Ecma/TC39/2014/033

Bringing SIMD-128 to JavaScript

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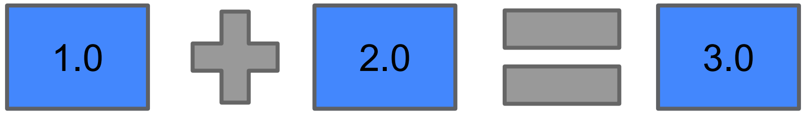
What is SIMD?

… and why does it matter?

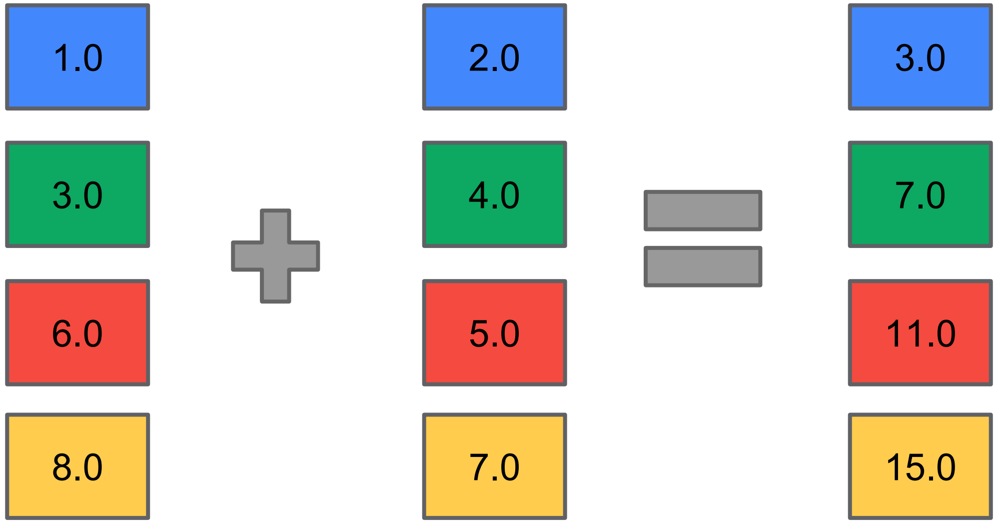
What is SIMD?

Single Instruction Single Data (SISD)



What is SIMD?

Single Instruction Multiple Data (SIMD)



