in class `A` the referenced entity.

There are two fundamental questions that need to be answered in order to decide whether the referent is allowed to access the referenced entity. The first is whether the name of the referenced entity is visible to the referent. If it is visible, then there is a separate question of whether the referent is accessible (see clause 7.5.3.2).

Access to a member of a type is permitted only if all three of the following conditions are met:

1. The type is visible.
2. The member is accessible.
3. All relevant security demands (see clause 7.5.3.3) have been granted.

7.5.3.1 Visibility of Types

Only type names, not member names, have controlled visibility. Type names fall into one of the following three categories
• **Exported** from the assembly in which they are defined. While a type may be marked to *allow* it to be exported from the assembly, it is the configuration of the assembly that decides whether the type name is made available.

• **Not exported** outside the assembly in which they are defined.

• Nested within another type. In this case, the type itself has the visibility of the type inside of which it is nested (its *enclosing type*). See clause 7.5.3.4.

7.5.3.2 **Accessibility of Members**

A type scopes all of its members, and it also specifies the accessibility rules for its members. Except where noted, accessibility is decided based only on the statically visible type of the member being referenced and the type and assembly that is making the reference. The CTS supports seven different rules for accessibility:

• **Compiler-Controlled** – accessible only through use of a definition, not a reference, hence only accessible from within a single compilation unit and under the control of the compiler.

• **Private** – accessible only to referents in the implementation of the exact type that defines the member.

• **Family** – accessible to referents that support the same type, i.e. an exact type and all of the types that inherit from it. For verifiable code (see Section 7.8), there is an additional requirement that may require a runtime check: the reference shall be made through an item whose exact type supports the exact type of the referent. That is, the item whose member is being accessed shall inherit from the type performing the access.

• **Assembly** – accessible only to referents in the same assembly that contains the implementation of the type.

• **Family-and-Assembly** – accessible only to referents that qualify for both Family and Assembly access.

• **Family-or-Assembly** – accessible only to referents that qualify for either Family or Assembly access.

• **Public** – accessible to all referents.

In general, a member of a type can have any one of these accessibility rules assigned to it. There are two exceptions, however:

1. Members defined by an interface shall be public.

2. When a type defines a virtual method that overrides an inherited definition, the accessibility shall either be identical in the two definitions or the overriding definition shall permit more access than the original definition. For example, it is possible to override an *assembly virtual* method with a new implementation that is *public virtual*, but not with one that is *family virtual*. In the case of overriding a definition derived from another assembly, it is not considered restricting access if the base definition has *Family-or-Assembly* access and the override has only *family* access.

**Rationale:** Languages including C++ allow this “widening” of access. Restricting access would provide an incorrect illusion of security since simply casting an object to the base class (which occurs implicitly on method call) would allow the method to be called despite the restricted accessibility. To prevent overriding a virtual method use *final* (see clause 7.10.2) rather than relying on limited accessibility.

**CLS Rule 10:** Accessibility shall not be changed when overriding inherited methods, except when overriding a method inherited from a different assembly with accessibility *Family-or-Assembly*. In this case the override shall have accessibility *family*.

**Note:**

CLS (consumer): need not accept types that widen access to inherited virtual methods.

CLS (extender): need not provide syntax to widen access to inherited virtual methods.
7.5.3.3 Security Permissions

Access to members is also controlled by security demands that may be attached to an assembly, type, method, property, or event. Security demands are not part of a type contract (see Section 7.6), and hence are not inherited. There are two kinds of demands:

- **An inheritance demand.** When attached to a type it requires that any type that wishes to inherit from this type shall have the specified security permission. When attached to a non-final virtual method it requires that any type that wishes to override this method shall have the specified permission. It shall not be attached to any other member.

- **A reference demand.** Any attempt to resolve a reference to the marked item shall have specified security permission.

Only one demand of each kind may be attached to any item. Attaching a security demand to an assembly implies that it is attached to all types in the assembly unless another demand of the same kind is attached to the type. Similarly, a demand attached to a type implies the same demand for all members of the type unless another demand of the same kind is attached to the member. For additional information, see Declarative Security in Partition II, and the classes in the System.Security namespace in Partition IV.

7.5.3.4 Nested Types

A type (called a nested type) can be a member of an enclosing type. A nested type has the same visibility as the enclosing type and has an accessibility as would any other member of the enclosing type. This accessibility determines which other types may make references to the nested type. That is, for a class to define a field or array element of a nested type, have a method that takes a nested type as a parameter or returns one as value, etc., the nested type shall be both visible and accessible to the referencing type. A nested type is part of the enclosing type so its methods have access to all members of its enclosing type, as well as family access to members of the type from which it inherits (see clause 7.9.8). The names of nested types are scoped by their enclosing type, not their assembly (only top-level types are scoped by their assembly). There is no requirement that the names of nested types be unique within an assembly.

7.6 Contracts

Contracts are named. They are the shared assumptions on a set of signatures (see clause 7.6.1) between all implementers and all users of the contract. The signatures are the part of the contract that can be checked and enforced.

Contracts are not types; rather they specify requirements on the implementation of types. Types state which contracts they abide by, i.e. which contracts all implementations of the type shall support. An implementation of a type can be verified to check that the enforceable parts of a contract, the named signatures, have been implemented. The kinds of contracts are:

- **Class contract** – A class contract is specified with a class definition. Hence, a class definition defines both the class contract and the class type. The name of the class contract and the name of the class type are the same. A class contract specifies the representation of the values of the class type. Additionally, a class contract specifies the other contracts that the class type supports, e.g., which interfaces, methods, properties and events shall be implemented. A class contract, and hence the class type, can be supported by other class types as well. A class type that supports the class contract of another class type is said to inherit from that class type.

- **Interface contract** – An interface contract is specified with an interface definition. Hence, an interface definition defines both the interface contract and the interface type. The name of the interface contract and the name of the interface type are the same. Many types can support an interface contract. Like a class contract, interface contracts specify which other contracts the interface supports, e.g. which interfaces, methods, properties and events shall be implemented.

CLS (frameworks): shall not rely on the ability to widen access to a virtual method, either in the exposed portion of the framework or by users of the framework.
Note: An interface type can never fully describe the representation of a value. Therefore an interface type can never support a class contract, and hence can never be a class type or an exact type.

- Method contract – A method contract is specified with a method definition. A method contract is a named operation that specifies the contract between the implementation(s) of the method and the callers of the method. A method contract is always part of a type contract (class, value type, or interface), and describes how a particular named operation is implemented. The method contract specifies the contracts that each parameter to the method shall support and the contracts that the return value shall support, if there is a return value.

- Property contract – A property contract is specified with a property definition. There is an extensible set of operations for handling a named value, which includes a standard pair for reading the value and changing the value. A property contract specifies method contracts for the subset of these operations that shall be implemented by any type that supports the property contract. A type can support many property contracts, but any given property contract can be supported by exactly one type. Hence, property definitions are a part of the type definition of the type that supports the property.

- Event contract – An event contract is specified with an event definition. There is an extensible set of operations for managing a named event, which includes three standard methods (register interest in an event, revoke interest in an event, fire the event). An event contract specifies method contracts for all of the operations that shall be implemented by any type that supports the event contract. A type can support many event contracts, but any given event contract can be supported by exactly one type. Hence, event definitions are a part of the type definition of the type that supports the event.

7.6.1 Signatures

Signatures are the part of a contract that can be checked and automatically enforced. Signatures are formed by adding constraints to types and other signatures. A constraint is a limitation on the use of or allowed operations on a value or location. Example constraints would be whether a location may be overwritten with a different value or whether a value may ever be changed.

All locations have signatures, as do all values. Assignment compatibility requires that the signature of the value, including constraints, is compatible with the signature of the location, including constraints. There are four fundamental kinds of signatures: type signatures, location signatures, parameter signatures, and method signatures.

CLS Rule 11: All types appearing in a signature shall be CLS-compliant.

CLS Rule 12: The visibility and accessibility of types and members shall be such that types in the signature of any member shall be visible and accessible whenever the member itself is visible and accessible. For example, a public method that is visible outside its assembly shall not have an argument whose type is visible only within the assembly.

Note:

CLS (consumer): need not accept types whose members violate these rules.

CLS (extender): need not provide syntax to violate these rules.

CLS (framework): shall not violate this rule in its exposed types and their members.

The following sections describe the various kinds of signatures. These descriptions are cumulative: the simplest signature is a type signature; a location signature is a type signature plus (optionally) some additional attributes; and so forth.

7.6.1.1 Type Signatures

Type signatures define the constraints on a value and its usage. A type, by itself, is a valid type signature. The type signature of a value cannot be determined by examining the value or even by knowing the class type of the value. The type signature of a value is derived from the location signature (see below) of the location from
which the value is loaded. Normally the type signature of a value is the type in the location signature from
which the value is loaded.

Rationale: The distinction between a Type Signature and a Location Signature (below) is not currently useful.
It is made because certain constraints, such as “constant,” are constraints on values not locations. Future
versions of this standard, or non-standard extensions, may introduce type constraints, thus making the
distinction meaningful.

7.6.1.2 Location Signatures

All locations are typed. This means that all locations have a location signature, which defines constraints on
the location, its usage, and on the usage of the values stored in the location. Any valid type signature is a valid
location signature. Hence, a location signature contains a type and may additionally contain the constant
constraint. The location signature may also contain location constraints that give further restrictions on the
uses of the location. The location constraints are:

- The init-only constraint promises (hence, requires) that once the location has been initialized, its
  contents never change. Namely, the contents are initialized before any access, and after
  initialization, no value may be stored in the location. The contents are always identical to the
  initialized value (see clause 7.2.3). This constraint, while logically applicable to any location,
  shall only be placed on fields (static or instance) of compound types.

- The literal constraint promises that the value of the location is actually a fixed value of a built-in
  type. The value is specified as part of the constraint. Compilers are required to replace all
  references to the location with its value, and the VES therefore need not allocate space for the
  location. This constraint, while logically applicable to any location, shall only be placed on static
  fields of compound types. Fields that are so marked are not permitted to be referenced from CIL
  (they shall be in-lined to their constant value at compile time), but are available using Reflection
  and tools that directly deal with the metadata.

CLS Rule 13: The value of a literal static is specified through the use of field initialization metadata (see
Partition II). A CLS compliant literal must have a value specified in field initialization metadata that is of
exactly the same type as the literal (or of the underlying type, if that literal is an enum).

Note:

CLS (consumer): must be able to read field initialization metadata for static literal fields and inline the value
specified when referenced. Consumers may assume that the type of the field initialization metadata is exactly
the same as the type of the literal field, i.e., a consumer tool need not implement conversions of the values.

CLS (extender): must avoid producing field initialization metadata for static literal fields in which the type of
the field initialization metadata does not exactly match the type of the field.

CLS (framework): should avoid the use of syntax specifying a value of a literal that requires conversion of the
value. Note that compilers may do the conversion themselves before persisting the field initialization metadata
resulting in a CLS compliant framework, but frameworks are encouraged not to rely on such implicit
conversions.

Note: It might seem reasonable to provide a volatile constraint on a location that would require that the value
stored in the location not be cached between accesses. Instead, CIL includes a volatile prefix to certain
instructions to specify that the value neither be cached nor computed using an existing cache. Such a constraint
may be encoded using a custom attribute (see Section 8.7), although this standard does not specify such an
attribute.

7.6.1.3 Local Signatures

A local signature specifies the contract on a local variable allocated during the running of a method. A local
signature contains a full location signature, plus it may specify one additional constraint:

The byref constraint states that the content of the corresponding location is a managed pointer. A managed
pointer may point to a local variable, parameter, field of a compound type, or element of an array. However,
when a call crosses a remoting boundary (see Section 11.5) a conforming implementation may use a copy-in/copy-out mechanism instead of a managed pointer. Thus programs shall not rely on the aliasing behavior of true pointers.

In addition, there is one special local signature. The typed reference local variable signature states that the local will contain both a managed pointer to a location and a runtime representation of the type that may be stored at that location. A typed reference signature is similar to a byref constraint, but while the byref specifies the type as part of the byref constraint (and hence as part of the type description), a typed reference provides the type information dynamically. A typed reference is a full signature in itself and can not be combined with other constraints. In particular, it is not possible to specify a byref whose type is typed reference.

The typed reference signature is actually represented as a built-in value type, like the integer and floating point types. In the Base Class Library (see Partition IV) the type is known as System.TypedReference and in the assembly language used in Partition II it is designated by the keyword typedref. This type shall only be used for parameters and local variables. It shall not be boxed, nor shall it be used as the type of a field, element of an array, return value, etc.

**CLS Rule 14:** Typed references are not CLS-compliant.

**Note:**

CLS (consumer): there is no need to accept this type.

CLS (extender): there is no need to provide syntax to define this type or to extend interfaces or classes that use this type.

CLS (framework): this type shall not appear in exposed members.

### 7.6.1.4 Parameter Signatures

Parameter signatures define constraints on how an individual value is passed as part of a method invocation. Parameter signatures are declared by method definitions. Any valid local signature is a valid parameter signature.

### 7.6.1.5 Method Signatures

Method signatures are composed of

- a calling convention,
- a list of zero or more parameter signatures, one for each parameter of the method,
- and a type signature for the result value if one is produced.

Method signatures are declared by method definitions. Only one constraint can be added to a method signature in addition to those of parameter signatures:

- The **varargs** constraint may be included to indicate that all arguments past this point are optional. When it appears, the calling convention shall be one that supports variable argument lists.

Method signatures are used in two different ways. They are used as part of a method definition and as a description of a calling site when calling through a function pointer. In this latter case, the method signature indicates

- the calling convention (which may include platform-specific calling conventions)
- the type of all the argument values that are being passed,
- if needed, a varargs marker indicating where the fixed parameter list ends and the variable parameter list begins

When used as part of a method definition, the varargs constraint is represented by the choice of calling convention.

**CLS Rule 15:** The varargs constraint is not part of the CLS, and the only calling convention supported by the CLS is the standard managed calling convention.
Note:

CLS (consumer): there is no need to accept methods with variable argument lists or unmanaged calling convention.

CLS (extender): there is no need to provide syntax to declare varargs methods or unmanaged calling conventions.

CLS (framework): neither varargs methods nor methods with unmanaged calling conventions may be exposed externally.

### 7.7 Assignment Compatibility

The constraints in the type signature and the location signature affect assignment compatibility of a value to a location. Assignment compatibility of a value (described by a type signature) to a location (described by a location signature) is defined as follows:

One of the types supported by the exact type of the value is the same as the type in the location signature.

This allows, for example, an instance of a class that inherits from a base class (hence supports the base class’s type contract) to be stored into a location whose type is that of the base class.

### 7.8 Type Safety and Verification

Since types specify contracts, it is important to know whether a given implementation lives up to these contracts. An implementation that lives up to the enforceable part of the contract (the named signatures) is said to be typesafe. An important part of the contract deals with restrictions on the visibility and accessibility of named items as well as the mapping of names to implementations and locations in memory.

Typesafe implementations only store values described by a type signature in a location that is assignment compatible with the location signature of the location (see clause 7.6.1). Typesafe implementations never apply an operation to a value that is not defined by the exact type of the value. Typesafe implementations only access locations that are both visible and accessible to them. In a typesafe implementation, the exact type of a value cannot change.

**Verification** is a mechanical process of examining an implementation and asserting that it is typesafe. Verification is said to fail if that process does not prove the type safety of an implementation. Verification is necessarily conservative: it may report failure for a typesafe implementation, but it never reports success for an implementation that is not typesafe. For example, most verification processes report implementations that do pointer-based arithmetic as failing verification, even if the implementation is in fact typesafe.

There are many different processes that can be the basis of verification. The simplest possible process simply says that all implementations are not typesafe. While correct and efficient this is clearly not particularly useful. By spending more resources (time and space) a process can correctly identify more typesafe implementations. It has been proven, however, that no mechanical process can in finite time and with no errors correctly identify all implementations as either typesafe or not typesafe. The choice of a particular verification process is thus a matter of engineering, based on the resources available to make the decision and the importance of detecting the typesafety of different programming constructs.

### 7.9 Type Definers

Type definers construct a new type from existing types. Implicit types (e.g., built-in types, arrays, and pointers including function pointers) are defined when they are used. The mention of an implicit type in a signature is in and of itself a complete definition of the type. Implicit types allow the VES to manufacture instances with a standard set of members, interfaces, etc. Implicit types need not have user-supplied names.

All other types shall be explicitly defined using an explicit type definition. The explicit type definers are:

- interface definitions – used to define interface types
- class definitions – used to define:
  - object types
Note: While class definitions always define class types, not all class types require a class definition. Array types and pointer types, which are implicitly defined, are also class types. See clause 7.2.3.

Similarly, not all types defined by a class definition are object types. Array types, explicitly defined object types, and boxed types are object types. Pointer types, function pointer types, and value types are not object types. See clause 7.2.3.

7.9.1 Array Types

An array type shall be defined by specifying the element type of the array, the rank (number of dimensions) of the array, and the upper and lower bounds of each dimension of the array. Hence, no separate definition of the array type is needed. The bounds (as well as indices into the array) shall be signed integers. While the actual bounds for each dimension are known at runtime, the signature may specify the information that is known at compile time: no bounds, a lower bound, or both an upper and lower bound.

Array elements shall be laid out within the array object in row-major order, i.e. the elements associated with the rightmost array dimension shall be laid out contiguously from lowest to highest index. The actual storage allocated for each array element may include platform-specific padding.

Values of an array type are objects; hence an array type is a kind of object type (see clause 7.2.3). Array objects are defined by the CTS to be a repetition of locations where values of the array element type are stored. The number of repeated values is determined by the rank and bounds of the array.

Only type signatures, not location signatures, are allowed as array element types.

Exact array types are created automatically by the VES when they are required. Hence, the operations on an array type are defined by the CTS. These generally are: allocating the array based on size and lower bound information, indexing the array to read and write a value, computing the address of an element of the array (a managed pointer), and querying for the rank, bounds, and the total number of values stored in the array.

CLS Rule 16: Arrays shall have elements with a CLS-compliant type and all dimensions of the array shall have lower bounds of zero. Only the fact that an item is an array and the element type of the array shall be required to distinguish between overloads. When overloading is based on two or more array types the element types shall be named types.

Note: so-called “jagged arrays” are CLS-compliant, but when overloading multiple array types they are one-dimensional, zero-based arrays of type System.Array.

CLS (consumer): there is no need to support arrays of non-CLS types, even when dealing with instances of System.Array. Overload resolution need not be aware of the full complexity of array types. Programmers should have access to the Get, Set, and Address methods on instances of System.Array if there is no language syntax for the full range of array types.

CLS (extender): there is no need to provide syntax to define non-CLS types of arrays or to extend interfaces or classes that use non-CLS array types. Shall provide access to the type System.Array, but may assume that all instances will have a CLS-compliant type. While the full array signature must be used to override an inherited method that has an array parameter, the full complexity of array types need not be made visible to programmers. Programmers should have access to the Get, Set, and Address methods on instances of System.Array if there is no language syntax for the full range of array types.

CLS (framework): non-CLS array types shall not appear in exposed members. Where possible, use only one-dimensional, zero-based arrays (vectors) of simple named types, since these are supported in the widest range of programming languages. Overloading on array types should be avoided, and when used shall obey the restrictions.

Array types form a hierarchy, with all array types inheriting from the type System.Array. This is an abstract class (see clause 7.9.6.2) that represents all arrays regardless of the type of their elements, their rank, or their upper and lower bounds. The VES creates one array type for each distinguishable array type. In general, array types are only distinguished by the type of their elements and their rank. The VES, however, treats single dimensional, zero-based arrays (also known as vectors) specially. Vectors are also distinguished by the type of
their elements, but a vector is distinct from a single-dimensional array of the same element type that has a non-zero lower bound. Zero-dimensional arrays are not supported.

Consider the following examples, using the syntax of CIL as described in Partition II:
Table 2: Array Examples

<table>
<thead>
<tr>
<th>Static specification of type</th>
<th>Actual type constructed</th>
<th>Allowed in CLS?</th>
</tr>
</thead>
<tbody>
<tr>
<td>int32[]</td>
<td>vector of int32</td>
<td>Yes</td>
</tr>
<tr>
<td>int32[0..5]</td>
<td>vector of int32</td>
<td>Yes</td>
</tr>
<tr>
<td>int32[1..5]</td>
<td>array, rank 1, of int32</td>
<td>No</td>
</tr>
<tr>
<td>int32[,]</td>
<td>array, rank 2, of int32</td>
<td>Yes</td>
</tr>
<tr>
<td>int32[0..3, 0..5]</td>
<td>array, rank 2, of int32</td>
<td>Yes</td>
</tr>
<tr>
<td>int32[0.., 0..]</td>
<td>array, rank 2, of int32</td>
<td>Yes</td>
</tr>
<tr>
<td>int32[1.., 0..]</td>
<td>array, rank 2, of int32</td>
<td>No</td>
</tr>
</tbody>
</table>

7.9.2 Unmanaged Pointer Types

An unmanaged pointer type (also known simply as a “pointer type”) is defined by specifying a location signature for the location the pointer references. Any signature of a pointer type includes this location signature. Hence, no separate definition of the pointer type is needed.

While pointer types are Reference Types, values of a pointer type are not objects (see clause 7.2.3), and hence it is not possible, given a value of a pointer type, to determine its exact type. The CTS provides two typesafe operations on pointer types: one to load the value from the location referenced by the pointer and the other to store an assignment compatible value into that location. The CTS also provides three operations on pointer types (byte-based address arithmetic): adding and subtracting integers from pointers, and subtracting one pointer from another. The results of the first two operations are pointers to the same type signature as the original pointer. See Partition III for details.

CLS Rule 17: Unmanaged pointer types are not CLS-compliant.

Note:
CLS (consumer): there is no need to support unmanaged pointer types.
CLS (extender): there is no need to provide syntax to define or access unmanaged pointer types.
CLS (framework): unmanaged pointer types shall not be externally exposed.

7.9.3 Delegates

Delegates are the object-oriented equivalent of function pointers. Unlike function pointers, delegates are object-oriented, type-safe, and secure. Delegates are created by defining a class that derives from the base type System.Delegate (see Partition IV). Each delegate type shall provide a method named Invoke with appropriate parameters, and each instance of a delegate forwards calls to its Invoke method to a compatible static or instance method on a particular object. The object and method to which it delegates are chosen when the delegate instance is created.

In addition to an instance constructor and an Invoke method, delegates may optionally have two additional methods: BeginInvoke and EndInvoke. These are used for asynchronous calls.

While, for the most part, delegates appear to be simply another kind of user defined class, they are tightly controlled. The implementations of the methods are provided by the VES, not user code. The only additional members that may be defined on delegate types are static or instance methods.

7.9.4 Interface Type Definition

An interface definition defines an interface type. An interface type is a named group of methods, locations and other contracts that shall be implemented by any object type that supports the interface contract of the same name. An interface definition is always an incomplete description of a value, and as such can never define a class type or an exact type, nor can it be an object type.
Zero or more object types can support an interface type, and only object types can support an interface type. An
interface type may require that objects that support it shall also support other (specified) interface types. An
object type that supports the named interface contract shall provide a complete implementation of the methods,
locations, and other contracts specified (but not implemented by) the interface type. Hence, a value of an object
type is also a value of all of the interface types the object type supports. Support for an interface contract is
declared, never inferred, i.e. the existence of implementations of the methods, locations, and other contracts
required by the interface type does not imply support of the interface contract.

CLS Rule 18: CLS-compliant interfaces shall not require the definition of non-CLS compliant methods in
order to implement them.

Note:

CLS (consumer): there is no need to deal with such interfaces.
CLS (extender): need not provide a mechanism for defining such interfaces..
CLS (framework): shall not expose any non-CLS compliant methods on interfaces it defines for external use.

Interfaces types are necessarily incomplete since they say nothing about the representation of the values of the
interface type. For this reason, an interface type definition shall not provide field definitions for values of the
interface type (i.e. instance fields), although it may declare static fields (see clause 7.4.3).

Similarly, an interface type definition shall not provide implementations for any methods on the values of its
type. However, an interface type definition may and usually does define method contracts (method name and
method signature) that shall be implemented by supporting types. An interface type definition may define and
implement static methods (see clause 7.4.3) since static methods are associated with the interface type itself
rather than with any value of the type.

Interfaces may have static or virtual methods, but shall not have instance methods.

CLS Rule 19: CLS-compliant interfaces shall not define static methods, nor shall they define fields.

Note:

CLS-compliant interfaces may define properties, events, and virtual methods.
CLS (consumer): need not accept interfaces that violate these rules.
CLS (extender): need not provide syntax to author interfaces that violate these rules.
CLS (framework): shall not externally expose interfaces that violate these rules. Where static methods,
instance methods, or fields are required a separate class may be defined that provides them.

Interface types may also define event and property contracts that shall be implemented by object types that
support the interface. Since event and property contracts reduce to sets of method contracts (Section 7.6), the
above rules for method definitions apply. For more information, see clause 7.11.4 and clause 7.11.3.

Interface type definitions may specify other interface contracts that implementations of the interface type are
required to support. See clause 7.9.11 for specifics.

An interface type is given a visibility attribute, as described in clause 7.5.3, that controls from where the
interface type may be referenced. An interface type definition is separate from any object type definition that
supports the interface type. Hence, it is possible, and often desirable, to have a different visibility for the
interface type and the implementing object type. However, since accessibility attributes are relative to the
implementing type rather than the interface itself, all members of an interface shall have public accessibility,
and no security permissions may be attached to members or to the interface itself.

7.9.5 Class Type Definition

All types other than interfaces, and those types for which a definition is automatically supplied by the CTS, are
defined by class definitions. A class type is a complete specification of the representation of the values of the
class type and all of the contracts (class, interface, method, property, and event) that are supported by the class
type. Hence, a class type is an exact type. A class definition, unless it specifies that the class is an abstract
**object type**, not only defines the class type: it also provides implementations for all of the contracts supported by the class type.

A class definition, and hence the implementation of the class type, always resides in some assembly. An assembly is a configured set of loadable code modules and other resources that together implement a unit of functionality.

**Note:** While class definitions always define class types, not all class types require a class definition. Array types and pointer types, which are implicitly defined, are also class types. See clause 7.2.3.

An explicit class definition is used to define:

- An object type (see clause 7.2.3).
- A value type and its associated boxed type (see clause 7.2.4).

An explicit class definition:

- Names the class type.
- Implicitly assigns the class type name to a scope, i.e. the assembly that contains the class definition, (see clause 7.5.2).
- Defines the class contract of the same name (see Section 7.6).
- Defines the representations and valid operations of all values of the class type using member definitions for the fields, methods, properties, and events (see Section 7.11).
- Defines the static members of the class type (see Section 7.11).
- Specifies any other interface and class contracts also supported by the class type.
- Supplies implementations for member and interface contracts supported by the class type.
- Explicitly declares a visibility for the type, either public or assembly (see clause 7.5.3).
- May optionally specify a method to be called to initialize the type.

The semantics of when, and what triggers execution of such type initialization methods, is as follows:

1. A type may have a type-initializer method, or not.
2. A type may be specified as having a relaxed semantic for its type-initializer method (for convenience below, we call this relaxed semantic **BeforeFieldInit**)
3. If marked **BeforeFieldInit** then the type’s initializer method is executed at, or sometime before, first access to any static field defined for that type
4. If *not* marked **BeforeFieldInit** then that type’s initializer method is executed at (i.e., is triggered by):
   - first access to any static or instance field of that type, or
   - first invocation of any static, instance or virtual method of that type
5. Execution of any type’s initializer method will *not* trigger automatic execution of any initializer methods defined by its base type, nor of any interfaces that the type implements

**Note:** **BeforeFieldInit** behavior is intended for initialization code with no interesting side-effects, where exact timing does not matter. Also, under **BeforeFieldInit** semantics, type initializers are allowed to be executed at or before first access to any static field of that Type -- at the discretion of the CLI

If a language wishes to provide more rigid behavior -- e.g. type initialization automatically triggers execution of parents initializers, in a top-to-bottom order, then it can do so by either:

- defining hidden static fields and code in each class constructor that touches the hidden static field of its parent and/or interfaces it implements, or
7.9.6 Object Type Definitions

All objects are instances of an object type. The object type of an object is set when the object is created and it is immutable. The object type describes the physical structure of the instance and the operations that are allowed on it. All instances of the same object type have the same structure and the same allowable operations. Object types are explicitly declared by a class type definition, with the exception of Array types, which are intrinsically provided by the VES.

7.9.6.1 Scope and Visibility

Since object type definitions are class type definitions, object type definitions implicitly specify the scope of the name of object type to be the assembly that contains the object type definition, see clause 7.5.2. Similarly, object type definitions shall also explicitly state the visibility attribute of the object type (either public or assembly); see clause 7.5.3.

7.9.6.2 Concreteness

An object type may be marked as abstract by the object type definition. An object type that is not marked abstract is by definition concrete. Only object types may be declared as abstract. Only an abstract object type is allowed to define method contracts for which the type or the VES does not also provide the implementation. Such method contracts are called abstract methods (see Section 7.11). All methods on an abstract class need not be abstract.

It is an error to attempt to create an instance of an abstract object type, whether or not the type has abstract methods. An object type that derives from an abstract object type may be concrete if it provides implementations for any abstract methods in the base object type and is not itself marked as abstract. Instances may be made of such a concrete derived class. Locations may have an abstract type, and instances of a concrete type that derives from the abstract type may be stored in them.

7.9.6.3 Type Members

Object type definitions include member definitions for all of the members of the type. Briefly, members of a type include fields into which values are stored, methods that may be invoked, properties that are available, and events that may be raised. Each member of a type may have attributes as described in Section 7.4.

- Fields of an object type specify the representation of values of the object type by specifying the component pieces from which it is composed (see clause 7.4.1). Static fields specify fields associated with the object type itself (see clause 7.4.3). The fields of an object type are named and they are typed via location signatures. The names of the members of the type are scoped to the type (see clause 7.5.2). Fields are declared using a field definition (see clause 7.11.2).

- Methods of an object type specify operations on values of the type (see clause 7.4.2). Static methods specify operations on the type itself (see clause 7.4.3). Methods are named and they have a method signature. The names of methods are scoped to the type (see clause 7.5.2). Methods are declared using a method definition (see clause 7.11.1).

- Properties of an object type specify named values that are accessible via methods that read and write the value. The name of the property is the grouping of the methods; the methods themselves are also named and typed via method signatures. The names of properties are scoped to the type (see clause 7.5.2). Properties are declared using a property definition (see clause 7.11.3).

- Events of an object type specify named state transitions in which subscribers may register/unregister interest via accessor methods. When the state changes, the subscribers are notified of the state transition. The name of the event is the grouping of the accessor methods; the methods themselves are also named and typed via method signatures. The names of events are scoped to the type (see clause 7.5.2). Events are declared using an event definition (see clause 7.11.4).
### 7.9.6.4 Supporting Interface Contracts

Object type definitions may declare that they support zero or more interface contracts. Declaring support for an interface contract places a requirement on the implementation of the object type to fully implement that interface contract. Implementing an interface contract always reduces to implementing the required set of methods, i.e. the methods required by the interface type.

The different types that the object type implements, i.e. the object type and any implemented interface types, are each a separate logical grouping of named members. If a class `Foo` implements an interface `IFoo` and `IFoo` declares a member method `int a()` and the class also declares a member method `int a()`, there are two members, one in the `IFoo` interface type and one in the `Foo` class type. An implementation of `Foo` will provide an implementation for both, potentially shared.

Similarly, if a class implements two interfaces `IFoo` and `IBar` each of which defines a method `int a()` the class will supply two method implementations, one for each interface, although they may share the actual code of the implementation.

**CLS Rule 20:** CLS-compliant classes, value types, and interfaces shall not require the implementation of non-CLS-compliant interfaces.

**Note:**
- CLS (consumer): need not accept classes, value types or interfaces that violate this rule.
- CLS (extender): need not provide syntax to author classes, value types, or interfaces that violate this rule.
- CLS (framework): shall not externally expose classes, value types, or interfaces that violate this rule.

### 7.9.6.5 Supporting Class Contracts

Object type definitions may declare support for one other class contract. Declaring support for another class contract is synonymous with object type inheritance (see clause 7.9.9).

### 7.9.6.6 Constructors

New values of an object type are created via constructors. Constructors shall be instance methods, defined via a special form of method contract, which defines the method contract as a constructor for a particular object type. The constructors for an object type are part of the object type definition. While the CTS and VES ensure that only a properly defined constructor is used to make new values of an object type, the ultimate correctness of a newly constructed object is dependent on the implementation of the constructor itself.

Object types shall define at least one constructor method, but that method need not be public. Creating a new value of an object type by invoking a constructor involves the following steps in order:

1. Space for the new value is allocated in managed memory.
2. VES data structures of the new value are initialized and user-visible memory is zeroed.
3. The specified constructor for the object type is invoked.

Inside the constructor, the object type may do any initialization it chooses (possibly none).

**CLS Rule 21:** An object constructor shall call some class constructor of its base class before any access occurs to inherited instance data. This does not apply to value types, which need not have constructors.

**CLS Rule 22:** An object constructor shall not be called except as part of the creation of an object, and an object shall not be initialized twice.

**Note:**
- CLS (consumer): Shall provide syntax for choosing the constructor to be called when an object is created.
- CLS (extender): Shall provide syntax for defining constructor methods with different signatures. May issue a compiler error if the constructor does not obey these rules.
CLS (framework): May assume that object creation includes a call to one of the constructors, and that no object is initialized twice. `System.MemberwiseClone` (see Partition IV) and deserialization (including object remoting) may not run constructors.

### 7.9.6.7 Finalizers

A class definition that creates an object type may supply an instance method to be called when an instance of the class is no longer accessible. The class `System.GC` (see Partition IV) provides limited control over the behavior of finalizers through the methods `SuppressFinalize` and `ReRegisterForFinalize`. Conforming implementations of the CLI may specify and provide additional mechanisms that affect the behavior of finalizers.

A conforming implementation of the CLI shall not automatically call a finalizer twice for the same object unless

- there has been an intervening call to `ReRegisterForFinalize` (not followed by a call to `SuppressFinalize`), or
- the program has invoked an implementation-specific mechanism that is clearly specified to produce an alteration to this behavior

**Rationale:** Programmers expect that finalizers are run precisely once on any given object unless they take an explicit action to cause the finalizer to be run multiple times.

It is legal to define a finalizer for a Value Type. That finalizer however will only be run for boxed instances of that Value Type.

**Note:** Since programmers may depend on finalizers to be called, the CLI should make every effort to ensure that finalizers are called, before it shuts down, for all objects that have not been exempted from finalization by a call to `SuppressFinalize`. The implementation should specify any conditions under which this behavior cannot be guaranteed.

**Note:** Since resources may become exhausted if finalizers are not called expeditiously, the CLI should ensure that finalizers are called soon after the instance becomes inaccessible. While relying on memory pressure to trigger finalization is acceptable, implementers should consider the use of additional metrics.

### 7.9.7 Value Type Definition

Not all types defined by a class definition are object types (see clause 7.2.3); in particular, value types are not object types but they are defined using a class definition. A class definition for a value type defines both the (unboxed) value type and the associated boxed type (see clause 7.2.4). The members of the class definition define the representation of both:

1. When a non-static method (i.e. an instance or virtual method) is called on the value type its `this` pointer is a managed reference to the instance, whereas when the method is called on the associated boxed type the `this` pointer is an object reference.

Instance methods on value types receive a `this` pointer that is a managed pointer to the unboxed type whereas virtual methods (including those on interfaces implemented by the value type) receive an instance of the boxed type.

1. Value types do not support interface contracts, but their associated boxed types do.
2. A value type does not inherit; rather the base type specified in the class definition defines the base type of the boxed type.
3. The base type of a boxed type shall not have any fields.
4. Unlike object types, instances of value types do not require a constructor to be called when an instance is created. Instead, the verification rules require that verifiable code initialize instances to zero (null for object fields).
7.9.8 **Type Inheritance**

Inheritance of types is another way of saying that the derived type guarantees support for all of the type contracts of the base type. In addition, the derived type usually provides additional functionality or specialized behavior. A type inherits from a base type by implementing the type contract of the base type. An interface type inherits from zero or more other interfaces. Value types do not inherit, although the associated boxed type is an object type and hence inherits from other types.

The derived class type shall support all of the supported interfaces contracts, class contracts, event contracts, method contracts, and property contracts of its base type. In addition, all of the locations defined by the base type are also defined in the derived type. The inheritance rules guarantee that code that was compiled to work with a value of a base type will still work when passed a value of the derived type. Because of this, a derived type also inherits the implementations of the base type. The derived type may extend, override, and/or hide these implementations.

7.9.9 **Object Type Inheritance**

With the sole exception of `System.Object`, which does not inherit from any other object type, all object types shall either explicitly or implicitly declare support for (inherit from) exactly one other object type. The graph of the inherits-relation shall form a singly rooted tree with `System.Object` at the base, i.e. all object types eventually inherit from the type `System.Object`.

An object type declares it shall not be used as a base type (be inherited from) by declaring that it is a sealed type.

**CLS Rule 23:** `System.Object` is CLS-compliant. Any other CLS-compliant class shall inherit from a CLS-compliant class.

Arrays are object types and as such inherit from other object types. Since arrays object types are manufactured by the VES, the inheritance of arrays is fixed. See clause 7.9.4.

7.9.10 **Value Type Inheritance**

Value Types, in their unboxed form, do not inherit from any type. Boxed value types shall inherit directly from `System.ValueType` unless they are enumerations, in which case they shall inherit from `System.Enum`. Boxed value types shall be sealed.

Logically, the boxed type corresponding to a value type

- Is an object type.
- Will specify which object type is its base type, i.e. the object type from which it inherits.
- Will have a base type that has no fields defined.
- Will be sealed to avoid dealing with the complications of value slicing

The more restrictive rules specified here allow for more efficient implementation without severely compromising functionality.

7.9.11 **Interface Type Inheritance**

Interface types may inherit from multiple interface types, i.e. an interface contract may list other interface contracts that shall also be supported. Any type that implements support for an interface type shall also implement support for all of the inherited interface types. This is different from object type inheritance in two ways.

- Object types form a single inheritance tree; interface types do not.
- Object type inheritance specifies how implementations are inherited; interface type inheritance does not, since interfaces do not define implementation. Interface type inheritance specifies additional contracts that an implementing object type shall support.
To highlight the last difference, consider an interface, `IFoo`, that has a single method. An interface, `IBar`, which inherits from it is requiring that any object type that supports `IBar` also support `IFoo`. It does not say anything about which methods `IBar` itself will have.

### 7.10 Member Inheritance

Only object types may inherit implementations, hence only object types may inherit members (see clause 7.9.8). Interface types, while they do inherit from other interface types, only inherit the requirement to implement method contracts, never fields or method implementations.

#### 7.10.1 Field Inheritance

A derived object type inherits all of the non-static fields of its base object type. This allows instances of the derived type to be used wherever instances of the base type are expected (the shapes, or layouts, of the instances will be the same). Static fields are not inherited. Just because a field exists does not mean that it may be read or written. The type visibility, field accessibility, and security attributes of the field definition (see clause 7.5.3) determine if a field is accessible to the derived object type.

#### 7.10.2 Method Inheritance

A derived object type inherits all of the instance and virtual methods of its base object type. It does not inherit constructors or static methods. Just because a method exists does not mean that it may be invoked. It shall be accessible via the typed reference that is being used by the referencing code. The type visibility, method accessibility, and security attributes of the method definition (see clause 7.5.3) determine if a method is accessible to the derived object type.

A derived object type may hide a non-virtual (i.e. static or instance) method of its base type by providing a new method definition with the same name or same name and signature. Either method may still be invoked, subject to method accessibility rules, since the type that contains the method always qualifies a method reference. Virtual methods may be marked as `final`, in which case they shall not be overridden in a derived object type. This ensures that the implementation of the method is available, by a virtual call, on any object that supports the contract of the base class that supplied the final implementation. If a virtual method is not final it is possible to demand a security permission in order to override the virtual method, so that the ability to provide an implementation can be limited to classes that have particular permissions. When a derived type overrides a virtual method, it may specify a new accessibility for the virtual method, but the accessibility in the derived class shall permit at least as much access as the access granted to the method it is overriding. See clause 7.5.3.

#### 7.10.3 Property and Event Inheritance

Properties and events are fundamentally constructs of the metadata intended for use by tools that target the CLI and are not directly supported by the VES itself. It is, therefore, the job of the source language compiler and the Reflection library [see Partition IV] to determine rules for name hiding, inheritance, and so forth. The source compiler shall generate CIL that directly accesses the methods named by the events and properties, not the events or properties themselves.

#### 7.10.4 Hiding, Overriding, and Layout

There are two separate issues involved in inheritance. The first is which contracts a type shall implement and hence which member names and signatures it shall provide. The second is the layout of the instance so that an instance of a derived type can be substituted for an instance of any of its base types. Only the non-static fields and the virtual methods that are part of the derived type affect the layout of an object.

The CTS provides independent control over both the names that are visible from a base type (hiding) and the sharing of layout slots in the derived class (overriding). Hiding is controlled by marking a member in the derived class as either `hide by name` or `hide by name-and-signature`. Hiding is always performed based on the kind of member, that is, derived field names may hide base field names, but not method names, property names, or event names. If a derived member is marked `hide by name`, then members of the same kind in the base class with the same name are not visible in the derived class; if the member is marked `hide by name-and-signature` then only a member of the same kind with exactly the same name and type (for fields) or method signature (for methods) is hidden in the derived class. Implementation of the distinction between these two
forms of hiding is provided entirely by source language compilers and the Reflection library; it has no direct impact on the VES itself.

For example:

```csharp
class Base
{
    field int32 A;
    field System.String A;
    method int32 A();
    method int32 A(int32);
}
class Derived inherits from Base
{
    field int32 A;
    hidebysig method int32 A();
}
```

The member names available in type `Derived` are:

<table>
<thead>
<tr>
<th>Kind of member</th>
<th>Type / Signature of member</th>
<th>Name of member</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field</td>
<td>int32</td>
<td>A</td>
</tr>
<tr>
<td>Method</td>
<td>() -&gt; int32</td>
<td>A</td>
</tr>
<tr>
<td>Method</td>
<td>(int32) -&gt; int32</td>
<td>A</td>
</tr>
</tbody>
</table>

While hiding applies to all members of a type, overriding deals with object layout and is applicable only to instance fields and virtual methods. The CTS provides two forms of member overriding, **new slot** and **expect existing slot**. A member of a derived type that is marked as a new slot will always get a new slot in the object’s layout, guaranteeing that the base field or method is available in the object by using a qualified reference that combines the name of the base type with the name of the member and its type or signature. A member of a derived type that is marked as expect existing slot will re-use (i.e. share or override) a slot that corresponds to a member of the same kind (field or method), name, and type if one already exists from the base type; if no such slot exists, a new slot is allocated and used.

The general algorithm that is used for determining the names in a type and the layout of objects of the type is roughly as follows:

- Flatten the inherited names (using the **hide by name** or **hide by name-and-signature** rule) ignoring accessibility rules.
- For each new member that is marked “expect existing slot”, look to see if an exact match on kind (i.e. field or method), name, and signature exists and use that slot if it is found, otherwise allocate a new slot.
- After doing this for all new members, add these new member-kind/name/signatures to the list of members of this type.
- Finally, remove any inherited names that match the new members based on the **hide by name** or **hide by name-and-signature** rules.

### 7.11 Member Definitions

Object type definitions, interface type definitions, and value type definitions may include member definitions. Field definitions define the representation of values of the type by specifying the substructure of the value. Method definitions define operations on values of the type and operations on the type itself (static methods). Property and event definitions may only be defined on object types. Property and events define named groups of accessors. Method definitions implement the named event or property behavior. Nested type declarations define types whose names are scoped by the enclosing type and whose instances have full access to all members of the enclosing class.

Depending on the kind of type definition, there are restrictions on the member definitions allowed.
7.11.1 Method Definitions

Method definitions are composed of a name, a method signature, and optionally an implementation of the method. The method signature defines the calling convention, type of the parameters to the method, and the return type of the method (see clause 7.6.1). The implementation is the code to execute when the method is invoked. A value type or object type may define only one method of a given name and signature. However, a derived object type may have methods that are of the same name and signature as its base object type. See clause 7.10.2 and clause 7.10.4.

The name of the method is scoped to the type (see clause 7.5.2). Methods may be given accessibility attributes (see clause 7.5.3). Methods may only be invoked with arguments that are assignment compatible with the parameters types of the method signature. The return value of the method shall also be assignment compatible with the location in which it is stored.

Methods may be marked as static, indicating that the method is not an operation on values of the type but rather an operation associated with the type as a whole. Methods not marked as static define the valid operations on a value of a type. When a non-static method is invoked, a particular value of the type, referred to as this or the this pointer, is passed as an implicit parameter.

A method definition that does not include a method implementation shall be marked as abstract. All non-static methods of an interface definition are abstract. Abstract method definitions are only allowed in object types that are marked as abstract.

A non-static method definition in an object type may be marked as virtual, indicating that an alternate implementation may be provided in derived types. All non-static method definitions in interface definitions shall be virtual methods. Virtual method may be marked as final, indicating that derived object types are not allowed to override the method implementation.

7.11.2 Field Definitions

Field definitions are composed of a name and a location signature. The location signature defines the type of the field and the accessing constraints, see clause 7.6.1. A value type or object type may define only one field of a given name and type. However, a derived object type may have fields that are of the same name and type as its base object type. See clause 7.10.1 and clause 7.10.4.

The name of the field is scoped to the type (see clause 7.5.2). Fields may be given accessibility attributes, see clause 7.5.3. Fields may only store values that are assignment compatible with the type of the field (see clause 7.3.1).

Fields may be marked as static, indicating that the field is not part of values of the type but rather a location associated with the type as a whole. Locations for the static fields are created when the type is loaded and initialized when the type is initialized.

Fields not marked as static define the representation of a value of a type by defining the substructure of the value (see clause 7.4.1). Locations for such fields are created within every value of the type whenever a new value is constructed. They are initialized during construction of the new value. A non-static field of a given name is always located at the same place within every value of the type.

A field that is marked serializable is to be serialized as part of the persistent state of a value of the type. This standard does not specify the mechanism by which this is accomplished.

7.11.3 Property Definitions

A property definition defines a named value and the methods that access the value. A property definition defines the accessing contracts on that value. Hence, the property definition specifies which accessing methods exist and their respective method contracts. An implementation of a type that declares support for a property contract shall implement the accessing methods required by the property contract. The implementation of the accessing methods defines how the value is retrieved and stored.

A property definition is always part of either an interface definition or a class definition. The name and value of a property definition is scoped to the object type or the interface type that includes the property definition. While all of the attributes of a member may be applied to a property (accessibility, static, etc.) these are not enforced by the CTS. Instead, the CTS requires that the method contracts that comprise the property shall
match the method implementations, as with any other method contract. There are no CIL instructions associated with properties, just metadata.

By convention, properties define a **getter** method (for accessing the current value of the property) and optionally a **setter** method (for modifying the current value of the property). The CTS places no restrictions on the set of methods associated with a property, their names, or their usage.

**CLS Rule 24:** The methods that implement the **getter** and **setter** methods of a property shall be marked **SpecialName** in the metadata.

**CLS Rule 25:** The accessibility of a property and of its accessors shall be identical.

**CLS Rule 26:** A property and its accessors shall all be static, all be virtual, or all be instance.

**CLS Rule 27:** The type of a property shall be the return type of the **getter** and the type of the last argument of the **setter**. The types of the parameters of the property shall be the types of the parameters to the **getter** and the types of all but the final parameter of the **setter**. All of these types shall be CLS-compliant, and shall not be managed pointers (i.e., shall not be passed by reference).

**CLS Rule 28:** Properties shall adhere to a specific naming pattern. See Section 9.4. The **SpecialName** attribute referred to in CLS rule 26 shall be ignored in appropriate name comparisons and shall adhere to identifier rules.

**Note:**

CLS (consumer): Shall ignore the **SpecialName** bit in appropriate name comparisons and shall adhere to identifier rules. Otherwise, no direct support other than the usual access to the methods that define the property.

CLS (extender): Shall ignore the **SpecialName** bit in appropriate name comparisons and shall adhere to identifier rules. Otherwise, no direct support other than the usual access to the methods that define the property. In particular, an extender need not be able to define properties.

CLS (framework): Shall design understanding that not all CLS languages will access the property using special syntax.

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### 7.11.4 Event Definitions

The CTS supports events in precisely the same way that it supports properties (see clause 7.11.3). The conventional methods, however, are different and include means for subscribing and unsubscribing to events as well as for firing the event.

**CLS Rule 29:** The methods that implement an event shall be marked **SpecialName** in the metadata.

**CLS Rule 30:** The accessibility of an event and of its accessors shall be identical.

**CLS Rule 31:** The **add** and **remove** methods for an event shall both either be present or absent.

**CLS Rule 32:** The **add** and **remove** methods for an event shall each take one parameter whose type defines the type of the event and that shall be derived from `System.Delegate`.

**CLS Rule 33:** Events shall adhere to a specific naming pattern. See Section 9.4. The **SpecialName** attribute referred to in CLS rule 31 shall be ignored in appropriate name comparisons and shall adhere to identifier rules.

**Note:**

CLS (consumer): Shall ignore the **SpecialName** bit in appropriate name comparisons and shall adhere to identifier rules. Otherwise, no direct support other than the usual access to the methods that define the event.

CLS (extender): Shall ignore the **SpecialName** bit in appropriate name comparisons and shall adhere to identifier rules. Otherwise, no direct support other than the usual access to the methods that define the event. In particular, an extender need not be able to define events.

CLS (framework): Shall design based on the understanding that not all CLS languages will access the event using special syntax.
7.11.5 Nested Type Definitions

A nested type definition is identical to a top-level type definition, with one exception: a top-level type has a visibility attribute, while the visibility of a nested type is the same as the visibility of the enclosing type. See clause 7.5.3.
8 CLI Metadata

This section and its subsections contain only informative text, with the exception of the CLS rules introduced here and repeated in Chapter 10. The metadata format is specified in Partition II.

New types – value types and reference types – are introduced into the CTS via type declarations expressed in metadata. In addition, metadata is a structured way to represent all information that the CLI uses to locate and load classes, lay out instances in memory, resolve method invocations, translate CIL to native code, enforce security, and set up runtime context boundaries. Every CLI PE/COFF module (see Partition II) carries a compact metadata binary that is emitted into the module by the CLI-enabled development tool or compiler.

Each CLI-enabled language will expose a language-appropriate syntax for declaring types and members and for annotating them with attributes that express which services they require of the infrastructure. Type imports are also handled in a language-appropriate way, and it is the development tool or compiler that consumes the metadata to expose the types that the developer sees.

Note that the typical component or application developer will not need to be aware of the rules for emitting and consuming CLI metadata. While it may help a developer to understand the structure of metadata, the rules outlined in this section are primarily of interest to tool builders and compiler writers.

8.1 Components and Assemblies

Each CLI component carries the metadata for declarations, implementations, and references specific to that component. Therefore, the component-specific metadata is referred to as component metadata, and the resulting component is said to be self-describing. In object models such as COM or CORBA, this information is represented by a combination of typelibs, IDL files, DLLRegisterServer, and a myriad of custom files in disparate formats and separate from the actual executable file. In contrast, the metadata is a fundamental part of a CLI component.

Collections of CLI components and other files are packaged together for deployment into assemblies, discussed in more detail in a later section. An assembly is a logical unit of functionality that serves as the primary unit of reuse in the CLI. Assemblies establish a name scope for types.

Types declared and implemented in individual components are exported for use by other implementations via the assembly in which the component participates. All references to a type are scoped by the identity of the assembly in whose context the type is being used. The CLI provides services to locate a referenced assembly and request resolution of the type reference. It is this mechanism that provides an isolation scope for applications: the assembly alone controls its composition.

8.2 Accessing Metadata

Metadata is emitted into and read from a CLI module using either direct access to the file format as described in Partition II or through the Reflection library. It is possible to create a tool that verifies a CLI module, including the metadata, during development, based on the specifications supplied in Partition III and Partition II.

When a class is loaded at runtime, the CLI loader imports the metadata into its own in-memory data structures, which can be browsed via the CLI Reflection services. The Reflection services should be considered as similar to a compiler; they automatically walk the inheritance hierarchy to obtain information about inherited methods and fields, they have rules about hiding by name or name-and-signature, rules about inheritance of methods and properties, and so forth.

8.2.1 Metadata Tokens

A metadata token is an implementation dependent encoding mechanism. Partition II describes the manner in which metadata tokens are embedded in various sections of a CLI PE/COFF module. Metadata tokens are embedded in CIL and native code to encode method invocations and field accesses at call sites; the token is
used by various infrastructure services to retrieve information from metadata about the reference and the type on which it was scoped in order to resolve the reference.

A metadata token is a typed identifier of a metadata object (type declaration, member declaration, etc.). Given a token, its type can be determined and it is possible to retrieve the specific metadata attributes for that metadata object. However, a metadata token is not a persistent identifier. Rather it is scoped to a specific metadata binary. A metadata token is represented as an index into a metadata data structure, so access is fast and direct.

### 8.2.2 Member Signatures in Metadata

Every location — including fields, parameters, method return values, and properties — has a type, and a specification for its type is carried in metadata.

A value type describes values that are represented as a sequence of bits. A reference type describes values that are represented as the location of a sequence of bits. The CLI provides an explicit set of built-in types, each of which has a default runtime form as either a value type or a reference type. The metadata APIs may be used to declare additional types, and part of the type specification of a variable encodes the identity of the type as well as which form (value or reference) the type is to take at runtime.

Metadata tokens representing encoded types are passed to CIL instructions that accept a type (newobj, newarray, ldtoken). See the CIL instruction set specification in Partition III.

These encoded type metadata tokens are also embedded in member signatures. To optimize runtime binding of field accesses and method invocations, the type and location signatures associated with fields and methods are encoded into member signatures in metadata. A member signature embodies all of the contract information that is used to decide whether a reference to a member succeeds or fails.

### 8.3 Unmanaged Code

It is possible to pass data from CLI managed code to unmanaged code. This always involves a transition from managed to unmanaged code, which has some runtime cost, but data can often be transferred without copying. When data must be reformatted the VES provides a reasonable specification of default behavior, but it is possible to use metadata to explicitly require other forms of marshalling (i.e. reformatted copying). The metadata also allows access to unmanaged methods through implementation-specific pre-existing mechanisms.

### 8.4 Method Implementation Metadata

For each method for which an implementation is supplied in the current CLI module, the tool or compiler will emit information used by the CIL-to-native code compilers, the CLI loader, and other infrastructure services. This information includes:

- Whether the code is managed or unmanaged.
- Whether the implementation is in native code or CIL (note that all CIL code is managed).
- The location of the method body in the current module, as an address relative to the start of the module file in which it is located (a Relative Virtual Address, or RVA). Or, alternatively, the RVA is encoded as 0 and other metadata is used to tell the infrastructure where the method implementation will be found, including:
  - An implementation to be located via the CLI Interoperability Services. See related specifications for details.
  - Forwarding calls through an imported global static method.

### 8.5 Class Layout

In the general case, the CLI loader is free to lay out the instances of a class in any way it chooses, consistent with the rules of the CTS. However, there are times when a tool or compiler needs more control over the layout. In the metadata, a class is marked with an attribute indicating whether its layout rule is:
• **autolayout**: A class marked “autolayout” indicates that the loader is free to lay out the class in any way it sees fit; any layout information that may have been specified is ignored. This is the default.

• **layoutsequential**: A class marked “layoutsequential” guides the loader to preserve field order as emitted, but otherwise the specific offsets are calculated based on the CLI type of the field; these may be shifted by explicit offset, padding, and/or alignment information.

• **explicitlayout**: A class marked “explicitlayout” causes the loader to ignore field sequence and to use the explicit layout rules provided, in the form of field offsets and/or overall class size or alignment. There are restrictions on legal layouts, specified in Partition II.

It is also possible to specify an overall size for a class. This enables a tool or compiler to emit a value type specification where only the size of the type is supplied. This is useful in declaring CLI built-in types (such as 32-bit integer). It is also useful in situations where the data type of a member of a structured value type does not have a representation in CLI metadata (e.g., C++ bit fields). In the latter case, as long as the tool or compiler controls the layout, and CLI doesn’t need to know the details or play a role in the layout, this is sufficient. Note that this means that the VES can move bits around but can’t marshal across machines – the emitting tool or compiler will need to handle the marshaling.

Optionally, a developer may specify a packing size for a class. This is layout information that is not often used but it allows a developer to control the alignment of the fields. It is not an alignment specification, per se, but rather serves as a modifier that places a ceiling on all alignments. Typical values are 1, 2, 4, 8, or 16.

For the full specification of class layout attributes, see the classes in `System.Runtime.InteropServices` in Partition IV.

8.6 **Assemblies: Name Scopes for Types**

An assembly is a collection of resources that are built to work together to deliver a cohesive set of functionality. An assembly carries all of the rules necessary to ensure that cohesion. It is the unit of access to resources in the CLI.

Externally, an assembly is a collection of exported resources, including types. Resources are exported by name. Internally, an assembly is a collection of public (exported) and private (internal to the assembly) resources. It is the assembly that determines which resources are to be exposed outside of the assembly and which resources are accessible only within the current assembly scope. It is the assembly that controls how a reference to a resource, public or private, is mapped onto the bits that implement the resource. For types in particular, the assembly may also supply runtime configuration information. A CLI module can be thought of as a packaging of type declarations and implementations, where the packaging decisions may change under the covers without affecting clients of the assembly.

The identity of a type is its assembly scope and its declared name. A type defined identically in two different assemblies is considered two different types.

**Assembly Dependencies**: An assembly may depend on other assemblies. This happens when implementations in the scope of one assembly reference resources that are scoped in or owned by another assembly.

- All references to other assemblies are resolved under the control of the current assembly scope. This gives an assembly an opportunity to control how a reference to another assembly is mapped onto a particular version (or other characteristic) of that referenced assembly (although that target assembly has sole control over how the referenced resource is resolved to an implementation).

- It is always possible to determine which assembly scope a particular implementation is running in. All requests originating from that assembly scope are resolved relative to that scope.

From a deployment perspective, an assembly may be deployed by itself, with the assumption that any other referenced assemblies will be available in the deployed environment. Or, it may be deployed with its dependent assemblies.

**Manifests**: Every assembly has a manifest that declares what files make up the assembly, what types are exported, and what other assemblies are required to resolve type references within the assembly. Just as CLI components are self-describing via metadata in the CLI component, so are assemblies self-describing via their
manifests. When a single file makes up an assembly it contains both the metadata describing the types defined in the assembly and the metadata describing the assembly itself. When an assembly contains more than one file with metadata, each of the files describes the types defined in the file, if any, and one of these files also contains the metadata describing the assembly (including the names of the other files, their cryptographic hashes, and the types they export outside of the assembly).

Applications: Assemblies introduce isolation semantics for applications. An application is simply an assembly that has an external entry point that triggers (or causes a hosting environment such as a browser to trigger) the creation of a new Application Domain. This entry point is effectively the root of a tree of request invocations and resolutions. Some applications are a single, self-contained assembly. Others require the availability of other assemblies to provide needed resources. In either case, when a request is resolved to a module to load, the module is loaded into the same Application Domain from which the request originated. It is possible to monitor or stop an application via the Application Domain.

References: A reference to a type always qualifies a type name with the assembly scope within which the reference is to be resolved – that is, an assembly establishes the name scope of available resources. However, rather than establishing relationships between individual modules and referenced assemblies, every reference is resolved through the current assembly. This allows each assembly to have absolute control over how references are resolved. See Partition II.

8.7 Metadata Extensibility

CLI metadata is extensible. There are three reasons this is important:

- The Common Language Specification (CLS) is a specification for conventions that languages and tools agree to support in a uniform way for better language integration. The CLS constrains parts of the CTS model, and the CLS introduces higher-level abstractions that are layered over the CTS. It is important that the metadata be able to capture these sorts of development-time abstractions that are used by tools even though they are not recognized or supported explicitly by the CLS.

- It should be possible to represent language-specific abstractions in metadata that are neither CLI nor CLS language abstractions. For example, it should be possible, over time, to enable languages like C++ to not require separate header files or IDL files in order to use types, methods, and data members exported by compiled modules.

- It should be possible, in member signatures, to encode types and type modifiers that are used in language-specific overloading. For example, to allow C++ to distinguish int from long even on 32-bit machines where both map to the underlying type int32.

This extensibility comes in the following forms:

- Every metadata object can carry custom attributes, and the metadata APIs provide a way to declare, enumerate, and retrieve custom attributes. Custom attributes may be identified by a simple name, where the value encoding is opaque and known only to the specific tool, language, or service that defined it. Or, custom attributes may be identified by a type reference, where the structure of the attribute is self-describing (via data members declared on the type) and any tool including the CLI Reflection services may browse the value encoding.


Note:

CLS (consumer): Shall be able to read attributes encoded using the restricted scheme.

CLS (extender): Must meet all requirements for CLS consumer and be able to author new classes and new attributes. Shall be able to attach attributes based on existing attribute classes to any metadata that is emitted. Shall implement the rules for the System.AttributeUsageAttribute (see Partition IV).
CLS (framework): Shall externally expose only attributes that are encoded within the CLS rules and following the conventions specified for System.AttributeUsageAttribute.

- In addition to CTS type extensibility, it is possible to emit custom modifiers into member signatures (see Types in Partition II). The CLI will honor these modifiers for purposes of method overloading and hiding, as well as for binding, but will not enforce any of the language-specific semantics. These modifiers can reference the return type or any parameter of a method, or the type of a field. They come in two kinds: **required modifiers** that anyone using the member must understand in order to correctly use it, and **optional modifiers** that may be ignored if the modifier is not understood.

CLS Rule 35: The CLS does not allow publicly visible required modifiers (modreq, see Partition II), but does allow optional modifiers (modopt, see Partition II) they do not understand.

Note:

CLS (consumer): Shall be able to read metadata containing optional modifiers and correctly copy signatures that include them. May ignore these modifiers in type matching and overload resolution. May ignore types that become ambiguous when the optional modifiers are ignored, or that use required modifiers.

CLS (extender): Shall be able to author overrides for inherited methods with signatures that include optional modifiers. Consequently, an extender must be able to copy such modifiers from metadata that it imports. There is no requirement to support required modifiers, nor to author new methods that have any kind of modifier in their signature.

CLS (framework): Shall not use required modifiers in externally visible signatures unless they are marked as not CLS-compliant. Shall not expose two members on a class that differ only by the use of optional modifiers in their signature unless only one is marked CLS-compliant.

8.8 Globals, Imports, and Exports

The CTS does not have the notion of **global statics**: all statics are associated with a particular class. Nonetheless, the metadata is designed to support languages that rely on static data that is stored directly in a PE/COFF file and accessed by its relative virtual address. In addition, while access to managed data and managed functions is mediated entirely through the metadata itself, the metadata provides a mechanism for accessing unmanaged data and unmanaged code.

CLS Rule 36: Global static fields and methods are not CLS-compliant.

Note:

CLS (consumer): Need not support global static fields or methods.

CLS (extender): Need not author global static fields or methods.

CLS (framework): Shall not define global static fields or methods.

8.9 Scoped Statics

The CTS does not include a model for file- or function-scoped static functions or data members. However, there are times when a compiler needs a metadata token to emit into CIL for a scoped function or data member. The metadata allows members to be marked so that they are never visible/accessible outside of the PE/COFF file in which they are declared and for which the compiler guarantees to enforce all access rules.

End informative text
9 Name and Type Rules for the Common Language Specification

9.1 Identifiers

Languages that are either case-sensitive or case-insensitive can support the CLS. Since its rules apply only to items exposed to other languages, private members or types that aren’t exported from an assembly may use any names they choose. For interoperation, however, there are some restrictions.

In order to make tools work well with a case-sensitive language it is important that the exact case of identifiers be maintained. At the same time, when dealing with non-English languages encoded in Unicode, there may be more than one way to represent precisely the same identifier that includes combining characters. The CLS requires that identifiers obey the restrictions of the appropriate Unicode standard and persist them in Canonical form C, which preserves case but forces combining characters into a standard representation. See CLS Rule 4, in Section 7.5.1.

At the same time, it is important that externally visible names not conflict with one another when used from a case-insensitive programming language. As a result, all identifier comparisons shall be done internally to CLS-compliant tools using the Canonical form KC, which first transforms characters to their case-canonical representation. See CLS Rule 4, in Section 7.5.1.

When a compiler for a CLS-compliant language supports interoperability with a non-CLS-compliant language it must be aware that the CTS and VES perform all comparisons using code-point (i.e. byte-by-byte) comparison. Thus, even though the CLS requires that persisted identifiers be in Canonical form C, references to non-CLS identifiers will have to be persisted using whatever encoding the non-CLS language chose to use. It is a language design issue, not covered by the CTS or the CLS, precisely how this should be handled.

9.2 Overloading

Note: The CTS, while it describes inheritance, object layout, name hiding, and overriding of virtual methods, does not discuss overloading at all. While this is surprising, it arises from the fact that overloading is entirely handled by compilers that target the CTS and not the type system itself. In the metadata, all references to types and type members are fully resolved and include the precise signature that is intended. This choice was made since every programming language has its own set of rules for coercing types and the VES does not provide a means for expressing those rules.

Following the rules of the CTS, it is possible for duplicate names to be defined in the same scope as long as they differ in either kind (field, method, etc.) or signature. The CLS imposes a stronger restriction for overloading methods. Within a single scope, a given name may refer to any number of methods provided they differ in any of the following:

- Number of parameters
- Type of each argument
- Calling convention
- Custom modifiers
- Return type
- Whether a parameter is passed by value or by reference (i.e. as a managed pointer or by-ref)

There is one exception to this rule. For the special names op_Implicit and op_Explicit described in clause 9.3.3 methods may be provided that differ only by their return type. These are marked specially and may be ignored by compilers that don’t support operator overloading.
Properties shall not be overloaded by type (that is, by the return type of their getter method), but they may be
overloaded with different number or types of indices (that is, by the number and types of the parameters of its
getter method). The overloading rules for properties are identical to the method overloading rules.

**CLS Rule 37:** Only properties and methods may be overloaded.

**CLS Rule 38:** Properties, instance methods, and virtual methods may be overloaded based only on the number
and types of their parameters, except the conversion operators named `op_Implicit` and `op_Explicit` which may
also be overloaded based on their return type.

**Note:**

**CLS (consumer):** May assume that only properties and methods are overloaded, and need not support
overloading based on return type unless providing special syntax for operator overloading. If return type
overloading isn’t supported, then the `op_Implicit` and `op_Explicit` may be ignored since the functionality shall
be provided in some other way by a CLS-compliant framework.

**CLS (extender):** Should not permit the authoring of overloads other than those specified here. It is not
necessary to support operator overloading at all, hence it is possible to entirely avoid support for overloading
on return type.

**CLS (framework):** Shall not publicly expose overloading except as specified here. Frameworks authors
should bear in mind that many programming languages, including Object-Oriented languages, do not support
overloading and will expose overloaded methods or properties through mangled names. Most languages
support neither operator overloading nor overloading based on return type, so `op_Implicit` and `op_Explicit`
shall always be augmented with some alternative way to gain the same functionality.

### 9.3 Operator Overloading

CLS-compliant consumer and extender tools are under no obligation to allow defining of operator overloading.
CLS-compliant consumer and extender tools do not have to provide a special mechanism to call these methods.

**Note:** This topic is addressed by the CLS so that
- languages that do provide operator overloading can describe their rules in a way that other
  languages can understand, and
- languages that do not provide operator overloading can still access the underlying functionality
  without the addition of special syntax.

Operator overloading is described by using the names specified below, and by setting a special bit in the
metadata (SpecialName) so that they do not collide with the user’s name space. A CLS-compliant producer
tool shall provide some means for setting this bit. If these names are used, they shall have precisely the
semantics described here.

#### 9.3.1 Unary Operators

Unary operators take one argument, perform some operation on it, and return the result. They are represented as
static methods on the class that defines the type of their one operand or their return type. *Table 4: Unary
Operator Names* shows the names that are defined.

**Table 4: Unary Operator Names**

<table>
<thead>
<tr>
<th>Name</th>
<th>ISO C++ Operator Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>op_Decrement</code></td>
<td>Similar to --</td>
</tr>
<tr>
<td><code>op_Increment</code></td>
<td>Similar to ++</td>
</tr>
<tr>
<td><code>op_UnaryNegation</code></td>
<td>- (unary)</td>
</tr>
<tr>
<td><code>op_UnaryPlus</code></td>
<td>+ (unary)</td>
</tr>
<tr>
<td><code>op_LogicalNot</code></td>
<td>!</td>
</tr>
<tr>
<td><code>op_True</code></td>
<td>Not defined</td>
</tr>
</tbody>
</table>
The \texttt{op\_True} and \texttt{op\_False} operators do not exist in C++. They are provided to support tri-state boolean types, such as those used in database languages.

### 9.3.2 Binary Operators

Binary operators take two arguments, perform some operation and return a value. They are represented as static methods on the class that defines the type of one of their two operands or the return type. Table 5: Binary Operator Names shows the names that are defined.

#### Table 5: Binary Operator Names

<table>
<thead>
<tr>
<th>Name</th>
<th>C++ Operator Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>op_Addition</td>
<td>+ (binary)</td>
</tr>
<tr>
<td>op_Subtraction</td>
<td>- (binary)</td>
</tr>
<tr>
<td>op_Multiply</td>
<td>* (binary)</td>
</tr>
<tr>
<td>op_Division</td>
<td>/</td>
</tr>
<tr>
<td>op_Modulus</td>
<td>%</td>
</tr>
<tr>
<td>op_ExclusiveOr</td>
<td>^</td>
</tr>
<tr>
<td>op_BitwiseAnd</td>
<td>&amp; (binary)</td>
</tr>
<tr>
<td>op_BitwiseOr</td>
<td></td>
</tr>
<tr>
<td>op_LogicalAnd</td>
<td>&amp;&amp;</td>
</tr>
<tr>
<td>op_LogicalOr</td>
<td></td>
</tr>
<tr>
<td>op_Assign</td>
<td>=</td>
</tr>
<tr>
<td>op_LeftShift</td>
<td>&lt;&lt;</td>
</tr>
<tr>
<td>op_RightShift</td>
<td>&gt;&gt;</td>
</tr>
<tr>
<td>op_SignedRightShift</td>
<td>Not defined</td>
</tr>
<tr>
<td>op_UnsignedRightShift</td>
<td>Not defined</td>
</tr>
<tr>
<td>op_Equality</td>
<td>==</td>
</tr>
<tr>
<td>op_GreaterThan</td>
<td>&gt;</td>
</tr>
<tr>
<td>op_LessThan</td>
<td>&lt;</td>
</tr>
<tr>
<td>op_Inequality</td>
<td>!=</td>
</tr>
<tr>
<td>op_GreaterThanOrEqual</td>
<td>&gt;=</td>
</tr>
<tr>
<td>op_LessThanOrEqual</td>
<td>&lt;=</td>
</tr>
<tr>
<td>op_UnsignedRightShiftAssign</td>
<td>Not defined</td>
</tr>
<tr>
<td>op_MemberSelection</td>
<td>- &gt;</td>
</tr>
<tr>
<td>op_RightShiftAssignment</td>
<td>&gt;&gt;=</td>
</tr>
<tr>
<td>op_MultiplicationAssignment</td>
<td>*=</td>
</tr>
<tr>
<td>op_PointerToMemberSelection</td>
<td>- &gt; *</td>
</tr>
<tr>
<td>op_SubtractionAssignment</td>
<td>-=</td>
</tr>
<tr>
<td>op_ExclusiveOrAssignment</td>
<td>^ =</td>
</tr>
<tr>
<td>op_LeftShiftAssignment</td>
<td>&lt;&lt;=</td>
</tr>
</tbody>
</table>
9.3.3 Conversion Operators

Conversion operators are unary operations that allow conversion from one type to another. The operator method shall be defined as a static method on either the operand or return type. There are two types of conversions:

- An implicit (widening) coercion shall not lose any magnitude or precision. These should be provided using a method named `op_Implicit`.
- An explicit (narrowing) coercion may lose magnitude or precision. These should be provided using a method named `op_Explicit`.

**Note:** Conversions provide functionality that can’t be generated in other ways, and many languages will not support the use of the conversion operators through special syntax. Therefore, CLS rules require that the same functionality be made available through an alternate mechanism. Using the more common `ToXxx` (where `Xxx` is the target type) and `FromYyy` (where `Yyy` is the name of the source type) naming pattern is recommended.

Because these operations may exist on the class of their operand type (so-called “from” conversions) and would therefore differ on their return type only, the CLS specifically allows that these two operators be overloaded based on their return type. The CLS, however, also requires that if this form of overloading is used then the language shall provide an alternate means for providing the same functionality since not all CLS languages will implement operators with special syntax.

**CLS Rule 39:** If either `op_Implicit` or `op_Explicit` is provided, an alternate means of providing the coercion shall be provided.

**Note:**

**CLS (consumer):** Where appropriate to the language design, use the existence of `op_Implicit` and/or `op_Explicit` in choosing method overloads and generating automatic coercions.

**CLS (extender):** Where appropriate to the language design, implement user-defined implicit or explicit coercion operators using the corresponding `op_Implicit`, `op_Explicit`, `ToXxx`, and/or `FromXxx` methods.

**CLS (framework):** If coercion operations are supported, they shall be provided as `FromXxx` and `ToXxx`, and optionally `op_Implicit` and `op_Explicit` as well. CLS frameworks are encouraged to provide such coercion operations.

9.4 Naming Patterns

See also Partition V.

While the CTS does not dictate the naming of properties or events, the CLS does specify a pattern to be observed.

For Events:

An individual event is created by choosing or defining a delegate type that is used to signal the event. Then, three methods are created with names based on the name of the event and with a fixed signature. For the examples below we define an event named `Click` that uses a delegate type named `EventHandler`.

```
Pattern: void add_<EventName> (<DelegateType> handler)
Example: void add_Click (EventHandler handler);
```
EventRemove, used to remove a handler for an event

Pattern: void remove_<EventName> (<DelegateType> handler)
Example: void remove_Click (EventHandler handler);

EventRaise, used to signal that an event has occurred

Pattern: void family raise_<EventName> (Event e)

For Properties:
An individual property is created by deciding on the type returned by its getter method and the types of the
getter’s parameters (if any). Then, two methods are created with names based on the name of the property and
these types. For the examples below we define two properties: Name takes no parameters and returns a
System.String, while Item takes a System.Object parameter and returns a System.Object. Item is referred
to as an indexed property, meaning that it takes parameters and thus may appear to the user as through it were
an array with indices

PropertyGet, used to read the value of the property

Pattern: <PropType> get_<PropName> (<Indices>)
Example: System.String get_Name ();
Example: System.Object get_Item (System.Object key);

PropertySet, used to modify the value of the property

Pattern: void set_<PropName> (<Indices>, <PropType>)
Example: void set_Name (System.String name);
Example: void set_Item (System.Object key, System.Object value);

9.5 Exceptions
The CLI supports an exception handling model, which is introduced in clause 11.4.2. CLS compliant
frameworks may define and throw externally visible exceptions, but there are restrictions on the type of objects
thrown:

<table>
<thead>
<tr>
<th>CLS Rule 40: Objects that are thrown shall be of type System.Exception or inherit from it. Nonetheless, CLS compliant methods are not required to block the propagation of other types of exceptions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Note:</td>
</tr>
<tr>
<td>CLS (consumer): Need not support throwing or catching of objects that are not of the specified type.</td>
</tr>
<tr>
<td>CLS (extender): Must support throwing of objects of type System.Exception or a type inheriting from it.</td>
</tr>
<tr>
<td>Need not support throwing of objects of other types.</td>
</tr>
<tr>
<td>CLS (framework): Shall not publicly expose thrown objects that are not of type System.Exception or a type inheriting from it.</td>
</tr>
</tbody>
</table>

9.6 Custom Attributes
In order to allow languages to provide a consistent view of custom attributes across language boundaries, the
Base Class Library provides support for the following rules defined by the CLS:

<table>
<thead>
<tr>
<th>CLS Rule 41: Attributes shall be of type System.Attribute, or inherit from it.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Note:</td>
</tr>
<tr>
<td>CLS (consumer): Need not support attributes that are not of the specified type.</td>
</tr>
<tr>
<td>CLS (extender): Must support the authoring of custom attributes.</td>
</tr>
<tr>
<td>CLS (framework): Shall not publicly expose attributes that are not of type System.Attribute or a type inheriting from it.</td>
</tr>
</tbody>
</table>
The use of a particular attribute class may be restricted in various ways by placing an attribute on the attribute class. The `System.AttributeUsageAttribute` is used to specify these restrictions. The restrictions supported by the `System.AttributeUsageAttribute` are:

- What kinds of constructs (types, methods, assemblies, etc.) may have the attribute applied to them. By default, instances of an attribute class can be applied to any construct. This is specified by setting the value of the `ValidOn` property of `System.AttributeUsageAttribute`. Several constructs may be combined.

- Multiple instances of the attribute class may be applied to a given piece of metadata. By default, only one instance of any given attribute class can be applied to a single metadata item. The `AllowMultiple` property of the attribute is used to specify the desired value.

- Do not inherit the attribute when applied to a type. By default, any attribute attached to a type should be inherited to types that derive from it. If multiple instances of the attribute class are allowed, the inheritance performs a union of the attributes inherited from the parent and those explicitly applied to the child type. If multiple instance are not allowed, then an attribute of that type applied directly to the child overrides the attribute supplied by the parent. This is specified by setting the `Inherited` property of `System.AttributeUsageAttribute` to the desired value.

**Note:** Since these are CLS rules and not part of the CTS itself, tools are required to specify explicitly the custom attributes they intend to apply to any given metadata item. That is, compilers or other tools that generate metadata must implement the `AllowMultiple` and `Inherit` rules. The CLI does not supply attributes automatically. The usage of attributes in the CLI is further described in [Partition II].
10 Collected CLS Rules

The complete set of CLS rules are collected here for reference. Recall that these rules apply only to “externally visible” items – types that are visible outside of their own assembly and members of those types that have public, family, or family-or-assembly accessibility. Furthermore, items may be explicitly marked as CLS-compliant or not using the System.CLSCompliantAttribute. The CLS rules apply only to items that are marked as CLS-compliant.

1. CLS rules apply only to those parts of a type that are accessible or visible outside of the defining assembly (see Section 6.3).

2. Members of non-CLS compliant types shall not be marked CLS-compliant. (see clause 6.3.1).

3. The CLS does not include boxed value types (see clause 7.2.4).

4. Assemblies shall follow Annex 7 of Technical Report 15 of the Unicode Standard 3.0 (ISBN 0-201-61633-5) governing the set of characters permitted to start and be included in identifiers, available on-line at http://www.unicode.org/unicode/reports/tr15/tr15-18.html. For CLS purposes, two identifiers are the same if their lowercase mappings (as specified by the Unicode locale-insensitive, 1-1 lowercase mappings) are the same. That is, for two identifiers to be considered different under the CLS they shall differ in more than simply their case. However, in order to override an inherited definition the CLI requires the precise encoding of the original declaration be used (see clause 7.5.1).

5. All names introduced in a CLS-compliant scope shall be distinct independent of kind, except where the names are identical and resolved via overloading. That is, while the CTS allows a single type to use the same name for a method and a field, the CLS does not (see clause 7.5.2).

6. Fields and nested types shall be distinct by identifier comparison alone, even though the CTS allows distinct signatures to be distinguished. Methods, properties, and events that have the same name (by identifier comparison) shall differ by more than just the return type, except as specified in CLS Rule 39 (see clause 7.5.2).

7. The underlying type of an enum shall be a built-in CLS integer type (see clause 7.5.2).

8. There are two distinct kinds of enums, indicated by the presence or absence of the System.FlagsAttribute custom attribute. One represents named integer values, the other named bit flags that can be combined to generate an unnamed value. The value of an enum is not limited to the specified values (see clause 7.5.2).

9. Literal static fields of an enum shall have the type of the enum itself (see clause 7.5.2).

10. Accessibility shall not be changed when overriding inherited methods, except when overriding a method inherited from a different assembly with accessibility Family-or-Assembly. In this case the override shall have accessibility family (see clause 7.5.3.2).

11. All types appearing in a signature shall be CLS-compliant (see clause 7.6.1).

12. The visibility and accessibility of types and members shall be such that types in the signature of any member shall be visible and accessible whenever the member itself is visible and accessible. For example, a public method that is visible outside its assembly shall not have an argument whose type is visible only within the assembly (see clause 7.6.1).

13. The value of a literal static is specified through the use of field initialization metadata (see Partition II). A CLS compliant literal must have a value specified in field initialization metadata that is of exactly the same type as the literal (or of the underlying type, if that literal is an enum). (see clause 7.6.1.2).

14. Typed references are not CLS-compliant (see clause 7.6.1.3).

15. The varargs constraint is not part of the CLS, and the only calling convention supported by the CLS is the standard managed calling convention (see clause 7.6.1.5).
16. Arrays shall have elements with a CLS-compliant type and all dimensions of the array shall have lower bounds of zero. Only the fact that an item is an array and the element type of the array shall be required to distinguish between overloads. When overloading is based on two or more array types the element types shall be named types. (see clause 7.9.1).

17. Unmanaged pointer types are not CLS-compliant (see clause 7.9.2).

18. CLS-compliant interfaces shall not require the definition of non-CLS compliant methods in order to implement them (see clause 7.9.4).

19. CLS-compliant interfaces shall not define static methods, nor shall they define fields (see clause 7.9.4).

20. CLS-compliant classes, value types, and interfaces shall not require the implementation of non-CLS-compliant interfaces (see clause 7.9.6.4).

21. An object constructor shall call some class constructor of its base class before any access occurs to inherited instance data. This does not apply to value types, which need not have constructors (see clause 7.9.6.6).

22. An object constructor shall not be called except as part of the creation of an object, and an object shall not be initialized twice (see clause 7.9.6.6).

23. System.Object is CLS-compliant. Any other CLS-compliant class shall inherit from a CLS-compliant class (see clause 7.9.9).

24. The methods that implement the getter and setter methods of a property shall be marked SpecialName in the metadata (see Partition II) (see clause 7.11.3).

25. The accessibility of a property and of its accessors shall be identical (see clause 7.11.3).

26. A property and its accessors shall all be static, all be virtual, or all be instance (see clause 7.11.3).

27. The type of a property shall be the return type of the getter and the type of the last argument of the setter. The types of the parameters of the property shall be the types of the parameters to the getter and the types of all but the final parameter of the setter. All of these types shall be CLS-compliant, and shall not be managed pointers (i.e. shall not be passed by reference) (see clause 7.11.3).

28. Properties shall adhere to a specific naming pattern. See Section 9.4. The SpecialName attribute referred to in CLS rule 26 shall be ignored in appropriate name comparisons and shall adhere to identifier rules (see clause 7.11.3).

29. The methods that implement an event shall be marked SpecialName in the metadata (see Partition II) (see clause 7.11.4).

30. The accessibility of an event and of its accessors shall be identical (see clause 7.11.4).

31. The add and remove methods for an event shall both either be present or absent (see clause 7.11.4).

32. The add and remove methods for an event shall each take one parameter whose type defines the type of the event and that shall be derived from System.Delegate (see clause 7.11.4).

33. Events shall adhere to a specific naming pattern. See Section 9.4. The SpecialName attribute referred to in CLS rule 31 shall be ignored in appropriate name comparisons and shall adhere to identifier rules (see clause 7.11.4).


35. The CLS does not allow publicly visible required modifiers (modreq, see Partition II), but does allow optional modifiers (modopt, see Partition II) they do not understand (see Section 8.7).

36. Global static fields and methods are not CLS-compliant (see Section 8.8).
37. Only properties and methods may be overloaded (see Section 9.2).

38. Properties, instance methods, and virtual methods may be overloaded based only on the number and types of their parameters, except the conversion operators named `op_Implicit` and `op_Explicit` which may also be overloaded based on their return type (see Section 9.2).

39. If either `op_Implicit` or `op_Explicit` is overloaded on its return type, an alternate means of providing the coercion shall be provided (see clause 9.3.3).

40. Objects that are thrown shall be of type `System.Exception` or inherit from it (see Section 9.5). Nonetheless, CLS compliant methods are not required to block the propagation of other types of exceptions.

41. Attributes shall be of type `System.Attribute`, or inherit from it (see Section 9.6).
11 Virtual Execution System

The Virtual Execution System (VES) provides an environment for executing managed code. It provides direct support for a set of built-in data types, defines a hypothetical machine with an associated machine model and state, a set of control flow constructs, and an exception handling model. To a large extent, the purpose of the VES is to provide the support required to execute the Common Intermediate Language instruction set (see Partition III).

11.1 Supported Data Types

The CLI directly supports the data types shown in Table 6: Data Types Directly Supported by the CLI. That is, these data types can be manipulated using the CIL instruction set (see Partition III).

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int8</td>
<td>8-bit 2’s complement signed value</td>
</tr>
<tr>
<td>unsigned int8</td>
<td>8-bit unsigned binary value</td>
</tr>
<tr>
<td>int16</td>
<td>16-bit 2’s complement signed value</td>
</tr>
<tr>
<td>unsigned int16</td>
<td>16-bit unsigned binary value</td>
</tr>
<tr>
<td>int32</td>
<td>32-bit 2’s complement signed value</td>
</tr>
<tr>
<td>unsigned int32</td>
<td>32-bit unsigned binary value</td>
</tr>
<tr>
<td>int64</td>
<td>64-bit 2’s complement signed value</td>
</tr>
<tr>
<td>unsigned int64</td>
<td>64-bit unsigned binary value</td>
</tr>
<tr>
<td>float32</td>
<td>32-bit IEC 60559:1989 floating point value</td>
</tr>
<tr>
<td>float64</td>
<td>64-bit IEC 60559:1989 floating point value</td>
</tr>
<tr>
<td>native int</td>
<td>native size 2’s complement signed value</td>
</tr>
<tr>
<td>native unsigned int</td>
<td>native size unsigned binary value, also unmanaged pointer</td>
</tr>
<tr>
<td>F</td>
<td>native size floating point number (internal to VES, not user visible)</td>
</tr>
<tr>
<td>O</td>
<td>native size object reference to managed memory</td>
</tr>
<tr>
<td>&amp;</td>
<td>native size managed pointer (may point into managed memory)</td>
</tr>
</tbody>
</table>

The CLI model uses an evaluation stack. Instructions that copy values from memory to the evaluation stack are “loads”; instructions that copy values from the stack back to memory are “stores”. The full set of data types in Table 6: Data Types Directly Supported by the CLI can be represented in memory. However, the CLI supports only a subset of these types in its operations upon values stored on its evaluation stack – int32, int64, native int. In addition the CLI supports an internal data type to represent floating point values on the internal evaluation stack. The size of the internal data type is implementation-dependent. For further information on the treatment of floating-point values on the evaluation stack, see clause 11.1.3 and Partition III. Short numeric values (int8, int16, unsigned int8, unsigned int16) are widened when loaded (memory-to-stack) and narrowed when stored (stack-to-memory). This reflects a computer model that assumes, for numeric and object references, memory cells are 1, 2, 4, or 8 bytes wide but stack locations are either 4 or 8 bytes wide. User-defined value types may appear in memory locations or on the stack and have no size limitation; the only built-in operations on them are those that compute their address and copy them between the stack and memory.

The only CIL instructions with special support for short numeric values (rather than support for simply the 4 or 8 byte integral values) are:

- Load and store instructions to/from memory: ldelem, ldind, stind, stelem
• Data conversion: conv, conv.ovf

• Array creation: newarr

The signed integer (int8, int16, int32, int64, and native int) and the respective unsigned integer (unsigned int8, unsigned int16, unsigned int32, unsigned int64, and native unsigned int) types differ only in how the bits of the integer are interpreted. For those operations where an unsigned integer is treated differently from a signed integer (e.g. comparisons or arithmetic with overflow) there are separate instructions for treating an integer as unsigned (e.g. g1t.un and add.ovf.u).

This instruction set design simplifies CIL-to-native code (e.g. JIT) compilers and interpreters of CIL by allowing them to internally track a smaller number of data types. See clause 11.3.2.1.

As described below, CIL instructions do not specify their operand types. Instead, the CLI keeps track of operand types based on data flow and aided by a stack consistency requirement described below. For example, the single add instruction will add two integers or two floats from the stack.

11.1.1 Native Size: native int, native unsigned int, O and &

The native-size, or generic, types (native int, native unsigned int, O, and &) are a mechanism in the CLI for deferring the choice of a value’s size. These data types exist as CIL types. But the CLI maps each to the native size for a specific processor. (For example, data type I would map to int32 on a Pentium processor, but to int64 on an IA64 processor). So, the choice of size is deferred until JIT compilation or runtime, when the CLI has been initialized and the architecture is known. This implies that field and stack frame offsets are also not known at compile time. For languages like Visual Basic, where field offsets are not computed early anyway, this is not a hardship. In languages like C or C++, where sizes must be known when source code is compiled, a conservative assumption that they occupy 8 bytes is sometimes acceptable (for example, when laying out compile-time storage).

11.1.1.1 Unmanaged Pointers as Type Native Unsigned Int

Rationale: For languages like C, when compiling all the way to native code, where the size of a pointer is known at compile time and there are no managed objects, the fixed-size unsigned integer types (unsigned int32 or unsigned int64) may serve as pointers. However choosing pointer size at compile time has its disadvantages. If pointers were chosen to be 32 bit quantities at compile time, the code would be restricted to 4 gigabytes of address space, even if it were run on a 64-bit machine. Moreover, a 64-bit CLI would need to take special care so those pointers passed back to 32-bit code would always fit in 32 bits. If pointers were chosen at compile time to be 64 bits, the code would run on a 32-bit machine, but pointers in every data structure would be twice as large as necessary on that CLI.

For other languages, where the size of a data type need not be known at compile time, it is desirable to defer the choice of pointer size from compile time to CLI initialization time. In that way, the same CLI code can handle large address spaces for those applications that need them, while also being able to reap the size benefit of 32 bit pointers for those applications that do not need a large address space.

The native unsigned int type is used to represent unmanaged pointers with the VES. The metadata allows unmanaged pointers to be represented in a strongly typed manner, but these types are translated into type native unsigned int for use by the VES.

11.1.1.2 Managed Pointer Types: O and &

The O datatype represents an object reference that is managed by the CLI. As such, the number of specified operations is severely limited. In particular, references shall only be used on operations that indicate that they operate on reference types (e.g. eq and ldind.ref), or on operations whose metadata indicates that references are allowed (e.g. call, ldsfld, and stfld).

The & datatype (managed pointer) is similar to the O type, but points to the interior of an object. That is, a managed pointer is allowed to point to a field within an object or an element within an array, rather than to a field on the ‘start’ of object or array.

Object references (O) and managed pointers (&) may be changed during garbage collection, since the data to which they refer may be moved.
In summary, object references, or \( \text{O} \) types, refer to the ‘outside’ of an object, or to an object as-a-whole. But managed pointers, or \& \( \text{U} \) types, refer to the interior of an object. The \& \( \text{U} \) types are sometimes called “by-ref types” in source languages, since passing a field of an object by reference is represented in the VES by using an \& \( \text{U} \) type to represent the type of the parameter.

In order to allow managed pointers to be used more flexibly, they are also permitted to point to areas that aren’t under the control of the CLI garbage collector, such as the evaluation stack, static variables, and unmanaged memory. This allows them to be used in many of the same ways that unmanaged pointers (U) are used. Verification restrictions guarantee that, if all code is verifiable, a managed pointer to a value on the evaluation stack doesn’t outlast the life of the location to which it points.

### 11.1.1.3 Portability: Storing Pointers in Memory

Several instructions, including \text{calli}, \text{cpblk}, \text{initblk}, \text{ldind.*}, and \text{stind.*}, expect an address on the top of the stack. If this address is derived from a pointer stored in memory, there is an important portability consideration.

1. Code that stores pointers in a native sized integer or pointer location (types \text{native int}, \text{O}, \text{native unsigned int}, or \&) is always fully portable.
2. Code that stores pointers in an 8 byte integer (type \text{int64} or \text{unsigned int64}) can be portable. But this requires that a \text{conv.ovf.u} instruction be used to convert the pointer from its memory format before its use as a pointer. This may cause a runtime exception if run on a 32-bit machine.
3. Code that uses any smaller integer type to store a pointer in memory (\text{int8}, \text{unsigned int8}, \text{int16}, \text{unsigned int16}, \text{int32}, \text{unsigned int32}) is never portable, even though the use of a unsigned int32 or int32 will work correctly on a 32-bit machine.

### 11.1.2 Handling of Short Integer Data Types

The CLI defines an evaluation stack that contains either 4-byte or 8-byte integers, but a memory model that encompasses in addition 1-byte and 2-byte integers. To be more precise, the following rules are part of the CLI model:

- Loading from 1-byte or 2-byte locations (arguments, locals, fields, statics, pointers) expands to 4-byte values. For locations with a known type (e.g. local variables) the type being accessed determines whether the load sign-extends (signed locations) or zero-extends (unsigned locations). For pointer dereference (\text{ldind.*}), the instruction itself identifies the type of the location (e.g. \text{ldind.u1} indicates an unsigned location, while \text{ldind.i1} indicates a signed location).
- Storing into a 1-byte or 2-byte location truncates to fit and will not generate an overflow error. Specific instructions (\text{conv.ovf.*}) can be used to test for overflow before storing.
- Calling a method assigns values from the evaluation stack to the arguments for the method, hence it truncates just as any other store would when the actual argument is larger than the formal argument.
- Returning from a method assigns a value to an invisible return variable, so it also truncates as a store would when the type of the value returned is larger than the return type of the method. Since the value of this return variable is then placed on the evaluation stack, it is then sign-extended or zero-extended as would any other load. Note that this truncation followed by extending is not identical to simply leaving the computed value unchanged.

It is the responsibility of any translator from CIL to native machine instructions to make sure that these rules are faithfully modeled through the native conventions of the target machine. The CLI does not specify, for example, whether truncation of short integer arguments occurs at the call site or in the target method.

### 11.1.3 Handling of Floating Point Datatypes

Floating-point calculations shall be handled as described in IEC 60559:1989. This standard describes encoding of floating point numbers, definitions of the basic operations and conversion, rounding control, and exception handling.
The standard defines special values, NaN, (not a number), +infinity, and –infinity. These values are returned
on overflow conditions. A general principle is that operations that have a value in the limit return an
appropriate infinity while those that have no limiting value return NaN, but see the standard for details.

Note: The following examples show the most commonly encountered cases.

X rem 0 = NaN
0 * +infinity = 0 * -infinity = NaN
(X / 0) = +infinity, if X>0
NaN, if X=0
-infinity, if X < 0
NaN op X = X op NaN = NaN for all operations
(+infinity) + (+infinity) = (+infinity)
X / (+infinity) = 0
X mod (-infinity) = -X
(+infinity) - (+infinity) = NaN

Note: This standard does not specify the behavior of arithmetic operations on denormalized floating point
numbers, nor does it specify when or whether such representations should be created. This is in keeping with
IEC 60559:1989. In addition, this standard does not specify how to access the exact bit pattern of NaNs that
are created, nor the behavior when converting a NaN between 32-bit and 64-bit representation. All of this
behavior is deliberately left implementation-specific.

For purposes of comparison, infinite values act like a number of the correct sign but with a very large
magnitude when compared with finite values. NaN is ‘unordered’ for comparisons (see clt, clt.un).

While the IEC 60559:1989 standard also allows for exceptions to be thrown under unusual conditions (such as
overflow and invalid operand), the CLI does not generate these exceptions. Instead, the CLI uses the NaN,
+infinity, and –infinity return values and provides the instruction ckfinite to allow users to generate an
exception if a result is NaN, +infinity, or –infinity.

The rounding mode defined in IEC 60559:1989 shall be set by the CLI to “round to the nearest number,” and
neither the CIL nor the class library provide a mechanism for modifying this setting. Conforming
implementations of the CLI need not be resilient to external interference with this setting. That is, they need not
restore the mode prior to performing floating-point operations, but rather may rely on it having been set as part of
their initialization.

For conversion to integers, the default operation supplied by the CIL is “truncate towards zero”. There are class
libraries supplied to allow floating-point numbers to be converted to integers using any of the other three
traditional operations (round to nearest integer, floor (truncate towards –infinity), ceiling (truncate towards
+infinity)).

Storage locations for floating point numbers (statics, array elements, and fields of classes) are of fixed size. The
supported storage sizes are float32 and float64. Everywhere else (on the evaluation stack, as arguments, as
return types, and as local variables) floating point numbers are represented using an internal floating-point type.
In each such instance, the nominal type of the variable or expression is either R4 or R8, but its value may be
represented internally with additional range and/or precision. The size of the internal floating-point
representation is implementation-dependent, may vary, and shall have precision at least as great as that of the
variable or expression being represented. An implicit widening conversion to the internal representation from
float32 or float64 is performed when those types are loaded from storage. The internal representation is
typically the native size for the hardware, or as required for efficient implementation of an operation. The
internal representation shall have the following characteristics:

• The internal representation shall have precision and range greater than or equal to the nominal
type.

• Conversions to and from the internal representation shall preserve value.

Note: This implies that an implicit widening conversion from float32 (or float64) to the internal representation,
followed by an explicit conversion from the internal representation to float32 (or float64), will result in a value
that is identical to the original float32 (or float64) value.
**Rationale:** This design allows the CLI to choose a platform-specific high-performance representation for floating point numbers until they are placed in storage locations. For example, it may be able to leave floating point variables in hardware registers that provide more precision than a user has requested. At the same time, CIL generators can force operations to respect language-specific rules for representations through the use of conversion instructions.

When a floating-point value whose internal representation has greater range and/or precision than its nominal type is put in a storage location it is automatically coerced to the type of the storage location. This may involve a loss of precision or the creation of an out-of-range value (NaN, +infinity, or -infinity). However, the value may be retained in the internal representation for future use, if it is reloaded from the storage location without having been modified. It is the responsibility of the compiler to ensure that the retained value is still valid at the time of a subsequent load, taking into account the effects of aliasing and other execution threads (see memory model section). This freedom to carry extra precision is not permitted, however, following the execution of an explicit conversion (conv.r4 or conv.r8), at which time the internal representation must be exactly representable in the associated type.

**Note:** To detect values that cannot be converted to a particular storage type, a conversion instruction (conv.r4, or conv.r8) may be used, followed by a check for a non-finite value using ckfinite. To detect underflow when converting to a particular storage type, a comparison to zero is required before and after the conversion.

**Note:** The use of an internal representation that is wider than float32 or float64 may cause differences in computational results when a developer makes seemingly unrelated modifications to their code, the result of which may be that a value is spilled from the internal representation (e.g. in a register) to a location on the stack.
11.1.4 CIL Instructions and Numeric Types

This clause contains only informative text

Most CIL instructions that deal with numbers take their operands from the evaluation stack (see clause 11.3.2.1), and these inputs have an associated type that is known to the VES. As a result, a single operation like add can have inputs of any numeric data type, although not all instructions can deal with all combinations of operand types. Binary operations other than addition and subtraction require that both operands be of the same type. Addition and subtraction allow an integer to be added to or subtracted from a managed pointer (types & and O). Details are specified in Partition II.

Instructions fall into the following categories:

**Numeric**: These instructions deal with both integers and floating point numbers, and consider integers to be signed. Simple arithmetic, conditional branch, and comparison instructions fit in this category.

**Integer**: These instructions deal only with integers. Bit operations and unsigned integer division/remainder fit in this category.

**Floating point**: These instructions deal only with floating point numbers.

**Specific**: These instructions deal with integer and/or floating point numbers, but have variants that deal specially with different sizes and unsigned integers. Integer operations with overflow detection, data conversion instructions, and operations that transfer data between the evaluation stack and other parts of memory (see clause 11.3.2) fit into this category.

**Unsigned/unordered**: There are special comparison and branch instructions that treat integers as unsigned and consider unordered floating point numbers specially (as in “branch if greater than or unordered”):

**Load constant**: The load constant (ldc.*) instructions are used to load constants of type int32, int64, float32 or float64. Native size constants (type native int) shall be created by conversion from int32 (conversion from int64 would not be portable) using conv.i or conv.u.

Table 7: CIL Instructions by Numeric Category shows the CIL instructions that deal with numeric values, along with the category to which they belong. Instructions that end in “.*” indicate all variants of the instruction (based on size of data and whether the data is treated as signed or unsigned).

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>add</td>
<td>Numeric</td>
</tr>
<tr>
<td>add.ovf.*</td>
<td>Specific</td>
</tr>
<tr>
<td>and</td>
<td>Integer</td>
</tr>
<tr>
<td>beq[.s]</td>
<td>Numeric</td>
</tr>
<tr>
<td>bge[.s]</td>
<td>Numeric</td>
</tr>
<tr>
<td>bge.un[.s]</td>
<td>Unsigned/unordered</td>
</tr>
<tr>
<td>bgt[.s]</td>
<td>Numeric</td>
</tr>
<tr>
<td>bgt.un[.s]</td>
<td>Unsigned/unordered</td>
</tr>
<tr>
<td>ble[.s]</td>
<td>Numeric</td>
</tr>
<tr>
<td>ble.un[.s]</td>
<td>Unsigned/unordered</td>
</tr>
<tr>
<td>blt[.s]</td>
<td>Numeric</td>
</tr>
<tr>
<td>blt.un[.s]</td>
<td>Unsigned/unordered</td>
</tr>
<tr>
<td>bne.un[.s]</td>
<td>Unsigned/unordered</td>
</tr>
<tr>
<td>ceq</td>
<td>Numeric</td>
</tr>
<tr>
<td>div</td>
<td>Numeric</td>
</tr>
<tr>
<td>div.un</td>
<td>Integer</td>
</tr>
<tr>
<td>ldc.*</td>
<td>Load constant</td>
</tr>
<tr>
<td>ldelem.*</td>
<td>Specific</td>
</tr>
<tr>
<td>ldind.*</td>
<td>Specific</td>
</tr>
<tr>
<td>mul</td>
<td>Numeric</td>
</tr>
<tr>
<td>mul.ovf.*</td>
<td>Specific</td>
</tr>
<tr>
<td>neg</td>
<td>Integer</td>
</tr>
<tr>
<td>newarr.*</td>
<td>Specific</td>
</tr>
<tr>
<td>not</td>
<td>Integer</td>
</tr>
<tr>
<td>or</td>
<td>Integer</td>
</tr>
<tr>
<td>rem</td>
<td>Numeric</td>
</tr>
<tr>
<td>rem.un</td>
<td>Integer</td>
</tr>
<tr>
<td>shl</td>
<td>Integer</td>
</tr>
</tbody>
</table>
11.1.5 CIL Instructions and Pointer Types

This clause contains only informative text

Rationale: Some implementations of the CLI will require the ability to track pointers to objects and to collect objects that are no longer reachable (thus providing memory management by "garbage collection"). This process moves objects in order to reduce the working set and thus will modify all pointers to those objects as they move. For this to work correctly, pointers to objects may only be used in certain ways. The \( O \) (object reference) and \& (managed pointer) datatypes are the formalization of these restrictions.

The use of object references is tightly restricted in the CIL. They are used almost exclusively with the “virtual object system” instructions, which are specifically designed to deal with objects. In addition, a few of the base instructions of the CIL handle object references. In particular, object references can be:

1. Loaded onto the evaluation stack to be passed as arguments to methods (ldloc, ldarg), and stored from the stack to their home locations (stloc, starg)
2. Duplicated or popped off the evaluation stack (dup, pop)
3. Tested for equality with one another, but not other data types (beq, beq.s, bne, bne.s, ceq)
4. Loaded-from / stored-into unmanaged memory, in type unmanaged code only (ldind.ref, stind.ref)
5. Created as a null reference (ldnull)
6. Returned as a value (ret)

Managed pointers have several additional base operations.

1. Addition and subtraction of integers, in units of bytes, returning a managed pointer (add, add.ovf.u, sub, sub.ovf.u)
2. Subtraction of two managed pointers to elements of the same array, returning the number of bytes between them (sub, sub.ovf.u)
3. Unsigned comparison and conditional branches based on two managed pointers (bge.un, bge.un.s, bgt.un, bgt.un.s, ble.un, ble.un.s, blt.un, blt.un.s, cgt.un, clt.un)

Arithmetic operations upon managed pointers are intended only for use on pointers to elements of the same array. Other uses of arithmetic on managed pointers is unspecified.

Rationale: Since the memory manager runs asynchronously with respect to programs and updates managed pointers, both the distance between distinct objects and their relative position can change.
11.1.6 Aggregate Data

This clause contains only informative text

The CLI supports aggregate data, that is, data items that have sub-components (arrays, structures, or object instances) but are passed by copying the value. The sub-components can include references to managed memory. Aggregate data is represented using a value type, which can be instantiated in two different ways:

- **Boxed**: as an Object, carrying full type information at runtime, and typically allocated on the heap by the CLI memory manager.

- **Unboxed**: as a “value type instance” that does not carry type information at runtime and that is never allocated directly on the heap. It can be part of a larger structure on the heap – a field of a class, a field of a boxed value type, or an element of an array. Or it can be in the local variables or incoming arguments array (see clause 11.3.2). Or it can be allocated as a static variable or static member of a class or a static member of another value type.

Because value type instances, specified as method arguments, are copied on method call, they do not have “identity” in the sense that Objects (boxed instances of classes) have.

11.1.6.1 Homes for Values

The home of a data value is where it is stored for possible reuse. The CLI directly supports the following home locations:

- An incoming **argument**
- A **local variable** of a method
- An **instance field** of an object or value type
- A **static** field of a class, interface, or module
- An **array element**

For each home location, there is a means to compute (at runtime) the address of the home location and a means to determine (at JIT compile time) the type of a home location. These are summarized in Table 8: Address and Type of Home Locations.

<table>
<thead>
<tr>
<th>Type of Home</th>
<th>Runtime Address Computation</th>
<th>JITTime Type Determination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argument</td>
<td><code>ldarga</code> for by-value arguments or <code>ldarg</code> for by-reference arguments</td>
<td>Method signature</td>
</tr>
<tr>
<td>Local Variable</td>
<td><code>ldloca</code> for by-value locals or <code>ldloc</code> for by-reference locals</td>
<td>Locals signature in method header</td>
</tr>
<tr>
<td>Field</td>
<td><code>ldflda</code></td>
<td>Type of field in the class, interface, or module</td>
</tr>
<tr>
<td>Static</td>
<td><code>ldsflda</code></td>
<td>Type of field in the class, interface, or module</td>
</tr>
<tr>
<td>Array Element</td>
<td><code>ldelema</code> for single-dimensional zero-based arrays or call the instance method <strong>Address</strong></td>
<td>Element type of array</td>
</tr>
</tbody>
</table>

In addition to homes, built-in values can exist in two additional ways (i.e. without homes):

1. as constant values (typically embedded in the CIL instruction stream using `ldc.*` instructions)
2. as an intermediate value on the evaluation stack, when returned by a method or CIL instruction.
11.1.6.2 Operations on Value Type Instances

Value type instances can be created, passed as arguments, returned as values, and stored into and extracted from locals, fields, and elements of arrays (i.e., copied). Like classes, value types may have both static and non-static members (methods and fields). But, because they carry no type information at runtime, value type instances are not substitutable for items of type Object; in this respect, they act like the built-in types int, long, and so forth. There are two operations, box and unbox, that convert between value type instances and Objects.

11.1.6.2.1 Initializing Instances of Value Types

There are three options for initializing the home of a value type instance. You can zero it by loading the address of the home (see Table 8: Address and Type of Home Locations) and using the initobj instruction (for local variables this is also accomplished by setting the zero initialize bit in the method’s header). You can call a user-defined constructor by loading the address of the home (see Table 8: Address and Type of Home Locations) and then calling the constructor directly. Or you can copy an existing instance into the home, as described in clause 11.1.6.2.

11.1.6.2.2 Loading and Storing Instances of Value Types

There are two ways to load a value type onto the evaluation stack:
- Directly load the value from a home that has the appropriate type, using an ldarg, ldloc, ldfld, or ldsfld instruction
- Compute the address of the value type, then use an ldobj instruction

Similarly, there are two ways to store a value type from the evaluation stack:
- Directly store the value into a home of the appropriate type, using a starg, stloc, stfld, or stsfld instruction
- Compute the address of the value type, then use a stobj instruction

11.1.6.2.3 Passing and Returning Value Types

Value types are treated just as any other value would be treated:
- To pass a value type by value, simply load it onto the stack as you would any other argument: use ldloc, ldarg, etc., or call a method that returns a value type. To access a value type parameter that has been passed by value use the ldarga instruction to compute its address or the ldarg instruction to load the value onto the evaluation stack.
- To pass a value type by reference, load the address of the value type as you normally would (see Table 8: Address and Type of Home Locations). To access a value type parameter that has been passed by reference use the ldarga instruction to load the address of the value type and then the ldobj instruction to load the value type onto the evaluation stack.
- To return a value type, just load the value onto an otherwise empty evaluation stack and then issue a ret instruction.

11.1.6.2.4 Calling Methods

Static methods on value types are handled no differently from static methods on an ordinary class: use a call instruction with a metadata token specifying the value type as the class of the method. Non-static methods (i.e. instance and virtual methods) are supported on value types, but they are given special treatment. A non-static method on a class (rather than a value type) expects a this pointer that is an instance of that class. This makes sense for classes, since they have identity and the this pointer represents that identity. Value types, however, have identity only when boxed. To address this issue, the this pointer on a non-static method of a value type is a by-ref parameter of the value type rather than an ordinary by-value parameter.

A non-static method on a value type may be called in the following ways:
- Given an unboxed instance of a value type, the compiler will know the exact type of the object statically. The call instruction can be used to invoke the function, passing as the first parameter (the this pointer) the address of the instance. The metadata token used with the call instruction shall specify the value type itself as the class of the method.
Given a boxed instance of a value type, there are three cases to consider:

- Instance or virtual methods introduced on the value type itself: unbox the instance and call the method directly using the value type as the class of the method.
- Virtual methods inherited from a parent class: use the `callvirt` instruction and specify the method on the `System.Object`, `System.ValueType` or `System.Enum` class as appropriate.
- Virtual methods on interfaces implemented by the value type: use the `callvirt` instruction and specify the method on the interface type.

### 11.1.6.2.5 Boxing and Unboxing

`Box` and `unbox` are conceptually equivalent to (and may be seen in higher-level languages as) casting between a value type instance and `System.Object`. Because they change data representations, however, boxing and unboxing are like the widening and narrowing of various sizes of integers (the `conv` and `conv.ovf` instructions) rather than the casting of reference types (the `isinst` and `castclass` instructions). The `box` instruction is a widening (always typesafe) operation that converts a value type instance to `System.Object` by making a copy of the instance and embedding it in a newly allocated object. `Unbox` is a narrowing (runtime exception may be generated) operation that converts a `System.Object` (whose runtime type is a value type) to a value type instance. This is done by computing the address of the embedded value type instance without making a copy of the instance.

### 11.1.6.6 Castclass and IsInst on Value Types

Casting to and from value type instances isn’t permitted (the equivalent operations are `box` and `unbox`). When boxed, however, it is possible to use the `isinst` instruction to see whether a value of type `System.Object` is the boxed representation of a particular class.

### 11.1.6.3 Opaque Classes

Some languages provide multi-byte data structures whose contents are manipulated directly by address arithmetic and indirection operations. To support this feature, the CLI allows value types to be created with a specified size but no information about their data members. Instances of these “opaque classes” are handled in precisely the same way as instances of any other class, but the `ldfld`, `stfld`, `ldflda`, `ldsfld`, and `stsfld` instructions shall not be used to access their contents.

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**End informative text**
11.2 Module Information

Partition II provides details of the CLI PE file format. The CLI relies on the following information about each method defined in a PE file:

- The *instructions* composing the method body, including all exception handlers.
- The *signature* of the method, which specifies the return type and the number, order, parameter passing convention, and built-in data type of each of the arguments. It also specifies the native calling convention (this does not affect the CIL virtual calling convention, just the native code).
- The *exception handling array*. This array holds information delineating the ranges over which exceptions are filtered and caught. See Partition II and clause 11.4.2.
- The size of evaluation stack that the method will require.
- The size of the locals array that the method will require.
- A “zero init flag” that indicates whether the local variables and memory pool should be initialized by the CLI (see also `localloc`).
- Type of each local variable in the form of a signature of the local variable array (called the “locals signature”).

In addition, the file format is capable of indicating the degree of portability of the file. There are two kinds of restrictions that may be described:

- Restriction to a specific (32-bit or 64-bit) native size for integers.
- Restriction to a specific “endian-ness” (i.e. whether bytes are stored left-to-right or right-to-left within a machine word).

11.3 Machine State

One of the design goals of the CLI is to hide the details of a method call frame from the CIL code generator. This allows the CLI (and not the CIL code generator) to choose the most efficient calling convention and stack layout. To achieve this abstraction, the call frame is integrated into the CLI. The machine state definitions below reflect these design choices, where machine state consists primarily of global state and method state.

11.3.1 The Global State

The CLI manages multiple concurrent threads of control (not necessarily the same as the threads provided by a host operating system), multiple managed heaps, and a shared memory address space.

**Note:** A thread of control can be thought of, somewhat simplistically, as a singly linked list of *method states*, where a new state is created and linked back to the current state by a method call instruction – the traditional model of a stack-based calling sequence. Notice that this model of the thread of control doesn’t correctly explain the operation of `tail`, `jmp`, or `throw` instructions.

**Figure 2: Machine State Model** illustrates the machine state model, which includes threads of control, method states, and multiple heaps in a shared address space. Method state, shown separately in **Figure 3: Method State**, is an abstraction of the stack frame. Arguments and local variables are part of the method state, but they can contain Object References that refer to data stored in any of the managed heaps. In general, arguments and local variables are only visible to the executing thread, while instance and static fields and array elements may be visible to multiple threads, and modification of such values is considered a side-effect.
Method state describes the environment within which a method executes. (In conventional compiler terminology, it corresponds to a superset of the information captured in the “invocation stack frame”). The CLI method state consists of the following items:

- An instruction pointer (IP). This points to the next CIL instruction to be executed by the CLI in the present method.
• An evaluation stack. The stack is empty upon method entry. Its contents are entirely local to the method and are preserved across call instructions (that’s to say, if this method calls another, once that other method returns, our evaluation stack contents are “still there”). The evaluation stack is not addressable. At all times it is possible to deduce which one of a reduced set of types is stored in any stack location at a specific point in the CIL instruction stream (see clause 11.3.2.1).

• A local variable array (starting at index 0). Values of local variables are preserved across calls (in the same sense as for the evaluation stack). A local variable may hold any data type. However, a particular slot shall be used in a type consistent way (where the type system is the one described in clause 11.3.2.1). Local variables are initialized to 0 before entry if the initialize flag for the method is set (see Section 11.2). The address of an individual local variable may be taken using the ldloca instruction.

• An argument array. The values of the current method’s incoming arguments (starting at index 0). These can be read and written by logical index. The address of an argument can be taken using the ldarga instruction. The address of an argument is also implicitly taken by the arglist instruction for use in conjunction with typesafe iteration through variable-length argument lists.

• A methodInfo handle. This contains read-only information about the method. In particular it holds the signature of the method, the types of its local variables, and data about its exception handlers.

• A local memory pool. The CLI includes instructions for dynamic allocation of objects from the local memory pool (localloc). Memory allocated in the local memory pool is addressable. The memory allocated in the local memory pool is reclaimed upon method context termination.

• A return state handle. This handle is used to restore the method state on return from the current method. Typically, this would be the state of the method’s caller. This corresponds to what in conventional compiler terminology would be the dynamic link.

• A security descriptor. This descriptor is not directly accessible to managed code but is used by the CLI security system to record security overrides (assert, permit-only, and deny).

The four areas of the method state – incoming arguments array, local variables array, local memory pool and evaluation stack – are specified as if logically distinct areas. A conforming implementation of the CLI may map these areas into one contiguous array of memory, held as a conventional stack frame on the underlying target architecture, or use any other equivalent representation technique.

11.3.2.1 The Evaluation Stack

Associated with each method state is an evaluation stack. Most CLI instructions retrieve their arguments from the evaluation stack and place their return values on the stack. Arguments to other methods and their return values are also placed on the evaluation stack. When a procedure call is made the arguments to the called methods become the incoming arguments array (see clause 11.3.2.2) to the method. This may require a memory copy, or simply a sharing of these two areas by the two methods.

The evaluation stack is made up of slots that can hold any data type, including an unboxed instance of a value type. The type state of the stack (the stack depth and types of each element on the stack) at any given point in a program shall be identical for all possible control flow paths. For example, a program that loops an unknown number of times and pushes a new element on the stack at each iteration would be prohibited.

While the CLI, in general, supports the full set of types described in Section 11.1, the CLI treats the evaluation stack in a special way. While some JIT compilers may track the types on the stack in more detail, the CLI only requires that values be one of:

• int64, an 8-byte signed integer
• int32, a 4-byte signed integer
• native int, a signed integer of either 4 or 8 bytes, whichever is more convenient for the target architecture
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- F, a floating point value (float32, float64, or other representation supported by the underlying hardware)
- & a managed pointer
- O an object reference
- * a “transient pointer,” which may be used only within the body of a single method, that points to a value known to be in unmanaged memory (see the CIL Instruction Set specification for more details. * types are generated internally within the CLI; they are not created by the user).
- A user-defined value type

The other types are synthesized through a combination of techniques:
- Shorter integer types in other memory locations are zero-extended or sign-extended when loaded onto the evaluation stack; these values are truncated when stored back to their home location.
- Special instructions perform numeric conversions, with or without overflow detection, between different sizes and between signed and unsigned integers.
- Special instructions treat an integer on the stack as though it were unsigned.
- Instructions that create pointers which are guaranteed not to point into the memory manager’s heaps (e.g. ldloca, ldarga, and ldsflda) produce transient pointers (type *) that may be used wherever a managed pointer (type &) or unmanaged pointer (type native unsigned int) is expected.
- When a method is called, an unmanaged pointer (type native unsigned int or *) is permitted to match a parameter that requires a managed pointer (type &). The reverse, however, is not permitted since it would allow a managed pointer to be “lost” by the memory manager.
- A managed pointer (type & may be explicitly converted to an unmanaged pointer (type native unsigned int), although this is not verifiable and may produce a runtime exception.

11.3.2.2 Local Variables and Arguments

Part of each method state is an array that holds local variables and an array that holds arguments. Like the evaluation stack, each element of these arrays can hold any single data type or an instance of a value type. Both arrays start at 0 (that is, the first argument or local variable is numbered 0). The address of a local variable can be computed using the ldloca instruction, and the address of an argument using the ldarga instruction.

Associated with each method is metadata that specifies:
- whether the local variables and memory pool memory will be initialized when the method is entered
- the type of each argument and the length of the argument array (but see below for variable argument lists)
- the type of each local variable and the length of the local variable array.

The CLI inserts padding as appropriate for the target architecture. That is, on some 64-bit architectures all local variables may be 64-bit aligned, while on others they may be 8-, 16-, or 32-bit aligned. The CIL generator shall make no assumptions about the offsets of local variables within the array. In fact, the CLI is free to reorder the elements in the local variable array, and different JITters may choose to order them in different ways.

11.3.2.3 Variable Argument Lists

The CLI works in conjunction with the class library to implement methods that accept argument lists of unknown length and type (“varargs methods”). Access to these arguments is through a typesafe iterator in the Class Library, called System.ArgIterator (see Partition IV).

The CLI includes one instruction provided specifically to support the argument iterator, arglist. This instruction may be used only within a method that is declared to take a variable number of arguments. It returns
a value that is needed by the constructor for a `System.ArgIterator` object. Basically, the value created by `arglist` provides access both to the address of the argument list that was passed to the method and a runtime data structure that specifies the number and type of the arguments that were provided. This is sufficient for the class library to implement the user visible iteration mechanism.

From the CLI point of view, varargs methods have an array of arguments like other methods. But only the initial portion of the array has a fixed set of types and only these may be accessed directly using the `ldarg`, `starg`, and `ldarga` instructions. The argument iterator allows access to both this initial segment and the remaining entries in the array.

### 11.3.2.4 Local Memory Pool

Part of each method state is a local memory pool. Memory can be explicitly allocated from the local memory pool using the `localloc` instruction. All memory in the local memory pool is reclaimed on method exit, and that is the only way local memory pool memory is reclaimed (there is no instruction provided to free local memory that was allocated during this method invocation). The local memory pool is used to allocate objects whose type or size is not known at compile time and which the programmer does not wish to allocate in the managed heap.

Because the local memory pool cannot be shrunk during the lifetime of the method, a language implementation cannot use the local memory pool for general-purpose memory allocation.

### 11.4 Control Flow

The CIL instruction set provides a rich set of instructions to alter the normal flow of control from one CIL instruction to the next.

- **Conditional and Unconditional Branch** instructions for use within a method, provided the transfer doesn’t cross a protected region boundary (see clause 11.4.2).
- **Method call** instructions to compute new arguments, transfer them and control to a known or computed destination method (see clause 11.4.1).
- **Tail call** prefix to indicate that a method should relinquish its stack frame before executing a method call (see clause 11.4.1).
- **Return** from a method, returning a value if necessary.
- **Method jump** instructions to transfer the current method’s arguments to a known or computed destination method (see clause 11.4.1).
- **Exception-related** instructions (see clause 11.4.2). These include instructions to initiate an exception, transfer control out of a protected region, and end a filter, catch clause, or finally clause.

While the CLI supports control transfers within a method, there are several restrictions that shall be observed:

1. Control transfer is never permitted to enter a catch handler or finally clause (see clause 11.4.2) except through the exception handling mechanism.
2. Control transfer out of a protected region (see clause 11.4.2) is only permitted through an exception instruction (`leave, end.filter, end.catch, or end.finally`).
3. The evaluation stack shall be empty after the return value is popped by a `ret` instruction.
4. Each slot on the stack shall have the same data type at any given point within the method body, regardless of the control flow that allows execution to arrive there.
5. In order for the JIT compilers to efficiently track the data types stored on the stack, the stack shall normally be empty at the instruction following an unconditional control transfer instruction (`br, br.s, ret, jmp, throw, end.filter, end.catch, or end.finally`). The stack may be non-empty at such an instruction only if at some earlier location within the method there has been a forward branch to that instruction.
6. Control is not permitted to simply “fall through” the end of a method. All paths shall terminate with one of these instructions: \texttt{ret}, \texttt{throw}, \texttt{jmp}, or (\texttt{tail}. followed by \texttt{call}, \texttt{calli}, or \texttt{callvirt}).

11.4.1 Method Calls

Instructions emitted by the CIL code generator contain sufficient information for different implementations of the CLI to use different native calling convention. All method calls initialize the method state areas (see clause 11.3.2) as follows:

1. The incoming arguments array is set by the caller to the desired values.
2. The local variables array always has \texttt{null} for Object types and for fields within value types that hold objects. In addition, if the “zero init flag” is set in the method header, then the local variables array is initialized to 0 for all integer types and 0.0 for all floating point types. Value Types are not initialized by the CLI, but verified code will supply a call to an initializer as part of the method’s entry point code.
3. The evaluation stack is empty.

11.4.1.1 Call Site Descriptors

Call sites specify additional information that enables an interpreter or JIT compiler to synthesize any native calling convention. All CIL calling instructions (\texttt{call}, \texttt{calli}, and \texttt{callvirt}) include a description of the call site. This description can take one of two forms. The simpler form, used with the \texttt{calli} instruction, is a “call site description” (represented as a metadata token for a stand-alone call signature) that provides:

- The number of arguments being passed.
- The data type of each argument.
- The order in which they have been placed on the call stack.
- The native calling convention to be used

The more complicated form, used for the \texttt{call} and \texttt{callvirt} instructions, is a “method reference” (a metadata \texttt{methodref} token) that augments the call site description with an identifier for the target of the call instruction.

11.4.1.2 Calling Instructions

The CIL has three call instructions that are used to transfer new argument values to a destination method. Under normal circumstances, the called method will terminate and return control to the calling method.

- \texttt{call} is designed to be used when the destination address is fixed at the time the CIL is linked. In this case, a method reference is placed directly in the instruction. This is comparable to a direct call to a static function in C. It may be used to call static or instance methods or the (statically known) superclass method within an instance method body.
- \texttt{calli} is designed for use when the destination address is calculated at run time. A method pointer is passed on the stack and the instruction contains only the call site description.
- \texttt{callvirt}, part of the CIL common type system instruction set, uses the class of an object (known only at runtime) to determine the method to be called. The instruction includes a method reference, but the particular method isn’t computed until the call actually occurs. This allows an instance of a subclass to be supplied and the method appropriate for that subclass to be invoked. The \texttt{callvirt} instruction is used both for instance methods and methods on interfaces. For further details, see the Common Type System specification and the CIL Instruction Set specification.

In addition, each of these instructions may be immediately preceded by a \texttt{tail}. instruction prefix. This specifies that the calling method terminates with this method call (and returns whatever value is returned by the called method). The \texttt{tail}. prefix instructs the JIT compiler to discard the caller’s method state prior to making the call (if the call is from untrusted code to trusted code the frame cannot be fully discarded for security reasons). When the called method executes a \texttt{ret} instruction, control returns not to the calling method but rather to wherever that method would itself have returned (typically, return to caller’s caller). Notice that the \texttt{tail}.
instruction shortens the lifetime of the caller’s frame so it is unsafe to pass managed pointers (type &amp;) as arguments.

Finally, there are two instructions that indicate an optimization of the tail case:

- **jmp** is followed by a methodref or methoddef token and indicates that the current method’s state should be discarded, its arguments should be transferred intact to the destination method, and control should be transferred to the destination. The signature of the calling method shall exactly match the signature of the destination method.

### 11.4.1.3 Computed Destinations

The destination of a method call may be either encoded directly in the CIL instruction stream (the call and jmp instructions) or computed (the callvirt, and calli instructions). The destination address for a callvirt instruction is automatically computed by the CLI based on the method token and the value of the first argument (the this pointer). The method token shall refer to a virtual method on a class that is a direct ancestor of the class of the first argument. The CLI computes the correct destination by locating the nearest ancestor of the first argument’s class that supplies an implementation of the desired method.

**Note:** The implementation can be assumed to be more efficient than the linear search implied here).

For the call instruction the CIL code is responsible for computing a destination address and pushing it on the stack. This is typically done through the use of a ldflt or ldvirtfn instruction at some earlier time. The ldflt instruction includes a metadata token in the CIL stream that specifies a method, and the instruction pushes the address of that method. The ldvirtfn instruction takes a metadata token for a virtual method in the CIL stream and an object on the stack. It performs the same computation described above for the callvirt instruction but pushes the resulting destination on the stack rather than calling the method.

The call instruction includes a call site description that includes information about the native calling convention that should be used to invoke the method. Correct CIL code shall specify a calling convention specified in the calli instruction that matches the calling convention for the method that is being called.

### 11.4.1.4 Virtual Calling Convention

The CIL provides a “virtual calling convention” that is converted by the JIT into a native calling convention. The JIT determines the optimal native calling convention for the target architecture. This allows the native calling convention to differ from machine to machine, including details of register usage, local variable homes, copying conventions for large call-by-value objects (as well as deciding, based on the target machine, what is considered “large”). This also allows the JIT to reorder the values placed on the CIL virtual stack to match the location and order of arguments passed in the native calling convention.

The CLI uses a single uniform calling convention for all method calls. It is the responsibility of the JITters to convert this into the appropriate native calling convention. The contents of the stack at the time of a call instruction (call, calli, or callvirt any of which may be preceded by tail) are as follows:

1. If the method being called is an instance method (class or interface) or a virtual method, the this pointer is the first object on the stack at the time of the call instruction. For methods on Objects (including boxed value types), the this pointer is of type O (object reference). For methods on value types, the this pointer is provided as a by-ref parameter; that is, the value is a pointer (managed, &, or unmanaged, * or native int) to the instance.

2. The remaining arguments appear on the stack in left-to-right order (that is, the lexically leftmost argument is the lowest on the stack, immediately following the this pointer, if any).

Clause 11.4.1.5 describes how each of the three parameter passing conventions (by-value, by-reference, and typed reference) should be implemented.

### 11.4.1.5 Parameter Passing

The CLI supports three kinds of parameter passing, all indicated in metadata as part of the signature of the method. Each parameter to a method has its own passing convention (e.g., the first parameter may be passed by-value while all others are passed by-ref). Parameters shall be passed in one of the following ways (see detailed descriptions below):
• **By-value** parameters, where the value of an object is passed from the caller to the callee.

• **By-ref** parameters, where the address of the data is passed from the caller to the callee, and the type of the parameter is therefore a managed or unmanaged pointer.

• **Typed reference** parameters, where a runtime representation of the data type is passed along with the address of the data, and the type of the parameter is therefore one specially supplied for this purpose.

It is the responsibility of the CIL generator to follow these conventions. Verification checks that the types of parameters match the types of values passed, but is otherwise unaware of the details of the calling convention.

11.4.1.5.1 **By-Value Parameters**

For built-in types (integers, floats, etc.) the caller copies the value onto the stack before the call. For objects the object reference (type `O`) is pushed on the stack. For managed pointers (type `&`) or unmanaged pointers (type `native unsigned int`), the address is passed from the caller to the callee. For value types, see the protocol in clause 11.1.6.2.

11.4.1.5.2 **By-Ref Parameters**

By-Ref Parameters are the equivalent of C++ reference parameters or PASCAL var parameters: instead of passing as an argument the value of a variable, field, or array element, its address is passed instead; and any assignment to the corresponding parameter actually modifies the corresponding caller’s variable, field, or array element. Much of this work is done by the higher-level language, which hides from the user the need to compute addresses to pass a value and the use of indirection to reference or update values.

Passing a value by reference requires that the value have a home (see clause 11.1.6.1) and it is the address of this home that is passed. Constants, and intermediate values on the evaluation stack, cannot be passed as by-ref parameters because they have no home.

The CLI provides instructions to support by-ref parameters:

• calculate addresses of home locations (see Table 8: Address and Type of Home Locations)

• load and store built-in data types through these address pointers (`ldind.*`, `stind.*`, `ldfld`, etc.)

• copy value types (`ldobj` and `cpobj`).

Some addresses (e.g., local variables and arguments) have lifetimes tied to that method invocation. These shall not be referenced outside their lifetimes, and so they should not be stored in locations that last beyond their lifetime. The CIL does not (and cannot) enforce this restriction, so the CIL generator shall enforce this restriction or the resulting CIL will not work correctly. For code to be verifiable (see Section 7.8) by-ref parameters may only be passed to other methods or referenced via the appropriate `stind` or `ldind` instructions.

11.4.1.5.3 **Typed Reference Parameters**

By-ref parameters and value types are sufficient to support statically typed languages (C++, Pascal, etc.). They also support dynamically typed languages that pay a performance penalty to box value types before passing them to polymorphic methods (Lisp, Scheme, SmallTalk, etc.). Unfortunately, they are not sufficient to support languages like Visual Basic that require by-reference passing of unboxed data to methods that are not statically restricted as to the type of data they accept. These languages require a way of passing both the address of the home of the data and the static type of the home. This is exactly the information that would be provided if the data were boxed, but without the heap allocation required of a box operation.

Typed reference parameters address this requirement. A typed reference parameter is very similar to a standard by-ref parameter but the static data type is passed as well as the address of the data. Like by-ref parameters, the argument corresponding to a typed reference parameter will have a home.

**Note:** If it were not for the fact that verification and the memory manager need to be aware of the data type and the corresponding address, a by-ref parameter could be implemented as a standard value type with two fields: the address of the data and the type of the data.

Like a regular by-ref parameter, a typed reference parameter can refer to a home that is on the stack, and that home will have a lifetime limited by the call stack. Thus, the CIL generator shall apply appropriate checks on
the lifetime of by-ref parameters; and verification imposes the same restrictions on the use of typed reference parameters as it does on by-ref parameters (see clause 11.4.1.5.2).

A typed reference is passed by either creating a new typed reference (using the \texttt{mkrefany} instruction) or by copying an existing typed reference. Given a typed reference argument, the address to which it refers can be extracted using the \texttt{refanyval} instruction; the type to which it refers can be extracted using the \texttt{refanynpe} instruction.

11.4.1.5.4 Parameter Interactions

A given parameter may be passed using any one of the parameter passing conventions: by-value, by-ref, or typed reference. No combination of these is allowed for a single parameter, although a method may have different parameters with different calling mechanisms.

A parameter that has been passed in as typed reference shall not be passed on as by-ref or by-value without a runtime type check and (in the case of by-value) a copy.

A by-ref parameter may be passed on as a typed reference by attaching the static type.

Table 9: Parameter Passing Conventions illustrates the parameter passing convention used for each data type.

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Pass By</th>
<th>How data is sent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-in value type (int, float, etc.)</td>
<td>Value</td>
<td>Copied to called method, type statically known at both sides</td>
</tr>
<tr>
<td></td>
<td>Reference</td>
<td>Address sent to called method, type statically known at both sides</td>
</tr>
<tr>
<td></td>
<td>Typed reference</td>
<td>Address sent along with type information to called method</td>
</tr>
<tr>
<td>User-defined value type</td>
<td>Value</td>
<td>Called method receives a copy; type statically known at both sides</td>
</tr>
<tr>
<td></td>
<td>Reference</td>
<td>Address sent to called method, type statically known at both sides</td>
</tr>
<tr>
<td></td>
<td>Typed reference</td>
<td>Address sent along with type information to called method</td>
</tr>
<tr>
<td>Object</td>
<td>Value</td>
<td>Reference to data sent to called method, type statically known and class available from reference</td>
</tr>
<tr>
<td></td>
<td>Reference</td>
<td>Address of reference sent to called method, type statically known and class available from reference</td>
</tr>
<tr>
<td></td>
<td>Typed reference</td>
<td>Address of reference sent to called method along with static type information, class (i.e. dynamic type) available from reference</td>
</tr>
</tbody>
</table>

11.4.2 Exception Handling

Exception handling is supported in the CLI through exception objects and protected blocks of code. When an exception occurs, an object is created to represent the exception. All exceptions objects are instances of some class (i.e. they can be boxed value types, but not pointers, unboxed value types, etc.). Users may create their own exception classes, typically by subclassing \texttt{System.Exception} (see Partition IV).

There are four kinds of handlers for protected blocks. A single protected block shall have exactly one handler associated with it:

- A \textbf{finally handler} that shall be executed whenever the block exits, regardless of whether that occurs by normal control flow or by an unhandled exception.
- A \textbf{fault handler} that shall be executed if an exception occurs, but not on completion of normal control flow.
- A \textbf{type-filtered handler} that handles any exception of a specified class or any of its sub-classes.
A user-filtered handler that runs a user-specified set of CIL instructions to determine whether
the exception should be ignored (i.e. execution should resume), handled by the associated handler,
or passed on to the next protected block. Protected regions, the type of the associated handler, and the location of the associated handler and (if needed)
user-supplied filter code are described through an Exception Handler Table associated with each method. The
exact format of the Exception Handler Table is specified in detail in Partition II. Details of the exception
handling mechanism are also specified in Partition II.

### 11.4.2.1 Exceptions Thrown by the CLI

CLI instructions can throw the following exceptions as part of executing individual instructions. The
documentation for each instruction lists all the exceptions the instruction can throw (except for the general
purpose ExecutionEngineException described below that may be generated by all instructions).

**Base Instructions** (see Partition III)

- ArithmeticException
- DivideByZeroException
- ExecutionEngineException
- InvalidAddressException
- OverflowException
- SecurityException
- StackOverflowException

**Object Model Instructions** (see Partition III)

- TypeLoadException
- IndexOutOfRangeException
- InvalidAddressException
- InvalidCastException
- MissingFieldException
- MissingMethodException
- NullReferenceException
- OutOfMemoryException
- SecurityException
- StackOverflowException

The ExecutionEngineException is special. It can be thrown by any instruction and indicates an unexpected
inconsistency in the CLI. Running exclusively verified code can never cause this exception to be thrown by a
conforming implementation of the CLI. However, unverified code (even though that code is conforming CIL)
can cause this exception to be thrown if it corrupts memory. Any attempt to execute non-conforming CIL or
non-conforming file formats can cause completely unspecified behavior: a conforming implementation of the
CLI need not make any provision for these cases.

There are no exceptions for things like ‘MetaDataTokenNotFound.’ CIL verification (see Partition V) will
detect this inconsistency before the instruction is executed, leading to a verification violation. If the CIL is not
verified this type of inconsistency shall raise the generic ExecutionEngineException.

Exceptions can also be thrown by the CLI, as well as by user code, using the `throw` instruction. The handing of
an exception is identical, regardless of the source.
11.4.2.2 Subclassing Of Exceptions

Certain types of exceptions thrown by the CLI may be subclassed to provide more information to the user. The specification of CIL instructions in Partition III describes what types of exceptions should be thrown by the runtime environment when an abnormal situation occurs. Each of these descriptions allows a conforming implementation to throw an object of the type described or an object of a subclass of that type.

**Note:** For instance, the specification of the `ckfinite` instruction requires that an exception of type `ArithmeticException` or a subclass of `ArithmeticException` be thrown by the CLI. A conforming implementation may simply throw an exception of type `ArithmeticException`, but it may also choose to provide more information to the programmer by throwing an exception of type `NotFiniteNumberException` with the offending number.

11.4.2.3 Resolution Exceptions

CIL allows types to reference, among other things, interfaces, classes, methods, and fields. Resolution errors occur when references are not found or are mismatched. Resolution exceptions can be generated by references from CIL instructions, references to base classes, to implemented interfaces, and by references from signatures of fields, methods and other class members.

To allow scalability with respect to optimization, detection of resolution exceptions is given latitude such that it may occur as early as install time and as late as execution time.

The latest opportunity to check for resolution exceptions from all references except CIL instructions is as part of initialization of the type that is doing the referencing (see Partition II). If such a resolution exception is detected the static initializer for that type, if present, shall not be executed.

The latest opportunity to check for resolution exceptions in CIL instructions is as part of the first execution of the associated CIL instruction. When an implementation chooses to perform resolution exception checking in CIL instructions as late as possible, these exceptions, if they occur, shall be thrown prior to any other non-resolution exception that the VES may throw for that CIL instruction. Once a CIL instruction has passed the point of throwing resolution errors (it has completed without exception, or has completed by throwing a non-resolution exception), subsequent executions of that instruction shall no longer throw resolution exceptions.

If an implementation chooses to detect some resolution errors, from any references, earlier than the latest opportunity for that kind of reference, it is not required to detect all resolution exceptions early.

An implementation that detects resolution errors early is allowed to prevent a class from being installed, loaded or initialized as a result of resolution exceptions detected in the class itself or in the transitive closure of types from following references of any kind.

For example, each of the following represents a permitted scenario. An installation program can throw resolution exceptions (thus failing the installation) as a result of checking CIL instructions for resolution errors in the set of items being installed. An implementation is allowed to fail to load a class as a result of checking CIL instructions in a referenced class for resolution errors. An implementation is permitted to load and initialize a class that has resolution errors in its CIL instructions.

The following exceptions are among those considered resolution exceptions:

- BadImageFormatException
- EntryPointNotFoundException
- MissingFieldException
- MissingMemberException
- MissingMethodException
- NotSupportedException
- TypeLoadException
- TypeUnloadedException

For example, when a referenced class cannot be found, a `TypeLoadException` is thrown. When a referenced method (whose class is found) cannot be found, a `MissingMethodException` is thrown. If a matching method being used consistently is accessible, but violates declared security policy, a `SecurityException` is thrown.
11.4.2.4 Timing of Exceptions

Certain types of exceptions thrown by CIL instructions may be detected before the instruction is executed. In these cases, the specific time of the throw is not precisely defined, but the exception should be thrown no later than the instruction is executed. That relaxation of the timing of exceptions is provided so that an implementation may choose to detect and throw an exception before any code is run, e.g., at the time of CIL to native code conversion.

There is a distinction between the time of detecting the error condition and throwing the associated exception. An error condition may be detected early (e.g., at JIT time), but the condition may be signaled later (e.g. at the execution time of the offending instruction) by throwing an exception.

The following exceptions are among those that may be thrown early by the runtime:

- MissingFieldException
- MissingMethodImplException
- SecurityException
- TypeLoadException

11.4.2.5 Overview of Exception Handling

See the Exception Handling specification in Partition II for details.

Each method in an executable has associated with it a (possibly empty) array of exception handling information. Each entry in the array describes a protected block, its filter, and its handler (which may be a catch handler, a filter handler, a finally handler, or a fault handler). When an exception occurs, the CLI searches the array for the first protected block that

- Protects a region including the current instruction pointer and
- Is a catch handler block and
- Whose filter wishes to handle the exception

If a match is not found in the current method, the calling method is searched, and so on. If no match is found the CLI will dump a stack trace and abort the program.

Some things to notice are:

- The ordering of the exception clauses in the Exception Handler Table is important. If handlers are nested, the most deeply nested try blocks shall come before the try blocks that enclose them.
- Exception handlers may access the local variables and the local memory pool of the routine that catches the exception, but any intermediate results on the evaluation stack at the time the exception was thrown are lost.
- An exception object describing the exception is automatically created by the CLI and pushed onto the evaluation stack as the first item upon entry of a filter or catch clause.
- Execution cannot be resumed at the location of the exception, except with a user-filtered handler.

11.4.2.6 CIL Support for Exceptions

The CIL has special instructions to:

- Throw and rethrow a user-defined exception.
Leave a protected block and execute the appropriate finally clauses within a method, without throwing an exception. This is also used to exit a catch clause. Notice that leaving a protected block does not cause the fault clauses to be called.

End a user-supplied filter clause (endfilter) and return a value indicating whether to handle the exception.

End a finally clause (endfinally) and continue unwinding the stack.

11.4.2.7 Lexical Nesting of Protected Blocks

A protected region (also called a “try block”) is described by two addresses: the trystart is the address of the first instruction to be protected and tryend is the address immediately following the last instruction to be protected. A handler region is described by two addresses: the handlerstart is the address of the first instruction of the handler and the handlerend is the address immediately following the last instruction of the handler.

There are three kinds of handlers: catch, finally, and fault. A single exception entry consists of

- Optional: a type token (the type of exception to be handled) or filterstart (the address of the first instruction of the user-supplied filter code)
- Required: protected region
- Required: handler region.

Every method has associated with it a set of exception entries, called the exception set.

If an exception entry contains a filterstart, then filterstart < handlerstart. The filter region starts at the instruction specified by filterstart and contains all instructions up to (but not including) that specified by handlerstart. If there is no filterstart then the filter region is empty (hence does not overlap with any region). No two regions (protected region, handler region, filter region) of a single exception entry may overlap with one another.

For every pair of exception entries in an exception set, one of the following must be true:

- They nest: all three regions of one entry must be within a single region of the other entry.
- They are disjoint: all six regions of the two entries are pairwise disjoint (no addresses overlap)
- They mutually protect: the protected regions are the same and the other regions are pairwise disjoint.

The encoding of an exception entry in the file format (see Partition II) guarantees that only a catch handler (not a fault handler or finally handler) can have a filter region.

11.4.2.8 Control Flow Restrictions on Protected Blocks

The following restrictions govern control flow into, out of, and between try blocks and their associated handlers.

1. CIL code shall not enter a filter, catch, fault or finally block except through the CLI exception handling mechanism.
2. There are only two ways to enter a try block from outside its lexical body:
   - Branching to or falling into the try block’s first instruction. The branch may be made using a conditional branch, an unconditional branch, or a leave instruction.
   - Using a leave instruction from that try’s catch block. In this case, correct CIL code may branch to any instruction within the try block, not just its first instruction, so long as that branch target is not protected by yet another try, nested within the first
3. Upon entry to a try block the evaluation stack shall be empty.
4. The only ways CIL code may leave a try, filter, catch, finally or fault block are as follows:
a. **throw** from any of them.

**leave** from the body of a **try** or **catch** (in this case the destination of the **leave** shall have an empty evaluation stack and the **leave** instruction has the side-effect of emptying the evaluation stack).

**endfilter** may appear only as the lexically last instruction of a **filter** block, and it shall always be present (even if it is immediately preceded by a **throw** or other unconditional control flow). If reached, the evaluation stack shall contain an **int32** when the **endfilter** is executed, and the value is used to determine how exception handling should proceed.

**endfinally** from anywhere within a **finally** or **fault**, with the side-effect of emptying the evaluation stack.

**rethrow** from within a **catch** block, with the side-effect of emptying the evaluation stack.

5. When the try block is exited with a leave instruction, the evaluation stack shall be empty.

6. When a catch or filter clause is exited with a leave instruction, the evaluation stack shall be empty. This involves popping, from the evaluation stack, the exception object that was automatically pushed onto the stack.

7. CIL code shall not exit any **try**, **filter**, **catch** finally or **fault** block using a **ret** instruction.

8. The **localloc** instruction cannot occur within an exception block: **filter**, **catch**, **finally**, or **fault**

### 11.5 Proxies and Remoting

A **remoting boundary** exists if it is not possible to share the identity of an object directly across the boundary. For example, if two objects exist on physically separate machines that do not share a common address space, then a remoting boundary will exist between them. There are other administrative mechanisms for creating remoting boundaries.

The VES provides a mechanism, called the **application domain**, to isolate applications running in the same operating system process from one another. Types loaded into one application domain are distinct from the same type loaded into another application domain, and instances of objects shall not be directly shared from one application domain to another. Hence, the application domain itself forms a remoting boundary.

The VES implements remoting boundaries based on the concept of a **proxy**. A proxy is an object that exists on one side of the boundary and represents an object on the other side. The proxy forwards references to instance fields and methods to the actual object for interpretation. Proxies do not forward references to static fields or calls to static methods.

The implementation of proxies is provided automatically for instances of types that derive from **System.MarshalByRefObject** (see Partition IV).

### 11.6 Memory Model and Optimizations

#### 11.6.1 The Memory Store

By “memory store” we mean the regular process memory that the CLI operates within. Conceptually, this store is simply an array of bytes. The index into this array is the address of a data object. The CLI accesses data objects in the memory store via the **ldind.*** and **stind.*** instructions.

#### 11.6.2 Alignment

Built-in datatypes shall be **properly aligned**, which is defined as follows:

- 1-byte, 2-byte, and 4-byte data is properly aligned when it is stored at a 1-byte, 2-byte, or 4-byte boundary, respectively.
- 8-byte data is properly aligned when it is stored on the same boundary required by the underlying hardware for atomic access to a **native int**.
Thus, int16 and unsigned int16 start on even address; int32, unsigned int32, and float32 start on an address divisible by 4; and int64, unsigned int64, and float64 start on an address divisible by 4 or 8, depending upon the target architecture. The native size types (native int, native unsigned int, and & ) are always naturally aligned (4 bytes or 8 bytes, depending on architecture). When generated externally, these should also be aligned to their natural size, although portable code may use 8 byte alignment to guarantee architecture independence. It is strongly recommended that float64 be aligned on an 8-byte boundary, even when the size of native int is 32 bits.

There is a special prefix instruction, unaligned, that may immediately precede a ldind, stind, initblk, or cpblk instruction. This prefix indicates that the data may have arbitrary alignment; the JIT is required to generate code that correctly performs the effect of the instructions regardless of the actual alignment. Otherwise, if the data is not properly aligned and no unaligned. prefix has been specified, executing the instruction may generate unaligned memory faults or incorrect data.

11.6.3 Byte Ordering

For datatypes larger than 1 byte, the byte ordering is dependent on the target CPU. Code that depends on byte ordering may not run on all platforms. The PE file format (see Section 11.2) allows the file to be marked to indicate that it depends on a particular type ordering.

11.6.4 Optimization

Conforming implementations of the CLI are free to execute programs using any technology that guarantees, within a single thread of execution, that side-effects and exceptions generated by a thread are visible in the order specified by the CIL. For this purpose volatile operations (including volatile reads) constitute side-effects. Volatile operations are specified in clause 11.6.7. There are no ordering guarantees relative to exceptions injected into a thread by another thread (such exceptions are sometimes called “asynchronous exceptions,” e.g., System.Threading.ThreadAbortException).

Rationale: An optimizing compiler is free to reorder side-effects and synchronous exceptions to the extent that this reordering does not change any observable program behavior.

Note: An implementation of the CLI is permitted to use an optimizing compiler, for example, to convert CIL to native machine code provided the compiler maintains (within each single thread of execution) the same order of side-effects and synchronous exceptions.

This is a stronger condition than ISO C++ (which permits reordering between a pair of sequence points) or ISO Scheme (which permits reordering of arguments to functions).

11.6.5 Locks and Threads

The logical abstraction of a thread of control is captured by an instance of the System.Threading.Thread object in the class library. Classes beginning with the string “System.Threading” (see Partition IV) provide much of the user visible support for this abstraction. To create consistency across threads of execution, the CLI provides the following mechanisms:

1. Synchronized methods. A lock that is visible across threads controls entry to the body of a synchronized method. For instance and virtual methods the lock is associated with the this pointer. For static methods the lock is associated with the type to which the method belongs. The lock is taken by the logical thread (see System.Threading.-Thread in Partition IV) and may be entered any number of times by the same thread; entry by other threads is prohibited while the first thread is still holding the lock. The CLI shall release the lock when control exits (by any means) the method invocation that first acquired the lock.

2. Explicit locks and monitors. These are provided in the class library, see System.Threading.Monitor. Many of the methods in the System.Threading.Monitor class accept an Object as argument, allowing direct access to the same lock that is used by synchronized methods. While the CLI is responsible for ensuring correct protocol when this lock is only used by synchronized methods, the user must accept this responsibility when using explicit monitors on these same objects.
3. **Volatile reads and writes.** The CIL includes a prefix, `volatile`, that specifies that the subsequent operation is to be performed with the cross-thread visibility constraints described in clause 11.6.7. In addition, the class library provides methods to perform explicit volatile reads (name) and writes (name), as well as a barrier synchronization (name).

4. **Built-in atomic reads and writes.** All reads and writes of certain properly aligned data types are guaranteed to occur atomically. See clause 11.6.6.

5. **Explicit atomic operations.** The class library provides a variety of atomic operations in the `System.Threading.Interlocked` class.

Acquiring a lock (`System.Threading.Monitor.Enter` or entering a synchronized method) shall implicitly perform a volatile read operation, and releasing a lock (`System.Threading.Monitor.Exit` or leaving a synchronized method) shall implicitly perform a volatile write operation. See clause 11.6.7.

### 11.6.6 Atomic Reads and Writes

A conforming CLI shall guarantee that read and write access to properly aligned memory locations no larger than the native word size (the size of type `native int`) is atomic (see clause 11.6.2). Atomic writes shall alter no bits other than those written. Unless explicit layout control (see Partition II (Controlling Instance Layout)) is used to alter the default behavior, data elements no larger than the natural word size (the size of a `native int`) shall be properly aligned. Object references shall be treated as though they are stored in the native word size.

**Note:** There is no guarantee about atomic update (read-modify-write) of memory, except for methods provided for that purpose as part of the class library (see Partition IV). An atomic write of a “small data item” (an item no larger than the native word size) is required to do an atomic read/write/modify on hardware that does not support direct writes to small data items.

**Note:** There is no guaranteed atomic access to 8-byte data when the size of a `native int` is 32 bits even though some implementations may perform atomic operations when the data is aligned on an 8-byte boundary.

### 11.6.7 Volatile Reads and Writes

The `volatile` prefix on certain instructions shall guarantee cross-thread memory ordering rules. They do not provide atomicity, other than that guaranteed by the specification of clause 11.6.6.

A volatile read has “acquire semantics” meaning that the read is guaranteed to occur prior to any references to memory that occur after the read instruction in the CIL instruction sequence. A volatile write has “release semantics” meaning that the write is guaranteed to happen after any memory references prior to the write instruction in the CIL instruction sequence.

A conforming implementation of the CLI shall guarantee this semantics of volatile operations. This ensures that all threads will observe volatile writes performed by any other thread in the order they were performed. But a conforming implementation is not required to provide a single total ordering of volatile writes as seen from all threads of execution.

An optimizing compiler that converts CIL to native code shall not remove any volatile operation, nor may it coalesce multiple volatile operations into a single operation.

**Rationale:** One traditional use of volatile operations is to model hardware registers that are visible through direct memory access. In these cases, removing or coalescing the operations may change the behavior of the program.

**Note:** An optimizing compiler from CIL to native code is permitted to reorder code, provided that it guarantees both the single-thread semantics described in Section 11.6 and the cross-thread semantics of volatile operations.

### 11.6.8 Other Memory Model Issues

All memory allocated for static variables (other than those assigned RVAs within a PE file, see Partition II) and objects shall be zeroed before they are made visible to any user code.
A conforming implementation of the CLI shall ensure that, even in a multi-threaded environment and without proper user synchronization, objects are allocated in a manner that prevents unauthorized memory access and prevents illegal operations from occurring. In particular, on multiprocessor memory systems where explicit synchronization is required to ensure that all relevant data structures are visible (for example, vtable pointers) the EE shall be responsible for either enforcing this synchronization automatically or for converting errors due to lack of synchronization into non-fatal, non-corrupting, user-visible exceptions.

It is explicitly not a requirement that a conforming implementation of the CLI guarantee that all state updates performed within a constructor be uniformly visible before the constructor completes. CIL generators may ensure this requirement themselves by inserting appropriate calls to the memory barrier or volatile write instructions.

11.7 Atomicity of Memory Accesses

The CLI makes several assumptions about atomicity of memory references, and these translate directly into rules required of either programmers or translators from high-level languages into CIL.

- Read and write access to word-length memory locations (types native int and native unsigned int) that are properly aligned is atomic. Correct translation from CIL to native code requires generation of native code sequences that supply this atomicity guarantee. There is no guarantee about atomic update (read-modify-write) of memory, except for methods provided for that purpose as part of the class library (see Partition IV).

- Read and write access to 4-byte data (int32 and unsigned int32) that is aligned on a 4-byte boundary is atomic, even on a 64-bit machine. Again, there is no guarantee about atomic read-modify-write.

- One- and Two-byte data that does not cross a word boundary will be read atomically, but writing may write the entire word back to memory.

- No other memory references are performed atomically.

When the CLI controls the layout of managed data, it pads the data so that if an object starts at a word boundary all of the fields that require 4 or fewer bytes will be aligned so that reads will be atomic. The managed heap always aligns data that it allocates to maintain this rule, so heap references (type O) to data that does not have explicit layout will occur atomically where possible. Similarly, static variables of managed classes are allocated so that they, too, are aligned when possible. The CLI aligns stack frames to word boundaries, but need not attempt to align to an 8-byte boundary on 32-bit machines even if the frame contains 8-byte values.
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1 Scope

Partition I of the Common Language Infrastructure (CLI) describes the overall architecture of the CLI, and provides the normative description of the Common Type System (CTS), the Virtual Execution System (VES), and the Common Language Specification (CLS). It also provides a non-normative description of the metadata and a comprehensive set of abbreviations, acronyms (Partition I) and definitions, included by reference (Partition I) from all other Partitions.

Partition II (this specification) provides the normative description of the metadata: its physical layout (as a file format), its logical contents (as a set of tables and their relationships), and its semantics (as seen from a hypothetical assembler, ilasm).
Overview

This document focuses on the structure and semantics of metadata. The semantics of metadata, which dictate much of the operation of the VES, are described using the syntax of ilasm, an assembler language for CIL. The ilasm syntax itself is considered a normative part of this ECMA standard. This constitutes Chapters 5 through 0. A complete syntax for ilasm is included in Partition V. The structure (both logical and physical) is covered in Chapters 21 through 24.

Rationale: An assembly language is really just syntax for specifying the metadata in a file and the CIL instructions in that file. Specifying ilasm provides a means of interchanging programs written directly for the CLI without the use of a higher-level language and also provides a convenient way to express examples.

The semantics of the metadata also can be described independently of the actual format in which the metadata is stored. This point is important because the storage format as specified Chapters 21 through 24 is engineered to be efficient for both storage space and access time but this comes at the cost of the simplicity desirable for describing its semantics.
3 Validation and Verification

Validation refers to a set of tests that can be performed on any file to check that the file format, metadata, and CIL are self-consistent. These tests are intended to ensure that the file conforms to the mandatory requirements of this specification. The behavior of conforming implementations of the CLI when presented with non-conforming files is unspecified.

Verification refers to a check of both CIL and its related metadata to ensure that the CIL code sequences do not permit any access to memory outside the program’s logical address space. In conjunction with the validation tests, verification ensures that the program cannot access memory or other resources to which it is not granted access.

Partition III specifies the rules for both valid and verifiable use of CIL instructions. Partition III also provides an informative description of rules for validating the internal consistency of metadata (the rules follow, albeit indirectly, from the specification in this Partition) as well as containing a normative description of the verification algorithm. A mathematical proof of soundness of the underlying type system is possible, and provides the basis for the verification requirements. Aside from these rules this standard does not specify:

- at what time (if ever) such an algorithm should be performed
- what a conforming implementation should do in case of failure of verification.

The following graph makes this relationship clearer (see next paragraph for a description):

![Figure 1: Relationship between valid and verifiable CIL](image)

In the above figure, the outer circle contains all code permitted by the ilasm syntax. The next circle represents all code that is valid CIL. The dotted inner circle represents all type safe code. Finally, the black innermost circle contains all code that is verifiable. (The difference between typesafe code and verifiable code is one of provability: code which passes the VES verification algorithm is, by-definition, verifiable; but that simple algorithm rejects certain code, even though a deeper analysis would reveal it as genuinely typesafe). Note that even if a program follows the syntax described in Partition V, the code may still not be valid, because valid code shall adhere to restrictions presented in this document and in Partition III.

Verification is a very stringent test. There are many programs that will pass validation but will fail verification. The VES cannot guarantee that these programs do not access memory or resources to which they are not granted access. Nonetheless, they may have been correctly constructed so that they do not access these resources. It is thus a matter of trust, rather than mathematical proof, whether it is safe to run these programs. A conforming implementation of the CLI may allow unverifiable code (valid code that does not pass verification) to be executed, although this may be subject to administrative trust controls that are not part of this standard. A conforming implementation of the CLI shall allow the execution of verifiable code, although this may be subject to additional implementation-specified trust controls.
4 Introductory Examples

This section and its subsections contain only informative text.

Before diving into the details, it is useful to see an introductory sample program to get a feeling for the ilasm assembly language. The next section shows the famous Hello World program, this time in the ilasm assembly language.

4.1 Hello World Example

This section gives a simple example to illustrate the general feel of ilasm. Below is code that prints the well known “Hello world!” salutation. The salutation is written by calling WriteLine, a static method found in the class System.Console that is part of the assembly mscorlib (see Partition IV).

Example (informative):

```
.assembly extern mscorlib {}
.assembly hello {}
.method static public void main() cil managed
{
    .entrypoint
    .maxstack 1
    ldstr "Hello world!"
    call void [mscorlib]System.Console::WriteLine(class System.String)
    ret
}
```

The .assembly extern declaration references an external assembly, mscorlib, which defines System.Console. The .assembly declaration in the second line declares the name of the assembly for this program. (Assemblies are the deployment unit for executable content for the CLI.) The .method declaration defines the global method main. The body of the method is enclosed in braces. The first line in the body indicates that this method is the entry point for the assembly (.entrypoint), and the second line in the body specifies that it requires at most one stack slot (.maxstack).

The method contains only three instructions. The ldstr instruction pushes the string constant "Hello world!" onto the stack and the call instruction invokes System.Console::WriteLine, passing the string as its only argument (note that string literals in CIL are instances of the standard class System.String). As shown, call instructions shall include the full signature of the called method. Finally, the last instruction returns (ret) from main.

4.2 Examples

This document contains integrated examples for most features of the CLI metadata. Many sections conclude with an example showing a typical use of the feature. All these examples are written using the ilasm assembly language. In addition, Partition V contains a longer example of a program written in the ilasm assembly language. All examples are, of course, informative only.

End informative text
5 General Syntax

This section describes aspects of the ilasm syntax that are common to many parts of the grammar. The term “ASCII” refers to the American Standard Code for Information Interchange, a standard seven-bit code that was proposed by ANSI in 1963, and finalized in 1968. The ASCII repertoire of Unicode is the set of 128 Unicode characters from U+0000 to U+007F.

5.1 General Syntax Notation

This document uses a modified form of the BNF syntax notation. The following is a brief summary of this notation.

**Bold** items are terminals. Items placed in angle brackets (e.g. `<int64>`) are names of syntax classes and shall be replaced by actual instances of the class. Items placed in square brackets (e.g. `[<float>]`) are optional, and any item followed by * can appear zero or more times. The character “|” means that the items on either side of it are acceptable. The options are sorted in alphabetical order (to be more specific: in ASCII order, ignoring “<” for syntax classes, and case-insensitive). If a rule starts with an optional term, the optional term is not considered for sorting purposes.

ilasm is a case-sensitive language. All terminals shall be used with the same case as specified in this reference.

**Example (informative):**

A grammar such as

```
<top> ::= <int32> | float <float> |
         floats [<float> [, <float>]*] | else <QSTRING>
```

would consider the following all to be legal:

```
12
float 3
float -4.3e7
floats
floats 2.4
floats 2.4, 3.7
else "Something \t weird"
```

but all of the following to be illegal:

```
else 3
3, 4
float 4.3, 2.4
float else
stuff
```

5.2 Terminals

The basic syntax classes used in the grammar are used to describe syntactic constraints on the input intended to convey logical restrictions on the information encoded in the metadata.
The syntactic constraints described in this clause are informative only. The semantic constraints (e.g. “shall be represented in 32 bits”) are normative.

<int32> is either a decimal number or “0x” followed by a hexadecimal number, and shall be represented in 32 bits.
<int64> is either a decimal number or “0x” followed by a hexadecimal number, and shall be represented in 64 bits.
<hexbyte> is a 2-digit hexadecimal number that fits into one byte.
<realnumber> is any syntactic representation for a floating point number that is distinct from that for all other terminal nodes. In this document, a period (.) is used to separate the integer and fractional parts, and “e” or “E” separates the mantissa from the exponent. Either (but not both) may be omitted.

Note: A complete assembler may also provide syntax for infinities and NaNs.

<QSTRING> is a string surrounded by double quote (") marks. Within the quoted string the character “\" can be used as an escape character, with “\t” for a tab character, “\n” for a new line character, or followed by three octal digits in order to insert an arbitrary byte into the string. The “+” operator can be used to concatenate string literals. This way, a long string can be broken across multiple lines by using “+” and a new string on each line. An alternative is using “\" as the last character in a line, in which case the line break is not entered into the generated string. Any white characters (space, line feed, carriage return, and tab) between the “\" and the first character on the next line are ignored. See also examples below.

Note: A complete assembler will need to deal with the full set of issues required to support Unicode encodings, see Partition I (especially CLS Rule 4).

<SQSTRING> is similar to <QSTRING> with the difference that it is surround by single quote (’) marks instead of double quote marks.

<ID> is a contiguous string of characters which starts with either an alphabetic character or one of “_”, “$”, “@” or “?” and is followed by any number of alphanumeric characters or any of “_”, “$”, “@”, or “?”.

<ID> is used in only two ways:
• As a label of a CIL instruction
• As an <id> which can either be an <ID> or an <SQSTRING>, so that special characters can be included.

Example (informative):
The following examples shows breaking of strings:

```c
cil
ldstr "Hello " + "World " +
"from CIL!"
```
and

```c
cil
ldstr "Hello World\n\040from CIL!"
```
become both "Hello World from CIL!".
5.3 Identifiers

Identifiers are used to name entities. Simple identifiers are just equivalent to an <ID>. However, the ilasm2 syntax allows the use of any identifier that can be formed using the Unicode character set (see Partition I). To achieve this an identifier is placed within single quotation marks. This is summarized in the following grammar.

\[
<\text{id}> ::=  \\
\quad <\text{ID}>  \\
\quad <\text{SQSTRING}>  
\]

Keywords may only be used as identifiers if they appear in single quotes (see Partition V for a list of all keywords).

Several <\text{id}>’s may be combined to form a larger <\text{id}>. The <\text{id}>’s are separated by a dot (.). An <\text{id}> formed in this way is called a <\text{dottedname}>.

\[
<\text{dottedname}> ::= <\text{id}> [. <\text{id}>]*  
\]

Rationale: 
<\text{dottedname}> is provided for convenience, since “.” can be included in an <\text{id}> using the <\text{SQSTRING}> syntax. <\text{dottedname}> is used in the grammar where “.” is considered a common character (e.g. fully qualified type names)

Examples (informative):

The following shows some simple identifiers:

\begin{verbatim}
A
Test
$Test
@Foo?
?q_X_
\end{verbatim}

The following shows identifiers in single quotes:

\begin{verbatim}
′Weird Identifier
′Odd\102Char′
′Embedded\nReturn′
\end{verbatim}

The following shows dotted names:

\begin{verbatim}
System.Console
A.B.C
′My Project′,′My Component′,′My Name′
\end{verbatim}

5.4 Labels and Lists of Labels

Labels are provided as a programming convenience; they represent a number that is encoded in the metadata. The value represented by a label is typically an offset in bytes from the beginning of the current method, although the precise encoding differs depending on where in the logical metadata structure or CIL stream the label occurs. For details of how labels are encoded in the metadata, see Chapters 21 through 24; for their encoding in CIL instructions see Partition III.

A simple label is a special name that represents an address. Syntactically, a label is equivalent to an <\text{id}>. Thus, labels may be also single quoted and may contain Unicode characters.

A list of labels is comma separated, and can be any combination of these simple labels.
Rationale: In a real assembler the syntax for `<labeloroffset>` might allow the direct specification of a number rather than requiring symbolic labels.

ilasm distinguishes between two kinds of labels: code labels and data labels. Code labels are followed by a colon (":") and represent the address of an instruction to be executed. Code labels appear before an instruction and they represent the address of the instruction that immediately follows the label. A particular code label name may not be declared more than once in a method.

In contrast to code labels, data labels specify the location of a piece of data and do not include the colon character. The data label may not be used as a code label, and a code label may not be used as a data label. A particular code label name may not be declared more than once in a module.

Example (informative):
The following defines a code label, ldstr_label, that represents the address of the ldstr instruction:
```
ldstr_label: ldstr "A label"
```

5.5 Lists of Hex Bytes
A list of bytes consists simply of one or more hex bytes. Hex bytes are pairs of characters 0 – 9, a – f, and A – F.

Example (informative):
```
bytes := <hexbyte> [<hexbyte>*]
```

5.6 Floating point numbers
There are two different ways to specify a floating-point number:
9. Use the dot (".") for the decimal point and "e" or "E" in front of the exponent. Both the decimal point and the exponent are optional.
10. Indicate that the floating-point value is derived from an integer using the keyword float32 or float64 and indicating the integer in parentheses.

Example (informative):
```
float32 ( <int32> )
```

Example (informative):
```
float64 ( <int64> )
```

Example (informative):
```
float64(128) // note: this converts the integer 128 to its fp value
```

5.7 Source Line Information
The metadata does not encode information about the lexical scope of variables or the mapping from source line numbers to CIL instructions. Nonetheless, it is useful to specify an assembler syntax for providing this information for use in creating alternate encodings of the information.
.line takes a line number, and optional column number (preceded by a colon) and single quoted string that specifies the name of the file the line number is referring to

<externSourceDecl> ::= .line <int32> [ : <int32> ] ["<SQSTRING>"]

5.8 File Names

Some grammar elements require that a file name be supplied. A file name is like any other name where "." is considered a normal constituent character. The specific syntax for file names follows the specifications of the underlying operating system.

<filename> ::= Section
<filename> ::= <dottedname>

5.9 Attributes and Metadata

Attributes of types and their members attach descriptive information to their definition. The most common attributes are predefined and have a specific encoding in the metadata associated with them (see Chapter 22). In addition, the metadata provides a way of attaching user-defined attributes to metadata, using several different encodings.

From a syntactic point of view, there are several ways for specifying attributes in ilasm:

- Using special syntax built into ilasm. For example the keyword private in a <classAttr> specifies that the visibility attribute on a type should be set to allow access only within the defining assembly.
- Using a general-purpose syntax in ilasm. The non-terminal <customDecl> describes this grammar (see Chapter 0). For some attributes, called pseudo-custom attributes, this grammar actually results in setting special encodings within the metadata (see clause 20.2.1).
- Some attributes are required to be set based on the settings of other attributes or information within the metadata and are not visible from the syntax of ilasm at all. These attributes, called hidden attributes
- Security attributes are treated specially. There is special syntax in ilasm that allows the XML representing security attributes to be described directly (see Chapter 19). While all other attributes defined either in the standard library or by user-provided extension are encoded in the metadata using one common mechanism described in Section 21.10, security attributes (distinguished by the fact that they inherit, directly or indirectly from System.Security.Permissions.SecurityAttribute, see Partition IV) shall be encoded as described in Section 21.11.

5.10 ilasm Source Files

An input to ilasm is a sequence of declarations, defined as follows:

<ILFile> ::= Reference
<ILFile> ::= 

The complete grammar for a top level declaration is shown below. The following sections will concentrate on the various parts of this grammar.

<decl> ::= Reference
<decl> ::= .assembly <dottedname> { <asmDecl>* }
| .assembly extern <dottedname> { <asmRefDecl>* }
| .class <classHead> { <classMember>* }
| .class extern <exportAttr> <dottedname> { <externClassDecl>* } | 6.7 |
| .corflags <int32> | 6.1 |
| .custom <customDecl> | 0 |
| .data <datadecl> | 15.3.1 |
| .field <fieldDecl> | 0 |
| .file [nometadata] <filename> [.hash = ( <bytes> )] [.entrypoint] | 6.2.3 |
| .mresource [public | private] <dottedname> {{ <QSTRING> }} { <manResDecl>* } | 6.2.7 |
| .method <methodHead> { <methodBodyItem>* } | 14 |
| .module [<filename>] | 6.4 |
| .module extern <filename> | 6.5 |
| .subsystem <int32> | 6.2 |
| .vtfixup <vtfixupDecl> | 14.5.1 |
| <externSourceDecl> | 5.7 |
| <securityDecl> | 18 |
6 Assemblies, Manifests and Modules

Assemblies and modules are grouping constructs, each playing a different role in the CLI.

An *assembly* is a set of one or more files deployed as a unit. An assembly always contains a *manifest* that specifies (see Section 6.1):

- Version, name, culture, and security requirements for the assembly.
- Which other files, if any, belong to the assembly along with a cryptographic hash of each file. The manifest itself resides in the metadata part of a file and that file is always part of the assembly.
- Which of the types defined in other files of the assembly are to be exported from the assembly. Types defined in the same file as the manifest are exported based on attributes of the type itself.
- Optionally, a digital signature for the manifest itself and the public key used to compute it.

A *module* is a single file containing executable content in the format specified here. If the module contains a manifest then it also specifies the modules (including itself) that constitute the assembly. An assembly shall contain only one manifest amongst all its constituent files. For an assembly to be executed (rather than dynamically loaded) the manifest shall reside in the module that contains the entry point.

While some programming languages introduce the concept of a *namespace*, there is no support in the CLI for this concept. Type names are always specified by their full name relative to the assembly in which they are defined.

6.1 Overview of Modules, Assemblies, and Files

This section contains informative text only.

The following picture should clarify the various forms of references:

![Figure 2: References](image)

Eight files are shown in the picture. The name of each file is shown below the file. Files that declare a module have an additional border around them and have names beginning with M. The other two files have a name beginning with F. These files may be resource files, like bitmaps, or other files that do not contain CIL code.

Files M1 and M4 declare an assembly in addition to the module declaration, namely assemblies A and B, respectively. The assembly declaration in M1 and M4 references other modules, shown with straight lines. Assembly A references M2 and M3. Assembly B references M3 and M5. Thus, both assemblies reference M3.

Usually, a module belongs only to one assembly, but it is possible to share it across assemblies. When Assembly A is loaded at runtime, an instance of M3 will be loaded for it. When Assembly B is loaded into the same application domain, possibly simultaneously with Assembly A, M3 will be shared for both assemblies. Both assemblies also reference F2, for which similar rules apply.
The module M2 references F1, shown by dotted lines. As a consequence F1 will be loaded as part of Assembly A, when A is executed. Thus, the file reference shall also appear with the assembly declaration. Similarly, M5 references another module, M6, which becomes part of B when B is executed. It follows, that assembly B shall also have a module reference to M6.

End informative text

6.2 Defining an Assembly

An assembly is specified as a module that contains a manifest in the metadata; see Section 21.2. The information for the manifest is created from the following portions of the grammar:

<table>
<thead>
<tr>
<th align="left">&lt;decl&gt; ::=</th>
<th align="left">Section</th>
</tr>
</thead>
<tbody>
<tr>
<td align="left"><code>assembly &lt;dottedname&gt; { &lt;asmDecl&gt;* }</code></td>
<td align="left">6.2</td>
</tr>
<tr>
<td align="left"><code>{ assembly extern &lt;dottedname&gt; { &lt;asmRefDecl&gt;* } }</code></td>
<td align="left">6.3</td>
</tr>
<tr>
<td align="left"><code>.corflags &lt;int32&gt;</code></td>
<td align="left">6.2</td>
</tr>
<tr>
<td align="left"><code>.file [nometadata] &lt;filename&gt; .hash = ( &lt;bytes&gt; ) [ .entrypoint ]</code></td>
<td align="left">6.2.3</td>
</tr>
<tr>
<td align="left"><code>.module extern &lt;filename&gt;</code></td>
<td align="left">6.5</td>
</tr>
<tr>
<td align="left">`.mresource [public</td>
<td align="left">private] &lt;dottedname&gt;`</td>
</tr>
<tr>
<td align="left"><code>{ ( &lt;QSTRING&gt; ) } { &lt;manResDecl&gt;* }</code></td>
<td align="left"></td>
</tr>
<tr>
<td align="left"><code>.subsystem &lt;int32&gt;</code></td>
<td align="left">6.2</td>
</tr>
<tr>
<td align="left"><code>...</code></td>
<td align="left"></td>
</tr>
</tbody>
</table>

The `assembly` directive declares the manifest and specifies to which assembly the current module belongs. A module shall contain at most one `assembly` directive. The `<dottedname>` specifies the name of the assembly.

Note: Since some platforms treat names in a case insensitive manner, two assemblies that have names that differ only in case should not be declared.

The `.corflags` directive sets a field in the CLI header of the output PE file (see clause 24.3.3.1). A conforming implementation of the CLI shall expect it to be 1. For backwards compatibility, the three least significant bits are reserved. Future versions of this standard may provide definitions for values between 8 and 65,535. Experimental and non-standard uses should thus use values greater than 65,535.

The `.subsystem` directive is used only when the assembly is directly executed (as opposed to used as a library for another program). It specifies the kind of application environment required for the program, by storing the specified value in the PE file header (see clause 24.2.2). While a full 32 bit integer may be supplied, a conforming implementation of the CLI need only respect two possible values:

If the value is 2, the program should be run using whatever conventions are appropriate for an application that has a graphical user interface.

If the value is 3, the program should be run using whatever conventions are appropriate for an application that has a direct console attached.

Example (informative):

```
.assembly CountDown
{
    .hash algorithm 32772
    .ver 1:0:0:0
}
```
6.2.1 Information about the Assembly (<asmDecl>)

The following grammar shows the information that can be specified about an assembly.