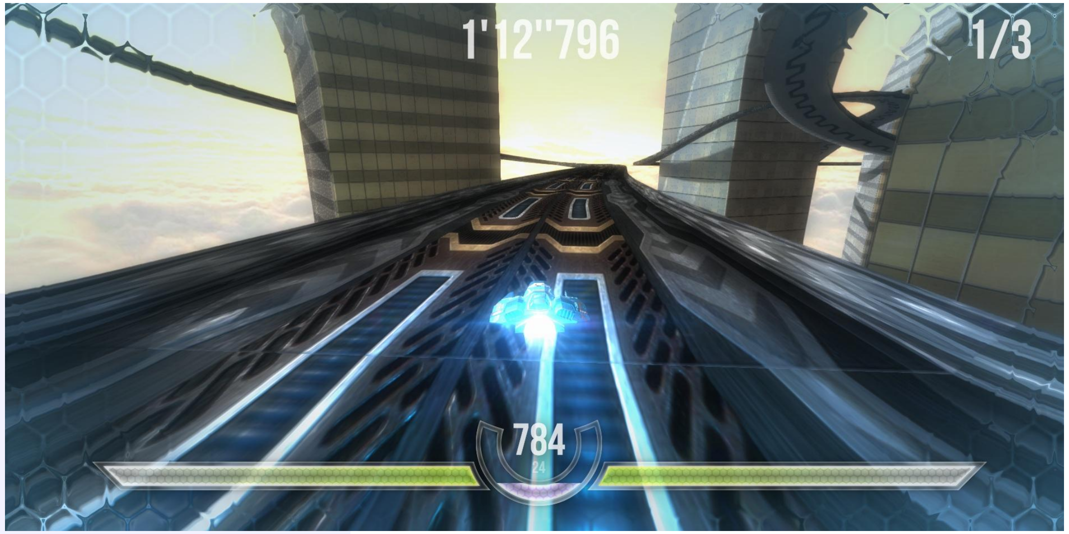
Vector Processor

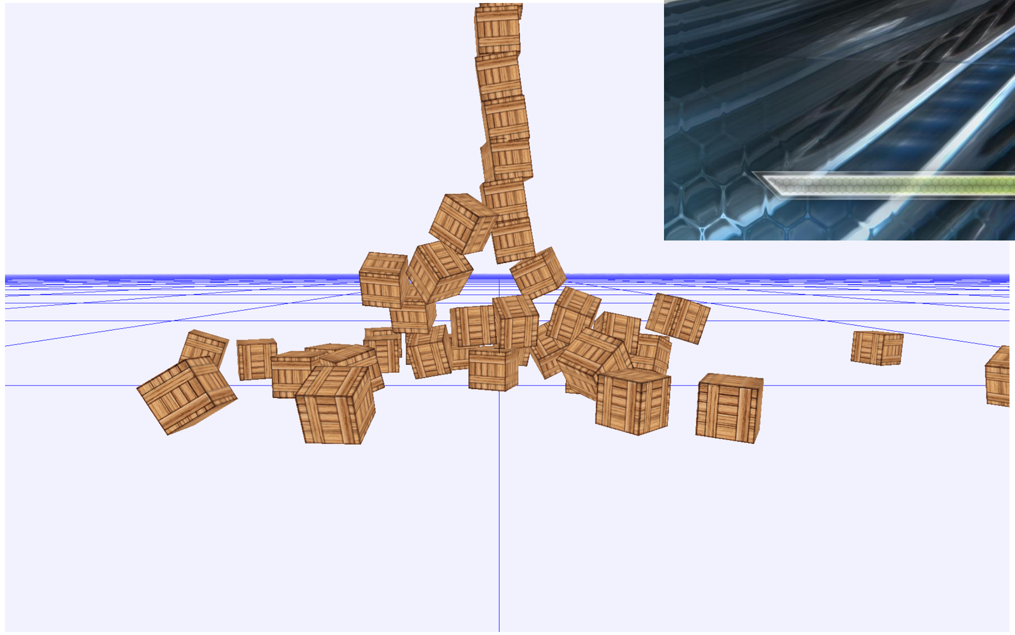
Why does SIMD matter?

- SIMD can provide substantial speedup to:
  - 3D Graphics
  - 3D Physics
  - Image Processing
  - Signal Processing
  - Numerical Processing
  - Crypto
  - Computer Vision
  - ...