<table>
<thead>
<tr>
<th>&lt;asmDecl&gt; ::=</th>
<th>Description</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>.custom &lt;customDecl&gt;</td>
<td>Custom attributes</td>
<td>0</td>
</tr>
<tr>
<td>.hash algorithm &lt;int32&gt;</td>
<td>Hash algorithm used in the .file directive</td>
<td>6.2.1.1</td>
</tr>
<tr>
<td>.culture &lt;QSTRING&gt;</td>
<td>Culture for which this assembly is built</td>
<td>6.2.1.2</td>
</tr>
<tr>
<td>.publickey = { &lt;bytes&gt; }</td>
<td>The originator's public key.</td>
<td>6.2.1.3</td>
</tr>
<tr>
<td>.ver &lt;int32&gt; : &lt;int32&gt; : &lt;int32&gt; : &lt;int32&gt;</td>
<td>Major version, minor version, revision, and build</td>
<td>6.2.1.4</td>
</tr>
<tr>
<td>&lt;securityDecl&gt;</td>
<td>Permissions needed, desired, or prohibited</td>
<td>19</td>
</tr>
</tbody>
</table>

6.2.1.1 Hash Algorithm

When an assembly consists of more than one file (see clause 6.2.3), the manifest for the assembly specifies both the name of the file and the cryptographic hash of the contents of the file. The algorithm used to compute the hash can be specified, and shall be the same for all files included in the assembly. All values are reserved for future use, and conforming implementations of the CLI shall use the SHA1 (see Partition I) hash function and shall specify this algorithm by using a value of 32772 (0x8004).

Rationale: SHA1 was chosen as the best widely available technology at the time of standardization (see Partition I). A single algorithm is chosen since all conforming implementations of the CLI would be required to implement all algorithms to ensure portability of executable images.

6.2.1.2 Culture

When present, this indicates that the assembly has been customized for a specific culture. The strings that shall be used here are those specified in Partition IV as acceptable with the class System.Globalization.CultureInfo. When used for comparison between an assembly reference and an assembly definition these strings shall be compared in a case insensitive manner.

Note: The culture names follow the IETF RFC1766 names. The format is “<language>-<country/region>”, where <language> is a lowercase two-letter code in ISO 639-1. <country/region> is an uppercase two-letter code in ISO 3166.

6.2.1.3 Originator’s Public Key

The CLI metadata allows the producer of an assembly to compute a cryptographic hash of the assembly (using the SHA1 hash function) and then encrypt it using the RSA algorithm (see Partition I) and a public/private key pair of the producer’s choosing. The results of this (an “SHA1/RSA digital signature”) can then be stored in the metadata along with the public part of the key pair required by the RSA algorithm. The .publickey directive is used to specify the public key that was used to compute the signature. To calculate the hash, the signature is zeroed, the hash calculated, then the result stored into the signature.

A reference to an assembly (see Section 6.3) captures some of this information at compile time. At runtime, the information contained in the assembly reference can be combined with the information from the manifest of
the assembly located at runtime to ensure that the same private key was used to create both the assembly seen
when the reference was created (compile time) and when it is resolved (runtime).

### 6.2.1.4 Version Numbers

The version number of the assembly, specified as four 32-bit integers. This version number shall be captured at
compile time and used as part of all references to the assembly within the compiled module. This standard
places no other requirement on the use of the version numbers.

**Note:** A conforming implementation may ignore version numbers entirely, or it may require that they match
precisely when binding a reference, or any other behavior deemed appropriate. By convention:

- the first of these is considered the major version number and assemblies with the same name but different
  major versions are not interchangeable. This would be appropriate, for example, for a major rewrite of a
  product where backwards compatibility cannot be assumed.
- the second of these is considered the minor version number and assemblies with the same name and major
  version but different minor versions indicate significant enhancements but with intention to be backward
  compatible. This would be appropriate, for example, on a “point release” of a product or a fully backward
  compatible new version of a product.
- the third of these is considered the revision number and assemblies with the same name, major and minor
  version number but different revisions are intended to be fully interchangeable. This would be appropriate, for
  example, to fix a security hole in a previously released assembly.
- the fourth of these is considered the build number and assemblies that differ only by build number are intended
to represent a recompilation from the same source. This would be appropriate, for example, because of
  processor, platform, or compiler changes.

### 6.2.2 Manifest Resources

A **manifest resource** is simply a named item of data associated with an assembly. A manifest resource is
introduced using the `.mresource` directive, which adds the manifest resource to the assembly manifest begun
by a preceding `.assembly` declaration.

<table>
<thead>
<tr>
<th>&lt;decl&gt; ::=</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>.mresource [public</td>
<td>private] &lt;dottedname&gt;</td>
</tr>
<tr>
<td>{ &lt;manResDecl&gt;* }</td>
<td></td>
</tr>
<tr>
<td></td>
<td>...</td>
</tr>
<tr>
<td><img src="#" alt="Table" /></td>
<td></td>
</tr>
</tbody>
</table>

If the manifest resource is declared public it is exported from the assembly. If it is declared private it is not
exported and hence only available from within the assembly. The `<dottedname>` is the name of the resource,
and the optional quoted string is a description of the resource.

<table>
<thead>
<tr>
<th>&lt;manResDecl&gt; ::=</th>
<th>Description</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>.assembly extern &lt;dottedname&gt;</td>
<td>Manifest resource is in external assembly with name &lt;dottedname&gt;.</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>.custom &lt;customDecl&gt;</td>
<td>Custom attribute.</td>
</tr>
<tr>
<td></td>
<td>.file &lt;dottedname&gt; at &lt;int32&gt;</td>
<td>Manifest resource is in file &lt;dottedname&gt; at byte offset &lt;int32&gt;.</td>
</tr>
</tbody>
</table>

For a resource stored in a file that is not a module (for example, an attached text file), the file shall be declared
in the manifest using a separate (top-level) `.file` declaration (see clause 6.2.3) and the byte offset shall be zero
Similarly, a resource that is defined in another assembly is referenced using `.assembly extern` which requires
that the assembly has been defined in a separate (top-level) `.assembly extern` directive (see Section 6.3).
6.2.3 Files in the Assembly

Assemblies may be associated with other files, e.g. documentation and other files that are used during execution. The declaration .file is used to add a reference to such a file to the manifest of the assembly: (See Section 21.19)

\[
<\text{decl}>::=\begin{align*}
\text{.file } & \text{[nometadata]} & \langle\text{filename}\rangle & \text{.hash } = ( \langle\text{bytes}\rangle ) & [\text{.entrypoint}] \\
\end{align*}
\]

The attribute nometadata is specified if the file is not a module according to this specification. Files that are marked as nometadata may have any format; they are considered pure data files.

The \text{.bytes} after the .hash specify a hash value computed for the file. The VES shall recompute this hash value prior to accessing this file and shall generate an exception if it does not match. The algorithm used to calculate this hash value is specified with .hash algorithm (see clause 6.2.1.1).

If specified, the .entrypoint directive indicates that the entyropoint of a multi-module assembly is contained in this file.

6.3 Referencing Assemblies

\[
<\text{asmRefDecl}>::=\text{.assembly extern }\langle\text{dottedname}\rangle\ [\text{ as }\langle\text{dottedname}\rangle]\ \\
&\{ <\text{asmRefDecl}>* \}
\]

An assembly mediates all accesses from the files that it contains to other assemblies. This is done through the metadata by requiring that the manifest for the executing assembly contain a declaration for any assembly referenced by the executing code. The syntax .assembly extern as a top-level declaration is used for this purpose. The optional as clause provides an alias which allows ilasm to address external assemblies that have the same name, but differing in version, culture, etc.

The dotted name used in .assembly extern shall exactly match the name of the assembly as declared with .assembly directive in a case sensitive manner. (So, even though an assembly might be stored within a file, within a filesystem that is case-blind, the names stored internally within metadata are case-sensitive, and shall match exactly.)

\[
<\text{asmRefDecl}>::=\begin{align*}
\text{.hash } & = ( \langle\text{bytes}\rangle ) & \text{Hash of referenced assembly} \\
\text{.custom } & <\langle\text{customDecl}\rangle> & \text{Custom attributes} \\
\text{.culture } & <\text{QSTRING}> & \text{Culture of the referenced assembly} \\
\text{.publickeytoken } & = ( \langle\text{bytes}\rangle ) & \text{The low 8 bytes of the SHA1 hash of the originator’s public key.} \\
\text{.publickey } & = ( \langle\text{bytes}\rangle ) & \text{The originator’s full public key} \\
\text{.ver } & <\text{int32}>; <\text{int32}>; <\text{int32}>; <\text{int32}> & \text{Major version, minor version, revision, and build}
\end{align*}
\]

These declarations are the same as those for .assembly declarations (clause 6.2.1), except for the addition of .publickeytoken. This declaration is used to store the low 8 bytes of the SHA1 hash of the originator’s public key in the assembly reference, rather than the full public key.

An assembly reference can store either a full public key or an 8 byte “publickeytoken.” Either can be used to validate that the same private key used to sign the assembly at compile time signed the assembly used at runtime. Neither is required to be present, and while both can be stored this is not useful.

A conforming implementation of the CLI need not perform this validation, but it is permitted to do so, and it may refuse to load an assembly for which the validation fails. A conforming implementation of the CLI may
also refuse to permit access to an assembly unless the assembly reference contains either the public key or the public key token. A conforming implementation of the CLI shall make the same access decision independent of whether a public key or a token is used.

**Rationale:** The full public key is cryptographically safer, but requires more storage space in the assembly reference.

**Example (informative):**

```
.assembly extern MyComponents
{
    .publickey = (BB AA BB EE 11 22 33 00)
    .hash = (2A 71 E9 47 F5 15 E6 07 35 E4 CB E3 B4 A1 D3 7F 7F A0 9C 24)
    .ver 2:10:2002:0
}
```

### 6.4 Declaring Modules

All CIL files are modules and are referenced by a logical name carried in the metadata rather than their file name. See Section 21.16.

<table>
<thead>
<tr>
<th>&lt;decl&gt; ::=</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>.module &lt;filename&gt;</td>
<td></td>
</tr>
<tr>
<td>.module extern &lt;filename&gt;</td>
<td>5.10</td>
</tr>
</tbody>
</table>

**Example (informative):**

```
.module CountDown.exe
```

### 6.5 Referencing Modules

When an item is in the current assembly but part of a different module than the one containing the manifest, the defining module shall be declared in the manifest of the assembly using the `.module extern` directive. The name used in the `.module extern` directive of the referencing assembly shall exactly match the name used in the `.module` directive (see Section 6.4) of the defining module. See Section 21.28.

<table>
<thead>
<tr>
<th>&lt;decl&gt; ::=</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>.module extern &lt;filename&gt;</td>
<td></td>
</tr>
<tr>
<td>.module extern Counter.dll</td>
<td>5.10</td>
</tr>
</tbody>
</table>

### 6.6 Declarations inside a Module or Assembly

Declarations inside a module or assembly are specified by the following grammar. More information on each option can be found in the corresponding section.

<table>
<thead>
<tr>
<th>&lt;decl&gt; ::=</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>.class &lt;classHead&gt; { &lt;classMember&gt;* }</td>
<td>0 0</td>
</tr>
<tr>
<td>.custom &lt;customDecl&gt;</td>
<td>0</td>
</tr>
<tr>
<td>.data &lt;datadecl&gt;</td>
<td>15.3.1</td>
</tr>
<tr>
<td>.field &lt;fieldDecl&gt;</td>
<td>0</td>
</tr>
</tbody>
</table>
6.7 Exported Type Definitions

The manifest module, of which there can only be one per assembly, includes the .assembly statement. To export a type defined in any other module of an assembly requires an entry in the assembly’s manifest. The following grammar is used to construct such an entry in the manifest:

\[
\text{<decl> ::= .class extern <exportAttr> <dottedname> { <externClassDecl>* } }
\]

The <exportAttr> value shall be either public or nested public and shall match the visibility of the type.

For example, suppose an assembly consists of two modules A.EXE and B.DLL. A.EXE contains the manifest. A public class “Foo” is defined in B.DLL. In order to export it – that is, to make it visible by, and usable from, other assemblies – a .class extern statement shall be included in A.EXE.

Conversely, a public class “Bar” defined in A.EXE does not need any .class extern statement.

Rationale: Tools should be able to retrieve a single module, the manifest module, to determine the complete set types defined by the assembly. Therefore, information from other modules within the assembly is replicated in the manifest module. By convention, the manifest module is also known as the assembly.
7 Types and Signatures

The metadata provides mechanisms to both define types and reference types. Chapter 9 describes the metadata associated with a type definition, regardless of whether the type is an interface, class or a value type.

The mechanism used to reference types is divided into two parts. The first is the creation of a logical description of user-defined types that are referenced but (typically) not defined in the current module. These are stored in a logical table in the metadata (see Section 21.35).

The second is a signature that encodes one or more type references, along with a variety of modifiers. The grammar non-terminal `<type>` describes an individual entry in a signature. The encoding of a signature is specified in Section 22.1.15.

7.1 Types

The following grammar completely specifies all built-in types including pointer types of the CLI system. It also shows the syntax for user defined types that can be defined in the CLI system:

```
<type> ::= Description Section
  bool          Boolean  7.2
| boxed <typeReference>  Boxed user-defined value type
| char          16-bit Unicode code point  7.2
| class <typeReference> User defined reference type.  7.3
| float32       32-bit floating point number  7.2
| float64       64-bit floating point number  7.2
| int8          Signed 8-bit integer  7.2
| int16         Signed 16-bit integer  7.2
| int32         Signed 32-bit integer  7.2
| int64         Signed 64-bit integer  7.2
| method <callConv> <type> *          Method pointer  0
|      ( <parameters> )
| native int    Signed integer whose size varies depending on platform (32- or 64-bit)  7.2
| native unsigned int    Unsigned integer whose size varies depending on platform (32- or 64-bit)  7.2
| object        See System.Object in Partition IV,
| string        See System.String in Partition IV,
| <type> &      Managed pointer to <type>. <type> shall not be a managed pointer type or typedref
| <type> *      Unmanaged pointer to <type>  13.4
| <type> [ [<bound> [,<bound>]*] ] Array of <type> with optional rank (number of dimensions) and bounds.  13.1 and 13.2
| <type> modopt ( <typeReference> ) Custom modifier that may be ignored by the caller.  0
```
| `<type>` modreq ( `<typeReference>` ) | Custom modifier that the caller shall understand. | 0 |
| `<type>` pinned | For local variables only. The garbage collector shall not move the referenced value. | 7.1.2 |
| `<type>` typedref | Typed reference, created by `mkrefany` and used by `refanytype` or `refanyval`. | 7.2 |
| `<typeReference>` | User defined value type (unboxed) | 0 |
| `unsigned int8` | Unsigned 8-bit integers | 7.2 |
| `unsigned int16` | Unsigned 16-bit integers | 7.2 |
| `unsigned int32` | Unsigned 32-bit integers | 7.2 |
| `unsigned int64` | Unsigned 64-bit integers | 7.2 |
| `void` | No type. Only allowed as a return type or as part of `void *` | 7.2 |

In several situations the grammar permits the use of a slightly simpler mechanism for specifying types, by just allowing type names (e.g. "System.GC") to be used instead of the full algebra (e.g. "class System.GC"). These are called type specifications:

```
<typeSpec> ::=  
  [ [ .module ] <dottedname> ]  
  | <typeReference>  
  | <type>  
```

7.1.1 modreq and modopt

Custom modifiers, defined using modreq ("required modifier") and modopt ("optional modifier"), are similar to custom attributes (see Chapter 0) except that modifiers are part of a signature rather than attached to a declaration. Each modifier associates a type reference with an item in the signature.

The CLI itself shall treat required and optional modifiers in the same manner. Two signatures that differ only by the addition of a custom modifier (required or optional) shall not be considered to match. Custom modifiers have no other effect on the operation of the VES.

**Rationale:** The distinction between required and optional modifiers is important to tools other than the CLI that deal with the metadata, typically compilers and program analysers. A required modifier indicates that there is a special semantics to the modified item that should not be ignored, while an optional modifier can simply be ignored.

For example, the concept of const in the C programming language can be modelled with an optional modifier since the caller of a method that has a constant parameter need not treat it in any special way. On the other hand, a parameter that shall be copy constructed in C++ shall be marked with a required custom attribute since it is the caller who makes the copy.

7.1.2 pinned

The signature encoding for pinned shall appear only in signatures that describe local variables (see clause 14.4.1.3). While a method with a pinned local variable is executing the VES shall not relocate the object to which the local refers. That is, if the implementation of the CLI uses a garbage collector that moves objects, the collector shall not move objects that are referenced by an active pinned local variable.
Rationale: If unmanaged pointers are used to dereference managed objects, these objects shall be pinned. This happens, for example, when a managed object is passed to a method designed to operate with unmanaged data.

7.2 Built-in Types

The CLI built-in types have corresponding value types defined in the Base Class Library. They shall be referenced in signatures only using their special encodings (i.e. not using the general purpose `valuetype` syntax). Partition I specifies the built-in types.

7.3 References to User-defined Types (`<typeReference>`)?

User-defined types are referenced either using their full name and a resolution scope or (if one is available in the same module) a type definition (see Chapter 9). A `<typeReference>` is used to capture the full name and resolution scope.

```
<typeReference> ::= [ <resolutionScope> ] <dottedname> [/ <dottedname>] *
<resolutionScope> ::= [ .module <filename> ] |
[ <assemblyRefName> ]
<assemblyRefName> ::= <dottedname>
```

The following resolution scopes are specified for un-nested types:

- **Current module (and, hence, assembly).** This is the most common case and is the default if no resolution scope is specified. The type shall be resolved to a definition only if the definition occurs in the same module as the reference.

  Note: A type reference that refers to a type in the same module and assembly is better represented using a type definition. Where this is not possible (for example, when referencing a nested type that has `compilercontrolled` accessibility) or convenient (for example, in some one-pass compilers) a type reference is equivalent and may be used.

- **Different module, current assembly.** The resolution scope shall be a module reference syntactically represented using the notation `[ .module <filename> ]`. The type shall be resolved to a definition only if the referenced module (see Section 6.4) and type (see Section 6.7) have been declared by the current assembly and hence have entries in the assembly’s manifest. Note that in this case the manifest is not physically stored with the referencing module.

- **Different assembly.** The resolution scope shall be an assembly reference syntactically represented using the notation `[ <assemblyRefName> ]`. The referenced assembly shall be declared in the manifest for the current assembly (see Section 6.3), the type shall be declared in the referenced assembly’s manifest, and the type shall be marked as exported from that assembly (see Section 6.7 and clause 9.1.1).

- For nested types, the resolution scope is always the enclosing type. (See Section 9.6). This is indicated syntactically by using a slash (`/`) to separate the enclosing type name from the nested type’s name.

Example (informative):

The proper way to refer to a type defined in the base class library. The name of the type is `System.Console` and it is found in the assembly named `mscorlib`.
A reference to the type named C.D in the module named x in the current assembly.

A reference to the type named C nested inside of the type named Foo.Bar in another assembly, named MyAssembly.

The following table lists all native types supported by the CLI and provides a description for each of them. A more complete description can be found in Partition IV in the definition of the enum System.Runtime.InteropServices.UnmanagedType, which provides the actual values used to encode the types. All encoding values from 0 through 63 are reserved for backward compatibility with existing implementations of the CLI. Values 64 through 127 are reserved for future use in this and related Standards.

<table>
<thead>
<tr>
<th>&lt;nativeType&gt; ::=</th>
<th>Description</th>
<th>Name in class library</th>
</tr>
</thead>
<tbody>
<tr>
<td>{ }</td>
<td>Native array. Type and size are determined at runtime from the actual marshaled array.</td>
<td>LPArray</td>
</tr>
<tr>
<td>bool</td>
<td>Boolean. 4-byte integer value where a non-zero value represents TRUE and 0 represents FALSE.</td>
<td>Bool</td>
</tr>
<tr>
<td>float32</td>
<td>32-bit floating point number.</td>
<td>FLOAT32</td>
</tr>
<tr>
<td>float64</td>
<td>64-bit floating point number.</td>
<td>FLOAT64</td>
</tr>
<tr>
<td>[unsigned] int</td>
<td>Signed or unsigned integer, sized to hold a pointer on the platform</td>
<td>SysUInt or SysInt</td>
</tr>
<tr>
<td>[unsigned] int8</td>
<td>Signed or unsigned 8-bit integer</td>
<td>unsigned int8 or int8</td>
</tr>
<tr>
<td>Type</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td><code>unsigned int16</code></td>
<td>Signed or unsigned 16-bit integer</td>
<td></td>
</tr>
<tr>
<td><code>unsigned int32</code></td>
<td>Signed or unsigned 32-bit integer</td>
<td></td>
</tr>
<tr>
<td><code>unsigned int64</code></td>
<td>Signed or unsigned 64-bit integer</td>
<td></td>
</tr>
<tr>
<td><code>lpstr</code></td>
<td>A pointer to a null terminated array of ANSI characters. Code page is implementation specific.</td>
<td></td>
</tr>
<tr>
<td><code>lptstr</code></td>
<td>A pointer to a null terminated array of platform characters (ANSI or Unicode). Code page and character encoding are implementation specific.</td>
<td></td>
</tr>
<tr>
<td><code>lpvoid</code></td>
<td>An untyped pointer, platform specifies size.</td>
<td></td>
</tr>
<tr>
<td><code>lpwstr</code></td>
<td>A pointer to a null terminated array of Unicode characters. Character encoding is implementation specific.</td>
<td></td>
</tr>
<tr>
<td><code>method</code></td>
<td>A function pointer.</td>
<td></td>
</tr>
<tr>
<td><code>&lt;nativeType&gt;[]</code></td>
<td>Array of <code>&lt;nativeType&gt;</code>. The length is determined at runtime by the size of the actual marshaled array.</td>
<td></td>
</tr>
<tr>
<td><code>&lt;nativeType&gt;[&lt;int32&gt;]</code></td>
<td>Array of <code>&lt;nativeType&gt;</code> of length <code>&lt;int32&gt;</code>.</td>
<td></td>
</tr>
<tr>
<td><code>&lt;nativeType&gt;[ + &lt;int32&gt;]</code></td>
<td>Array of <code>&lt;nativeType&gt;</code> with runtime supplied element size. The <code>int32</code> specifies a parameter to the current method (counting from parameter number 0) that, at runtime, will contain the size of an element of the array in bytes. Can only be applied to methods, not fields.</td>
<td></td>
</tr>
<tr>
<td><code>&lt;nativeType&gt;[ &lt;int32&gt; + &lt;int32&gt;]</code></td>
<td>Array of <code>&lt;nativeType&gt;</code> with runtime supplied element size. The first <code>int32</code> specifies the number of elements in the array. The second <code>int32</code> specifies which parameter to the current method (counting from parameter number 1) will specify the additional number of elements in the array. Can only be applied to methods, not fields.</td>
<td></td>
</tr>
</tbody>
</table>

**Example (informative):**

```csharp
.method int32 M1(int32 marshal(int32), bool[] marshal(bool[5]) )

Method M1 takes two arguments: an int32, and an array of 5 bools
```

```csharp
.method int32 M2(int32 marshal(int32), bool[] marshal(bool[+1]) )

Method M2 takes two arguments: an int32, and an array of bools: the number of elements in that array is given by the value of the first parameter
```
Method M3 takes two arguments: an int32, and an array of bools: the number of elements in that array is given as 7 plus the value of the first parameter.
Visibility, Accessibility and Hiding

Partition I specifies visibility and accessibility. In addition to these attributes, the metadata stores information about method name hiding. Hiding controls which method names inherited from a base type are available for compile-time name binding.

8.1 Visibility of Top-Level Types and Accessibility of Nested Types

Visibility is attached only to top-level types, and there are only two possibilities: visible to types within the same assembly, or visible to types regardless of assembly. For nested types (i.e. types that are members of another type) the nested type has an accessibility that further refines the set of methods that can reference the type. A nested type may have any of the 7 accessibility modes (see Partition I), but has no direct visibility attribute of its own, using the visibility of its enclosing type instead.

Because the visibility of a top-level type controls the visibility of the names of all of its members, a nested type cannot be more visible than the type in which it is nested. That is, if the enclosing type is visible only within an assembly then a nested type with public accessibility is still only available within the assembly. By contrast, a nested type that has assembly accessibility is restricted to use within the assembly even if the enclosing type is visible outside the assembly.

To make the encoding of all types consistent and compact, the visibility of a top-level type and the accessibility of a nested type are encoded using the same mechanism in the logical model of clause 22.1.14.

8.2 Accessibility

Accessibility is encoded directly in the metadata. See, for example, clause 21.24.

8.3 Hiding

Hiding is a compile-time concept that applies to individual methods of a type. The CTS specifies two mechanisms for hiding, specified by a single bit:

- hide-by-name, meaning that the introduction of a name in a given type hides all inherited members of the same kind (method or field) with the same name.

- hide-by-name-and-sig, meaning that the introduction of a name in a given type hides any inherited member of the same kind but with precisely the same type (for fields) or signature (for methods, properties, and events).

There is no runtime support for hiding. A conforming implementation of the CLI treats all references as though the names were marked hide-by-name-and-sig. Compilers that desire the effect of hide-by-name can do so by marking method definitions with the newslot attribute (see clause 14.4.2.3) and correctly choosing the type used to resolve a method reference (see clause 14.1.3).
9 Defining Types

Types (i.e., classes, value types, and interfaces) may be defined at the top-level of a module:

\[\text{<decl>}' ::= \\
\text{.class} 
\text{<classHead>} \{ \text{<classMember>}* \} \\
\text{| ...} \]

The logical metadata table created by this declaration is specified in Section 21.34.

Rationale: For historical reasons, many of the syntactic classes used for defining types incorrectly use “class” instead of “type” in their name. All classes are types, but “types” is a broader term encompassing value types, and interfaces.

9.1 Type Header (<classHead>)

A type header consists of

- any number of type attributes
- a name (an <id>)
- a base type (or parent type), which defaults to [mscorlib]System.Object
- an optional list of interfaces whose contract this type and all its descendent types shall satisfy

\[\text{<classAttr>}' ::= \\
\text{<classAttr>}* \text{<id>} [\text{extends} <typeReference>] [\text{implements} <typeReference> [, <typeReference>]*] \]

The extends keyword defines the base type of a type. A type shall extend from exactly one other type. If no type is specified, ilasm will add an extend clause to make the type inherit from System.Object.

The implements keyword defines the interfaces of a type. By listing an interface here, a type declares that all of its concrete implementations will support the contract of that interface, including providing implementations of any virtual methods the interface declares. See also Chapter 10 and Chapter 11.

Example (informative):

```csharp
.class private auto autochar CounterTextBox
    implements [.module Counter]CountDisplay
{ // body of the class
}
```

This code declares the class CounterTextBox, which extends the class System.Windows.Forms.TextBox in the assembly System.Windows.Forms and implements the interface CountDisplay in the module Counter of the current assembly. The attributes private, auto and autochar are described in the following sections.

A type can have any number of custom attributes attached. Custom attributes are attached as described in Chapter 0. The other (predefined) attributes of a type may be grouped into attributes that specify visibility, type layout information, type semantics information, inheritance rules, interoperation information, and information on special handling. The following subsections provide additional information on each group of predefined attributes.

\[\text{<classAttr>}' ::= \\
\text{Description} | \text{Section} \]
### 9.1.1 Visibility and Accessibility Attributes

```
<classAttr> ::= ...
```

- **abstract**  
  Type is `abstract`.  
  [9.1.4]
- **ansi**  
  Marshal strings to platform as ANSI.  
  [9.1.5]
- **auto**  
  Auto layout of type.  
  [9.1.2]
- **autochar**  
  Marshal strings to platform based on platform.  
  [9.1.5]
- **beforefieldinit**  
  Calling static methods does not initialize type.  
  [9.1.6]
- **explicit**  
  Layout of fields is provided explicitly.  
  [9.1.2]
- **interface**  
  Interface declaration.  
  [9.1.3]
- **nested assembly**  
  Assembly accessibility for nested type.  
  [9.1.1]
- **nested famandassem**  
  Family and Assembly accessibility for nested type.  
  [9.1.1]
- **nested family**  
  Family accessibility for nested type.  
  [9.1.1]
- **nested famorassem**  
  Family or Assembly accessibility for nested type.  
  [9.1.1]
- **nested private**  
  Private accessibility for nested type.  
  [9.1.1]
- **nested public**  
  Public accessibility for nested type.  
  [9.1.1]
- **private**  
  Private visibility of top-level type.  
  [9.1.1]
- **public**  
  Public visibility of top-level type.  
  [9.1.1]
- **rtspecialname**  
  Special treatment by runtime.  
  [9.1.6]
- **sealed**  
  The type cannot be subclassed.  
  [9.1.4]
- **sequential**  
  The type is laid out sequentially.  
  [9.1.2]
- **serializable**  
  Type may be serialized.  
  [9.1.6]
- **specialname**  
  Special treatment by tools.  
  [9.1.6]
- **unicode**  
  Marshal strings to platform as Unicode.  
  [9.1.5]

See Partition I. A type that is not nested inside another shall have exactly one visibility (private or public) and shall not have an accessibility. Nested types shall have no visibility, but instead shall have exactly one of the accessibility attributes (nested assembly, nested famandassem, nested family, nested famorassem, nested private, or nested public). The default visibility for top-level types is private. The default accessibility for nested types is nested private.
9.1.2 Type Layout Attributes

\[
\text{<classAttr>} ::= \ldots
\begin{align*}
| & \text{auto} \\
| & \text{explicit} \\
| & \text{sequential}
\end{align*}
\]

The type layout specifies how the fields of an instance of a type are arranged. A given type shall have only one layout attribute specified. By convention, ilasm supplies auto if no layout attribute is specified.

- **auto**: the layout shall be done by the CLI, with no user-supplied constraints
- **explicit**: the layout of the fields is explicitly provided (see Section 9.7).
- **sequential**: the CLI shall lay out the fields in sequential order, based on the order of the fields in the logical metadata table (see Section 21.15).

**Rationale:** The default **auto** layout should provide the best layout for the platform on which the code is executing. **sequential** layout is intended to instruct the CLI to match layout rules commonly followed by languages like C and C++ on an individual platform, where this is possible while still guaranteeing verifiable layout. **explicit** layout allows the CIL generator to specify the precise layout semantics.

9.1.3 Type Semantics Attributes

\[
\text{<classAttr>} ::= \ldots
\begin{align*}
| & \text{interface}
\end{align*}
\]

The type semantic attributes specify whether an interface, class, or value type shall be defined. The interface attribute specifies an interface. If this attribute is not present and the definition extends (directly or indirectly) `System.ValueType` a value type shall be defined (see Chapter 0). Otherwise, a class shall be defined (see Chapter 10).

Note that the runtime size of a value type shall not exceed 1 MByte (0x100000 bytes)

9.1.4 Inheritance Attributes

\[
\text{<classAttr>} ::= \ldots
\begin{align*}
| & \text{abstract} \\
| & \text{sealed}
\end{align*}
\]

Attributes that specify special semantics are **abstract** and **sealed**. These attributes may be used together.

- **abstract** specifies that this type shall not be instantiated. If a type contains abstract methods, the type shall be declared as an abstract type.
- **sealed** specifies that a type shall not have subclasses. All value types shall be sealed.

**Rationale:** Virtual methods of sealed types are effectively instance methods, since they cannot be overridden. Framework authors should use sealed classes sparingly since they do not provide a convenient building block for user extensibility. Sealed classes may be necessary when the implementation of a set of virtual methods for a single class (typically inherited from different interfaces) becomes interdependent or depends critically on implementation details not visible to potential subclasses.

A type that is both **abstract** and **sealed** should have only static members, and serves as what some languages call a namespace.

9.1.5 Interoperation Attributes

\[
\text{<classAttr>} ::= \ldots
\begin{align*}
| & \text{ansi}
\end{align*}
\]
These attributes are for interoperation with unmanaged code. They specify the default behavior to be used when calling a method (static, instance, or virtual) on the class that has an argument or return type of System.String and does not itself specify marshalling behavior. Only one value shall be specified for any type, and the default value is ansi.

ansi specifies that marshalling shall be to and from ANSI strings
unicode specifies that marshalling shall be to and from Unicode strings
autochar specifies either ANSI or Unicode behavior, depending on the platform on which the CLI is running.

9.1.6 Special Handling Attributes

These attributes may be combined in any way.
beforefieldinit instructs the CLI that it need not initialize the type before a static method is called. See clause 9.5.3.
specialname indicates that the name of this item may have special significance to tools other than the CLI. See, for example, Partition I.
rtspecialname indicates that the name of this item has special significance to the CLI. There are no currently defined special type names; this is for future use. Any item marked rtspecialname shall also be marked specialname.

Rationale: If an item is treated specially by the CLI, then tools should also be made aware of that. The converse is not true.

9.2 Body of a Type Definition

A type may contain any number of further declarations. The directives .event, .field, .method, and .property are used to declare members of a type. The directive .class inside a type declaration is used to create a nested type, which is discussed in further detail in Section 9.6.

| .class <classHead> { <classMember>* } | Defines a nested type. | 9.6 |
| .custom <customDecl> | Custom attribute. | 0 |
| .data <datadecl> | Defines static data associated with the type. | 15.3 |
| .event <eventHead> { <eventMember>* } | Declares an event. | 17 |
| .field <fieldDecl> | Declares a field belonging to the type. | 0 |
| .method <methodHead> { <methodBodyItem>* } | Declares a method of the type. | 14 |
| .override <typeSpec> :: <methodName> with <callConv> <type> <typeSpec> :: <methodName> ( <parameters> ) | Specifies that the first method is overridden by | 9.3.2 |
9.3 Introducing and Overriding Virtual Methods

A virtual method of a base type is overridden by providing a direct implementation of the method (using a method definition, see Section 14.4) and not specifying it to be newslot (see clause 14.4.2.3). An existing method body may also be used to implement a given virtual declaration using the .override directive (see clause 9.3.2).

9.3.1 Introducing a Virtual Method

A virtual method is introduced in the inheritance hierarchy by defining a virtual method (see Section 14.4). The versioning semantics differ depending on whether or not the definition is marked as newslot (see clause 14.4.2.3):

If the definition is marked newslot then the definition always creates a new virtual method, even if a base class provides a matching virtual method. Any reference to the virtual method created before the new virtual function was defined will continue to refer to the original definition.

If the definition is not marked newslot then it creates a new virtual method only if there is no virtual method of the same name and signature inherited from a base class. If the inheritance hierarchy changes so that the definition matches an inherited virtual function the definition will be treated as a new implementation of the inherited function.

9.3.2 The .override Directive

The .override directive specifies that a virtual method should be implemented (overridden), in this type, by a virtual method with a different name but with the same signature. It can be used to provide an implementation for a virtual method inherited from a base class or a virtual method specified in an interface implemented by this type. The .override directive specifies a Method Implementation (MethodImpl) in the metadata (see clause 14.1.4).

The first <typeSpec> :: <methodName> pair specifies the virtual method that is being overridden. It shall reference either an inherited virtual method or a virtual method on an interface that the current type implements. The remaining information specifies the virtual method that provides the implementation.

While the syntax specified here and the actual metadata format (see Section 21.25) allows any virtual method to be used to provide an implementation, a conforming program shall provide a virtual method actually implemented directly on the type containing the .override directive.
**Rationale:** The metadata is designed to be more expressive than can be expected of all implementations of the VES.

**Example (informative):**

The following example shows a typical use of the .override directive. A method implementation is provided for a method declared in an interface (see Chapter 11).

```csharp
.class interface I
{
    .method public virtual abstract void m() cil managed {}
}

.class C implements I
{
    .method virtual public void m2()
    { // body of m2
        .override I::m with instance void C::m2()
    }
}
```

The .override directive specifies that the C::m2 body shall provide the implementation of be used to implement I::m on objects of class C.

### 9.3.3 Accessibility and Overriding

If a type overrides an inherited method, it may *widen*, but it shall not *narrow*, the accessibility of that method. As a principle, if a client of a type is allowed to access a method of that type, then it should also be able to access that method (identified by name and signature) in any derived type. Table 7.1 specifies *narrow* and *widen* in this context — a “Yes” denotes that the subclass can apply that accessibility, a “No” denotes it is illegal.

**Table 7.1: Legal Widening of Access to a Virtual Method**

<table>
<thead>
<tr>
<th>Subclass</th>
<th>Base type Accessibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>private</td>
</tr>
<tr>
<td>private</td>
<td>Yes</td>
</tr>
<tr>
<td>family</td>
<td>Yes</td>
</tr>
<tr>
<td>assembly</td>
<td>Yes</td>
</tr>
<tr>
<td>famandassem</td>
<td>Yes</td>
</tr>
<tr>
<td>famorassem</td>
<td>Yes</td>
</tr>
<tr>
<td>public</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Note:** A method may be overridden even if it may not be accessed by the subclass.

If a method has assembly accessibility, then it shall have public accessibility if it is being overridden by a method in a different assembly. A similar rule applies to famandassem, where also famorassem is allowed outside the assembly. In both cases assembly or famandassem, respectively, may be used inside the same assembly.
A special rule applies to `famorassem`, as shown in the table. This is the only case where the accessibility is apparently narrowed by the subclass. A `famorassem` method may be overridden with `family` accessibility by a type in another assembly.

**Rationale:** Because there is no way to specify “family or specific other assembly” it is not possible to specify that the accessibility should be unchanged. To avoid narrowing access, it would be necessary to specify an accessibility of public, which would force widening of access even when it is not desired. As a compromise, the minor narrowing of “family” alone is permitted.

### 9.4 Method Implementation Requirements

A type (concrete or abstract) may provide

- implementations for instance, static, and virtual methods that it introduces
- implementations for methods declared in interfaces that it has specified it will implement, or that its base type has specified it will implement
- alternative implementations for virtual methods inherited from its parent
- implementations for virtual methods inherited from an abstract base type that did not provide an implementation

A concrete (i.e. non-abstract) type shall provide either directly or by inheritance an implementation for

- all methods declared by the type itself
- all virtual methods of interfaces implemented by the type
- all virtual methods that the type inherits from its base type

### 9.5 Special Members

There are three special members, all methods, that can be defined as part of a type: instance constructors, instance finalizers, and type initializers.

#### 9.5.1 Instance constructors

Instance constructors initialize an instance of a type. An instance constructor is called when an instance of a type is created by the newobj instruction (see Partition III). Instance constructors shall be instance (not static or virtual) methods, they shall be named `ctor` and marked both `rtspecialname` and `specialname` (see clause 14.4.2.6). Instance constructors may take parameters, but shall not return a value. Instance constructors may be overloaded (i.e. a type may have several instance constructors). Each instance constructor shall have a unique signature. Unlike other methods, instance constructors may write into fields of the type that are marked with the `initonly` attribute (see clause 15.1.2).
Example (informative):
The following shows the definition of an instance constructor that does not take any parameters:
```
.class X {
  .method public rtspecialname specialname instance void .ctor() cil managed
  { .maxstack 1
    // call super constructor
    ldarg.0 // load this pointer
    call instance void [mscorlib]System.Object::.ctor()
    // do other initialization work
    ret
  }
}
```

9.5.2 Instance Finalizer
The behavior of finalizers is specified in Partition I. The finalize method for a particular type is specified by overriding the virtual method `Finalize` in `System.Object`.

9.5.3 Type Initializer
Types may contain special methods called type initializers to initialize the type itself.
All types (classes, interfaces, and value types) may have a type initializer. This method shall be static, take no parameters, return no value, be marked with `rtspecialname` and `specialname` (see clause 14.4.2.6), and be named `.cctor`.
Like instance initializers, type initializers may write into static fields of their type that are marked with the `initonly` attribute (see clause 15.1.2).

Note: Type initializers are often simple methods that initialize the type's static fields from stored constants or via simple computations. There are, however, no limitations on what code is permitted in a type initializer.

9.5.3.1 Type Initialization Guarantees
The CLI shall provide the following guarantees regarding type initialization (but see also clause 9.5.3.2 and clause 9.5.3.3):
11. When type initializers are executed is specified in Partition I
12. A type initializer shall run exactly once for any given type, unless explicitly called by user code
13. No method other than those called directly or indirectly from the type initializer will be able to access members of a type before its initializer completes execution.

9.5.3.2 Relaxed Guarantees
A type can be marked with the attribute `beforefieldinit` (see clause 9.1.6) to indicate that all the guarantees specified in clause 9.5.3.1 are not required. In particular, the final requirement of guarantee 1 need not be provided: the type initializer need not run before a static method is called or referenced.

Rationale: When code can be executed in multiple application domains it becomes particularly expensive to ensure this final guarantee. At the same time, examination of large bodies of managed code have shown that this final guarantee is rarely required, since type initializers are almost always simple methods for initializing
static fields. Leaving it up to the CIL generator (and hence, possibly, to the programmer) to decide whether this guarantee is required therefore provides efficiency when it is desired at the cost of consistency guarantees.

9.5.3.3 Races and Deadlocks

In addition to the type initialization guarantees specified in clause 9.5.3.1 the CLI shall ensure two further guarantees for code that is called from a type initializer:

14. Static variables of a type are in a known state prior to any access whatsoever.
15. Type initialization alone shall not create a deadlock unless some code called from a type initializer (directly or indirectly) explicitly invokes blocking operations.

Rationale:

Consider the following two class definitions:

```csharp
class public A extends [mscorlib]System.Object
{
    .field static public class A a
    .field static public class B b

    .method public static rtspecialname specialname void .cctor ()
    { ldnull      // b=null
      stsfld class B A::b
      ldssfld class A B::a  // a=B.a
      stsfld class A A::a
      ret
    }
}

class public B extends [mscorlib]System.Object
{
    .field static public class A a
    .field static public class B b

    .method public static rtspecialname specialname void .cctor ()
    { ldnull  // a=null
      stsfld class A B::a
      ldssfld class B A::b  // b=A.b
      stffld class B B::b
      ret
    }
}
```

After loading these two classes, an attempt to reference any of the static fields causes a problem, since the type initializer for each of A and B requires that the type initializer of the other be invoked first. Requiring that no access to a type be permitted until its initializer has completed would create a deadlock situation. Instead, the CLI provides a weaker guarantee: the initializer will have started to run, but it need not have completed. But this alone would allow the full uninitialized state of a type to be visible, which would make it difficult to guarantee repeatable results.
There are similar, but more complex, problems when type initialization takes place in a multi-threaded system. In these cases, for example, two separate threads might start attempting to access static variables of separate types (A and B) and then each would have to wait for the other to complete initialization.

A rough outline of the algorithm is as follows:

1. At class load time (hence prior to initialization time) store zero or null into all static fields of the type.
2. If the type is initialized you are done.
2.1. If the type is not yet initialized, try to take an initialization lock.
2.2. If successful, record this thread as responsible for initializing the type and proceed to step 2.3.
2.2.1. If not, see whether this thread or any thread waiting for this thread to complete already holds the lock.
2.2.2. If so, return since blocking would create a deadlock. This thread will now see an incompletely initialized state for the type, but no deadlock will arise.
2.2.3 If not, block until the type is initialized then return.
2.3 Initialize the parent type and then all interfaces implemented by this type.
2.4 Execute the type initialization code for this type.
2.5 Mark the type as initialized, release the initialization lock, awaken any threads waiting for this type to be initialized, and return.

9.6 Nested Types

Nested types are specified in Partition I. Interfaces may be nested inside of classes and value types, but classes and value types shall not be nested inside of interfaces. For information about the logical tables associated with nested types, see Section 21.29.

Note: A nested type is not associated with an instance of its enclosing type. The nested type has its own base type and may be instantiated independent of the enclosing type. This means that the instance members of the enclosing type are not accessible using the this pointer of the nested type.

A nested type may access any members of its enclosing type, including private members, as long as the member is static or the nested type has a reference to an instance of the enclosing type. Thus, by using nested types a type may give access to its private members to another type.

On the other side, the enclosing type may not access any private or family members of the nested type. Only members with assembly, famorassem, or public accessibility can be accessed by the enclosing type.

Example (informative):

The following example shows a class declared inside another class. Both classes declare a field. The nested class may access both fields, while the enclosing class does not have access to the field b.

```csharp
.class private auto autochar CounterTextBox
    implements [module Counter]IcountDisplay
{
    .field static private int32 a
    /* Nested class. Declares the NegativeNumberException */
    .class nested assembly NonPositiveNumberException extends [mscorlib]System.Exception
    { .field static private int32 b
        // body of nested class
    } // end of nested class NegativeNumberException
```
9.7 Controlling Instance Layout

The CLI supports both sequential and explicit layout control, see clause 9.1.2. For explicit layout it is also necessary to specify the precise layout of an instance, see also Section 21.18 and Section 21.16.

```
<fieldDecl> ::= 
  [(<int32>)] <fieldAttr>* <type> <id>
```

The optional int32 specified in brackets at the beginning of the declaration specifies the byte offset from the beginning of the instance of the type. This form of explicit layout control shall not be used with global fields specified using the at notation (see clause 15.3.2).

Offset values shall be 0 or greater; they cannot be negative. It is possible to overlap fields in this way, even though it is not recommended. The field may be accessed using pointer arithmetic and lldind to load the field indirectly or stind to store the field indirectly (see Partition III). See Section 21.18 and Section 21.16 for encoding of this information. For explicit layout, every field shall be assigned an offset.

The .pack directive specifies that fields should be placed within the runtime object at addresses which are a multiple of the specified number, or at natural alignment for that field type, whichever is smaller. e.g., .pack 2 would allow 32-bit-wide fields to be started on even addresses – whereas without any .pack directive, they would be naturally aligned – that is to say, placed on addresses that are a multiple of 4. The integer following .pack shall be one of 0, 1, 2, 4, 8, 16, 32, 64 or 128. (A value of zero indicates that the pack size used should match the default for the current platform). The .pack directive shall not be supplied for any type with explicit layout control.

The directive .size specifies that a memory block of the specified amount of bytes shall be allocated for an instance of the type. e.g., .size 32 would create a block of 32 bytes for the instance. The value specified shall be greater than or equal to the calculated size of the class, based upon its field sizes and any .pack directive. Note that if this directive applies to a value type, then the size shall be less than 1 MByte.

**Note:** Metadata that controls instance layout is not a “hint,” it is an integral part of the VES that shall be supported by all conforming implementations of the CLI.

**Example (informative):**

The following class uses sequential layout of its fields:

```csharp
.class sequential public SequentialClass
{
  .field public int32 a // store at offset 0 bytes
  .field public int32 b // store at offset 4 bytes
}
```

The following class uses explicit layout of its fields:

```csharp
.class explicit public ExplicitClass
{
  .field [0] public int32 a // store at offset 0 bytes
  .field [6] public int32 b // store at offset 6 bytes
}
```

The following value type uses .pack to pack its fields together:

```csharp
.class value sealed public MyClass extends [mscorlib]System.ValueType
{
  .pack 2
  .field public int8 a // store at offset 0 bytes
  .field public int32 b // store at offset 2 bytes (not 4)
}
```
The following class specifies a contiguous block of 16 bytes:

```java
.class public BlobClass
{
  .size 16
}
```

9.8 Global Fields and Methods

In addition to types with static members, many languages have the notion of data and methods that are not part of a type at all. These are referred to as global fields and methods.

It is simplest to understand global fields and methods in the CLI by imagining that they are simply members of an invisible abstract public class. In fact, the CLI defines such a special class, named `<Module>`, that does not have a base type and does not implement any interfaces. The only noticeable difference is in how definitions of this special class are treated when multiple modules are combined together, as is done by a class loader. This process is known as metadata merging.

For an ordinary type, if the metadata merges two definitions of the same type, it simply discards one definition on the assumption they are equivalent and that any anomaly will be discovered when the type is used. For the special class that holds global members, however, members are unioned across all modules at merge time. If the same name appears to be defined for cross-module use in multiple modules then there is an error. In detail:

- If no member of the same kind (field or method), name, and signature exists, then add this member to the output class.

- If there are duplicates and no more than one has an accessibility other than `compilercontrolled`, then add them all in the output class.

- If there are duplicates and two or more have an accessibility other than `compilercontrolled` an error has occurred.
10 Semantics of Classes

Classes, as specified in Partition I, define types in an inheritance hierarchy. A class (except for the built-in class `System.Object`) shall declare exactly one parent class. A class shall declare zero or more interfaces that it implements (see Chapter 11). A concrete class may be instantiated to create an object, but an abstract class (see clause 9.1.4) shall not be instantiated. A class may define fields (static or instance), methods (static, instance, or virtual), events, properties, and nested types (classes, value types, or interfaces).

Instances of a class (objects) are created only by explicitly using the `newobj` instruction (see Partition III). When a variable or field that has a class as its type is created (for example, by calling a method that has a local variable of a class type) the value shall initially be null, a special value that is assignment compatible with all class types even though it is not an instance of any particular class.
11 Semantics of Interfaces

Interfaces, as specified in Partition I, define a contract that other types may implement. Interfaces may have static fields and methods, but they shall not have instance fields or methods. Interfaces may define virtual methods, but only if they are `abstract` (see Partition I and clause 14.4.2.4).

**Rationale:** Interfaces cannot define instance fields for the same reason that the CLI does not support multiple inheritance of base types: in the presence of dynamic loading of data types there is no known implementation technique that is both efficient when used and has no cost when not used. By contrast, providing static fields and methods need not affect the layout of instances and therefore does not raise these issues.

Interfaces may be nested inside any type (interface, class, or value type). Classes and value types shall not be nested inside of interfaces.

11.1 Implementing Interfaces

Classes and value types shall implement zero or more interfaces. Implementing an interface implies that all concrete instances of the class or value type shall provide an implementation for each `abstract` virtual method declared in the interface. In order to implement an interface, a class or value type shall either explicitly declare that it does so (using the implements attribute in its type definition, see Section 9.1) or shall be derived from a base class that implements the interface.

**Note:** An `abstract` class (since it cannot be instantiated) need not provide implementations of the virtual methods it implements, but any concrete class derived from it shall provide the implementation.

Merely providing implementations for all of the `abstract` methods of an interface is not sufficient to have a type implement that interface. Conceptually, this represents that fact that an interface represents a contract that may have more requirements than are captured in the set of `abstract` methods. From an implementation point of view, this allows the layout of types to be constrained only by those interfaces that are explicitly declared.

Interfaces shall declare that they require the implementation of zero or more other interfaces. If one interface, A, declares that it requires the implementation of another interface, B, then A implicitly declares that it requires the implementation of all interfaces required by B. If a class or value type declares that it implements A, then all concrete instances shall provide implementations of the virtual methods declared in A and all of the interfaces A requires.

**Example (informative):**

The following class implements the interface IStartStopEventSource defined in the module Counter.

```csharp
{ // body of class
}
```

11.2 Implementing Virtual Methods on Interfaces

Classes that implement an interface (see Section 11.1) are required to provide implementations for the `abstract` virtual methods defined by the interface. There are three mechanisms for providing this implementation:

- directly specifying an implementation, using the same name and signature as appears in the interface
- inheritance of an existing implementation from the base type
- use of an explicit MethodImpl (see clause 14.1.4).

The Virtual Execution System shall determine the appropriate implementation of a virtual method to be used for an interface `abstract` method using the following algorithm.
• If the parent class implements the interface, start with the same virtual methods that it provides, otherwise create an interface that has empty slots for all virtual functions.

• If this class explicitly specifies that it implements the interface or if the class defines any **public virtual newslot** functions whose name and signature match a virtual method on the interface, then use these new virtual methods to implement the corresponding interface method.

• If there are any virtual methods in the interface that still have empty slots, see if there are any **public virtual** methods available on this class (directly or inherited) and use these to implement the corresponding methods on the interface.

• If the current class is not **abstract** and there are any interface methods that still have empty slots, then the program is not valid.

**Rationale:** Interfaces can be thought of as specifying, primarily, a set of virtual methods that shall be implemented by any class that implements the interface. The class specifies a mapping from its own virtual methods to those of the interface. Thus it is virtual methods, not specific implementations of those methods, that are associated with interfaces. Overriding a virtual method on a class with a specific implementation will thus affect not only the virtual method named in the class but also any interface virtual methods to which that same virtual method has been mapped.
12 Semantics of Value Types

In contrast to classes, value types (see Partition I) are not accessed by using a reference but are stored directly in the location of that type.

**Rationale:** Value types are used to describe the type of small data items. They can be compared to struct (as opposed to pointers to struct) types in C++. Compared to reference types, value types are accessed faster since there is no additional indirection involved. As elements of arrays they do not require allocating memory for the pointers as well as for the data itself. Typical value types are complex numbers, geometric points, or dates.

Like other types, value types may have fields (static or instance), methods (static, instance, or virtual), properties, events, and nested types. A value type may be converted into a corresponding reference type (its boxed form, a class automatically created for this purpose by the VES when a value type is defined) by a process called boxing. A boxed value type may be converted back into its value type representation, the unboxed form, by a process called unboxing. Value types shall be sealed, and they shall have a base type of either System.ValueType or System.Enum (see Partition IV). Value types shall implement zero or more interfaces, but this has meaning only in their boxed form (see Section 12.3).

Unboxed value types are not considered subtypes of another type and it is not valid to use the isinst instruction (see Partition III) on unboxed value types. The isinst instruction may be used for boxed value types. Unboxed value types shall not be assigned the value null and they shall not be compared to null.

Value types support layout control in the same way as reference types do (see Section 9.7). This is especially important when values are imported from native code.

12.1 Referencing Value Types

The unboxed form of a value type shall be referred to by using the valuetype keyword followed by a type reference. The boxed form of a value type shall be referred to by using the boxed keyword followed by a type reference.

```plaintext
<valueTypeReference> ::= 
  boxed <typeReference> | 
  valuetype <typeReference>
```

12.2 Initializing Value Types

Like classes, value types may have both instance constructors (see clause 9.5.1) and type initializers (see clause 9.5.3). Unlike classes that are automatically initialized to null, however, the following rules constitute the only guarantee about the initialisation of (unboxed) value types:

- Static variables shall be initialized to zero when a type is loaded (see clause 9.5.3.3), hence statics whose type is a value type are zero-initialized when the type is loaded.
- Local variables shall be initialized to zero if the appropriate bit in the method header (see clause 24.4.4) is set.
- Arrays shall be zero initialized.
- Instances of classes (i.e. objects) shall be zero initialized prior to calling their instance constructor.

**Rationale:** Guaranteeing automatic initialization of unboxed value types is both difficult and expensive, especially on platforms that support thread-local storage and allow threads to be created outside of the CLI and then passed to the CLI for management.

**Note:** Boxed value types are classes and follow the rules for classes.

The instruction initobj (see Partition III) performs zero-initialization under program control. If a value type has a constructor, an instance of its unboxed type can be created as is done with classes. The newobj instruction
(see Partition III) is used along with the initializer and its parameters to allocate and initialize the instance. The instance of the value type will be allocated on the stack. The Base Class Library provides the method System.Array.Initialize (see Partition IV) to zero all instances in an array of unboxed value types.

Example (informative):
The following code declares and initializes three value type variables. The first variable is zero-initialized, the second is initialized by calling an instance constructor, and the third by creating the object on the stack and storing it into the local.

```
.assembly Test { }
.assembly extern System.Drawing {
 .ver 1:0:3102:0
 .publickeytoken = (b03f5f7f11d50a3a)
}
.method public static void Start()
{
 .maxstack 3
 .entrypoint
 .locals init (valuetype [System.Drawing]System.Drawing.Size Zero,
    valuetype [System.Drawing]System.Drawing.Size Init,

 // Zero initialize the local named Zero
 ldloca Zero       // load address of local variable

 // Call the initializer on the local named Init
 ldloca Init       // load address of local variable
 ldc.i4 425        // load argument 1 (width)
 ldc.i4 300        // load argument 2 (height)

 // Create a new instance on the stack and store into Store. Note that
 // stobj is used here – but one could equally well use stloc, stfld, etc.
 ldloca Store      // load address of local variable
 ldc.i4 425        // load argument 1 (width)
 ldc.i4 300        // load argument 2 (height)
```
12.3 Methods of Value Types

Value types may have static, instance and virtual methods. Static methods of value types are defined and called
the same way as static methods of class types. As with classes, both instance and virtual methods of a boxed or
unboxed value type may be called using the call instruction. The callvirt instruction shall not be used with
unboxed value types, but it may be used on boxed value types.

Instance and virtual methods of classes shall be coded to expect a reference to an instance of the class as the
this pointer. By contrast, instance and virtual methods of value types shall be coded to expect a managed
pointer (see Partition I) to an unboxed instance of the value type. The CLI shall convert a boxed value type
into a managed pointer to the unboxed value type when a boxed value type is passed as the this pointer to a
virtual method whose implementation is provided by the unboxed value type.

Note: This operation is the same as unboxing the instance, since the unbox instruction (see Partition III) is
defined to return a managed pointer to the value type that shares memory with the original boxed instance.

The following diagrams may help understand the relationship between the boxed and unboxed representations
of a value type.

Rationale: An important use of instance methods on value types is to change internal state of the instance.
This cannot be done if an instance of the unboxed value type is used for the this pointer, since it would be
operating on a copy of the value, not the original value: unboxed value types are copied when they are passed
as arguments.

Virtual methods are used to allow multiple types to share implementation code, and this requires that all
classes that implement the virtual method share a common representation defined by the class that first
introduces the method. Since value types can (and in the Base Class Library do) implement interfaces and
virtual methods defined on System.Object, it is important that the virtual method be callable using a boxed
value type so it can be manipulated as would any other type that implements the interface. This leads to the
requirement that the EE automatically unbox value types on virtual calls.
Table 1: Type of this given CIL instruction and declaring type of instance method.

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Value Type (Boxed or Unboxed)</th>
<th>Interface</th>
<th>Class Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>call</td>
<td>managed pointer to value type</td>
<td>illegal</td>
<td>object reference</td>
</tr>
<tr>
<td>callvirt</td>
<td>managed pointer to value type</td>
<td>object reference</td>
<td>object reference</td>
</tr>
</tbody>
</table>

Example (informative):
The following converts an integer of the value type int32 into a string. Recall that int32 corresponds to the unboxed value type System.Int32 defined in the Base Class Library. Suppose the integer is declared as:

```
.locals init (int32 x)
```

Then the call is made as shown below:

```
ldloca x // load managed pointer to local variable
call instance string
    valuetype [mscorlib]System.Convert::ToString()
```

However, if System.Object (a class) is used as the type reference rather than System.Int32 (a value type), the value of x shall be boxed before the call is made and the code becomes:

```
ldloc x
box valuetype [mscorlib]System.Int32
callvirt instance string [mscorlib]System.Object::ToString()
```
13 Semantics of Special Types

Special Types are those that are referenced from CIL, but for which no definition is supplied: the VES supplies the definitions automatically based on information available from the reference.

13.1 Vectors

Vectors are single-dimension arrays with a zero lower bound. They have direct support in CIL instructions (newarr, ldlem, stelem, and ldlema, see Partition III). The CIL Framework also provides methods that deal with multidimensional arrays, or single-dimension arrays with a non-zero lower bound (see Section 13.2). Two vectors are the same type if their element types are the same, regardless of their actual upper bounds.

Vectors have a fixed size and element type, determined when they are created. All CIL instructions shall respect these values. That is, they shall reliably detect attempts to index beyond the end of the vector, attempts to store the incorrect type of data into an element of a vector, and attempts to take addresses of elements of a vector with an incorrect data type. See Partition III.

Example (informative):

Declaring a vector of Strings:

```csharp
.field string[] errorStrings
```

Declaring a vector of function pointers:

```csharp
.field method instance void*(int32) [] myVec
```

Create a vector of 4 strings, and store it into the field errorStrings.
The four strings lie at errorStrings[0] through errorStrings[3]:

```csharp
ldc.i4.4
newarr string
stfld string[] CountDownForm::errorStrings
```

Store the string "First" into errorStrings[0]:

```csharp
ldfld string[] CountDownForm::errorStrings
ldc.i4.0
ldstr "First"
stelem
```

Vectors are subtypes of System.Array, an abstract class pre-defined by the CLI. It provides several methods that can be applied to all vectors. See Partition IV.

13.2 Arrays

While vectors (see Section 13.1) have direct support through CIL instructions, all other arrays are supported by the VES by creating subtypes of the abstract class System.Array (see Partition IV).

The rank of an array is the number of dimensions. The CLI does not support arrays with rank 0. The type of an array (other than a vector) shall be determined by the type of its elements and the number of dimensions.
... lower and upper bounds unspecified. In the case of multi-dimensional arrays, the ellipsis may be omitted

| <int32> | zero lower bound, <int32> upper bound
| <int32> ... | lower bound only specified
| <int32> ... <int32> | both bounds specified

The fundamental operations provided by the CIL instruction set for vectors are provided by methods on the class created by the VES.

The VES shall provide two constructors for arrays. One takes a sequence of numbers giving the number of elements in each dimension (a lower bound of zero is assumed). The second takes twice as many arguments: a sequence of lower bounds, one for each dimension; followed by a sequence of lengths, one for each dimension (where length is the number of elements required).

In addition to array constructors, the VES shall provide the instance methods *Get*, *Set*, and *Address* to access specific elements and compute their addresses. These methods take a number for each dimension, to specify the target element. In addition, *Set* takes an additional final argument specifying the value to store into the target element.

**Example (informative):**

Creates an array, MyArray, of strings with two dimensions, with indexes 5..10 and 3..7. Stores the string "One" into MyArray[5, 3], retrieves it and prints it out. Then computes the address of MyArray[5, 4], stores "Test" into it, retrieves it, and prints it out.

```assembly
.assembly Test { }
.assembly extern mscorlib { }

.method public static void Start()
{
    .maxstack 5
    .entrypoint
    .locals (class [mscorlib]System.String[,] myArray)

    ldc.i4.5 // load lower bound for dim 1
    ldc.i4.6 // load (upper bound - lower bound + 1) for dim 1
    ldc.i4.3 // load lower bound for dim 2
    ldc.i4.5 // load (upper bound - lower bound + 1) for dim 2
    newobj instance void string[,].cctor(int32, int32, int32, int32)
    stloc myArray

    ldloc myArray
    ldc.i4.5
    ldc.i4.3
    ldstr "One"
    call instance void string[,].Set(int32, int32, string)
```
ldloc myArray
ldc.i4.5
ldc.i4.3
call instance string string[,,]::Get(int32, int32)
call void [mscorlib]System.Console::WriteLine(string)

ldloc myArray
ldc.i4.5
ldc.i4.4
call instance string & string[,,]::Address(int32, int32)
ldstr "Test"
stind.ref

ldloc myArray
ldc.i4.5
ldc.i4.4
call instance string string[,,]::Get(int32, int32)
call void [mscorlib]System.Console::WriteLine(string)
ret
}

The following text is informative

Whilst the elements of multi-dimensional arrays can be thought of as laid out in contiguous memory, arrays of arrays are different – each dimension (except the last) holds an array reference. The following picture illustrates the difference:

On the left is a [6, 10] rectangular array. On the right is not one, but a total of five arrays. The vertical array is an array of arrays, and references the four horizontal arrays. Note how the first and second elements of the vertical array both reference the same horizontal array.

Note that all dimensions of a multi-dimensional array shall be of the same size. But in an array of arrays, it is possible to reference arrays of different sizes. For example, the figure on the right shows the vertical array referencing arrays of lengths 8, 8, 3, null, 6 and 1.
There is no special support for these so-called jagged arrays in either the CIL instruction set or the VES. They are simply vectors whose elements are themselves either the base elements or (recursively) jagged arrays.

13.3 Enums

An enum, short for enumeration, defines a set of symbols that all have the same type. A type shall be an enum if and only if it has an immediate base type of System.Enum. Since System.Enum itself has an immediate base type of System.ValueType (see Partition IV), enums are value types (see Chapter 0). The symbols of an enum are represented by an underlying type: one of { bool, char, int8, unsigned int8, int16, unsigned int16, int32, unsigned int32, int64, unsigned int64, float32, float64, native int, unsigned native int }

Note: The CLI does not provide a guarantee that values of the enum type are integers corresponding to one of the symbols (unlike Pascal). In fact, the CLS (see Partition I, CLS) defines a convention for using enums to represent bit flags which can be combined to form integral value that are not named by the enum type itself.

 Enums obey additional restrictions beyond those on other value types. Enums shall contain only fields as members (they shall not even define type initializers or instance constructors); they shall not implement any interfaces; they shall have auto field layout (see clause 9.1.2); they shall have exactly one instance field and it shall be of the underlying type of the enum; all other fields shall be static and literal (see Section 15.1); and they shall not be initialized with the initobj instruction.

Rationale: These restrictions allow a very efficient implementation of enums.

The single, required, instance field stores the value of an instance of the enum. The static literal fields of an enum declare the mapping of the symbols of the enum to the underlying values. All of these fields shall have the type of the enum and shall have field init metadata that assigns them a value (see Section 15.2).

For binding purposes (e.g. for locating a method definition from the method reference used to call it) enums shall be distinct from their underlying type. For all other purposes, including verification and execution of code, an unboxed enum freely interconverts with its underlying type. Enums can be boxed (see Chapter 0) to a corresponding boxed instance type, but this type is not the same as the boxed type of the underlying type, so boxing does not lose the original type of the enum.

Example (informative):

Declare an enum type, then create a local variable of that type. Store a constant of the underlying type into the enum (showing automatic coercion from the underlying type to the enum type). Load the enum back and print it as the underlying type (showing automatic coercion back). Finally, load the address of the enum and extract the contents of the instance field and print that out as well.

.assembly Test { }
.assembly extern mscorlib { }
.class sealed public ErrorCodes extends [mscorlib]System.Enum
{ .field public unsigned int8 MyValue
  .field public static literal valuetype ErrorCodes no_error = int8(0)
  .field public static literal valuetype ErrorCodes format_error = int8(1)
  .field public static literal valuetype ErrorCodes overflow_error = int8(2)
  .field public static literal valuetype ErrorCodes nonpositive_error =
```csharp
int8(3)
}

.method public static void Start()
{
    .maxstack 5
    .entrypoint
    .locals init (valuetype ErrorCodes errorCode)

    ldc.i4.1 // load 1 (= format_error)
    stloc errorCode // store in local, note conversion to enum
    ldloc errorCode
    call void [mscorlib]System.Console::WriteLine(int32)
    ldloca errorCode // address of enum
    ldfld unsigned int8 valuetype ErrorCodes::MyValue
    call void [mscorlib]System.Console::WriteLine(int32)
    ret
}
```

### 13.4 Pointer Types

<table>
<thead>
<tr>
<th>&lt;type&gt; ::= _</th>
<th>&lt;type&gt; &amp;</th>
<th>&lt;type&gt; *</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.4.2</td>
<td>13.4.1</td>
<td></td>
</tr>
</tbody>
</table>

A pointer type shall be defined by specifying a signature that includes the type for the location it points at. A pointer may be managed (reported to the CLI garbage collector, denoted by &, see clause 13.4.2) or unmanaged (not reported, denoted by *, see clause 13.4.1).

Pointers may contain the address of a field (of an object or value type) or an element of an array. Pointers differ from object references in that they do not point to an entire type instance, but rather to the interior of an instance. The CLI provides two type-safe operations on pointers:

- **loading** the value from the location referenced by the pointer
- **storing** an assignment-compatible value into the location referenced by the pointer

For pointers into the same array or object (see Partition I) the following arithmetic operations are supported:

- Adding an integer value to a pointer, where that value is interpreted as a number of bytes, results in a pointer of the same kind
- Subtracting an integer value (number of bytes) from a pointer results in a pointer of the same kind. Note that subtracting a pointer from an integer value is not permitted.
- Two pointers, regardless of kind, can be subtracted from one another, producing an integer value that specifies the number of bytes between the addresses they reference.
The following is informative text

Pointers are compatible with unsigned int32 on 32-bit architectures, and with unsigned int64 on 64-bit architectures. They are best considered as unsigned int, whose size varies depending upon the runtime machine architecture.

The CIL instruction set (see Partition III) contains instructions to compute addresses of fields, local variables, arguments, and elements of vectors:

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ldarga</td>
<td>Load address of argument</td>
</tr>
<tr>
<td>ldelema</td>
<td>Load address of vector element</td>
</tr>
<tr>
<td>ldflda</td>
<td>Load address of field</td>
</tr>
<tr>
<td>ldloca</td>
<td>Load address of local variable</td>
</tr>
<tr>
<td>ldsflda</td>
<td>Load address of static field</td>
</tr>
</tbody>
</table>

Once a pointer is loaded onto the stack, the ldind class of instructions may be used to load the data item to which it points. Similarly, the stind class of instructions can be used to store data into the location.

Note that the CLI will throw an InvalidOperationException for an ldflda instruction if the address is not within the current application domain. This situation arises typically only from the use of objects with a base type of System.MarshalByRefObject (see Partition IV).

13.4.1 Unmanaged Pointers

Unmanaged pointers (*) are the traditional pointers used in languages like C and C++. There are no restrictions on their use, although for the most part they result in code that cannot be verified. While it is perfectly legal to mark locations that contain unmanaged pointers as though they were unsigned integers (and this is, in fact, how they are treated by the VES), it is often better to mark them as unmanaged pointers to a specific type of data. This is done by using * in a signature for a return value, local variable or an argument or by using a pointer type for a field or array element.

- Unmanaged pointers are not reported to the garbage collector and can be used in any way that an integer can be used.
- Verifiable code cannot dereference unmanaged pointers.
- Unverified code can pass an unmanaged pointer to a method that expects a managed pointer. This is safe only if one of the following is true:
  - The unmanaged pointer refers to memory that is not in memory used by the CLI for storing instances of objects ("garbage collected memory" or "managed memory").
  - The unmanaged pointer contains the address of a field within an object.
  - The unmanaged pointer contains the address of an element within an array.
  - The unmanaged pointer contains the address where the element following the last element in an array would be located.

13.4.2 Managed Pointers

Managed pointers (&) may point to an instance of a value type, a field of an object, a field of a value type, an element of an array, or the address where an element just past the end of an array would be stored (for pointer indexes into managed arrays). Managed pointers cannot be null, and they shall be reported to the garbage collector even if they do not point to managed memory.

Managed pointers are specified by using & in a signature for a return value, local variable or an argument or by using a by-ref type for a field or array element.
Managed pointers can be passed as arguments, stored in local variables, and returned as values.

If a parameter is passed by reference, the corresponding argument is a managed pointer.

Managed pointers cannot be stored in static variables, array elements, or fields of objects or value types.

Managed pointers are \textit{not} interchangeable with object references.

A managed pointer cannot point to another managed pointer, but it can point to an object reference or a value type.

A managed pointer can point to a local variable, or a method argument.

Managed pointers that do not point to managed memory can be converted (using \texttt{conv.u} or \texttt{conv.ovf.u}) into unmanaged pointers, but this is not verifiable.

Unverified code that erroneously converts a managed pointer into an unmanaged pointer can seriously compromise the integrity of the CLI. See \texttt{Partition III} (Managed Pointers) for more details.
13.5 Method Pointers

\[
\text{<type>} ::= \ldots \\
| \text{method <callConv> <type>} * \text{<parameters>} |
\]

Variables of type method pointer shall store the address of the entry point to a method with compatible signature. A pointer to a static or instance method is obtained with the \text{ldftn} instruction, while a pointer to a virtual method is obtained with the \text{ldvirtftn} instruction. A method may be called by using a method pointer with the \text{calli} instruction. See Partition III for the specification of these instructions.

\textbf{Note:} Like other pointers, method pointers are compatible with unsigned int64 on 64-bit architectures with unsigned int32 and on 32-bit architectures. The preferred usage, however, is \text{unsigned native int}, which works on both 32- and 64-bit architectures.

**Example (informative):**

Call a method using a pointer. The method \text{MakeDecision::Decide} returns a method pointer to either \text{AddOne} or \text{Negate}, alternating on each call. The main program call \text{MakeDecision::Decide} three times and after each call uses a CALLI instruction to call the method specified. The output printed is "-1 2 -1" indicating successful alternating calls.

```
.assembly Test { }
.assembly externmscorlib { }
.method public static int32 AddOne(int32 Input)
{ .maxstack 5
  ldarg Input
  ldc.i4.1
  add
  ret
}

.method public static int32 Negate(int32 Input)
{ .maxstack 5
  ldarg Input
  neg
  ret
}

.class value sealed public MakeDecision extends [mscorlib]System.ValueType
{ .field static bool Oscillate
  .method public static method int32 *(int32) Decide()
  { ldstr bool valuetype MakeDecision:::Oscillate
    dup
  }
```
not
  stsfld bool valuetype MakeDecision::Oscillate
  brfalse NegateIt
  ldftn int32 AddOne(int32)
  ret
NegateIt:
  ldftn int32 Negate(int32)
  ret
}
}

.method public static void Start()
{
  .maxstack 2
  .entrypoint

  ldc.i4.1
call method int32 *(int32) valuetype MakeDecision::Decide()
calli int32(int32)
call void [mscorlib]System.Console::WriteLine(int32)

  ldc.i4.1
call method int32 *(int32) valuetype MakeDecision::Decide()
calli int32(int32)
call void [mscorlib]System.Console::WriteLine(int32)

  ldc.i4.1
call method int32 *(int32) valuetype MakeDecision::Decide()
calli int32(int32)
call void [mscorlib]System.Console::WriteLine(int32)

  ret
}

13.6 Delegates

Delegates (see Partition I) are the object-oriented equivalent of function pointers. Unlike function pointers, delegates are object-oriented, type-safe, and secure. Delegates are reference types, and are declared in the form of Classes. Delegates shall have an immediate base type of System.MulticastDelegate, which in turns has an immediate base type of System.Delegate (see Partition IV).

Delegates shall be declared sealed, and the only members a Delegate shall have are either two or four methods as specified here. These methods shall be declared runtime and managed (see clause 14.4.3). They shall not
have a body, since it shall be automatically created by the VES. Other methods available on delegates are
inherited from the classes `System.Delegate` and `System.MulticastDelegate` in the Base Class Library (see
Partition IV).

**Rationale:** A better design would be to simply have delegate classes derive directly from
`System.Delegate`. Unfortunately, backward compatibility with an existing CLI does not permit this
design.

The instance constructor (named `.ctor` and marked `specialname` and `rtspecialname`, see clause 9.5.1) shall
take exactly two parameters. The first parameter shall be of type `System.Object` and the second parameter
shall be of type `System.IntPtr`. When actually called (via a newobj instruction, see Partition III), the first
argument shall be an instance of the class (or one of its subclasses) that defines the target method and the
second argument shall be a method pointer to the method to be called.

The `Invoke` method shall be `virtual` and have the same signature (return type, parameter types, calling
convention, and modifiers, see Section 7.1) as the target method. When actually called the arguments passed
shall match the types specified in this signature.

The `BeginInvoke` method (see clause 13.6.2.1), if present, shall be `virtual` have a signature related to, but not
the same as, that of the `Invoke` method. There are two differences in the signature. First, the return type shall
be `System.IAsyncResult` (see Partition IV). Second, there shall be two additional parameters that follow those

The `EndInvoke` method (see clause 13.6.2) shall be `virtual` have the same return type as the `Invoke` method. It
shall take as parameters exactly those parameters of `Invoke` that are managed pointers, in the same order they
occur in the signature for `Invoke`. In addition, there shall be an additional parameter of type
`System.IAsyncResult`.

**Example (informative):**

The following example declares a Delegate used to call functions that
take a single integer and return void. It provides all four methods so
it can be called either synchronously or asynchronously. Because there
are no parameters that are passed by reference (i.e. as managed
pointers) there are no additional arguments to `EndInvoke`.

```csharp
.assembly Test { }
.assembly extern mscorlib { }

.class private sealed StartStopEventHandler
    extends [mscorlib]System.MulticastDelegate
    { .method public specialname rtspecialname instance
        void .ctor(object Instance, native int Method)
            runtime managed ()
        .method public virtual void Invoke(int32 action) runtime managed ()
        .method public virtual
            class [mscorlib]System.IAsyncResult
            BeginInvoke(int32 action,
                class [mscorlib]System.AsyncCallback callback,
                object Instance) runtime managed ()
        .method public virtual
            void EndInvoke(class [mscorlib]System.IAsyncResult result)
```
As with any class, an instance is created using the `newobj` instruction in conjunction with the instance constructor. The first argument to the constructor shall be the object on which the method is to be called, or it shall be null if the method is a static method. The second argument shall be a method pointer to a method on the corresponding class and with a signature that matches that of the delegate class being instantiated.

### 13.6.1 Synchronous Calls to Delegates

The synchronous mode of calling delegates corresponds to regular method calls and is performed by calling the virtual method named `Invoke` on the delegate. The delegate itself is the first argument to this call (it serves as the `this` pointer), followed by the other arguments as specified in the signature. When this call is made, the caller shall block until the called method returns. The called method shall be executed on the same thread as the caller.

#### Example (informative):

Continuing the previous example, define a class `Test` that declares a method, `onStartStop`, appropriate for use as the target for the delegate.

```csharp
.class public Test
{
    .field public int32 MyData

    .method public void onStartStop(int32 action)
    { ret // put your code here
    }

    .method public specialname rtspecialname
    instance void .ctor(int32 Data)
    { ret // call parent constructor, store state, etc.
    }
}
```

Then define a main program. This one constructs an instance of `Test` and then a delegate that targets the `onStartStop` method of that instance. Finally, call the delegate.

```csharp
.method public static void Start()
{
    .maxstack 3
    .entrypoint
    .locals (class StartStopEventHandler DelegateOne, class Test InstanceOne)
    // Create instance of Test class
    ldc.i4.1
    newobj instance void Test::.ctor(int32)
    stloc InstanceOne
    // Create delegate to onStartStop method of that class
```
```csharp
ldloc InstanceOne
ldftn instance void Test::onStartStop(int32)
newobj void StartStopEventHandler::.ctor(object, native int)
stloc DelegateOne
// Invoke the delegate, passing 100 as an argument
ldloc DelegateOne
ldc.i4 100
callvirt instance void StartStopEventHandler::Invoke(int32)
ret
}
// Note that the example above creates a delegate to a non-virtual
// function. If onStartStop had instead been a virtual function, use
// the following code sequence instead :

ldloc InstanceOne
dup
ldvirtftn instance void Test::onStartStop(int32)
newobj void StartStopEventHandler::.ctor(object, native int)
stloc DelegateOne
// Invoke the delegate, passing 100 as an argument
ldloc DelegateOne
```

**Note:** The code sequence above shall use `dup`—not `ldloc InstanceOne` twice. The `dup` code sequence is easily recognized as typesafe, whereas alternatives would require more complex analysis. Verifiability of code is discussed in **Partition III**.

### 13.6.2 Asynchronous Calls to Delegates

In the asynchronous mode, the call is dispatched, and the caller shall continue execution without waiting for the method to return. The called method shall be executed on a separate thread.

To call delegates asynchronously, the `BeginInvoke` and `EndInvoke` methods are used.

**Note:** if the caller thread terminates before the callee completes, the callee thread is unaffected. The callee thread continues execution and terminates silently.

**Note:** the callee may throw exceptions. Any unhandled exception propagates to the caller via the `EndInvoke` method.

### 13.6.2.1 The `BeginInvoke` Method

An asynchronous call to a delegate shall begin by making a virtual call to the `BeginInvoke` method. `BeginInvoke` is similar to the `Invoke` method (see clause 13.6.1), but has three differences:

- It has a two additional parameters, appended to the list, of type `System.AsyncCallback`, and `System.Object`.
- The return type of the method is `System.IAsyncResult`.

Although the `BeginInvoke` method therefore includes parameters that represent return values, these values are not updated by this method. The results instead are obtained from the `EndInvoke` method (see below).
Unlike a synchronous call, an asynchronous call shall provide a way for the caller to determine when the call has been completed. The CLI provides two such mechanisms. The first is through the result returned from the call. This object, an instance of the interface `System.IAsyncResult`, can be used to wait for the result to be computed, it can be queried for the current status of the method call, and it contains the `System.Object` value that was passed to the call to `BeginInvoke`. See Partition IV.

The second mechanism is through the `System.AsyncCallback` delegate passed to `BeginInvoke`. The VES shall call this delegate when the value is computed or an exception has been raised indicating that the result will not be available. The value passed to this callback is the same value passed to the call to `BeginInvoke`. A value of null may be passed for `System.AsyncCallback` to indicate that the VES need not provide the callback.

**Rationale:** This model supports both a polling approach (by checking the status of the returned `System.IAsyncResult`) and an event-driven approach (by supplying a `System.AsyncCallback`) to asynchronous calls.

A synchronous call returns information both through its return value and through output parameters. Output parameters are represented in the CLI as parameters with managed pointer type. Both the returned value and the values of the output parameters are not available until the VES signals that the asynchronous call has completed successfully. They are retrieved by calling the `EndInvoke` method on the delegate that began the asynchronous call.

### 13.6.2.2 The `EndInvoke` Method

The `EndInvoke` method can be called at any time after `BeginInvoke`. It shall suspend the thread that calls it until the asynchronous call completes. If the call completes successfully, `EndInvoke` will return the value that would have been returned had the call been made synchronously, and its managed pointer arguments will point to values that would have been returned to the out parameters of the synchronous call.

`EndInvoke` requires as parameters the value returned by the originating call to `BeginInvoke` (so that different calls to the same delegate can be distinguished, since they may execute concurrently) as well as any managed pointers that were passed as arguments (so their return values can be provided).
14 Defining, Referencing, and Calling Methods

Methods may be defined at the global level (outside of any type):

```xml
<decl> ::= ...
  | .method <methodHead> ( <methodBodyItem>* )
```

as well as inside a type:

```xml
<classMember> ::= ...
  | .method <methodHead> ( <methodBodyItem>* )
```

14.1 Method Descriptors

There are four constructs in *ilasm* connected with methods. These correspond with different metadata constructs, as described in Chapter 21.

14.1.1 Method Declarations

A *MethodDecl*, or method declaration, supplies the method name and signature (parameter and return types), but not its body. That is, a method declaration provides a `<methodHead>` but no `<methodBodyItem>`s. These are used at call sites to specify the call target (*call* or *callvirt* instructions, see Partition III) or to declare an abstract method. A *MethodDecl* has no direct logical counterpart in the metadata; it can be either a *Method* or a *MethodRef*.

14.1.2 Method Definitions

A *Method*, or method definition, supplies the method name, attributes, signature and body. That is, a method definition provides a `<methodHead>` as well as one or more `<methodBodyItem>`s. The body includes the method’s CIL instructions, exception handlers, local variable information, and additional runtime or custom metadata about the method. See Chapter 178.

14.1.3 Method References

A *MethodRef*, or method reference, is a reference to a method. It is used when a method is called whose definition lies in another module or assembly. A *MethodRef* shall be resolved by the VES into a *Method* before the method is called at runtime. If a matching *Method* cannot be found, the VES shall throw a `System.MissingMethodException`. See Chapter 21.

14.1.4 Method Implementations

A *MethodImpl*, or method implementation, supplies the executable body for an existing virtual method. It associates a *Method* (representing the body) with a *MethodDecl* or *Method* (representing the virtual method). A *MethodImpl* is used to provide an implementation for an inherited virtual method or a virtual method from an interface when the default mechanism (matching by name and signature) would not provide the correct result. See Section 21.25.

14.2 Static, Instance, and Virtual Methods

Static methods are methods that are associated with a type, not with its instances.

Instance methods are associated with an instance of a type: within the body of an instance method it is possible to reference the particular instance on which the method is operating (via the *this pointer*). It follows that instance methods may only be defined in classes or value types, but not in interfaces or outside of a type (globally). However, notice

| 16. instance methods on classes (including boxed value types), have a *this* pointer that is by default an object reference to the class on which the method is defined |
17. Instance methods on (unboxed) value types, have a this pointer that is by default a managed pointer to an instance of the type on which the method is defined.

18. There is a special encoding (denoted by the syntactic item explicit in the calling convention, see Section 14.3) to specify the type of the this pointer, overriding the default values specified here.

19. The this pointer may be null.

Virtual methods are associated with an instance of a type in much the same way as for instance methods. However, unlike instance methods, it is possible to call a virtual method in such a way that the implementation of the method shall be chosen at runtime by the VES depends upon the type of object used for the this pointer. The particular Method that implements a virtual method is determined dynamically at runtime (a virtual call) when invoked via the callvirt instruction; whilst the binding is decided at compile time when invoked via the call instruction (see Partition III).

With virtual calls (only) the notion of inheritance becomes important. A subclass may override a virtual method inherited from its base classes, providing a new implementation of the method. The method attribute newslot specifies that the CLI shall not override the virtual method definition of the base type, but shall treat the new definition as an independent virtual method definition.

Abstract virtual methods (which shall only be defined in abstract classes or interfaces) shall be called only with a callvirt instruction. Similarly, the address of an abstract virtual method shall be computed with the ldvirtftn instruction, and the ldftn instruction shall not be used.

**Rationale:** With a concrete virtual method there is always an implementation available from the class that contains the definition, thus there is no need at runtime to have an instance of a class available. Abstract virtual methods, however, receive their implementation only from a subtype or a class that implements the appropriate interface, hence an instance of a class that actually implements the method is required.

### 14.3 Calling Convention

```
<callConv> ::= [instance [explicit]] [<callKind>]
```

A calling convention specifies how a method expects its arguments to be passed from the caller to the called method. It consists of two parts; the first deals with the existence and type of the this pointer, while the second relates to the mechanism for transporting the arguments.

If the attribute instance is present it indicates that a this pointer shall be passed to the method. It shall be used for both instance and virtual methods.

Normally, a parameter list (which always follows the calling convention) does not provide information about the type of the this pointer, since this can be deduced from other information. When the combination instance explicit is specified, however, the first type in the subsequent parameter list specifies the type of the this pointer and subsequent entries specify the types of the parameters themselves.

```
<callKind> ::= 
  | default
  | unmanaged cdecl
  | unmanaged fastcall
  | unmanaged stdcall
  | unmanaged thiscall
  | vararg
```

Managed code shall have only the default or vararg calling kind. default shall be used in all cases except when a method accepts an arbitrary number of arguments, in which case vararg shall be used.

When dealing with methods implemented outside the CLI it is important to be able to specify the calling convention required. For this reason there are 16 possible encodings of the calling kind. Two are used for the managed calling kinds. Four are reserved with defined meaning across many platforms:
• **unmanaged cdecl** is the calling convention used by standard C

• **unmanaged stdcall** specifies a standard C++ call

• **unmanagedfastcall** is a special optimized C++ calling convention

• **unmanaged thiscall** is a C++ call that passes a this pointer to the method

Four more are reserved for existing calling conventions, but their use is not portable. Four more are reserved for future standardization, and two are available for non-standard experimental use.

(By "portable" is meant a feature that is available on all conforming implementations of the CLI)

### 14.4 Defining Methods

<table>
<thead>
<tr>
<th><code>&lt;methodHead&gt;</code> ::=</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;methAttr&gt;*</code> [鹑&lt;callConv&gt;] [鹑&lt;paramAttr&gt;*] <code>&lt;type&gt;</code></td>
</tr>
<tr>
<td><code>[marshal ( [鹑&lt;nativeType&gt;] )]</code></td>
</tr>
<tr>
<td><code>&lt;methodName&gt;</code> { <code>&lt;parameters&gt;</code> } <code>&lt;implAttr&gt;*</code></td>
</tr>
</tbody>
</table>

The method head (see also Chapter 17) consists of

• the calling convention (`<callConv>`, see Section 14.3)

• any number of predefined method attributes (`<paramAttr>`, see clause 14.4.2)

• a return type with optional attributes

• optional marshalling information (see Section 7.4)

• a method name

• a signature

• and any number of implementation attributes (`<implAttr>`, see clause 14.4.3)

Methods that do not have a return value shall use `void` as the return type.

<table>
<thead>
<tr>
<th><code>&lt;methodName&gt;</code> ::=</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>.cctor</code></td>
</tr>
<tr>
<td><code>.ctor</code></td>
</tr>
<tr>
<td><code>&lt;dottedname&gt;</code></td>
</tr>
</tbody>
</table>

Method names are either simple names or the special names used for instance constructors and type initializers.

<table>
<thead>
<tr>
<th><code>&lt;parameters&gt;</code> ::= [鹑&lt;param&gt; [, &lt;param&gt;]*]</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;param&gt;</code> ::=</td>
</tr>
<tr>
<td><code>...</code></td>
</tr>
<tr>
<td><code>[鹑&lt;paramAttr&gt;*] </code>&lt;type&gt;` [marshal ( [鹑&lt;nativeType&gt;] )] [鹑&lt;id&gt;]</td>
</tr>
</tbody>
</table>

The `<id>`, if present, is the name of the parameter. A parameter may be referenced either by using its name or the zero-based index of the parameter. In CIL instructions it is always encoded using the zero-based index (the name is for ease of use in ilasm).