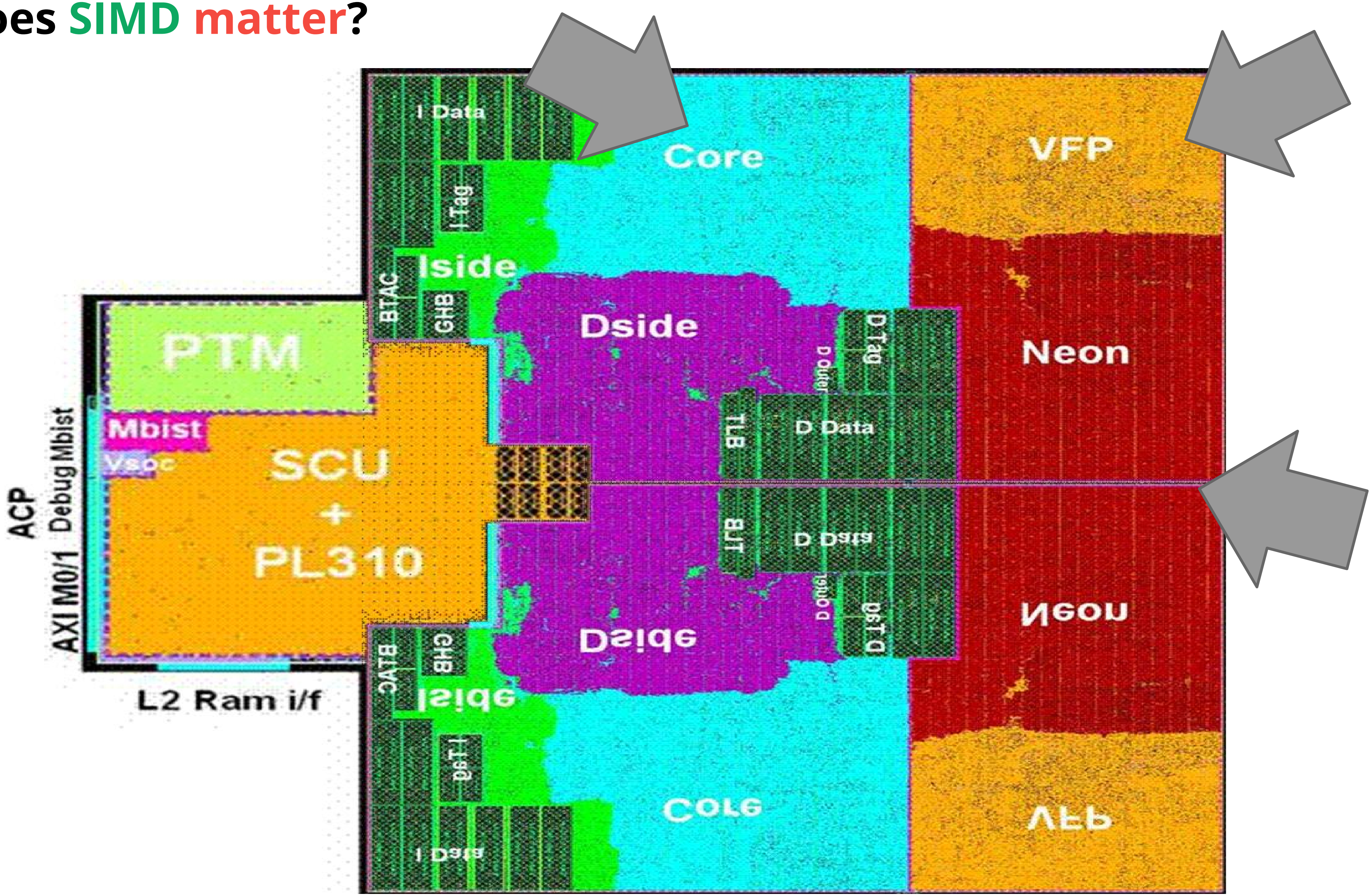
Why does SIMD matter to the web?

- SIMD can provide substantial speedup to:
  - WebGL
  - Canvas
  - Animation
  - Games
  - Physics
  - ASM.js
  - Crypto





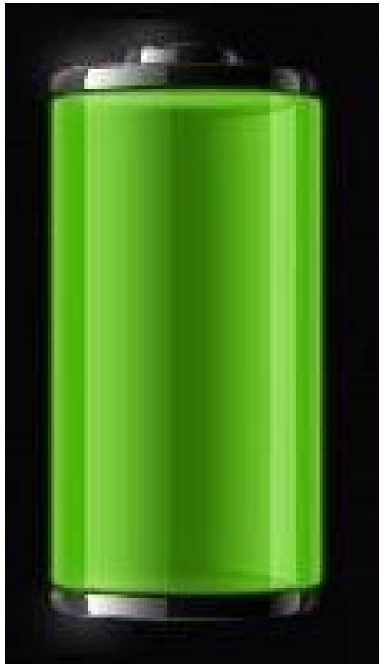
Why does SIMD matter?



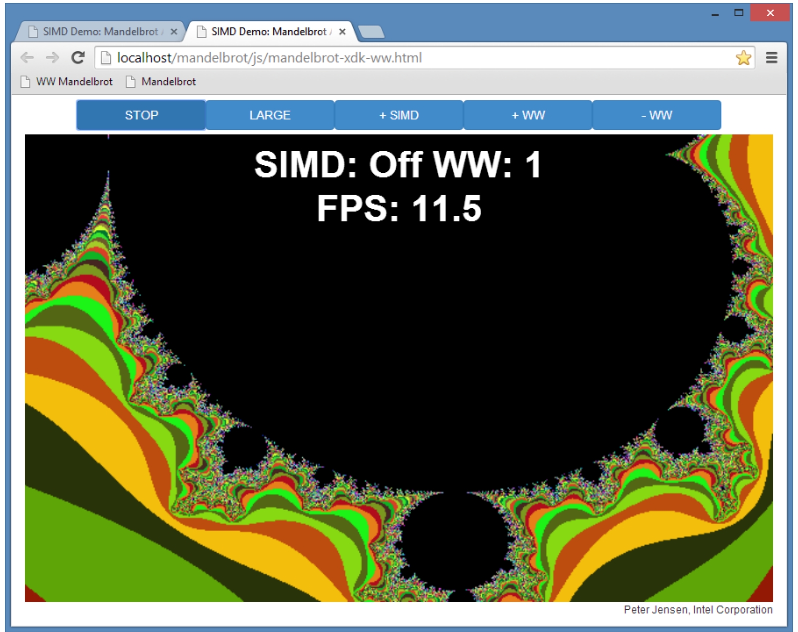
Why does SIMD matter?

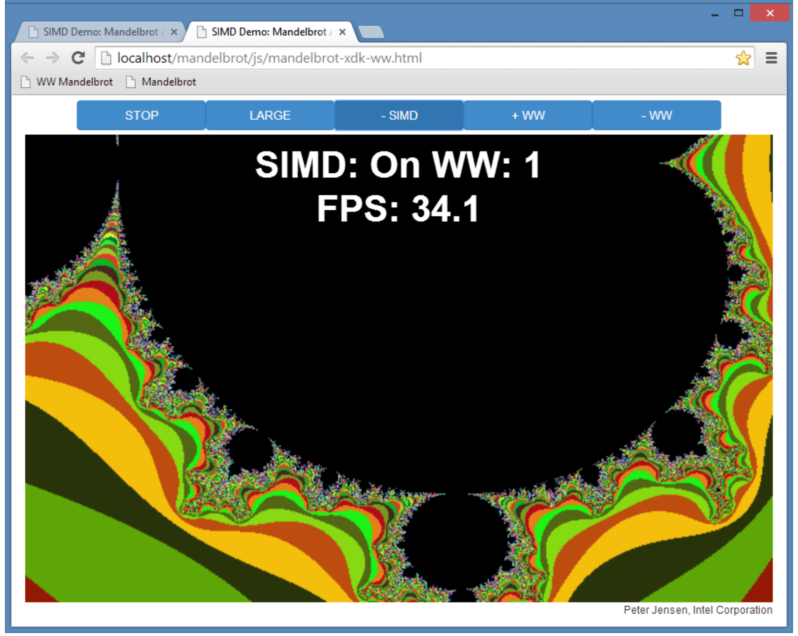
- SIMD requires fewer instructions to be executed
  - Fewer instructions means longer battery life

VS



DEMO: Mandelbrot






```
// z(i+1) = z(i)^2 + c
// terminate when |z| > 2.0
// returns 4 iteration counts

function mandelx4(c_re4, c_im4) {
  var z_re4  = c_re4;
  var z_im4  = c_im4;
  var four4  = SIMD.float32x4.splat(4.0);
  var two4   = SIMD.float32x4.splat(2.0);
  var count4 = SIMD.int32x4.splat(0);
  var one4   = SIMD.int32x4.splat(1);

  for (var i = 0; i < max_iterations; ++i) {
    var z_re24 = SIMD.float32x4.mul(z_re4, z_re4);
    var z_im24 = SIMD.float32x4.mul(z_im4, z_im4);
    var mi4 = SIMD.float32x4.lessThanOrEqual
                (SIMD.float32x4.add(z_re24, z_im24), four4);
    // if all 4 values are greater than 4.0
    // there's no reason to continue
    if (mi4.signMask === 0x00) {
      break;
    }
    var new_re4 = SIMD.float32x4.sub(z_re24, z_im24);
    var new_im4 = SIMD.float32x4.mul
                    (SIMD.float32x4.mul(two4, z_re4), z_im4);
    z_re4  = SIMD.float32x4.add(c_re4, new_re4);
    z_im4  = SIMD.float32x4.add(c_im4, new_im4);
    count4 = SIMD.int32x4.add(count4, SIMD.int32x4.and (mi4,
one4));
  }
  return count4;
}
```