Note that, in contrast to calling a vararg method, the definition of a vararg method does not include any ellipsis ("...")

<table>
<thead>
<tr>
<th><code>&lt;paramAttr&gt;</code> ::=</th>
</tr>
</thead>
<tbody>
<tr>
<td>[鹑in]</td>
</tr>
<tr>
<td>[鹑opt]</td>
</tr>
</tbody>
</table>
The parameter attributes shall be attached to the parameters (see Section 21.30) and hence are not part of a method signature.

Note: Unlike parameter attributes, custom modifiers (modopt and modreq) are part of the signature. Thus, modifiers form part of the method’s contract while parameter attributes are not.

in and out shall only be attached to parameters of pointer (managed or unmanaged) type. They specify whether the parameter is intended to supply input to the method, return a value from the method, or both. If neither is specified in is assumed. The CLI itself does not enforce the semantics of these bits, although they may be used to optimize performance, especially in scenarios where the call site and the method are in different application domains, processes, or computers.

opt specifies that this parameter is intended to be optional from an end-user point of view. The value to be supplied is stored using the .param syntax (see clause 14.4.1.4).

### 14.4.1 Method Body

The method body shall contain the instructions of a program. However, it may also contain labels, additional syntactic forms and many directives that provide additional information to ilasm and are helpful in the compilation of methods of some languages.

<table>
<thead>
<tr>
<th>&lt;methodBodyItem&gt; ::=</th>
<th>Description</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>.custom &lt;customDecl&gt;</td>
<td>Definition of custom attributes.</td>
<td>0</td>
</tr>
<tr>
<td>.data &lt;datadecl&gt;</td>
<td>Emits data to the data section</td>
<td>15.3</td>
</tr>
<tr>
<td>.emitbyte &lt;unsigned int8&gt;</td>
<td>Emits a byte to the code section of the method.</td>
<td>14.4.1.1</td>
</tr>
<tr>
<td>.entrypoint</td>
<td>Specifies that this method is the entry point to the application (only one such method is allowed).</td>
<td>14.4.1.2</td>
</tr>
<tr>
<td>.locals [init]</td>
<td>Defines a set of local variables for this method.</td>
<td>14.4.1.3</td>
</tr>
<tr>
<td>{ &lt;localsSignature&gt; }</td>
<td></td>
<td></td>
</tr>
<tr>
<td>.maxstack &lt;int32&gt;</td>
<td>int32 specifies the maximum number of elements on the evaluation stack during the execution of the method</td>
<td>14.4.1</td>
</tr>
<tr>
<td>.override</td>
<td>Use current method as the implementation for the method specified.</td>
<td>9.3.2</td>
</tr>
<tr>
<td>&lt;typeSpec&gt;::&lt;methodName&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>.param [ &lt;int32&gt; ]</td>
<td>Store a constant &lt;fieldInit&gt; value for parameter &lt;int32&gt;</td>
<td>14.4.1.4</td>
</tr>
<tr>
<td>[= &lt;fieldInit&gt;]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>.externSourceDecl</td>
<td>.line or #line</td>
<td>5.7</td>
</tr>
<tr>
<td>.instr</td>
<td>An instruction</td>
<td>Partition V</td>
</tr>
<tr>
<td>&lt;id&gt; :</td>
<td>A label</td>
<td>0</td>
</tr>
<tr>
<td>.securityDecl</td>
<td>.permission or .permissionset</td>
<td>19</td>
</tr>
<tr>
<td>.sehBlock</td>
<td>An exception block</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 14.4.1.1 .emitbyte

<methodBodyItem> ::= ...

| .emitbyte <unsigned int8> | | |
Emits an unsigned 8 bit value directly into the CIL stream of the method. The value is emitted at the position
where the directive appears.

**Note:** the `.emitbyte` directive is used for generating tests. It is not required in generating regular programs.

14.4.1.2 `.entrypoint`

The `.entrypoint` directive marks the current method, which shall be static, as the entry point to an application.
The VES shall call this method to start the application. An executable shall have exactly one entry point
method. This entry point method may be a global method or may appear inside a type. (The effect of the
directive is to place the metadata token for this method into the CLI header of the PE file).

The entry point method shall either accept no arguments or a vector of strings. If it accepts a vector of strings,
the strings shall represent the arguments to the executable, with index 0 containing the first argument. The
mechanism for specifying these arguments is platform-specific and is not specified here.

The return type of the entry point method shall be void, int32, or unsigned int32. If an int32 or unsigned int32
is returned, the executable may return an exit code to the host environment. A value of 0 shall indicate that the
application terminated ordinarily.

The accessibility of the entry point method shall not prevent its use in starting execution. Once started the VES
shall treat the entry point as it would any other method.

Example (informative):

The following example prints the first argument and return successfully
to the operating system:

```
.method public static int32 MyEntry(string[] s) CIL managed
{ .entrypoint
  .maxstack 2
  ldarg.0 // load and print the first argument
  ldc.i4.0
  ldelem.ref
  call void [mscorlib]System.Console::WriteLine(string)
  ldc.i4.0 // return success
  ret
}
```

14.4.1.3 `.locals`

The `.locals` statement declares local variables (see Partition I) for the current method.

The `<id>`, if present, is the name of the local.

If `init` is specified, the variables are initialized to their default values according to their type. Reference types
are initialized to `null` and value types are zeroed out.
Note: Verifiable methods shall include the `init` keyword. See Partition III.

14.4.1.4 `.param`

```xml
<methodBodyItem> ::= ...
    | .param [ <int32> ] [ = <fieldInit> ]
```

Stores in the metadata a constant value associated with method parameter number `<int32>`, see Section 21.9. While the CLI requires that a value be supplied for the parameter, some tools may use the presence of this attribute to indicate that the tool rather than the user is intended to supply the value of the parameter. Unlike CIL instructions, `.param` uses index 0 to specify the return value of the method, index 1 is the first parameter of the method, and so forth.

Note: The CLI attaches no semantic whatsoever to these values – it is entirely up to compilers to implement any semantic they wish (eg so-called default argument values).

14.4.2 Predefined Attributes on Methods

```xml
<methAttr> ::=
  abstract
  assembly
  compilercontrolled
  famandassem
  family
  famorassem
  final
  hidebysig
  newslot
  pinvokeimpl ( <QSTRING> [ as <QSTRING> ] <pinvAttr>* )
  private
  public
  rtspecialname
  specialname
  static
  virtual
```

<table>
<thead>
<tr>
<th>Description</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>The method is <code>abstract</code> (shall also be virtual).</td>
<td>14.4.2.4</td>
</tr>
<tr>
<td>Assembly accessibility</td>
<td>14.4.2.1</td>
</tr>
<tr>
<td>Compiler-controlled accessibility.</td>
<td>14.4.2.1</td>
</tr>
<tr>
<td>Family and Assembly accessibility</td>
<td>14.4.2.1</td>
</tr>
<tr>
<td>Family accessibility</td>
<td>14.4.2.1</td>
</tr>
<tr>
<td>Family or Assembly accessibility</td>
<td>14.4.2.1</td>
</tr>
<tr>
<td>This virtual method cannot be overridden by subclasses.</td>
<td>14.4.2.2</td>
</tr>
<tr>
<td>Hide by signature. Ignored by the runtime.</td>
<td>14.4.2.2</td>
</tr>
<tr>
<td>Specifies that this method shall get a new slot in the virtual method table.</td>
<td>14.4.2.3</td>
</tr>
<tr>
<td>Method is actually implemented in native code on the underlying platform</td>
<td>14.4.2.5</td>
</tr>
<tr>
<td>Private accessibility</td>
<td>14.4.2.1</td>
</tr>
<tr>
<td>Public accessibility.</td>
<td>14.4.2.1</td>
</tr>
<tr>
<td>The method name needs to be treated in a special way by the runtime.</td>
<td>14.4.2.6</td>
</tr>
<tr>
<td>The method name needs to be treated in a special way by some tool.</td>
<td>14.4.2.6</td>
</tr>
<tr>
<td>Method is static.</td>
<td>14.4.2.2</td>
</tr>
<tr>
<td>Method is virtual.</td>
<td>14.4.2.2</td>
</tr>
</tbody>
</table>

The following combinations of predefined attributes are illegal:

- `static` combined with any of `final`, `virtual`, or `newslot`
- `abstract` combined with any of `final` or `pinvokeimpl`
- `compilercontrolled` combined with any of `virtual`, `final`, `specialname`, or `rtspecialname`
14.4.2.1 Accessibility Information

<methAttr> ::= ...
   |   assembly
   |   compilercontrolled
   |   famandassem
   |   family
   |   famorassem
   |   private
   |   public

Only one of these attributes shall be applied to a given method. See Partition I.

14.4.2.2 Method Contract Attributes

<methAttr> ::= ...
   |   final
   |   hidebysig
   |   static
   |   virtual

These attributes may be combined, except a method shall not be both static and virtual; only virtual methods may be final; and abstract methods shall not be final.

final methods shall not be overridden by subclasses of this type.

hidebysig is supplied for the use of tools and is ignored by the VES. It specifies that the declared method hides all methods of the parent types that have a matching method signature; when omitted the method should hide all methods of the same name, regardless of the signature.

Rationale: Some languages use a hide-by-name semantics (C++) while others use a hide-by-name-and-signature semantics (C#, Java™)

Static and virtual are described in Section 0.

14.4.2.3 Overriding Behavior

<methAttr> ::= ...
   |   newslot

newslot shall only be used with virtual methods. See Section 9.3.

14.4.2.4 Method Attributes

<methAttr> ::= ...
   |   abstract

abstract shall only be used with virtual methods that are not final. It specifies that an implementation of the method is not provided but shall be provided by a subclass. Abstract methods shall only appear in abstract types (see clause 9.1.4).

14.4.2.5 Interoperation Attributes

<methAttr> ::= ...
   |   pinvokeimpl ( <QSTRING> [ as <QSTRING> ] <pinvAttr>* )
See clause 0 (and Section 21.20).

14.4.2.6 Special Handling Attributes

<methAttr> ::= ...
| rtspecialname
| specialname

The attribute rtspecialname specifies that the method name shall be treated in a special way by the runtime. Examples of special names are .ctor (object constructor) and .cctor (type initializer).

specialname indicates that the name of this method has special meaning to some tools.

14.4.3 Implementation Attributes of Methods

<implAttr> ::= ...
| cil
| forwardref
| internalcall
| managed
| native
| noinlining
| runtime
| synchronized
| unmanaged

<table>
<thead>
<tr>
<th>Description</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>The method contains standard CIL code.</td>
<td>14.4.3.1</td>
</tr>
<tr>
<td>The body of this method is not specified with this declaration.</td>
<td>14.4.3.3</td>
</tr>
<tr>
<td>Denotes the method body is provided by the CLI itself</td>
<td>14.4.3.3</td>
</tr>
<tr>
<td>The method is a managed method.</td>
<td>14.4.3.2</td>
</tr>
<tr>
<td>The method contains native code.</td>
<td>14.4.3.1</td>
</tr>
<tr>
<td>The runtime shall not expand the method inline.</td>
<td>14.4.3.3</td>
</tr>
<tr>
<td>The body of the method is not defined but produced by the runtime.</td>
<td>14.4.3.1</td>
</tr>
<tr>
<td>The method shall be executed in a single threaded fashion.</td>
<td>14.4.3.3</td>
</tr>
<tr>
<td>Specifies that the method is unmanaged.</td>
<td>14.4.3.2</td>
</tr>
</tbody>
</table>

14.4.3.1 Code Implementation Attributes

<cil> ::= ...
| native
| runtime

These attributes are exclusive, they specify the type of code the method contains.

cil specifies that the method body consists of cil code. Unless the method is declared abstract, the body of the method shall be provided if cil is used.

native specifies that a method was implemented using native code, tied to a specific processor for which it was generated. native methods shall not have a body but instead refer to a native method that declares the body. Typically, the PInvoke functionality (see clause 0) of the CLI is used to refer to a native method.

runtime specifies that the implementation of the method is automatically provided by the runtime and is primarily used for the method of delegates (see Section 13.6).

14.4.3.2 Managed or Unmanaged

<implAttr> ::= ...
| cil
| native
| runtime
These shall not be combined. Methods implemented using CIL are managed. Unmanaged is used primarily with PInvoke (see clause 0).

### 14.4.3.3 Implementation Information

These attributes may be combined.

- **forwardref** specifies that the body of the method is provided elsewhere. This attribute shall not be present when an assembly is loaded by the VES. It is used for tools (like a static linker) that will combine separately compiled modules and resolve the forward reference.

- **internalcall** specifies that the method body is provided by this CLI (and is typically used by low-level methods in a system library). It shall not be applied to methods that are intended for use across implementations of the CLI.

- **noinlining** specifies that the body of this method should not be included into the code of any caller methods, by a CIL-to-native-code compiler; it shall be kept as a separate routine.

**Rationale:** specifying that a method not be inlined ensures that it remains ‘visible’ for debugging (e.g., displaying stack traces) and profiling. It also provides a mechanism for the programmer to override the default heuristics a CIL-to-native-code compiler uses for inlining.

- **synchronized** specifies that the whole body of the method shall be single threaded. If this method is an instance or virtual method a lock on the object shall be obtained before the method is entered. If this method is a static method a lock on the type shall be obtained before the method is entered. If a lock cannot be obtained the requesting thread shall not proceed until it is granted the lock. This may cause deadlocks. The lock is released when the method exits, either through a normal return or an exception. Exiting a synchronized method using a **tail** call shall be implemented as though the **tail** had not been specified. **noinlining** specifies that the runtime shall not inline this method. Inlining refers to the process of replacing the call instruction with the body of the called method. This may be done by the runtime for optimization purposes.

### 14.4.4 Scope Blocks

A **scopeBlock** is used to group elements of a method body together. For example, it is used to designate the code sequence that constitutes the body of an exception handler.

### 14.4.5 **vararg** Methods

**vararg** methods accept a variable number of arguments. They shall use the **vararg** calling convention (see Section 14.3).

At each call site, a method reference shall be used to describe the types of the actual arguments that are passed. The fixed part of the argument list shall be separated from the additional arguments with an ellipsis (see Partition I).

The **vararg** arguments shall be accessed by obtaining a handle to the argument list using the CIL instruction **arglist** (see Partition III). The handle may be used to create an instance of the value type `System.ArgIterator` which provides a typesafe mechanism for accessing the arguments (see Partition IV).

**Example (informative):**
The following example shows how a vararg method is declared and how the first vararg argument is accessed, assuming that at least one additional argument was passed to the method:

```
.method public static vararg void MyMethod(int32 required) {

    .maxstack 3
    .locals init (valuetype System.ArgIterator it, int32 x)
    ldloca    it    // initialize the iterator
    initobj   valuetype System.ArgIterator
    ldloca    it
    arglist   // obtain the argument handle
    call instance void System.ArgIterator::.ctor(valuetype System.RuntimeArgumentHandle) // call constructor of iterator
    /* argument value will be stored in x when retrieved, so load address of x */
    ldloca    x
    ldloca    it
    // retrieve the argument, the argument for required does not matter
    call instance typedref System.ArgIterator::GetNextArg()
    call object System.TypedReference::ToObject(typedref)  // retrieve the object
    castclass System.Int32   // cast and unbox
    unbox int32
    cpobj int32             // copy the value into x
    // first vararg argument is stored in x
    ret
}
```

14.5 Unmanaged Methods

In addition to supporting managed code and managed data, the CLI provides facilities for accessing pre-existing native code from the underlying platform, known as unmanaged code. These facilities are, by necessity, platform dependent and hence are only partially specified here.

This standard specifies:

- A mechanism in the file format for providing function pointers to managed code that can be called from unmanaged code (see clause 14.5.1).
- A mechanism for marking certain method definitions as being implemented in unmanaged code (called platform invoke, see clause 0).
- A mechanism for marking call sites used with method pointers to indicate that the call is to an unmanaged method (see clause 14.5.3).
- A small set of pre-defined data types that can be passed (marshaled) using these mechanisms on all implementations of the CLI (see clause 14.5.4). The set of types is extensible through the use of custom attributes and modifiers, but these extensions are platform-specific.
14.5.1 Method Transition Thunks

Note: This mechanism is not part of the Kernel Profile, so it may not be present in all conforming implementations of the CLI. See Partition IV.

In order to call from unmanaged code into managed code some platforms require a specific transition sequence to be performed. In addition, some platforms require that the representation of data types be converted (data marshalling). Both of these problems are solved by the .vtfixup directive. This directive may appear several times only at the top level of a CIL assembly file, as shown by the following grammar:

```
<decl> ::= Section .vtfixup <vtfixupDecl>
| ...
```

The .vtfixup directive declares that at a certain memory location there is a table that contains metadata tokens referring to methods that shall be converted into method pointers. The CLI will do this conversion automatically when the file is loaded into memory for execution. The declaration specifies the number of entries in the table, what kind of method pointer is required, the width of an entry in the table, and the location of the table:

```
<vtfixupDecl> ::= [
    <int32>
] <vtfixupAttr>* at <dataLabel>
```

```
<vtfixupAttr> ::= fromunmanaged
| int32
| int64
```

The attributes int32 and int64 are mutually exclusive and int32 is the default. These attributes specify the width of each slot in the table. Each slot contains a 32-bit metadata token (zero-padded if the table has 64 bit slots), and the CLI converts it into a method pointer of the same width as the slot.

If fromunmanaged is specified, the CLI will generate a thunk that will convert the unmanaged method call to a managed call, call the method, and return the result to the unmanaged environment. The thunk will also perform data marshalling in the platform-specific manner described for platform invoke.

The ilasm syntax does not specify a mechanism for creating the table of tokens, but a compiler may simply emit the tokens as byte literals into a block specified using the .data directive.

14.5.2 Platform Invoke

Methods defined in native code may be invoked using the platform invoke (also known as PInvoke or p/invoke) functionality of the CLI. Platform invoke will switch from managed to unmanaged state and back and also handle necessary data marshalling. Methods that need to be called using PInvoke are marked as pinvokeimpl.

In addition, the methods shall have the implementation attributes native and unmanaged (see clause 14.4.2.4).

| <methAttr> ::= pinvokeimpl ( <QSTRING> [as <QSTRING>] <pinvAttr>* ) | Implemented in native code |
| Description | Section |
| Implemented in native code | 14.4.2 |

The first quoted string is a platform-specific description indicating where the implementation of the method is located (for example, on Microsoft Windows™ this would be the name of the DLL that implements the method). The second (optional) string is the name of the method as it exists on that platform, since the platform may use name-mangling rules that force the name as it appears to a managed program to differ from the name as seen in the native implementation (this is common, for example, when the native code is generated by a C++ compiler).
Only static methods, defined at global scope (ie, outside of any type), may be marked `pinvokeimpl`. A method declared with `pinvokeimpl` shall not have a body specified as part of the definition.

<table>
<thead>
<tr>
<th><code>&lt;pinvAttr&gt;</code> ::=</th>
<th>Description (platform specific, suggestion only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ansi</td>
<td>ANSI character set.</td>
</tr>
<tr>
<td>autochar</td>
<td>Determine character set automatically.</td>
</tr>
<tr>
<td>cdecl</td>
<td>Standard C style call</td>
</tr>
<tr>
<td>fastcall</td>
<td>C stylefastcall.</td>
</tr>
<tr>
<td>stdcall</td>
<td>Standard C++ style call</td>
</tr>
<tr>
<td>thiscall</td>
<td>The method accepts an implicit this pointer.</td>
</tr>
<tr>
<td>unicode</td>
<td>Unicode character set.</td>
</tr>
<tr>
<td>platformapi</td>
<td>Use call convention appropriate to target platform.</td>
</tr>
</tbody>
</table>

The attributes `ansi`, `autochar`, and `unicode` are mutually exclusive. They govern how strings will be marshaled for calls to this method: `ansi` indicates that the native code will receive (and possibly return) a platform-specific representation that corresponds to a string encoded in the ANSI character set (typically this would match the representation of a C or C++ string constant); `autochar` indicates a platform-specific representation that is “natural” for the underlying platform; and `unicode` indicates a platform-specific representation that corresponds to a string encoded for use with Unicode methods on that platform.

The attributes `cdecl`, `fastcall`, `stdcall`, `thiscall`, and `platformapi` are mutually exclusive. They are platform-specific and specify the calling conventions for native code.

Example (informative):

```
The following shows the declaration of the method MessageBeep located in the Microsoft Windows™ DLL user32.dll:
.method public static pinvokeimpl("user32.dll" stdcall) int8 MessageBeep(unsigned int32) native unmanaged {}
```

14.5.3 Via Function Pointers

Unmanaged functions can also be called via function pointers. There is no difference between calling managed or unmanaged functions with pointers. However, the unmanaged function needs to be declared with `pinvokeimpl` as described in clause 0. Calling managed methods with function pointers is described in Section 0.

14.5.4 Data Type Marshaling

While data type marshaling is necessarily platform-dependent, this standard specifies a minimum set of data types that shall be supported by all conforming implementations of the CLI. Additional data types may be supported in an implementation-dependent manner, using custom attributes and/or custom modifiers to specify any special handling required on the particular implementation.

The following data types shall be marshaled by all conforming implementations of the CLI; the native data type to which they conform is implementation specific:

- All integer data types (`int8`, `int16`, `unsigned int8`, `bool`, `char` etc.) including the `native` integer types.
- Enumerations, as their underlying data type.
- All floating point data types (`float32` and `float64`), if they are supported by the CLI implementation for managed code.
- The type `string`. 
• Unmanaged pointers to any of the above types.

In addition, the following types shall be supported for marshaling from managed code to unmanaged code, but need not be supported in the reverse direction (i.e. as return types when calling unmanaged methods or as parameters when calling from unmanaged methods into managed methods):

• One-dimensional zero-based arrays of any of the above

• Delegates (the mechanism for calling from unmanaged code into a delegate is platform-specific; it should not be assumed that marshaling a delegate will produce a function pointer that can be used directly from unmanaged code)

Finally, the type GCHandle can be used to marshal an object to unmanaged code. The unmanaged code receives a platform-specific data type that can be used as an “opaque handle” to a specific object. See Partition IV.
15 Defining and Referencing Fields

Fields are typed memory locations that store the data of a program. The CLI allows the declaration of both instance and static fields. While static fields are associated with a type and shared across all instances of that type, instance fields are associated with a particular instance of that type. When instantiated, the instance has its own copy of that field.

The CLI also supports global fields, which are fields declared outside of any type definition. Global fields shall be static.

A field is defined by the .field directive: (see Section 21.15)

\[
\text{<field> ::= .field <fieldDecl>}
\]

\[
\text{<fieldDecl> ::= [ [<int32>] ] <fieldAttr>* <type> <id> [= <fieldInit> | at <dataLabel>]}
\]

The <fieldDecl> has the following parts:

- an optional integer specifying the byte offset of the field within an instance (see Section 9.7). If present, the type containing this field shall have the explicit layout attribute. An offset shall not be supplied for global or static fields.
- any number of field attributes (see Section 15.2)
- type
- name
- optionally either a <fieldInit> form or a data label

Global fields shall have a data label associated with them. This specifies where, in the PE file, the data for that field is located. Static fields of a type may, but do not need to, be assigned a data label.

Example (informative):

\[
\text{.field private class [.module Counter.dll]Counter counter}
\]

15.1 Attributes of Fields

Attributes of a field specify information about accessibility, contract information, interoperation attributes, as well as information on special handling.

The following subsections contain additional information on each group of predefined attributes of a field.

\[
\text{<fieldAttr> ::= assembly | famandassem | family | famorassem | initonly | literal | marshal(<nativeType>) | notserialized | private}
\]
### 15.1.1 Accessibility Information

The accessibility attributes are `assembly`, `famandassem`, `family`, `famorassem`, `private`, `compilercontrolled` and `public`. These attributes are mutually exclusive.

Accessibility attributes are described in Section 8.2.

### 15.1.2 Field Contract Attributes

Field contract attributes are `initonly`, `literal`, `static` and `notserialized`. These attributes may be combined. Only static fields may be literal. The default is an instance field that may be serialized.

- **static**: specifies that the field is associated with the type itself rather than with an instance of the type. Static fields can be accessed without having an instance of a type, e.g. by static methods. As a consequence, a static field is shared, within an application domain, between all instances of a type, and any modification of this field will affect all instances. If `static` is not specified, an `instance` field is created.

- **initonly**: marks fields which are constant after they are initialized. These fields may only be mutated inside a constructor. If the field is a static field, then it may be mutated only inside the type initializer of the type in which it was declared. If it is an instance field, then it may be mutated only in one of the instance constructors of the type in which it was defined. It may not be mutated in any other method or in any other constructor, including constructors of subclasses.

**Note:** The VES need not check whether `initonly` fields are mutated outside the constructors. The VES need not report any errors if a method changes the value of a constant. However, such code is not valid and is not verifiable.

- **literal**: specifies that this field represents a constant value; they shall be assigned a value. In contrast to `initonly` fields, `literal` fields do not exist at runtime. There is no memory allocated for them. `literal` fields become part of the metadata but cannot be accessed by the code. `literal` fields are assigned a value by using the `<fieldInit>` syntax (see Section 15.2).

**Note:** It is the responsibility of tools generating CIL to replace source code references to the literal with its actual value. Hence changing the value of a literal requires recompilation of any code that references the literal. Literal values are, thus, not version-resilient.

### 15.1.3 Interoperation Attributes

There is one attribute for interoperation with pre-existing native applications; it is platform-specific and shall not be used in code intended to run on multiple implementations of the CLI. The attribute is `marshal` and specifies that the field’s contents should be converted to and from a specified native data type when passed to unmanaged code. Every conforming implementation of the CLI will have default marshaling rules as well as restrictions on what automatic conversions can be specified using the `marshal` attribute. See also clause 14.5.4

**Note:** Marshaling of user-defined types is not required of all implementations of the CLI. It is specified in this standard so that implementations which choose to provide it will allow control over its behavior in a consistent manner. While this is not sufficient to guarantee portability of code that uses this feature, it does increase the likelihood that such code will be portable.

### 15.1.4 Other Attributes

The attribute `rtspecialname` indicates that the field name shall be treated in a special way by the runtime.
There are currently no field names that are required to be marked with `rtspecialname`. It is provided for extensions, future standardization, and to increase consistency between the declaration of fields and methods (instance and type initializer methods shall be marked with this attribute).

The attribute `specialname` indicates that the field name has special meaning to tools other than the runtime, typically because it marks a name that has meaning for the Common Language Specification (CLS, see Partition I).

### 15.2 Field Init Metadata

The `<fieldInit>` metadata can be optionally added to a field declaration. The use of this feature may not be combined with a data label.

The `<fieldInit>` information is stored in metadata and this information can be queried from metadata. But the CLI does not use this information to automatically initialize the corresponding fields. The field initializer is typically used with literal fields (see clause 15.1.2) or parameters with default values. See Section 21.9.

The following table lists the options for a field initializer. Note that while both the type and the field initializer are stored in metadata there is no requirement that they match. (Any importing compiler is responsible for coercing the stored value to the target field type). The description column in the table below provides additional information.

<table>
<thead>
<tr>
<th><code>&lt;fieldInit&gt;</code> ::=</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>`bool ( true</td>
<td>false )`</td>
</tr>
<tr>
<td><code>bytearray ( &lt;bytes&gt; )</code></td>
<td>String of bytes, stored without conversion. May be be padded with one zero byte to make the total byte-count an even number</td>
</tr>
<tr>
<td><code>char ( &lt;int32&gt; )</code></td>
<td>16 bit unsigned integer (Unicode character)</td>
</tr>
<tr>
<td><code>float32 ( &lt;float64&gt; )</code></td>
<td>32 bit floating point number, with the floating point number specified in parentheses.</td>
</tr>
<tr>
<td><code>float64 ( &lt;int64&gt; )</code></td>
<td><code>&lt;int32&gt;</code> is binary representation of float</td>
</tr>
<tr>
<td><code>float64 ( &lt;float64&gt; )</code></td>
<td>64 bit floating point number, with the floating point number specified in parentheses.</td>
</tr>
<tr>
<td><code>int8 ( &lt;int8&gt; )</code></td>
<td>8 bit integer with the integer specified in parentheses.</td>
</tr>
<tr>
<td><code>int16 ( &lt;int16&gt; )</code></td>
<td>16 bit integer with the integer specified in parentheses.</td>
</tr>
<tr>
<td><code>int32 ( &lt;int32&gt; )</code></td>
<td>32 bit integer with the integer specified in parentheses.</td>
</tr>
<tr>
<td><code>int64 ( &lt;int64&gt; )</code></td>
<td>64 bit integer with the integer specified in parentheses.</td>
</tr>
<tr>
<td><code>&lt;QSTRING&gt;</code></td>
<td>String. <code>&lt;QSTRING&gt;</code> is stored as Unicode</td>
</tr>
<tr>
<td><code>nullref</code></td>
<td>Null object reference</td>
</tr>
</tbody>
</table>
Example (informative):

The following example shows a typical use of this:

```mml
.field public static literal valuetype ErrorCodes no_error = int8(0)
```

The field named no_error is a literal of type ErrorCodes (a value type) for which no memory is allocated. Tools and compilers can look up the value and detect that it is intended to be an 8 bit signed integer whose value is 0.

15.3 Embedding Data in a PE File

There are several ways to declare a data field that is stored in a PE file. In all cases, the .data directive is used.

Data can be embedded in a PE file by using the .data directive at the top-level.

```
<decl> ::= .data <datadecl>
```

Data may also be declared as part of a type:

```
<classMember> ::= .data <datadecl>
```

Yet another alternative is to declare data inside a method:

```
<methodBodyItem> ::= .data <datadecl>
```

15.3.1 Data Declaration

A .data directive contains an optional data label and the body which defines the actual data. A data label shall be used if the data is to be accessed by the code.

```
<dataDecl> ::= [<dataLabel>] <ddBody>
```

The body consists either of one data item or a list of data items in braces. A list of data items is similar to an array.

```
<ddBody> ::= ...
```

A list of items consists of any number of items:

```
<ddItemList> ::= <ddItem> [, <ddItemList>]
```

The list may be used to declare multiple data items associated with one label. The items will be laid out in the order declared. The first data item is accessible directly through the label. To access the other items, pointer arithmetic is used, adding the size of each data item to get to the next one in the list. The use of pointer arithmetic will make the application not verifiable. (Each data item shall have a <dataLabel> if it is to be referenced afterwards; missing a <dataLabel> is useful in order to insert alignment padding between data items)
A data item declares the type of the data and provides the data in parentheses. If a list of data items contains items of the same type and initial value, the grammar below can be used as a short cut for some of the types: the number of times the item shall be replicated is put in brackets after the declaration.

| `ddItem` ::= |
| `& ( <id> )` | Address of label |
| `char * ( <QSTRING> )` | Array of (Unicode) characters |
| `bytearray ( <bytes> )` | Array of bytes |
| `float32 [ ( <float64> ) ] [ [ <int32> ] ]` | 32-bit floating point number, may be replicated |
| `float64 [ ( <float64> ) ] [ [ <int32> ] ]` | 64-bit floating point number, may be replicated |
| `int8 [ ( <int8> ) ] [ [ <int32> ] ]` | 8-bit integer, may be replicated |
| `int16 [ ( <int16> ) ] [ [ <int32> ] ]` | 16-bit integer, may be replicated |
| `int32 [ ( <int32> ) ] [ [ <int32> ] ]` | 32-bit integer, may be replicated |
| `int64 [ ( <int64> ) ] [ [ <int32> ] ]` | 64-bit integer, may be replicated |

**Example (informative):**

The following declares a 32 bit signed integer with value 123:

```
.data theInt = int32(123)
```

The following declares 10 replications of an 8 bit unsigned integer with value 3:

```
.data theBytes = int8 (3) [10]
```

### 15.3.2 Accessing Data from the PE File

The data stored in a PE File using the `.data` directive can be accessed through a static variable, either global or a member of a type, declared at a particular position of the data:

```
<fieldDecl> ::= <fieldAttr>* <type> <id> at <dataLabel>
```

The data is then accessed by a program as it would access any other static variable, using instructions such as `ldsfld`, `ldsflda`, and so on (see Partition III).

The ability to access data from within the PE File may be subject to platform-specific rules, typically related to section access permissions within the PE File format itself.

**Example (informative):**

The following accesses the data declared in the example of clause 15.3.1. First a static variable needs to be declared for the data, e.g. a global static variable:

```
.field public static int32 myInt at theInt
```

Then the static variable can be used to load the data:

```
ldsfld int32 myInt
// data on stack
```

### 15.4 Initialization of Non-Literal Static Data

This section and its subsections contain only informative text.
Many languages that support static data (i.e. variables that have a lifetime that is the entire program) provide for a means to initialize that data before the program begins running. There are three common mechanisms for doing this, and each is supported in the CLI.

15.4.1 Data Known at Link Time
When the correct value to be stored into the static data is known at the time the program is linked (or compiled for those languages with no linker step), the actual value can be stored directly into the PE file, typically into the data area (see Section 15.3). References to the variable are made directly to the location where this data has been placed in memory, using the OS supplied fix-up mechanism to adjust any references to this area if the file loads at an address other than the one assumed by the linker.

In the CLI, this technique can be used directly if the static variable has one of the primitive numeric types or is a value type with explicit type layout and no embedded references to managed objects. In this case the data is laid out in the data area as usual and the static variable is assigned a particular RVA (i.e. offset from the start of the PE file) by using a data label with the field declaration (using the at syntax).

This mechanism, however, does not interact well with the CLI notion of an application domain (see Partition I). An application domain is intended to isolate two applications running in the same OS process from one another by guaranteeing that they have no shared data. Since the PE file is shared across the entire process, any data accessed via this mechanism is visible to all application domains in the process, thus violating the application domain isolation boundary.

15.5 Data Known at Load Time
When the correct value is not known until the PE file is loaded (for example, if it contains values computed based on the load addresses of several PE files) it may be possible to supply arbitrary code to run as the PE file is loaded, but this mechanism is platform-specific and may not be available in all conforming implementations of the CLI.

15.5.1 Data Known at Run Time
When the correct value cannot be determined until type layout is computed, the user shall supply code as part of a type initializer to initialize the static data. The guarantees about type initialization are covered in clause 9.5.3.1. As will be explained below, global statics are modeled in the CLI as though they belonged to a type, so the same guarantees apply to both global and type statics.

Because the layout of managed types need not occur until a type is first referenced, it is not possible to statically initialize managed types by simply laying the data out in the PE file. Instead, there is a type initialization process that proceeds in the following steps:

20. All static variables are zeroed.
21. The user-supplied type initialization procedure, if any, is invoked as described in clause 9.5.3.

Within a type initialization procedure there are several techniques:

- **Generate explicit code** that stores constants into the appropriate fields of the static variables. For small data structures this can be efficient, but it requires that the initializer be converted to native code, which may prove to be both a code space and an execution time problem.

- **Box value types.** When the static variable is simply a boxed version of a primitive numeric type or a value type with explicit layout, introduce an additional static variable with known RVA that holds the unboxed instance and then simply use the box instruction to create the boxed copy.

- **Create a managed array from a static native array of data.** This can be done by marshaling the native array to a managed array. The specific marshaler to be used depends on the native array. E.g., it may be a safearray.

- **Default initialize a managed array of a value type.** The Base Class Library provides a method that zeroes the storage for every element of an array of unboxed value types (System.Runtime.CompilerServices.InitializeArray)
End informative text
16 Defining Properties

A Property is declared by using the .property directive. Properties may only be declared inside of types (i.e.,
global Properties are not supported).

```
<classMember> ::= .property <propHead> { <propMember>* }
```

See Section 21.31 and Section 21.32 for how Property information is stored in metadata.

```
[propHead] ::= [specialname][rtspecialname] <callConv> <type> <id> ( <parameters> )
```

The property directive specifies a calling convention (see Section 14.3), type, name, and parameter in
parentheses. specialname marks the Property as special to other tools, while rtspecialname marks Property as
special to the CLI. The signature for the property (i.e., the <propHead> production) shall match the signature
of the property’s .get method (see below).

Rationale: There are currently no property names that are required to be marked with rtspecialname. It is
provided for extensions, future standardization, and to increase consistency between the declaration of
properties and methods (instance and type initializer methods shall be marked with this attribute).

While the CLI places no constraints on the methods that make up a property, the CLS (see Partition I) specifies
a set of consistency constraints.

A property may contain any number of methods in its body. The following table shows these and provides
short descriptions of each item:

```
<propMember> ::= Description Section
| .custom <customDecl> Custom attribute. 0
| .get <callConv> <type> [typeSpec ::] Specifies the getter for the
  <methodName> ( <parameters> ) property.
| .other <callConv> <type> [typeSpec ::] Specifies a method for the
  <methodName> ( <parameters> ) property other than the getter or
  setter.
| .set <callConv> <type> [typeSpec ::] Specifies the setter for the
  <methodName> ( <parameters> ) property.
| <externSourceDecl> .line or #line 5.7
```

.get specifies the getter for this property. The <typeSpec> defaults to the current type. Only one getter may be
specified for a property. To be CLS compliant, the definition of getter shall be marked specialname.

.set specifies the setter for this property. The <typeSpec> defaults to the current type. Only one setter may be
specified for a property. To be CLS compliant, the definition of setter shall be marked specialname.

.other is used to specify any other methods that this property comprises.

In addition, custom attributes (see Chapter 0) or source line declarations may be specified.

Example (informative):

This example shows the declaration of the property used in the example in Part 5.

```
.class public auto autochar MyCount extends [mscorlib]System.Object {
  .method virtual hidebysig public specialname instance int32
    get_Count() { ...
```
// body of getter
}

.method virtual hidebysig public specialname instance void
set_Count(int32 newCount) {
// body of setter
}

.method virtual hidebysig public instance void reset_Count() {
// body of refresh method
}

// the declaration of the property
.property int32 Count() {
    .get instance int32 get_Count()
    .set instance void set_Count(int32)
    .other instance void reset_Count()
}
}
# 17 Defining Events

Events are declared inside types with the `.event` directive; there are no global events.

```plaintext
<classMember> ::= 
  .event <eventHead> { <eventMember>* } 
  | ... 
```

See Section 21.13 and Section 21.11

```plaintext
<eventHead> ::= 
  [specialname] [rtspecialname] [<typeSpec>] <id> 
```

In typical usage, the `<typeSpec>` (if present) identifies a delegate whose signature matches the arguments passed to the event’s fire method.

The event head may contain the keywords `specialname` or `rtspecialname`. `specialname` marks the name of the property for other tools, while `rtspecialname` marks the name of the event as special for the runtime.

**Rationale:** There are currently no event names that are required to be marked with `rtspecialname`. It is provided for extensions, future standardization, and to increase consistency between the declaration of events and methods (instance and type initializer methods shall be marked with this attribute).

```plaintext
<eventMember> ::= 
  .addon <callConv> <type> [<typeSpec>] <methodName> ( <parameters> ) 
  | .custom <customDecl> 
  | .fire <callConv> <type> [<typeSpec>] <methodName> ( <parameters> ) 
  | .other <callConv> <type> [<typeSpec>] <methodName> ( <parameters> ) 
  | .removeon <callConv> <type> [<typeSpec>] <methodName> ( <parameters> ) 
  | <externSourceDecl> 
```

The `.addon` directive specifies the `add` method, and the `<typeSpec>` defaults to the same type as the event. The CLS specifies naming conventions and consistency constraints for events, and requires that the definition of the `add` method be marked with `specialname`.

The `.removeon` directive specifies the `remove` method, and the `<typeSpec>` defaults to the same type as the event. The CLS specifies naming conventions and consistency constraints for events, and requires that the definition of the `remove` method be marked with `specialname`.

The `.fire` directive specifies the `fire` method, and the `<typeSpec>` defaults to the same type as the event. The CLS specifies naming conventions and consistency constraints for events, and requires that the definition of the `fire` method be marked with `specialname`.

An event may contain any number of other methods specified with the `.other` directive. From the point of view of the CLI, these methods are only associated with each other through the event. If they have special semantics, this needs to be documented by the implementer.

Events may also have custom attributes (Chapter 0) associated with them and they may declare source line information.

**Example (informative):**

This shows the declaration of an event, its corresponding delegate, and typical implementations of the `add`, `remove`, and `fire` method of the
event. The event and the methods are declared in a class called Counter.

// the delegate

[class private sealed auto autochar TimeUpEventHandler extends
  [mscorlib]System.MulticastDelegate {

  .method public hidebysig specialname rtspecialname instance void
  .ctor(object 'object', native int 'method') runtime managed {}

  .method public hidebysig virtual instance void Invoke() runtime managed {}

  .method public hidebysig newslot virtual instance class
  [mscorlib]System.IAsyncResult BeginInvoke(class
  [mscorlib]System.AsyncCallback callback, object 'object') runtime managed {}

  .method public hidebysig newslot virtual instance void
  EndInvoke(class [mscorlib]System.IAsyncResult result) runtime managed {}

}]

// the class that declares the event

[class public auto autochar Counter extends [mscorlib]System.Object {

  // field to store the handlers, initialized to null
  .field private class TimeUpEventHandler timeUpEventHandler

  // the event declaration
  .event TimeUpEventHandler startStopEvent {

    .addon instance void add_TimeUp(class TimeUpEventHandler 'handler')

    .remove instance void remove_TimeUp(class TimeUpEventHandler
    'handler')

    .fire instance void fire_TimeUpEvent()

  }

  // the add method, combines the handler with existing delegates
  .method public hidebysig virtual specialname instance void
  add_TimeUp(class TimeUpEventHandler 'handler') {

    .maxstack 4
    ldarg.0
dup
    ldfld class TimeUpEventHandler Counter::TimeUpEventHandler
    ldarg 'handler'
call class [mscorlib]System.Delegate
    [mscorlib]System.Delegate::Combine(class [mscorlib]System.Delegate,
    class [mscorlib]System.Delegate)
castclass TimeUpEventHandler
stfld class TimeUpEventHandler Counter::timeUpEventHandler
ret

// the remove method, removes the handler from the multicast delegate
.method virtual public specialname void remove_TimeUp(class
TimeUpEventHandler 'handler') {
    .maxstack 4
    ldarg.0
dup
    ldfld class TimeUpEventHandler Counter::timeUpEventHandler
    ldarg 'handler'
call class[mscorlib]System.Delegate
    [mscorlib]System.Delegate::Remove(class [mscorlib]System.Delegate,
class [mscorlib]System.Delegate)
castclass TimeUpEventHandler
    stfld class TimeUpEventHandler Counter::timeUpEventHandler
    ret
}

// the fire method
.method virtual family specialname void fire_TimeUpEvent() {
    .maxstack 3
    ldarg.0
    ldfld class TimeUpEventHandler Counter::timeUpEventHandler
callvirt instance void TimeUpEventHandler::Invoke()
    ret
}
} // end of class Counter
18 Exception Handling

In the CLI, a method may define a range of CIL instructions that are said to be protected. This is called the try block. It can then associate one or more handlers with that try block. If an exception occurs during execution anywhere within the try block, an exception object is created that describes the problem. The CIL then takes over, transferring control from the point at which the exception was thrown, to the block of code that is willing to handle that exception. See Partition I.

```
<sehBlock> ::= <tryBlock> <sehClause> [<sehClause>*]
```

The next few sections expand upon this simple description, by describing the five kinds of code block that take part in exception processing: try, catch, filter, finally, and fault. (note that there are restrictions upon how many, and what kinds of <sehClause> a given <tryBlock> may have; see Partition I, for details.

The remaining syntax items are described in detail below; they are collected here for reference.

```
<tryBlock> ::= .try <label> to <label> Protect region from first label to prior to second
| .try <scopeBlock> <scopeBlock> is protected

<sehClause> ::= catch <typeReference> <handlerBlock> Catch all objects of the specified type
| fault <handlerBlock> Handle all exceptions but not normal exit
| filter <label> <handlerBlock> Enter handler only if filter succeeds
| finally <handlerBlock> Handle all exceptions and normal exit

<handlerBlock> ::= handler <label> to <label> Handler range is from first label to prior to second
| <scopeBlock> <scopeBlock> is the handler block
```

18.1 Protected Blocks

A try, or protected, or guarded, block is declared with the .try directive.

```
<tryBlock> ::= .try <label> to <label> Protect region from first label to prior to second.
| .try <scopeBlock> <scopeBlock> is protected
```

In the first, the protected block is delimited by two labels. The first label is the first instruction to be protected, while the second label is the instruction just beyond the last one to be protected. Both labels shall be defined prior to this point.

The second uses a scope block (see clause 14.4.4) after the .try directive – the instructions within that scope are the ones to be protected.

18.2 Handler Blocks

```
<handlerBlock> ::= handler <label> to <label> Handler range is from first label to prior to second
```
In the first syntax, the labels enclose the instructions of the handler block, the first label being the first instruction of the handler while the second is the instruction immediately after the handler. Alternatively, the handler block is just a scope block.

### 18.3 Catch

A catch block is declared using the `catch` keyword. This specifies the type of exception object the clause is designed to handle, and the handler code itself.

```csharp
<sehClause> ::= catch <typeReference> <handlerBlock>
```

**Example (informative):**

```csharp
.try {
  ...
  // protected instructions
  leave exitSEH  // normal exit
}
catch [mscorlib]System.FormatException {
  ...
  // handle the exception
  pop          // pop the exception object
  leave exitSEH // leave catch handler
}
exitSEH:       // continue here
```

### 18.4 Filter

A filter block is declared using the `filter` keyword.

```csharp
| filter <label> <handlerBlock>
| filter <scope> <handlerBlock>
```

The filter code begins at the specified label and ends at the first instruction of the handler block. (Note that the CLI demands that the filter block shall immediately precede, within the CIL stream, its corresponding handler block)

**Example (informative):**

```csharp
.method public static void m () {
  .try {
    ...
    // protected instructions
    leave exitSEH  // normal exit
  }
  filter {
    ...
    // decide whether to handle
    pop          // pop exception object
    ldc.i4.1     // EXCEPTION_EXECUTE_HANDLER
    endfilter   // return answer to CLI
  }
```
18.5 Finally

A finally block is declared using the finally keyword. This specifies the handler code, with this grammar:

```
<sehClause> ::= ...
| finally <handlerBlock>
```

The last possible CIL instruction that can be executed in a finally handler shall be `endfinally`.

**Example (informative):**

```
.method public static void m() {
    startTry:
    ...
    // protected instructions
    leave exitTry // shall use leave
    }
    finally {
    ...
    // finally handler
    endfinally
    }
    exitTry: // back to normal
```

18.6 Fault Handler

A fault block is declared using the fault keyword. This specifies the handler code, with this grammar:

```
<sehClause> ::= ...
| fault <handlerBlock>
```

The last possible CIL instruction that can be executed in a fault handler shall be `endfault`.

**Example (informative):**

```
.method public static void m() {
    startTry:
    ...
    // protected instructions
    leave exitSEH // shall use leave
    endTry:
    }
    startFault:
```
... // fault handler instructions

default
endFault:

.try startTry to endTry fault handler startFault to endFault

exitSEH: // back to normal

)
19 Declarative Security

Many languages that target the CLI use attribute syntax to attach declarative security attributes to items in the metadata. This information is actually converted by the compiler into an XML-based representation that is stored in the metadata, see Section 21.11. By contrast, ilasm requires the conversion information to be represented in its input.

In .permission, <typeReference> specifies the permission class and <nameValPairs> specifies the settings.

In .permissionset the bytes specify the serialized version of the security settings:

<table>
<thead>
<tr>
<th>&lt;secAction&gt; ::=</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>assert</td>
<td>Assert permission so that callers do not need it.</td>
</tr>
<tr>
<td>demand</td>
<td>Demand permission of all callers.</td>
</tr>
<tr>
<td>deny</td>
<td>Deny permission so checks will fail.</td>
</tr>
<tr>
<td>inheritcheck</td>
<td>Demand permission of a subclass.</td>
</tr>
<tr>
<td>linkcheck</td>
<td>Demand permission of caller.</td>
</tr>
<tr>
<td>permitonly</td>
<td>Reduce permissions so check will fail.</td>
</tr>
<tr>
<td>reqopt</td>
<td>Request optional additional permissions.</td>
</tr>
<tr>
<td>reqrefuse</td>
<td>Refuse to be granted these permissions.</td>
</tr>
<tr>
<td>request</td>
<td>Hint that permission may be required.</td>
</tr>
</tbody>
</table>

| <nameValPairs> ::= <nameValPair> [, <nameValPair>]* |

| <nameValPair> ::= <SQSTRING> = <SQSTRING> |
20 Custom Attributes

Custom attributes add user-defined annotations to the metadata. Custom attributes allow an instance of a type to be stored with any element of the metadata. This mechanism can be used to store application specific information at compile time and access it either at runtime or when another tool reads the metadata. While any user-defined type can be used as an attribute, CLS compliance requires that attributes will be instances of types whose parent is System.Attribute. The CLI predefines some attribute types and uses them to control runtime behavior. Some languages redefine a predefined attribute type to represent language features not directly represented in the CTS. Users or other tools are welcome to define and use additional attribute types.

Custom attributes are declared using the directive .custom. Followed by this directive is the method declaration for a custom constructor, optionally followed by a <bytes> in parentheses:

```
<customDecl> ::=  
  <ctor> [ = ( <bytes> ) ]
```

The <ctor> item represents a method declaration (see Section 14.4), specific for the case where the method's name is .ctor.

For example:
```
.custom instance void myAttribute::.ctor(bool, bool) = (0 0 0 0 0 0 0 0)
```

Custom attributes can be attached to any item in metadata, except a custom attribute itself. Commonly, custom attributes are attached to assemblies, modules, classes, interfaces, value types, methods, fields, properties and events (the custom attribute is attached to the immediately preceding declaration).

The <bytes> item is not required if the constructor takes no arguments. In these cases, all that matters is the presence of the custom attribute.

If the constructor takes parameters, their values shall be specified in the <bytes> item. The format for this ‘blob’ is defined in Section 22.3.

Example (informative):
```
The following example shows a class that is marked with the System.SerializableAttribute and a method that is marked with the System.Runtime.Remoting.OneWayAttribute. The keyword serializable corresponds to the System.SerializableAttribute.

.class public MyClass {
  .custom void [mscorlib]System.SerializableAttribute::.ctor ()
  .method public static void main() {
    .custom void
    ret
  }
}
```

20.1 CLS Conventions: Custom Attribute Usage

CLS imposes certain conventions upon the use of Custom Attributes in order to improve cross-language operation. See Partition I for details.
20.2 Attributes Used by the CLI

There are two kinds of Custom Attributes, called (genuine) Custom Attributes, and Pseudo Custom Attributes. Custom Attributes and Pseudo Custom Attributes are treated differently, at the time they are defined, as follows:

- A Custom Attribute is stored directly into the metadata; the ‘blob’ which holds its defining data is stored as-is. That ‘blob’ can be retrieved later.
- A Pseudo Custom Attribute is recognized because its name is one of a short list. Rather than store its ‘blob’ directly in metadata, that ‘blob’ is parsed, and the information it contains is used to set bits and/or fields within metadata tables. The ‘blob’ is then discarded; it cannot be retrieved later.

Pseudo Custom Attributes therefore serve to capture user directives, using the same familiar syntax the compiler provides for regular Custom Attributes, but these user directives are then stored into the more space-efficient form of metadata tables. Tables are also faster to check at runtime than (genuine) Custom Attributes.

Many Custom Attributes are invented by higher layers of software. They are stored and returned by the CLI, without its knowing or caring what they ‘mean’. But all Pseudo Custom Attributes, plus a collection of regular Custom Attributes, are of special interest to compilers and to the CLI. An example of such Custom Attributes is `System.Reflection.DefaultMemberAttribute`. This is stored in metadata as a regular Custom Attribute ‘blob’, but reflection uses this Custom Attribute when called to invoke the default member (property) for a type.

The following subsections list all of the Pseudo Custom Attributes and distinguished Custom Attributes, where distinguished means that the CLI and/or compilers pay direct attention to them, and their behavior is affected in some way.

In order to prevent name collisions into the future, all custom attributes in the `System` namespace are reserved for standardization.

20.2.1 Pseudo Custom Attributes

The following table lists the CLI Pseudo Custom Attributes. They are defined in either the `System` or the `System.Reflection` namespaces.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AssemblyAlgorithmIDAttribute</td>
<td>Records the ID of the hash algorithm used (reserved only)</td>
</tr>
<tr>
<td>AssemblyFlagsAttribute</td>
<td>Records the flags for this assembly (reserved only)</td>
</tr>
<tr>
<td>DllImportAttribute</td>
<td>Provides information about code implemented within an unmanaged library</td>
</tr>
<tr>
<td>FieldOffsetAttribute</td>
<td>Specifies the byte offset of fields within their enclosing class or value type</td>
</tr>
<tr>
<td>InAttribute</td>
<td>Indicates that a method parameter is an [in] argument</td>
</tr>
<tr>
<td>MarshalAsAttribute</td>
<td>Specifies how a data item should be marshalled between managed and unmanaged code -- see Section 0.</td>
</tr>
<tr>
<td>MethodImplAttribute</td>
<td>Specifies details of how a method is implemented</td>
</tr>
<tr>
<td>OutAttribute</td>
<td>Indicates that a method parameter is an [out] argument</td>
</tr>
<tr>
<td>StructLayoutAttribute</td>
<td>Allows the caller to control how the fields of a class or value type are laid out in managed memory</td>
</tr>
</tbody>
</table>

Not all of these Pseudo Custom Attributes are specified in this standard, but all of them are reserved and shall not be used for other purposes. For details on these attributes, see the documentation for the corresponding class in Partition IV.

The Pseudo Custom Attributes above affect bits and fields in metadata, as follows:
AssemblyAlgorithmIDAttribute: sets the Assembly.HashAlgId field
AssemblyFlagsAttribute: sets the Assembly.Flags field
DllImportAttribute: sets the Method.Flags.PinvokeImpl bit for the attributed method; also, adds a new row into the ImplMap table (setting MappingFlags, MemberForwarded, ImportName and ImportScope columns)
FieldOffsetAttribute: sets the FieldLayout.OffSet value for the attributed field
InAttribute: sets the Param.Flags.In bit for the attributed parameter
MarshalAsAttribute: sets the Field.Flags.HasFieldMarshal bit for the attributed field (or the Param.Flags.HasFieldMarshal bit for the attributed parameter); also enters a new row into the FieldMarshal table for both Parent and NativeType columns.
MethodImplAttribute: sets the Method.ImplFlags field of the attributed method
OutAttribute: sets the Param.Flags.Out bit for the attributed parameter
StructLayoutAttribute: sets theTypeDef.Flags.LayoutMask sub-field for the attributed type. And, optionally, theTypeDef.Flags.StringFormatMask sub-field, the ClassLayout.PackingSize, and ClassLayout.ClassSize fields for that type.

20.2.2 Custom Attributes Defined by the CLS

The CLS specifies certain Custom Attributes and requires that conformant languages support them. These attributes are located under System.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AttributeUsageAttribute</td>
<td>Used to specify how an attribute is intended to be used.</td>
</tr>
<tr>
<td>ObsoleteAttribute</td>
<td>Indicates that an element is not to be used.</td>
</tr>
<tr>
<td>CLSCompliantAttribute</td>
<td>Indicates whether or not an element is declared to be CLS compliant through an instance field on the attribute object.</td>
</tr>
</tbody>
</table>

20.2.3 Custom Attributes for Security

The following Custom Attributes affect the security checks performed upon method invocations at runtime. They are defined in the System.Security namespace.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DynamicSecurityMethodAttribute</td>
<td>Indicates to the CLI that the method requires space to be allocated for a security object</td>
</tr>
<tr>
<td>SuppressUnmanagedCodeSecurityAttribute</td>
<td>Indicates the target method, implemented as unmanaged code, should skip per-call checks</td>
</tr>
</tbody>
</table>

The following Custom Attributes are defined in the System.Security.Permissions namespace. Note that these are all base classes; the actual instances of security attributes found in assemblies will be sub-classes of these.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CodeAccessSecurityAttribute</td>
<td>This is the base attribute class for declarative security using custom attributes.</td>
</tr>
<tr>
<td>DnsPermissionAttribute</td>
<td>Custom attribute class for declarative security with DnsPermission</td>
</tr>
<tr>
<td>EnvironmentPermissionAttribute</td>
<td>Custom attribute class for declarative security with EnvironmentPermission.</td>
</tr>
</tbody>
</table>
FileIOPermissionAttribute | Custom attribute class for declarative security with FileIOPermission.
---|---
ReflectionPermissionAttribute | Custom attribute class for declarative security with ReflectionPermission.
SecurityAttribute | This is the base attribute class for declarative security from which CodeAccessSecurityAttribute is derived.
SecurityPermissionAttribute | Indicates whether the attributed method can affect security settings.
SiteIdentityPermissionAttribute | Custom attribute class for declarative security with SiteIdentityPermission.
SocketPermissionAttribute | Custom attribute class for declarative security with SocketPermission.
StrongNameIdentityPermissionAttribute | Custom attribute class for declarative security with StrongNameIdentityPermission.
WebPermissionAttribute | Custom attribute class for declarative security with WebPermission.

Note that any other security-related Custom Attributes (ie, any Custom Attributes that derive from System.Security.Permissions.SecurityAttribute) included into an assembly, may cause a conforming implementation of the CLI to reject such an assembly when it is loaded, or throw an exception at runtime if any attempt is made to access those security-related Custom Attributes. (This statement in fact holds true for any Custom Attributes that cannot be resolved; security-related Custom Attributes are just one particular case)

### 20.2.4 Custom Attributes for TLS

A Custom Attribute that denotes a TLS (thread-local storage) field is defined in the System namespace

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ThreadStaticAttribute</td>
<td>Provides for type member fields that are relative for the thread.</td>
</tr>
</tbody>
</table>

### 20.2.5 Custom Attributes, Various

The following Custom Attributes control various aspects of the CLI:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ConditionalAttribute</td>
<td>Used to mark methods as callable, based on some compile-time condition. If the condition is false, the method will not be called</td>
</tr>
<tr>
<td>DecimalConstantAttribute</td>
<td>Stores the value of a decimal constant in metadata</td>
</tr>
<tr>
<td>DefaultMemberAttribute</td>
<td>Defines the member of a type that is the default member used by reflection’s InvokeMember.</td>
</tr>
<tr>
<td>FlagsAttribute</td>
<td>Custom attribute indicating an enumeration should be treated as a bitfield; that is, a set of flags</td>
</tr>
<tr>
<td>IndexerNameAttribute</td>
<td>Indicates the name by which an indexer will be known in programming languages that do not support indexers directly</td>
</tr>
<tr>
<td>ParamArrayAttribute</td>
<td>Indicates that the method will allow a variable number of arguments in its invocation</td>
</tr>
</tbody>
</table>
21 Metadata Logical Format: Tables

This section defines the structures that describe metadata, and how they are cross-indexed. This corresponds to how metadata is laid out, after being read into memory from a PE file. (For a description of metadata layout inside the PE file itself, see Chapter 23)

Metadata is stored in two kinds of structure – tables (arrays of records), and heaps. There are four heaps in any module: String, Blob, Userstring and Guid. The first three are byte arrays (so valid indexes into these heaps might be 0, 23, 25, 39, etc). The Guid heap is an array of GUIDs, each 16 bytes wide. Its first element is numbered 1, its second 2, and so on.

Each entry in each column of each table is either a constant or an index.

Constants are either literal values (eg ALG_SID_SHA1 = 4, stored in the HashAlgId column of the Assembly table), or, more commonly, bitmasks. Most bitmasks (they are almost all called “Flags”) are 2 bytes wide (eg the Flags column in the Field table), but there are a few that are 4 bytes (eg the Flags column in the TypeDef table)

Each index is either 2 bytes wide, or 4 bytes wide. The index points into another (or the same) table, or into one of the four heaps. The size of each index column in a table is only made 4 bytes if it needs to be, for that particular module. So, if a particular column indexes a table, or tables, whose highest row number fits in a 2-byte value, the indexer column need only be 2 bytes wide. Conversely, for huge tables, containing 64K rows or more, an indexer of that table will be 4 bytes wide.

Note that indexes begin at 1, meaning the first row in any given metadata table. An index value of zero denotes that it does not index a row at all (it behaves like a null reference)

The columns that index a metadata table are of two sorts:

- Simple – that column indexes one, and only one, table. e.g., the FieldList column in the TypeDef table always indexes the Field table. So all values in that column are simple integers, giving the row number in the target table

- Coded – that column indexes any of several tables. e.g., the Extends column in the TypeDef table can index into the TypeDef table, or into the TypeRef table. A few bits of that index value are reserved to define which table it targets. For the most part, this specification talks of index values after being decoded into row numbers within the target table. However, the specification includes a description of these coded indexes in the section that describes the physical layout of Metadata (Chapter 23).

Metadata preserves name strings, as created by a compiler or code generator, unchanged. Essentially it treats each string as an opaque 'blob'. In particular, it preserves case. The CLI imposes no limit on the size of names stored in metadata and subsequently processed by the CLI

Matching AssemblyRefs and ModuleRefs to their corresponding Assembly and Module shall be performed case-blind (see Partition I). However, all other name matches (type, field, method, property, event) is exact – so that this level of resolution is the same across all platforms, whether their OS is case-sensitive or not.

Tables are given both a name (eg "Assembly") and numbered (eg 0x20). The number for each table is listed immediately with its title in the following sections.

A few of the tables represent extensions to regular CLI files. Specifically, ENCLog and ENCMAP, which occur in temporary images, generated during "Edit and Continue" or "incremental compilation" scenarios, whilst debugging. Both table types are reserved for future use.

References to the methods or fields of a Type are stored together in a metadata table called the MemberRef table. However, sometimes, for clearer explanation, this specification distinguishes between these two kinds of reference, calling them “MethodRef” and “FieldRef”.

This contains informative text only
21.1 Metadata Validation Rules

The sections that follow describe the schema for each kind of metadata table, and explain the detailed rules that guarantee metadata emitted into any PE file is valid. Checking that metadata is valid ensures that later processing - checking the CIL instruction stream for type safety, building method tables, CIL-to-native-code compilation, data marshalling, etc will not cause the CLI to crash or behave in an insecure fashion.

In addition, some of the rules are used to check compliance with the CLS requirements (see Partition I even though these are not related to valid Metadata. These are marked with a trailing [CLS] tag.

The rules for valid metadata refer to an individual module. A module is any collection of metadata that could typically be saved to a disk file. This includes the output of compilers and linkers, or the output of script compilers (where often the metadata is held only in memory, but never actually saved to a file on disk).

The rules address intra-module validation only. So, validator software, for example, that checks conformance with this spec, need not resolve references or walk type hierarchies defined in other modules. However, it should be clear that even if two modules, A and B, analyzed separately, contain only valid metadata, they may still be in error when viewed together (e.g., a call from Module A, to a method defined in module B, might specify a callsite signature that does not match the signatures defined for that method in B).

All checks are categorized as ERROR, WARNING or CLS.

- An ERROR reports something that might cause a CLI to crash or hang, it might run but produce wrong answers; or it might be entirely benign. There may exist conforming implementations of the CLI that will not accept metadata that violates an ERROR rule, and therefore such metadata is invalid and is not portable.

- A WARNING reports something, not actually wrong, but possibly a slip on the part of the compiler. Normally, it indicates a case where a compiler could have encoded the same information in a more compact fashion or where the metadata represents a construct that can have no actual use at runtime. All conforming implementations will support metadata that violate only WARNING rules; hence such metadata is both valid and portable.

- A CLS reports lack of compliance with common language specification (see Partition I). Such metadata is both valid and portable, but there may exist programming languages that cannot process it, even though all conforming implementations of the CLI support the constructs.

Validation rules fall into a few broad categories, as follows:

- **Number of Rows**: A few tables are allowed only one row (e.g. Module table). Most have no such restriction.

- **Unique Rows**: No table may contain duplicate rows, where “duplicate” is defined in terms of its key column, or combination of columns

- **Valid Indexes**: Columns which are indexes shall point somewhere sensible, as follows:
  - Every index into the String, Blob or Userstring heaps shall point into that heap, neither before its start (offset 0), nor after its end
  - Every index into the Guid heap shall lie between 1 and the maximum element number in this module, inclusive
  - Every index (row number) into another metadata table shall lie between 0 and that table’s row count + 1 (for some tables, the index may point just past the end of any target table, meaning it indexes nothing)

- **Valid Bitmasks**: Columns which are bitmasks shall only have valid permutations of bits set

- **Valid RVAs**: There are restrictions upon fields and methods that are assigned RVAs (Relative Virtual Addresses; these are byte offsets, expressed from the address at which the corresponding PE file is loaded into memory)
Note that some of the rules listed below say "nothing" - for example, some rules state that a particular table is allowed zero or more rows - so there is no way that the check can fail. This is done simply for completeness, to record that such details have indeed been addressed, rather than overlooked.

The CLI imposes no limit on the size of names stored in metadata, and subsequently processed by a CLI implementation.

### 21.2 Assembly: 0x20

The `Assembly` table has the following columns:

- `HashAlgId` (a 4 byte constant of type `AssemblyHashAlgorithm`, clause 22.1.1)
- `MajorVersion`, `MinorVersion`, `BuildNumber`, `RevisionNumber` (2 byte constants)
- `Flags` (a 4 byte bitmask of type `AssemblyFlags`, clause 22.1.2)
- `PublicKey` (index into `Blob` heap)
- `Name` (index into `String` heap)
- `Culture` (index into `String` heap)

The `Assembly` table is defined using the `.assembly` directive (see Section 6.2); its columns are obtained from the respective `.hash algorithm`, `.ver`, `.publickey`, and `.culture` (see clause 6.2.1 For an example see Section 6.2).

This contains informative text only

22. The `Assembly` table may contain zero or one row [ERROR]
23. `HashAlgId` should be one of the specified values [ERROR]
24. `Flags` may have only those values set that are specified [ERROR]
25. `PublicKey` may be null or non-null
26. `Name` shall index a non-null string in the String heap [ERROR]
27. The string indexed by `Name` can be of unlimited length
28. `Culture` may be null or non-null
29. If `Culture` is non-null, it shall index a single string from the list specified (see clause 22.1.3) [ERROR]

Note: `Name` is a simple name (e.g., "Foo" - no drive letter, no path, no file extension); on POSIX-compliant systems `Name` contains no colon, no forward-slash, no backslash, no period.

### 21.3 AssemblyOS: 0x22

The `AssemblyOS` table has the following columns:

- `OSPlatformID` (a 4 byte constant)
- `OSMajorVersion` (a 4 byte constant)
- `OSMinorVersion` (a 4 byte constant)

This record should not be emitted into any PE file. If present in a PE file, it should be treated as if all its fields were zero. It should be ignored by the CLI.
21.4 AssemblyProcessor : 0x21

The AssemblyProcessor table has the following column:

- Processor (a 4 byte constant)

This record should not be emitted into any PE file. If present in a PE file, it should be treated as if its field were zero. It should be ignored by the CLI.

21.5 AssemblyRef : 0x23

The AssemblyRef table has the following columns:

- MajorVersion, MinorVersion, BuildNumber, RevisionNumber (2 byte constants)
- Flags (a 4 byte bitmask of type AssemblyFlags, clause 22.1.2)
- PublicKeyOrToken (index into Blob heap – the public key or token that identifies the author of this Assembly)
- Name (index into String heap)
- Culture (index into String heap)
- HashValue (index into Blob heap)

The table is defined by the .assembly extern directive (see Section 6.3). Its columns are filled using directives similar to those of the Assembly table except for the PublicKeyOrToken column which is defined using the .publickeytoken directive. For an example see Section 6.3.
This contains informative text only

30. MajorVersion, MinorVersion, BuildNumber, RevisionNumber can each have any value

31. Flags may have only one possible bit set – the PublicKey bit (see clause 22.1.2). All other bits shall be zero. [ERROR]

32. PublicKeyOrToken may be null, or non-null (note that the Flags.PublicKey bit specifies whether the 'blob' is a full public key, or the short hashed token)

33. If non-null, then PublicKeyOrToken shall index a valid offset in the Blob heap [ERROR]

34. Name shall index a non-null string, in the String heap (there is no limit to its length). [ERROR]

35. Culture may be null or non-null. If non-null, it shall index a single string from the list specified (see clause 22.1.3) [ERROR]

36. HashValue may be null or non-null

37. If non-null, then HashValue shall index a non-empty 'blob' in the Blob heap [ERROR]

38. The AssemblyRef table shall contain no duplicates, where duplicate rows have the same MajorVersion, MinorVersion, BuildNumber, RevisionNumber, PublicKeyOrToken, Name and Culture [WARNING]

Note: Name is a simple name (e.g., "Foo" - no drive letter, no path, no file extension); on POSIX-compliant systems Name contains no colon, no forward-slash, no backslash, no period.

End informative text

21.6 AssemblyRefOS : 0x25

The AssemblyRefOS table has the following columns:

• OSPortPlatformId (4 byte constant)
• OSMajorVersion (4 byte constant)
• OSMMinorVersion (4 byte constant)
• AssemblyRef (index into the AssemblyRef table)

These records should not be emitted into any PE file. If present in a PE file, they should be treated as-if their fields were zero. They should be ignored by the CLI.

21.7 AssemblyRefProcessor : 0x24

The AssemblyRefProcessor table has the following columns:

• Processor (4 byte constant)
• AssemblyRef (index into the AssemblyRef table)

These records should not be emitted into any PE file. If present in a PE file, they should be treated as-if their fields were zero. They should be ignored by the CLI.

21.8 ClassLayout : 0x0F

The ClassLayout table is used to define how the fields of a class or value type shall be laid out by the CLI (normally, the CLI is free to reorder and/or insert gaps between the fields defined for a class or value type).

Rationale: This feature is used to make a managed value type be laid out in exactly the same way as an unmanaged C struct – with this condition true, the managed value type can be handed to unmanaged code, which accesses the fields exactly as if that block of memory had been laid out by unmanaged code.

The information held in the ClassLayout table depends upon the Flags value for {AutoLayout, SequentialLayout, ExplicitLayout} in the owner class or value type.
A type has layout if it is marked SequentialLayout or ExplicitLayout. If any type within an inheritance chain has layout, then so shall all its parents, up to the one that descends immediately from System.Object, or from System.ValueType.

This contains informative text only

Layout cannot begin part way down the chain. But it is legal to stop “having layout” at any point down the chain.

For example, in the diagrams below, Class A derives from System.Object; class B derives from A; class C derives from B. System.Object has no layout. But A, B and C are all defined with layout, and that is legal.

![Diagram](image)

Similarly with Classes E, F and G. G has no layout. This too is legal. The following picture shows two illegal setups:

![Diagram](image)

On the left, the “chain with layout” does not start at the ‘highest’ class. And on the right, there is a ‘hole’ in the “chain with layout”.

Layout information for a class or value type is held in two tables – the ClassLayout and FieldLayout tables, as shown in this diagram:

![Diagram](image)
This example shows how row 3 of the `ClassLayout` table points to row 2 in the `TypeDef` table (the definition for a class, called “MyClass”). Rows 4 through 6 of the `FieldLayout` table point to corresponding rows in the `TypeDef` table. This illustrates how the CLI stores the explicit offsets for the three fields that are defined in “MyClass” (there is always one row in the `FieldLayout` table for each field in the owning class or value type). So, the `ClassLayout` table acts as an extension to those rows of the `TypeDef` table that have layout info; since many classes do not have layout info, this design overall saves space.

**End informative text**

The `ClassLayout` table has the following columns:

- **PackingSize** (a 2 byte constant)
- **ClassSize** (a 4 byte constant)
- **Parent** (index into `TypeDef` table)

The rows of the `ClassLayout` table are defined by placing `.pack` and `.size` directives on the body of a parent type declaration (see Section 9.2). For an example see Section 9.7.

This contains informative text only

39. A `ClassLayout` table may contain zero or more or rows
40. **Parent** shall index a valid row in the `TypeDef` table, corresponding to a Class or ValueType (not to an Interface) [ERROR]
41. The Class or ValueType indexed by **Parent** shall not be `AutoLayout` - i.e., it shall be one of `SequentialLayout` or `ExplicitLayout`. (See clause 22.1.14). Put another way, `AutoLayout` types shall not own any rows in the `ClassLayout` table. [ERROR]
42. If **Parent** indexes a `SequentialLayout` type, then: [ERROR]
   o **PackingSize** shall be one of `{ 0, 1, 2, 4, 8, 16, 32, 64, 128 }` (0 means use the default pack size for the platform that the application is running on)
   o if **ClassSize** is non-zero, then it shall be greater than or equal to the calculated size of the class, based upon its field sizes and **PackingSize** (compilers request padding at the end of a class by providing a value for `ClassSize` that is larger than its calculated size) [ERROR]
   o a **ClassSize** of zero does not mean the class has zero size. It means, no size was specified at definition time. Instead, the actual size is calculated from the field types, taking account of packing size (default or specified) and natural alignment on the target, runtime platform
   o if **Parent** indexes a ValueType, then **ClassSize** shall be less than 1 MByte (0x100000 bytes)
43. Note that `ExplicitLayout` types might result in verifiable types, so long as that layout does not create union types.
44. If **Parent** indexes an `ExplicitLayout` type, then [ERROR]
   o if **ClassSize** is non-zero, then it shall be greater than or equal to the calculated size of the class, based upon the rows it owns in the `FieldLayout` table (compilers create padding at the end of a class by providing a value for `ClassSize` that is larger than its calculated size)
   o a **ClassSize** of zero does not mean the class has zero size. It means, no size was specified at definition time. Instead, the actual size is calculated from the field types, their specified offsets, and any beyond-end alignment packing performed by the target platform
   o if **Parent** indexes a ValueType, then **ClassSize** shall be less than 1 MByte (0x100000 bytes)
   o **PackingSize** shall be 0 (because it makes no sense to provide explicit offsets for each field, as well as a packing size)
45. Layout along the length of an inheritance chain shall follow the rules specified above (starts at ‘highest’ Type, with no ‘holes’, etc) [ERROR]
End informative text

21.9 Constant : 0x0B

The Constant table is used to store compile-time, constant values for fields, parameters and properties.

The Constant table has the following columns:

- **Type** (a 1 byte constant, followed by a 1-byte padding zero) : see Clause 22.1.15. The encoding of Type for the nullref value for <fieldInit> in ilasm (see Section 15.2) is ELEMENT_TYPE_CLASS with a Value of zero. Unlike uses of ELEMENT_TYPE_CLASS in signatures, this one is not followed by a type token.

- **Parent** (index into the Param or Field or Property table; more precisely, a HasConst coded index)

- **Value** (index into Blob heap)

Note that Constant information does not directly influence runtime behavior. Compilers inspect this information, at compile time, when importing metadata; but the value of the constant itself, if used, becomes embedded into the CIL stream the compiler emits. There are no CIL instructions to access the Constant table at runtime.

A row in the Constant table for a parent is created whenever a compile-time value is specified for that parent, for an example see Section 15.2.

This contains informative text only

46. **Type** shall be exactly one of: ELEMENT_TYPE_BOOLEAN, ELEMENT_TYPE_CHAR, ELEMENT_TYPE_I1, ELEMENT_TYPE_U1, ELEMENT_TYPE_I2, ELEMENT_TYPE_U2, ELEMENT_TYPE_I4, ELEMENT_TYPE_U4, ELEMENT_TYPE_I8, ELEMENT_TYPE_U8, ELEMENT_TYPE_R4, ELEMENT_TYPE_R8, ELEMENT_TYPE_STRING; or ELEMENT_TYPE_CLASS with a Value of zero (See clause 22.1.15) [ERROR]

47. **Type** shall not be any of: ELEMENT_TYPE_I1, ELEMENT_TYPE_U2, ELEMENT_TYPE_U4, ELEMENT_TYPE_U8 (See clause 22.1.15) [CLS]

48. **Parent** shall index a valid row in the Field or Property or Param table [ERROR]

49. There shall be no duplicate rows, based upon **Parent** [ERROR]

50. **Constant.Type** must match exactly the declared type of the Param, Field or Property identified by **Parent** (in the case where the parent is an enum, it must match exactly the underlying type of that enum) [CLS]

End informative text

21.10 CustomAttribute : 0x0C

The CustomAttribute table has the following columns:

- **Parent** (index into any metadata table, except the CustomAttribute table itself; more precisely, a HasCustomAttribute coded index)

- **Type** (index into the Method or MethodRef table; more precisely, a CustomAttributeType coded index)

- **Value** (index into Blob heap)

The CustomAttribute table stores data that can be used to instantiate a Custom Attribute (more precisely, an object of the specified Custom Attribute class) at runtime. The column called **Type** is slightly misleading – it actually indexes a constructor method – the owner of that constructor method is the Type of the Custom Attribute.
A row in the `CustomAttribute` table for a parent is created by the `.custom` attribute, which gives the value of the Type column and optionally that of the Value column (see Chapter 0).

This contains informative text only

All binary values are stored in little-endian format (except `PackedLen` items - used only as counts for the number of bytes to follow in a UTF8 string)

51. It is legal for there to be no `CustomAttribute` present at all - that is, for the `CustomAttribute.Value` field to be null

52. `Parent` can be an index into any metadata table, except the `CustomAttribute` table itself [ERROR]

53. `Type` shall index a valid row in the `Method` or `MethodRef` table. That row shall be a constructor method (for the class of which this information forms an instance) [ERROR]

54. `Value` may be null or non-null

55. If `Value` is non-null, it shall index a 'blob' in the Blob heap [ERROR]

56. The following rules apply to the overall structure of the Value 'blob'(see Section 22.3):
   o `Prolog` shall be 0x0001 [ERROR]
   o There shall be as many occurrences of `FixedArg` as are declared in the Constructor method [ERROR]
   o `NumNamed` may be zero or more
   o There shall be exactly `NumNamed` occurrences of `NamedArg` [ERROR]
   o Each `NamedArg` shall be accessible by the caller [ERROR]
   o If `NumNamed` = 0 then there shall be no further items in the `CustomAttribute` [ERROR]

57. The following rules apply to the structure of `FixedArg` (see Section 22.3):
   o If this item is not for a vector (a single-dimension array with lower bound of 0), then there shall be exactly one `Elem` [ERROR]
   o If this item is for a vector, then:
     o `NumElem` shall be 1 or more [ERROR]
     o This shall be followed by `NumElem` occurrences of `Elem` [ERROR]

58. The following rules apply to the structure of `Elem` (see Section 22.3):
   o If this is a simple type or an enum (see Section 22.3 for how this is defined), then `Elem` consists simply of its value [ERROR]
   o If this is a string, or a Type, then `Elem` consists of a `SerString` – `PackedLen` count of bytes, followed by the UTF8 characters [ERROR]
   o If this is a boxed simple value type (bool, char, float32, float64, int8, int16, int32, int64, unsigned int8, unsigned int16, unsigned int32 or unsigned int64), then `Elem` consists of the corresponding type denoter (ELEMENT_TYPE_BOOLEAN, ELEMENT_TYPE_CHAR, ELEMENT_TYPE_I1, ELEMENT_TYPE_U1, ELEMENT_TYPE_I2, ELEMENT_TYPE_U2, ELEMENT_TYPE_I4, ELEMENT_TYPE_U4, ELEMENT_TYPE_I8, ELEMENT_TYPE_U8, ELEMENT_TYPE_R4, ELEMENT_TYPE_R8), followed by its value. [ERROR]

59. The following rules apply to the structure of `NamedArg` (see Section 22.3):
   o The single byte `FIELD` (0x53) or `PROPERTY` (0x54) [ERROR]
   o The type of the field or property -- one of ELEMENT_TYPE_BOOLEAN, ELEMENT_TYPE_CHAR, ELEMENT_TYPE_I1, ELEMENT_TYPE_U1, ELEMENT_TYPE_I2, ELEMENT_TYPE_U2, ELEMENT_TYPE_I4, ELEMENT_TYPE_U4, ELEMENT_TYPE_I8, ELEMENT_TYPE_U8,
ELEMENT_TYPE_R4, ELEMENT_TYPE_R8, ELEMENT_TYPE_STRING or the constant 0x50 (for an argument of type System.Type)

- The name of the Field or Property, respectively with the previous item, as a SerString – PackedLen count of bytes, followed by the UTF8 characters of the name [ERROR]
- A FixedArg (see above) [ERROR]

End informative text

21.11 DeclSecurity : 0x0E

Security attributes, which derive from System.Security.Permissions.SecurityAttribute (see Partition IV), can be attached to aTypeDef, aMethod or to an Assembly. All constructors of this class shall take a System.Security.Permissions.SecurityAction value as their first parameter, describing what should be done with the permission on the type, method or assembly to which it is attached. Code access security attributes, which derive from System.Security.Permissions.CodeAccessSecurityAttribute, may have any of the security actions.

These different security actions are encoded in the DeclSecurity table as a 2-byte enum (see below). All security custom attributes for a given security action on a method, type or assembly shall be gathered together and one System.Security.PermissionSet instance shall be created, stored in the Blob heap, and referenced from the DeclSecurity table.

Note: The general flow from a compiler’s point of view is as follows. The user specifies a custom attribute through some language-specific syntax that encodes a call to the attribute’s constructor. If the attribute’s type is derived (directly or indirectly) from System.Security.Permissions.SecurityAttribute then it is a security custom attribute and requires special treatment, as follows (other custom attributes are handled by simply recording the constructor in the metadata as described in Section 21.10). The attribute object is constructed, and provides a method (CreatePermission) to convert it into a security permission object (an object derived from System.Security.Permission). All the permission objects attached to a given metadata item with the same security action are combined together into a System.Security.PermissionSet. This permission set is converted into a form that is ready to be stored in XML using its ToXML method to create a System.Security.SecurityElement. Finally, the XML that is required for the metadata is created using the ToString method on the security element.

The DeclSecurity table has the following columns:

- **Action** (2 byte value)
- **Parent** (index into the TypeDef, Method or Assembly table; more precisely, a HasDeclSecurity coded index)
- **PermissionSet** (index into Blob heap)

**Action** is a 2-byte representation of Security Actions, see System.Security.SecurityAction in Partition IV. The values 0 through 0xFF are reserved for future standards use. Values 0x20 through 0x7F and 0x100 through 0x07FF are for uses where the action may be ignored if it is not understood or supported. Values 0x80 through 0xFF and 0x0800 through 0xFFFF are for uses where the action shall be implemented for secure operation; in implementations where the action is not available no access to the assembly, type, or method shall be permitted.

<table>
<thead>
<tr>
<th>Security Action</th>
<th>Note</th>
<th>Explanation of behavior</th>
<th>Legal Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assert</td>
<td>1</td>
<td>Without further checks satisfy Demand for specified permission</td>
<td>Method, Type</td>
</tr>
<tr>
<td>Demand</td>
<td>1</td>
<td>Check all callers in the call chain have been granted specified permission, throw SecurityException (see Partition IV) on failure</td>
<td>Method, Type</td>
</tr>
<tr>
<td>Deny</td>
<td>1</td>
<td>Without further checks refuse Demand for specified permission</td>
<td>Method, Type</td>
</tr>
<tr>
<td>Method</td>
<td>Type</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Specified permission</td>
<td>Method, Type</td>
<td>Specified permission shall be granted in order to inherit from class or override virtual method.</td>
<td></td>
</tr>
<tr>
<td>LinkDemand 1</td>
<td>Method, Type</td>
<td>Check immediate caller has been granted specified permission, throw SecurityException (see Partition IV) on failure.</td>
<td></td>
</tr>
<tr>
<td>PermitOnly 1</td>
<td>Method, Type</td>
<td>Without further checks refuse Demand for all permissions other than those specified.</td>
<td></td>
</tr>
<tr>
<td>RequestMinimum</td>
<td>Assembly</td>
<td>Specify minimum permissions required to run Assembly</td>
<td></td>
</tr>
<tr>
<td>RequestOptional</td>
<td>Assembly</td>
<td>Specify optional permissions to grant Assembly</td>
<td></td>
</tr>
<tr>
<td>RequestRefuse</td>
<td>Assembly</td>
<td>Specify permissions not to be granted Assembly</td>
<td></td>
</tr>
<tr>
<td>NonCasDemand 2</td>
<td>Method, Type</td>
<td>Check that current assembly has been granted specified permission, throw SecurityException (see Partition IV) otherwise.</td>
<td></td>
</tr>
<tr>
<td>NonCasLinkDemand 2</td>
<td>Method, Type</td>
<td>Check that immediate caller has been granted specified permission, throw SecurityException (see Partition IV) otherwise.</td>
<td></td>
</tr>
<tr>
<td>PrejitGrant</td>
<td>Assembly</td>
<td>Reserved for implementation-specific use Assembly</td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** Specified attribute shall derive from System.Security.Permissions.CodeAccessSecurityAttribute


`Parent` is a Meta Data token that identifies the `Method`, `Type` or `Assembly` on which security custom attributes serialized in `PermissionSet` was defined.

`PermissionSet` is a 'blob' that contains the XML serialization of a permission set. The permission set contains the permissions that were requested with an `Action` on a specific `Method`, `Type` or `Assembly` (see `Parent`).

The rows of the `DeclSecurity` table are filled by attaching a .permission or .permissionset directive that specifies the `Action` and `PermissionSet` on a parent assembly (see Section 6.6) or parent type or method (see Section 9.2).

---

This contains informative text only

60. `Action` may have only those values set that are specified [ERROR]

61. `Parent` shall be one of `TypeDef`, `MethodDef`, or `Assembly`. That is, it shall index a valid row in the `TypeDef` table, the `MethodDef` table, or the `Assembly` table [ERROR]

62. If `Parent` indexes a row in the `TypeDef` table, that row should not define an Interface. The security system ignores any such parent; compilers should not emit such permissions sets [WARNING]

63. If `Parent` indexes a `TypeDef`, then its `TypeDef.Flags.HasSecurity` bit should be set [ERROR]

64. If `Parent` indexes a `MethodDef`, then its `MethodDef.Flags.HasSecurity` bit should be set [ERROR]

65. `PermissionSet` should index a 'blob' in the Blob heap [ERROR]

66. The format of the 'blob' indexed by `PermissionSet` should represent a valid, serialized CLI object graph. The serialized form of all standardized permissions is specified in Partition IV. [ERROR]

End informative text
21.12 EventMap : 0x12

The EventMap table has the following columns:

- Parent (index into the TypeDef table)
- EventList (index into Event table). It marks the first of a contiguous run of Events owned by this Type. The run continues to the smaller of:
  - the last row of the Event table
  - the next run of Events, found by inspecting the EventList of the next row in the EventMap table

Note that EventMap info does not directly influence runtime behavior; what counts is the info stored for each method that the event comprises.

This contains informative text only

67. EventMap table may contain zero or more rows
68. There shall be no duplicate rows, based upon Parent (a given class has only one ‘pointer’ to the start of its event list) [ERROR]
69. There shall be no duplicate rows, based upon EventList (different classes cannot share rows in the Event table) [ERROR]

End informative text

21.13 Event : 0x14

Events are treated within metadata much like Properties – a way to associate a collection of methods defined on given class. There are two required methods – add_ and remove_, plus optional raise_ and others. All of the methods gathered together as an Event shall be defined on the class.

The association between a row in the TypeDef table and the collection of methods that make up a given Event, is held in three separate tables (exactly analogous to that used for Properties) – see the below:

Row 3 of the EventMap table indexes row 2 of the TypeDef table on the left (MyClass), whilst indexing row 4 of the Event table on the right – the row for an Event called DocChanged. This setup establishes that MyClass has an Event called DocChanged. But what methods in the Method table are gathered together as ‘belonging’ to event DocChanged? That association is contained in the MethodSemantics table – its row 2 indexes event DocChanged to the right, and row 2 in the Method table to the left (a method called add_DocChanged). Also, row 3 of the MethodSemantics table indexes DocChanged to the right, and row 3 in the Method table to the left.
(a method called remove_DocChanged). As the shading suggests, MyClass has another event, called TimedOut, with two methods, add_TimedOut and remove_TimedOut.

Event tables do a little more than group together existing rows from other tables. The Event table has columns for EventFlags, Name (e.g., DocChanged and TimedOut in the example here) and EventType. In addition, the MethodSemantics table has a column to record whether the method it points at is an add_. remove_. raise_. or other.