SIMD-128 for EcmaScript

SIMD in JavaScript

- Based on work for Dart Language
  - Landed in Dart VM in Spring of 2013
- Fixed 128-bit vector types as close to the metal while remaining portable
  - SSE
  - NEON
  - Efficient scalar fallback could be implemented
- Scales with other forms of parallelism (e.g. Web Workers)
- Polyfill + benchmarks
  - https://github.com/johnmccutchan/ecmascript_simd

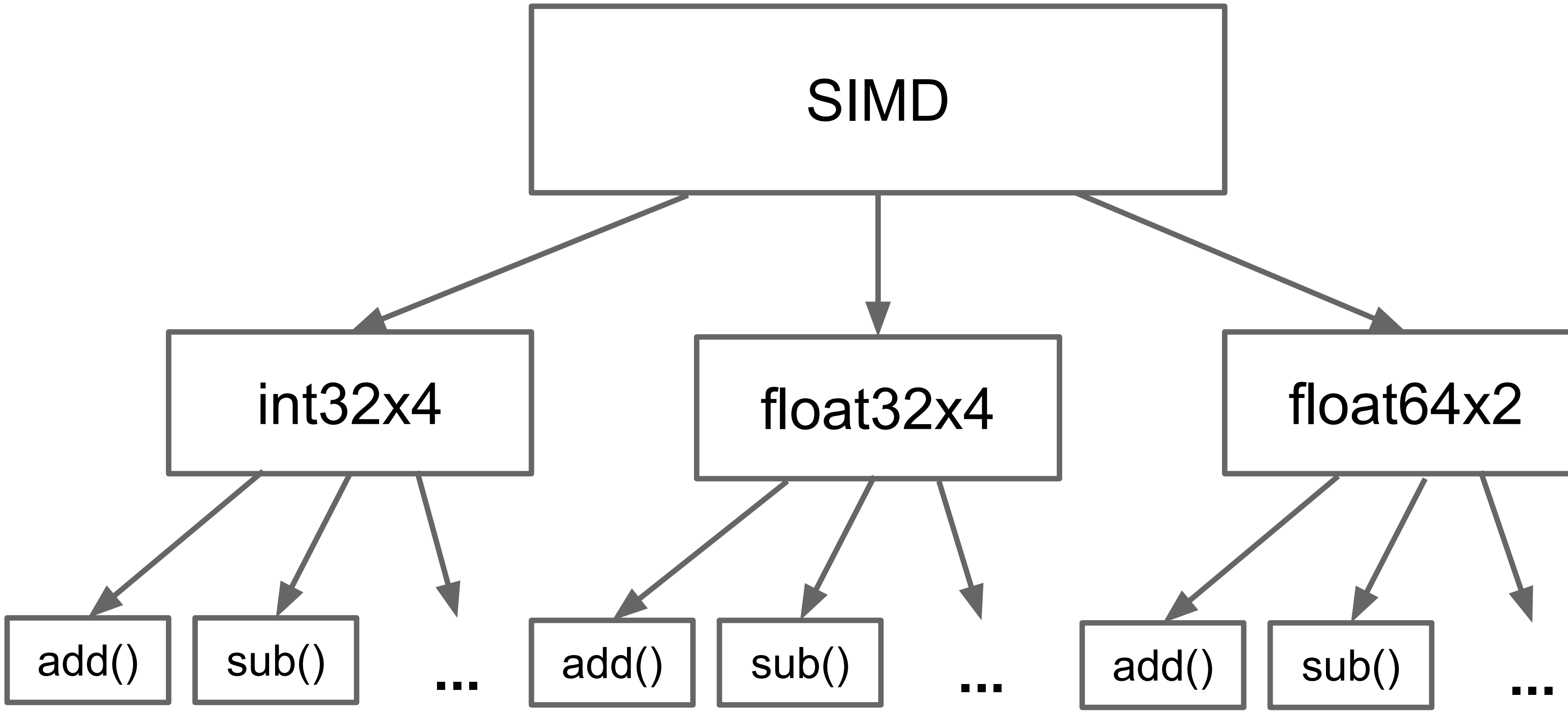
SIMD in JavaScript

1. SIMD module
    a. New “value” types
    b. Composable operations
        i. Arithmetic
        ii. Logical
        iii. Comparisons
        iv. Reordering (shuffling)
        v. Conversions
2. Extension to Typed Data
    a. A new array type for each