The Event table has the following columns:

- EventFlags (a 2 byte bitmask of type EventAttribute, clause 22.1.4)
- Name (index into String heap)
- EventType (index into TypeDef, TypeRef or TypeSpec tables; more precisely, a TypeDefOrRef coded index) [this corresponds to the Type of the Event; it is not the Type that owns this event]

Note that Event information does not directly influence runtime behavior; what counts is the information stored for each method that the event comprises.

The EventMap and Event tables result from putting the .event directive on a class (see Chapter 17).

**This contains informative text only**

70. The Event table may contain zero or more rows
71. Each row shall have one, and only one, owner row in the EventMap table [ERROR]
72. EventFlags may have only those values set that are specified (all combinations valid) [ERROR]
73. Name shall index a non-null string in the String heap [ERROR]
74. The Name string shall be a valid CLS identifier [CLS]
75. EventType may be null or non-null
76. If EventType is non-null, then it shall index a valid row in the TypeDef or TypeRef table [ERROR]
77. If EventType is non-null, then the row in TypeDef, TypeRef or TypeSpec table that it indexes shall be a Class (not an Interface; not a ValueType) [ERROR]
78. For each row, there shall be one add_ and one remove_ row in the MethodSemantics table [ERROR]
79. For each row, there can be zero or one raise_ row, as well as zero or more other rows in the MethodSemantics table [ERROR]
80. Within the rows owned by a given row in the TypeDef table, there shall be no duplicates based upon Name [ERROR]
81. There shall be no duplicate rows based upon Name, where Name fields are compared using CLS conflicting-identifier-rules [CLS]

**End informative text**

### 21.14 ExportedType : 0x27

The ExportedType table holds a row for each type, defined within other modules of this Assembly, that is exported out of this Assembly. In essence, it stores TypeDef row numbers of all types that are marked public in other modules that this Assembly comprises.

The actual target row in a TypeDef table is given by the combination of TypeDefId (in effect, row number) and Implementation (in effect, the module that holds the target TypeDef table). Note that this is the only occurrence in metadata of foreign tokens – that is token values that have a meaning in another module. (Regular token values are indexes into table in the current module)
The full name of the type need not be stored directly. Instead, it may be split into two parts at any included "." (although typically this done at the last "." in the full name). The part preceding the "." is stored as the TypeNamespace and that following the "." is stored as the TypeName. If there is no "." in the full name, then the TypeNamespace shall be the index of the empty string.

The ExportedType table has the following columns:

- **Flags** (a 4 byte bitmask of type TypeAttributes, clause 22.1.14)
- **TypeDefId** (4 byte index into a TypeDef table of another module in this Assembly). This field is used as a hint only. If the entry in the target TypeDef table matches the TypeName and TypeNamespace entries in this table, resolution has succeeded. But if there is a mismatch, the CLI shall fall back to a search of the target TypeDef table
- **TypeName** (index into the String heap)
- **TypeNamespace** (index into the String heap)
- **Implementation.** This can be an index (more precisely, an Implementation coded index) into one of 2 tables, as follows:
  - **File table**, where that entry says which module in the current assembly holds the TypeDef
  - **ExportedType table**, where that entry is the enclosing Type of the current nested Type

The rows in the ExportedType table are the result of the .class extern directive (see Section 6.7).

---

The term “FullName” refers to the string created as follows: if the TypeNamespace is null, then use the TypeName, otherwise use the concatenation of TypeNamespace, ".", and TypeName.

82. The ExportedType table may contain zero or more rows

83. There shall be no entries in the ExportedType table for Types that are defined in the current module - just for Types defined in other modules within the Assembly [ERROR]

84. Flags may have only those values set that are specified [ERROR]

85. If Implementation indexes the File table, then Flags.VisibilityMask shall be public (see clause 22.1.14) [ERROR]

86. If Implementation indexes the ExportedType table, then Flags.VisibilityMask shall be NestedPublic (see see clause 22.1.14) [ERROR]

87. If non-null, TypeDefId should index a valid row in a TypeDef table in a module somewhere within this Assembly (but not this module), and the row so indexed should have its Flags.Public = 1 (see see clause 22.1.14) [WARNING]

88. TypeName shall index a non-null string in the String heap [ERROR]

89. TypeNamespace may be null, or non-null

90. If TypeNamespace is non-null, then it shall index a non-null string in the String heap [ERROR]

91. FullName shall be a valid CLS identifier [CLS]

92. If this is a nested Type, then TypeNamespace should be null, and TypeName should represent the unmangled, simple name of the nested Type [ERROR]

93. Implementation shall be a valid index into either: [ERROR]

- the File table; that file shall hold a definition of the target Type in its TypeDef table
- a different row in the current ExportedType table - this identifies the enclosing Type of the current, nested Type
94. **FullName** shall match exactly the corresponding **FullName** for the row in the **TypeDef** table indexed by **TypeDefId** [ERROR]

95. Ignoring nested Types, there shall be no duplicate rows, based upon **FullName** [ERROR]

96. For nested Types, there shall be no duplicate rows, based upon **TypeName** and enclosing Type [ERROR]

97. The complete list of Types exported from the current Assembly is given as the catenation of the **ExportedType** table with all public Types in the current **TypeDef** table, where “public” means a **Flags.tdVisibilityMask** of either **Public** or **NestedPublic**. There shall be no duplicate rows, in this concatenated table, based upon **FullName** (add Enclosing Type into the duplicates check if this is a nested Type) [ERROR]

---

21.15 **Field : 0x04**

The **Field** table has the following columns:

- **Flags** (a 2 byte bitmask of type **FieldAttributes**, clause 22.1.5)
- **Name** (index into String heap)
- **Signature** (index into Blob heap)

Conceptually, each row in the **Field** table is owned by one, and only one, row in the **TypeDef** table. However, the owner of any row in the **Field** table is not stored anywhere in the **Field** table itself. There is merely a ‘forward-pointer’ from each row in the **TypeDef** table (the **FieldList** column), as shown in the following illustration.

The **TypeDef** table has rows 1 through 4. The first row in the **TypeDef** table corresponds to a pseudo type, inserted automatically by the CLI. It is used to denote those rows in the **Field** table corresponding to global variables. The **Field** table has rows 1 through 6. Type 1 (pseudo type for ‘module’) owns rows 1 and 2 in the **Field** table. Type 2 owns no rows in the **Field** table, even though its **FieldList** indexes row 3 in the **Field** table. Type 3 owns rows 3 through 5 in the **Field** table. Type 4 owns row 6 in the **Field** table. (The next pointers in the diagram show the next free row in each table) So, in the **Field** table, rows 1 and 2 belong to Type 1 (global variables); rows 3 through 5 belong to Type 3; row 6 belongs to Type 4.

Each row in the **Field** table results from a toplevel **.field** directive (see Section 5.10), or a **.field** directive inside a Type (see Section 9.2). For an example see Section 0.

---

This contains informative text only

98. **Field** table may contain zero or more rows

99. Each row shall have one, and only one, owner row in the **TypeDef** table [ERROR]

100. The owner row in the **TypeDef** table shall not be an Interface [CLS]

101. **Flags** may have only those set that are specified [ERROR]

102. The **FieldAccessMask** subfield of **Flags** shall contain precisely one of **Compilercontrolled**, **Private**, **FamANDAssem**, **Assembly**, **Family**, **FamORAssem**, or **Public** (see clause 22.1.5) [ERROR]
103. Flags may set 0 or 1 of Literal or InitOnly (not both) (see clause 22.1.5) [ERROR]
104. If Flags.Literal = 1 then Flags.Static shall be 1 too (see clause 22.1.5) [ERROR]
105. If Flags.RTSpecialName = 1, then Flags.SpecialName shall also be 1 (see clause 22.1.5) [ERROR]
106. If Flags.HasFieldMarshal = 1, then this row shall ‘own’ exactly one row in the FieldMarshal table (see clause 22.1.5) [ERROR]
107. If Flags.HasDefault = 1, then this row shall ‘own’ exactly one row in the Constant table (see clause 22.1.5) [ERROR]
108. If Flags.HasFieldRVA = 1, then this row shall ‘own’ exactly one row in the Field’s RVA table (see clause 22.1.5) [ERROR]
109. Name shall index a non-null string in the String heap [ERROR]
110. The Name string shall be a valid CLS identifier [CLS]
111. Signature shall index a valid field signature in the Blob heap [ERROR]
112. If Flags.Compilercontrolled = 1 (see clause 22.1.5), then this row is ignored completely in duplicate checking.
113. If the owner of this field is the internally-generated type called <Module>, it denotes that this field is defined at module scope (commonly called a global variable). In this case:
   o Flags.Static shall be 1 [ERROR]
   o Flags.MemberAccessMask subfield shall be one of Public, Compilercontrolled, or Private (see clause 22.1.5) [ERROR]
   o module-scope fields are not allowed [CLS]
114. There shall be no duplicate rows in the Field table, based upon owner+Name+Signature (where owner is the owning row in theTypeDef table, as described above) (Note however that if Flags.Compilercontrolled = 1, then this row is completely excluded from duplicate checking) [ERROR]
115. There shall be no duplicate rows in the Field table, based upon owner+Name, where Name fields are compared using CLS conflicting-identifier-rules. So, for example,"int i" and "float i" would be considered CLS duplicates. (Note however that if Flags.Compilercontrolled = 1, then this row is completely excluded from duplicate checking, as noted above) [CLS]
116. If this is a field of an Enum, and Name string = "value__" then:
   b. RTSpecialName shall be 1 [ERROR]
      owner row in TypeDef table shall derive directly from System.Enum [ERROR]
      the owner row in TypeDef table shall have no other instance fields [CLS]
      its Signature shall be one of (see clause 22.1.15): [CLS]
      • ELEMENT_TYPE_U1
      • ELEMENT_TYPE_I2
      • ELEMENT_TYPE_I4
      • ELEMENT_TYPE_I8
117. its Signature shall be an integral type.

End informative text
21.16 FieldLayout: 0x10

The FieldLayout table has the following columns:

- **Offset** (a 4 byte constant)
- **Field** (index into the Field table)

Note that each Field in any Type is defined by its Signature. When a Type instance (ie, an object) is laid out by the CLI, each Field is one of three kinds:

- **Scalar** – for any member of built-in, such as int32. The size of the field is given by the size of that intrinsic, which varies between 1 and 8 bytes
- **ObjectRef** – for CLASS, STRING, OBJECT, ARRAY, SZARRAY
- **Pointer** – for PTR, FN PTR
- **ValueType** – for VALUETYPE. The instance of that ValueType is actually laid out in this object, so the size of the field is the size of that ValueType

(This lists above use an abbreviation – each all-caps name should be prefixed by ELEMENT_TYPE_, so, for example, STRING is actually ELEMENT_TYPE_STRING. See clause 22.1.15)

Note that metadata specifying explicit structure layout may be valid for use on one platform but not another, since some of the rules specified here are dependent on platform-specific alignment rules.

A row in the FieldLayout table is created if the .field directive for the parent field has specified a field offset (see Section 9.7).

This contains informative text only

118. A FieldLayout table may contain zero or more or rows
119. The Type whose Fields are described by each row of the FieldLayout table shall have Flags.ExplicitLayout (see clause 22.1.14) set [ERROR]
120. Offset shall be zero or more (cannot be negative) [ERROR]
121. Field shall index a valid row in the Field table [ERROR]
122. The row in the Field table indexed by Field shall be non-static (ie its Flags.Static shall be 0) [ERROR]
123. Among the rows owned by a given Type there shall be no duplicates, based upon Field. That is, a given Field of a Type cannot be given two offsets. [ERROR]
124. Each Field of kind ObjectRef shall be naturally aligned within the Type [ERROR]
125. No Field of kind ObjectRef may overlap any other Field no matter what its kind, wholly or partially [ERROR]
126. Among the rows owned by a given Type it is perfectly legal for several rows to have the same value of Offset, so long as they are not of type ObjectRef (used to define C unions, for example) [ERROR]
127. If ClassSize in the owner ClassLayout row is non-zero, then no Field may extend beyond that ClassSize (ie, the Field Offset value plus the Field’s calculated size shall not exceed ClassSize) (note that it is legal, and common, for ClassSize to be supplied as larger than the calculated object size - the CLI pads the object with trailing bytes up to the ClassSize value) [ERROR]
128. Every Field of an ExplicitLayout Type shall be given an offset - that is, it shall have a row in the FieldLayout table [ERROR]

End informative text
21.17 FieldMarshal : 0x0D

The `FieldMarshal` table has two columns. It ‘links’ an existing row in the `Field` or `Param` table, to information in the Blob heap that defines how that field or parameter (which, as usual, covers the method return, as parameter number 0) should be marshalled when calling to or from unmanaged code via PInvoke dispatch.

Note that `FieldMarshal` information is used only by code paths that arbitrate operation with unmanaged code. In order to execute such paths, the caller, on most platforms, would be installed with elevated security permission. Once it invokes unmanaged code, it lies outside the regime that the CLI can check - it is simply trusted not to violate the type system.

The `FieldMarshal` table has the following columns:

- **Parent** (index into `Field` or `Param` table; more precisely, a `HasFieldMarshal` coded index)
- **NativeType** (index into the Blob heap)

For the detailed format of the 'blob', see Section 0.

A row in the `FieldMarshal` table is created if the `.field` directive for the parent field has specified a `.marshall` attribute (see Section 15.1).

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### This contains informative text only

129. A `FieldMarshal` table may contain zero or more rows

130. **Parent** shall index a valid row in the Field or Param table (**Parent** values are encoded to say which of these two tables each refers to) [ERROR]

131. **NativeType** shall index a non-null 'blob' in the Blob heap [ERROR]

132. No two rows can point to the same parent. In other words, after the **Parent** values have been decoded to determine whether they refer to the Field or the Param table, no two rows can point to the same row in the Field table or in the Param table [ERROR]

133. The following checks apply to the `MarshalSpec` 'blob' (see Section 0):

   c. **NativeIntrinsic** shall be exactly one of the constant values in its production [ERROR]

   If **NativeIntrinsic** has the value `BYVALSTR`, then **Parent** shall point to a row in the Field table, not the Param table [ERROR]

   If **FIXEDARRAY**, then **Parent** shall point to a row in the Field table, not the Param table [ERROR]

   If **FIXEDARRAY**, then **NumElem** shall be 1 or more [ERROR]

   If **FIXEDARRAY**, then **ArrayElemType** shall be exactly one of the constant values in its production [ERROR]

   If **ARRAY**, then **ArrayElemType** shall be exactly one of the constant values in its production [ERROR]

   If **ARRAY**, then **ParamNum** may be zero

   If **ARRAY**, then **ParamNum** cannot be < 0 [ERROR]

   If **ARRAY**, and **ParamNum** > 0, then **Parent** shall point to a row in the Param table, not in the Field table [ERROR]

   If **ARRAY**, and **ParamNum** > 0, then **ParamNum** cannot exceed the number of parameters supplied to the MethodDef (or MethodRef if a `VARARG` call) of which the parent Param is a member [ERROR]

   If **ARRAY**, then **ElemMult** shall be >= 1 [ERROR]

   If **ARRAY** and **ElemMult** <> 1 issue a warning, because it is probably a mistake [WARNING]

   If **ARRAY** and **ParamNum** == 0, then **NumElem** shall be >= 1 [ERROR]
If \texttt{ARRAY} and \texttt{ParamNum} \neq 0 and \texttt{NumElem} \neq 0 then issue a warning, because it is probably a mistake [WARNING].

\textbf{End informative text}

\textbf{21.18 FieldRVA : 0x1D}

The \texttt{FieldRVA} table has the following columns:

\begin{itemize}
  \item \texttt{RVA} (a 4 byte constant)
  \item \texttt{Field} (index into \texttt{Field} table)
\end{itemize}

Conceptually, each row in the \texttt{FieldRVA} table is an extension to exactly one row in the \texttt{Field} table, and records the RVA (Relative Virtual Address) within the image file at which this field’s initial value is stored.

A row in the \texttt{FieldRVA} table is created for each static parent field that has specified the optional \texttt{data} label (see \textbf{Chapter 0}). The RVA column is the relative virtual address of the data in the PE file (see \textbf{Section 15.3}).

\textbf{This contains informative text only}

134. \texttt{RVA} shall be non-zero [ERROR]
135. \texttt{RVA} shall point into the current module’s data area (not its metadata area) [ERROR]
136. \texttt{Field} shall index a valid table in the \texttt{Field} table [ERROR]
137. Any field with an RVA shall be a \texttt{ValueType} (not a Class, and not an Interface). Moreover, it shall not have any private fields (and likewise for any of its fields that are themselves \texttt{ValueTypes}). (If any of these conditions were breached, code could overlay that global static and access its private fields.) Moreover, no fields of that \texttt{ValueType} can be Object References (into the GC heap) [ERROR]
138. So long as two RVA-based fields comply with the previous conditions, the ranges of memory spanned by the two \texttt{ValueTypes} may overlap, with no further constraints. This is not actually an additional rule; it simply clarifies the position with regard to overlapped RVA-based fields

\textbf{End informative text}

\textbf{21.19 File : 0x26}

The \texttt{File} table has the following columns:

\begin{itemize}
  \item \texttt{Flags} (a 4 byte bitmask of type FileAttributes, \textbf{clause 22.1.6})
  \item \texttt{Name} (index into String heap)
  \item \texttt{HashValue} (index into Blob heap)
\end{itemize}

The rows of the \texttt{File} table result from .\texttt{file} directives in an Assembly (see \textbf{clause 6.2.3}).

\textbf{This contains informative text only}

139. \texttt{Flags} may have only those values set that are specified (all combinations valid) [ERROR]
140. \texttt{Name} shall index a non-null string in the String heap. It shall be in the format \texttt{<filename>.<extension>} (eg “foo.dll”, but \textit{not} “c:\utilis\foo.dll”) [ERROR]
141. \texttt{HashValue} shall index a non-empty ‘blob’ in the Blob heap [ERROR]
142. There shall be no duplicate rows - rows with the same \texttt{Name} value [ERROR]
143. If this module contains a row in the \texttt{Assembly} table (that is, if this module “holds the manifest”) then there shall not be any row in the \texttt{File} table for this module - i.e., no self-reference [ERROR]
144. If the File table is empty, then this, by definition, is a single-file assembly. In this case, the ExportedType table should be empty [WARNING]

End informative text

21.20 ImplMap : 0x1C

The ImplMap table holds information about unmanaged methods that can be reached from managed code, using PInvoke dispatch.

Each row of the ImplMap table associates a row in the Method table (MemberForwarded) with the name of a routine (ImportName) in some unmanaged DLL (ImportScope).

Note: A typical example would be: associate the managed Method stored in row N of the Method table (so MemberForwarded would have the value N) with the routine called “GetEnvironmentVariable” (the string indexed by ImportName) in the DLL called “kernel32” (the string in the ModuleRef table indexed by ImportScope). The CLI intercepts calls to managed Method number N, and instead forwards them as calls to the unmanaged routine called “GetEnvironmentVariable” in “kernel32.dll” (including marshalling any arguments, as required).

The CLI does not support this mechanism to access fields that are exported from a DLL – only methods.

The ImplMap table has the following columns:

- **MappingFlags** (a 2 byte bitmask of type PInvokeAttributes, clause 22.1.7)
- **MemberForwarded** (index into the Field or Method table; more precisely, a MemberForwarded coded index. However, it only ever indexes the Method table, since Field export is not supported)
- **ImportName** (index into the String heap)
- **ImportScope** (index into the ModuleRef table)

A row is entered in the ImplMap table for each parent Method (see Section 14.5) that is defined with a .pinvokeimpl interoperation attribute specifying the MappingFlags, ImportName and ImportScope. For an example see Section 14.5.

This contains informative text only

- 145. ImplMap may contain zero or more rows
- 146. MappingFlags may have only those values set that are specified [ERROR]
- 147. MemberForwarded shall index a valid row in the Method table [ERROR]
- 148. The MappingFlags CharSetMask (see clause 22.1.7) in the row of the Method table indexed by MemberForwarded shall have at most one of the following bits set: CharSetAnsi, CharSetUnicode, or CharSetAuto [if none set, the default is CharSetNotSpec] [ERROR]
- 149. ImportName shall index a non-null string in the String heap [ERROR]
- 150. ImportScope shall index a valid row in the ModuleRef table [ERROR]
- 151. The row indexed in the Method table by MemberForwarded shall have its Flags.PinvokeImpl = 1, and Flags.Static = 1 [ERROR]

End informative text

21.21 InterfaceImpl : 0x09

The InterfaceImpl table has the following columns:

- **Class** (index into the TypeDef table)
- Interface (index into the TypeDef, TypeRef or TypeSpec table; more precisely, a TypeDefOrRef coded index)

The InterfaceImpl table records which interfaces a Type implements. Conceptually, each row in the InterfaceImpl table says that Class implements Interface.

**This contains informative text only**

1. Interface shall index a valid row in the TypeDef table [ERROR]
2. Interface shall index a valid row in the TypeDef or TypeRef table [ERROR]
3. The row in the TypeDef, TypeRef or TypeSpec table indexed by Interface shall be an interface (Flags.Interface = 1), not a Class or ValueType [ERROR]

155. There should be no duplicates in the InterfaceImpl table, based upon non-null- Class and Interface values [WARNING]
156. There can be many rows with the same value for Class (a class can implement many interfaces)
157. There can be many rows with the same value for Interface (many classes can implement the same interface)

**End informative text**

21.22 ManifestResource : 0x28

The ManifestResource table has the following columns:

- Offset (a 4 byte constant)
- Flags (a 4 byte bitmask of type ManifestResourceAttributes, clause 22.1.8)
- Name (index into the String heap)
- Implementation (index into File table, or AssemblyRef table, or null; more precisely, an Implementation coded index)

The Offset specifies the byte offset within the referenced file at which this resource record begins. The Implementation specifies which file holds this resource. The rows in the table result from .mresource directives on the Assembly (see clause 6.2.2).

**This contains informative text only**

158. The ManifestResource table may contain zero or more rows
159. Offset shall be a valid offset into the target file, starting from the Resource entry in the COR header [ERROR]
160. Flags may have only those values set that are specified [ERROR]
161. The VisibilityMask (see clause 22.1.8) subfield of Flags shall be one of Public or Private [ERROR]
162. Name shall index a non-null string in the String heap [ERROR]
163. Implementation may be null or non-null (if null, it means the resource is stored in the current file)
164. If Implementation is null, then Offset shall be a valid offset in the current file, starting from the Resource entry in the CLI header [ERROR]
165. If `Implementation` is non-null, then it shall index a valid row in the `File` or `AssemblyRef` table [ERROR]
166. There shall be no duplicate rows, based upon `Name` [ERROR]
167. If the resource is an index into the `File` table, `Offset` shall be zero [ERROR]

**End informative text**

### 21.23 MemberRef : 0x0A

The `MemberRef` table combines two sorts of references – to Fields and to Methods of a class, known as ‘MethodRef’ and ‘FieldRef’, respectively. The `MemberRef` table has the following columns:

- **Class** (index into the `TypeRef`, `ModuleRef`, `Method`, `TypeSpec` or `TypeDef` tables; more precisely, a `MemberRefParent` coded index)
- **Name** (index into String heap)
- **Signature** (index into Blob heap)

An entry is made into the `MemberRef` table whenever a reference is made, in the CIL code, to a method or field which is defined in another module or assembly. (Also, an entry is made for a call to a method with a `VARARG` signature, even when it is defined in the same module as the callsite)

**This contains informative text only**

168. `Class` shall be one of ...

   e. a `TypeRef` token, if the class that defines the member is defined in another module. (Note: it is unusual, but legal, to use a `TypeRef` token when the member is defined in this same module - its `TypeDef` token can be used instead)

   a `ModuleRef` token, if the member is defined, in another module of the same assembly, as a global function or variable

   a `MethodDef` token, when used to supply a call-site signature for a varargs method that is defined in this module. The `Name` shall match the `Name` in the corresponding `MethodDef` row. The `Signature` shall match the `Signature` in the target method definition [ERROR]

   a `TypeSpec` token, if the member is a member of a constructed type

169. `Class` shall not be null (this would indicate an unresolved reference to a global function or variable) [ERROR]

170. `Name` shall index a non-null string in the String heap [ERROR]

171. The `Name` string shall be a valid CLS identifier [CLS]

172. `Signature` shall index a valid field or method signature in the Blob heap. In particular, it shall embed exactly one of the following ‘calling conventions’: [ERROR]

   f. DEFAULT (0x0)

   VARARG (0x5)

   FIELD (0x6)

173. The `MemberRef` table shall contain no duplicates, where duplicate rows have the same `Class`, `Name` and `Signature` [WARNING]

174. `Signature` shall not have the `VARARG` (0x5) calling convention [CLS]

175. There shall be no duplicate rows, where `Name` fields are compared using CLS conflicting-identifier-rules [CLS]
There shall be no duplicate rows, where Name fields are compared using CLS conflicting-identifier-rules. (note, particular, that the return type, and whether parameters are marked ELEMENT_TYPE_BYREF (see clause 22.1.15) are ignored in the CLS. For example, int foo() and double foo() result in duplicate rows by CLS rules. Similarly, void bar(int i) and void bar(int& i) also result in duplicate rows by CLS rules) [CLS]

If Class and Name resolve to a field, then that field shall not have a value of Compilercontrolled (see clause 22.1.5) in its Flags.FieldAccessMask subfield [ERROR]

If Class and Name resolve to a method, then that method shall not have a value of he Compilercontrolled in its Flags.MemberAccessMask (see clause 22.1.9) subfield [ERROR]

The Method table has the following columns:

- RVA (a 4 byte constant)
- ImplFlags (a 2 byte bitmask of type MethodImplAttributes, clause 22.1.9)
- Flags (a 2 byte bitmask of type MethodAttribute, clause 22.1.9)
- Name (index into String heap)
- Signature (index into Blob heap)
- ParamList (index into Param table). It marks the first of a contiguous run of Parameters owned by this method. The run continues to the smaller of:
  - the last row of the Param table
  - the next run of Parameters, found by inspecting the ParamList of the next row in the Method table

Conceptually, every row in the Method table is owned by one, and only one, row in theTypeDef table. The rows in the Method table result from .method directives (see Chapter 14). The RVA column is computed when the image for the PE file is emitted and points to the COR_ILMETHOD structure for the body of the method (see Chapter 24.4)

The following combined bit settings in Flags are illegal [ERROR]

- Static | Final
- Static | Virtual
- Static | NewSlot
- Final | Abstract
- Abstract | PInvokeImpl
- Compilercontrolled | Virtual
Compilercontrolled | Final
Compilercontrolled | SpecialName
Compilercontrolled | RTSpecialName

185. An abstract method shall be virtual. So: if Flags.Abstract = 1 then Flags.Virtual shall also be 1 [ERROR]

186. If Flags.RTSpecialName = 1 then Flags.SpecialName shall also be 1 [ERROR]

187. If Flags.HasSecurity = 1, then at least one of the following conditions shall be true: [ERROR]
   o this Method owns at least row in the DeclSecurity table
   o this Method has a custom attribute called SuppressUnmanagedCodeSecurityAttribute

188. If this Method owns one (or more) rows in the DeclSecurity table then Flags.HasSecurity shall be 1 [ERROR]

189. If this Method has a custom attribute called SuppressUnmanagedCodeSecurityAttribute then Flags.HasSecurity shall be 1 [ERROR]

190. A Method may have a custom attribute called DynamicSecurityMethodAttribute - but this has no effect whatsoever upon the value of its Flags.HasSecurity

191. Name shall index a non-null string in the String heap [ERROR]

192. Interfaces cannot have instance constructors. So, if this Method is owned by an Interface, then its Name cannot be .ctor [ERROR]

193. Interfaces can only own virtual methods (not static or instance methods). So, if this Method is owned by an Interface, Flags.Static shall be clear [ERROR]

194. The Name string shall be a valid CLS identifier (unless Flags.RTSpecialName is set - for example, .ctor is legal) [CLS]

195. Signature shall index a valid method signature in the Blob heap [ERROR]

196. If Flags.Compilercontrolled = 1, then this row is ignored completely in duplicate checking

197. If the owner of this method is the internally-generated type called <Module>, it denotes that this method is defined at module scope. (In C++, the method is called global and can be referenced only within its compiland, from its point of declaration forwards.) In this case:
   h. Flags.Static shall be 1 [ERROR]
   Flags.Abstract shall be 0 [ERROR]
   Flags.Virtual shall be 0 [ERROR]
   Flags.MemberAccessMask subfield shall be one of Compilercontrolled, Public, or Private [ERROR]

module-scope methods are not allowed [CLS]

198. It makes no sense for ValueTypes, which have no identity, to have synchronized methods (unless they are boxed). So, if the owner of this method is a ValueType then the method cannot be synchronized. i.e. ImplFlags.Synchronized shall be 0 [ERROR]

199. There shall be no duplicate rows in the Method table, based upon owner+Name+Signature (where owner is the owning row in the TypeDef table). (Note however that if Flags.Compilercontrolled = 1, then this row is completely excluded from duplicate checking) [ERROR]

200. There shall be no duplicate rows in the Method table, based upon owner+Name+Signature, where Name fields are compared using CLS conflicting-identifier-rules; also, the Type defined in the signatures shall be different. So, for example, "int i" and "float i" would be considered CLS duplicates; also, the return type of the method is ignored (Note however that if Flags.Compilercontrolled = 1, then this row is completely excluded from duplicate checking as explained above) [CLS]
201. If any of Final, NewSlot, HideBySig are set in Flags, then Flags.Virtual shall also be set [ERROR]

202. If Flags.PInvokeImpl is set, then Flags.Virtual shall be 0 [ERROR]

203. If Flags.Abstract != 1 then exactly one of the following shall also be true: [ERROR]
   o RVA != 0
   o Flags.PInvokeImpl = 1
   o ImplFlags.Runtime = 1

204. If the method is Compilercontrolled, then the RVA shall be non-zero or marked with PInvokeImpl = 1 [ERROR]

205. Signature shall have exactly one of the following managed calling conventions [ERROR]
   i. DEFAULT (0x0)
   VARARG (x5)

206. Signature shall have the calling conventions DEFAULT (0x0). [CLS]

207. Signature: If and only if the method is not Static then the calling convention byte in Signature has its HASTHIS (0x20) bit set [ERROR]

208. Signature: If the method is static, then the HASTHIS (0x20) bit in the calling convention byte shall be 0 [ERROR]

209. If EXPPLICITTHIS (0x40) in the signature is set, then HASTHIS (0x20) shall also be set (note in passing: if EXPPLICITTHIS is set, then the code is not verifiable) [ERROR]

210. The EXPPLICITTHIS (0x40) bit can be set only in signatures for function pointers: signatures whose MethodDefSig is preceded by FNPTR (0x1B) [ERROR]

211. If RVA = 0, then either: [ERROR]
   o Flags.Abstract = 1, or
   o ImplFlags.Runtime = 1, or
   o Flags.PInvokeImpl = 1, or

212. If RVA != 0, then: [ERROR]
   j. Flags.Abstract shall be 0, and
   ImplFlags.CodeTypeMask shall be have exactly one of the following values: Native, CIL, or Runtime, and
   RVA shall point into the CIL code stream in this file

213. If Flags.PInvokeImpl = 1 then [ERROR]
   o RVA = 0 and the method owns a row in the ImplMap table, OR

214. If Flags.RTSpecialName = 1 then Name shall be one of: [ERROR]
   k. .ctor (object constructor method)
   .cctor (class constructor method)

215. Conversely, if Name is any of the above special names then Flags.RTSpecialName shall be set [ERROR]

216. If Name = .ctor (object constructor method) then:
   l. return type in Signature shall be ELEMENT_TYPE_VOID (see clause 22.1.15) [ERROR]
   Flags.Static shall be 0 [ERROR]
Flags.Abstract shall be 0 [ERROR]
Flags.Virtual shall be 0 [ERROR]

‘Owner’ type shall be a valid Class or ValueType (not <Module> and not an Interface) in the
TypeDef table [ERROR]

there can be 0 or more .ctors for any given ‘owner’

217. If Name = .cctor (class constructor method) then:
m. return type in Signature shall be ELEMENT_TYPE_VOID (see clause 22.1.15) [ERROR]
Signature shall have DEFAULT (0x0) for its calling convention [ERROR]
there shall be no parameters supplied in Signature [ERROR]
Flags.Static shall be set [ERROR]
Flags.Virtual shall be clear [ERROR]
Flags.Abstract shall be clear [ERROR]

218. Among the set of methods owned by any given row in the Typedef table there can be 0 or 1
methods named .cctor (never 2 or more) [ERROR]

End informative text

21.25 MethodImpl : 0x19

MethodImpls let a compiler override the default inheritance rules provided by the CLI. Their original use was
to allow a class “C”, that inherited method “Foo” from interfaces I and J, to provide implementations for both
methods (rather than have only one slot for “Foo” in its vtable). But MethodImpls can be used for other reasons
too, limited only by the compiler writer’s ingenuity within the constraints defined in the Validation rules below.

In the example above, Class specifies “C”, MethodDeclaration specifies I::Foo, MethodBody specifies the
method which provides the implementation for I::Foo (either a method body within “C”, or a method body
implemented by a superclass of “C”)

The MethodImpl table has the following columns:
  • Class (index into Typedef table)
  • MethodBody (index into Method or MemberRef table; more precisely, a MethodDefOrRef coded
index)
  • MethodDeclaration (index into Method or MemberRef table; more precisely, a MethodDefOrRef
coded index)

ilasm uses the .override directive to specify the rows of the MethodImpl table (see clause 9.3.2).

This contains informative text only

219. The MethodImpl table may contain zero or more rows
220. Class shall index a valid row in the Typedef table [ERROR]
221. MethodBody shall index a valid row in the Method or MethodRef table [ERROR]
222. The method indexed by MethodDeclaration shall have Flags.Virtual set [ERROR]
223. The owner Type of the method indexed by MethodDeclaration shall not have Flags.Sealed = 0
[ERROR]
224. The method indexed by MethodBody shall be a member of Class or some superclass of Class
MethodImpls do not allow compilers to ‘hook’ arbitrary method bodies) [ERROR]
225. The method indexed by MethodBody shall be virtual [ERROR]
226. The method indexed by MethodBody shall have its Method.RVA != 0 (cannot be an unmanaged method reached via PInvoke, for example) [ERROR]

227. MethodDeclaration shall index a method in the ancestor chain of Class (reached via its Extends chain) or in the interface tree of Class (reached via its InterfaceImpl entries) [ERROR]

228. The method indexed by MethodDeclaration shall not be final (its Flags.Final shall be 0) [ERROR]

229. The method indexed by MethodDeclaration shall be accessible to Class [ERROR]

230. The method signature defined by MethodBody shall match those defined by MethodDeclaration [ERROR]

231. There shall be no duplicate rows, based upon Class+MethodDeclaration [ERROR]

End informative text

21.26 MethodSemantics : 0x18

The MethodSemantics table has the following columns:

- Semantics (a 2 byte bitmask of type MethodSemanticsAttributes, clause 22.1.10)
- Method (index into the Method table)
- Association (index into the Event or Property table; more precisely, a HasSemantics coded index)

The rows of the MethodSemantics table are filled by .property (see Chapter 16) and .event directives (see Chapter 17). See clause 21.13 for more information.

This contains informative text only

232. MethodSemantics table may contain zero or more rows

233. Semantics may have only those values set that are specified [ERROR]

234. Method shall index a valid row in the Method table, and that row shall be for a method defined on the same class as the Property or Event this row describes [ERROR]

235. All methods for a given Property or Event shall have the same accessibility (ie the MemberAccessMask subfield of their Flags row) and cannot be Compilercontrolled [CLS]

236. Semantics: constrained as follows:

   o If this row is for a Property, then exactly one of Setter, Getter, or Other shall be set [ERROR]
   o If this row is for an Event, then exactly one of AddOn, RemoveOn, Fire, or Other shall be set [ERROR]

237. If this row is for an Event, and its Semantics is AddOn or RemoveOn, then the row in the Method table indexed by Method shall take a Delegate as a parameter, and return void [ERROR]

238. If this row is for an Event, and its Semantics is Fire, then the row indexed in the Method table by Method may return any type

239. For each property, there shall be a setter, or a getter, or both [CLS]

240. Any getter method for a property whose Name is xxx shall be called get_xxx [CLS]

241. Any setter method for a property whose Name is xxx shall be called set_xxx [CLS]

242. If a property provides both getter and setter methods, then these methods shall have the same value in the Flags.MemberAccessMask subfield [CLS]
243. If a property provides both getter and setter methods, then these methods shall have the same
value for their Method.Flags.Virtual [CLS]
244. Any getter and setter methods shall have Method.Flags.SpecialName = 1 [CLS]
245. Any getter method shall have a return type which matches the signature indexed by the
Property.Type field [CLS]
246. The last parameter for any setter method shall have a type which matches the signature indexed
by the Property.Type field [CLS]
247. Any setter method shall have return type ELEMENT_TYPE_VOID (see clause 22.1.15) in
Method.Signature [CLS]
248. If the property is indexed, the indexes for getter and setter shall agree in number and type [CLS]
249. Any AddOn method for an event whose Name is xxx shall have the signature: void add_xxx
(<DelegateType> handler) [CLS]
250. Any RemoveOn method for an event whose Name is xxx shall have the signature: void
remove_xxx(<DelegateType> handler) [CLS]
251. Any Fire method for an event whose Name is xxx shall have the signature: void raise_xxx(Event
e) [CLS]

End informative text

21.27 Module : 0x00

The Module table has the following columns:

• Generation (2 byte value, reserved, shall be zero)
• Name (index into String heap)
• Mvid (index into Guid heap; simply a Guid used to distinguish between two versions of the same
module)
• EncId (index into Guid heap, reserved, shall be zero)
• EncBaseId (index into Guid heap, reserved, shall be zero)

The Mvid column shall index a unique GUID in the GUID heap (see Section 23.2.5) that identifies this instance
of the module. The Mvid may be ignored on read by conforming implementations of the CLI. The Mvid should
be newly generated for every module, using the algorithm specified in ISO/IEC 11578:1996 (Annex A) or
another compatible algorithm.

Note: The term GUID stands for Globally Unique IDentifier, a 16-byte long number typically displayed using
its hexadecimal encoding. A GUID may be generated by several well-known algorithms including those used
for UUIDs (Universally Unique IDentifiers) in RPC and CORBA, as well as CLSIDs, GUIDs, and IIDs in
COM.

Rationale: While the VES itself makes no use of the Mvid, other tools (such as debuggers, which are outside
the scope of this standard) rely on the fact that the Mvid almost always differs from one module to another.

The Generation, EncId and EncBaseId columns can be written as zero, and can be ignored by conforming
implementations of the CLI. The rows in the Module table result from .module directives in the Assembly
(see Section 6.4).

This contains informative text only

252. The Module table shall contain one and only one row [ERROR]
253. Name shall index a non-null string. This string should match exactly any corresponding
ModuleRef.Name string that resolves to this module. [ERROR]
254. *Mvid* shall index a non-null GUID in the Guid heap [ERROR]

\[ \text{End informative text} \]

21.28 **ModuleRef : 0x1A**

The *ModuleRef* table has the following column:

- **Name** (index into String heap)

The rows in the *ModuleRef* table result from .module extern directives in the Assembly (see Section 6.5).

\[ \text{This contains informative text only} \]

255. *Name* shall index a non-null string in the String heap. This string shall enable the CLI to locate the target module (typically, it might name the file used to hold the module) [ERROR]

256. There should be no duplicate rows [WARNING]

257. *Name* should match an entry in the *Name* column of the *File* table. Moreover, that entry shall enable the CLI to locate the target module (typically it might name the file used to hold the module) [ERROR]

\[ \text{End informative text} \]

21.29 **NestedClass : 0x29**

The *NestedClass* table has the following columns:

- **NestedClass** (index into the *TypeDef* table)
- **EnclosingClass** (index into the *TypeDef* table)

The *NestedClass* table records which Type definitions are nested within which other Type definition. In a typical high-level language, including *ilasm*, the nested class is defined as lexically ‘inside’ the text of its enclosing Type.

\[ \text{This contains informative text only} \]

258. The *NestedClass* table may contain zero or more rows

259. *NestedClass* shall index a valid row in the *TypeDef* table [ERROR]

260. *EnclosingClass* shall index a valid row in the *TypeDef* table (note particularly, it is not allowed to index the *TypeRef* table) [ERROR]

261. There should be no duplicate rows (ie same values for *NestedClass* and *EnclosingClass*) [WARNING]

262. A given Type can only be nested by one encloser. So, there cannot be two rows with the same value for *NestedClass*, but different value for *EnclosingClass* [ERROR]

263. A given Type can ‘own’ several different nested Types, so it is perfectly legal to have two or more rows with the same value for *EnclosingClass* but different values for *NestedClass*

\[ \text{End informative text} \]

21.30 **Param : 0x08**

The *Param* table has the following columns:
• *Flags* (a 2-byte bitmask of type ParamAttributes, clause 22.1.12)
• *Sequence* (a 2-byte constant)
• *Name* (index into String heap)

Conceptually, every row in the *Param* table is owned by one, and only one, row in the *Method* table.

The rows in the *Param* table result from the parameters in a method declaration (see Section 14.4), or from a
`param` attribute attached to a method (see clause 14.4.1).

---

**This contains informative text only**

264. *Param* table may contain zero or more rows

265. Each row shall have one, and only one, owner row in the *MethodDef* table [ERROR]

266. *Flags* may have only those values set that are specified (all combinations valid) [ERROR]

267. *Sequence* shall have a value >= 0 and <= number of parameters in owner method. A *Sequence*
value of 0 refers to the owner method’s return type; its parameters are then numbered from 1
onwards [ERROR]

268. Successive rows of the *Param* table that are owned by the same method shall be ordered by
increasing *Sequence* value - although gaps in the sequence are allowed [WARNING]

269. If *Flags.HasDefault* = 1 then this row shall own exactly one row in the *Constant* table [ERROR]

270. If *Flags.HasDefault* = 0, then there shall be no rows in the *Constant* table owned by this row
[ERROR]

271. parameters cannot be given default values, so *Flags.HasDefault* shall be 0 [CLS]

272. if *Flags.FieldMarshal* = 1 then this row shall own exactly one row in the *FieldMarshal* table
[ERROR]

273. *Name* may be null or non-null

274. If *Name* is non-null, then it shall index a non-null string in the String heap [WARNING]

---

**End informative text**

### 21.31 Property: 0x17

Properties within metadata are best viewed as a means to gather together collections of methods defined on a
class, give them a name, and not much else. The methods are typically *get_* and *set_* methods, already defined
on the class, and inserted like any other methods into the *Method* table. The association is held together by
three separate tables – see the below:
Row 3 of the PropertyMap table indexes row 2 of the TypeDef table on the left (MyClass), whilst indexing row 4 of the Property table on the right – the row for a property called Foo. This setup establishes that MyClass has a property called Foo. But what methods in the Method table are gathered together as ‘belonging’ to property Foo? That association is contained in the MethodSemantics table – its row 2 indexes property Foo to the right, and row 2 in the Method table to the left (a method called get_Foo). Also, row 3 of the MethodSemantics table indexes Foo to the right, and row 3 in the Method table to the left (a method called set_Foo). As the shading suggests, MyClass has another property, called Bar, with two methods, get_Bar and set_Bar.

Property tables do a little more than group together existing rows from other tables. The Property table has columns for Flags, Name (eg Foo and Bar in the example here) and Type. In addition, the MethodSemantics table has a column to record whether the method it points at is a set_, a get_ or other.

Note: The CLS (see Partition I) refers to instance, virtual, and static properties. The signature of a property (from the Type column) can be used to distinguish a static property, since instance and virtual properties will have the “HASTHIS” bit set in the signature (see clause 22.2.1) while a static property will not. The distinction between an instance and a virtual property depends on the signature of the getter and setter methods, which the CLS requires to be either both virtual or both instance.

The Property (0x17) table has the following columns:

- Flags (a 2 byte bitmask of type PropertyAttributes, clause 22.1.13)
- Name (index into String heap)
- Type (index into Blob heap) [the name of this column is misleading. It does not index a TypeDef or TypeRef table – instead it indexes the signature in the Blob heap of the Property)

This contains informative text only

275. Property table may contain zero or more rows
276. Each row shall have one, and only one, owner row in the PropertyMap table (as described above) [ERROR]
277. PropFlags may have only those values set that are specified (all combinations valid) [ERROR]
278. Name shall index a non-null string in the String heap [ERROR]
279. The Name string shall be a valid CLS identifier [CLS]
280. Type shall index a non-null signature in the Blob heap [ERROR]
281. The signature indexed by Type shall be a valid signature for a property (ie, low nibble of leading byte is 0x8). Apart from this leading byte, the signature is the same as the property’s get_ method [ERROR]
282. Within the rows owned by a given row in the TypeDef table, there shall be no duplicates based upon Name+Type [ERROR]

283. There shall be no duplicate rows based upon Name, where Name fields are compared using CLS conflicting-identifier-rules (in particular, properties cannot be overloaded by their Type – a class cannot have two properties, "int Foo" and "String Foo", for example) [CLS]

End informative text

21.32 PropertyMap : 0x15

The PropertyMap table has the following columns:

- Parent (index into the TypeDef table)
- PropertyList (index into Property table). It marks the first of a contiguous run of Properties owned by Parent. The run continues to the smaller of:
  - the last row of the Property table
  - the next run of Properties, found by inspecting the PropertyList of the next row in this PropertyMap table

The PropertyMap and Property tables result from putting the .property directive on a class (see Chapter 16).

This contains informative text only

284. PropertyMap table may contain zero or more rows

285. There shall be no duplicate rows, based upon Parent (a given class has only one ‘pointer’ to the start of its property list) [ERROR]

286. There shall be no duplicate rows, based upon PropertyList (different classes cannot share rows in the Property table) [ERROR]

End informative text

21.33 StandAloneSig : 0x11

Signatures are stored in the metadata Blob heap. In most cases, they are indexed by a column in some table – Field.Signature, Method.Signature, MemberRef.Signature, etc. However, there are two cases that require a metadata token for a signature that is not indexed by any metadata table. The StandAloneSig table fulfills this need. It has just one column, that points to a Signature in the Blob heap.

The signature shall describe either:

- a method – code generators create a row in the StandAloneSig table for each occurrence of a calli CIL instruction. That row indexes the call-site signature for the function pointer operand of the calli instruction
- local variables – code generators create one row in the StandAloneSig table for each method, to describe all of its local variables. The .locals directive in ilasm generates a row in the StandAloneSig table.

The StandAloneSig table has the following column:

- Signature (index into the Blob heap)

Example (informative):

```csharp
// On encountering the calli instruction, ilasm generates a signature
// in the blob heap (DEFAULT, ParamCount = 1, RetType = int32, Param1 = int32),
```
// indexed by the StandAloneSig table:

.assembly Test {}

.method static int32 AddTen(int32)
{
    ldarg.0
    ldc.i4 10
    add
    ret
}

.class Test
{
    .method static void main()
    {
        .entrypoint
        ldc.i4.1
        ldftn int32 AddTen(int32)
        calli int32(int32)
        pop
        ret
    }
}

This contains informative text only

287. The StandAloneSig table may contain zero or more rows.
288. Signature shall index a valid signature in the Blob heap [ERROR]
289. The signature 'blob' indexed by Signature shall be a valid METHOD OR LOCALS signature [ERROR]
290. Duplicate rows are allowed

End informative text

21.34 TypeDef : 0x02

The TypeDef table has the following columns:
• Flags (a 4 byte bitmask of type TypeAttributes, clause 22.1.14)
• Name (index into String heap)
• Namespace (index into String heap)
• Extends (index into TypeDef, TypeRef or TypeSpec table; more precisely, a TypeDefOrRef coded index)
• FieldList (index into Field table; it marks the first of a contiguous run of Fields owned by this Type). The run continues to the smaller of:
  o the last row of the Field table
• the next run of Fields, found by inspecting the FieldList of the next row in thisTypeDef
  table

• MethodList (index into Method table; it marks the first of a contiguous run of Methods owned by
  this Type). The run continues to the smaller of:
  • the last row of the Method table
  • the next run of Methods, found by inspecting the MethodList of the next row in thisTypeDef
    table

Note that any type shall be one, and only one, of
• Class (Flags.Interface = 0, and derives ultimately from System.Object)
• Interface (Flags.Interface = 1)
• Value type, derived ultimately from System.ValueType

For any given type, there are two separate, and quite distinct ‘inheritance’ chains of pointers to other types (the
pointers are actually implemented as indexes into metadata tables). The two chains are:
• Extension chain – defined via the Extends column of theTypeDef table. Typically, a derived
  Class extends a base Class (always one, and only one, base Class)
• Interface chains – defined via the InterfaceImpl table. Typically, a Class implements zero, one or
  more Interfaces

These two chains (extension and interface) are always kept separate in metadata. The Extends chain represents
one-to-one relations – that is, one Class extends (or ‘derives from’) exactly one other Class (called its
immediate base Class). The Interface chains may represent one-to-many relations – that is, one Class might
well implement two or more Interfaces.

Example (informative, written in C#):

```csharp
interface IA {void m1(int i); }  
interface IB {void m2(int i, int j); }  
class C : IA, IB {  
    int f1, f2;  
    public void m1(int i) (f1 = i; )  
    public void m2(int i, int j) (f1 = i; f2 = j;)
}
// In metadata, Interface IA extends nothing; Interface IB  
// extends nothing; class C extends System.Object and implements  
// Interfaces IA and IB
```

An Interface can also ‘inherit’ from one or more other Interfaces – metadata stores those links via the
InterfaceImpl table (the nomenclature is a little inappropriate here – there is no “implementation” involved –
perhaps a clearer name might have been Interface table, or InterfaceInherit table)

Example (informative, written in C#):

```csharp
interface IA {void m1(int i); }  
interface IB {void m2(int i, int j); }  
interface IC : IA, IB {void m3(int i, int j, int k);}  
class C : IC {  
    int f1, f2, f3;
```
There are also a few specialized types. One is the user-defined Enum – which shall derive directly from System.Enum (via the Extends field).

Another slightly specialized type is a nested type which is declared in ilasm as lexically nested within an enclosing type declaration. Whether a type is nested can be determined by the value of its Flags.Visibility sub-field – it shall be one of the set {NestedPublic, NestedPrivate, NestedFamily, NestedAssembly, NestedFamANDAssem, NestedFamORAssem}.

The roots of the inheritance hierarchies look like this:

There is one system-defined root – System.Object. All Classes and ValueTypes shall derive, ultimately, from System.Object; Classes can derive from other Classes (through a single, non-looping chain) to any depth required. This Extends inheritance chain is shown with heavy arrows.

(See below for details of the System.Delegate Class)

Interfaces do not inherit from one another, however, they specify zero or more other interfaces which shall be implemented. The Interface requirement chain is shown as light, dashed arrows. This includes links between Interfaces and Classes/ValueTypes – where the latter are said to implement that interface or interfaces.

Regular ValueTypes (ie excluding Enums – see later) are defined as deriving directly from System.ValueType. Regular ValueTypes cannot be derived to a depth of more than one. (Another way to state this is that user-defined ValueTypes shall be sealed.) User-defined Enums shall derive directly from System.Enum. Enums cannot be derived to a depth of more than one below System.Enum. (Another way to state this is that user-defined Enums shall be sealed.) System_ENUM derives directly from System.ValueType.

The hierarchy below System_Delegate is as follows:
User-defined delegates derive directly from `System.MulticastDelegate`. Delegates cannot be derived to a depth of more than one.

For the directives to declare types see Chapter 9.

This contains informative text only

291. `TypeDef` table may contain one or more rows. There is always one row (row zero) that represents the pseudo class that acts as parent for functions and variables defined at module scope.

292. Flags:
   
n. `Flags` may have only those values set that are specified [ERROR]
   
can set 0 or 1 of `SequentialLayout` and `ExplicitLayout` (if none set, then defaults to `AutoLayout`) [ERROR]
   
can set 0 or 1 of `UnicodeClass` and `AutoClass` (if none set, then defaults to `AnsiClass`) [ERROR]
   
If `Flags.HasSecurity` = 1, then at least one of the following conditions shall be true: [ERROR]
   
   • this Type owns at least one row in the `DeclSecurity` table
   
   • this Type has a custom attribute called `SuppressUnmanagedCodeSecurityAttribute`
   
If this Type owns one (or more) rows in the `DeclSecurity` table then `Flags.HasSecurity` shall be 1 [ERROR]

If this Type has a custom attribute called `SuppressUnmanagedCodeSecurityAttribute` then `Flags.HasSecurity` shall be 1 [ERROR]

Note that it is legal for an Interface to have `HasSecurity` set. However, the security system ignores any permission requests attached to that Interface

293. `Name` shall index a non-null string in the String heap [ERROR]

294. The `Name` string shall be a valid CLS identifier [CLS]

295. `Namespace` may be null or non-null

296. If non-null, then `Namespace` shall index a non-null string in the String heap [ERROR]

297. If non-null, `Namespace`’s string shall be a valid CLS Identifier [CLS]

298. Every Class (with the sole exception of `System.Object`) shall extend one, and only one, other Class - so `Extends` for a Class shall be non-null [ERROR]

299. `System.Object` shall have an `Extends` value of null [ERROR]

300. `System.ValueType` shall have an `Extends` value of `System.Object` [ERROR]

301. With the sole exception of `System.Object`, for any Class, `Extends` shall index a valid row in the `TypeDef` or `TypeRef` table, where valid means 1 ≤ row ≤ rowcount. In addition, that row itself shall be a Class (not an Interface or ValueType) In addition, that base Class shall not be sealed (its `Flags.Sealed` shall be 0) [ERROR]
302. A Class cannot extend itself, or any of its children (ie its derived Classes), since this would introduce loops in the hierarchy tree [ERROR]
303. An Interface never extends another Type - so Extends shall be null (Interfaces do implement other Interfaces, but recall that this relationship is captured via the InterfaceImpl table, rather than the Extends column) [ERROR]
304. FieldList can be null or non-null
305. A Class or Interface may ‘own’ zero or more fields
306. A ValueType shall have a non-zero size - either by defining at least one field, or by providing a non-zero ClassSize [ERROR]
307. If FieldList is non-null, it shall index a valid row in the Field table, where valid means 1 <= row <= rowcount+1 [ERROR]
308. MethodList can be null or non-null
309. A Type may ‘own’ zero or more methods
310. The runtime size of a ValueType shall not exceed 1 MByte (0x100000 bytes) [ERROR]
311. If MethodList is non-null, it shall index a valid row in the Method table, where valid means 1 <= row <= rowcount+1 [ERROR]
312. A Class which has one or more abstract methods cannot be instantiated, and shall have Flags.Abstract = 1. Note that the methods owned by the class include all of those inherited from its base class and interfaces it implements, plus those defined via its MethodList. (The CLI shall analyze class definitions at runtime; if it finds a class to have one or more abstract methods, but has Flags.Abstract = 0, it will throw an exception) [ERROR]
313. An Interface shall have Flags.Abstract = 1 [ERROR]
314. It is legal for an abstract Type to have a constructor method (ie, a method named .ctor)
315. Any non-abstract Type (ie Flags.Abstract = 0) shall provide an implementation (body) for every method its contract requires. Its methods may be inherited from its base class, from the interfaces it implements, or defined by itself. The implementations may be inherited from its base class, or defined by itself [ERROR]
316. An Interface (Flags.Interface == 1) can own static fields (Field.Static == 1) but cannot own instance fields (Field.Static == 0) [ERROR]
317. An Interface cannot be sealed (if Flags.Interface == 1, then Flags.Sealed shall be 0) [ERROR]
318. All of the methods owned by an Interface (Flags.Interface == 1) shall be abstract (Flags.Abstract == 1) [ERROR]
319. There shall be no duplicate rows in theTypeDef table, based on Namespace+Name (unless this is a nested type - see below) [ERROR]
320. If this is a nested type, there shall be no duplicate row in theTypeDef table, based upon Namespace+Name+OwnerRowInNestedClassTable [ERROR]
321. There shall be no duplicate rows, where Namespace+Name fields are compared using CLS conflicting-identifier-rules (unless this is a nested type - see below) [CLS]
322. If this is a nested type, there shall be no duplicate rows, based upon Namespace+Name+OwnerRowInNestedClassTable and where Namespace+Name fields are compared using CLS conflicting-identifier-rules [CLS]
323. If Extends = System.Enum (ie, type is a user-defined Enum) then:
   o. shall be sealed (Sealed == 1) [ERROR]
   shall not have any methods of its own (MethodList chain shall be zero length) [ERROR]
shall not implement any interfaces (no entries in InterfaceImpl table for this type) [ERROR]
shall not have any properties  [ERROR]
shall not have any events  [ERROR]
any static fields shall be literal (have Flags.Literal = 1) [ERROR]
shall have at least one static, literal field. If more than one, they shall all be of the same type.
    Any such static literal fields shall be of the type of the Enum [CLS]
shall be at least one instance field, of integral type [ERROR]
shall be exactly one instance field [CLS]
the Name string of the instance field shall be "value__"; it shall marked RTSpecialName; its type
    shall be one of (see clause 22.1.15):  [CLS]
        • ELEMENT_TYPE_U1
        • ELEMENT_TYPE_I2
        • ELEMENT_TYPE_I4
        • ELEMENT_TYPE_I8
shall be no other members (ie, apart from any static literals, and the one instance field called
"value__")  [CLS]
324. A Nested type (defined above) shall own exactly one row in the NestedClass table - where ‘owns’
    means a row in that NestedClass table whose NestedClass column holds the TypeDef token for
    this type definition [ERROR]
325. A ValueType shall be sealed [ERROR]

End informative text

21.35 TypeError : 0x01
The TypeError table has the following columns:
• ResolutionScope (index into Module, ModuleRef, AssemblyRef or TypeError tables, or null; more
    precisely, a ResolutionScope coded index)
• Name (index into String heap)
• Namespace (index into String heap)

This contains informative text only

326. ResolutionScope shall be exactly one of:
    p. null - in this case, there shall be a row in the ExportedType table for this Type - its
        Implementation field shall contain a File token or an AssemblyRef token that says where the
type is defined [ERROR]
    a TypeError token, if this is a nested type (which can be determined by, for example, inspecting the
        Flags column in its TypeDef table - the accessibility subfield is one of the tdNestedXXX set)
        [ERROR]
    a ModuleRef token, if the target type is defined in another module within the same Assembly as
        this one [ERROR]
    a Module token, if the target type is defined in the current module - this should not occur in a CLI
        ("compressed metadata") module  [WARNING]
an AssemblyRef token, if the target type is defined in a different Assembly from the current module [ERROR]

327. Name shall index a non-null string in the String heap [ERROR]

328. Namespace may be null, or non-null

329. If non-null, Namespace shall index a non-null string in the String heap [ERROR]

330. The Name string shall be a valid CLS identifier [CLS]

331. There shall be no duplicate rows, where a duplicate has the same ResolutionScope, Name and Namespace [ERROR]

332. There shall be no duplicate rows, where Name and Namespace fields are compared using CLS conflicting-identifier-rules [CLS]

End informative text

21.36 TypeSpec : 0x1B

The TypeSpec table has just one column, which indexes the specification of a Type, stored in the Blob heap. This provides a metadata token for that Type (rather than simply an index into the Blob heap) – this is required, typically, for array operations – creating, or calling methods on the array class.

The TypeSpec table has the following column:

- Signature (index into the Blob heap, where the blob is formatted as specified in clause 22.2.14)

Note that TypeSpec tokens can be used with any of the CIL instructions that take a TypeDef or TypeRef token – specifically:

castclass, cpobj, initobj, isinst, ldelema, ldobj, mkrefany, newarr, refanyval, sizeof, stobj, box, unbox

This contains informative text only

The TypeSpec table may contain zero or more rows

Signature shall index a valid Type specification in the Blob heap [ERROR]

There shall be no duplicate rows, based upon Signature [ERROR]

End informative text
22 Metadata Logical Format: Other Structures

22.1 Bitmasks and Flags

This section explains the various flags and bitmasks used in the various metadata tables.

22.1.1 Values for AssemblyHashAlgorithm

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0x0000</td>
<td></td>
</tr>
<tr>
<td>Reserved (MD5)</td>
<td>0x8003</td>
<td></td>
</tr>
<tr>
<td>SHA1</td>
<td>0x8004</td>
<td></td>
</tr>
</tbody>
</table>

22.1.2 Values for AssemblyFlags

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PublicKey</td>
<td>0x0001</td>
<td>The assembly reference holds the full (unhashed) public key.</td>
</tr>
<tr>
<td>SideBySideCompatible</td>
<td>0x0000</td>
<td>The assembly is side by side compatible</td>
</tr>
<tr>
<td>&lt;reserved&gt;</td>
<td>0x0030</td>
<td>Reserved: both bits shall be zero</td>
</tr>
<tr>
<td>EnableJITcompileTracking</td>
<td>0x8000</td>
<td>Reserved (a conforming implementation of the CLI may ignore this setting on read; some implementations might use this bit to indicate that a CIL-to-native-code compiler should generate CIL-to-native code map)</td>
</tr>
<tr>
<td>DisableJITcompileOptimizer</td>
<td>0x4000</td>
<td>Reserved (a conforming implementation of the CLI may ignore this setting on read; some implementations might use this bit to indicate that a CIL-to-native-code compiler should not generate optimized code)</td>
</tr>
</tbody>
</table>

22.1.3 Values for Culture

<table>
<thead>
<tr>
<th>ar-SA</th>
<th>ar-IQ</th>
<th>ar-EG</th>
<th>ar-LY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ar-DZ</td>
<td>ar-MA</td>
<td>ar-TN</td>
<td>ar-GM</td>
</tr>
<tr>
<td>ar-YE</td>
<td>ar-SY</td>
<td>ar-JO</td>
<td>ar-LB</td>
</tr>
<tr>
<td>ar-KW</td>
<td>ar-AE</td>
<td>ar-BH</td>
<td>ar-QA</td>
</tr>
<tr>
<td>bg-BG</td>
<td>ca-ES</td>
<td>zh-TW</td>
<td>zh-CN</td>
</tr>
<tr>
<td>zh-HK</td>
<td>zh-SG</td>
<td>zh-MO</td>
<td>cs-CZ</td>
</tr>
<tr>
<td>da-DK</td>
<td>de-DE</td>
<td>de-CH</td>
<td>de-AI</td>
</tr>
<tr>
<td>de-LU</td>
<td>de-LI</td>
<td>el-GR</td>
<td>en-US</td>
</tr>
<tr>
<td>en-GB</td>
<td>en-AU</td>
<td>en-CA</td>
<td>en-NL</td>
</tr>
<tr>
<td>en-IE</td>
<td>en-ZA</td>
<td>en-JM</td>
<td>en-CB</td>
</tr>
<tr>
<td>en-BZ</td>
<td>en-TT</td>
<td>en-ZW</td>
<td>en-PH</td>
</tr>
<tr>
<td>es-ES-Ts</td>
<td>es-MX</td>
<td>es-ES-Is</td>
<td>es-GT</td>
</tr>
<tr>
<td>es-CR</td>
<td>es-PA</td>
<td>es-DO</td>
<td>es-VE</td>
</tr>
<tr>
<td>es-CO</td>
<td>es-PE</td>
<td>es-AR</td>
<td>es-EC</td>
</tr>
<tr>
<td>es-CL</td>
<td>es-UY</td>
<td>es-FY</td>
<td>es-BO</td>
</tr>
</tbody>
</table>
Note on RFC 1766 Locale names: a typical string would be “en-US”. The first part (“en” in the example) uses ISO 639 characters (“Latin-alphabet characters in lowercase. No diacritical marks of modified characters are used”). The second part (“US” in the example) uses ISO 3166 characters (similar to ISO 639, but uppercase). In other words, the familiar ASCII characters – a-z and A-Z respectively. However, whilst RFC 1766 recommends the first part is lowercase, the second part uppercase, it allows mixed case. Therefore, the validation rule checks only that Culture is one of the strings in the list above – but the check is totally case-blind – where case-blind is the familiar fold on values less than U+0080

22.1.4 Flags for Events [EventAttributes]

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpecialName</td>
<td>0x0200</td>
<td>Event is special.</td>
</tr>
<tr>
<td>RTSpecialName</td>
<td>0x0400</td>
<td>CLI provides 'special' behavior, depending upon the name of the event</td>
</tr>
</tbody>
</table>

22.1.5 Flags for Fields [FieldAttributes]

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FieldAccessMask</td>
<td>0x0007</td>
<td>Member not referenceable</td>
</tr>
<tr>
<td>Compilercontrolled</td>
<td>0x0000</td>
<td>Accessible only by the parent type</td>
</tr>
<tr>
<td>Private</td>
<td>0x0001</td>
<td>Accessible only by the parent type</td>
</tr>
<tr>
<td>FamANDAssem</td>
<td>0x0002</td>
<td>Accessible by sub-types only in this Assembly</td>
</tr>
<tr>
<td>Assembly</td>
<td>0x0003</td>
<td>Accessibly by anyone in the Assembly</td>
</tr>
<tr>
<td>Family</td>
<td>0x0004</td>
<td>Accessibly by type and sub-types</td>
</tr>
<tr>
<td>FamORAssem</td>
<td>0x0005</td>
<td>Accessibly by sub-types anywhere, plus anyone in assembly</td>
</tr>
<tr>
<td>Flag</td>
<td>Value</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------</td>
<td>--------------------------------------------------------------</td>
</tr>
<tr>
<td>Public</td>
<td>0x0006</td>
<td>Accessibly by anyone who has visibility to this scope field contract attributes</td>
</tr>
<tr>
<td>Static</td>
<td>0x0010</td>
<td>Defined on type, else per instance</td>
</tr>
<tr>
<td>InitOnly</td>
<td>0x0020</td>
<td>Field may only be initialized, not written to after init</td>
</tr>
<tr>
<td>Literal</td>
<td>0x0040</td>
<td>Value is compile time constant</td>
</tr>
<tr>
<td>NotSerialized</td>
<td>0x0080</td>
<td>Field does not have to be serialized when type is remoted</td>
</tr>
<tr>
<td>SpecialName</td>
<td>0x0200</td>
<td>Field is special</td>
</tr>
</tbody>
</table>

**Interop Attributes**

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PInvokeImpl</td>
<td>0x2000</td>
<td>Implementation is forwarded through PInvoke.</td>
</tr>
</tbody>
</table>

**Additional flags**

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTSpecialName</td>
<td>0x0400</td>
<td>CLI provides 'special' behavior, depending upon the name of the field</td>
</tr>
<tr>
<td>HasFieldMarshal</td>
<td>0x1000</td>
<td>Field has marshalling information</td>
</tr>
<tr>
<td>HasDefault</td>
<td>0x8000</td>
<td>Field has default</td>
</tr>
<tr>
<td>HasFieldRVA</td>
<td>0x0100</td>
<td>Field has RVA</td>
</tr>
</tbody>
</table>

**22.1.6 Flags for Files [FileAttributes]**

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ContainsMetaData</td>
<td>0x0000</td>
<td>This is not a resource file</td>
</tr>
<tr>
<td>ContainsNoMetaData</td>
<td>0x0001</td>
<td>This is a resource file or other non-metadata-containing file</td>
</tr>
</tbody>
</table>

**22.1.7 Flags for ImplMap [PInvokeAttributes]**

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoMangle</td>
<td>0x0001</td>
<td>PInvoke is to use the member name as specified</td>
</tr>
</tbody>
</table>

**Character set**

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CharSetMask</td>
<td>0x0006</td>
<td>This is a resource file or other non-metadata-containing file</td>
</tr>
<tr>
<td>CharSetNotSpec</td>
<td>0x0000</td>
<td></td>
</tr>
<tr>
<td>CharSetAnsi</td>
<td>0x0002</td>
<td></td>
</tr>
<tr>
<td>CharSetUnicode</td>
<td>0x0004</td>
<td></td>
</tr>
<tr>
<td>CharSetAuto</td>
<td>0x0006</td>
<td></td>
</tr>
<tr>
<td>SupportsLastError</td>
<td>0x0040</td>
<td>Information about target function. Not relevant for fields</td>
</tr>
</tbody>
</table>

**Calling convention**

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CallConvMask</td>
<td>0x0700</td>
<td></td>
</tr>
<tr>
<td>CallConvWinapi</td>
<td>0x0100</td>
<td></td>
</tr>
<tr>
<td>CallConvCdecl</td>
<td>0x0200</td>
<td></td>
</tr>
<tr>
<td>CallConvStdcall</td>
<td>0x0300</td>
<td></td>
</tr>
<tr>
<td>CallConvThiscall</td>
<td>0x0400</td>
<td></td>
</tr>
</tbody>
</table>
### Flags for ManifestResource [ManifestResourceAttributes]

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VisibilityMask</td>
<td>0x0007</td>
<td>The Resource is exported from the Assembly</td>
</tr>
<tr>
<td>Public</td>
<td>0x0001</td>
<td>The Resource is private to the Assembly</td>
</tr>
</tbody>
</table>

### Flags for Methods [MethodAttributes]

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MemberAccessMask</td>
<td>0x0007</td>
<td></td>
</tr>
<tr>
<td>Compilercontrolled</td>
<td>0x0000</td>
<td>Member not referenceable</td>
</tr>
<tr>
<td>Private</td>
<td>0x0001</td>
<td>Accessible only by the parent type</td>
</tr>
<tr>
<td>FamANDAssem</td>
<td>0x0002</td>
<td>Accessible by sub-types only in this Assembly</td>
</tr>
<tr>
<td>Assem</td>
<td>0x0003</td>
<td>Accessibly by anyone in the Assembly</td>
</tr>
<tr>
<td>Family</td>
<td>0x0004</td>
<td>Accessible only by type and sub-types</td>
</tr>
<tr>
<td>FamORAssem</td>
<td>0x0005</td>
<td>Accessibly by sub-types anywhere, plus anyone in assembly</td>
</tr>
<tr>
<td>Public</td>
<td>0x0006</td>
<td>Accessibly by anyone who has visibility to this scope</td>
</tr>
<tr>
<td>Static</td>
<td>0x0010</td>
<td>Defined on type, else per instance</td>
</tr>
<tr>
<td>Final</td>
<td>0x0020</td>
<td>Method may not be overridden</td>
</tr>
<tr>
<td>Virtual</td>
<td>0x0040</td>
<td>Method is virtual</td>
</tr>
<tr>
<td>HideBySig</td>
<td>0x0080</td>
<td>Method hides by name+sig, else just by name</td>
</tr>
<tr>
<td>VtableLayoutMask</td>
<td>0x0100</td>
<td>Use this mask to retrieve vtable attributes</td>
</tr>
<tr>
<td>ReuseSlot</td>
<td>0x0000</td>
<td>Method reuses existing slot in vtable</td>
</tr>
<tr>
<td>NewSlot</td>
<td>0x0100</td>
<td>Method always gets a new slot in the vtable</td>
</tr>
<tr>
<td>Abstract</td>
<td>0x0400</td>
<td>Method does not provide an implementation</td>
</tr>
<tr>
<td>SpecialName</td>
<td>0x0800</td>
<td>Method is special</td>
</tr>
</tbody>
</table>

### Interop attributes

- **PInvokeImpl**: 0x2000 Implementation is forwarded through PInvoke
- **UnmanagedExport**: 0x0008 Reserved: shall be zero for conforming implementations

### Additional flags

- **RTSpecialName**: 0x1000 CLI provides 'special' behavior, depending upon the name of the method
- **HasSecurity**: 0x4000 Method has security associate with it
Method calls another method containing security code.

### 22.1.10 Flags for Methods [MethodImplAttributes]

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CodeTypeMask</td>
<td>0x0003</td>
<td>Method impl is CIL</td>
</tr>
<tr>
<td>IL</td>
<td>0x0000</td>
<td>Method impl is native</td>
</tr>
<tr>
<td>Native</td>
<td>0x0001</td>
<td>Method impl is native</td>
</tr>
<tr>
<td>OPTIL</td>
<td>0x0002</td>
<td>Reserved: shall be zero in conforming implementations</td>
</tr>
<tr>
<td>Runtime</td>
<td>0x0003</td>
<td>Method impl is provided by the runtime</td>
</tr>
<tr>
<td>ManagedMask</td>
<td>0x0004</td>
<td>Flags specifying whether the code is managed or unmanaged.</td>
</tr>
<tr>
<td>Unmanaged</td>
<td>0x0004</td>
<td>Method impl is unmanaged, otherwise managed</td>
</tr>
<tr>
<td>Managed</td>
<td>0x0000</td>
<td>Method impl is managed</td>
</tr>
</tbody>
</table>

### Implementation info and interop

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ForwardRef</td>
<td>0x0010</td>
<td>Indicates method is defined; used primarily in merge scenarios</td>
</tr>
<tr>
<td>PreserveSig</td>
<td>0x0080</td>
<td>Reserved: conforming implementations may ignore</td>
</tr>
<tr>
<td>InternalCall</td>
<td>0x1000</td>
<td>Reserved: shall be zero in conforming implementations</td>
</tr>
<tr>
<td>Synchronized</td>
<td>0x0200</td>
<td>Method is single threaded through the body</td>
</tr>
<tr>
<td>NoInlining</td>
<td>0x0008</td>
<td>Method may not be inlined</td>
</tr>
<tr>
<td>MaxMethodImplVal</td>
<td>0xffff</td>
<td>Range check value</td>
</tr>
</tbody>
</table>

### 22.1.11 Flags for MethodSemantics [MethodSemanticsAttributes]

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setter</td>
<td>0x0001</td>
<td>Setter for property</td>
</tr>
<tr>
<td>Getter</td>
<td>0x0002</td>
<td>Getter for property</td>
</tr>
<tr>
<td>Other</td>
<td>0x0004</td>
<td>Other method for property or event</td>
</tr>
<tr>
<td>AddOn</td>
<td>0x0008</td>
<td>AddOn method for event</td>
</tr>
<tr>
<td>RemoveOn</td>
<td>0x0010</td>
<td>RemoveOn method for event</td>
</tr>
<tr>
<td>Fire</td>
<td>0x0020</td>
<td>Fire method for event</td>
</tr>
</tbody>
</table>

### 22.1.12 Flags for Params [ParamAttributes]

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>In</td>
<td>0x0001</td>
<td>Param is [In]</td>
</tr>
<tr>
<td>Out</td>
<td>0x0002</td>
<td>Param is [out]</td>
</tr>
<tr>
<td>Optional</td>
<td>0x0004</td>
<td>Param is optional</td>
</tr>
<tr>
<td>HasDefaultValue</td>
<td>0x1000</td>
<td>Param has default value</td>
</tr>
<tr>
<td>HasFieldMarshal</td>
<td>0x2000</td>
<td>Param has FieldMarshal</td>
</tr>
</tbody>
</table>
### 22.1.13 Flags for Properties [PropertyAttributes]

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpecialName</td>
<td>0x0200</td>
<td>Property is special</td>
</tr>
<tr>
<td>RTSpecialName</td>
<td>0x0400</td>
<td>Runtime(metadata internal APIs) should check name encoding</td>
</tr>
<tr>
<td>HasDefault</td>
<td>0x1000</td>
<td>Property has default</td>
</tr>
<tr>
<td>Unused</td>
<td>0xe9ff</td>
<td>Reserved: shall be zero in a conforming implementation</td>
</tr>
</tbody>
</table>

### 22.1.14 Flags for Types [TypeAttributes]

#### Visibility attributes

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VisibilityMask</td>
<td>0x00000007</td>
<td>Use this mask to retrieve visibility information</td>
</tr>
<tr>
<td>NotPublic</td>
<td>0x00000000</td>
<td>Class has no public scope</td>
</tr>
<tr>
<td>Public</td>
<td>0x00000001</td>
<td>Class has public scope</td>
</tr>
<tr>
<td>NestedPublic</td>
<td>0x00000002</td>
<td>Class is nested with public visibility</td>
</tr>
<tr>
<td>NestedPrivate</td>
<td>0x00000003</td>
<td>Class is nested with private visibility</td>
</tr>
<tr>
<td>NestedFamily</td>
<td>0x00000004</td>
<td>Class is nested with family visibility</td>
</tr>
<tr>
<td>NestedAssembly</td>
<td>0x00000005</td>
<td>Class is nested with assembly visibility</td>
</tr>
<tr>
<td>NestedFamANDAssem</td>
<td>0x00000006</td>
<td>Class is nested with family and assembly visibility</td>
</tr>
<tr>
<td>NestedFamORAssem</td>
<td>0x00000007</td>
<td>Class is nested with family or assembly visibility</td>
</tr>
</tbody>
</table>

#### Class layout attributes

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LayoutMask</td>
<td>0x00000018</td>
<td>Use this mask to retrieve class layout information</td>
</tr>
<tr>
<td>AutoLayout</td>
<td>0x00000000</td>
<td>Class fields are auto-laid out</td>
</tr>
<tr>
<td>SequentialLayout</td>
<td>0x00000008</td>
<td>Class fields are laid out sequentially</td>
</tr>
<tr>
<td>ExplicitLayout</td>
<td>0x00000010</td>
<td>Layout is supplied explicitly</td>
</tr>
</tbody>
</table>

#### Class semantics attributes

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClassSemanticsMask</td>
<td>0x00000020</td>
<td>Use this mask to retrieve class semantics information</td>
</tr>
<tr>
<td>Class</td>
<td>0x00000000</td>
<td>Type is a class</td>
</tr>
<tr>
<td>Interface</td>
<td>0x00000020</td>
<td>Type is an interface</td>
</tr>
</tbody>
</table>

#### Special semantics in addition to class semantics

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>0x00000080</td>
<td>Class is abstract</td>
</tr>
<tr>
<td>Sealed</td>
<td>0x00000100</td>
<td>Class cannot be extended</td>
</tr>
</tbody>
</table>
### Implementation Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Import</td>
<td>0x00001000</td>
<td>Class/Interface is imported</td>
</tr>
<tr>
<td>Serializable</td>
<td>0x00002000</td>
<td>Class is serializable</td>
</tr>
</tbody>
</table>

### String formatting Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>StringFormatMask</td>
<td>0x00030000</td>
<td>Use this mask to retrieve string information for native interop</td>
</tr>
<tr>
<td>AnsiClass</td>
<td>0x00000000</td>
<td>LPSTR is interpreted as ANSI</td>
</tr>
<tr>
<td>UnicodeClass</td>
<td>0x00010000</td>
<td>LPSTR is interpreted as Unicode</td>
</tr>
<tr>
<td>AutoClass</td>
<td>0x00020000</td>
<td>LPSTR is interpreted automatically</td>
</tr>
</tbody>
</table>

### Class Initialization Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeforeFieldInit</td>
<td>0x00100000</td>
<td>Initialize the class before first static field access</td>
</tr>
</tbody>
</table>

### Additional Flags

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTSpecialName</td>
<td>0x00000800</td>
<td>CLI provides 'special' behavior, depending upon the name of the Type</td>
</tr>
<tr>
<td>HasSecurity</td>
<td>0x00040000</td>
<td>Type has security associate with it</td>
</tr>
</tbody>
</table>

### 22.1.15 Element Types used in Signatures

The following table lists the values for ELEMENT_TYPE constants. These are used extensively in metadata signature blobs – see Section 22.2

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEMENT_TYPE_END</td>
<td>0x00</td>
<td>Marks end of a list</td>
</tr>
<tr>
<td>ELEMENT_TYPE_VOID</td>
<td>0x01</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_BOOLEAN</td>
<td>0x02</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_CHAR</td>
<td>0x03</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_I1</td>
<td>0x04</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_U1</td>
<td>0x05</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_I2</td>
<td>0x06</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_U2</td>
<td>0x07</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_I4</td>
<td>0x08</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_U4</td>
<td>0x09</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_I8</td>
<td>0x0a</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_U8</td>
<td>0x0b</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_R4</td>
<td>0x0c</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_R8</td>
<td>0x0d</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_STRING</td>
<td>0x0e</td>
<td></td>
</tr>
<tr>
<td>ELEMENT_TYPE_PTR</td>
<td>0x0f</td>
<td>Followed by &lt;type&gt; token</td>
</tr>
</tbody>
</table>
22.2 Blobs and Signatures

The word `signature` is conventionally used to describe the type info for a function or method – that is, the type of each of its parameters, and the type of its return value. Within metadata, the word `signature` is also used to describe the type info for fields, properties, and local variables. Each Signature is stored as a (counted) byte array in the Blob heap. There are five kinds of Signature, as follows:

- MethodRefSig – differs from a MethodDefSig only for VARARG calls
- MethodDefSig
- FieldSig
- PropertySig
- LocalVarSig
- TypeSpec

The value of the leading byte of a Signature 'blob' indicates what kind of Signature it is. This section defines the binary 'blob' format for each kind of Signature. In the syntax diagrams that accompany many of the definitions, shading is used to combine what would otherwise be multiple diagrams into a single diagram; the accompanying text describes the use of shading.

Note that Signatures are compressed before being stored into the Blob heap (described below) by compressing the integers embedded in the signature. The maximum encodable integer is 29 bits long, 0x1FFFFFFF. The compression algorithm used is as follows (bit 0 is the least significant bit):
• If the value lies between 0 (0x00) and 127 (0x7F), inclusive, encode as a one-byte integer (bit #7 is clear, value held in bits #6 through #0)

• If the value lies between $2^8$ (0x80) and $2^{14} - 1$ (0x3FFF), inclusive, encode as a two-byte integer with bit #15 set, bit #14 clear (value held in bits #13 through #0)

• Otherwise, encode as a 4-byte integer, with bit #31 set, bit #30 set, bit #29 clear (value held in bits #28 through #0)

• A null string should be represented with the reserved single byte 0xFF, and no following data

**Note:** The table below shows several examples. The first column gives a value, expressed in familiar (C-like) hex notation. The second column shows the corresponding, compressed result, as it would appear in a PE file, with successive bytes of the result lying at successively higher byte offsets within the file. (This is the opposite order from how regular binary integers are laid out in a PE file)

<table>
<thead>
<tr>
<th>Original Value</th>
<th>Compressed Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x03</td>
<td>03</td>
</tr>
<tr>
<td>0x7F</td>
<td>7F (7 bits set)</td>
</tr>
<tr>
<td>0x80</td>
<td>8080</td>
</tr>
<tr>
<td>0x2E57</td>
<td>AE57</td>
</tr>
<tr>
<td>0x3FFF</td>
<td>BFFF</td>
</tr>
<tr>
<td>0x4000</td>
<td>C000 4000</td>
</tr>
<tr>
<td>0x1FFF FFFF</td>
<td>DFFF FFFF</td>
</tr>
</tbody>
</table>

Thus, the most significant bits (the first ones encountered in a PE file) of a “compressed” field, can reveal whether it occupies 1, 2, or 4 bytes, as well as its value. For this to work, the “compressed” value, as explained above, is stored in big-endian order - with the most significant byte at the smallest offset within the file.

Signatures make extensive use of constant values called `ELEMENT_TYPE_xxx` – see Clause 22.1.15. In particular, signatures include two modifiers called:

- `ELEMENT_TYPE_BYREF` – this element is a managed pointer (see Partition I). This modifier can only occur in the definition of Param (clause 22.2.10) or RetType (clause 22.2.11). It shall not occur within the definition of a Field (clause 22.2.4)

- `ELEMENT_TYPE_PTR` – this element is an unmanaged pointer (see Partition I). This modifier can occur in the definition of Param (clause 22.2.10) or RetType (clause 22.2.11) or Field (clause 22.2.4)

### 22.2.1 MethodDefSig

A MethodDefSig is indexed by the Method.Signature column. It captures the signature of a method or global function. The syntax chart for a MethodDefSig is:

```
  MethodDefSig
     \- HASTHIS \- EXPLICITTHIS \- DEFAULT \- ParamCount
               \- VARARG
               \- RetType \- Param
```
This chart uses the following abbreviations:

- HASTHIS = 0x20, used to encode the keyword `instance` in the calling convention, see Section 14.3
- EXPLICITTHIS = 0x40, used to encode the keyword `explicit` in the calling convention, see Section 14.3
- DEFAULT = 0x0, used to encode the keyword `default` in the calling convention, see Section 14.3
- VARARG = for 0x5, used to encode the keyword `vararg` in the calling convention, see Section 14.3

The first byte of the Signature holds bits for HASTHIS, EXPLICITTHIS and calling convention – DEFAULT or VARARG. These are OR’d together.

- ParamCount is an integer that holds the number of parameters (0 or more). It can be any number between 0 and 0x1FFFFFFF. The compiler compresses it too (see Partition II Metadata Validation) – before storing into the 'blob' (ParamCount counts just the method parameters – it does not include the method’s return type).

The RetType item describes the type of the method’s return value (see clause 22.2.11)

The Param item describes the type of each of the method’s parameters. There shall be ParamCount instances of the Param item (see clause 22.2.10).

### 22.2.2 MethodRefSig

A MethodRefSig is indexed by the MemberRef.Signature column. This provides the callsite Signature for a method. Normally, this callsite Signature shall match exactly the Signature specified in the definition of the target method. For example, if a method Foo is defined that takes two uint32s and returns void; then any callsite shall index a signature that takes exactly two uint32s and returns void. In this case, the syntax chart for a MethodRefSig is identical with that for a MethodDefSig – see clause 22.2.1.

The Signature at a callsite differs from that at its definition, only for a method with the VARARG calling convention. In this case, the callsite Signature is extended to include info about the extra VARARG arguments (for example, corresponding to the “...” in C syntax). The syntax chart for this case is:

```plaintext
StandaloneMethodSig
```

This chart uses the following abbreviations:
HASTHIS = 0x20, used to encode the keyword instance in the calling convention, see Section 14.3
EXPLICITTHIS = 0x40, used to encode the keyword explicit in the calling convention, see Section 14.3
DEFAULT = 0x0, used to encode the keyword default in the calling convention, see Section 14.3
VARARG = for 0x5, used to encode the keyword vararg in the calling convention, see Section 14.3
SENTINEL = 0x41 (see clause 22.1.15), used to encode “...” in the parameter list, see Section 14.3

- The first byte of the Signature holds bits for HASTHIS, EXPLICITTHIS and calling convention – DEFAULT, VARARG, C, STDCALL, THISCALL, or FASTCALL. These are OR’d together.
- ParamCount is an integer that holds the number of parameters (0 or more). It can be any number between 0 and 0x1FFFFFFF The compiler compresses it too (see Partition II Metadata Validation) – before storing into the ‘blob’ (ParamCount counts just the method parameters – it does not include the method’s return type)
- The RetType item describes the type of the method’s return value (see clause 22.2.11)
- The Param item describes the type of each of the method’s parameters. There shall be ParamCount instances of the Param item (see clause 22.2.10).

The Param item describes the type of each of the method’s parameters. There shall be ParamCount instances of the Param item. This starts just like the MethodDefSig for a VARARG method (see clause 22.2.1). But then a SENTINEL token is appended, followed by extra Param items to describe the extra VARARG arguments. Note that the ParamCount item shall indicate the total number of Param items in the Signature – before and after the SENTINEL byte (0x41).

In the unusual case that a callsite supplies no extra arguments, the signature shall not include a SENTINEL (this is the route shown by the lower arrow that bypasses SENTINEL and goes to the end of the MethodRefSig definition)

22.2.3 StandAloneMethodSig

A StandAloneMethodSig is indexed by the StandAloneSig.Signature column. It is typically created as preparation for executing a calli instruction. It is similar to a MethodRefSig, in that it represents a callsite signature, but its calling convention may specify an unmanaged target (the calli instruction invokes either managed, or unmanaged code). Its syntax chart is:
This chart uses the following abbreviations (see Section 14.3):

- HASTHIS for 0x20
- EXPLICITTHIS for 0x40
- DEFAULT for 0x0
- VARARG for 0x5
- C for 0x1
- STDCALL for 0x2
- THISCALL for 0x3
- FASTCALL for 0x4
- SENTINEL for 0x41 (see clause 22.1.15 and Section 14.3)

- The first byte of the Signature holds bits for HASTHIS, EXPLICITTHIS and calling convention – DEFAULT, VARARG, C, STDCALL, THISCALL, or FASTCALL. These are OR'd together.

- ParamCount is an integer that holds the number of parameters (0 or more). It can be any number between 0 and 0x1FFFFFFF. The compiler compresses it too (see Partition II Metadata Validation) – before storing into the blob (ParamCount counts just the method parameters – it does not include the method’s return type)

- The RetType item describes the type of the method’s return value (see clause 22.2.11)

- The Param item describes the type of each of the method’s parameters. There shall be ParamCount instances of the Param item (see clause 22.2.10).

This is the most complex of the various method signatures. Two separate charts have been combined into one in this diagram, using shading to distinguish between them. Thus, for the following calling conventions:

- DEFAULT (managed), STDCALL, THISCALL and FASTCALL (unmanaged), the signature ends just before the SENTINEL item (these are all non vararg signatures). However, for the managed and unmanaged vararg calling conventions:

- VARARG (managed) and C (unmanaged), the signature can include the SENTINEL and final Param items (they are not required, however). These options are indicated by the shading of boxes in the syntax chart.
22.2.4 FieldSig

A FieldSig is indexed by the Field.Signature column, or by the MemberRef.Signature column (in the case where it specifies a reference to a field, not a method, of course). The Signature captures the field’s definition. The field may be a static or instance field in a class, or it may be a global variable. The syntax chart for a FieldSig looks like this:

![FieldSig Diagram]

This chart uses the following abbreviations:
- FIELD for 0x6
- CustomMod is defined in clause 22.2.7. Type is defined in clause 22.2.12

22.2.5 PropertySig

A PropertySig is indexed by the Property.Type column. It captures the type information for a Property – essentially, the signature of its getter method:
- how many parameters are supplied to its getter method
- the base type of the Property – the type returned by its getter method
- type information for each parameter in the getter method – that is, the index parameters

Note that the signatures of getter and setter are related precisely as follows:
- The types of a getter’s paramCount parameters are exactly the same as the first paramCount parameters of the setter
- The return type of a getter is exactly the same as the type of the last parameter supplied to the setter

The syntax chart for a PropertySig looks like this:

![PropertySig Diagram]

This chart uses the following abbreviations:
- PROPERTY for 0x8
- Type specifies the type returned by the Getter method for this property. Type is defined in clause 22.2.12
- Param is defined in clause 22.2.10.
- ParamCount is an integer that holds the number of index parameters in the getter methods (0 or more). (See clause 22.2.1) (ParamCount counts just the method parameters – it does not include the method’s base type of the Property)

22.2.6 LocalVarSig

A LocalVarSig is indexed by the StandAloneSig.Signature column. It captures the type of all the local variables in a method. Its syntax chart is:
This chart uses the following abbreviations:

- **LOCAL_SIG** for 0x7, used for the .locals directive, see clause 14.4.1.3
- **BYREF** for `ELEMENT_TYPE_BYREF` (see clause 22.1.15)
- **Constraint** is defined in clause 22.2.9.
- **Type** is defined in clause 22.2.12
- **Count** is an unsigned integer that holds the number of local variables. It can be any number between 1 and 0xFFFE.

There shall be **Count** instances of the **Type** in the LocalVarSig

### 22.2.7 CustomMod

The **CustomMod** (custom modifier) item in Signatures has a syntax chart like this:

This chart uses the following abbreviations:

- **CMOD_OPT** for `ELEMENT_TYPE_CMOD_OPT` (see clause 22.1.15)
- **CMOD_REQD** for `ELEMENT_TYPE_CMOD_REQD` (see clause 22.1.15)

The **CMOD_OPT** or **CMOD_REQD** value is compressed, see Section 22.2.

The **CMOD_OPT** or **CMOD_REQD** is followed by a metadata token that indexes a row in the TypeDef table or the TypeRef table. However, these tokens are encoded and compressed – see clause 22.2.8 for details.

If the CustomModifier is tagged **CMOD_OPT**, then any importing compiler can freely ignore it entirely. Conversely, if the CustomModifier is tagged **CMOD_REQD**, any importing compiler shall 'understand' the semantic implied by this CustomModifier in order to reference the surrounding Signature.

### 22.2.8 TypeDefOrRefEncoded

These items are compact ways to store a TypeDef or TypeRef token in a Signature (see clause 22.2.12).

Consider a regular TypeRef token, such as 0x01000012. The top byte of 0x01 indicates that this is a TypeRef token (see Partition V for a list of the supported metadata token types). The lower 3 bytes (0x000012) index row number 0x12 in the TypeRef table.

The encoded version of this TypeRef token is made up as follows:
333. encode the table that this token indexes as the least significant 2 bits. The bit values to use are 0, 1 and 2, specifying the target table is the **TypeDef**, **TypeRef** or **TypeSpec** table, respectively.

334. shift the 3-byte row index (0x0000012 in this example) left by 2 bits and OR into the 2-bit encoding from step 1.

335. compress the resulting value (see Section 22.2). This example yields the following encoded value:

- a) encoded = value for TypeRef table = 0x01 (from 1. above)
- b) encoded = ( 0x0000012 << 2 ) | 0x01
  - = 0x48 | 0x01
  - = 0x49
- c) encoded = Compress (0x49)
  - = 0x49

So, instead of the original, regular TypeRef token value of 0x01000012, requiring 4 bytes of space in the Signature 'blob', this TypeRef token is encoded as a single byte.

### 22.2.9 Constraint

The **Constraint** item in Signatures currently has only one possible value – **ELEMENT_TYPE_PINNED** (see clause 22.1.15), which specifies that the target type is pinned in the runtime heap, and will not be moved by the actions of garbage collection.

A **Constraint** can only be applied within a LocalVarSig (not a FieldSig). The Type of the local variable shall either be a reference type (in other words, it points to the actual variable – for example, an Object, or a String); or it shall include the **BYREF** item. The reason is that local variables are allocated on the runtime stack – they are never allocated from the runtime heap; so unless the local variable points at an object allocated in the GC heap, pinning makes no sense.

### 22.2.10 Param

The **Param** (parameter) item in Signatures has this syntax chart:

```
Param
```

This chart uses the following abbreviations:

- **BYREF** for 0x10 (See clause 22.1.15)
- **TYPEDBYREF** for 0x16 (See clause 22.1.15)

**CustomMod** is defined in clause 22.2.7. **Type** is defined in clause 22.2.12

### 22.2.11 RetType

The **RetType** (return type) item in Signatures has this syntax chart:
**RetType** is identical to **Param** except for one extra possibility, that it can include the type **VOID**. This chart uses the following abbreviations:

- **BYREF** for **ELEMENT_TYPE_BYREF** (see clause 22.1.15)
- **TYPEDBYREF** for **ELEMENT_TYPE_TYPEDBYREF** (see clause 22.1.15)
- **VOID** for **ELEMENT_TYPE_VOID** (see clause 22.1.15)

### 22.2.12 Type

**Type** is encoded in signatures as follows (I1 is an abbreviation for **ELEMENT_TYPE_I1**, etc., see clause 22.1.15):

```
Type ::= BOOLEAN | CHAR | I1 | U1 | I2 | U2 | I4 | U4 | I8 | U8 | R4 | R8 | I | U |
    | VALUETYPE TypeDefOrRefEncoded
    | CLASS TypeDefOrRefEncoded
    | STRING
    | OBJECT
    | PTR CustomMod* VOID
    | PTR CustomMod* Type
    | FNPTR MethodDefSig
    | FNPTR MethodRefSig
    | ARRAY Type ArrayShape (general array, see clause 22.2.13)
    | SZARRAY CustomMod* Type (single dimensional, zero-based array i.e. vector)
```

### 22.2.13 ArrayShape

An ArrayShape has the following syntax chart:

```
Rank NumSizes Size NumLoBounds LoBound
```

- **Rank** is an integer (stored in compressed form, see Section 22.2) that specifies the number of dimensions in the array (shall be 1 or more). **NumSizes** is a compressed integer that says how many dimensions have specified sizes (it shall be 0 or more). **Size** is a compressed integer specifying the size of that dimension – the sequence starts at the first dimension, and goes on for a total of **NumSizes** items. Similarly, **NumLoBounds** is a compressed integer that says how many dimensions have specified lower bounds (it shall be 0 or more). And **LoBound** is a compressed integer specifying the lower bound of that dimension – the sequence starts at the first
dimension, and goes on for a total of NumLoBounds items. None of the dimensions in these two sequences can be skipped, but the number of specified dimensions can be less than Rank.

Here are a few examples, all for element type int32:

<table>
<thead>
<tr>
<th>Type</th>
<th>Rank</th>
<th>NumSizes</th>
<th>Size</th>
<th>NumLoBounds</th>
<th>LoBound</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0...2]</td>
<td>I4</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>[,,,,,,]</td>
<td>I4</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>[0...3, 0...2,,,,]</td>
<td>I4</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>[1...2, 6...8]</td>
<td>I4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>[5, 3...5, , ]</td>
<td>I4</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: definitions can nest, since the Type may itself be an array

22.2.14 TypeSpec

The signature in the Blob heap indexed by a TypeSpec token has the following format –

TypeSpecBlob ::= 
| PTR CustomMod* VOID |
| PTR CustomMod* Type |
| FNPTR MethodDefSig |
| FNPTR MethodRefSig |
| ARRAY Type ArrayShape |
| SZARRAY CustomMod* Type |

For compactness, the ELEMENT_TYPE_ prefixes have been omitted from this list. So, for example, “PTR” is shorthand for ELEMENT_TYPE_PTR. (see clause 22.1.15) Note that a TypeSpecBlob does not begin with a calling-convention byte, so it differs from the various other signatures that are stored into Metadata.

22.2.15 Short Form Signatures

The general specification for signatures leaves some leeway in how to encode certain items. For example, it appears legal to encode a String as either

long-form: (ELEMENT_TYPE_CLASS, TypeRef-to-System.String )
short-form: ELEMENT_TYPE_STRING

Only the short form is valid. The following table shows which short-forms should be used in place of each long-form item. (As usual, for compactness, the ELEMENT_TYPE_ prefix have been omitted here – so VALUETYPE is short for ELEMENT_TYPE_VALUETYPE)

<table>
<thead>
<tr>
<th>Long Form</th>
<th>Short Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prefix</td>
<td>TypeRef to:</td>
</tr>
<tr>
<td>CLASS</td>
<td>System.String STRING</td>
</tr>
<tr>
<td>CLASS</td>
<td>System.Object OBJECT</td>
</tr>
<tr>
<td>VALUETYPE</td>
<td>System.Void VOID</td>
</tr>
<tr>
<td>VALUETYPE</td>
<td>System.Boolean BOOLEAN</td>
</tr>
<tr>
<td>VALUETYPE</td>
<td>System.Char CHAR</td>
</tr>
<tr>
<td>VALUETYPE</td>
<td>System.Byte U1</td>
</tr>
<tr>
<td>VALUETYPE</td>
<td>System.SByte I1</td>
</tr>
<tr>
<td>VALUETYPE</td>
<td>System.Int16 i2</td>
</tr>
</tbody>
</table>
### 22.3 Custom Attributes

A Custom Attribute has the following syntax chart:

![CustomAttribute Chart](image)

1. All binary values are stored in little-endian format (except PackedLen items – used only as counts for the number of bytes to follow in a UTF8 string)

2. `CustomAttrib` starts with a `Prolog` – an unsigned int16, with value 0x0001

3. Next comes a description of the fixed arguments for the constructor method. Their number and type is found by examining that constructor’s MethodDef; this info is not repeated in the `CustomAttrib` itself. As the syntax chart shows, there can be zero or more `FixedArgs`.

4. Next is a description of the optional “named” fields and properties. This starts with `NumNamed` – an unsigned int16 giving the number of “named” properties or fields that follow. Note that `NumNamed` shall always be present. If its value is zero, there are no “named” properties or fields to follow (and of course, in this case, the `CustomAttrib` shall end immediately after `NumNamed`). In the case where `NumNamed` is non-zero, it is followed by `NumNamed` repeats of `NamedArgs`.

#### FixedArg

- The format for each `FixedArg` depends upon whether that argument is single, or an `SZARRAY` – this is shown in the upper and lower paths, respectively, of the syntax chart. So each `FixedArg` is either a single `Elem`, or `NumElem` repeats of `Elem`.

  - (`SZARRAY` is the single byte 0x1d, and denotes a vector – a single-dimension array with a lower bound of zero)
NumElem is an unsigned int32 specifying the number of elements in the `szarray` `Elem`.

An `Elem` takes one of three forms:

- if the parameter kind is simple (`bool`, `char`, `float32`, `float64`, `int8`, `int16`, `int32`, `int64`, `unsigned int8`, `unsigned int16`, `unsigned int32` or `unsigned int64`) then the 'blob' contains its binary value (`Val`). This pattern is also used if the parameter kind is an `enum` -- simply store the value of the enum's underlying integer type.
- if the parameter kind is string or type, then the blob contains a `SerString` -- a `PackedLen` count of bytes, followed by the UTF8 characters. (a type is stored as a string giving the full name of that type)
- if the parameter kind is a boxed simple value type (`bool`, `char`, `float32`, `float64`, `int8`, `int16`, `int32`, `int64`, `unsigned int8`, `unsigned int16`, `unsigned int32` or `unsigned int64`) then the blob contains the value type's `FieldOrPropType` (see below), followed by its binary value (`Val`).

`Val` is the binary value for a simple type. A `bool` is a single byte with value 0 (false) or 1 (true); `char` is a two-byte unicode character; and the others have their obvious meaning.

A `NamedArg` is simply a `FixedArg` (discussed above) preceded by information to identify which field or property it represents.

`FIELD` is the single byte 0x53

`PROPERTY` is the single byte 0x54

The `FieldOrPropType` shall be exactly one of: `ELEMENT_TYPE_BOOLEAN`, `ELEMENT_TYPE_CHAR`, `ELEMENT_TYPE_I1`, `ELEMENT_TYPE_U1`, `ELEMENT_TYPE_I2`, `ELEMENT_TYPE_U2`, `ELEMENT_TYPE_I4`, `ELEMENT_TYPE_U4`, `ELEMENT_TYPE_I8`, `ELEMENT_TYPE_U8`, `ELEMENT_TYPE_R4`, `ELEMENT_TYPE_R8`, `ELEMENT_TYPE_STRING` or the constant 0x50 (for an argument of type `Type`). (See clause 22.1.15)

The `FieldOrPropName` is the name of the field or property, stored as a `SerString` (defined above).

The `SerString` used to encode an argument of type `Type` includes the full type name, followed optionally by the assembly where it is defined, its version, culture and public key token. If the assembly name is omitted, the CLI looks first in this assembly, and then the assembly named `mscorlib`.
For example, consider the Type string “Ozzy.OutBack.Kangaroo+Wallaby, MyAssembly” for a class “Wallaby” nested within class “Ozzy.OutBack.Kangaroo”, defined in the assembly “MyAssembly”.

### 22.4 Marshalling Descriptors

A Marshalling Descriptor is like a signature – it’s a ‘blob’ of binary data. It describes how a field or parameter (which, as usual, covers the method return, as parameter number 0) should be marshalled when calling to or from unmanaged code via PInvoke dispatch. The ilasm syntax `marshal` can be used to create a marshalling descriptor, as can the pseudo custom attribute `MarshalAsAttribute` -- see clause 20.2.1.

Note that a conforming implementation of the CLI need only support marshalling of the types specified earlier – see clause 14.5.4.

Marshalling descriptors make use of constants named NATIVE_TYPE_xxx. Their names and values are listed in the following table:

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NATIVE_TYPE_BOOLEAN</td>
<td>0x02</td>
</tr>
<tr>
<td>NATIVE_TYPE_I1</td>
<td>0x03</td>
</tr>
<tr>
<td>NATIVE_TYPE_U1</td>
<td>0x04</td>
</tr>
<tr>
<td>NATIVE_TYPE_I2</td>
<td>0x05</td>
</tr>
<tr>
<td>NATIVE_TYPE_U2</td>
<td>0x06</td>
</tr>
<tr>
<td>NATIVE_TYPE_I4</td>
<td>0x07</td>
</tr>
<tr>
<td>NATIVE_TYPE_U4</td>
<td>0x08</td>
</tr>
<tr>
<td>NATIVE_TYPE_I8</td>
<td>0x09</td>
</tr>
<tr>
<td>NATIVE_TYPE_U8</td>
<td>0x0a</td>
</tr>
<tr>
<td>NATIVE_TYPE_R4</td>
<td>0x0b</td>
</tr>
<tr>
<td>NATIVE_TYPE_R8</td>
<td>0x0c</td>
</tr>
<tr>
<td>NATIVE_TYPE_LPSTR</td>
<td>0x14</td>
</tr>
<tr>
<td>NATIVE_TYPE_INT</td>
<td>0x1f</td>
</tr>
<tr>
<td>NATIVE_TYPE_UINT</td>
<td>0x20</td>
</tr>
<tr>
<td>NATIVE_TYPE_FUNC</td>
<td>0x26</td>
</tr>
<tr>
<td>NATIVE_TYPE_ARRAY</td>
<td>0x2a</td>
</tr>
</tbody>
</table>

The ‘blob’ has the following format –

\[\text{MarshalSpec ::= NativeInstrinsic} \]

\[\text{NativeInstrinsic ::= ARRAY ArrayElemType ParamNum ElemMult NumElem} \]

\[\text{NativeInstrinsic ::= BOOLEAN | I1 | U1 | I2 | U2 | I4 | U4 | I8 | U8 | R4 | R8} \]

\[\text{CURRENCY | BSTR | LPSTR | LPWSTR | LPTSTR} \]

\[\text{INT | UINT | FUNC | LPVOID} \]

For compactness, the NATIVE_TYPE_ prefixes have been omitted in the above lists. So, for example, “ARRAY” is shorthand for NATIVE_TYPE_ARRAY

\[\text{NumElem} \] is an integer (compressed as described in Section 22.2) that specifies how many elements are in the array.

\[\text{ArrayElemType ::= NativeInstrinsic | BOOLEAN | I1 | U1 | I2 | U2} \]
ParamNum is an integer (compressed as described in Section 22.2) specifying the parameter in the method call that provides the number of elements in the array – see below.

ElemMult is an integer compressed as described in Section 22.2 (says by what factor to multiply – see below)

Note:
For example, in the method declaration:

```c
Foo (int ar1[], int size1, byte ar2[], int size2)
```

The `ar1` parameter might own a row in the `FieldMarshal` table, which indexes a `MarshalSpec` in the Blob heap with the format:

```
ARRAY MAX 2 1 0
```

This says the parameter is marshalled to a `NATIVE_TYPE_ARRAY`. There is no additional info about the type of each element (signified by that `NATIVE_TYPE_MAX`). The value of `ParamNum` is 2, which indicates that parameter number 2 in the method (the one called “size1”) will specify the number of elements in the actual array – let’s suppose its value on a particular call is 42. The value of `ElemMult` is 1. The value of `NumElem` is 0. The calculated total size, in bytes, of the array is given by the formula:

```c
if ParamNum == 0
    SizeInBytes = NumElem * sizeof (elem)
else
    SizeInBytes = ( @ParamNum * ElemMult + NumElem ) * sizeof (elem)
endif
```

The syntax “@ParamNum” is used here to denote the value passed in for parameter number `ParamNum` – it would be 42 in this example. The size of each element is calculated from the metadata for the `ar1` parameter in `Foo`’s signature – an `ELEMENT_TYPE_I4` (see clause 22.1.15) of size 4 bytes.
23 Metadata Physical Layout

The physical on-disk representation of metadata is a direct reflection of the logical representation described in Chapter 21 and Chapter 22. That is, data is stored in streams representing the metadata tables and heaps. The main complication is that, where the logical representation is abstracted from the number of bytes needed for indexing into tables and columns, the physical representation has to take care of that explicitly by defining how to map logical metadata heaps and tables into their physical representations.

23.1 Fixed Fields

Complete CLI components (metadata and CIL instructions) are stored in a subset of the current Portable Executable (PE) File Format (see Chapter 24). Because of this heritage, some of the fields in the physical representation of metadata have fixed values. When writing these fields they shall be set to the value indicated, on reading they may be ignored.

23.2 File Headers

23.2.1 Metadata root

The root of the physical metadata starts with a magic signature, several bytes of version and other miscellaneous information, followed by a count and an array of stream headers, one for each stream that is present. The actual encoded tables and heaps are stored in the streams, which immediately follow this array of headers.

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>Signature</td>
<td>Magic signature for physical metadata : 0x424A5342.</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>MajorVersion</td>
<td>Major version, 1 (ignore on read)</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>MinorVersion</td>
<td>Minor version, 0 (ignore on read)</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>Reserved</td>
<td>Reserved, always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>Length</td>
<td>Length of version string in bytes, say ( m ).</td>
</tr>
<tr>
<td>16</td>
<td>( m )</td>
<td>Version</td>
<td>UTF8-encoded version string of length ( m ) (ignore on read)</td>
</tr>
<tr>
<td>( 16 + m )</td>
<td></td>
<td>Padding to next 4 byte boundary, say ( x ).</td>
<td></td>
</tr>
<tr>
<td>( x )</td>
<td>2</td>
<td>Flags</td>
<td>Reserved, always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>( x+2 )</td>
<td>2</td>
<td>Streams</td>
<td>Number of streams, say ( n ).</td>
</tr>
<tr>
<td>( x+4 )</td>
<td></td>
<td>StreamHeaders</td>
<td>Array of ( n ) StreamHdr structures.</td>
</tr>
</tbody>
</table>

23.2.2 Stream Header

A stream header gives the names, and the position and length of a particular table or heap. Note that the length of a Stream header structure is not fixed, but depends on the length of its name field (a variable length null-terminated string).

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>Offset</td>
<td>Memory offset to start of this stream from start of the metadata root (see clause 23.2.1)</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Size</td>
<td>Size of this stream in bytes, shall be a multiple of 4.</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Name</td>
<td>Name of the stream as null terminated variable length array of ASCII characters, padded with ( 0 ) characters</td>
</tr>
</tbody>
</table>

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Both logical tables and heaps are stored in streams. There are five possible kinds of streams. A stream header
with name “#Strings” that points to the physical representation of the string heap where identifier strings are
stored; a stream header with name “#US” that points to the physical representation of the user string heap; a
stream header with name “#Blob” that points to the physical representation of the blob heap, a stream header
with name “#GUID” that points to the physical representation of the GUID heap; and a stream header with
name “#~” that points to the physical representation of a set of tables. (see Chapter 22)
Each kind of stream may occur at most once, that is, a meta-data file may not contain two “#US” streams, or
five “#Blob” streams. Streams need not be there if they are empty.
The next sections will describe the structure of each kind of stream in more detail.

23.2.3 #Strings heap
The stream of bytes pointed to by a “#Strings” header is the physical representation of the logical string heap.
The physical heap may contain garbage, that is, it may contain parts that are unreachable from any of the tables,
but parts that are reachable from a table shall contain a valid null terminated UTF8 string. When the #String
heap is present, the first entry is always the empty string (ie \0).

23.2.4 #US and #Blob heaps
The stream of bytes pointed to by a “#US” or “#Blob” header are the physical representation of logical
Userstring and ‘blob’ heaps respectively. Both these heaps may contain garbage, as long as any part that is
reachable from any of the tables contains a valid ‘blob’. Individual blobs are stored with their length encoded in
the first few bytes:
• If the first one byte of the ‘blob’ is 0x0bs, then the rest of the ‘blob’ contains the (bs) bytes of actual
data.
• If the first two bytes of the ‘blob’ are 10bs and x, then the rest of the ‘blob’ contains the (bs << 8 +
x) bytes of actual data.
• If the first four bytes of the ‘blob’ are 110bs, x, y, and z, then the rest of the ‘blob’ contains the (bs
<< 24 + x << 16 + y << 8 + z) bytes of actual data.
The first entry in both these heap is the empty ‘blob’ that consists of the single byte 0x00.

23.2.5 #GUID heap
The “#GUID” header points to a sequence of 128-bit GUIDs. There might be unreachable GUIDs stored in the
stream.

23.2.6 #~ stream
The “#~” streams contain the actual physical representations of the logical metadata tables (see Chapter 21). A
“#~” stream has the following top-level structure:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>Reserved</td>
<td>Reserved, always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>MajorVersion</td>
<td>Major version of table schemata, always 1 (see Section 23.1).</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>MinorVersion</td>
<td>Minor version of table schemata, always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>HeapSizes</td>
<td>Bit vector for heap sizes.</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Reserved</td>
<td>Reserved, always 1 (see Section 23.1).</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>Valid</td>
<td>Bit vector of present tables, let n be the number of bits that are 1.</td>
</tr>
<tr>
<td>16</td>
<td>8</td>
<td>Sorted</td>
<td>Bit vector of sorted tables.</td>
</tr>
</tbody>
</table>
The HeapSizes field is a bitvector that encodes how wide indexes into the various heaps are. If bit 0 is set, indexes into the "#String" heap are 4 bytes wide; if bit 1 is set, indexes into the "#GUID" heap are 4 bytes wide; bit 2 is not used; if bit 3 is set, indexes into the "#Blob" heap are 4 bytes wide. Conversely, if the HeapSize bit for a particular heap is not set, indexes into that heap are 2 bytes wide.

<table>
<thead>
<tr>
<th>Bit position</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x01</td>
<td>Size of &quot;#String&quot; stream $\geq 2^{16}$.</td>
</tr>
<tr>
<td>0x02</td>
<td>Size of &quot;#GUID&quot; stream $\geq 2^{16}$</td>
</tr>
<tr>
<td>0x04</td>
<td>Size of &quot;#Blob&quot; stream $\geq 2^{16}$.</td>
</tr>
</tbody>
</table>

The Valid field is a 64 bits wide bitvector that has a specific bit set for each table that is stored in the stream; the mapping of tables to indexes is given at the start of Chapter 21. For example when the DeclSecurity table is present in the logical metadata, bit 0x0e should be set in the Valid vector. It is illegal to include non-existent tables in Valid, so all bits above 0x2b shall be zero.

The Rows array contains the number of rows for each of the tables that are present. When decoding physical metadata to logical metadata, the number of 1’s in Valid indicates the number of elements in the Rows array.

A crucial aspect in the encoding of a logical table is its schema. The schema for each table is given in Chapter 21. For example, the table with assigned index 0x02 is a TypeDef table, which, according to its specification in Section 21.34, has the following columns: 4 byte-wide flags, index into the String heap, another index into String heap, index into TypeDef or TypeRef table, index into Field table, index into Method table.

The physical representation of a table with schema $(C_0, \ldots, C_{n-1})$ with $n$ rows consists of the concatenation of the physical representation of each of its rows. The physical representation of a row with schema $(C_0, \ldots, C_{n-1})$ is the concatenation of the physical representation of each of its elements. The physical representation of a row cell $e$ at a column with type $C$ is defined as follows:

- If $e$ is a constant, it is stored using the number of bytes as specified for its column type $C$ (i.e. a 2 byte bitmask of type PropertyAttributes)
- If $e$ is an index into the GUID heap, 'blob', or String heap, it is stored using the number of bytes as defined in the HeapSizes field.
- If $e$ is a simple index into a table with index $i$, it is stored using 2 bytes if table $i$ has less than $2^{16}$ rows, otherwise it is stored using 4 bytes.
- If $e$ is a coded index that points into table $i$, out of $n$ possible tables $t_0, \ldots, t_{n-1}$, then it is stored as $e \ll (\log n) \cdot \lfloor \log \{ t_0, \ldots, t_{n-1} \}[t_i]$ using 2 bytes if the maximum number of rows of tables $t_0, \ldots, t_{n-1}$, is less than $2^{16} - (\log n)$, and using 4 bytes otherwise. The family of finite maps $\lfloor t_0, \ldots, t_{n-1} \rfloor$ is defined below. Note that decoding a physical row requires the inverse of this mapping. [For example, the Parent column of the Constant table indexes a row in the Field, Param or Property tables. The actual table is encoded into the low 2 bits of the number, using the values: 0 => Field, 1 => Param,2 => Property. The remaining bits hold the actual row number being indexed. For example, a value of 0x321, indexes row number 0xC8 in the Param table.]

<table>
<thead>
<tr>
<th>TypeDefOrRef: 2 bits to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>_TYPEDEF</td>
<td>0</td>
</tr>
<tr>
<td>TYPEREF</td>
<td>1</td>
</tr>
<tr>
<td>Typespec</td>
<td>2</td>
</tr>
<tr>
<td>HasConstant: 2 bits to encode tag</td>
<td>Tag</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>FieldDef</td>
<td>0</td>
</tr>
<tr>
<td>ParamDef</td>
<td>1</td>
</tr>
<tr>
<td>Property</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HasCustomattribute: 5 bits to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>MethodDef</td>
<td>0</td>
</tr>
<tr>
<td>FieldDef</td>
<td>1</td>
</tr>
<tr>
<td>TypeRef</td>
<td>2</td>
</tr>
<tr>
<td>TypeDef</td>
<td>3</td>
</tr>
<tr>
<td>ParamDef</td>
<td>4</td>
</tr>
<tr>
<td>InterfaceImpl</td>
<td>5</td>
</tr>
<tr>
<td>MemberRef</td>
<td>6</td>
</tr>
<tr>
<td>Module</td>
<td>7</td>
</tr>
<tr>
<td>Permission</td>
<td>8</td>
</tr>
<tr>
<td>Property</td>
<td>9</td>
</tr>
<tr>
<td>Event</td>
<td>10</td>
</tr>
<tr>
<td>Signature</td>
<td>11</td>
</tr>
<tr>
<td>ModuleRef</td>
<td>12</td>
</tr>
<tr>
<td>TypeSpec</td>
<td>13</td>
</tr>
<tr>
<td>Assembly</td>
<td>14</td>
</tr>
<tr>
<td>AssemblyRef</td>
<td>15</td>
</tr>
<tr>
<td>File</td>
<td>16</td>
</tr>
<tr>
<td>ExportedType</td>
<td>17</td>
</tr>
<tr>
<td>ManifestResource</td>
<td>18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HasFieldMarshall: 1 bit to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>FieldDef</td>
<td>0</td>
</tr>
<tr>
<td>ParamDef</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HasDeclSecurity: 2 bits to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>TypeDef</td>
<td>0</td>
</tr>
<tr>
<td>MethodDef</td>
<td>1</td>
</tr>
<tr>
<td>Assembly</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MemberRefParent: 3 bits to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not used</td>
<td>0</td>
</tr>
<tr>
<td>TypeRef</td>
<td>1</td>
</tr>
<tr>
<td>ModuleRef</td>
<td>2</td>
</tr>
<tr>
<td>MethodDef</td>
<td>3</td>
</tr>
<tr>
<td>TypeSpec</td>
<td>4</td>
</tr>
<tr>
<td>HasSemantics: 1 bit to encode tag</td>
<td>Tag</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Event</td>
<td>0</td>
</tr>
<tr>
<td>Property</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MethodDefOrRef: 1 bit to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>MethodDef</td>
<td>0</td>
</tr>
<tr>
<td>MemberRef</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MemberForwarded: 1 bit to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>FieldDef</td>
<td>0</td>
</tr>
<tr>
<td>MethodDef</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Implementation: 2 bits to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>File</td>
<td>0</td>
</tr>
<tr>
<td>AssemblyRef</td>
<td>1</td>
</tr>
<tr>
<td>ExportedType</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CustomAttributeType: 3 bits to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not used</td>
<td>0</td>
</tr>
<tr>
<td>Not used</td>
<td>1</td>
</tr>
<tr>
<td>MethodDef</td>
<td>2</td>
</tr>
<tr>
<td>MemberRef</td>
<td>3</td>
</tr>
<tr>
<td>Not used</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ResolutionScope: 2 bits to encode tag</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
<td>0</td>
</tr>
<tr>
<td>ModuleRef</td>
<td>1</td>
</tr>
<tr>
<td>AssemblyRef</td>
<td>2</td>
</tr>
<tr>
<td>TypeRef</td>
<td>3</td>
</tr>
</tbody>
</table>
24 File Format Extensions to PE

This contains informative text only

The file format for CLI components is a strict extension of the current Portable Executable (PE) File Format. This extended PE format enables the operating system to recognize runtime images, accommodates code emitted as CIL or native code, and accommodates runtime metadata as an integral part of the emitted code. There are also specifications for a subset of the full Windows PE/COFF file format, in sufficient detail that a tool or compiler can use the specifications to emit valid CLI images.

The PE format frequently uses the term RVA (Relative Virtual Address). An RVA is the address of an item once loaded into memory, with the base address of the image file subtracted from it (i.e. the offset from the base address where the file is loaded). The RVA of an item will almost always differ from its position within the file on disk. To compute the file position of an item with RVA \( r \), search all the sections in the PE file to find the section with RVA \( s \), length \( l \) and file position \( p \) in which the RVA lies, ie \( s \leq r < s+l \). The file position of the item is then given by \( p+(r-s) \).

End informative text

24.1 Structure of the Runtime File Format

The figure below provides a high-level view of the CLI file format. All runtime images contain the following:

- PE headers, with specific guidelines on how field values should be set in a runtime file.
- A CLI header that contains all of the runtime specific data entries. The runtime header is read-only and shall be placed in any read-only section.
- The sections that contain the actual data as described by the headers, including imports/exports, data, and code.

The CLI header (see clause 24.3.3) is found using CLI Header directory entry in the PE header. The CLI header in turn contains the address and sizes of the runtime data (metadata see Chapter 23 and CIL, see Chapter 24.4) in the rest of the image. Note that the runtime data can be merged into other areas of the PE format with the other data based on the attributes of the sections (such as read only versus execute, etc.).

24.2 PE Headers

A PE image starts with an MS-DOS header followed by a PE signature, followed by the PE file header, and then the PE optional header followed by PE section headers.
24.2.1 MS-DOS Header

The PE format starts with an MS-DOS stub of exactly the following 128 bytes to be placed at the front of the module. At offset 0x3c in the DOS header is a 4 byte unsigned integer offset lfanew to the PE signature (shall be “PE0000”), immediately followed by the PE file header.

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x4d</td>
<td>0x5a</td>
<td>0x90</td>
<td>0x00 0x03 0x00 0x00 0x00 0x00 0x00</td>
</tr>
<tr>
<td>0x04</td>
<td>0x00</td>
<td>0x00</td>
<td>0x00 0xFF 0xFF 0x00 0x00 0x00 0x00</td>
</tr>
<tr>
<td>0xb8</td>
<td>0x00</td>
<td>0x00</td>
<td>0x00 0x00 0x00 0x00 0x00 0x00 0x00</td>
</tr>
<tr>
<td>0x40</td>
<td>0x00</td>
<td>0x00</td>
<td>0x00 0x00 0x00 0x00 0x00 0x00 0x00</td>
</tr>
<tr>
<td>0x00</td>
<td>0x00</td>
<td>0x00</td>
<td>0x00 0x00 0x00 0x00 0x00 0x00 0x00</td>
</tr>
<tr>
<td>0x00</td>
<td>0x00</td>
<td>0x00</td>
<td>0x00 0x00 0x00 0x00 0x00 0x00 0x00</td>
</tr>
<tr>
<td>0x00</td>
<td>0x00</td>
<td>0x00</td>
<td>0x00 0x00 0x00 0x00 0x00 0x00 0x00</td>
</tr>
<tr>
<td>0x00</td>
<td>0x00</td>
<td>0x00</td>
<td>0x00 0x00 0x00 0x00 0x00 0x00 0x00</td>
</tr>
<tr>
<td>0x0f</td>
<td>0x1f</td>
<td>0xba</td>
<td>0x0e 0xb4 0x09 0xcd</td>
</tr>
<tr>
<td>0x21</td>
<td>0xbb8</td>
<td>0x01</td>
<td>0x4e 0xcd 0x21 0x54 0x68</td>
</tr>
<tr>
<td>0x69</td>
<td>0x73</td>
<td>0x20</td>
<td>0x70 0x72 0x6f 0x67 0x72</td>
</tr>
<tr>
<td>0x61</td>
<td>0x6d</td>
<td>0x20</td>
<td>0x63 0x61 0x6e 0x6e 0x6f</td>
</tr>
<tr>
<td>0x74</td>
<td>0x20</td>
<td>0x62</td>
<td>0x65 0x20 0x72 0x75 0x6e</td>
</tr>
<tr>
<td>0x20</td>
<td>0x69</td>
<td>0x6e</td>
<td>0x20 0x44 0x4f 0x53 0x20</td>
</tr>
<tr>
<td>0x6d</td>
<td>0x6f</td>
<td>0x64</td>
<td>0x65 0x2e 0x0d 0x0d 0x0a</td>
</tr>
<tr>
<td>0x24</td>
<td>0x00</td>
<td>0x00</td>
<td>0x00 0x00 0x00 0x00 0x00</td>
</tr>
</tbody>
</table>

24.2.2 PE File Header

Immediately after the PE signature is the PE File header consisting of the following:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>Machine</td>
<td>Always 0x14c (see Section 23.1).</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Number of Sections</td>
<td>Number of sections; indicates size of the Section Table, which immediately follows the headers.</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Time/Date Stamp</td>
<td>Time and date the file was created in seconds since January 1st 1970 00:00:00 or 0.</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>Pointer to Symbol Table</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>Number of Symbols</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>Optional Header Size</td>
<td>Size of the optional header, the format is described below.</td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>Characteristics</td>
<td>Flags indicating attributes of the file, see Characteristics.</td>
</tr>
</tbody>
</table>

24.2.2.1 Characteristics

A CIL-only DLL sets flag 0x2000 to 1, while an CIL only .exe has flag 0x2000 set to zero:

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMAGE_FILE_DLL</td>
<td>0x2000</td>
<td>The image file is a dynamic-link library (DLL).</td>
</tr>
</tbody>
</table>

Except for the IMAGE_FILE_DLL flag (0x2000), flags 0x0002, 0x0004, 0x0008, 0x0100 and 0x0020 shall all be set, while all others shall always be zero (see Section 23.1).
24.2.3 PE Optional Header

Immediately after the PE Header is the PE Optional Header. This header contains the following information:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Header part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>28</td>
<td>Standard fields</td>
<td>These define general properties of the PE file, see 24.2.3.1.</td>
</tr>
<tr>
<td>28</td>
<td>68</td>
<td>NT-specific fields</td>
<td>These include additional fields to support specific features of Windows, see 24.2.3.2.</td>
</tr>
<tr>
<td>96</td>
<td>128</td>
<td>Data directories</td>
<td>These fields are address/size pairs for special tables, found in the image file (for example, Import Table and Export Table).</td>
</tr>
</tbody>
</table>

24.2.3.1 PE Header Standard Fields

These fields are required for all PE files and contain the following information:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>Magic</td>
<td>Always 0x10B (see Section 23.1).</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>LMajor</td>
<td>Always 6 (see Section 23.1).</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>LMinor</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Code Size</td>
<td>Size of the code (text) section, or the sum of all code sections if there are multiple sections.</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>Initialized Data Size</td>
<td>Size of the initialized data section, or the sum of all such sections if there are multiple data sections.</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>Uninitialized Data Size</td>
<td>Size of the uninitialized data section, or the sum of all such sections if there are multiple uninitialized data sections.</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>Entry Point RVA</td>
<td>RVA of entry point, needs to point to bytes 0xFF 0x25 followed by the RVA+0x4000000 in a section marked execute/read for EXEs or 0 for DLLs</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>Base Of Code</td>
<td>RVA of the code section, always 0x004000000 for exes and 0x1000000000 for DLL.</td>
</tr>
<tr>
<td>24</td>
<td>4</td>
<td>Base Of Data</td>
<td>RVA of the data section.</td>
</tr>
</tbody>
</table>

This contains informative text only

The entry point RVA shall always be either the x86 entry point stub or be 0. On non-CLI aware platforms, this stub will call the entry point API of mscorelib (_CorExeMain or _CorDllMain). The mscorelib entry point will use the module handle to load the meta data from the image, and invoke the entry point specified in the CLI header.

End informative text

24.2.3.2 PE Header Windows NT-Specific Fields

These fields are Windows NT specific:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>4</td>
<td>Image Base</td>
<td>Always 0x4000000 (see Section 23.1).</td>
</tr>
<tr>
<td>32</td>
<td>4</td>
<td>Section Alignment</td>
<td>Always 0x2000 (see Section 23.1).</td>
</tr>
<tr>
<td>36</td>
<td>4</td>
<td>File Alignment</td>
<td>Either 0x200 or 0x1000.</td>
</tr>
<tr>
<td>Offset</td>
<td>Size</td>
<td>Field</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
<td>----------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>40</td>
<td>2</td>
<td>OS Major</td>
<td>Always 4 (see Section 23.1).</td>
</tr>
<tr>
<td>42</td>
<td>2</td>
<td>OS Minor</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>44</td>
<td>2</td>
<td>User Major</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>46</td>
<td>2</td>
<td>User Minor</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>48</td>
<td>2</td>
<td>SubSys Major</td>
<td>Always 4 (see Section 23.1).</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
<td>SubSys Minor</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>52</td>
<td>4</td>
<td>Reserved</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>56</td>
<td>4</td>
<td>Image Size</td>
<td>Size, in bytes, of image, including all headers and padding; shall be a multiple of Section Alignment.</td>
</tr>
<tr>
<td>60</td>
<td>4</td>
<td>Header Size</td>
<td>Combined size of MS-DOS Header, PE Header, PE Optional Header and padding; shall be a multiple of the file alignment.</td>
</tr>
<tr>
<td>64</td>
<td>4</td>
<td>File Checksum</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>68</td>
<td>2</td>
<td>SubSystem</td>
<td>Subsystem required to run this image. Shall be either IMAGE_SUBSYSTEM_WINDOWS_CE_GUI (0x3) or IMAGE_SUBSYSTEM_WINDOWS_GUI (0x2).</td>
</tr>
<tr>
<td>70</td>
<td>2</td>
<td>DLL Flags</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>72</td>
<td>4</td>
<td>Stack Reserve Size</td>
<td>Always 0x100000 (1Mb) (see Section 23.1).</td>
</tr>
<tr>
<td>76</td>
<td>4</td>
<td>Stack Commit Size</td>
<td>Always 0x1000 (4Kb) (see Section 23.1).</td>
</tr>
<tr>
<td>80</td>
<td>4</td>
<td>Heap Reserve Size</td>
<td>Always 0x100000 (1Mb) (see Section 23.1).</td>
</tr>
<tr>
<td>84</td>
<td>4</td>
<td>Heap Commit Size</td>
<td>Always 0x1000 (4Kb) (see Section 23.1).</td>
</tr>
<tr>
<td>88</td>
<td>4</td>
<td>Loader Flags</td>
<td>Always 0 (see Section 23.1)</td>
</tr>
<tr>
<td>92</td>
<td>4</td>
<td>Number of Data Directories</td>
<td>Always 0x10 (see Section 23.1).</td>
</tr>
</tbody>
</table>

### 24.2.3.3 PE Header Data Directories

The optional header data directories give the address and size of several tables that appear in the sections of the PE file. Each data directory entry contains the RVA and Size of the structure it describes.

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>96</td>
<td>8</td>
<td>Export Table</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>104</td>
<td>8</td>
<td>Import Table</td>
<td>RVA of Import Table, (see clause 24.3.1).</td>
</tr>
<tr>
<td>112</td>
<td>8</td>
<td>Resource Table</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>120</td>
<td>8</td>
<td>Exception Table</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>128</td>
<td>8</td>
<td>Certificate Table</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>136</td>
<td>8</td>
<td>Base Relocation Table</td>
<td>Relocation Table, set to 0 if unused (see clause 24.3.1).</td>
</tr>
<tr>
<td>144</td>
<td>8</td>
<td>Debug</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>152</td>
<td>8</td>
<td>Copyright</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>160</td>
<td>8</td>
<td>Global Ptr</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>168</td>
<td>8</td>
<td>TLS Table</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
</tbody>
</table>
The tables pointed to by the directory entries are stored in one of the PE file’s sections; these sections themselves are described by section headers.

### 24.3 Section Headers

Immediately following the optional header is the Section Table, which contains a number of section headers. This positioning is required because the file header does not contain a direct pointer to the section table; the location of the section table is determined by calculating the location of the first byte after the headers.

Each section header has the following format, for a total of 40 bytes per entry:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8</td>
<td>Name</td>
<td>An 8-byte, null-padded ASCII string. There is no terminating null if the string is exactly eight characters long.</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>VirtualSize</td>
<td>Total size of the section when loaded into memory in bytes rounded to Section Alignment. If this value is greater than Size of Raw Data, the section is zero-padded.</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>VirtualAddress</td>
<td>For executable images this is the address of the first byte of the section, when loaded into memory, relative to the image base.</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>SizeOfRawData</td>
<td>Size of the initialized data on disk in bytes, shall be a multiple of FileAlignment from the PE header. If this is less than VirtualSize the remainder of the section is zero filled. Because this field is rounded while the VirtualSize field is not it is possible for this to be greater than VirtualSize as well. When a section contains only uninitialized data, this field should be 0.</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>PointerToRawData</td>
<td>RVA to section’s first page within the PE file. This shall be a multiple of FileAlignment from the optional header. When a section contains only uninitialized data, this field should be 0.</td>
</tr>
<tr>
<td>24</td>
<td>4</td>
<td>PointerToRelocations</td>
<td>RVA of Relocation section.</td>
</tr>
<tr>
<td>28</td>
<td>4</td>
<td>PointerToLinenumbers</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>32</td>
<td>2</td>
<td>NumberOfLinenumbers</td>
<td>Number of relocations, set to 0 if unused.</td>
</tr>
<tr>
<td>34</td>
<td>2</td>
<td>NumberOfRelocations</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>36</td>
<td>4</td>
<td>Characteristics</td>
<td>Flags describing section’s characteristics, see below.</td>
</tr>
</tbody>
</table>

The following table defines the possible characteristics of the section:

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMAGE_SCN_CNT_CODE</td>
<td>0x00000020</td>
<td>Section contains executable code.</td>
</tr>
<tr>
<td>IMAGE_SCN_CNT_INITIALIZED_DATA</td>
<td>0x00000040</td>
<td>Section contains initialized data.</td>
</tr>
</tbody>
</table>
24.3.1 Import Table and Import Address Table (IAT)

The Import Table and the Import Address Table (IAT) are used to import the \_CorExeMain (for a .exe) or \_CorDllMain (for a .dll) entries of the runtime engine (mscoree.dll). The Import Table directory entry points to a one element zero terminated array of Import Directory entries (in a general PE file there is one entry for each imported DLL):

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>ImportLookupTable RVA</td>
<td>RVA of the Import Lookup Table</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>DateTimeStamp</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>ForwarderChain</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>Name</td>
<td>RVA of null terminated ASCII string “mscoree.dll”.</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>ImportAddressTable</td>
<td>RVA of Import Address Table (this is the same as the RVA of the IAT descriptor in the optional header).</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>End of Import Table. Shall be filled with zeros.</td>
<td></td>
</tr>
</tbody>
</table>

The Import Lookup Table and the Import Address Table (IAT) are both one element, zero terminated arrays of RVAs into the Hint/Name table. Bit 31 of the RVA shall be set to 0. In a general PE file there is one entry in this table for every imported symbol.

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>Hint/Name Table RVA</td>
<td>A 31-bit RVA into the Hint/Name Table. Bit 31 shall be set to 0 indicating import by name.</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>End of table, shall be filled with zeros.</td>
<td></td>
</tr>
</tbody>
</table>

The IAT should be in an executable and writable section as the loader will replace the pointers into the Hint/Name table by the actual entry points of the imported symbols.

The Name/Hint table contains the name of the dll-entry that is imported.

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>Hint</td>
<td>Shall be 0.</td>
</tr>
<tr>
<td>2</td>
<td>variable</td>
<td>Name</td>
<td>Case sensitive, null-terminated ASCII string containing name to import. Shall be “_CorExeMain” for a .exe file and “_CorDllMain” for a .dll file.</td>
</tr>
</tbody>
</table>

24.3.2 Relocations

In a pure CIL image, a single fixup of type IMAGE_REL_BASED_HIGHLOW (0x3) is required for the x86 startup stub which access the IAT to load the runtime engine on down level loaders. When building a mixed CIL/native image or when the image contains embedded RVAs in user data, the relocation section contains relocations for these as well.

The relocation section contains a Fix-Up Table. The fixup table is broken into blocks of fixups. Each block represents the fixups for a 4K page and block shall start on a 32-bit boundary. The last fixup block has PageRVA field set to 0.
Each fixup block starts with the following structure:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>PageRVA</td>
<td>The RVA of the block in which the fixup needs to be applied.</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Block Size</td>
<td>Total number of bytes in the fixup block, including the Page RVA and Block Size fields, as well as the Type/Offset fields that follow.</td>
</tr>
</tbody>
</table>

The Block Size field is then followed by (BlockSize –8)/2 Type/Offset. Each entry is a word (2 bytes) and has the following structure:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>bits</td>
<td>Type Stored in high 4 bits of word. Value indicating which type of fixup is to be applied (described below)</td>
</tr>
<tr>
<td>0</td>
<td>12</td>
<td>bits</td>
<td>Offset Stored in remaining 12 bits of word. Offset from starting address specified in the Page RVA field for the block. This offset specifies where the fixup is to be applied.</td>
</tr>
</tbody>
</table>

To apply a fixup, a delta is calculated as the difference between the preferred base address, and the base where the image is actually loaded. The fixup applies the delta to the 32-bit field at Offset. If the image is loaded at its preferred base, the delta would be zero, and thus the fixups would not have to be applied.

### 24.3.3 CLI Header

The CLI header contains all of the runtime-specific data entries and other information. The header should be placed in a read only, sharable section of the image. This header is defined as follows:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>Cb</td>
<td>Size of the header in bytes</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>MajorRuntimeVersion</td>
<td>The minimum version of the runtime required to run this program, currently 2.</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>MinorRuntimeVersion</td>
<td>The minor portion of the version, currently 0.</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>MetaData</td>
<td>RVA of the physical meta data (see Chapter 23).</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>Flags</td>
<td>Flags describing this runtime image. (see clause 24.3.3.1).</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>EntryPointToken</td>
<td>Token for the MethodDef or File of the entry point for the image</td>
</tr>
<tr>
<td>24</td>
<td>8</td>
<td>Resources</td>
<td>Location of CLI resources. (See Partition V ).</td>
</tr>
<tr>
<td>32</td>
<td>8</td>
<td>StrongNameSignature</td>
<td>RVA of the hash data for this PE file used by the CLI loader for binding and versioning</td>
</tr>
<tr>
<td>40</td>
<td>8</td>
<td>CodeManagerTable</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>48</td>
<td>8</td>
<td>VTableFixups</td>
<td>RVA of an array of locations in the file that contain an array of function pointers (e.g., vtable slots), see below.</td>
</tr>
<tr>
<td>56</td>
<td>8</td>
<td>ExportAddressTableJumps</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
<tr>
<td>64</td>
<td>8</td>
<td>MangedNativeHeader</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
</tbody>
</table>
24.3.3.1 Runtime Flags

The following flags describe this runtime image and are used by the loader.

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMIMAGE_FLAGS_ILONLY</td>
<td>0x00000001</td>
<td>Always 1 (see Section 23.1).</td>
</tr>
<tr>
<td>COMIMAGE_FLAGS_32BITREQUIRED</td>
<td>0x00000002</td>
<td>Image may only be loaded into a 32-bit process, for instance if there are 32-bit vtablefixups, or casts from native integers to int32. CLI implementations that have 64 bit native integers shall refuse loading binaries with this flag set.</td>
</tr>
<tr>
<td>COMIMAGE_FLAGS_STRONGNAMESIGNED</td>
<td>0x00000008</td>
<td>Image has a strong name signature.</td>
</tr>
<tr>
<td>COMIMAGE_FLAGS_TRACKDEBUGDATA</td>
<td>0x00010000</td>
<td>Always 0 (see Section 23.1).</td>
</tr>
</tbody>
</table>

24.3.3.2 Entry Point Meta Data Token

- The entry point token (see Clause 14.4.1.2) is always a MethodDef token (see Section 21.24) or File token (see Section 21.19) when the entry point for a multi-module assembly is not in the manifest assembly. The signature and implementation flags in metadata for the method indicate how the entry is run.

24.3.3.3 Vtable Fixup

Certain languages, which choose not to follow the common type system runtime model, may have virtual functions which need to be represented in a v-table. These v-tables are laid out by the compiler, not by the runtime. Finding the correct v-table slot and calling indirectly through the value held in that slot is also done by the compiler. The VtableFixups field in the runtime header contains the location and size of an array of Vtable Fixups (see clause 14.5.1). V-tables shall be emitted into a read-write section of the PE file.

Each entry in this array describes a contiguous array of v-table slots of the specified size. Each slot starts out initialized to the metadata token value for the method they need to call. At image load time, the runtime Loader will turn each entry into a pointer to machine code for the CPU and can be called directly.

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>VirtualAddress</td>
<td>RVA of Vtable</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Size</td>
<td>Number of entries in Vtable</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>Type</td>
<td>Type of the entries, as defined in table below</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Constant</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>COR_VTABLE_32BIT</td>
<td>0x01</td>
<td>Vtable slots are 32 bits.</td>
</tr>
<tr>
<td>COR_VTABLE_64BIT</td>
<td>0x02</td>
<td>Vtable slots are 64 bits.</td>
</tr>
<tr>
<td>COR_VTABLE_FROM_UNMANAGED</td>
<td>0x04</td>
<td>Transition from unmanaged to manged code.</td>
</tr>
<tr>
<td>COR_VTABLE_CALL_MOST_DERIVED</td>
<td>0x10</td>
<td>Call most derived method described by the token (only valid for virtual methods).</td>
</tr>
</tbody>
</table>

24.3.3.4 Strong Name Signature

This header entry points to the strong name hash for an image that can be used to deterministically identify a module from a referencing point (see Section 6.2.1.3).
24.4 Common Intermediate Language Physical Layout

This section contains the layout of the data structures used to describe a CIL method and its exceptions. Method bodies can be stored in any read-only section of a PE file. The MethodDef (see Section 21.24) records in metadata carry each method's RVA.

A method consists of a method header immediately followed by the method body, possible followed by extra method data sections (see Section 24.4.5), typically exception handling data. If exception-handling data is present, then CorILMethod_MoreSects flag (see clause 24.4.4) shall be specified in the method header and for each chained item after that.

There are two flavors of method headers - tiny (see clause 24.4.2) and fat (see clause 24.4.3). The three least significant bits in a method header indicate which type is present (see clause 24.4.1). The tiny header is 1 byte long and represents only the method's code size. A method is given a tiny header if it has no local variables, maxstack is 8 or less, the method has no exceptions, the method size is less than 64 bytes, and the method has no flags above 0x7. Fat headers carry full information - local vars signature token, maxstack, code size, flag. Method headers shall be 4-byte aligned.

24.4.1 Method Header Type Values

The three least significant bits of the first byte of the method header indicate what type of header is present. These 3 bits will be one and only one of the following:

<table>
<thead>
<tr>
<th>Value</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CorILMethod_TinyFormat</td>
<td>0x2</td>
<td>The method header is tiny (see clause 24.4.2).</td>
</tr>
<tr>
<td>CorILMethod_FatFormat</td>
<td>0x3</td>
<td>The method header is fat (see clause 24.4.3).</td>
</tr>
</tbody>
</table>

24.4.2 Tiny Format

Tiny headers use a 5 bit length encoding. The following is true for all tiny headers:

- No local variables are allowed
- No exceptions
- No extra data sections
- The operand stack need be no bigger than 8 entries

The first encoding has the following format:

<table>
<thead>
<tr>
<th>Start Bit</th>
<th>Count of Bits</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>Flags (CorILMethod_TinyFormat shall be set, see clause 24.4.4).</td>
</tr>
</tbody>
</table>

24.4.3 Fat Format

The fat format is used whenever the tiny format is not sufficient. This may be true for one or more of the following reasons:

- The method is too large to encode the size
- There are exceptions
- There are extra data sections
- There are local variables
- The operand stack needs more than 8 entries

A fat header has the following structure
24.4.4 Flags for Method Headers

The first byte of a method header may also contain the following flags, valid only for the Fat format, that indicate how the method is to be executed:

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CorILMethod_Fat</td>
<td>0x3</td>
<td>Method header is fat.</td>
</tr>
<tr>
<td>CorILMethod_TinyFormat</td>
<td>0x2</td>
<td>Method header is tiny.</td>
</tr>
<tr>
<td>CorILMethod_MoreSects</td>
<td>0x8</td>
<td>More sections follow after this header (see Section 24.4.5).</td>
</tr>
<tr>
<td>CorILMethod_InitLocals</td>
<td>0x10</td>
<td>Call default constructor on all local variables.</td>
</tr>
</tbody>
</table>

24.4.5 Method Data Section

At the next 4-byte boundary following the method body can be extra method data sections. These method data sections start with a two byte header (1 byte flags, 1 byte for the length of the actual data) or a four byte header (1 byte for flags, and 3 bytes for length of the actual data). The first byte determines the kind of the header, and what data is in the actual section:

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CorILMethod_Sect_EHTable</td>
<td>0x1</td>
<td>Exception handling data.</td>
</tr>
<tr>
<td>CorILMethod_Sect_OptILTable</td>
<td>0x2</td>
<td>Reserved, shall be 0.</td>
</tr>
<tr>
<td>CorILMethod_Sect_FatFormat</td>
<td>0x40</td>
<td>Data format is of the fat variety, meaning there is a 3 byte length. If not set, the header is small with a 1 byte length</td>
</tr>
<tr>
<td>CorILMethod_Sect_MoreSects</td>
<td>0x80</td>
<td>Another data section occurs after this current section</td>
</tr>
</tbody>
</table>

Currently, the method data sections are only used for exception tables (see Chapter 0). The layout of a small exception header structure as is a follows:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>Kind</td>
<td>Flags as described above.</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>DataSize</td>
<td>Size of the data for the block, including the header, say $n*12+4$.</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Reserved</td>
<td>Padding, always 0.</td>
</tr>
</tbody>
</table>
The layout of a fat exception header structure is as follows:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>Kind</td>
<td>Which type of exception block is being used</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>DataSize</td>
<td>Size of the data for the block, including the header, say ( n*24+4 ).</td>
</tr>
<tr>
<td>4</td>
<td>( n )</td>
<td>Clauses</td>
<td>( n ) fat exception clauses (see Section 24.4.6).</td>
</tr>
</tbody>
</table>

24.4.6 Exception Handling Clauses

Exception handling clauses also come in small and fat versions.

The small form of the exception clause should be used whenever the code size for the try block and handler code is smaller than or equal to 256 bytes. The format for a small exception clause is as follows:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>Flags</td>
<td>Flags, see below.</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>TryOffset</td>
<td>Offset in bytes of try block from start of the header.</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>TryLength</td>
<td>Length in bytes of the try block</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>HandlerOffset</td>
<td>Location of the handler for this try block</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>HandlerLength</td>
<td>Size of the handler code in bytes</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>ClassToken</td>
<td>Meta data token for a type-based exception handler</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>FilterOffset</td>
<td>Offset in method body for filter-based exception handler</td>
</tr>
</tbody>
</table>

The layout of fat form of exception handling clauses is as follows:

<table>
<thead>
<tr>
<th>Offset</th>
<th>Size</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>Flags</td>
<td>Flags, see below.</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>TryOffset</td>
<td>Offset in bytes of try block from start of the header.</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>TryLength</td>
<td>Length in bytes of the try block</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>HandlerOffset</td>
<td>Location of the handler for this try block</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>HandlerLength</td>
<td>Size of the handler code in bytes</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>ClassToken</td>
<td>Meta data token for a type-based exception handler</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>FilterOffset</td>
<td>Offset in method body for filter-based exception handler</td>
</tr>
</tbody>
</table>

The following flag values are used for each exception-handling clause:

<table>
<thead>
<tr>
<th>Flag</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>COR_ILEXCEPTION_CLAUSE_EXCEPTION</td>
<td>0x0000</td>
<td>A typed exception clause</td>
</tr>
<tr>
<td>COR_ILEXCEPTION_CLAUSE_FILTER</td>
<td>0x0001</td>
<td>An exception filter and handler clause</td>
</tr>
<tr>
<td>COR_ILEXCEPTION_CLAUSE_FINALLY</td>
<td>0x0002</td>
<td>A finally clause</td>
</tr>
<tr>
<td>COR_ILEXCEPTION_CLAUSE_FAULT</td>
<td>0x0004</td>
<td>Fault clause (finally that is called on exception only)</td>
</tr>
</tbody>
</table>
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Partition III
CIL Instruction Set
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<table>
<thead>
<tr>
<th>Line</th>
<th>Instruction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.7</td>
<td>bge.un.&lt;length&gt;</td>
<td>branch on greater than or equal to, unsigned or unordered</td>
</tr>
<tr>
<td>3.8</td>
<td>bgt.&lt;length&gt;</td>
<td>branch on greater than</td>
</tr>
<tr>
<td>3.9</td>
<td>bgt.un.&lt;length&gt;</td>
<td>branch on greater than, unsigned or unordered</td>
</tr>
<tr>
<td>3.10</td>
<td>ble.&lt;length&gt;</td>
<td>branch on less than or equal to</td>
</tr>
<tr>
<td>3.11</td>
<td>ble.un.&lt;length&gt;</td>
<td>branch on less than or equal to, unsigned or unordered</td>
</tr>
<tr>
<td>3.12</td>
<td>blt.&lt;length&gt;</td>
<td>branch on less than</td>
</tr>
<tr>
<td>3.13</td>
<td>blt.un.&lt;length&gt;</td>
<td>branch on less than, unsigned or unordered</td>
</tr>
<tr>
<td>3.14</td>
<td>bne.un.&lt;length&gt;</td>
<td>branch on not equal or unordered</td>
</tr>
<tr>
<td>3.15</td>
<td>br.&lt;length&gt;</td>
<td>unconditional branch</td>
</tr>
<tr>
<td>3.16</td>
<td>break - breakpoint instruction</td>
<td></td>
</tr>
<tr>
<td>3.17</td>
<td>brfalse.&lt;length&gt;</td>
<td>branch on false, null, or zero</td>
</tr>
<tr>
<td>3.18</td>
<td>brtrue.&lt;length&gt;</td>
<td>branch on non-false or non-null</td>
</tr>
<tr>
<td>3.19</td>
<td>call - call a method</td>
<td></td>
</tr>
<tr>
<td>3.20</td>
<td>calli - indirect method call</td>
<td></td>
</tr>
<tr>
<td>3.21</td>
<td>ceq - compare equal</td>
<td></td>
</tr>
<tr>
<td>3.22</td>
<td>cgt - compare greater than</td>
<td></td>
</tr>
<tr>
<td>3.23</td>
<td>cgt.un - compare greater than, unsigned or unordered</td>
<td></td>
</tr>
<tr>
<td>3.24</td>
<td>ckfinite – check for a finite real number</td>
<td></td>
</tr>
<tr>
<td>3.25</td>
<td>clt - compare less than</td>
<td></td>
</tr>
<tr>
<td>3.26</td>
<td>clt.un - compare less than, unsigned or unordered</td>
<td></td>
</tr>
<tr>
<td>3.27</td>
<td>conv.&lt;to type&gt; - data conversion</td>
<td></td>
</tr>
<tr>
<td>3.28</td>
<td>conv.ovf.&lt;to type&gt; - data conversion with overflow detection</td>
<td></td>
</tr>
<tr>
<td>3.29</td>
<td>conv.ovf.&lt;to type&gt;.un - unsigned data conversion with overflow detection</td>
<td></td>
</tr>
<tr>
<td>3.30</td>
<td>cpblk - copy data from memory to memory</td>
<td></td>
</tr>
<tr>
<td>3.31</td>
<td>div - divide values</td>
<td></td>
</tr>
<tr>
<td>3.32</td>
<td>div.un - divide integer values, unsigned</td>
<td></td>
</tr>
<tr>
<td>3.33</td>
<td>dup – duplicate the top value of the stack</td>
<td></td>
</tr>
<tr>
<td>3.34</td>
<td>endfilter - end filter clause of SEH</td>
<td></td>
</tr>
<tr>
<td>3.35</td>
<td>endfinally – end the finally or fault clause of an exception block</td>
<td></td>
</tr>
<tr>
<td>3.36</td>
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<td></td>
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<th></th>
<th>Instruction</th>
<th>Page</th>
</tr>
</thead>
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<td>4.14</td>
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<td>4.15</td>
<td>ldstr – load a literal string</td>
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</tr>
<tr>
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<td>123</td>
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<td>124</td>
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<tr>
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</tr>
</tbody>
</table>
1 Scope

This specification is a detailed description of the Common Intermediate Language (CIL) instruction set, part of the specification of the Common Language Infrastructure. Partition I describes the architecture of the CLI and provides an overview of a large number of issues relating to the CIL instruction set. That overview is essential to an understanding of the instruction set as described here.

Each instruction description describes a set of related CLI machine instructions. Each instruction definition consists of five parts:

- A table describing the binary format, assembly language notation and description of each variant of the instruction. See the Instruction Variant Table section.
- A stack transition diagram that describes the state of the evaluation stack before and after the instruction is executed. See Section 1.3.
- An English description of the instruction. See the English Description section.
- A list of exceptions that might be thrown by the instruction. See Partition I for details. There are three exceptions which may be thrown by any instruction and are not listed with the instruction:
  - ExecutionEngineException indicates that the internal state of the Execution Engine is corrupted and execution cannot continue. [Note: in a system that executes only verifiable code this exception is not thrown.]
  - StackOverflowException indicates that the hardware stack size has been exceeded. The precise timing of this exception and the conditions under which it occurs are implementation specific. [Note: this exception is unrelated to the maximum stack size described in clause 1.7.4. That size relates to the depth of the evaluation stack that is part of the method state defined in Partition I, while this exception has to do with the implementation of that method state on physical hardware.]
  - OutOfMemoryException indicates that the available memory space has been exhausted, either because the instruction inherently allocates memory (newobj, newarr) or for an implementation-specific reason (for example, an implementation based on just-in-time compilation to native code may run out of space to store the translated method while executing the first call or callvirt to a given method).
- A section describing the verifiability conditions associated with the instruction. See Section 1.8.

In addition, operations that have a numeric operand also specify an operand type table that describes how they operate based on the type of the operand. See Section 1.5.

Note that not all instructions are included in all CLI Profiles. See Partition IV for details.

1.1 Data Types

While the Common Type System (CTS) defines a rich type system and the Common Language Specification (CLS) specifies a subset that can be used for language interoperability, the CLI itself deals with a much simpler set of types. These types include user-defined value types and a subset of the built-in types. The subset is collectively known as the “basic CLI types”:

- A subset of the full numeric types (int32, int64, native int, and F)
- Object references (o) without distinction between the type of object referenced
- Pointer types (native unsigned int and &) without distinction as to the type pointed to

Note that object references and pointer types may be assigned the value null. This is defined throughout the CLI to be zero (a bit pattern of all bits zero)

1.1.1 Numeric Data Types

- The CLI only operates on the numeric types int32 (4 byte signed integers), int64 (8 byte signed integers), native int (native size integers), and F (native size floating-point numbers). The CIL instruction set, however, allows additional data types to be implemented:
• **Short integers.** The evaluation stack only holds 4 or 8 byte integers, but other locations (arguments, local variables, statics, array elements, fields) may hold 1 or 2 byte integers. Loading from these locations onto the stack either zero-extends (ldind.u*, ldelem.u*, etc.) or sign-extends (ldind.i*, ldelem.i*, etc.) to a 4 byte value. Storing to integers (stind.ul, stelem.i2, etc.) truncates. Use the conv.ovf.* instructions to detect when this truncation results in a value that doesn’t correctly represent the original value.

**Note:** Short integers are loaded as 4-byte numbers on all architectures and these 4-byte numbers must always be tracked as distinct from 8-byte numbers. This helps portability of code by ensuring that the default arithmetic behavior (i.e. when no conv or conv.ovf instruction are executed) will have identical results on all implementations.

Convert instructions that yield short integer values actually leave an int32 (32-bit) value on the stack, but it is guaranteed that only the low bits have meaning (i.e. the more significant bits are all zero for the unsigned conversions or a sign extension for the signed conversions). To correctly simulate the full set of short integer operations a conversion to the short form is required before the div, rem, shr, comparison and conditional branch instructions.

In addition to the explicit conversion instructions there are four cases where the CLI handles short integers in a special way:

336. Assignment to a local (stloc) or argument (starg) whose type is declared to be a short integer type automatically truncates to the size specified for the local or argument.

337. Loading from a local (ldloc) or argument (ldarg) whose type is declared to be a short signed integer type automatically sign extends.

338. Calling a procedure with an argument that is a short integer type is equivalent to assignment to the argument value, so it truncates.

339. Returning a value from a method whose return type is a short integer is modeled as storing into a short integer within the called procedure (i.e. the CLI automatically truncates) and then loading from a short integer within the calling procedure (i.e. the CLI automatically zero- or sign-extends).

In the last two cases it is up to the native calling convention to determine whether values are actually truncated or extended, as well as whether this is done in the called procedure or the calling procedure. The CIL instruction sequence is unaffected and it is as though the CIL sequence included an appropriate conv instruction.

• **4 byte integers.** The shortest value actually stored on the stack is a 4-byte integer. These can be converted to 8-byte integers or native-size integers using conv.* instructions. Native-size integers can be converted to 4-byte integers, but doing so is not portable across architectures. The conv.i4 and conv.u4 can be used for this conversion if the excess significant bits should be ignored; the conv.ovf.i4 and conv.ovf.u4 instructions can be used to detect the loss of information. Arithmetic operations allow 4-byte integers to be combined with native size integers, resulting in native size integers. 4-byte integers may not be directly combined with 8-byte integers (they must be converted to 8-byte integers first).

• **Native size integers.** Native size integers can be combined with 4-byte integers using any of the normal arithmetic instructions, and the result will be a native-size integer. Native size integers must be explicitly converted to 8-byte integers before they can be combined with 8-byte integers.

• **8 byte integers.** Supporting 8 byte integers on 32 bit hardware may be expensive, whereas 32 bit arithmetic is available and efficient on current 64 bit hardware. For this reason, numeric instructions allow int32 and I data types to be intermixed (yielding the largest type used as input), but these types cannot be combined with int64s. Instead, an native int or int32 must be explicitly converted to int64 before it can be combined with an int64.

• **Unsigned integers.** Special instructions are used to interpret integers on the stack as though they were unsigned, rather than tagging the stack locations as being unsigned.
Floating-point numbers. See also Partition I, Handling of Floating Point Datatypes. Storage locations for floating-point numbers (statics, array elements, and fields of classes) are of fixed size. The supported storage sizes are float32 and float64. Everywhere else (on the evaluation stack, as arguments, as return types, and as local variables) floating-point numbers are represented using an internal floating-point type. In each such instance, the nominal type of the variable or expression is either float32 or float64, but its value may be represented internally with additional range and/or precision. The size of the internal floating-point representation is implementation-dependent, may vary, and shall have precision at least as great as that of the variable or expression being represented. An implicit widening conversion to the internal representation from float32 or float64 is performed when those types are loaded from storage. The internal representation is typically the natural size for the hardware, or as required for efficient implementation of an operation. The internal representation shall have the following characteristics:

- The internal representation shall have precision and range greater than or equal to the nominal type.
- Conversions to and from the internal representation shall preserve value. [Note: This implies that an implicit widening conversion from float32 (or float64) to the internal representation, followed by an explicit conversion from the internal representation to float32 (or float64), will result in a value that is identical to the original float32 (or float64) value.]

Note: The above specification allows a compliant implementation to avoid rounding to the precision of the target type on intermediate computations, and thus permits the use of wider precision hardware registers, as well as the application of optimizing transformations which result in the same or greater precision, such as contractions. Where exactly reproducible behavior is required by a language or application, explicit conversions may be used.

When a floating-point value whose internal representation has greater range and/or precision than its nominal type is put in a storage location, it is automatically coerced to the type of the storage location. This may involve a loss of precision or the creation of an out-of-range value (NaN, +infinity, or -infinity). However, the value may be retained in the internal representation for future use, if it is reloaded from the storage location without having been modified. It is the responsibility of the compiler to ensure that the memory location is still valid at the time of a subsequent load, taking into account the effects of aliasing and other execution threads (see memory model section). This freedom to carry extra precision is not permitted, however, following the execution of an explicit conversion (conv.r4 or conv.r8), at which time the internal representation must be exactly representable in the associated type.

Note: To detect values that cannot be converted to a particular storage type, use a conversion instruction (conv.r4 or conv.r8) and then check for an out-of-range value using ckfinite. To detect underflow when converting to a particular storage type, a comparison to zero is required before and after the conversion.

Note: This standard does not specify the behavior of arithmetic operations on denormalized floating point numbers, nor does it specify when or whether such representations should be created. This is in keeping with IEC 60559:1989. In addition, this standard does not specify how to access the exact bit pattern of NaNs that are created, nor the behavior when converting a NaN between 32-bit and 64-bit representation. All of this behavior is deliberately left implementation-specific.

1.1.2 Boolean Data Type

A CLI Boolean type occupies one byte in memory. A bit pattern of all zeroes denotes a value of false. A bit pattern with any bit set (analogous to a non-zero integer) denotes a value of true.

1.1.3 Object References

Object references (type O) are completely opaque. There are no arithmetic instructions that allow object references as operands, and the only comparison operations permitted are equality (and inequality) between two object references. There are no conversion operations defined on object references. Object references are created by certain CIL object instructions (notably newobj and newarr). Object references can be passed as arguments, stored as local variables, returned as values, and stored in arrays and as fields of objects.
1.1.4 Runtime Pointer Types

There are two kinds of pointers: unmanaged pointers and managed pointers. For pointers into the same array or object (see Partition I), the following arithmetic operations are defined:

- Adding an integer to a pointer, where the integer is interpreted as a number of bytes, results in a pointer of the same kind.
- Subtracting an integer (number of bytes) from a pointer results in a pointer of the same kind. Note that subtracting a pointer from an integer is not permitted.
- Two pointers, regardless of kind, can be subtracted from one another, producing an integer that specifies the number of bytes between the addresses they reference.

None of these operations is allowed in verifiable code.

It is important to understand the impact on the garbage collector of using arithmetic on the different kinds of pointers. Since unmanaged pointers must never reference memory that is controlled by the garbage collector, performing arithmetic on them can endanger the memory safety of the system (hence it is not verifiable) but since they are not reported to the garbage collector there is no impact on its operation.

Managed pointers, however, are reported to the garbage collector. As part of garbage collection both the contents of the location to which they point and the pointer itself can be modified. The garbage collector will ignore managed pointers if they point into memory that is not under its control (the evaluation stack, the call stack, static memory, or memory under the control of another allocator). If, however, a managed pointer refers to memory controlled by the garbage collector it must point to either a field of an object, an element of an array, or the address of the element just past the end of an array. If address arithmetic is used to create a managed pointer that refers to any other location (an object header or a gap in the allocated memory) the garbage collector’s operation is unspecified.

1.1.4.1 Unmanaged Pointers

Unmanaged pointers are the traditional pointers used in languages like C and C++. There are no restrictions on their use, although for the most part they result in code that cannot be verified. While it is perfectly legal to mark locations that contain unmanaged pointers as though they were unsigned integers (and this is, in fact, how they are treated by the CLI), it is often better to mark them as unmanaged pointers to a specific type of data. This is done by using `ELEMENT_TYPE_PTR` in a signature for a return value, local variable or an argument or by using a pointer type for a field or array element.

Unmanaged pointers are not reported to the garbage collector and can be used in any way that an integer can be used.

- Unmanaged pointers should be treated as unsigned (i.e. use `conv.ovf.u` rather than `conv.ovf.i`, etc.).
- Verifiable code cannot use unmanaged pointers to reference memory.
- Unverified code can pass an unmanaged pointer to a method that expects a managed pointer. This is safe only if one of the following is true:
  - The unmanaged pointer refers to memory that is not in memory managed by the garbage collector
  - The unmanaged pointer refers to a field within an object
  - The unmanaged pointer refers to an element within an array
  - The unmanaged pointer refers to the location where the element following the last element in an array would be located

1.1.4.2 Managed Pointers (type `&`)

Managed pointers (`&`) may point to a local variable, a method argument, a field of an object, a field of a value type, an element of an array, or the address where an element just past the end of an array would be stored (for pointer indexes into managed arrays). Managed pointers cannot be `null`. (They must be reported to the garbage collector, even if they do not point to managed memory)
Managed pointers are specified by using `ELEMENT_TYPE_BYREF` in a signature for a return value, local variable or an argument or by using a by-ref type for a field or array element.

- Managed pointers can be passed as arguments and stored in local variables.
- If you pass a parameter by reference, the corresponding argument is a managed pointer.
- Managed pointers cannot be stored in static variables, array elements, or fields of objects or value types.
- Managed pointers are not interchangeable with object references.
- A managed pointer cannot point to another managed pointer, but it can point to an object reference or a value type.
- Managed pointers that do not point to managed memory can be converted (using `conv.u` or `conv.ovf.u`) into unmanaged pointers, but this is not verifiable.
- Unverified code that erroneously converts a managed pointer into an unmanaged pointer can seriously compromise the integrity of the CLI. This conversion is safe if any of the following is known to be true:
  - The managed pointer does not point into the garbage collector’s memory area
  - The memory referred to has been pinned for the entire time that the unmanaged pointer is in use
  - A garbage collection cannot occur while the unmanaged pointer is in use
  - The garbage collector for the given implementation of the CLI is known to not move the referenced memory

### 1.2 Instruction Variant Table

In Chapter 3 an Instruction Variant Table is presented for each instruction. It describes each variant of the instructions. The “Format” column of the table lists the opcode for the instruction variant, along with any arguments that follow the instruction in the instruction stream. For example:

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 0A &lt;unsigned int16&gt;</td>
<td>Ldarga argNum</td>
<td>fetch the address of argument argNum.</td>
</tr>
<tr>
<td>0F &lt;unsigned int8&gt;</td>
<td>Ldarga.s argNum</td>
<td>fetch the address of argument argNum, short form</td>
</tr>
</tbody>
</table>

The first one or two hex numbers in the “Format” column show how this instruction is encoded (its “opcode”). So, the `ldarga` instruction is encoded as a byte holding FE, followed by another holding 0A. Italics type names represent numbers that should follow in the instruction stream. In this example a 2-byte quantity that is to be treated as an unsigned integer directly follows the FE 0A opcode.

Any of the fixed size built-in types (int8, unsigned int8, int16, unsigned int16, int32, unsigned int32, int64, unsigned int64, float32, and float64) can appear in format descriptions. These types define the number of bytes for the argument and how it should be interpreted (signed, unsigned or floating-point). In addition, a metadata token can appear, indicated as `<T>`. Tokens are encoded as 4-byte integers. All argument numbers are encoded least-significant-byte-at-smallest-address (a pattern commonly termed “little-endian”). Bytes for instruction opcodes and arguments are packed as tightly as possible (no alignment padding is done).

The assembly format column defines an assembly code mnemonic for each instruction variant. For those instructions that have instruction stream arguments, this column also assigns names to each of the arguments to the instruction. For each instruction argument, there is a name in the assembly format. These names are used later in the instruction description.
1.2.1 Opcode Encodings

CIL opcodes are one or more bytes long; they may be followed by zero or more operand bytes. All opcodes whose first byte lies in the ranges 0x00 through 0xEF, or 0xFC through 0xFF are reserved for standardization. Opcodes whose first byte lies in the range 0xF0 through 0xFB inclusive, are available for experimental purposes. The use of experimental opcodes in any method renders the method invalid and hence unverifiable.

The currently defined encodings are specified in Table 1: Opcode Encodings.
### Table 10: Opcode Encodings

<table>
<thead>
<tr>
<th>Opcode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td>nop</td>
</tr>
<tr>
<td>0x01</td>
<td>break</td>
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<tr>
<td>0x02</td>
<td>ldarg.0</td>
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<tr>
<td>0x03</td>
<td>ldarg.1</td>
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<td>ldarg.2</td>
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<td>stloc.2</td>
</tr>
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<td>stloc.3</td>
</tr>
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<td>ldarg.s</td>
</tr>
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<td>dup</td>
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<td>pop</td>
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<td>jmp</td>
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<td>call</td>
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<td>cali</td>
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<td>bgt.s</td>
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<td>bne.un.s</td>
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<td>0x68</td>
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<tr>
<td>0x83</td>
<td>conv.ovf.i2.un</td>
</tr>
<tr>
<td>0x84</td>
<td>conv.ovf.i4.un</td>
</tr>
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<td>0x85</td>
<td>conv.ovf.i8.un</td>
</tr>
<tr>
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<td>conv.ovf.u1.un</td>
</tr>
<tr>
<td>0x87</td>
<td>conv.ovf.u2.un</td>
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<tr>
<td>0x88</td>
<td>conv.ovf.u4.un</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>---</td>
</tr>
<tr>
<td>0x89</td>
<td>conv.ovf.u8.un</td>
</tr>
<tr>
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<td>conv.ovf.i.un</td>
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<td>conv.ovf.u.un</td>
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<td>0x90</td>
<td>ldelem.u1</td>
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<td>ldelem.i2</td>
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<tr>
<td>0x92</td>
<td>ldelem.u2</td>
</tr>
<tr>
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<td>ldelem.r4</td>
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<td>ldelem.u4</td>
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<tr>
<td>0x96</td>
<td>ldelem.i8</td>
</tr>
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<td>0x97</td>
<td>ldelem.i</td>
</tr>
<tr>
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<td>ldelem.i8</td>
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<tr>
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<tr>
<td>0x9e</td>
<td>stelem.i4</td>
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<tr>
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<td>stelem.i8</td>
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<tr>
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<tr>
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<td>conv.ovf.i1</td>
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<tr>
<td>0xb5</td>
<td>conv.ovf.i2</td>
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<td>conv.ovf.u2</td>
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<td>conv.ovf.u4</td>
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<tr>
<td>0xb8</td>
<td>conv.ovf.u4</td>
</tr>
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</tr>
<tr>
<td>Hex Code</td>
<td>Symbol</td>
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<td>---------</td>
<td>--------</td>
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<tr>
<td>0xFE 0x0F</td>
<td>localloc</td>
</tr>
<tr>
<td>0xFE 0x11</td>
<td>endfilter</td>
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<td>0xFE 0x12</td>
<td>unaligned.</td>
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<tr>
<td>0xFE 0x13</td>
<td>volatile.</td>
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<tr>
<td>0xFE 0x14</td>
<td>tail.</td>
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<tr>
<td>0xFE 0x15</td>
<td>initobj</td>
</tr>
<tr>
<td>0xFE 0x17</td>
<td>cpblk</td>
</tr>
<tr>
<td>0xFE 0x18</td>
<td>initblk</td>
</tr>
<tr>
<td>0xFE 0x1A</td>
<td>rethrow</td>
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<td>0xFE 0x1C</td>
<td>sizeof</td>
</tr>
<tr>
<td>0xFE 0x1D</td>
<td>refanytype</td>
</tr>
</tbody>
</table>
1.3 Stack Transition Diagram

The stack transition diagram displays the state of the evaluation stack before and after the instruction is executed. Below is a typical stack transition diagram.

..., value1, value2 → ..., result

This diagram indicates that the stack must have at least two elements on it, and in the definition the topmost value ("top of stack" or "most recently pushed") will be called value2 and the value underneath (pushed prior to value2) will be called value1. (In diagrams like this, the stack grows to the right, along the page). The instruction removes these values from the stack and replaces them by another value, called result in the description.

1.4 English Description

The English description describes any details about the instructions that are not immediately apparent once the format and stack transition have been described.

1.5 Operand Type Table

Many CIL operations take numeric operands on the stack. These operations fall into several categories, depending on how they deal with the types of the operands. The following tables summarize the valid types of operand types and the type of the result. Notice that the type referred to here is the type as tracked by the CLI rather than the more detailed types used by tools such as CIL verification. The types tracked by the CLI are: int32, int64, native int, F, O, and &.

A op B (used for add, div, mul, rem, and sub). The table below shows the result type, for each possible combination of operand types. Boxes holding simply a result type, apply to all five instructions. Boxes marked * indicate an invalid CIL instruction. Shaded boxes indicate a CIL instruction that is not verifiable. Boxes with a list of instructions are valid only for those instructions.

<table>
<thead>
<tr>
<th>A’s Type</th>
<th>B’s Type</th>
<th>int32</th>
<th>int64</th>
<th>native int</th>
<th>F</th>
<th>&amp; (add)</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>int32</td>
<td>int64</td>
<td>x</td>
<td></td>
<td>native int</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>int64</td>
<td>native int</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>native int</td>
<td>native int</td>
<td>x</td>
<td>x</td>
<td>&amp; (add) x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>F</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&amp; (add, sub)</td>
<td>x</td>
<td>&amp; (add, sub)</td>
<td>x</td>
<td>native int (sub)</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Used for the neg instruction. Boxes marked * indicate an invalid CIL instruction. All valid uses of this instruction are verifiable.

<table>
<thead>
<tr>
<th>Operand Type</th>
<th>Result Type</th>
<th>int32</th>
<th>int64</th>
<th>native int</th>
<th>F</th>
<th>&amp;</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>int32</td>
<td>int64</td>
<td>native int</td>
<td>F</td>
<td>&amp;</td>
<td>O</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These return a boolean value or branch based on the top two values on the stack. Used for beq, beq.s, bge, bge.s, bge.un, bge.un.s, bgt, bgt.s, bgt.un, bgt.un.s, ble, ble.s, ble.un, ble.un.s, blt, blt.s, blt.un,
**Table 13: Binary Comparison or Branch Operations**

<table>
<thead>
<tr>
<th></th>
<th>int32</th>
<th>int64</th>
<th>native int</th>
<th>F</th>
<th>&amp;</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>int32</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>int64</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>native int</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>beq[], bne.un[], ceq</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>x</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>&amp;</td>
<td>x</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>beq[], bne.un[], ceq</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>✓</td>
</tr>
</tbody>
</table>

340. Except for `beq`, `bne.un` (or short versions) or `ceq` these combinations make sense if both operands are known to be pointers to elements of the same array. However, there is no security issue for a CLI that does not check this constraint.

**Note:** if the two operands are not pointers into the same array, then the result is simply the distance apart in the garbage-collected heap of two unrelated data items. This distance apart will almost certainly change at the next garbage collection. Essentially, the result cannot be used to compute anything useful.

341. `cgt.un` is allowed and verifiable on ObjectRefs (O). This is commonly used when comparing an ObjectRef with null (there is no “compare-not-equal” instruction, which would otherwise be a more obvious solution).

These operate only on integer types. Used for `and`, `div.un`, `not`, `or`, `rem.un`, `xor`. The `div.un` and `rem.un` instructions treat their arguments as unsigned integers and produce the bit pattern corresponding to the unsigned result. As described in the CLI Specification, however, the CLI makes no distinction between signed and unsigned integers on the stack. The `not` instruction is unary and returns the same type as the input. The `shl` and `shr` instructions return the same type as their first operand and their second operand must be of type native unsigned int. Boxes marked ✗ indicate invalid CIL sequences. All other boxes denote verifiable combinations of operands.

**Table 14: Integer Operations**

<table>
<thead>
<tr>
<th></th>
<th>int32</th>
<th>int64</th>
<th>native int</th>
<th>F</th>
<th>&amp;</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>int32</td>
<td>int32</td>
<td>x</td>
<td>native int</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>int64</td>
<td>x</td>
<td>int64</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>native int</td>
<td>native int</td>
<td>x</td>
<td>native int</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>F</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>&amp;</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>O</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Below are the legal combinations of operands and result for the shift instructions: `shl`, `shr`, `shr.un`. Boxes marked ✗ indicate invalid CIL sequences. All other boxes denote verifiable combinations of operand. If the
“Shift-By” operand is larger than the width of the “To-Be-Shifted” operand, then the results are implementation-defined. (eg shift an int32 integer left by 37 bits)

Table 15: Shift Operations

<table>
<thead>
<tr>
<th>Shift-By</th>
<th>int32</th>
<th>int64</th>
<th>native int</th>
<th>F &amp;</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>To Be Shifted</td>
<td>int32</td>
<td>int32</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td></td>
<td>int64</td>
<td>int64</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
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<tr>
<td></td>
<td>native int</td>
<td>native int</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td></td>
<td>&amp;</td>
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<td>✗</td>
<td>✗</td>
<td>✗</td>
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<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>

These operations generate an exception if the result cannot be represented in the target data type. Used for add.ovf, add.ovf.un, mul.ovf, mul.ovf.un, sub.ovf, sub.ovf.un. The shaded uses are not verifiable, while boxes marked ✗ indicate invalid CIL sequences.