float32x4	4 IEEE-754 32-bit Floating Point Numbers
int32x4	4 32-bit Signed Integers
float64x2	2 IEEE-754 64-bit Floating Point Numbers

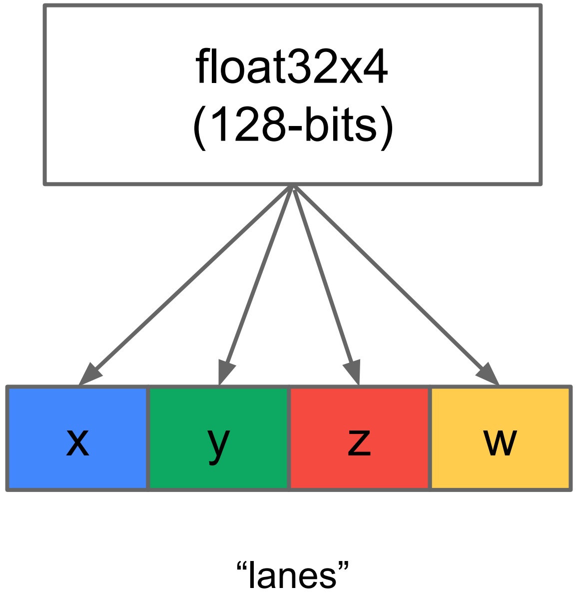
Float32x4Array	Typed Array of float32x4
Int32x4Array	Typed Array of int32x4
Float64x2Array	Typed Array of float64x2

Object Hierarchy



SIMD-128 for EcmaScript Code Snippets

SIMD in JavaScript



Constructing

```
var a = SIMD.float32x4(1.0, 2.0, 3.0, 4.0);
```

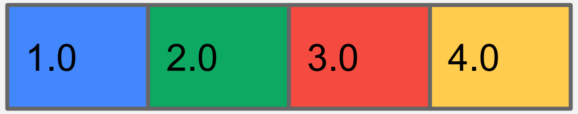
1.0	2.0	3.0	4.0

```
var b = SIMD.float32x4.zero();
```

0.0	0.0	0.0	0.0

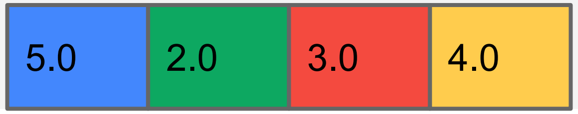
Accessing and Modifying Individual Elements

```
var a = SIMD.float32x4(1.0, 2.0, 3.0, 4.0);
```




```
var b = a.x; // 1.0

var c = a.withX(5.0);
```