Table 16: Overflow Arithmetic Operations

<table>
<thead>
<tr>
<th></th>
<th>int32</th>
<th>int64</th>
<th>native int</th>
<th>F &amp;</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>int32</td>
<td>int32</td>
<td>✗</td>
<td>native int</td>
<td>✗</td>
<td>&amp; add.ovf.un</td>
</tr>
<tr>
<td>int64</td>
<td>✗</td>
<td>int64</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>native int</td>
<td>native int</td>
<td>✗</td>
<td>native int</td>
<td>✗</td>
<td>&amp; add.ovf.un</td>
</tr>
<tr>
<td>F</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>&amp;</td>
<td>&amp; add.ovf.un, sub.ovf.un</td>
<td>✗</td>
<td>&amp; add.ovf.un, sub.ovf.un</td>
<td>✗</td>
<td>native int sub.ovf.un</td>
</tr>
<tr>
<td>O</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>

These operations convert the top item on the evaluation stack from one numeric type to another. The result type is guaranteed to be representable as the data type specified as part of the operation (i.e. the conv.u2 instruction returns a value that can be stored in a unsigned int16). The stack, however, can only store values that are a minimum of 4 bytes wide. Used for the conv.<to type>, conv.ovf.<to type>, and conv.ovf.<to type>.un instructions. The shaded uses are not verifiable, while boxes marked ✗ indicate invalid CIL sequences.

Table 17: Conversion Operations

<table>
<thead>
<tr>
<th>Convert-To</th>
<th>Input (from evaluation stack)</th>
<th>int32</th>
<th>int64</th>
<th>native int</th>
<th>F</th>
<th>&amp;</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>int8</td>
<td>Truncate¹</td>
<td>Truncate¹</td>
<td>Truncate¹</td>
<td>Truncate to zero²</td>
<td>✗</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>unsigned int8</td>
<td>Nop</td>
<td>Truncate¹</td>
<td>Truncate¹</td>
<td>Truncate to zero²</td>
<td>✗</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>int16</td>
<td>Sign extend</td>
<td>Nop</td>
<td>Sign extend</td>
<td>Truncate to zero²</td>
<td>Stop GC tracking</td>
<td>Stop GC tracking</td>
<td></td>
</tr>
<tr>
<td>unsigned int16</td>
<td>Sign extend</td>
<td>Nop</td>
<td>Sign extend</td>
<td>Truncate to zero²</td>
<td>Stop GC tracking</td>
<td>Stop GC tracking</td>
<td></td>
</tr>
</tbody>
</table>
unsigned int64 | Zero extend | Nop | Zero extend | Truncate to zero | Stop GC tracking |
---|---|---|---|---|---|
native int | Sign extend | Truncate | Nop | Truncate to zero | Stop GC tracking |
native unsigned int | Zero extend | Truncate | Nop | Truncate to zero | Stop GC tracking |
All Float Types | To Float | To Float | To Float | Change precision | × | × |

342. “Truncate” means that the number is truncated to the desired size; ie, the most significant bytes of the input value are simply ignored. If the result is narrower than the minimum stack width of 4 bytes, then this result is zero extended (if the target type is unsigned) or sign-extended (if the target type is signed). Thus, converting the value 0x1234 ABCD from the evaluation stack to an 8-bit datum yields the result 0xCD; if the target type were int8, this is sign-extended to give 0xFFFF FFCD; if, instead, the target type were unsigned int8, this is zero-extended to give 0x0000 00CD.

343. “Trunc to 0” means that the floating-point number will be converted to an integer by truncation toward zero. Thus 1.1 is converted to 1 and –1.1 is converted to –1.

344. Converts from the current precision available on the evaluation stack to the precision specified by the instruction. If the stack has more precision than the output size the conversion is performed using the IEC 60559:1989 “round to nearest” mode to compute the low order bit of the result.

345. “Stop GC Tracking” means that, following the conversion, the item’s value will not be reported to subsequent garbage-collection operations (and therefore will not be updated by such operations)

1.6 Implicit Argument Coercion

While the CLI operates only on 6 types (int32, native int, int64, F, O, and &) the metadata supplies a much richer model for parameters of methods. When about to call a method, the CLI performs implicit type conversions, detailed in the following table. (Conceptually, it inserts the appropriate conv.* instruction into the CIL stream, which may result in an information loss through truncation or rounding) This implicit conversion occurs for boxes marked ✓. Shaded boxes are not verifiable. Boxes marked × indicate invalid CIL sequences. (A compiler is of course free to emit explicit conv.* or conv.*.ovf instructions to achieve any desired effect)

| Type In Signature | Stack Parameter |
|---|---|---|---|---|---|---|
| int32 | native int | int64 | F | & | O |
| int8 | ✓ | ✓ | × | × | × | × |
| unsigned int8, bool | ✓ | ✓ | × | × | ✓ | × |
| int16 | ✓ | ✓ | × | × | × | × |
| unsigned int16, char | ✓ | ✓ | × | × | × | × |
| int32 | ✓ | ✓ | × | × | × | × |
| unsigned int32 | ✓ | ✓ | × | × | × | × |
| int64 | × | × | ✓ | × | × | × |
| unsigned int64 | × | × | ✓ | × | × | × |
### Restrictions on CIL Code Sequences

As well as detailed restrictions on CIL code sequences to ensure:

- Valid CIL
- Verifiable CIL

there are a few further restrictions, imposed to make it easier to construct a simple CIL-to-native-code compiler. This section specifies the general restrictions that apply in addition to this listed for individual instructions.

#### 1.7.1 The Instruction Stream

The implementation of a method is provided by a contiguous block of CIL instructions, encoded as specified below. The address of the instruction block for a method as well as its length is specified in the file format (see Partition II, Common Intermediate Language Physical Layout). The first instruction is at the first byte (lowest address) of the instruction block.

Instructions are variable in size. The size of each instruction can be determined (decoded) from the content of the instruction bytes themselves. The size of and ordering of the bytes within an instruction is specified by each instruction definition. Instructions follow each other without padding in a stream of bytes that is both alignment and byte-order insensitive.
Each instruction occupies an exact number of bytes, and until the end of the instruction block, the next
instruction begins immediately at the next byte. It is invalid for the instruction block (as specified by the
block’s length) to end without forming a complete last instruction.

Instruction prefixes extend the length of an instruction without introducing a new instruction; an instruction
having one or more prefixes introduces only one instruction that begins at the first byte of the first instruction
prefix.

**Note:** Until the end of the instruction block, the instruction following any control transfer instruction is
decoded as an instruction and thus participates in locating subsequent instructions even if it is not the target of a
branch. Only instructions may appear in the instruction stream, even if unreachable. There are no address-
relative data addressing modes and raw data cannot be directly embedded within the instruction stream. Certain
instructions allow embedding of immediate data as part of the instruction, however that differs from allowing
raw data embedded directly in the instruction stream. Unreachable code may appear as the result of machine-
generated code and is allowed, but it must always be in the form of properly formed instruction sequences.

The instruction stream can be translated and the associated instruction block discarded prior to execution of the
translation. Thus, even instructions that capture and manipulate code addresses, such as `call`, `ret`, etc. can be
virtualized to operate on translated addresses instead of addresses in the CIL instruction stream.

### 1.7.2 Valid Branch Targets

The set of addresses composed of the first byte of each instruction identified in the instruction stream defines
the only valid instruction targets. Instruction targets include branch targets as specified in branch instructions,
targets specified in exception tables such as protected ranges (see Partition I and Partition II), filter, and handler
targets.

Branch instructions specify branch targets as either a one-byte or four-byte signed relative offset; the size of the
offset is differentiated by the opcode of the instruction. The offset is defined as being relative to the byte
following the branch instruction. **[Note: Thus, an offset value of zero targets the immediately following
instruction.]**

The value of a one-byte offset is computed by interpreting that byte as a signed 8-bit integer. The value of a
four-byte offset is can be computed by concatenating the bytes into a signed integer in the following manner:
the byte of lowest address forms the least significant byte, and the byte with highest address forms the most
significant byte of the integer. **[Note: This representation is often called “a signed integer in little-endian byte-
order”]**.

### 1.7.3 Exception Ranges

Exception tables describe ranges of instructions that are protected by catch, fault, or finally handlers (see
Partition I and Partition II). The starting address of a protected block, filter clause, or handler shall be a valid
branch target as specified in clause 1.7.2. It is invalid for a protected block, filter clause, or handler to end
without forming a complete last instruction.

### 1.7.4 Must Provide Maxstack

Every method specifies a maximum number of items that can be pushed onto the CIL Evaluation. The value is
stored in the `IMAGE_COR_ILMETHOD` structure that precedes the CIL body of each method. A method that
specifies a maximum number of items less than the amount required by a static analysis of the method (using a
traditional control flow graph without analysis of the data) is invalid (hence also unverifiable) and need not be
supported by a conforming implementation of the CLI.

**Note:** Maxstack is related to analysis of the program, not to the size of the stack at runtime. It does not specify
the maximum size in bytes of a stack frame, but rather the number of items that must be tracked by an analysis
tool.

**Rationale:** By analyzing the CIL stream for any method, it is easy to determine how many items will be pushed
on the CIL Evaluation stack. However, specifying that maximum number ahead of time helps a CIL-to-native-
code compiler (especially a simple one that does only a single pass through the CIL stream) in allocating
internal data structures that model the stack and/or verification algorithm.
1.7.5 Backward Branch Constraints

It must be possible, with a single forward-pass through the CIL instruction stream for any method, to infer the exact state of the evaluation stack at every instruction (where by “state” we mean the number and type of each item on the evaluation stack).

In particular, if that single-pass analysis arrives at an instruction, call it location X, that immediately follows an unconditional branch, and where X is not the target of an earlier branch instruction, then the state of the evaluation stack at X, clearly, cannot be derived from existing information. In this case, the CLI demands that the evaluation stack at X be empty.

Following on from this rule, it would clearly be invalid CIL if a later branch instruction to X were to have a non-empty evaluation stack.

Rationale: This constraint ensures that CIL code can be processed by a simple CIL-to-native-code compiler. It ensures that the state of the evaluation stack at the beginning of each CIL can be inferred from a single, forward-pass analysis of the instruction stream.

Note: the stack state at location X in the above can be inferred by various means: from a previous forward branch to X; because X marks the start of an exception handler, etc.

See the following sections for further information:
- Exceptions: Partition I
- Verification conditions for branch instructions: Chapter 3
- The tail. prefix: Section 3.19

1.7.6 Branch Verification Constraints

The target of all branch instruction must be a valid branch target (see clause 1.7.2) within the method holding that branch instruction.

1.8 Verifiability

Memory safety is a property that ensures programs running in the same address space are correctly isolated from one another (see Partition I). Thus, it is desirable to test whether programs are memory safe prior to running them. Unfortunately, it is provably impossible to do this with 100% accuracy. Instead, the CLI can test a stronger restriction, called verifiability. Every program that is verified is memory safe, but some programs that are not verifiable are still memory safe.

It is perfectly acceptable to generate CIL code that is not verifiable, but which is known to be memory safe by the compiler writer. Thus, conforming CIL may not be verifiable, even though the producing compiler may know that it is memory safe. Several important uses of CIL instructions are not verifiable, such as the pointer arithmetic versions of add that are required for the faithful and efficient compilation of C programs. For non-verifiable code, memory safety is the responsibility of the application programmer.

CIL contains a verifiable subset. The Verifiability description gives details of the conditions under which a use of an instruction falls within the verifiable subset of CIL. Verification tracks the types of values in much finer detail than is required for the basic functioning of the CLI, because it is checking that a CIL code sequence respects not only the basic rules of the CLI with respect to the safety of garbage collection, but also the typing rules of the CTS. This helps to guarantee the sound operation of the entire CLI.

The verifiability section of each operation description specifies requirements both for correct CIL generation and for verification. Correct CIL generation always requires guaranteeing that the top items on the stack correspond to the types shown in the stack transition diagram. The verifiability section specifies only requirements for correct CIL generation that are not captured in that diagram. Verification tests both the requirements for correct CIL generation and the specific verification conditions that are described with the instruction. The operation of CIL sequences that do not meet the CIL correctness requirements is unspecified. The operation of CIL sequences that meet the correctness requirements but are not verifiable may violate type safety and hence may violate security or memory access constraints.
1.8.1 Flow Control Restrictions for Verifiable CIL

This section specifies a verification algorithm that, combined with information on individual CIL instructions (see Chapter 3) and metadata validation (see Partition II), guarantees memory integrity.

The algorithm specified here creates a minimum level for all compliant implementations of the CLI in the sense that any program that is considered verifiable by this algorithm shall be considered verifiable and run correctly on all compliant implementations of the CLI.

The CLI provides a security permission (see Partition IV) that controls whether or not the CLI shall run programs that may violate memory safety. Any program that is verifiable according to this specification does not violate memory safety, and a conforming implementation of the CLI shall run such programs. The implementation may also run other programs provided it is able to show they do not violate memory safety (typically because they use a verification algorithm that makes use of specific knowledge about the implementation).

Note: While a compliant implementation is required to accept and run any program this verification algorithm states is verifiable, there may be programs that are accepted as verifiable by a given implementation but which this verification algorithm will fail to consider verifiable. Such programs will run in the given implementation but need not be considered verifiable by other implementations.

For example, an implementation of the CLI may choose to correctly track full signatures on method pointers and permit programs to execute the calli instruction even though this is not permitted by the verification algorithm specified here.

Implementers of the CLI are urged to provide a means for testing whether programs generated on their implementation meet this portable verifiability standard. They are also urged to specify where their verification algorithms are more permissive than this standard.

Only valid programs shall be verifiable. For ease of explanation, the verification algorithm described here assumes that the program is valid and does not explicitly call for tests of all validity conditions. Validity conditions are specified on a per-CIL instruction basis (see Chapter 3), and on the overall file format in Partition II.

1.8.1.1 Verification Algorithm

The verification algorithm shall attempt to associate a valid stack state with every CIL instruction. The stack state specifies the number of slots on the CIL stack at that point in the code and for each slot a required type that must be present in that slot. The initial stack state is empty (there are no items on the stack).

Verification assumes that the CLI zeroes all memory other than the evaluation stack before it is made visible to programs. A conforming implementation of the CLI shall provide this observable behavior. Furthermore, verifiable methods shall have the “zero initialize” bit set, see Partition II (Flags for Method Headers). If this bit is not set, then a CLI may throw a Verification exception at any point where a local variable is accessed, and where the assembly containing that method has not been granted SecurityPermission.SkipVerification.

Rationale: This requirement strongly enhances program portability, and a well-known technique (definite assignment analysis) allows a compiler from CIL to native code to minimize its performance impact. Note that a CLI may optionally choose to perform definite-assignment analysis – in such a case, it may confirm that a method, even without the “zero initialize” bit set, may in fact be verifiable (and therefore not throw a Verification exception).

Note: Definite assignment analysis can be used by the CLI to determine which locations are written before they are read. Such locations needn’t be zeroed, since it isn’t possible to observe the contents of the memory as it was provided by the EE.

Performance measurements on C++ implementations (which does not require definite assignment analysis) indicate that adding this requirement has almost no impact, even in highly optimized code. Furthermore, customers incorrectly attribute bugs to the compiler when this zeroing is not performed, since such code often fails when small, unrelated changes are made to the program.

The verification algorithm shall simulate all possible control flow paths through the code and ensures that a legal stack state exists for every reachable CIL instruction. The verification algorithm does not take advantage...
of any data values during its simulation (e.g. it does not perform constant propagation), but uses only type
assignments. Details of the type system used for verification and the algorithm used to merge stack states are
provided in clause 1.8.1.3. The verification algorithm terminates as follows:

350. Successfully, when all control paths have been simulated.

351. Unsuccessfully when it is not possible to compute a valid stack state for a particular CIL
instruction.

352. Unsuccessfully when additional tests specified in this clause fail.

There is a control flow path from every instruction to the subsequent instruction, with the exception of the
unconditional branch instructions, throw, rethrow, and ret. Finally, there is a control flow path from each
branch instruction (conditional or unconditional) to the branch target (targets, plural, for the switch
instruction).

Verification simulates the operation of each CIL instruction to compute the new stack state, and any type
mismatch between the specified conditions on the stack state (see Chapter 3) and the simulated stack state shall
cause the verification algorithm to fail. (Note that verification simulates only the effect on the stack state: it
does not perform the actual computation). The algorithm shall also fail if there is an existing stack state at the
next instruction address (for conditional branches or instructions within a try block there may be more than one
such address) that cannot be merged with the stack state just computed. For rules of this merge operation, see
clause 1.8.1.3.

1.8.1.2 Verification Type System

The verification algorithm compresses types that are logically equivalent, since they cannot lead to memory
safety violations. The types used by the verification algorithm are specified in clause 1.8.1.2.1, the type
compatibility rules are specified in clause 1.8.1.2.2, and the rules for merging stack states are in clause 1.8.1.3.

1.8.1.2.1 Verification Types

The following table specifies the mapping of types used in the CLI and those used in verification. Notice that
verification compresses the CLI types to a smaller set that maintains information about the size of those types
in memory, but then compresses these again to represent the fact that the CLI stack expands 1, 2 and 4 byte
built-in types into 4-byte types on the stack. Similarly, verification treats floating-point numbers on the stack as
64-bit quantities regardless of the actual representation.

Arrays are objects, but with special compatibility rules.

There is a special encoding for null that represents an object known to be the null value, hence with
indeterminate actual type.

In the following table, “CLI Type” is the type as it is described in metadata. The “Verification Type” is a
corresponding type used for type compatibility rules in verification (see clause 1.8.1.2.2) when considering the
types of local variables, incoming arguments, and formal parameters on methods being called. The column
“Verification Type (in stack state)” is used to simulate instructions that load data onto the stack, and shows the
types that are actually maintained in the stack state information of the verification algorithm. The column
“Managed Pointer to Type” shows the type tracked for managed pointers.

<table>
<thead>
<tr>
<th>CLI Type</th>
<th>Verification Type</th>
<th>Verification Type (in stack state)</th>
<th>Managed Pointer to Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>int8, unsigned int8, bool</td>
<td>int8</td>
<td>int32</td>
<td>&amp; int8</td>
</tr>
<tr>
<td>int16, unsigned int16, char</td>
<td>int16</td>
<td>int32</td>
<td>&amp; int16</td>
</tr>
<tr>
<td>int32, unsigned int32</td>
<td>int32</td>
<td>int32</td>
<td>&amp; int32</td>
</tr>
<tr>
<td>int64, unsigned int64</td>
<td>int64</td>
<td>int64</td>
<td>&amp; int64</td>
</tr>
<tr>
<td>native int, native unsigned int</td>
<td>native int</td>
<td>native int</td>
<td>&amp; native int</td>
</tr>
<tr>
<td>float32</td>
<td>float32</td>
<td>float64</td>
<td>&amp; float32</td>
</tr>
<tr>
<td>float64</td>
<td>float64</td>
<td>float64</td>
<td>&amp; float64</td>
</tr>
</tbody>
</table>
A method can be defined as returning a managed pointer, but calls upon such methods are not verifiable.

**Rationale:** some uses of returning a managed pointer are perfectly verifiable (e.g., returning a reference to a field in an object); but some not (e.g., returning a pointer to a local variable of the called method). Tracking this in the general case is a burden, and therefore not included in this standard.

### 1.8.1.2.2 Verification Type Compatibility

The following rules define type compatibility. We use $s$ and $t$ to denote verification types, and the notation "$s := t$" to indicate that the verification type $t$ can be used wherever the verification type $s$ can be used, while "$s \neq t$" indicates that $t$ cannot be used where $s$ is expected. These are the verification type compatibility (see Partition I) rules. We use $t[]$ to denote an array (of any rank) whose elements are of type $t$, and $t*$ to denote a managed pointer to type $t$.

353. $[\cdot := \cdot]$ is reflexive] For all verification types $s$, $s := s$

354. $[\cdot := \cdot]$ is transitive] For all verification types $s$, $t$, and $u$ if $s := t$ and $t := u$, then $s := u$.

355. $s := t$ if $s$ is the base class of $t$ or an interface implemented by $t$ and $t$ is not a value type.

356. $s := t$ if $s$ and $t$ are both interfaces and the implementation of $t$ requires the implementation of $s$

357. $s := \text{null}$ if $s$ is an object type or an interface

358. $s[] := t[]$ if $s := t$ and the arrays are either both vectors (zero-based, rank one) or neither is a vector and both have the same rank.

359. If $s$ and $t$ are method pointers, then $s := t$ if the signatures (return types, parameter types, calling convention, and any custom attributes or custom modifiers) are the same.

360. Otherwise $s \neq t$

### 1.8.1.3 Merging Stack States

As the verification algorithm simulates all control flow paths it shall merge the simulated stack state with any existing stack state at the next CIL instruction in the flow. If there is no existing stack state, the simulated stack state is stored for future use. Otherwise the merge shall be computed as follows and stored to replace the existing stack state for the CIL instruction. If the merge fails, the verification algorithm shall fail.

The merge shall be computed by comparing the number of slots in each stack state. If they differ, the merge shall fail. If they match, then the overall merge shall be computed by merging the states slot-by-slot as follows. Let $t$ be the type from the slot on the newly computed state and $s$ be the type from the corresponding slot on the previously stored state. The merged type, $u$, shall be computed as follows (recall that $s := t$ is the compatibility function defined in clause 1.8.1.2.2):

361. if $s := t$ then $u = s$

362. Otherwise if $t := s$ then $u = t$

363. Otherwise, if $s$ and $t$ are both object types, then let $v$ be the closest common supertype of $s$ and $t$ then $u = v$.

364. Otherwise, the merge shall fail.

### 1.8.1.4 Class and Object Initialization Rules

The VES ensures that all statics are initially zeroed (i.e. built-in types are 0 or false, object references are null), hence the verification algorithm does not test for definite assignment to statics.

An object constructor shall not return unless a constructor for the base class or a different construct for the object’s class has been called on the newly constructed object. The verification algorithm shall treat the this
pointer as uninitialized unless the base class constructor has been called. No operations can be performed on an
uninitialized this except for storing into and loading from the object’s fields.

Note: If the constructor generates an exception the this pointer in the corresponding catch block is still
uninitialized.

1.8.1.5 Delegate Constructors

The verification algorithm shall require that one of the following code sequences is used for constructing
delegates; no other code sequence in verifiable code shall contain a newobj instruction for a delegate type.
There shall be only one instance constructor method for a Delegate (overloading is not allowed)
The verification algorithm shall fail if a branch target is within these instruction sequences (other than at the
start of the sequence).

Note: See Partition II for the signature of delegates and a validity requirement regarding the signature of the
method used in the constructor and the signature of Invoke and other methods on the delegate class.

1.8.1.5.1 Delegating via Virtual Dispatch

The following CIL instruction sequence shall be used or the verification algorithm shall fail. The sequence
begins with an object on the stack.

dup
ldvirtftn mthd ; Method shall be on the class of the object,
; or one of its parent classes, or an interface
; implemented by the object
newobj delegateclass::.ctor(object, native int)

Rationale: The dup is required to ensure that it is precisely the same object stored in the delegate as was used
to compute the virtual method. If another object of a subtype were used the object and the method wouldn’t
match and could lead to memory violations.

1.8.1.5.2 Delegating via Instance Dispatch

The following CIL instruction sequence shall be used or the verification algorithm shall fail. The sequence
begins with either null or an object on the stack.

ldftn mthd ; Method shall either be a static method or
; a method on the class of the object on the stack or
; one of the object’s parent classes
newobj delegateclass::.ctor(object, native int)

1.9 Metadata Tokens

Many CIL instructions are followed by a "metadata token". This is a 4-byte value, that specifies a row in a
metadata table, or a starting byte offset in the User String heap. The most-significant byte of the token specifies
the table or heap. For example, a value of 0x02 specifies the TypeDef table; a value of 0x70 specifies the User
String heap. The value corresponds to the number assigned to that metadata table (see Partition II for the full
list of tables) or to 0x70 for the User String heap. The least-significant 3 bytes specify the target row within that
metadata table, or starting byte offset within the User String heap. The rows within metadata tables are
numbered one upwards, whilst offsets in the heap are numbered zero upwards. (So, for example, the metadata
token with value 0x02000007 specifies row number 7 in the TypeDef table)

1.10 Exceptions Thrown

A CIL instruction can throw a range of exceptions. The CLI can also throw the general purpose exception
called ExecutionEngineException. See Partition I for details.
Prefixes to Instructions

These special values are reserved to precede specific instructions. They do not constitute full instructions in their own right. It is not valid CIL to branch to the instruction following the prefix, but the prefix itself is a valid branch target. It is not valid CIL to have a prefix without immediately following it by one of the instructions it is permitted to precede.
2.1 tail. (prefix) – call terminates current method

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 14</td>
<td>tail.</td>
<td>Subsequent call terminates current method</td>
</tr>
</tbody>
</table>

**Description:**
The tail. instruction must immediately precede a call, calli, or callvirt instruction. It indicates that the current method’s stack frame is no longer required and thus can be removed before the call instruction is executed. Because the value returned by the call will be the value returned by this method, the call can be converted into a cross-method jump.

The evaluation stack must be empty except for the arguments being transferred by the following call. The instruction following the call instruction must be a ret. Thus the only legal code sequence is

```
tail. call (or calli or callvirt) somewhere
ret
```

Correct CIL must not branch to the call instruction, but it is permitted to branch to the ret. The only values on the stack must be the arguments for the method being called.

The tail. call (or calli or callvirt) instruction cannot be used to transfer control out of a try, filter, catch, or finally block. See Partition I.

The current frame cannot be discarded when control is transferred from untrusted code to trusted code, since this would jeopardize code identity security. Security checks may therefore cause the tail. to be ignored, leaving a standard call instruction.

Similarly, in order to allow the exit of a synchronized region to occur after the call returns, the tail. prefix is ignored when used to exit a method that is marked synchronized.

There may also be implementation-specific restrictions that prevent the tail. prefix from being obeyed in certain cases. While an implementation is free to ignore the tail. prefix under these circumstances, they should be clearly documented as they can affect the behavior of programs.

CLI implementations are required to honor tail. call requests where caller and callee methods can be statically determined to lie in the same assembly; and where the caller is not in a synchronized region; and where caller and callee satisfy all conditions listed in the “Verifiability” rules below. (To “honor” the tail. prefix means to remove the caller’s frame, rather than revert to a regular call sequence). Consequently, a CLI implementation need not honor tail. calli or tail. callvirt sequences.

**Rationale:** tail. calls allow some linear space algorithms to be converted to constant space algorithms and are required by some languages. In the presence of ldloca and ldarga instructions it isn’t always possible for a compiler from CIL to native code to optimally determine when a tail. can be automatically inserted.

**Exceptions:**
None.

**Verifiability:**
Correct CIL obeys the control transfer constraints listed above. In addition, no managed pointers can be passed to the method being called if they point into the stack frame that is about to be removed. The return type of the method being called must be compatible with the return type of the current method. Verification requires that no managed pointers are passed to the method being called, since it does not track pointers into the current frame.
2.2 unaligned. (prefix) – pointer instruction may be unaligned

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 12 &lt;unsigned int8&gt;</td>
<td>unaligned. alignment</td>
<td>Subsequent pointer instruction may be unaligned</td>
</tr>
</tbody>
</table>

Stack Transition:
...
... addr \rightarrow ...
... addr

Description:
Unaligned. specifies that address (an unmanaged pointer (&), or native int) on the stack may not be aligned to the natural size of the immediately following ldind, stind, ldfld, stfld, ldboj, stobj, initblk, or cpblk instruction. That is, for a ldind.i4 instruction the alignment of addr may not be to a 4-byte boundary. For initblk and cpblk the default alignment is architecture dependent (4-byte on 32-bit CPUs, 8-byte on 64-bit CPUs). Code generators that do not restrict their output to a 32-bit word size (see Partition I and Partition II) must use unaligned. if the alignment is not known at compile time to be 8-byte.

The value of alignment shall be 1, 2, or 4 and means that the generated code should assume that addr is byte, double byte, or quad byte aligned, respectively.

Rationale: While the alignment for a cpblk instruction would logically require two numbers (one for the source and one for the destination), there is no noticeable impact on performance if only the lower number is specified.

The unaligned. and volatile. prefixes may be combined in either order. They must immediately precede a ldind, stind, ldfld, stfld, ldboj, stobj, initblk, or cpblk instruction. Only the volatile. prefix is allowed for the ldsfld and stsfld instructions.

Note: See Partition I, 12.7 for information about atomicity and data alignment.

Exceptions:
None.

Verifiability:
An unaligned. prefix shall be immediately followed by one of the instructions listed above.
2.3 volatile. (prefix) - pointer reference is volatile

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 13</td>
<td>volatile.</td>
<td>Subsequent pointer reference is volatile</td>
</tr>
</tbody>
</table>

Stack Transition:
..., addr \(\rightarrow\) ..., addr

Description:
volatile. specifies that \(addr\) is a volatile address (i.e. it may be referenced externally to the current thread of execution) and the results of reading that location cannot be cached or that multiple stores to that location cannot be suppressed. Marking an access as volatile. affects only that single access; other accesses to the same location must be marked separately. Access to volatile locations need not be performed atomically. [see Partition I]

The unaligned. and volatile. prefixes may be combined in either order. They must immediately precede a ldind, stind, ldfld, stfld, ldobj, stobj, initblk, or cpblk instruction. Only the volatile. prefix is allowed for the ldsfld and stsfld instructions.

Exceptions:
None.

Verifiability:
A volatile. prefix should be immediately followed by one of the instructions listed above.
3 Base Instructions

These instructions form a “Turing Complete” set of basic operations. They are independent of the object model that may be employed. Operations that are specifically related to the CTS’s object model are contained in the Object Model Instructions section.
3.1 add - add numeric values

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>58</td>
<td>add</td>
<td>Add two values, returning a new value</td>
</tr>
</tbody>
</table>

Stack Transition:
...
value1, value2 → ...
result

Description:
The `add` instruction adds `value2` to `value1` and pushes the result on the stack. Overflow is not detected for integral operations (but see `add.ovf`); floating-point overflow returns +inf or -inf.

The acceptable operand types and their corresponding result data type is encapsulated in Table2: Binary Numeric Operations.

Exceptions:
None.

Verifiability:
See Table2: Binary Numeric Operations.
### 3.2 add.ovf.<signed> - add integer values with overflow check

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>D6</td>
<td>add.ovf</td>
<td>Add signed integer values with overflow check.</td>
</tr>
<tr>
<td>D7</td>
<td>add.ovf.un</td>
<td>Add unsigned integer values with overflow check.</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value1, value2 → ..., result

**Description:**

The `add.ovf` instruction adds `value1` and `value2` and pushes the result on the stack. The acceptable operand types and their corresponding result data type is encapsulated in Table 7: Overflow Arithmetic Operations.

**Exceptions:**

`OverflowException` is thrown if the result can not be represented in the result type.

**Verifiability:**

See Table 7: Overflow Arithmetic Operations.
3.3 and - bitwise AND

<table>
<thead>
<tr>
<th>Format</th>
<th>Instruction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5F</td>
<td>And</td>
<td>Bitwise AND of two integral values, returns an integral value</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value1, value2 → ..., result

**Description:**
The `and` instruction computes the bitwise AND of the top two values on the stack and pushes the result on the stack. The acceptable operand types and their corresponding result data type is encapsulated in Table 5: Integer Operations.

**Exceptions:**
None.

**Verifiability:**
See Table 5: Integer Operations.
3.4 arglist - get argument list

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 00</td>
<td>arglist</td>
<td>return argument list handle for the current method</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... → ..., argListHandle

**Description:**
The `arglist` instruction returns an opaque handle (an unmanaged pointer, type `native int`) representing the argument list of the current method. This handle is valid only during the lifetime of the current method. The handle can, however, be passed to other methods as long as the current method is on the thread of control. The `arglist` instruction may only be executed within a method that takes a variable number of arguments.

**Rationale:** This instruction is needed to implement the C "va_" macros used to implement procedures like 'printf'. It is intended for use with the class library implementation of System.ArgIterator.

**Exceptions:**
None.

**Verifiability:**
It is incorrect CIL generation to emit this instruction except in the body of a method whose signature indicates it accepts a variable number of arguments. Within such a method its use is verifiable, but verification requires that the result is an instance of the `System.RuntimeArgumentHandle` class.
3.5 beq.<length> – branch on equal

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3B &lt;int32&gt;</td>
<td>beq target</td>
<td>branch to target if equal</td>
</tr>
<tr>
<td>2E &lt;int8&gt;</td>
<td>beq.s target</td>
<td>branch to target if equal, short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value1, value2 \(\rightarrow\) ...

**Description:**

The `beq` instruction transfers control to `target` if `value1` is equal to `value2`. The effect is identical to performing a `ceq` instruction followed by a `brtrue target`. `Target` is represented as a signed offset (4 bytes for `beq`, 1 byte for `beq.s`) from the beginning of the instruction following the current instruction.

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of `try`, `catch`, `filter`, and `finally` blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the `leave` instruction instead; see Partition I for details).

**Exceptions:**

None.

**Verifiability:**

Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.6  \texttt{bge.<\texttt{length}>} – branch on greater than or equal to

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C &lt;int32&gt;</td>
<td>\texttt{bge target}</td>
<td>branch to \textit{target} if greater than or equal to</td>
</tr>
<tr>
<td>2F &lt;int8&gt;</td>
<td>\texttt{bge.s target}</td>
<td>branch to \textit{target} if greater than or equal to, short form</td>
</tr>
</tbody>
</table>

\textit{Stack Transition:}

\[ \ldots, \text{value1}, \text{value2} \rightarrow \ldots \]

\textbf{Description:}

The \texttt{bge} instruction transfers control to \textit{target} if \textit{value1} is greater than or equal to \textit{value2}. The effect is identical to performing a \texttt{clt} instruction followed by a \texttt{brfalse target}. \textit{Target} is represented as a signed offset (4 bytes for \texttt{bge}, 1 byte for \texttt{bge.s}) from the beginning of the instruction following the current instruction.

The effect of a “\texttt{bge target}” instruction is identical to:

- If stack operands are integers, then: \texttt{clt} followed by a \texttt{brfalse target}
- If stack operands are floating-point, then: \texttt{clt.un} followed by a \texttt{brfalse target}

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of \texttt{try, catch, filter, and finally} blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the \texttt{leave} instruction instead; see Partition I for details).

\textbf{Exceptions:}

None.

\textbf{Verifiability:}

Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.7 bge.un.<length> – branch on greater than or equal to, unsigned or unordered

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>41 &lt;int32&gt;</td>
<td>bge.un target</td>
<td>branch to target if greater than or equal to (unsigned or unordered)</td>
</tr>
<tr>
<td>34 &lt;int8&gt;</td>
<td>bge.un.s target</td>
<td>branch to target if greater than or equal to (unsigned or unordered), short form</td>
</tr>
</tbody>
</table>

Stack Transition:

..., value1, value2 → ...

Description:

The bge.un instruction transfers control to target if value1 is greater than or equal to value2, when compared unsigned (for integer values) or unordered (for float point values). The effect is identical to performing a clt instruction followed by a brfalse target. Target is represented as a signed offset (4 bytes for bge.un, 1 byte for bge.un.s) from the beginning of the instruction following the current instruction.

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of try, catch, filter, and finally blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the leave instruction instead; see Partition I for details).

Exceptions:

None.

Verifiability:

Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.8  **bgt.<length> – branch on greater than**

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D &lt;int32&gt;</td>
<td>bgt target</td>
<td>branch to target if greater than</td>
</tr>
<tr>
<td>30 &lt;int8&gt;</td>
<td>bgt.s target</td>
<td>branch to target if greater than, short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...
,..., value1, value2 → ...

**Description:**
The `bgt` instruction transfers control to `target` if `value1` is greater than `value2`. The effect is identical to performing a `cgt` instruction followed by a `brtrue target`. `Target` is represented as a signed offset (4 bytes for `bgt`, 1 byte for `bgt.s`) from the beginning of the instruction following the current instruction.

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of `try`, `catch`, `filter`, and `finally` blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the `leave` instruction instead; see Partition I for details).

**Exceptions:**
None.

**Verifiability:**
Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.9  \texttt{bgt.un.<length>} – branch on greater than, unsigned or unordered

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{42 \textless \text{int32}}</td>
<td>\texttt{bgt.un target}</td>
<td>branch to target if greater than (unsigned or unordered)</td>
</tr>
<tr>
<td>\texttt{35 \textless \text{int8}}</td>
<td>\texttt{bgt.un.s target}</td>
<td>branch to target if greater than (unsigned or unordered), short form</td>
</tr>
</tbody>
</table>

\textit{Stack Transition:}

\[ \ldots, \text{value1}, \text{value2} \rightarrow \ldots \]

\textit{Description:}

The \texttt{bgt.un} instruction transfers control to target if value1 is greater than value2, when compared unsigned (for integer values) or unordered (for float point values). The effect is identical to performing a \texttt{cgt.un} instruction followed by a \texttt{brtrue target}. Target is represented as a signed offset (4 bytes for \texttt{bgt.un}, 1 byte for \texttt{bgt.un.s}) from the beginning of the instruction following the current instruction.

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of \texttt{try}, \texttt{catch}, \texttt{filter}, and \texttt{finally} blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the \texttt{leave} instruction instead; see Partition I for details).

\textit{Exceptions:}

None.

\textit{Verifiability:}

Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.10 ble.<length> – branch on less than or equal to

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3E &lt;int32&gt;</td>
<td>ble target</td>
<td>branch to target if less than or equal to</td>
</tr>
<tr>
<td>31 &lt;int8&gt;</td>
<td>ble.s target</td>
<td>branch to target if less than or equal to, short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...
value1, value2 → ...

**Description:**
The ble instruction transfers control to target if value1 is less than or equal to value2. Target is represented as a signed offset (4 bytes for ble, 1 byte for ble.s) from the beginning of the instruction following the current instruction.

The effect of a "ble target" instruction is identical to:

- If stack operands are integers, then: cgt followed by a brfalse target
- If stack operands are floating-point, then: cgt.un followed by a brfalse target

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of try, catch, filter, and finally blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the leave instruction instead; see Partition I for details).

**Exceptions:**
None.

**Verifiability:**
Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.11 ble.un.<length> – branch on less than or equal to, unsigned or unordered

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>43 &lt;int32&gt;</td>
<td>ble.un target</td>
<td>branch to target if less than or equal to (unsigned or unordered)</td>
</tr>
<tr>
<td>36 &lt;int8&gt;</td>
<td>ble.un.s target</td>
<td>branch to target if less than or equal to (unsigned or unordered), short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value1, value2 → ...

**Description:**

The ble.un instruction transfers control to target if value1 is less than or equal to value2, when compared unsigned (for integer values) or unordered (for float point values). Target is represented as a signed offset (48 bytes for ble.un, 1 byte for ble.un.s) from the beginning of the instruction following the current instruction.

The effect of a “ble.un target” instruction is identical to:

- If stack operands are integers, then : cgt.un followed by a brfalse target
- If stack operands are floating-point, then : cgt followed by a brfalse target

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of try, catch, filter, and finally blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the leave instruction instead; see Partition I for details).

**Exceptions:**

None.

**Verifiability:**

Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.12 blt.<length> – branch on less than

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3F &lt;int32&gt;</td>
<td>blt target</td>
<td>branch to target if less than</td>
</tr>
<tr>
<td>32 &lt;int8&gt;</td>
<td>blt.s target</td>
<td>branch to target if less than, short form</td>
</tr>
</tbody>
</table>

Stack Transition:
...
..., value1, value2 → ...

Description:
The blt instruction transfers control to target if value1 is less than value2. The effect is identical to performing a clt instruction followed by a brtrue target. Target is represented as a signed offset (4 bytes for blt, 1 byte for blt.s) from the beginning of the instruction following the current instruction.

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of try, catch, filter, and finally blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the leave instruction instead; see Partition I for details).

Exceptions:
None.

Verifiability:
Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.13  blt.un.<length> – branch on less than, unsigned or unordered

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>44 &lt;int32&gt;</td>
<td>blt.un target</td>
<td>Branch to target if less than (unsigned or unordered)</td>
</tr>
<tr>
<td>37 &lt;int8&gt;</td>
<td>blt.un.s target</td>
<td>Branch to target if less than (unsigned or unordered), short form</td>
</tr>
</tbody>
</table>

Stack Transition:
...
value1, value2 → ...

Description:
The blt.un instruction transfers control to target if value1 is less than value2, when compared unsigned (for integer values) or unordered (for float point values). The effect is identical to performing a clt.un instruction followed by a brtrue target. Target is represented as a signed offset (4 bytes for blt.un, 1 byte for blt.un.s) from the beginning of the instruction following the current instruction.

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of try, catch, filter, and finally blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the leave instruction instead; see Partition I for details).

Exceptions:
None.

Verifiability:
Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.14  bne.un<length> – branch on not equal or unordered

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 &lt;int32&gt;</td>
<td>bne.un target</td>
<td>branch to target if unequal or unordered</td>
</tr>
<tr>
<td>33 &lt;int8&gt;</td>
<td>bne.un.s target</td>
<td>branch to target if unequal or unordered, short form</td>
</tr>
</tbody>
</table>

Stack Transition:
... value1, value2 → ...

Description:
The bne.un instruction transfers control to target if value1 is not equal to value2, when compared unsigned (for integer values) or unordered (for float point values). The effect is identical to performing a ceq instruction followed by a brfalse target. Target is represented as a signed offset (4 bytes for bne.un, 1 byte for bne.un.s) from the beginning of the instruction following the current instruction.

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of try, catch, filter, and finally blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the leave instruction instead; see Partition I for details).

Exceptions:
None.

Verifiability:
Correct CIL must observe all of the control transfer rules specified above and must guarantee that the top two items on the stack correspond to the types shown in Table 4: Binary Comparison or Branch Operations.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
### 3.15 \texttt{br.<length>} – unconditional branch

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>38 &lt;\texttt{int32}&gt;</td>
<td>\texttt{br target}</td>
<td>branch to \texttt{target}</td>
</tr>
<tr>
<td>2B &lt;\texttt{int8}&gt;</td>
<td>\texttt{br.s target}</td>
<td>branch to \texttt{target}, short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**
\[ \ldots \rightarrow \ldots \]

**Description:**
The \texttt{br} instruction unconditionally transfers control to \texttt{target}. \texttt{Target} is represented as a signed offset (4 bytes for \texttt{br}, 1 byte for \texttt{br.s}) from the beginning of the instruction following the current instruction.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of \texttt{try, catch, filter, and finally} blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the \texttt{leave} instruction instead; see Partition I for details).

**Rationale:** While a \texttt{leave} instruction can be used instead of a \texttt{br} instruction when the evaluation stack is empty, doing so may increase the resources required to compile from CIL to native code and/or lead to inferior native code. Therefore CIL generators should use a \texttt{br} instruction in preference to a \texttt{leave} instruction when both are legal.

**Exceptions:**
None.

**Verifiability:**
Correct CIL must observe all of the control transfer rules specified above.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
### 3.16 break – breakpoint instruction

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>break</td>
<td>inform a debugger that a breakpoint has been reached.</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., → ...

**Description:**

The `break` instruction is for debugging support. It signals the CLI to inform the debugger that a breakpoint has been tripped. It has no other effect on the interpreter state.

The `break` instruction has the smallest possible instruction size so that code can be patched with a breakpoint with minimal disturbance to the surrounding code.

The `break` instruction may trap to a debugger, do nothing, or raise a security exception: the exact behavior is implementation-defined

**Exceptions:**

None.

**Verifiability:**

The `break` instruction is always verifiable.
3.17 brfalse.<length> - branch on false, null, or zero

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>39 &lt;int32&gt;</td>
<td>brfalse target</td>
<td>branch to target if value is zero (false)</td>
</tr>
<tr>
<td>2C &lt;int8&gt;</td>
<td>brfalse.s target</td>
<td>branch to target if value is zero (false), short form</td>
</tr>
<tr>
<td>39 &lt;int32&gt;</td>
<td>bnull target</td>
<td>branch to target if value is null (alias for brfalse)</td>
</tr>
<tr>
<td>2C &lt;int8&gt;</td>
<td>bnull.s target</td>
<td>branch to target if value is null (alias for brfalse.s), short form</td>
</tr>
<tr>
<td>39 &lt;int32&gt;</td>
<td>bzero target</td>
<td>branch to target if value is zero (alias for brfalse)</td>
</tr>
<tr>
<td>2C &lt;int8&gt;</td>
<td>bzero.s target</td>
<td>branch to target if value is zero (alias for brfalse.s), short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value → ...

**Description:**
The brfalse instruction transfers control to target if value (of type int32, int64, object reference, managed pointer, unmanaged pointer or native int) is zero (false). If value is non-zero (true) execution continues at the next instruction.

*Target* is represented as a signed offset (4 bytes for brfalse, 1 byte for brfalse.s) from the beginning of the instruction following the current instruction.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of try, catch, filter, and finally blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the leave instruction instead; see Partition I for details).

**Exceptions:**
None.

**Verifiability:**
Correct CIL must observe all of the control transfer rules specified above and must guarantee there is a minimum of one item on the stack.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
### 3.18 brtrue.<length> - branch on non-false or non-null

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A &lt;int32&gt;</td>
<td>brtrue target</td>
<td>branch to target if value is non-zero (true)</td>
</tr>
<tr>
<td>2D &lt;int8&gt;</td>
<td>brtrue.s target</td>
<td>branch to target if value is non-zero (true), short form</td>
</tr>
<tr>
<td>3A &lt;int32&gt;</td>
<td>brinst target</td>
<td>branch to target if value is a non-null object reference (alias for brtrue)</td>
</tr>
<tr>
<td>2D &lt;int8&gt;</td>
<td>brinst.s target</td>
<td>branch to target if value is a non-null object reference, short form (alias for brtrue.s)</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value → ...

**Description:**

The `brtrue` instruction transfers control to target if `value` (of type native int) is nonzero (true). If `value` is zero (false) execution continues at the next instruction.

If the `value` is an object reference (type `o`) then `brinst` (an alias for `brtrue`) transfers control if it represents an instance of an object (i.e. isn't the null object reference, see `ldnull`).

Target is represented as a signed offset (4 bytes for `brtrue`, 1 byte for `brtrue.s`) from the beginning of the instruction following the current instruction.

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of try, catch, filter, and finally blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the `leave` instruction instead; see Partition I for details).

**Exceptions:**

None.

**Verifiability:**

Correct CIL must observe all of the control transfer rules specified above and must guarantee there is a minimum of one item on the stack.

In addition, verifiable code requires the type-consistency of the stack, locals and arguments for every possible path to the destination instruction. See Section 1.5 for more details.
3.19 call – call a method

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>28 &lt;T&gt;</code></td>
<td><code>call method</code></td>
<td>Call method described by <code>method</code></td>
</tr>
</tbody>
</table>

**Stack Transition:**

`..., arg1, arg2 ... argn` \(\rightarrow\) `..., retval` (not always returned)

**Description:**

The `call` instruction calls the method indicated by the descriptor `method`. Method is a metadata token (either a `methodref` or `methoddef` (See Partition II) that indicates the method to call and the number, type, and order of the arguments that have been placed on the stack to be passed to that method as well as the calling convention to be used. See Partition I for a detailed description of the CIL calling sequence. The `call` instruction may immediately preceded by a `tail` prefix to specify that the current method state should be released before transferring control (see Section 2.1).

The metadata token carries sufficient information to determine whether the call is to a static method, an instance method, a virtual method, or a global function. In all of these cases the destination address is determined entirely from the metadata token (Contrast with the `callvirt` instruction for calling virtual methods, where the destination address also depends upon the runtime type of the instance reference pushed before the callvirt; see below).

If the method does not exist in the class specified by the metadata token, the base classes are searched to find the most derived class which defines the method and that method is called.

**Rationale:** This implements “call superclass” behavior.

The arguments are placed on the stack in left-to-right order. That is, the first argument is computed and placed on the stack, then the second argument, etc. There are three important special cases:

365. Calls to an instance (or virtual, see below) method must push that instance reference (the `this` pointer) before any of the user-visible arguments. The signature carried in the metadata does not contain an entry in the parameter list for the `this` pointer but uses a bit (called HASTHIS) to indicate whether the method requires passing the `this` pointer (see Partition I).

366. It is legal to call a virtual method using `call` (rather than `callvirt`); this indicates that the method is to be resolved using the class specified by `method` rather than as specified dynamically from the object being invoked. This is used, for example, to compile calls to “methods on super” (i.e. the statically known parent class).

367. Note that a delegate’s `Invoke` method may be called with either the `call` or `callvirt` instruction.

**Exceptions:**

`SecurityException` may be thrown if system security does not grant the caller access to the called method.

The security check may occur when the CIL is converted to native code rather than at runtime.

**Verifiability:**

Correct CIL ensures that the stack contains the correct number and type of arguments for the method being called.

For a typical use of the `call` instruction, verification checks that (a) `method` refers to a valid `methodref` or `methoddef` token; (b) the types of the objects on the stack are consistent with the types expected by the method call, and (c) the method is accessible from the callsite, and (d) the method is not abstract (i.e., it has an implementation).

The `call` instruction may also be used to call an object’s superclass constructor, or to initialize a value type location by calling an appropriate constructor, both of which are treated as special cases by verification. A `call` annotated by `tail` is also a special case.
If the target method is global (defined outside of any type), then the method must be static.
3.20 calli—indirect method call

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>calli callsitedescr</td>
<td>Call method indicated on the stack with arguments described by callsitedescr.</td>
</tr>
</tbody>
</table>

Stack Transition:

... arg1, arg2 ... argn, ftn \rightarrow ... retVal (not always returned)

Description:

The calli instruction calls ftn (a pointer to a method entry point) with the arguments arg1 ... argn. The types of these arguments are described by the signature callsitedescr. See Partition I for a description of the CIL calling sequence. The calli instruction may be immediately preceded by a tail. prefix to specify that the current method state should be released before transferring control. If the call would transfer control to a method of higher trust than the origin method the stack frame will not be released; instead, the execution will continue silently as if the tail. prefix had not been supplied.

[A callee of “higher trust” is defined as one whose permission grant-set is a strict superset of the grant-set of the caller]

The ftn argument is assumed to be a pointer to native code (of the target machine) that can be legitimately called with the arguments described by callsitedescr (a metadata token for a stand-alone signature). Such a pointer can be created using the ldftn or ldvirtftn instructions, or have been passed in from native code.

The standalone signature specifies the number and type of parameters being passed, as well as the calling convention (See Partition II) The calling convention is not checked dynamically, so code that uses a calli instruction will not work correctly if the destination does not actually use the specified calling convention.

The arguments are placed on the stack in left-to-right order. That is, the first argument is computed and placed on the stack, then the second argument, etc. The argument-building code sequence for an instance or virtual method must push that instance reference (the this pointer, which must not be null) before any of the user-visible arguments.

Exceptions:

SecurityException may be thrown if the system security does not grant the caller access to the called method. The security check may occur when the CIL is converted to native code rather than at runtime.

Verifiability:

Correct CIL requires that the function pointer contains the address of a method whose signature matches that specified by callsitedescr and that the arguments correctly correspond to the types of the destination function’s parameters.

Verification checks that ftn is a pointer to a function generated by ldftn or ldvirtfn.
3.21 ceq - compare equal

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 01</td>
<td>ceq</td>
<td>push 1 (of type int32) if value1 equals value2, else 0</td>
</tr>
</tbody>
</table>

Stack Transition:
..., value1, value2 → ..., result

Description:
The ceq instruction compares value1 and value2. If value1 is equal to value2, then 1 (of type int32) is pushed on the stack. Otherwise 0 (of type int32) is pushed on the stack.

For floating-point number, ceq will return 0 if the numbers are unordered (either or both are NaN). The infinite values are equal to themselves.

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

Exceptions:
None.

Verifiability:
Correct CIL provides two values on the stack whose types match those specified in Table 4: Binary Comparison or Branch Operations. There are no additional verification requirements.
3.22  cgt - compare greater than

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 02</td>
<td>cgt</td>
<td>push 1 (of type int32) if value1 &gt; value2, else 0</td>
</tr>
</tbody>
</table>

Stack Transition:
...
result

Description:
The cgt instruction compares value1 and value2. If value1 is strictly greater than value2, then 1 (of type int32) is pushed on the stack. Otherwise 0 (of type int32) is pushed on the stack.

For floating-point numbers, cgt returns 0 if the numbers are unordered (that is, if one or both of the arguments are NaN).

As per IEC 60559:1989 spec, infinite values are ordered with respect to normal numbers (e.g. +infinity > 5.0 > -infinity).

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

Exceptions:
None.

Verifiability:
Correct CIL provides two values on the stack whose types match those specified in Table 4: Binary Comparison or Branch Operations. There are no additional verification requirements.
### 3.23 cgt.un - compare greater than, unsigned or unordered

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 03</td>
<td>cgt.un</td>
<td>push 1 (of type int32) if ( value1 &gt; value2 ), unsigned or unordered, else 0</td>
</tr>
</tbody>
</table>

**Stack Transition:**

\[ ..., value1, value2 \rightarrow ..., result \]

**Description:**

The `cgt.un` instruction compares `value1` and `value2`. A value of 1 (of type `int32`) is pushed on the stack if:

- for floating-point numbers, either `value1` is strictly greater than `value2`, or `value1` is not ordered with respect to `value2`;
- for integer values, `value1` is strictly greater than `value2` when considered as unsigned numbers.

Otherwise 0 (of type `int32`) is pushed on the stack.

As per IEC 60559:1989 spec, infinite values are ordered with respect to normal numbers (e.g. `+\infty > 5.0 > -\infty`).

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

**Exceptions:**

None.

**Verifiability:**

Correct CIL provides two values on the stack whose types match those specified in Table 4: Binary Comparison or Branch Operations. There are no additional verification requirements.
### 3.24 ckfinite – check for a finite real number

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3</td>
<td>ckfinite</td>
<td>throw ArithmeticException if value is not a finite number</td>
</tr>
</tbody>
</table>

**Stack Transition:**

`...` value $\rightarrow$ `...` value

**Description:**

The `ckfinite` instruction throws `ArithmeticException` if `value` (a floating-point number) is either a “not a number” value (NaN) or ± infinity value. `ckfinite` leaves the value on the stack if no exception is thrown. Execution is unspecified if `value` is not a floating-point number.

**Exceptions:**

`ArithmeticException` is thrown if `value` is not a ‘normal’ number.

**Verifiability:**

Correct CIL guarantees that `value` is a floating-point number. There are no additional verification requirements.
### 3.25 clt - compare less than

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 04</td>
<td>clt</td>
<td>push 1 (of type int32) if value1 &lt; value2, else 0</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... , value1, value2 → ... , result

**Description:**

The clt instruction compares value1 and value2. If value1 is strictly less than value2, then 1 (of type int32) is pushed on the stack. Otherwise 0 (of type int32) is pushed on the stack.

For floating-point numbers, clt will return 0 if the numbers are unordered (that is one or both of the arguments are NaN).

As per IEC 60559:1989 spec, infinite values are ordered with respect to normal numbers (e.g. +infinity > 5.0 > -infinity).

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

**Exceptions:**

None.

**Verifiability:**

Correct CIL provides two values on the stack whose types match those specified in Table 4: Binary Comparison or Branch Operations. There are no additional verification requirements.
3.26 clt.un - compare less than, unsigned or unordered

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 05</td>
<td>clt.un</td>
<td>push 1 (of type int32) if value1 &lt; value2, unsigned or unordered, else 0</td>
</tr>
</tbody>
</table>

Stack Transition:

..., value1, value2 \rightarrow ..., result

Description:
The clt.un instruction compares value1 and value2. A value of 1 (of type int32) is pushed on the stack if

- for floating-point numbers, either value1 is strictly less than value2, or value1 is not ordered with respect to value2
- for integer values, value1 is strictly less than value2 when considered as unsigned numbers

Otherwise 0 (of type int32) is pushed on the stack.

As per IEC 60559:1989 spec, infinite values are ordered with respect to normal numbers (e.g. +infinity > 5.0 > -infinity).

The acceptable operand types are encapsulated in Table 4: Binary Comparison or Branch Operations.

Exceptions:
None.

Verifiability:
Correct CIL provides two values on the stack whose types match those specified in Table 4: Binary Comparison or Branch Operations. There are no additional verification requirements.
### 3.27 conv.<to type> - data conversion

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>67</td>
<td>conv.i1</td>
<td>Convert to int8, pushing int32 on stack</td>
</tr>
<tr>
<td>68</td>
<td>conv.i2</td>
<td>Convert to int16, pushing int32 on stack</td>
</tr>
<tr>
<td>69</td>
<td>conv.i4</td>
<td>Convert to int32, pushing int32 on stack</td>
</tr>
<tr>
<td>6A</td>
<td>conv.i8</td>
<td>Convert to int64, pushing int64 on stack</td>
</tr>
<tr>
<td>6B</td>
<td>conv.r4</td>
<td>Convert to float32, pushing ( F ) on stack</td>
</tr>
<tr>
<td>6C</td>
<td>conv.r8</td>
<td>Convert to float64, pushing ( F ) on stack</td>
</tr>
<tr>
<td>D2</td>
<td>conv.u1</td>
<td>Convert to unsigned int8, pushing int32 on stack</td>
</tr>
<tr>
<td>D1</td>
<td>conv.u2</td>
<td>Convert to unsigned int16, pushing int32 on stack</td>
</tr>
<tr>
<td>6D</td>
<td>conv.u4</td>
<td>Convert to unsigned int32, pushing int32 on stack</td>
</tr>
<tr>
<td>6E</td>
<td>conv.u8</td>
<td>Convert to unsigned int64, pushing int64 on stack</td>
</tr>
<tr>
<td>D3</td>
<td>conv.i</td>
<td>Convert to native int, pushing native int on stack</td>
</tr>
<tr>
<td>E0</td>
<td>conv.u</td>
<td>Convert to native unsigned int, pushing native int on stack</td>
</tr>
<tr>
<td>76</td>
<td>conv.r.un</td>
<td>Convert unsigned integer to floating-point, pushing ( F ) on stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value \( \rightarrow \) ..., result

**Description:**

Convert the value on top of the stack to the type specified in the opcode, and leave that converted value on the top of the stack. Note that integer values of less than 4 bytes are extended to int32 (not native int) when they are loaded onto the evaluation stack, and floating-point values are converted to the \( F \) type.

Conversion from floating-point numbers to integral values truncates the number toward zero. When converting from an float64 to an float32, precision may be lost. If value is too large to fit in an float32, the IEC 60559:1989 positive infinity (if value is positive) or IEC 60559:1989 negative infinity (if value is negative) is returned. If overflow occurs converting one integer type to another the high order bits are silently truncated. If the result is smaller than an int32, then the value is sign-extended to fill the slot.

If overflow occurs converting a floating-point type to an integer the value returned is unspecified. The conv.r.un operation takes an integer off the stack, interprets it as unsigned, and replaces it with a floating-point number to represent the integer; either a float32, if this is wide enough to represent the integer without loss of precision, else a float64.

No exceptions are ever thrown. See conv.ovf for instructions that will throw an exception when the result type cannot properly represent the result value.

The acceptable operand types and their corresponding result data type is encapsulated in Table 8: Conversion Operations.

**Exceptions:**

None.

**Verifiability:**

Correct CIL has at least one value, of a type specified in Table 8: Conversion Operations, on the stack. The same table specifies a restricted set of types that are acceptable in verified code.
3.28 conv.ovf.<to type> - data conversion with overflow detection

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>conv.ovf.i1</td>
<td>Convert to an int8 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>B5</td>
<td>conv.ovf.i2</td>
<td>Convert to an int16 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>B7</td>
<td>conv.ovf.i4</td>
<td>Convert to an int32 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>B9</td>
<td>conv.ovf.i8</td>
<td>Convert to an int64 (on the stack as int64) and throw an exception on overflow</td>
</tr>
<tr>
<td>B4</td>
<td>conv.ovf.u1</td>
<td>Convert to an unsigned int8 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>B6</td>
<td>conv.ovf.u2</td>
<td>Convert to an unsigned int16 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>B8</td>
<td>conv.ovf.u4</td>
<td>Convert to an unsigned int32 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>BA</td>
<td>conv.ovf.u8</td>
<td>Convert to an unsigned int64 (on the stack as int64) and throw an exception on overflow</td>
</tr>
<tr>
<td>D4</td>
<td>conv.ovf.i</td>
<td>Convert to a native int (on the stack as native int) and throw an exception on overflow</td>
</tr>
<tr>
<td>D5</td>
<td>conv.ovf.u</td>
<td>Convert to a native unsigned int (on the stack as native int) and throw an exception on overflow</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value \(\rightarrow\) ..., result

**Description:**

Convert the value on top of the stack to the type specified in the opcode, and leave that converted value on the top of the stack. If the value is too large or too small to be represented by the target type, an exception is thrown.

Conversions from floating-point numbers to integral values truncate the number toward zero. Note that integer values of less than 4 bytes are extended to int32 (not native int) on the evaluation stack.

The acceptable operand types and their corresponding result data type is encapsulated in Table 8: Conversion Operations.

**Exceptions:**

OverflowException is thrown if the result can not be represented in the result type

**Verifiability:**

Correct CIL has at least one value, of a type specified in Table 8: Conversion Operations, on the stack. The same table specifies a restricted set of types that are acceptable in verified code.
3.29 *conv.ovf.<to type>.un* – unsigned data conversion with overflow detection

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>conv.ovf.i1.un</td>
<td>Convert unsigned to an int8 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>83</td>
<td>conv.ovf.i2.un</td>
<td>Convert unsigned to an int16 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>84</td>
<td>conv.ovf.i4.un</td>
<td>Convert unsigned to an int32 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>85</td>
<td>conv.ovf.i8.un</td>
<td>Convert unsigned to an int64 (on the stack as int64) and throw an exception on overflow</td>
</tr>
<tr>
<td>86</td>
<td>conv.ovf.u1.un</td>
<td>Convert unsigned to an unsigned int8 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>87</td>
<td>conv.ovf.u2.un</td>
<td>Convert unsigned to an unsigned int16 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>88</td>
<td>conv.ovf.u4.un</td>
<td>Convert unsigned to an unsigned int32 (on the stack as int32) and throw an exception on overflow</td>
</tr>
<tr>
<td>89</td>
<td>conv.ovf.u8.un</td>
<td>Convert unsigned to an unsigned int64 (on the stack as int64) and throw an exception on overflow</td>
</tr>
<tr>
<td>8A</td>
<td>conv.ovf.i.un</td>
<td>Convert unsigned to a native int (on the stack as native int) and throw an exception on overflow</td>
</tr>
<tr>
<td>8B</td>
<td>conv.ovf.u.un</td>
<td>Convert unsigned to a native unsigned int (on the stack as native int) and throw an exception on overflow</td>
</tr>
</tbody>
</table>

*Stack Transition:*

..., value → ..., result

*Description:*

Convert the value on top of the stack to the type specified in the opcode, and leave that converted value on the top of the stack. If the value cannot be represented, an exception is thrown. The item at the top of the stack is treated as an unsigned value.

Conversions from floating-point numbers to integral values truncate the number toward zero. Note that integer values of less than 4 bytes are extended to int32 (not native int) on the evaluation stack.

The acceptable operand types and their corresponding result data type is encapsulated in Table 8: Conversion Operations.

*Exceptions:*

OverflowException is thrown if the result cannot be represented in the result type.

*Verifiability:*

Correct CIL has at least one value, of a type specified in Table 8: Conversion Operations, on the stack. The same table specifies a restricted set of types that are acceptable in verified code.
3.30 **cpblk - copy data from memory to memory**

<table>
<thead>
<tr>
<th>Format</th>
<th>Instruction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 17</td>
<td>cpblk</td>
<td>Copy data from memory to memory</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... destaddr, srcaddr, size → ...

**Description:**

The `cpblk` instruction copies `size` (of type unsigned int32) bytes from address `srcaddr` (of type `native int`, or `&`) to address `destaddr` (of type `native int`, or `&`). The behavior of `cpblk` is unspecified if the source and destination areas overlap.

`cpblk` assumes that both `destaddr` and `srcaddr` are aligned to the natural size of the machine (but see the `unaligned` prefix instruction). The `cpblk` instruction may be immediately preceded by the `unaligned` prefix instruction to indicate that either the source or the destination is unaligned.

**Rationale:** `cpblk` is intended for copying structures (rather than arbitrary byte-runs). All such structures, allocated by the CLI, are naturally aligned for the current platform. Therefore, there is no need for the compiler that generates `cpblk` instructions to be aware of whether the code will eventually execute on a 32-bit or 64-bit platform.

The operation of the `cpblk` instruction may be altered by an immediately preceding `volatile` or `unaligned` prefix instruction.

**Exceptions:**

`NullReferenceException` may be thrown if an invalid address is detected.

**Verifiability:**

The `cpblk` instruction is never verifiable. Correct CIL ensures the conditions specified above.
3.31  \texttt{div} - divide values

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5B</td>
<td>\texttt{div}</td>
<td>Divide two values to return a quotient or floating-point result</td>
</tr>
</tbody>
</table>

**Stack Transition:**

\[
\ldots, \text{value1, value2} \rightarrow \ldots, \text{result}
\]

**Description:**

\(\text{result} = \text{value1} \text{ div} \text{ value2}\) satisfies the following conditions:

\[|\text{result}| = |\text{value1}| / |\text{value2}|,\text{ and}\]

\[
sign(\text{result}) = +, \text{ if } sign(\text{value1}) = sign(\text{value2}), \text{ or} \]

\[
-., \text{ if } sign(\text{value1}) \neq sign(\text{value2})
\]

The \texttt{div} instruction computes \texttt{result} and pushes it on the stack.

Integer division truncates towards zero.

Floating-point division is per IEC 60559:1989 (IEEE 754). In particular division of a finite number by 0 produces the correctly signed infinite value and

\[0 / 0 = \text{NaN} \]

\[\text{infinity} / \text{infinity} = \text{NaN}.\]

\[X / \text{infinity} = 0\]

The acceptable operand types and their corresponding result data type is encapsulated in Table 2: Binary Numeric Operations.

**Exceptions:**

Integral operations throw ArithmeticException if the result cannot be represented in the result type. This can happen if \texttt{value1} is the maximum negative value, and \texttt{value2} is -1.

Integral operations throw DivideByZeroException if \texttt{value2} is zero.

Floating-point operations never throw an exception (they produce NaNs or infinities instead, see Partition I).

**Example:**

\[+14 \text{ div} 3 \text{ is } 4\]

\[+14 \text{ div} -3 \text{ is } -4\]

\[-14 \text{ div} 3 \text{ is } -4\]

\[-14 \text{ div} -3 \text{ is } 4\]

**Verifiability:**

See Table 2: Binary Numeric Operations.
### 3.32 div.un - divide integer values, unsigned

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5C</td>
<td>div.un</td>
<td>Divide two values, unsigned, returning a quotient</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... , value1, value2 \(\rightarrow\) ... , result

**Description:**

The `div.un` instruction computes `value1` divided by `value2`, both taken as unsigned integers, and pushes the result on the stack.

The acceptable operand types and their corresponding result data type are encapsulated in Table 5: Integer Operations.

**Exceptions:**

`DivideByZeroException` is thrown if `value2` is zero.

**Example:**

\[
\begin{align*}
+5 \text{ div.un } +3 & \quad \text{is } 1 \\
+5 \text{ div.un } -3 & \quad \text{is } 0 \\
-5 \text{ div.un } +3 & \quad \text{is } 14316557630 \text{ or } 0x55555553 \\
-5 \text{ div.un } -3 & \quad \text{is } 0
\end{align*}
\]

**Verifiability:**

See Table 5: Integer Operations.
3.33 dup – duplicate the top value of the stack

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>dup</td>
<td>duplicate value on the top of the stack</td>
</tr>
</tbody>
</table>

Stack Transition:

..., value \(\rightarrow\) ..., value, value

Description:
The `dup` instruction duplicates the top element of the stack.

Exceptions:
None.

Verifiability:
No additional requirements.
3.34  endfilter – end filter clause of SEH

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 11</td>
<td></td>
<td>End filter clause of SEH exception handling</td>
</tr>
</tbody>
</table>

Stack Transition:
... \( \rightarrow \) ...

Description:
Return from filter clause of an exception (see the Exception Handling section of Partition I for a discussion of exceptions). Value (which must be of type int32 and is one of a specific set of values) is returned from the filter clause. It should be one of:

- **exception_continue_search** (0) to continue searching for an exception handler
- **exception_execute_handler** (1) to start the second phase of exception handling where finally blocks are run until the handler associated with this filter clause is located. Then the handler is executed.

Other integer values will produce unspecified results.

The entry point of a filter, as shown in the method’s exception table, must be the (lexically) first instruction in the filter’s code block. The **endfilter** must be the (lexically) last instruction in the filter’s code block (hence there can only be one **endfilter** for any single filter block). After executing the **endfilter** instruction, control logically flows back to the CLI exception handling mechanism.

Control cannot be transferred into a filter block except through the exception mechanism. Control cannot be transferred out of a filter block except through the use of a throw instruction or executing the final **endfilter** instruction. In particular, it is not legal to execute a ret or leave instruction within a filter block. It is not legal to embed a try block within a filter block. If an exception is thrown inside the filter block, it is intercepted and a value of **exception_continue_search** is returned.

Exceptions:
None.

Verifiability:
Correct CIL guarantees the control transfer restrictions specified above. Also, the stack must contain exactly one item (of type int32).
3.35  **endfinally** – end the finally or fault clause of an exception block

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>Endfault</td>
<td>End fault clause of an exception block</td>
</tr>
<tr>
<td>DC</td>
<td>Endfinally</td>
<td>End finally clause of an exception block</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... → ...

**Description:**

Return from the finally or fault clause of an exception block; see the Exception Handling section of Partition I for details.

Signals the end of the finally or fault clause so that stack unwinding can continue until the exception handler is invoked. The **endfinally** or **endfault** instruction transfers control back to the CLI exception mechanism. This then searches for the next finally clause in the chain, if the protected block was exited with a **leave** instruction. If the protected block was exited with an exception, the CLI will search for the next finally or fault, or enter the exception handler chosen during the first pass of exception handling.

An endfinally instruction may only appear lexically within a finally block. Unlike the endfilter instruction, there is no requirement that the block end with an endfinally instruction, and there can be as many endfinally instructions within the block as required. These same restrictions apply to the endfault instruction and the fault block, mutatis mutandis.

Control cannot be transferred into a finally (or fault) block except through the exception mechanism. Control cannot be transferred out of a finally (or fault) block except through the use of a **throw** instruction or executing the endfinally (or endfault) instruction. In particular, it is not legal to “fall out” of a finally (or fault) block or to execute a **ret** or **leave** instruction within a finally (or fault) block.

Note that the endfault and endfinally instructions are aliases – they correspond to the same opcode.

**Exceptions:**

None.

**Verifiability:**

Correct CIL guarantees the control transfer restrictions specified above. There are no additional verification requirements.
### 3.36 `initblk` - initialize a block of memory to a value

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 18</td>
<td>initblk</td>
<td>Set a block of memory to a given byte</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... addr, value, size → ...

**Description:**

The `initblk` instruction sets size (of type `unsigned int32`) bytes starting at addr (of type `native int` or &) to value (of type `unsigned int8`). `initblk` assumes that addr is aligned to the natural size of the machine (but see the `unaligned` prefix instruction).

**Rationale:** `initblk` is intended for initializing structures (rather than arbitrary byte-runs). All such structures, allocated by the CLI, are naturally aligned for the current platform. Therefore, there is no need for the compiler that generates `initblk` instructions to be aware of whether the code will eventually execute on a 32-bit or 64-bit platform.

The operation of the `initblk` instructions may be altered by an immediately preceding `volatile` or `unaligned` prefix instruction.

**Exceptions:**

`NullReferenceException` may be thrown if an invalid address is detected.

**Verifiability:**

The `initblk` instruction is never verifiable. Correct CIL code ensures the restrictions specified above.
3.37  jmp – jump to method

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 &lt;T&gt;</td>
<td>jmp method</td>
<td>Exit current method and jump to specified method</td>
</tr>
</tbody>
</table>

Stack Transition:

... → ...

Description:
Transfer control to the method specified by method, which is a metadata token (either a methodref or methoddef (See Partition II). The current arguments are transferred to the destination method.

The evaluation stack must be empty when this instruction is executed. The calling convention, number and type of arguments at the destination address must match that of the current method.

The jmp instruction cannot be used to transferred control out of a try, filter, catch, fault or finally block; or out of a synchronized region. If this is done, results are undefined. See Partition I.

Exceptions:
None.

Verifiability:
The jmp instruction is never verifiable. Correct CIL code obeys the control flow restrictions specified above.
3.38  ldarg.<length> - load argument onto the stack

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 09 &lt;unsigned int16&gt;</td>
<td>ldarg num</td>
<td>Load argument numbered num onto stack.</td>
</tr>
<tr>
<td>0E &lt;unsigned int8&gt;</td>
<td>ldarg.s num</td>
<td>Load argument numbered num onto stack, short form.</td>
</tr>
<tr>
<td>02</td>
<td>ldarg.0</td>
<td>Load argument 0 onto stack</td>
</tr>
<tr>
<td>03</td>
<td>ldarg.1</td>
<td>Load argument 1 onto stack</td>
</tr>
<tr>
<td>04</td>
<td>ldarg.2</td>
<td>Load argument 2 onto stack</td>
</tr>
<tr>
<td>05</td>
<td>ldarg.3</td>
<td>Load argument 3 onto stack</td>
</tr>
</tbody>
</table>

Stack Transition:

... → ..., value

Description:

The ldarg num instruction pushes the num'th incoming argument, where arguments are numbered 0 onwards (see Partition 1) onto the evaluation stack. The ldarg instruction can be used to load a value type or a built-in value onto the stack by copying it from an incoming argument. The type of the value is the same as the type of the argument, as specified by the current method’s signature.

The ldarg.0, ldarg.1, ldarg.2, and ldarg.3 instructions are efficient encodings for loading any of the first 4 arguments. The ldarg.s instruction is an efficient encoding for loading argument numbers 4 through 255.

For procedures that take a variable-length argument list, the ldarg instructions can be used only for the initial fixed arguments, not those in the variable part of the signature. (See the arglist instruction)

Arguments that hold an integer value smaller than 4 bytes long are expanded to type int32 when they are loaded onto the stack. Floating-point values are expanded to their native size (type #).

Exceptions:

None.

Verifiability:

Correct CIL guarantees that num is a valid argument index. See Section 1.5 for more details on how verification determines the type of the value loaded onto the stack.
3.39 ldarga.<length> - load an argument address

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 0A &lt;unsigned int16&gt;</td>
<td>ldarga argNum</td>
<td>fetch the address of argument argNum.</td>
</tr>
<tr>
<td>0F &lt;unsigned int8&gt;</td>
<td>ldarga.s argNum</td>
<td>fetch the address of argument argNum, short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...
,..., address of argument number argNum

**Description:**
The ldarga instruction fetches the address (of type &, i.e. managed pointer) of the argNum’th argument, where arguments are numbered 0 onwards. The address will always be aligned to a natural boundary on the target machine (cf. cpblk and initblk). The short form (ldarga.s) should be used for argument numbers 0 through 255.

For procedures that take a variable-length argument list, the ldarga instructions can be used only for the initial fixed arguments, not those in the variable part of the signature.

**Rationale:** ldarga is used for by-ref parameter passing (see Partition I). In other cases, ldarg and starg should be used.

**Exceptions:**
None.

**Verifiability:**
Correct CIL ensures that argNum is a valid argument index. See Section 1.5 for more details on how verification determines the type of the value loaded onto the stack.
### 3.40 **ldc.<type> - load numeric constant**

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 &lt;int32&gt;</td>
<td>ldc.i4 num</td>
<td>Push ( num ) of type ( \text{int32} ) onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>21 &lt;int64&gt;</td>
<td>ldc.i8 num</td>
<td>Push ( num ) of type ( \text{int64} ) onto the stack as ( \text{int64} ).</td>
</tr>
<tr>
<td>22 &lt;float32&gt;</td>
<td>ldc.r4 num</td>
<td>Push ( num ) of type ( \text{float32} ) onto the stack as ( \text{F} ).</td>
</tr>
<tr>
<td>23 &lt;float64&gt;</td>
<td>ldc.r8 num</td>
<td>Push ( num ) of type ( \text{float64} ) onto the stack as ( \text{F} ).</td>
</tr>
<tr>
<td>16</td>
<td>ldc.i4.0</td>
<td>Push 0 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>17</td>
<td>ldc.i4.1</td>
<td>Push 1 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>18</td>
<td>ldc.i4.2</td>
<td>Push 2 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>19</td>
<td>ldc.i4.3</td>
<td>Push 3 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>1A</td>
<td>ldc.i4.4</td>
<td>Push 4 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>1B</td>
<td>ldc.i4.5</td>
<td>Push 5 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>1C</td>
<td>ldc.i4.6</td>
<td>Push 6 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>1D</td>
<td>ldc.i4.7</td>
<td>Push 7 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>1E</td>
<td>ldc.i4.8</td>
<td>Push 8 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>15</td>
<td>ldc.i4.m1</td>
<td>Push -1 onto the stack as ( \text{int32} ).</td>
</tr>
<tr>
<td>15</td>
<td>ldc.i4.M1</td>
<td>Push -1 of type ( \text{int32} ) onto the stack as ( \text{int32} ) (alias for ( \text{ldc.i4.m1} )).</td>
</tr>
<tr>
<td>1F &lt;int8&gt;</td>
<td>ldc.i4.s num</td>
<td>Push ( num ) onto the stack as ( \text{int32} ), short form.</td>
</tr>
</tbody>
</table>

**Stack Transition:**

\[ \ldots \rightarrow \ldots, \text{num} \]

**Description:**

The `ldc num` instruction pushes number \( num \) onto the stack. There are special short encodings for the integers –128 through 127 (with especially short encodings for –1 through 8). All short encodings push 4 byte integers on the stack. Longer encodings are used for 8 byte integers and 4 and 8 byte floating-point numbers, as well as 4-byte values that do not fit in the short forms.

There are three ways to push an 8 byte integer constant onto the stack:

368. use the `ldc.i8` instruction for constants that must be expressed in more than 32 bits

369. use the `ldc.i4` instruction followed by a `conv.i8` for constants that require 9 to 32 bits

370. use a short form instruction followed by a `conv.i8` for constants that can be expressed in 8 or fewer bits

There is no way to express a floating-point constant that has a larger range or greater precision than a 64 bit IEC 60559:1989 number, since these representations are not portable across architectures.

**Exceptions:**

None.

**Verifiability:**

The `ldc` instruction is always verifiable.
3.41 ldftn - load method pointer

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 06 &lt;T&gt;</td>
<td>ldftn method</td>
<td>Push a pointer to a method referenced by method on the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... → ..., ftn

**Description:**

The `ldftn` instruction pushes an unmanaged pointer (type `native int`) to the native code implementing the method described by `method` (a metadata token, either a `methoddef` or `methodref`; see Partition II) onto the stack. The value pushed can be called using the `calli` instruction if it references a managed method (or a stub that transitions from managed to unmanaged code).

The value returned points to native code using the calling convention specified by `method`. Thus a method pointer can be passed to unmanaged native code (e.g. as a callback routine). Note that the address computed by this instruction may be to a thunk produced specially for this purpose (for example, to re-enter the CIL interpreter when a native version of the method isn’t available).

**Exceptions:**

None.

**Verifiability:**

Correct CIL requires that `method` is a valid `methoddef` or `methodref` token. Verification tracks the type of the value pushed in more detail than the “`native int`” type, remembering that it is a method pointer. Such a method pointer can then be used with `calli` or to construct a delegate.
3.42 *ldind.*<type>* - load value indirect onto the stack*

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>ldind.i1</td>
<td>Indirect load value of type int8 as int32 on the stack.</td>
</tr>
<tr>
<td>48</td>
<td>ldind.i2</td>
<td>Indirect load value of type int16 as int32 on the stack.</td>
</tr>
<tr>
<td>4A</td>
<td>ldind.i4</td>
<td>Indirect load value of type int32 as int32 on the stack.</td>
</tr>
<tr>
<td>4C</td>
<td>ldind.i8</td>
<td>Indirect load value of type int64 as int64 on the stack.</td>
</tr>
<tr>
<td>47</td>
<td>ldind.u1</td>
<td>Indirect load value of type unsigned int8 as int32 on the stack.</td>
</tr>
<tr>
<td>49</td>
<td>ldind.u2</td>
<td>Indirect load value of type unsigned int16 as int32 on the stack.</td>
</tr>
<tr>
<td>4B</td>
<td>ldind.u4</td>
<td>Indirect load value of type unsigned int32 as int32 on the stack.</td>
</tr>
<tr>
<td>4E</td>
<td>ldind.r4</td>
<td>Indirect load value of type float32 as F on the stack.</td>
</tr>
<tr>
<td>4C</td>
<td>ldind.u8</td>
<td>Indirect load value of type unsigned int64 as int64 on the stack (alias for ldind.i8).</td>
</tr>
<tr>
<td>4F</td>
<td>ldind.r8</td>
<td>Indirect load value of type float64 as F on the stack.</td>
</tr>
<tr>
<td>4D</td>
<td>ldind.i</td>
<td>Indirect load value of type native int as native int on the stack.</td>
</tr>
<tr>
<td>50</td>
<td>ldind.ref</td>
<td>Indirect load value of type object ref as O on the stack.</td>
</tr>
</tbody>
</table>

*Stack Transition:*

`..., addr \rightarrow ..., value`

*Description:*
The ldind instruction indirectly loads a value from address *addr* (an unmanaged pointer, native int, or managed pointer, a) onto the stack. The source value is indicated by the instruction suffix. All of the ldind instructions are shortcuts for a ldobj instruction that specifies the corresponding built-in value class. Note that integer values of less than 4 bytes are extended to int32 (not native int) when they are loaded onto the evaluation stack. Floating-point values are converted to F type when loaded onto the evaluation stack.

Correct CIL ensures that the ldind instructions are used in a manner consistent with the type of the pointer.

The address specified by *addr* must be aligned to the natural size of objects on the machine or a NullableException may occur (but see the unaligned, prefix instruction). The results of all CIL instructions that return addresses (e.g. ldloca and ldarga) are safely aligned. For datatypes larger than 1 byte, the byte ordering is dependent on the target CPU. Code that depends on byte ordering may not run on all platforms.

The operation of the ldind instructions may be altered by an immediately preceding volatile, or unaligned, prefix instruction.

*Rationale:* Signed and unsigned forms for the small integer types are needed so that the CLI can know whether to sign extend or zero extend. The ldind.u8 and ldind.u4 variants are provided for convenience; ldind.u8 is an alias for ldind.i8; ldind.u4 and ldind.i4 have different opcodes, but their effect is identical.

*Exceptions:* NullableException may be thrown if an invalid address is detected.

*Verifiability:*
Correct CIL only uses an `ldind` instruction in a manner consistent with the type of the pointer.
3.43 ldloc - load local variable onto the stack

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 0C&lt;unsigned int16&gt;</td>
<td>ldloc indx</td>
<td>Load local variable of index indx onto stack.</td>
</tr>
<tr>
<td>11 &lt;unsigned int8&gt;</td>
<td>ldloc.s indx</td>
<td>Load local variable of index indx onto stack, short form.</td>
</tr>
<tr>
<td>06</td>
<td>ldloc.0</td>
<td>Load local variable 0 onto stack.</td>
</tr>
<tr>
<td>07</td>
<td>ldloc.1</td>
<td>Load local variable 1 onto stack.</td>
</tr>
<tr>
<td>08</td>
<td>ldloc.2</td>
<td>Load local variable 2 onto stack.</td>
</tr>
<tr>
<td>09</td>
<td>ldloc.3</td>
<td>Load local variable 3 onto stack.</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... → ..., value

**Description:**
The ldloc indx instruction pushes the contents of the local variable number indx onto the evaluation stack, where local variables are numbered 0 onwards. Local variables are initialized to 0 before entering the method only if the initialize flag on the method is true (see Partition I). The ldloc.0, ldloc.1, ldloc.2, and ldloc.3 instructions provide an efficient encoding for accessing the first four local variables. The ldloc.s instruction provides an efficient encoding for accessing local variables 4 through 255.

The type of the value is the same as the type of the local variable, which is specified in the method header. See Partition I.

Local variables that are smaller than 4 bytes long are expanded to type int32 when they are loaded onto the stack. Floating-point values are expanded to their native size (type F).

**Exceptions:**
VerificationException is thrown if the the “zero initialize” bit for this method has not been set, and the assembly containing this method has not been granted SecurityPermission.SkipVerification (and the CIL does not perform automatic definite-assignment analysis).

**Verifiability:**
Correct CIL ensures that indx is a valid local index. See Section 1.5 for more details on how verification determines the type of a local variable. For the ldloca indx instruction, indx must lie in the range 0 to 65534 inclusive (specifically, 65535 is not valid)

**Rationale:**
The reason for excluding 65535 is pragmatic: likely implementations will use a 2-byte integer to track both a local’s index, as well as the total number of locals for a given method. If an index of 65535 had been made legal, it would require a wider integer to track the number of locals in such a method.

Also, for verifiable code, this instruction must guarantee that it is not loading an uninitialized value – whether that initialization is done explicitly by having set the “zero initialize” bit for the method, or by previous instructions (where the CLI performs definite-assignment analysis).
3.44  ldloca.<length> - load local variable address

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 0D &lt;unsigned int16&gt;</td>
<td>ldloca index</td>
<td>Load address of local variable with index indx</td>
</tr>
<tr>
<td>12 &lt;unsigned int8&gt;</td>
<td>ldloca.s index</td>
<td>Load address of local variable with index indx, short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...
..., address

**Description:**
The `ldloca` instruction pushes the address of the local variable number index onto the stack, where local variables are numbered 0 onwards. The value pushed on the stack is already aligned correctly for use with instructions like `ldind` and `stind`. The result is a managed pointer (type &). The `ldloca.s` instruction provides an efficient encoding for use with the local variables 0 through 255.

**Exceptions:**
`VerificationException` is thrown if the “zero initialize” bit for this method has not been set, and the assembly containing this method has not been granted SecurityPermission.SkipVerification (and the CIL does not perform automatic definite-assignment analysis)

**Verifiability:**
Correct CIL ensures that indx is a valid local index. See Section 1.5 for more details on how verification determines the type of a local variable. For the `ldloca indx` instruction, indx must lie in the range 0 to 65534 inclusive (specifically, 65535 is not valid)

**Rationale:** The reason for excluding 65535 is pragmatic: likely implementations will use a 2-byte integer to track both a local’s index, as well as the total number of locals for a given method. If an index of 65535 had been made legal, it would require a wider integer to track the number of locals in such a method.

Also, for verifiable code, this instruction must guarantee that it is not loading an uninitialized value – whether that initialization is done explicitly by having set the “zero initialize” bit for the method, or by previous instructions (where the CLI performs definite-assignment analysis)
### 3.45 ldnull – load a null pointer

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>ldnull</td>
<td>Push null reference on the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... → ..., null value

**Description:**
The `ldnull` pushes a null reference (type `null`) on the stack. This is used to initialize locations before they become live or when they become dead.

**Rationale:** It might be thought that `ldnull` is redundant: why not use `ldc.i4.0` or `ldc.i8.0` instead? The answer is that `ldnull` provides a size-agnostic null – analogous to a `ldc.i` instruction, which does not exist. However, even if CIL were to include a `ldc.i` instruction it would still benefit verification algorithms to retain the `ldnull` instruction because it makes type tracking easier.