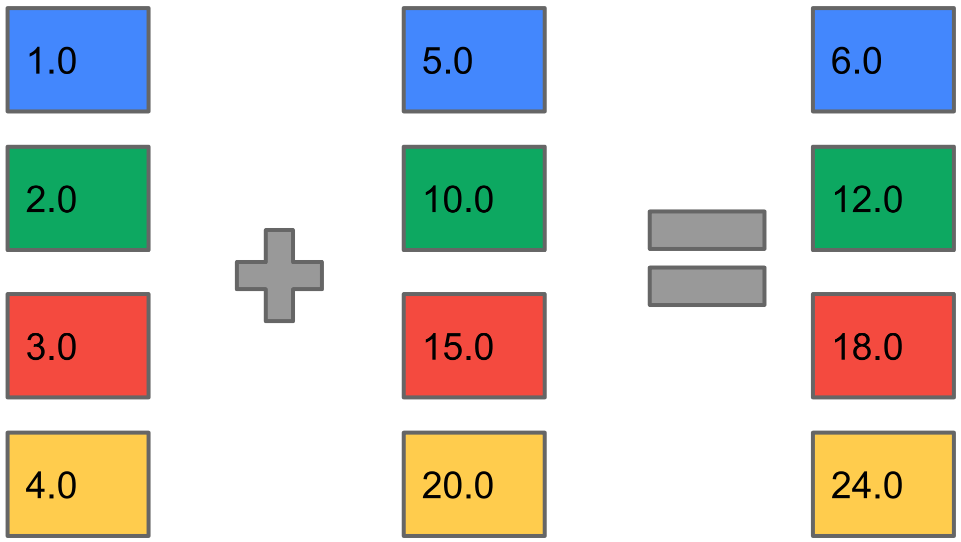


Arithmetic

```
var a = SIMD.float32x4(1.0, 2.0, 3.0, 4.0);

var b = SIMD.float32x4(5.0, 10.0, 15.0, 20.0);

var c = SIMD.float32x4.add(a,b);
```