**Exceptions:**
None.

**Verifiability:**
The `ldnull` instruction is always verifiable, and produces a value that verification considers compatible with any other reference type.
3.46 leave.<length> – exit a protected region of code

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD &lt;int32&gt;</td>
<td>leave target</td>
<td>Exit a protected region of code.</td>
</tr>
<tr>
<td>DE &lt;int8&gt;</td>
<td>leave.s target</td>
<td>Exit a protected region of code, short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...
→

**Description:**
The `leave` instruction unconditionally transfers control to `target`. Target is represented as a signed offset (4 bytes for `leave`, 1 byte for `leave.s`) from the beginning of the instruction following the current instruction.

The `leave` instruction is similar to the `br` instruction, but it can be used to exit a `try`, `filter`, or `catch` block whereas the ordinary branch instructions can only be used in such a block to transfer control within it. The `leave` instruction empties the evaluation stack and ensures that the appropriate surrounding `finally` blocks are executed.

It is not legal to use a `leave` instruction to exit a `finally` block. To ease code generation for exception handlers it is legal from within a `catch` block to use a `leave` instruction to transfer control to any instruction within the associated `try` block.

If an instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

**Exceptions:**
None.

**Verifiability:**
Correct CIL requires the computed destination lie within the current method. See Section 1.5 for more details.
### 3.47 localloc – allocate space in the local dynamic memory pool

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 0F</td>
<td>localloc</td>
<td>Allocate space from the local memory pool.</td>
</tr>
</tbody>
</table>

**Stack Transition:**

...size → ...address

**Description:**

The `localloc` instruction allocates size (type native unsigned int) bytes from the local dynamic memory pool and returns the address (a managed pointer, type `&`) of the first allocated byte. The block of memory returned is initialized to 0 only if the initialize flag on the method is true (see Partition I). The area of memory is newly allocated. When the current method returns the local memory pool is available for reuse.

Address is aligned so that any built-in data type can be stored there using the `stind` instructions and loaded using the `ldind` instructions.

The `localloc` instruction cannot occur within an exception block: `filter`, `catch`, `finally`, or `fault`.

**Rationale:** Localloc is used to create local aggregates whose size must be computed at runtime. It can be used for C’s intrinsic `alloca` method.

**Exceptions:**

- StackOverflowException is thrown if there is insufficient memory to service the request.

**Verifiability:**

Correct CIL requires that the evaluation stack be empty, apart from the `size` item. This instruction is never verifiable.
### 3.48 mul - multiply values

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5A</td>
<td>mul</td>
<td>Multiply values</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value1, value2 → ..., result

**Description:**

The `mul` instruction multiplies `value1` by `value2` and pushes the result on the stack. Integral operations silently truncate the upper bits on overflow (see `mul.ovf`).

For floating-point types, $0 \times \text{infinity} = \text{NaN}$.

The acceptable operand types and their corresponding result data types are encapsulated in Table 2: Binary Numeric Operations.

**Exceptions:**

None.

**Verifiability:**

See Table 2: Binary Numeric Operations.
3.49  **mul.ovf.<type>** - multiply integer values with overflow check

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>D8</td>
<td>mul.ovf</td>
<td>Multiply signed integer values. Signed result must fit in same size</td>
</tr>
<tr>
<td>D9</td>
<td>mul.ovf.un</td>
<td>Multiply unsigned integer values. Unsigned result must fit in same size</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... value1, value2 \(\rightarrow\) ... result

**Description:**

The **mul.ovf** instruction multiplies integers, value1 and value2, and pushes the result on the stack. An exception is thrown if the result will not fit in the result type.

The acceptable operand types and their corresponding result data types are encapsulated in Table 7: Overflow Arithmetic Operations.

**Exceptions:**

OverflowException is thrown if the result can not be represented in the result type.

**Verifiability:**

See Table 8: Conversion Operations.
3.50 neg - negate

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>neg</td>
<td>Negate value</td>
</tr>
</tbody>
</table>

Stack Transition:

..., value → ..., result

Description:
The `neg` instruction negates `value` and pushes the result on top of the stack. The return type is the same as the operand type.

Negation of integral values is standard two's complement negation. In particular, negating the most negative number (which does not have a positive counterpart) yields the most negative number. To detect this overflow use the `sub.ovf` instruction instead (i.e. subtract from 0).

Negating a floating-point number cannot overflow; negating `NaN` returns `NaN`.

The acceptable operand types and their corresponding result data types are encapsulated in Table 3: Unary Numeric Operations.

Exceptions:
None.

Verifiability:
See Table 3: Unary Numeric Operations.
3.51 **nop – no operation**

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>nop</td>
<td>Do nothing</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... → ...

**Description:**

The *nop* operation does nothing. It is intended to fill in space if bytecodes are patched.

**Exceptions:**

None.

**Verifiability:**

The *nop* instruction is always verifiable.
3.52  not - bitwise complement

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>66</td>
<td>not</td>
<td>Bitwise complement</td>
</tr>
</tbody>
</table>

**Stack Transition:**
```
..., value --> ..., result
```

**Description:**
Compute the bitwise complement of the integer value on top of the stack and leave the result on top of the stack. The return type is the same as the operand type.

The acceptable operand types and their corresponding result data type is encapsulated in Table 5: Integer Operations.

**Exceptions:**
None.

**Verifiability:**
See Table 5: Integer Operations.
### 3.53 or - bitwise OR

<table>
<thead>
<tr>
<th>Format</th>
<th>Instruction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>or</td>
<td>Bitwise OR of two integer values, returns an integer.</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... value1, value2 \(\rightarrow\) ..., result

**Description:**

The or instruction computes the bitwise OR of the top two values on the stack and leaves the result on the stack.

The acceptable operand types and their corresponding result data type is encapsulated in Table 5: Integer Operations.

**Exceptions:**

None.

**Verifiability:**

See Table 5: Integer Operations.
3.54 **pop – remove the top element of the stack**

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>pop</td>
<td>pop a value from the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... , value \(\rightarrow\) ...

**Description:**
The `pop` instruction removes the top element from the stack.

**Exceptions:**
None.

**Verifiability:**
No additional requirements.
3.55 rem - compute remainder

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5D</td>
<td>rem</td>
<td>Remainder of dividing value1 by value2</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value1, value2 $\rightarrow$ ..., result

**Description:**

The acceptable operand types and their corresponding result data type is encapsulated in Table 2: Binary Numeric Operations.

**For integer operands**

\[ result = value1 \text{ rem } value2 \] satisfies the following conditions:

\[ result = value1 - value2 \times (value1 \text{ div } value2), \text{ and} \]

\[ 0 \leq |result| < |value2|, \text{ and} \]

\[ \text{sign}(result) = \text{sign}(value1), \]

where \text{div} is the division instruction, which truncates towards zero.

The \text{rem} instruction computes result and pushes it on the stack.

**For floating-point operands**

\text{rem} is defined similarly, except that, if value2 is zero or value1 is infinity the result is NaN. If value2 is infinity, the result is value1 (negated for –infinity). This definition is different from the one for floating-point remainder in the IEC 60559:1989 Standard. That Standard specifies that value1 \text{ div } value2 is the nearest integer instead of truncating towards zero. System.Math.IEEERemainder (see Partition IV) provides the IEC 60559:1989 behavior.

**Exceptions:**

Integral operations throw DivideByZeroException if value2 is zero.

Integral operations may throw ArithmeticException if value1 is the maximum negative value and value2 is -1.

**Example:**

\[ +10 \text{ rem } +6 \text{ is 4 } \quad (+10 \text{ div } +6 = 1) \]
\[ +10 \text{ rem } -6 \text{ is 4 } \quad (+10 \text{ div } -6 = -1) \]
\[ -10 \text{ rem } +6 \text{ is } -4 \quad (-10 \text{ div } +6 = -1) \]
\[ -10 \text{ rem } -6 \text{ is } -4 \quad (-10 \text{ div } -6 = 1) \]

For the various floating-point values of 10.0 and 6.0, \text{rem} gives the same values; System.Math.IEEERemainder, however, gives the following values.

\[ \text{System.Math.IEEERemainder}(+10.0,+6.0) \text{ is } -2 \quad (+10.0 \text{ div } +6.0 = 1.666..7) \]
\[ \text{System.Math.IEEERemainder}(+10.0,-6.0) \text{ is } -2 \quad (+10.0 \text{ div } -6.0 = -1.666..7) \]
\[ \text{System.Math.IEEERemainder}(-10.0,+6.0) \text{ is } 2 \quad (-10.0 \text{ div } +6.0 = -1.666..7) \]
\[ \text{System.Math.IEEERemainder}(-10.0,-6.0) \text{ is } 2 \quad (-10.0 \text{ div } -6.0 = 1.666..7) \]

**Verifiability:**

See Table 2: Binary Numeric Operations.
3.56 rem.un - compute integer remainder, unsigned

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5E</td>
<td>rem.un</td>
<td>Remainder of unsigned dividing value1 by value2</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...
,..., value1, value2 → ...
,..., result

**Description:**
result = value1 rem.un value2 satisfies the following conditions:
result = value1 - value2 × (value1 div.un value2), and
0 ≤ result < value2,
where div.un is the unsigned division instruction. The rem.un instruction computes result and pushes it on the stack. Rem.un treats its arguments as unsigned integers, while rem treats them as signed integers. Rem.un is unspecified for floating-point numbers.
The acceptable operand types and their corresponding result data type are encapsulated in Table 5: Integer Operations.

**Exceptions:**
Integral operations throw DivideByZeroException if value2 is zero.

**Example:**
+5 rem.un +3 is 2
(+5 div.un +3 = 1)
+5 rem.un -3 is 5
(+5 div.un -3 = 0)
-5 rem.un +3 is 2
(-5 div.un +3 = 1431655763 or 0x55555553)
-5 rem.un -3 is -5 or 0xffffffffb
(-5 div.un -3 = 0)

**Verifiability:**
See Table 5: Integer Operations.
3.57 ret – return from method

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A</td>
<td>Ret</td>
<td>Return from method, possibly returning a value</td>
</tr>
</tbody>
</table>

**Stack Transition:**

retVal on callee evaluation stack (not always present) ➔

..., retVal on caller evaluation stack (not always present)

**Description:**

Return from the current method. The return type, if any, of the current method determines the type of value to be fetched from the top of the stack and copied onto the stack of the method that called the current method. The evaluation stack for the current method must be empty except for the value to be returned.

The `ret` instruction cannot be used to transfer control out of a `try`, `filter`, `catch`, or `finally` block. From within a `try` or `catch`, use the `leave` instruction with a destination of a `ret` instruction that is outside all enclosing exception blocks. Because the `filter` and `finally` blocks are logically part of exception handling, not the method in which their code is embedded, correctly generated CIL does not perform a method return from within a `filter` or `finally`. See Partition I.

**Exceptions:**

None.

**Verifiability:**

Correct CIL obeys the control constraints describe above. Verification requires that the type of `retVal` is compatible with the declared return type of the current method.
### 3.58 shl - shift integer left

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>62</td>
<td>Shl</td>
<td>Shift an integer to the left (shifting in zeros)</td>
</tr>
</tbody>
</table>

**Stack Transition:**

```
..., value, shiftAmount → ..., result
```

**Description:**

The `shl` instruction shifts `value` (int32, int64 or native int) left by the number of bits specified by `shiftAmount`. `shiftAmount` is of type int32, int64 or native int. The return value is unspecified if `shiftAmount` is greater than or equal to the size of `value`. See Table 15: Shift Operations for details of which operand types are allowed, and their corresponding result type.

**Exceptions:**

None.

**Verifiability:**

See Table 5: Integer Operations.
## 3.59 shr - shift integer right

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>Shr</td>
<td>Shift an integer right, (shift in sign), return an integer</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... value, shiftAmount ➔ ..., result

**Description:**

The `shr` instruction shifts `value` (int32, int64 or native int) right by the number of bits specified by `shiftAmount`. `shiftAmount` is of type int32, int64 or native int. The return value is unspecified if `shiftAmount` is greater than or equal to the width of `value`. `shr` replicates the high order bit on each shift, preserving the sign of the original value in the result. See Table 15: Shift Operations for details of which operand types are allowed, and their corresponding result type.

**Exceptions:**

None.

**Verifiability:**

See Table 5: Integer Operations.
3.60  shr.un - shift integer right, unsigned

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>shr.un</td>
<td>Shift an integer right, (shift in zero), return an integer</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value, shiftAmount → ..., result

**Description:**

The shr.un instruction shifts value (int32, int64 or native int) right by the number of bits specified by shiftAmount. shiftAmount is of type int32 or native int. The return value is unspecified if shiftAmount is greater than or equal to the width of value. shr.un inserts a zero bit on each shift. See Table 15: Shift Operations for details of which operand types are allowed, and their corresponding result type.

**Exceptions:**

None.

**Verifiability:**

See Table 5: Integer Operations.
3.61 **starg.<length>* - store a value in an argument slot

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 0B &lt;unsigned int16&gt;</td>
<td>starg num</td>
<td>Store a value to the argument numbered num</td>
</tr>
<tr>
<td>10 &lt;unsigned int8&gt;</td>
<td>starg.s num</td>
<td>Store a value to the argument numbered num, short form</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... value → ...

**Description:**

The **starg num** instruction pops a value from the stack and places it in argument slot num (see Partition I). The type of the value must match the type of the argument, as specified in the current method’s signature. The **starg.s** instruction provides an efficient encoding for use with the first 256 arguments.

For procedures that take a variable argument list, the **starg** instructions can be used only for the initial fixed arguments, not those in the variable part of the signature.

Storing into arguments that hold an integer value smaller than 4 bytes long truncates the value as it moves from the stack to the argument. Floating-point values are rounded from their native size (type F) to the size associated with the argument.

**Exceptions:**

None.

**Verifiability:**

Correct CIL requires that num is a valid argument slot.

Verification also checks that the verification type of value matches the type of the argument, as specified in the current method’s signature (verification types are less detailed than CLI types).
3.62  **stind.<type> - store value indirect from stack**

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>stind.i1</td>
<td>Store value of type int8 into memory at address</td>
</tr>
<tr>
<td>53</td>
<td>stind.i2</td>
<td>Store value of type int16 into memory at address</td>
</tr>
<tr>
<td>54</td>
<td>stind.i4</td>
<td>Store value of type int32 into memory at address</td>
</tr>
<tr>
<td>55</td>
<td>stind.i8</td>
<td>Store value of type int64 into memory at address</td>
</tr>
<tr>
<td>56</td>
<td>stind.r4</td>
<td>Store value of type float32 into memory at address</td>
</tr>
<tr>
<td>57</td>
<td>stind.r8</td>
<td>Store value of type float64 into memory at address</td>
</tr>
<tr>
<td>DF</td>
<td>stind.i</td>
<td>Store value of type native int into memory at address</td>
</tr>
<tr>
<td>51</td>
<td>stind.ref</td>
<td>Store value of type object ref (type o) into memory at address</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., addr, val \(\rightarrow\) ...

**Description:**

The *stind* instruction stores a value *val* at address *addr* (an unmanaged pointer, type native int, or managed pointer, type o). The address specified by *addr* must be aligned to the natural size of *val* or a

NullReferenceException may occur (but see the *unaligned* prefix instruction). The results of all CIL instructions that return addresses (e.g. *ldloca* and *ldarga*) are safely aligned. For datatypes larger than 1 byte, the byte ordering is dependent on the target CPU. Code that depends on byte ordering may not run on all platforms.

Type safe operation requires that the *stind* instruction be used in a manner consistent with the type of the pointer.

The operation of the *stind* instruction may be altered by an immediately preceding volatile. or unaligned. prefix instruction.

**Exceptions:**

NullReferenceException is thrown if *addr* is not naturally aligned for the argument type implied by the instruction suffix

**Verifiability:**

Correct CIL ensures that *addr* be a pointer whose type is known and is assignment compatible with that of *val*.
3.63  **stloc - pop value from stack to local variable**

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 0E <code>&lt;unsigned int16&gt;</code></td>
<td>stloc indx</td>
<td>Pop value from stack into local variable indx.</td>
</tr>
<tr>
<td>13 <code>&lt;unsigned int8&gt;</code></td>
<td>stloc.s indx</td>
<td>Pop value from stack into local variable indx, short form.</td>
</tr>
<tr>
<td>0A</td>
<td>stloc.0</td>
<td>Pop value from stack into local variable 0.</td>
</tr>
<tr>
<td>0B</td>
<td>stloc.1</td>
<td>Pop value from stack into local variable 1.</td>
</tr>
<tr>
<td>0C</td>
<td>stloc.2</td>
<td>Pop value from stack into local variable 2.</td>
</tr>
<tr>
<td>0D</td>
<td>stloc.3</td>
<td>Pop value from stack into local variable 3.</td>
</tr>
</tbody>
</table>

*Stack Transition:*

..., value \(\rightarrow\) ...

*Description:*

The `stloc indx` instruction pops the top value off the evaluation stack and moves it into local variable number `indx` (see Partition I), where local variables are numbered 0 onwards. The type of `value` must match the type of the local variable as specified in the current method’s locals signature. The `stloc.0`, `stloc.1`, `stloc.2`, and `stloc.3` instructions provide an efficient encoding for the first four local variables; the `stloc.s` instruction provides an efficient encoding for local variables 4 through 255.

Storing into locals that hold an integer value smaller than 4 bytes long truncates the value as it moves from the stack to the local variable. Floating-point values are rounded from their native size (type `float`) to the size associated with the argument.

*Exceptions:*

None.

*Verifiability:*

Correct CIL requires that `indx` is a valid local index. For the `stloc indx` instruction, `indx` must lie in the range 0 to 65534 inclusive (specifically, 65535 is not valid)

*Rationale: The reason for excluding 65535 is pragmatic: likely implementations will use a 2-byte integer to track both a local’s index, as well as the total number of locals for a given method. If an index of 65535 had been made legal, it would require a wider integer to track the number of locals in such a method.*

Verification also checks that the verification type of `value` matches the type of the local, as specified in the current method’s locals signature.
\textbf{3.64 sub - subtract numeric values}

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>59</td>
<td>sub</td>
<td>Subtract value2 from value1, returning a new value</td>
</tr>
</tbody>
</table>

\textit{Stack Transition:}

\[ ..., value1, value2 \rightarrow ..., result \]

\textit{Description:}

The \textit{sub} instruction subtracts \textit{value2} from \textit{value1} and pushes the result on the stack. Overflow is not detected for the integral operations (see \textit{sub.ovf}); for floating-point operands, \textit{sub} returns $+\text{inf}$ on positive overflow, $-\text{inf}$ on negative overflow, and zero on floating-point underflow.

The acceptable operand types and their corresponding result data type is encapsulated in Table 11: Binary Numeric Operations.

\textit{Exceptions:}

None.

\textit{Verifiability:}

See Table 2: Binary Numeric Operations.
3.65  sub.ovf.<type> - subtract integer values, checking for overflow

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>sub.ovf</td>
<td>Subtract native int from an native int. Signed result must fit in same size</td>
</tr>
<tr>
<td>DB</td>
<td>sub.ovf.un</td>
<td>Subtract native unsigned int from a native unsigned int. Unsigned result must fit in same size</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value1, value2 → ..., result

**Description:**
The sub.ovf instruction subtracts value2 from value1 and pushes the result on the stack. The type of the values and the return type is specified by the instruction. An exception is thrown if the result does not fit in the result type.

The acceptable operand types and their corresponding result data type is encapsulated in Table 7: Overflow Arithmetic Operations.

**Exceptions:**
OverflowException is thrown if the result can not be represented in the result type.

**Verifiability:**
See Table 7: Overflow Arithmetic Operations.
3.66 switch – table switch on value

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 45 \langle \text{unsigned int32} \rangle \langle \text{int32} \rangle \ldots \langle \text{int32} \rangle )</td>
<td>( \text{switch } (t1, t2 \ldots tn) )</td>
<td>jump to one of ( n ) values</td>
</tr>
</tbody>
</table>

Stack Transition:

\( \ldots, \text{value} \rightarrow \ldots, \)

Description:

The `switch` instruction implements a jump table. The format of the instruction is an unsigned int32 representing the number of targets \( N \), followed by \( N \) int32 values specifying jump targets; these targets are represented as offsets (positive or negative) from the beginning of the instruction following this switch instruction.

The switch instruction pops \( \text{value} \) off the stack and compares it, as an unsigned integer, to \( N \). If \( \text{value} \) is less than \( N \), execution is transferred to the \( \text{value} \)th target, where targets are numbered from 0 (i.e., a \( \text{value} \) of 0 takes the first target, a \( \text{value} \) of 1 takes the second target, etc). If \( \text{value} \) is not less than \( N \), execution continues at the next instruction (fall through).

If the target instruction has one or more prefix codes, control can only be transferred to the first of these prefixes.

Control transfers into and out of `try`, `catch`, `filter`, and `finally` blocks cannot be performed by this instruction. (Such transfers are severely restricted and must use the `leave` instruction instead; see Partition I for details).

Exceptions:

None.

Verifiability:

Correct CIL obeys the control transfer constraints listed above. In addition, verification requires the type-consistency of the stack, locals and arguments for every possible way of reaching all destination instructions. See Section 1.5 for more details.
### 3.67 xor - bitwise XOR

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>61</td>
<td>xor</td>
<td>Bitwise XOR of integer values, returns an integer</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., value1, value2 → ..., result

**Description:**

The `xor` instruction computes the bitwise XOR of the top two values on the stack and leaves the result on the stack.

The acceptable operand types and their corresponding result data type is encapsulated in Table 14: Integer Operations.

**Exceptions:**

None.

**Verifiability:**

See Table 14: Integer Operations.
4 Object Model Instructions

The instructions described in the base instruction set are independent of the object model being executed. Those instructions correspond closely to what would be found on a real CPU. The object model instructions are less built-in than the base instructions in the sense that they could be built out of the base instructions and calls to the underlying operating system.

Rationale: The object model instructions provide a common, efficient implementation of a set of services used by many (but by no means all) higher-level languages. They embed in their operation a set of conventions defined by the common type system. This include (among other things):

- Field layout within an object
- Layout for late bound method calls (vtables)
- Memory allocation and reclamation
- Exception handling
- Boxing and unboxing to convert between reference-based Objects and Value Types

For more details, see Partition I.

4.1 box – convert value type to object reference

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8C &lt;T&gt;</td>
<td>box valTypeTok</td>
<td>Convert valueType to a true object reference</td>
</tr>
</tbody>
</table>

Stack Transition:

... , valueType → ... , obj

Description:

A value type has two separate representations (see Partition I) within the CLI:

- A ‘raw’ form used when a value type is embedded within another object or on the stack.
- A ‘boxed’ form, where the data in the value type is wrapped (boxed) into an object so it can exist as an independent entity.

The box instruction converts the ‘raw’ valueType (an unboxed value type) into an instance of type Object (of type o). This is accomplished by creating a new object and copying the data from valueType into the newly allocated object. ValTypeTok is a metadata token (a typedef or typedef) indicating the type of valueType (See Partition II)

Exceptions:

- OutOfMemoryException is thrown if there is insufficient memory to satisfy the request.
- TypeLoadException is thrown if class cannot be found. This is typically detected when CIL is converted to native code rather than at runtime.

Verifiability:

Correct CIL ensures that valueType is of the correct value type, and that valTypeTok is a typedef or typedef metadata token for that value type.
### 4.2 callvirt — call a method associated, at runtime, with an object

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>6F&lt;T&gt;</code></td>
<td>callvirt method</td>
<td>Call a method associated with <code>obj</code></td>
</tr>
</tbody>
</table>

#### Stack Transition:

`...`, `obj`, `arg1`, `... argN` → `...`, `returnVal` (not always returned)

#### Description:

The **callvirt** instruction calls a late-bound method on an object. That is, the method is chosen based on the runtime type of `obj` rather than the compile-time class visible in the `method` metadata token. **Callvirt** can be used to call both virtual and instance methods. See [Partition I](#) for a detailed description of the CIL calling sequence. The **callvirt** instruction may be immediately preceded by a **tail** prefix to specify that the current stack frame should be released before transferring control. If the call would transfer control to a method of higher trust than the original method the stack frame will not be released.

[A callee of “higher trust” is defined as one whose permission grant-set is a strict superset of the grant-set of the caller]

### Exceptions:

- **MissingMethodException** is thrown if a non-static method with the indicated name and signature could not be found in `obj`’s class or any of its superclasses. This is typically detected when CIL is converted to native code, rather than at runtime.

- **NullReferenceException** is thrown if `obj` is null.

- **SecurityException** is thrown if system security does not grant the caller access to the called method. The security check may occur when the CIL is converted to native code rather than at runtime.

### Verifiability:

Correct CIL ensures that the destination method exists and the values on the stack correspond to the types of the parameters of the method being called.

In its typical use, **callvirt** is verifiable if (a) the above restrictions are met, (b) the verification type of `obj` is consistent with the method being called, (c) the verification types of the arguments on the stack are consistent with the types expected by the method call, and (d) the method is accessible from the callsite. A **callvirt** annotated by **tail** has additional considerations – see [Section 1.5](#).
4.3 castclass – cast an object to a class

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>74 &lt;T&gt;</td>
<td>castclass class</td>
<td>Cast obj to class</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...
, obj → ...
, obj2

**Description:**
The `castclass` instruction attempts to cast `obj` (an `O`) to the `class`. `Class` is a metadata token (a `typedef` or `typeref`), indicating the desired class. If the class of the object on the top of the stack does not implement `class` (if `class` is an interface), and is not a subclass of `class` (if `class` is a regular class), then an `InvalidCastException` is thrown.

Note that:
371. Arrays inherit from `System.Array`
372. If `Foo` can be cast to `Bar`, then `Foo[]` can be cast to `Bar[]`
373. For the purposes of 2., enums are treated as their underlying type: thus `E1[]` can cast to `E2[]` if `E1` and `E2` share an underlying type

If `obj` is null, `castclass` succeeds and returns null. This behavior differs from `isInst`.

**Exceptions:**
InvalidCastException is thrown if `obj` cannot be cast to `class`.

TypeLoadException is thrown if `class` cannot be found. This is typically detected when CIL is converted to native code rather than at runtime.

**Verifiability:**
Correct CIL ensures that `class` is a valid `TypeDef` or `TypeDef` token, and that `obj` is always either null or an object reference.
4.4  \texttt{cobj} - copy a value type

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\langle T\rangle$</td>
<td>Cobj \textit{classTok}</td>
<td>Copy a value type from \textit{srcValObj} to \textit{destValObj}</td>
</tr>
</tbody>
</table>

\textbf{Stack Transition:} \\
\texttt{..., destValObj, srcValObj} $\rightarrow$ \texttt{...}

\textbf{Description:} \\
The \texttt{cobj} instruction copies the value type located at the address specified by \textit{srcValObj} (an unmanaged pointer, \texttt{native int}, or a managed pointer, \&) to the address specified by \textit{destValObj} (also a pointer). Behavior is unspecified if \textit{srcValObj} and \textit{destValObj} are not pointers to instances of the class represented by \textit{classTok} (a \texttt{typeref} or \texttt{typedef}), or if \textit{classTok} does not represent a value type.

\textbf{Exceptions:} \\
\texttt{NullReferenceException} may be thrown if an invalid address is detected.

\textbf{Verifiability:} \\
Correct CIL ensures that \textit{classTok} is a valid \texttt{Typeref} or \texttt{TypeDef} token for a value type, as well as that \textit{srcValObj} and \textit{destValObj} are both pointers to locations of that type.

Verification requires, in addition, that \textit{srcValObj} and \textit{destValObj} are both managed pointers (not unmanaged pointers).
4.5 initobj - initialize a value type

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 15 &lt;T&gt;</td>
<td>initobj classTok</td>
<td>Initialize a value type</td>
</tr>
</tbody>
</table>

Stack Transition:

..., addrOfValObj → …,

Description:

The initobj instruction initializes all the fields of the object represented by the address addrOfValObj (of type native int, or & to null or a 0 of the appropriate built-in type. After this method is called, the instance is ready for the constructor method to be called. Behavior is unspecified if either addrOfValObj is not a pointer to an instance of the class represented by classTok (a typedef of typedef; see Partition II), or classTok does not represent a value type.

Notice that, unlike newobj, the constructor method is not called by initobj. Initobj is intended for initializing value types, while newobj is used to allocate and initialize objects.

Exceptions:

None.

Verifiability:

Correct CIL ensures that classTok is a valid typedef or typedef token specifying a value type, and that valObj is a managed pointer to an instance of that value type.
4.6 isinst – test if an object is an instance of a class or interface

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 &lt;T&gt;</td>
<td>isinst class</td>
<td>test if obj is an instance of class, returning NULL or an instance of that class or interface</td>
</tr>
</tbody>
</table>

Stack Transition:

..., obj → ..., result

Description:
The isinst instruction tests whether obj (type o) is an instance of class. Class is a metadata token (a typeref or typedef see Partition II) indicating the desired class. If the class of the object on the top of the stack implements class (if class is an interface) or is a subclass of class (if class is a regular class), then it is cast to the type class and the result is pushed on the stack, exactly as though castclass had been called. Otherwise NULL is pushed on the stack. If obj is NULL, isinst returns NULL.

Note that:
374. Arrays inherit from System.Array
375. If Foo can be cast to Bar, then Foo[] can be cast to Bar[]
376. For the purposes of 2., enums are treated as their underlying type: thus E1[] can cast to E2[] if E1 and E2 share an underlying type

Exceptions:
TypeLoadException is thrown if class cannot be found. This is typically detected when CIL is converted to native code rather than at runtime.

Verifiability:
Correct CIL ensures that class is a valid typeref or typedef token indicating a class, and that obj is always either null or an object reference
4.7  ldelem.<type> – load an element of an array

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>ldelem.i1</td>
<td>Load the element with type int8 at index onto the top of the stack as an int32</td>
</tr>
<tr>
<td>92</td>
<td>ldelem.i2</td>
<td>Load the element with type int16 at index onto the top of the stack as an int32</td>
</tr>
<tr>
<td>94</td>
<td>ldelem.i4</td>
<td>Load the element with type int32 at index onto the top of the stack as an int32</td>
</tr>
<tr>
<td>96</td>
<td>ldelem.i8</td>
<td>Load the element with type int64 at index onto the top of the stack as an int64</td>
</tr>
<tr>
<td>91</td>
<td>ldelem.u1</td>
<td>Load the element with type unsigned int8 at index onto the top of the stack as an int32</td>
</tr>
<tr>
<td>93</td>
<td>ldelem.u2</td>
<td>Load the element with type unsigned int16 at index onto the top of the stack as an int32</td>
</tr>
<tr>
<td>95</td>
<td>ldelem.u4</td>
<td>Load the element with type unsigned int32 at index onto the top of the stack as an int32</td>
</tr>
<tr>
<td>96</td>
<td>ldelem.u8</td>
<td>Load the element with type unsigned int64 at index onto the top of the stack as an int64 (alias for ldelem.i8)</td>
</tr>
<tr>
<td>98</td>
<td>ldelem.r4</td>
<td>Load the element with type float32 at index onto the top of the stack as an F</td>
</tr>
<tr>
<td>99</td>
<td>ldelem.r8</td>
<td>Load the element with type float64 at index onto the top of the stack as an F</td>
</tr>
<tr>
<td>97</td>
<td>ldelem.i</td>
<td>Load the element with type native int at index onto the top of the stack as a native int</td>
</tr>
<tr>
<td>9A</td>
<td>ldelem.ref</td>
<td>Load the element of type object, at index onto the top of the stack as an O</td>
</tr>
</tbody>
</table>

Stack Transition:
...array, index ➔ ..., value

Description:
The ldelem instruction loads the value of the element with index index (of type int32 or native int) in the zero-based one-dimensional array array and places it on the top of the stack. Arrays are objects and hence represented by a value of type O. The return value is indicated by the instruction.

For one-dimensional arrays that aren’t zero-based and for multidimensional arrays, the array class provides a Get method.

Note that integer values of less than 4 bytes are extended to int32 (not native int) when they are loaded onto the evaluation stack. Floating-point values are converted to F type when loaded onto the evaluation stack.

Exceptions:
NullReferenceException is thrown if array is null.
IndexOutOfRangeException is thrown if index is negative, or larger than the bound of array.
ArrayTypeMismatchException is thrown if array doesn’t hold elements of the required type.
Verifiability:
Correct CIL code requires that `array` is either null or a zero-based, one-dimensional array whose declared element type matches exactly the type for this particular instruction suffix (e.g., `ldelem.r4` can only be applied to a zero-based, one-dimensional array of `float32`'s)
4.8 ldelema – load address of an element of an array

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F \langle T \rangle$</td>
<td>ldelema class</td>
<td>Load the address of element at index onto the top of the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... array, index \(\rightarrow\)... address

**Description:**

The `ldelema` instruction loads the address of the element with index `index` (of type `int32` or `native int`) in the zero-based one-dimensional array `array` (of element type `class`) and places it on the top of the stack. Arrays are objects and hence represented by a value of type `Object`. The return address is a managed pointer (type `&`).

For one-dimensional arrays that aren’t zero-based and for multidimensional arrays, the array class provides a `Address` method.

**Exceptions:**

- `NullReferenceException` is thrown if `array` is null.
- `IndexOutOfRangeException` is thrown if `index` is negative, or larger than the bound of `array`.
- `ArrayTypeMismatchException` is thrown if `array` doesn’t hold elements of the required type.

**Verifiability:**

Correct CIL ensures that `class` is a `typeparam` or `typedef` token to a class, and that `array` is indeed always either null or a zero-based, one-dimensional array whose declared element type matches `class` exactly.
### 4.9 ldfld – load field of an object

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7B &lt;T&gt;</td>
<td>ldfld field</td>
<td>Push the value of field of object, or value type, obj, onto the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., obj → ... value

**Description:**

The ldfld instruction pushes onto the stack the value of a field of obj. obj must be an object (type o), a managed pointer (type &), an unmanaged pointer (type native int), or an instance of a value type. The use of an unmanaged pointer is not permitted in verifiable code. field is a metadata token (a fielddef or fieldref see Partition II) that must refer to a field member. The return type is that associated with field. ldfld pops the object reference off the stack and pushes the value for the field in its place. The field may be either an instance field (in which case obj must not be null) or a static field.

The ldfld instruction may be preceded by either or both of the unaligned. and volatile. prefixes.

**Exceptions:**

NullReferenceException is thrown if obj is null and the field is not static.

MissingFieldException is thrown if field is not found in the metadata. This is typically checked when CIL is converted to native code, not at runtime.

**Verifiability:**

Correct CIL ensures that field is a valid token referring to a field, and that obj will always have a type compatible with that required for the lookup being performed. For verifiable code, obj may not be an unmanaged pointer.
4.10 ldflda – load field address

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C &lt;T&gt;</td>
<td>ldflda field</td>
<td>Push the address of field of object obj on the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... , obj  \( \rightarrow \) ... , address

**Description:**
The *ldflda* instruction pushes the address of a field of *obj*. *obj* is either an object, type `o`, a managed pointer, type `&`, or an unmanaged pointer, type `native int`. The use of an unmanaged pointer is not allowed in verifiable code. The value returned by *ldflda* is a managed pointer (type `&`) unless *obj* is an unmanaged pointer, in which case it is an unmanaged pointer (type `native int`).

*field* is a metadata token (a `fieldref` or `fielddef`; see Partition II) that must refer to a field member. The field may be either an instance field (in which case *obj* must not be null) or a static field.

**Exceptions:**

- *InvalidOperationException* is thrown if the *obj* is not within the application domain from which it is being accessed. The address of a field that is not inside the accessing application domain cannot be loaded.
- *MissingFieldException* is thrown if *field* is not found in the metadata. This is typically checked when CIL is converted to native code, not at runtime.
- *NullReferenceException* is thrown if *obj* is null and the field isn’t static.

**Verifiability:**
Correct CIL ensures that *field* is a valid `fieldref` token and that *obj* will always have a type compatible with that required for the lookup being performed.

**Note:** Using *ldflda* to compute the address of a static, init-only field and then using the resulting pointer to modify that value outside the body of the class initializer may lead to unpredictable behavior. It cannot, however, compromise memory integrity or type safety so it is not tested by verification.
### 4.11 ldlen – load the length of an array

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8E</td>
<td>ldlen</td>
<td>push the length (of type native unsigned int) of <code>array</code> on the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... array → ... length

**Description:**

The `ldlen` instruction pushes the number of elements of `array` (a zero-based, one-dimensional array) on the stack.

Arrays are objects and hence represented by a value of type `object`. The return value is a `native unsigned int`.

**Exceptions:**

`NullReferenceException` is thrown if `array` is null.

**Verifiability:**

Correct CIL ensures that `array` is indeed always either null or a zero-based, one-dimensional array.
4.12 ldobj - copy value type to the stack

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>71 <code>&lt;T&gt;</code></td>
<td>ldobj classTok</td>
<td>Copy instance of value type classTok to the stack.</td>
</tr>
</tbody>
</table>

Stack Transition:

`..., addrOfValObj` → `..., valObj`

Description:

The `ldobj` instruction copies the value pointed to by `addrOfValObj` (of type managed pointer, &, or unmanaged pointer, native unsigned int) to the top of the stack. The number of bytes copied depends on the size of the class represented by `classTok`. `ClassTok` is a metadata token (a `typeof` or `typedef`; see Partition II) representing a value type.

Rationale: The `ldobj` instruction is used to pass a value type as a parameter. See Partition I.

It is unspecified what happens if `addrOfValObj` is not an instance of the class represented by `ClassTok` or if `ClassTok` does not represent a value type.

The operation of the `ldobj` instruction may be altered by an immediately preceding `volatile` or `unaligned` prefix instruction.

Exceptions:

TypeLoadException is thrown if `class` cannot be found. This is typically detected when CIL is converted to native code rather than at runtime.

Verifiability:

Correct CIL ensures that `classTok` is a metadata token representing a value type and that `addrOfValObj` is a pointer to a location containing a value of the type specified by `classTok`. Verifiable code additionally requires that `addrOfValObj` is a managed pointer of a matching type.
4.13 ldsfld – load static field of a class

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7E &lt;T&gt;</td>
<td>ldsfld field</td>
<td>Push the value of field on the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., ➔ ..., value

**Description:**
The `ldsfld` instruction pushes the value of a static (shared among all instances of a class) field on the stack. The instruction may have a `volatile` prefix.

**Exceptions:**
None.

**Verifiability:**
Correct CIL ensures that field is a valid metadata token referring to a static field member.
4.14  ldsflda – load static field address

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7F &lt;T&gt;</td>
<td>ldsflda field</td>
<td>Push the address of the static field, field, on the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...
⇒ ...
address

**Description:**
The ldsflda instruction pushes the address (a managed pointer, type & if field refers to a type whose memory is managed; otherwise an unmanaged pointer, type native int) of a static field on the stack. field is a metadata token (a fieldref or fielddef; see Partition II) referring to a static field member. (Note that field may be a static global with assigned RVA, in which case its memory is unmanaged; where RVA stands for Relative Virtual Address, the offset of the field from the base address at which its containing PE file is loaded into memory)

**Exceptions:**
MissingFieldException is thrown if field is not found in the metadata. This is typically checked when CIL is converted to native code, not at runtime.

**Verifiability:**
Correct CIL ensures that field is a valid metadata token referring to a static field member if field refers to a type whose memory is managed.

**Note:** Using ldsflda to compute the address of a static, init-only field and then using the resulting pointer to modify that value outside the body of the class initializer may lead to unpredictable behavior. It cannot, however, compromise memory integrity or type safety so it is not tested by verification.
4.15  ldstr – load a literal string

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>72 &lt;T&gt;</td>
<td>ldstr string</td>
<td>push a string object for the literal string</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...
...
..., string

**Description:**
The `ldstr` instruction pushes a new string object representing the literal stored in the metadata as `string` (that must be a string literal).

The `ldstr` instruction allocates memory and performs any format conversion required to convert from the form used in the file to the string format required at runtime. The CLI guarantees that the result of two `ldstr` instructions referring to two metadata tokens that have the same sequence of characters return precisely the same string object (a process known as “string interning”).

**Exceptions:**
None.

**Verifiability:**
Correct CIL requires that `mdToken` is a valid string literal metadata token.
4.16  ldtoken - load the runtime representation of a metadata token

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0 &lt;T&gt;</td>
<td>ldtoken token</td>
<td>Convert metadata token to its runtime representation</td>
</tr>
</tbody>
</table>

*Stack Transition:*

```
... → ..., RuntimeHandle
```

*Description:*

The `ldtoken` instruction pushes a RuntimeHandle for the specified metadata token. The token must be one of:

- A `methoddef` or `methodref`: pushes a `RuntimeMethodHandle`
- A `typedef` or `typeref`: pushes a `RuntimeTypeHandle`
- A `fielddef` or `fieldref`: pushes a `RuntimeFieldHandle`

The value pushed on the stack can be used in calls to Reflection methods in the system class library.

*Exceptions:*

None.

*Verifiability:*

Correct CIL requires that `token` describes a valid metadata token.
4.17  ldvirtftn - load a virtual method pointer

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 07 &lt;T&gt;</td>
<td>ldvirtftn mthd</td>
<td>Push address of virtual method mthd on the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... object  ➔ ... ftn

**Description:**

The ldvirtftn instruction pushes an unmanaged pointer (type native int) to the native code implementing the virtual method associated with object and described by the method reference mthd (a metadata token, either a methoddef or methodref; see Partition II) onto the stack. The value pushed can be called using the calli instruction if it references a managed method (or a stub that transitions from managed to unmanaged code).

The value returned points to native code using the calling convention specified by mthd. Thus a method pointer can be passed to unmanaged native code (e.g. as a callback routine) if that routine expects the corresponding calling convention. Note that the address computed by this instruction may be to a thunk produced specially for this purpose (for example, to re-enter the CLI when a native version of the method isn’t available).

**Exceptions:**

None.

**Verifiability:**

Correct CIL ensures that mthd is a valid methoddef or methodref token. Also that mthd references a non-static method that is defined for object. Verification tracks the type of the value pushed in more detail than the ‘native int’ type, remembering that it is a method pointer. Such a method pointer can then be used in verified code with calli or to construct a delegate.
4.18 mkrefany – push a typed reference on the stack

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C6 &lt;T&gt;</td>
<td>mkrefany class</td>
<td>push a typed reference to ptr of type class onto the stack</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., ptr \rightarrow ..., typedRef

**Description:**
The `mkrefany` instruction supports the passing of dynamically typed references. *Ptr* must be a pointer (type `&`, `native int`) that holds the address of a piece of data. *Class* is the class token (a `typedef` or `typeref`; see Partition II) describing the type of *ptr*. `mkrefany` pushes a typed reference on the stack, that is an opaque descriptor of *ptr* and *class*. The only legal operation on a typed reference on the stack is to pass it to a method that requires a typed reference as a parameter. The callee can then use the `refanytype` and `refanyval` instructions to retrieve the type (*class*) and address (*ptr*) respectively.

**Exceptions:**
`TypeLoadException` is thrown if *class* cannot be found. This is typically detected when CIL is converted to native code rather than at runtime.

**Verifiability:**
Correct CIL ensures that *class* is a valid `typedef` or `typeref` token describing some type and that *ptr* is a pointer to exactly that type. Verification additionally requires that *ptr* be a managed pointer. Verification will fail if it cannot deduce that *ptr* is a pointer to an instance of *class*.
### newarr – create a zero-based, one-dimensional array

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8D &lt;T&gt;</td>
<td>newarr etype</td>
<td>create a new array with elements of type etype</td>
</tr>
</tbody>
</table>

#### Stack Transition:

..., numElements → ..., array

#### Description:

The `newarr` instruction pushes a reference to a new zero-based, one-dimensional array whose elements are of type `elemtype`, a metadata token (a `typeref` or `typedef`; see Partition II). `numElems` (of type native int) specifies the number of elements in the array. Valid array indexes are $0 \leq \text{index} < \text{numElems}$. The elements of an array can be any type, including value types.

Zero-based, one-dimensional arrays of numbers are created using a metadata token referencing the appropriate value type (`System.Int32`, etc.). Elements of the array are initialized to 0 of the appropriate type.

One-dimensional arrays that aren’t zero-based and multidimensional arrays are created using `newobj` rather than `newarr`. More commonly, they are created using the methods of `System.Array` class in the Base Framework.

#### Exceptions:

- `OutOfMemoryException` is thrown if there is insufficient memory to satisfy the request.
- `OverflowException` is thrown if `numElems` is $< 0$

#### Verifiability:

Correct CIL ensures that `etype` is a valid `typeref` or `typedef` token.
4.20 newobj – create a new object

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>73 &lt;T&gt;</td>
<td>newobj ctor</td>
<td>allocate an uninitialized object or value type and call ctor</td>
</tr>
</tbody>
</table>

**Stack Transition:**
...,, arg1,, argN \rightarrow ..., obj

**Description:**
The `newobj` instruction creates a new object or a new instance of a value type. `Ctor` is a metadata token (a `methodref` or `methoddef` that must be marked as a constructor; see Partition II) that indicates the name, class and signature of the constructor to call. If a constructor exactly matching the indicated name, class and signature cannot be found, `MissingMethodException` is thrown.

The `newobj` instruction allocates a new instance of the class associated with `constructor` and initializes all the fields in the new instance to 0 (of the proper type) or `null` as appropriate. It then calls the constructor with the given arguments along with the newly created instance. After the constructor has been called, the now initialized object reference is pushed on the stack.

From the constructor’s point of view, the uninitialized object is argument 0 and the other arguments passed to `newobj` follow in order.

All zero-based, one-dimensional arrays are created using `newarr`, not `newobj`. On the other hand, all other arrays (more than one dimension, or one-dimensional but not zero-based) are created using `newobj`.

Value types are not usually created using `newobj`. They are usually allocated either as arguments or local variables, using `newarr` (for zero-based, one-dimensional arrays), or as fields of objects. Once allocated, they are initialized using `initobj`. However, the `newobj` instruction can be used to create a new instance of a value type on the stack, that can then be passed as an argument, stored in a local, etc.

**Exceptions:**
`OutOfMemoryException` is thrown if there is insufficient memory to satisfy the request.

`MissingMethodException` is thrown if a constructor method with the indicated name, class and signature could not be found. This is typically detected when CIL is converted to native code, rather than at runtime.

**Verifiability:**
Correct CIL ensures that `constructor` is a valid `methodref` or `methoddef` token, and that the arguments on the stack are compatible with those expected by the constructor. Verification considers a delegate constructor as a special case, checking that the method pointer passed in as the second argument, of type `native int`, does indeed refer to a method of the correct type.
### 4.21 refanytype – load the type out of a typed reference

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 1D</td>
<td>Refanytype</td>
<td>Push the type token stored in a typed reference</td>
</tr>
</tbody>
</table>

**Stack Transition:**

```
..., TypedRef \rightarrow ..., type
```

**Description:**

Retrieves the type token embedded in `TypedRef`. See the `mkrefany` instruction.

**Exceptions:**

None.

**Verifiability:**

Correct CIL ensures that `TypedRef` is a valid typed reference (created by a previous call to `mkrefany`). The `refanytype` instruction is always verifiable.
4.22 refanyval – load the address out of a typed reference

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2 &lt;T&gt;</td>
<td>refanyval type</td>
<td>Push the address stored in a typed reference</td>
</tr>
</tbody>
</table>

*Stack Transition:*

..., `TypedRef` \(\rightarrow\) ..., address

*Description:*

Retrieves the address (of type \&) embedded in `TypedRef`. The type of reference in `TypedRef` must match the type specified by `type` (a metadata token, either a `typedef` or a `typeref`; see Partition II). See the `mkrefany` instruction.

*Exceptions:*

`InvalidCastException` is thrown if `type` is not identical to the type stored in the `TypedRef` (i.e., the `class` supplied to the `mkrefany` instruction that constructed that `TypedRef`).

`TypeLoadException` is thrown if `type` cannot be found.

*Verifiability:*

Correct CIL ensures that `TypedRef` is a valid typed reference (created by a previous call to `mkrefany`). The `refanyval` instruction is always verifiable.
4.23 rethrow – rethrow the current exception

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 1A</td>
<td>rethrow</td>
<td>Rethrow the current exception</td>
</tr>
</tbody>
</table>

Stack Transition:
...
...

Description:
The `rethrow` instruction is only permitted within the body of a `catch` handler (see Partition I). It throws the same exception that was caught by this handler.

Exceptions:
The original exception is thrown.

Verifiability:
Correct CIL uses this instruction only within the body of a `catch` handler (not of any exception handlers embedded within that `catch` handler). If a rethrow occurs elsewhere, then an exception will be thrown, but precisely which exception is undefined.
4.24 sizeof – load the size in bytes of a value type

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 1C &lt;T&gt;</td>
<td>sizeof valueType</td>
<td>Push the size, in bytes, of a value type as a unsigned int32</td>
</tr>
</tbody>
</table>

**Stack Transition:**

..., → ..., size (4 bytes, unsigned)

**Description:**

Returns the size, in bytes, of a value type. ValueType must be a metadata token (a typedef or typedef; see Partition II) that specifies a value type.

**Rationale:** The definition of a value type can change between the time the CIL is generated and the time that it is loaded for execution. Thus, the size of the type is not always known when the CIL is generated. The sizeof instruction allows CIL code to determine the size at runtime without the need to call into the Framework class library. The computation can occur entirely at runtime or at CIL-to-native-code compilation time. sizeof returns the total size that would be occupied by each element in an array of this value type – including any padding the implementation chooses to add. Specifically, array elements lie sizeof bytes apart.

**Exceptions:**

None.

**Verifiability:**

Correct CIL ensures that ValueType is a typedef or typedef referring to a value type. It is always verifiable.
4.25 stelem.<type> – store an element of an array

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9C</td>
<td>stelem.i1</td>
<td>Replace array element at index with the int8 value on the stack</td>
</tr>
<tr>
<td>9D</td>
<td>stelem.i2</td>
<td>Replace array element at index with the int16 value on the stack</td>
</tr>
<tr>
<td>9E</td>
<td>stelem.i4</td>
<td>Replace array element at index with the int32 value on the stack</td>
</tr>
<tr>
<td>9F</td>
<td>stelem.i8</td>
<td>Replace array element at index with the int64 value on the stack</td>
</tr>
<tr>
<td>A0</td>
<td>stelem.r4</td>
<td>Replace array element at index with the float32 value on the stack</td>
</tr>
<tr>
<td>A1</td>
<td>stelem.r8</td>
<td>Replace array element at index with the float64 value on the stack</td>
</tr>
<tr>
<td>A2</td>
<td>stelem.ref</td>
<td>Replace array element at index with the ref value on the stack</td>
</tr>
</tbody>
</table>

Stack Transition:

..., array, index, value \rightarrow ..., 

Description:
The stelem instruction replaces the value of the element with zero-based index index (of type int32 or native int) in the one-dimensional array array with value. Arrays are objects and hence represented by a value of type 0. Note that stelem.ref implicitly casts value to the element type of array before assigning the value to the array element. This cast can fail, even for verified code. Thus the stelem.ref instruction may throw the InvalidCastException.

For one-dimensional arrays that aren’t zero-based and for multidimensional arrays, the array class provides a StoreElement method.

Exceptions:

NullReferenceException is thrown if array is null.

IndexOutOfRangeException is thrown if index is negative, or larger than the bound of array.

ArrayTypeMismatchException is thrown if array doesn’t hold elements of the required type.

Verifiability:
Correct CIL requires that array be a zero-based, one-dimensional array whose declared element type matches exactly the type for this particular instruction suffix (eg stelem.r4 can only be applied to a zero-based, one-dimensional array of float32’s); also that index lies within the bounds of array.
4.26 stfld – store into a field of an object

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7D &lt;T&gt;</td>
<td>stfld field</td>
<td>Replace the value of field of the object obj with val</td>
</tr>
</tbody>
</table>

Stack Transition:
...
obj, value → ...

Description:
The stfld instruction replaces the value of a field of an obj (an O) or via a pointer (type native int, or &)
with value. field is a metadata token (a fieldref or fielddef; see Partition II) that refers to a field member
reference. stfld pops the value and the object reference off the stack and updates the object.

The stfld instruction may have a prefix of either or both of unaligned and volatile.

Exceptions:
NullReferenceException is thrown if obj is null and the field isn’t static.

MissingFieldException is thrown if field is not found in the metadata. This is typically checked when CIL is
converted to native code, not at runtime.

Verifiability:
Correct CIL ensures that field is a valid token referring to a field, and that obj and value will always have types
appropriate for the assignment being performed. For verifiable code, obj may not be an unmanaged pointer.

Note: Using stfld to change the value of a static, init-only field outside the body of the class initializer may
lead to unpredictable behavior. It cannot, however, compromise memory integrity or type safety so it is not
tested by verification.
4.27  

**stobj - store a value type from the stack into memory**  

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$81 &lt;T&gt;$</td>
<td>stobj classTok</td>
<td>Store a value of type classTok from the stack into memory</td>
</tr>
</tbody>
</table>

**Stack Transition:**

... addr, valObj $\rightarrow$ ...

**Description:**

The *stobj* instruction copies the value type *valObj* into the address specified by *addr* (a pointer of type *native int*, or $\&$). The number of bytes copied depends on the size of the class represented by *classTok*. *classTok* is a metadata token (a *typedef* or *typeref*; see Partition II) representing a value type.

It is unspecified what happens if *valObj* is not an instance of the class represented by *classTok* or if *classTok* does not represent a value type.

The operation of the *stobj* instruction may be altered by an immediately preceding *volatile* or *unaligned* prefix instruction.

**Exceptions:**

*TypeLoadException* is thrown if *class* cannot be found. This is typically detected when CIL is converted to native code rather than at runtime.

**Verifiability:**

Correct CIL ensures that *classTok* is a metadata token representing a value type and that *valObj* is a pointer to a location containing an initialized value of the type specified by *classTok*. In addition, verifiable code requires that *valObj* be a managed pointer.
4.28 stsfld – store a static field of a class

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 &lt;T&gt;</td>
<td>stsfld field</td>
<td>Replace the value of field with val</td>
</tr>
</tbody>
</table>

Stack Transition:
...

Description:
The *stsfld* instruction replaces the value of a static field with a value from the stack. *field* is a metadata token (a *fieldref* or *fielddef*; see Partition II) that must refer to a static field member. *Stsfld* pops the value off the stack and updates the static field with that value.

The *stsfld* instruction may be prefixed by *volatile*.

Exceptions:
*MissingFieldException* is thrown if *field* is not found in the metadata. This is typically checked when CIL is converted to native code, not at runtime.

Verifiability:
Correct CIL ensures that *field* is a valid token referring to a static field, and that *value* will always have a type appropriate for the assignment being performed.

Note: Using *stsfld* to change the value of a static, init-only field outside the body of the class initializer may lead to unpredictable behavior. It cannot, however, compromise memory integrity or type safety so it is not tested by verification.
### 4.29 throw – throw an exception

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7A</td>
<td>throw</td>
<td>Throw an exception</td>
</tr>
</tbody>
</table>

**Stack Transition:**

\( ..., \text{object} \rightarrow ..., \)

**Description:**

The `throw` instruction throws the exception `object` (type o) on the stack. For details of the exception mechanism, see Partition I.

**Note:** While the CLI permits any object to be thrown, the common language specification (CLS) describes a specific exception class that must be used for language interoperability.

**Exceptions:**

- `NullReferenceException` is thrown if `obj` is null.

**Verifiability:**

Correct CIL ensures that `class` a valid `TypeRef` token indicating a class, and that `obj` is always either null or an object reference, i.e. of type o.
4.30 unbox – Convert boxed value type to its raw form

<table>
<thead>
<tr>
<th>Format</th>
<th>Assembly Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>79 &lt;T&gt;</td>
<td>unbox valuetype</td>
<td>Extract the value type data from obj, its boxed representation</td>
</tr>
</tbody>
</table>

**Stack Transition:**
... obj → ..., valueTypePtr

**Description:**
A value type has two separate representations (see Partition I) within the CLI:
- A ‘raw’ form used when a value type is embedded within another object.
- A ‘boxed’ form, where the data in the value type is wrapped (boxed) into an object so it can exist as an independent entity.

The unbox instruction converts obj (of type o), the boxed representation of a value type, to valueTypePtr (a managed pointer, type a), its unboxed form. Valuetype is a metadata token (a typedef or typedef) indicating the type of value type contained within obj. If obj is not a boxed instance of valuetype, or, if obj is a boxed enum and valuetype is not its underlying type, then this instruction will throw an InvalidCastException.

Unlike box, which is required to make a copy of a value type for use in the object, unbox is not required to copy the value type from the object. Typically it simply computes the address of the value type that is already present inside of the boxed object.

**Exceptions:**
InvalidCastException is thrown if obj is not a boxed valuetype (or if obj is a boxed enum and valuetype is not its underlying type)

NullReferenceException is thrown if obj is null.

TypeLoadException is thrown if class cannot be found. This is typically detected when CIL is converted to native code rather than at runtime.

**Verifiability:**
Correct CIL ensures that valuetype is a typedef or typedef metadata token for some value type, and that obj is always an object reference, i.e. of type o, and represents a boxed instance of a valuetype value type.
Common Language Infrastructure (CLI)
Partition IV:
Profiles and Libraries
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1 Overview

Note:

While compiler writers are most concerned with issues of file format, instruction set design, and a common type system, application programmers are most interested in the programming library that is available to them in the language they are using. The Common Language Infrastructure (CLI) specifies a Common Language Specification (CLS, see Partition I) that shall be used to define the externally visible aspects (method signatures, etc.) when they are intended to be used from a wide range of programming languages. Since it is the goal of the CLI Libraries to be available from as many programming languages as possible, all of its functionality is available through CLS-compliant types and type members.

The CLI Libraries are designed with the following goals in mind:

• Wide reach across programming languages
• Consistent design patterns throughout
• Features on parity with the ISO C library of 1990
• Features for more recent programming paradigms, notably networking, XML, runtime type inspection, instance creation, and dynamic method dispatch
• Factoring into self-consistent libraries with minimal interdependence

This document provides an overview of the CLI Libraries and a specification of their factoring into Profiles and Libraries. A companion document, considered to be part of this Partition but distributed in XML format, provides details of each class, value type, and interface in the CLI Libraries. While the normative specification of the CLI Libraries is in XML form, it can be processed using an XSL transform to produce easily browsed information about the Class Libraries

Partition V contains an informative annex describing programming conventions used in defining the CLI Libraries. These conventions, while not normative, can significantly simplify the use of libraries. Implementers are encouraged to follow them when creating additional (non-Standard) Libraries.
2 Libraries and Profiles

Libraries and Profiles, defined below, are constructs created for the purpose of standards
conformance/compliance. They specify a set of features that shall be present in an implementation of the
Common Language Infrastructure (CLI) and a set of types that shall be available to programs run by that CLI.

Note: There need not be any direct support for Libraries and Profiles in the Virtual Execution System (VES).
They are not represented in the metadata and they have no impact on the structure or performance of an
implementation of the CLI. Libraries and Profiles may span assemblies (the deployment unit), and the names of
types in a single Library or Profile are not required to have a common prefix ("namespace").

There is, in general, no way to test whether a feature is available at runtime, nor a way to enquire whether a
particular Profile or Library is available. If present, however, the Reflection Library makes it possible to test at
runtime for the existence of particular methods and types.

2.1 Libraries

A Library specifies three things:

- A set of types that shall be available, including their grouping into assemblies.
- A set of features of the CLI that shall be available. Note: The set of features required for any particular Library is a subset of the complete set of CLI features. Each Library described in Chapter 5 has text that defines what CLI features are required for implementations that support the Library.
- Modifications to types defined in other Libraries. These modifications are typically the addition of methods and interfaces to types belonging to the other Library, and additional exceptions that may be thrown by methods of the other Library’s types. These modifications shall provide only additional functionality or specify behavior where it was previously unspecified; they shall not be used to alter previously specified behavior.

Example (informative): Consider the Extended Numerics Library. Since it provides a new base data type, Double, it also specifies that the method ToDouble be added to the System.Convert class that is part of the Base Class Library. It also defines a new exception, System.NotFiniteNumberException, and specifies existing methods in other Libraries methods that throw it (as it happens, there are no such methods).

In the XML specification of the Libraries, each type specifies the Library to which it belongs. For those members (e.g., Console.WriteLine(float)) that are part of one Library (Extended Numerics) but whose type is in another Library (BCL), the XML specifies the Library that defines the method. See Chapter 7.

2.2 Profiles

A Profile is simply a set of Libraries, grouped together to form a consistent whole that provides a fixed level of functionality. A conforming implementation of the CLI shall specify a Profile it implements, as well as any additional Libraries that it provides. The Kernel Profile (see Section 0) shall be included in all conforming implementations of the CLI. Thus, all Libraries and CLI features that are part of the Kernel Profile are available in all conforming implementations. This minimal feature set is described in Chapter 0.

Rationale: The rules for combining Libraries together are complex, since each Library may add members to types defined in other libraries. By standardizing a small number of Profiles we specify completely the interaction of the Libraries that are part of each Profile. A Profile provides a consistent target for vendors of devices, compilers, tools, and applications. Each Profile specifies a trade-off of CLI feature and implementation complexity against resource constraints. By defining a very small number of Profiles we increase the market for each Profile, making each a desirable target for a class of applications across a wide range of implementations and tool sets.
2.3 Structure of the Standard

This standard specifies two Standard Profiles (see Chapter 0) and 7 Standard Libraries (see Chapter 5). The following diagram shows the relationship between the Libraries and the Profiles:

The Extended Array Library and the Extended Numerics Library are not part of either Profile, but may be combined with either of them. Doing so adds the appropriate methods, exceptions, and interfaces to the types specified in the Profile.
3 The Standard Profiles

There are two Standard Profiles. The smallest conforming implementation of the CLI is the Kernel Profile, while the Compact Profile contains additional features useful for applications targeting a more resource-rich set of devices.

A conforming implementation of the CLI shall throw an appropriate exception (for example, System.NotImplementedException, System.MissingMethodException, or System.ExecutionEngineException) when it encounters a feature specified in this Standard but not supported by the particular Profile (see Partition III).

Note: Implementers should consider providing tools that statically detect features they do not support so users have an option of checking programs for the presence of such features before running them.

Note: Vendors of compliant CLI implementations should specify exactly which configurations of Standard Libraries and Standard Profiles they support.

Note: “Features” may be something like the use of a floating point CIL instruction in the implementation of a method when the CLI upon which it is running does not support the Extended Numerics Library. Or, the “feature” might be a call to a method that this Standard specifies exists only when a particular Library is implemented and yet the code making the call is running on an implementation of the CLI that does not support that particular library.

3.1 The Kernel Profile

This profile is the minimal possible conforming implementation of the CLI. It contains the types commonly found in a modern programming language class library plus the classes needed by compilers targeting the CLI.

Contents: Base Class Library, Runtime Infrastructure Library

3.2 The Compact Profile

This Profile is designed to allow implementation on devices with only modest amounts of physical memory yet provides more functionality than the Kernel Profile alone. It also contains everything required to implement the ECMAScript compact profile proposed within Standard ECMA-327.

Contents: Kernel Profile, XML Library, Networking Library, Reflection Library
4 Kernel Profile Feature Requirements

All conforming implementations of the CLI support at least the Kernel Profile and consequently all CLI features required by the Kernel Profile must be implemented by all conforming implementations. This section defines that minimal feature set by enumerating the set of features that are not required, i.e., a minimal conforming implementation must implement all CLI features except those specified in the remainder of this section. The feature requirements of individual Libraries as specified in Chapter 5 are defined by reference to restricted items described in this section. For ease of reference, each feature has a name indicated by the name of the section heading. Where Libraries do not specify any additional feature requirement, it shall be assumed that only the features of the Kernel Profile as described in this Section are required.

4.1 Features Excluded from Kernel Profile

The following internal data types and constructs, specified elsewhere in this Standard, are not required of CLI implementations that conform only to the Kernel Profile. All other CLI features are required. Implementations that conform only to the Kernel Profile. All other CLI features are required.

4.1.1 Floating Point

The floating point feature set consists of the user-visible floating-point data types float32 and float64, and support for an internal representation of floating-point numbers.

If omitted: The CIL instructions that deal specifically with these data types throw the System.NotImplementedException exception. These instructions are: ckfinite, conv.r.un, conv.r4, conv.r8, ldc.r4, ldc.r8, ldelem.r4, ldelem.r8, ldind.r4, ldind.r8, stelem.r4, stelem.r8, stind.r4, stind.r8. Any attempt to reference a signature including the floating-point data types shall throw the System.NotImplementedException exception. The precise timing of the exception is not specified.

Note: These restrictions guarantee that the VES will not encounter any floating-point data. Hence the implementation of the arithmetic instructions (add, etc.) need not handle those types.

Part of Library: Extended Numerics (see Section 5.6)

4.1.2 Non-vector Arrays

The non-vector arrays feature set includes the support for arrays with more than one dimension or with lower bounds other than zero. This includes support for signatures referencing such arrays, runtime representations of such arrays, and marshalling of such arrays to and from native data types.

If omitted: Any attempt to reference a signature including a non-vector array shall throw the System.NotImplementedException exception. The precise timing of the exception is not specified.

Note: The generic type System.Array is part of the Kernel Profile and is available in all conforming implementations of the CLI. An implementation that does not provide the non-vector array feature set can correctly assume that all instances of that class are vectors.

Part of Library: Extended Arrays (see Section 5.7).

4.1.3 Reflection

The reflection feature set supports full reflection on data types. All of its functionality is exposed through methods in the Reflection Library.

If omitted: The Kernel profile specifies an opaque type, System.Type, instances of which uniquely represent any type in the system and provide access to the name of the type.

Note: With just the Kernel profile there is no requirement, for example, to determine the members of the type, dynamically create instances of the type, or invoke methods of the type given an instance of System.Type. This can simplify the implementation of the CLI compared to that required when the Reflection Library is available.

Part of Library: Reflection (see Section 0).
4.1.4 Application Domains

The application domain feature set supports multiple application domains. The Kernel profile requires that a single application domain exist.

If omitted: Methods for creating application domains (part of the Base Class Library, see Section 5.2) throw the System.NotImplementedException exception.

Part of Library: (none)

4.1.5 Remoting

The remoting feature set supports remote method invocation. It is provided primarily through special semantics of the class System.MarshalByRefObject as described in Partition I.

If omitted: The class System.MarshalByRefObject shall be treated as a simple class with no special meaning.

Part of Library: (none)

4.1.6 Varargs

The varargs feature set supports variable length argument lists and runtime typed pointers.

If omitted: Any attempt to reference a method with the varargs calling convention or the signature encodings associated with varargs methods (see Partition II) shall throw the System.NotImplementedException exception. Methods using the CIL instructions arglist, refanytype, mkrefany, and refanyval shall throw the System.NotImplementedException exception. The precise timing of the exception is not specified. The type System.TypedReference need not be defined.

Part of Library: (none)

4.1.7 Frame Growth

The frame growth feature set supports dynamically extending a stack frame.

If omitted: Methods using the CIL localloc instruction shall throw the System.NotImplementedException exception. The precise timing of the exception is not specified.

Part of Library: (none)

4.1.8 Filtered Exceptions

The filtered exceptions feature set supports user-supplied filters for exceptions.

If omitted: Methods using the CIL endfilter instruction or with an exceptionentry that contains a non-null filterstart (see Partition I) shall throw the System.NotImplementedException exception. The precise timing of the exception is not specified.

Part of Library: (none)
5 The Standard Libraries

The detailed content of each Library, in terms of the types it provides and the changes it makes to types in other Libraries, is provided in XML form. This section provides an informative description of each Library’s purpose as well as specifying the features of the CLI required by each Library beyond those required by the Kernel Profile.

5.1 Runtime Infrastructure Library

The Runtime Infrastructure Library is part of the Kernel Profile. It provides the services needed by a compiler to target the CLI and the facilities needed to dynamically load types from a stream in the file format specified in Partition II. For example, it provides `System.BadImageFormatException`, which is thrown when a stream that does not have the correct format is loaded.

Name used in XML: RuntimeInfrastructure TC39/TG

CLI Feature Requirement: None

5.2 Base Class Library

The Base Class Library is part of the Kernel Profile. It is a simple runtime library for a modern programming language. It serves as the Standard for the runtime library for the language C# (Standard ECMA-yyyy) as well as one of the CLI Standard Libraries. It provides types to represent the built-in data types of the CLI, simple file access, custom attributes, security attributes, string manipulation, formatting, streams, collections, and so forth.

Name used in XML: BCL

CLI Feature Requirement: None

5.3 Network Library

The Network Library is part of the Compact Profile. It provides simple networking services including direct access to network ports as well as HTTP support.

Name used in XML: Networking

CLI Feature Requirement: None

5.4 Reflection Library

The Reflection Library is part of the Compact Profile. It provides the ability to examine the structure of types, create instances of types, and invoke methods on types, all based on a description of the type.

Name used in XML: Reflection

CLI Feature Requirement: Must support Reflection, see Section 0.

5.5 XML Library

The XML Library is part of the Compact Profile. It provides a simple “pull-style” parser for XML. It is designed for resource-constrained devices, yet provides a simple user model. A conforming implementation of the CLI that includes the XML Library shall also implement the Network Library (see Section 5.3).

Name used in XML: XML

CLI Feature Requirement: None

5.6 Extended Numerics Library

The Extended Numerics Library is not part of any Profile, but can be supplied as part of any CLI implementation. It provides the support for floating-point (`System.Single`, `System.Double`) and extended-precision (`System.Decimal`) data types. Like the Base Class Library, this Library is directly referenced by the C# Standard (ECMA-yyyy).
Note: Programmers who use this library will benefit if implementations specify which arithmetic operations on these data types are implemented primarily through hardware support.

Rationale: The Extended Numerics Library is kept separate because some commonly available processors do not provide direct support for the data types. While software emulation can be provided, the performance difference is often so large (1,000 fold or more) that it is unreasonable to build software using floating-point operations without being aware of whether the underlying implementation is hardware-based.

CLI Feature Requirement: Floating Point, see clause 0.

5.7 Extended Array Library

This Library is not part of any Profile, but can be supplied as part of any CLI implementation. It provides support for non-vector arrays. That is, arrays that have more than one dimension, and arrays that have non-zero lower bounds.

CLI Feature Requirement: Non-vector Arrays, see clause 0.
6 Implementation-Specific Modifications to the System Libraries

Implementers are encouraged to extend or modify the types specified in this Standard to provide additional functionality. Implementers should notice, however, that type names beginning with “System.” and bearing the special Standard Public Key are intended for use by the Standard Libraries: such names not currently in use may be defined in a future version of this Standard.

To allow programs compiled against the Standard Libraries to work when run on implementations that have extended or modified the Standard Libraries, such extensions or modifications shall obey the following rules:

- The contract specified by virtual methods shall be maintained in new classes that override them.
- New exceptions may be thrown, but where possible these should be subclasses of the exceptions already specified as thrown rather than entirely new exception types. Exceptions initiated by methods of types defined in the Standard Libraries shall be derived from System.Exception.
- Interfaces and virtual methods shall not be added to an existing interface. Nor shall they be added to an abstract class unless the class provides an implementation.

**Rationale:** An interface or virtual method may be added only where it carries an implementation. This allows programs written when the interface or method was not present to continue to work.

- Instance methods shall not be implemented as virtual methods.

**Rationale:** Methods specified as instance (non-static, non-virtual) in this standard are not permitted to be implemented as virtual methods in order to reduce the likelihood of creating non-portable files by using implementation-supplied libraries at compile time. Even though a compiler need not take a dependence on the distinction between virtual and instance methods, it is easy for a user to inadvertently override a virtual method and thus create non-portable code. The alternative of providing special files corresponding to this Standard for use at compile time is prone to user error.

**Note:** The following common extensions are permitted by these rules.

- Adding new members to existing types.
- Concrete (non-abstract) classes may implement interfaces not defined in this standard.
- Adding fields (values) to enumerations.
- An implementation may insert a new type into the hierarchy between a type specified in this standard and the type specified as its base type. That is, this standard specifies an inheritance relation between types but does not specify the immediate base type.

**Rationale:** An implementation may wish to split functionality across several types in order to provide non-standard extension mechanisms, or may wish to provide additional non-standard functionality through the new base type. As long as programs do not reference these non-standard types they will remain portable across conforming implementations of the CLI.
7 Semantics of the XML Specification

The XML specification conforms to the Document Type Definition (DTD) in Figure 7-1. Only types that are included in a specified library are included in the XML.

There are three types of elements/attributes:

- **Normative**: An element or attribute is normative such that the XML specification would be incomplete without it.
- **Informative**: An element or attribute is informative if it specifies information that helps clarify the XML specification, but without it the specification still stands alone.
- **Rendering/Formatting**: An element or attribute is for rendering or formatting if it specifies information to help an XML rendering tool.

The text associated with an element or an attribute (e.g. #PCDATA, #CDATA) is, unless explicitly stated otherwise, normative or informative depending on the element or attribute with which it is associated, as described in the figure.

[Note: Many of the elements and attributes in the DTD are for rendering purposes.]

---

**Figure 7-1: XML DTD**

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!ELEMENT AssemblyCulture (#PCDATA)>
(Normative) Specifies the culture of the assembly that defines the current type. Currently this value is always “none”. It is reserved for future use.
<!ELEMENT AssemblyInfo (AssemblyName, AssemblyPublicKey, AssemblyVersion, AssemblyCulture, Attributes)>
(Normative) Specifies information about the assembly of a given type. These correspond to sections of the metadata of an assembly as described in Partition II and include information from the AssemblyName, AssemblyPublicKey, AssemblyVersion, AssemblyCulture and Attributes elements.
<!ELEMENT AssemblyName (#PCDATA)>
(Normative) Specifies the name of the assembly of which a given type is a member. For example, all of the types in the BCL are members of the “mscorlib” assembly.
<!ELEMENT AssemblyPublicKey (#PCDATA)>
(Normative) Specifies the public key of the assembly. The public key is represented as a 128-bit value.
<!ELEMENT AssemblyVersion (#PCDATA)>
(Normative) Specifies the version of the assembly in the form 1.0.x.y, where x is a build number and y is a revision number.
<!ELEMENT Attribute (AttributeName, Excluded, ExcludedTypeName?, ExcludedLibraryName?)>
(Normative) Specifies the text for a custom attribute on a type or a member of a type. This includes the attribute name and whether or not the attribute type itself is contained in another library.
<!ELEMENT AttributeName (#PCDATA)>
(Normative) Specifies the name of the custom attribute associated with a type or member of a type. Also contains the data needed to instantiate the attribute.
<!ELEMENT Attributes (Attribute*)>
(Normative) Specifies the list of the attributes on a given type or member of a type.
<!ELEMENT Base (BaseTypeName?, ExcludedBaseTypeName?, ExcludedLibraryName?)>
(Normative) Specifies the information related to the base type of the current type. Although the ExcludedBaseTypeName and ExcludedLibraryName elements are rarely found within this element, they are required when a type inherits from a type not found in the current library.
<!ELEMENT BaseTypeName (#PCDATA)>
(Normative) Specifies the fully qualified name of the class from which a type inherits (i.e. the type’s base class).
<!ELEMENT Docs (summary?, altmember?, altcompliant?, param*, returns?, value?, exception*, threadsafe?, remarks?, example?, permission?, platnote*, example?)>
```
(Normative) Specifies the textual documentation of a given type or member of a type.

```xml
<!ELEMENT Excluded (#PCDATA)>
```

(Normative) Specifies, by a '0' or '1', whether a given member can be excluded from the current type in the absence of a given library. '0' specifies that it cannot be excluded.

```xml
<!ELEMENT ExcludedBaseTypeName (#PCDATA)>
```

(Normative) Specifies the fully qualified name of the type that the current type must inherit from if a given library were present in an implementation. The library name is specified in the ExcludedLibraryName element. An example is the System.Type class that inherits from System.Object, but if the Reflection library is present, it must inherit from System.Reflection.MemberInfo.

```xml
<!ELEMENT ExcludedLibrary (#PCDATA)>
```

(Normative) Specifies the library that must be present in order for a given member of a type to be required to be implemented. For example, System.Console.WriteLine(double) need only be implemented if the ExtendedNumerics library is available.

```xml
<!ELEMENT ExcludedLibraryName (#PCDATA)>
```

(Normative) This element appears only in the description of custom attributes. It specifies the name of the library that defines the described attribute. For example, the member that is invoked when no member name is specified for System.Text.StringBuilder (in C#, this is the indexer) is called "chars". The attribute needed for this is System.Reflection.DefaultMemberAttribute. This is found in the RuntimeInfrastructure library. This element is used with the ExcludedTypeName element.

```xml
<!ELEMENT ExcludedTypeName (#PCDATA)>
```

(Normative) Specifies the fully qualified name of the attribute that is needed for a member to successfully specify the given attribute. This element is related to the ExcludedLibraryName element and is used for attributes.

```xml
<!ELEMENT Interface (InterfaceName, Excluded)>
```

(Normative) Specifies information about an interface that a type implements. This element contains sub-elements specifying the interface name and whether another library is needed for the interface to be required in the current library.

```xml
<!ELEMENT InterfaceName (#PCDATA)>
```

(Normative) Represents the fully-qualified interface name that a type implements.

```xml
<!ELEMENT Interfaces (Interface*)>
```

(Normative) Specifies information on the interfaces, if any, a type implements. There is one Interface element for each interface implemented by the type.

```xml
<!ELEMENT Libraries (Types+)>
```

(Normative) This is the root element. Specifies all of the information necessary for all of the class libraries of the standard. This includes all of the types and all children elements underneath.

```xml
<!ELEMENT Member (MemberSignature+, MemberType, Attributes?, ReturnValue, Parameters, MemberValue?, Docs, Excluded, ExcludedLibrary*)>
```

(Normative) Specifies information about a member of a type. This information includes the signatures, type of the member, parameters, etc., all of which are elements in the XML specification.

```xml
<!ATTLIST Member
  MemberName NMTOKEN #REQUIRED
>
```

(Normative) MemberName specifies the name of the current member.

```xml
<!ELEMENT MemberOfLibrary (#PCDATA)>
```

(Normative) PCDATA is the name of the library containing the type.

```xml
<!ELEMENT MemberSignature EMPTY>
```

(Normative) Specifies the text (in source code format) for the signature of a given member of a type.

```xml
<!ATTLIST MemberSignature
  Language CDATA #REQUIRED
  Value CDATA #REQUIRED
>
```

(Normative) CDATA is the programming language the signature is written in. All members are described in both ILASM and C#.
<!ELEMENT MemberType (#PCDATA)>
   (Normative) Specifies the kind of the current member. The member kinds are: method, property, constructor, field, and event.

<!ELEMENT MemberValue (#PCDATA)>
   (Normative) Specifies the value of a static literal field.

<!ELEMENT Members (Member*)>
   (Normative) Specifies information about all of the members of a given type.

<!ELEMENT PRE EMPTY>
   (Rendering/Formatting) This element exists for rendering purposes only to specify, for example, that future text should be separated from the previous text

<!ELEMENT Parameter (Attributes?)>
   (Normative) Specifies the information about a specific parameter of a method or property.

<!ATTLIST Parameter
   Name NMTOKEN #REQUIRED
   (Normative) Specifies the name of the parameter.

   Type CDATA #REQUIRED
   (Normative) Specifies the fully-qualified name of the type of the parameter.

<!ELEMENT Parameters (Parameter*)>
   (Normative) Specifies information for the parameters of a given method or property. The information specified is included in each Parameter element of this element. This element will contain one Parameter for each parameter of the method or property.

<!ELEMENT ReturnType (#PCDATA)>
   (Normative) Specifies the fully-qualified name of the type that the current member returns.

<!ELEMENT ReturnValue (ReturnType?)>
   (Normative) Specifies the return type of a member. ReturnType shall be present for all kinds of members except constructors.

<!ELEMENT SPAN (#PCDATA | paramref | SPAN | see | block)>
   (Rendering/Formatting) This element specifies that the text should be segmented from other text (e.g. with a carriage return). References to parameters, other types, and even blocks of text can be included within a SPAN element.

<!ELEMENT ThreadingSafetyStatement (#PCDATA)>
   (Normative) Specifies a thread safety statement for a given type.

<!ELEMENT Type (TypeSignature+, MemberOfLibrary, AssemblyInfo, ThreadingSafetyStatement?, TypeKind, Docs, Base, Interfaces, Attributes?, Members, TypeExcluded)>
   (Normative) Specifies all of the information for a given type.

<!ATTLIST Type
   Name NMTOKEN #REQUIRED
   (Informative) Specifies the simple name (e.g. “String” rather than “System.String”) of a given type.

   FullName NMTOKEN #REQUIRED
   (Normative) Specifies the fully-qualified name of a given type.

   FullNameSP NMTOKEN #REQUIRED
   (Informative) Specifies the fully-qualified name with each ‘.’ of the fully qualified name replaced by an ‘_’.

<!ELEMENT TypeExcluded (#PCDATA)>
   (Normative) PCDATA shall be ‘0’.

<!ELEMENT TypeSignature EMPTY>
(Normative) Specifies the text for the signature (in code representation) of a given type.

```xml
<!ATTLIST TypeSignature
  Language CDATA #REQUIRED
  (Normative) Specifies the language the specified type signature is written in. All type signatures are specified in both ILASM and C#.
  Value CDATA #REQUIRED
  (Normative) CDATA is the type signature in the specified language.
>
<!ELEMENT Types (Type*)>
(Informative) Specifies information about all of the types of a library.

<!ATTLIST Types
  Library NMTOKEN #REQUIRED
  (Normative) Specifies the library in which all of the types are defined. An example of such a library is “BCL”.
>
<!ELEMENT altcompliant EMPTY>
(Informative) Specifies that an alternative, CLS compliant method call exists for the current non-CLS compliant method. For example, this element exists in the System.IO.TextWriter.WriteLine(ulong) method to show that System.IO.TextWriter.WriteLine(long) is an alternative, CLS compliant method.

<!ATTLIST altcompliant
  cref CDATA #REQUIRED
  (Informative) Specifies the link to the actual documentation for the alternative CLS compliant method. [Note: In this specification, CDATA matches the documentation comment format specified in Appendix E of the C# Language specification.]
>
<!ELEMENT altmember EMPTY>
(Informative) Specifies that an alternative, equivalent member call exists for the current method. This element is used for operator overloads.

<!ATTLIST altmember
  cref CDATA #REQUIRED
  (Informative) Specifies the link to the actual documentation for the alternative member call. [Note: In this specification, CDATA matches the documentation comment format specified in Appendix E of the C# Language specification.]
>
<!ELEMENT block (#PCDATA | see | para | paramref | list | block | c | subscript | code | sup | pi)*>
(Rendering/Formatting) Specifies that the children should be formatted according to the type specified as an attribute.

<!ATTLIST block
  subset CDATA #REQUIRED
  (Rendering/Formatting) This attribute is reserved for future use and currently only has the value of ‘none’.
  type NMTOKEN #REQUIRED
  (Rendering/Formatting) Specifies the type of block that follows, one of: usage, overrides, note, example, default, behaviors.
>
<!ELEMENT c (#PCDATA | para | paramref | code | see)*>
(Rendering/Formatting) Specifies that the text is the output of a code sample.

<!ELEMENT code (#PCDATA)>
(Informative) Specifies the text is a code sample.

<!ATTLIST code
  lang CDATA #IMPLIED
<ELEMENT codelink EMPTY>
  (Informative) Specifies a piece of code to which a link may be made from another sample. [Note: the XML format specified here does not provide a means of creating such a link.]
<!ATTLIST codelink
  SampleID CDATA #REQUIRED
  (Informative) SampleID is the unique id assigned to this code sample.
  SnippetID CDATA #REQUIRED
  (Informative) SnippetID is the unique id assigned to a section of text within the sample code.
>
</ELEMENT description (#PCDATA | paramref | para | see | c | permille | block | sub)*>
  (Normative) Specifies the text for a description for a given term element in a list or table. This element also specifies the text for a column header in a table.
</ELEMENT example (#PCDATA | para | code | c | codelink | see)*>
  (Informative) Specifies that the text will be an example on the usage of a type or a member of a given type.
</ELEMENT exception (#PCDATA | paramref | see | para | SPAN | block)>
  (Normative) Specifies text that provides the information for an exception that can be thrown by a member of a type. This element can contain just text or other rendering options such as blocks, etc.
<!ATTLIST exception
  cref CDATA #REQUIRED
  (Rendering/Formatting) Specifies a link to the documentation of the exception. [Note: In this specification, CDATA matches the documentation comment format specified in Appendix E of the C# Language specification.]
>
</ELEMENT i (#PCDATA)>
  (Rendering/Formatting) Specifies that the text should be italicized.
</ELEMENT item (term, description*)>
  (Rendering/Formatting) Specifies a specific item of a list or a table.
</ELEMENT list (listheader?, item*)>
  (Rendering/Formatting) Specifies that the text should be displayed in a list format.
<!ATTLIST list
  type NMTOKEN #REQUIRED
  (Rendering/Formatting) Specifies the type of list in which the following text will be represented. Values in the specification are: bullet, number and table.
>
</ELEMENT listheader (term, description*)>
  (Rendering/Formatting) Specifies the header of all columns in a given list or table.
</ELEMENT onequarter EMPTY>
  (Rendering/Formatting) Specifies that text, in the form of ß, is to be displayed.
</ELEMENT para (#PCDATA | see | block | paramref | c | onequarter | superscript | sup | permille | SPAN | list | pi | theta | sub)*)>
  (Rendering/Formatting) Specifies that the text is part of what can be considered a paragraph of its own.
</ELEMENT param (#PCDATA | paramref | see | block | para | SPAN)*>
  (Normative) Specifies the information on the meaning or purpose of a parameter. The name of the parameter and a textual description will be associated with this element.
(Nomrative) Specifies the name of the parameter being described.

<!ELEMENT paramref EMPTY>
(Normative) Specifies a reference to a parameter of a member of a type.

<!ATTLIST paramref
    name CDATA #REQUIRED

(Informative) Specifies the name of the parameter to which the \paramref element is referring.

<!ELEMENT permille EMPTY>
(Normative) Represents the current text is to be displayed as the ‘‰’ symbol.

<!ELEMENT permission (#PCDATA | see | paramref | para | block)*>
(Normative) Specifies the permission, given as a fully-qualified type name and supportive text, needed to call a member of a type.

<!ATTLIST permission
    cref CDATA #REQUIRED

(Informative) Specifies a link to the documentation of the permission. [Note: In this specification, CDATA matches the documentation comment format specified in Appendix E of the C# Language specification.]

<!ELEMENT pi EMPTY>
(Normative) Represents the current text is to be displayed as the ‘π’ symbol.

<!ELEMENT pre EMPTY>
(Normative) Specifies a break between the preceding and following text.

<!ELEMENT remarks (#PCDATA | para | block | list | c | paramref | see | note | pre | SPAN | code | PRE)*>
(Normative) Specifies additional information, beyond that supplied by the summary, on a type or member of a type.

<!ELEMENT returns (#PCDATA | para | list | paramref | see)*>
(Normative) Specifies text that describes the return value of a given type member.

<!ELEMENT see EMPTY>
(Informative) Specifies a link to another type or member.

<!ATTLIST see
    cref CDATA #IMPLIED

(Informative) cref specifies the fully-qualified name of the type or member to link to. [Note: In this specification, CDATA matches the documentation comment format specified in Appendix E of the C# Language specification.]

langword CDATA #IMPLIED
(Informative) langword specifies that the link is to a language agnostic keyword such as “null”.

qualify CDATA #IMPLIED
(Informative) Qualify indicates that the type or member specified in the link must be displayed as fully-qualified. Value of this attribute is ‘true’ or ‘false’, with a default value of ‘false’

<!ELEMENT sub (#PCDATA | paramref)*>
(Normative) Specifies that current piece of text is to be displayed in subscript notation.

<!ELEMENT subscript EMPTY>
(Normative) Specifies that current piece of text is to be displayed in subscript notation.

<!ATTLIST subscript
    term CDATA #REQUIRED
7.1 Value Types as Objects

Throughout the textual descriptions of methods in the XML there are places where a parameter of type object or an interface type is expected, but the description refers to passing a value type for that parameter. In these cases, the caller shall box the value type before making the call.
Files of this Standard can be freely downloaded from the ECMA web site (www.ecma.ch). This site gives full information on ECMA, ECMA activities, ECMA Standards and Technical Reports.