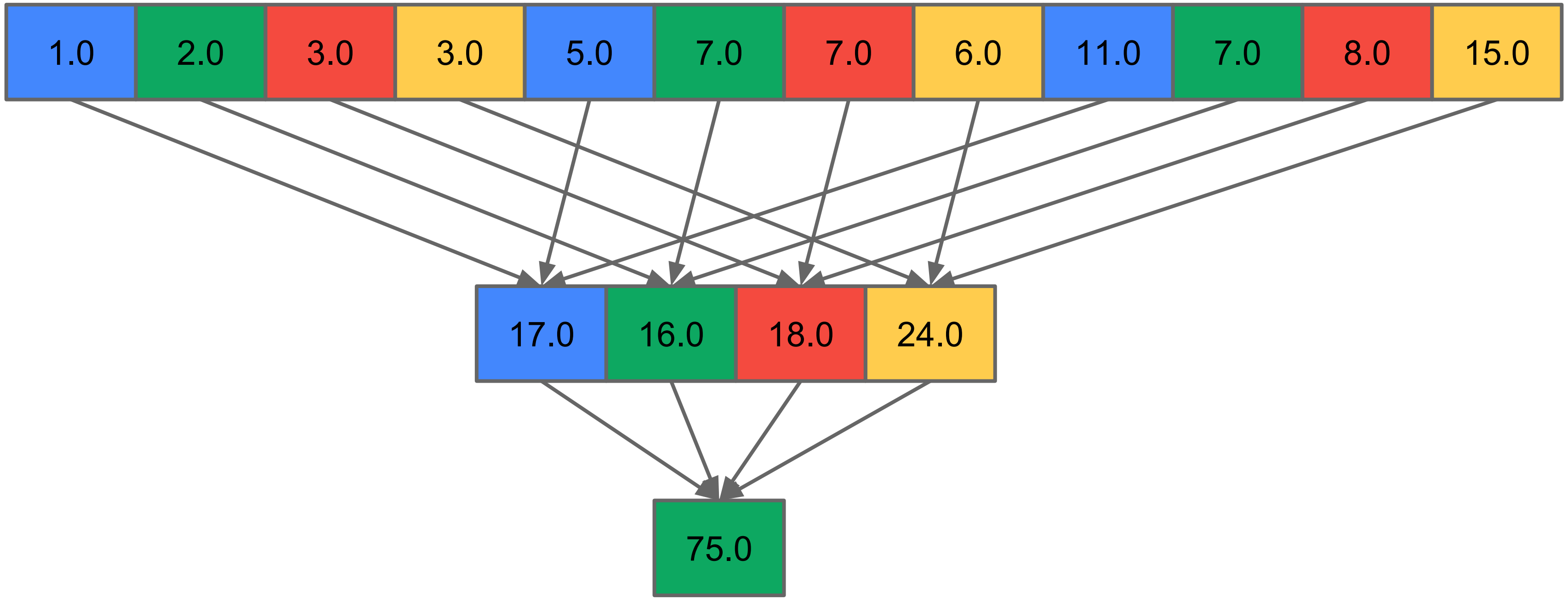


Example

```
function average(list) {
  var n = list.length;
  var sum = 0.0;
  for (int i = 0; i < n; i++) {
    sum += list[i];
  }
  return sum / n;
}
```

```
function average(f32x4list) {
  var n = f32x4list.length;
  var sum = SIMD.float32x4.zero();
  for (int i = 0; i < n; i++) {
    sum = SIMD.float32x4.add(sum, f32x4list.getAt(i));
  }
  var total = sum.x + sum.y + sum.z + sum.w;
  return total / (n * 4);
}
```

Example



SIMD in JavaScript

75% fewer loads
75% fewer adds
(+ single precision)

5 times faster!

The inner loop

```
sum = SIMD.float32x4.add(sum, float32x4list.getAt(i));
```

```
  ;; Load list[i]
0x4ccddce 0f104c3807 movups xmm1,[eax+edi*0x1+0x7]
  ;; sum +=
0x4ccddde 0f59ca     addps xmm2,xmm1
```

Load 4 floats

Add 4 floats

Shuffling

```
var a = SIMD.float32x4(1.0, 2.0, 3.0, 4.0);
```

1.0	2.0	3.0	4.0

```
var b = SIMD.float32x4.shuffle(a, SIMD.float32x4.XXYY);
```

1.0	1.0	2.0	2.0

```
var c = SIMD.float32x4.shuffle(a, SIMD.float32x4.WWWW);
```

4.0	4.0	4.0	4.0

```
var d = SIMD.float32x4.shuffle(a, SIMD.float32x4.WZYX);
```

4.0	3.0	2.0	1.0

Branching

```
max = function(a, b) {
  if (a > b) {
    return a;
  } else {
    return b;
  }
}

max(4.0, 5.0) -> 5.0
```

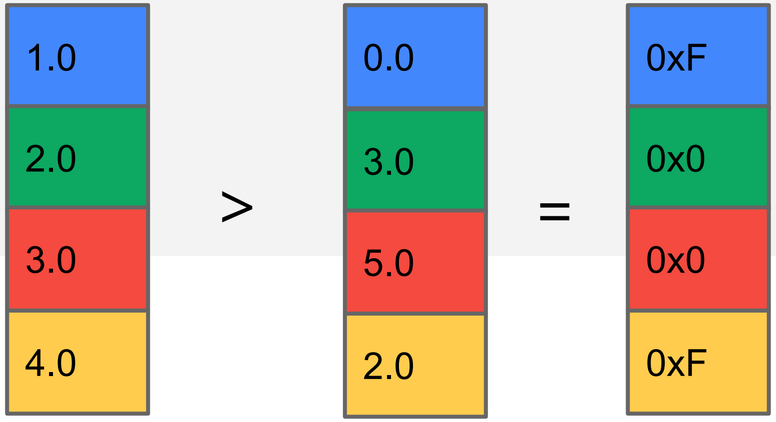
Branching

```
max = function(a, b) {
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

1.0	2.0	3.0	4.0
0.0	3.0	5.0	2.0

Branching

```
max = function(a, b) {
  var greaterThan = SIMD.float32x4.greaterThan(a, b);
  return SIMD.float32x4.select(a, b, greaterThan);
}
```



Branching

```
max = function(a, b) {
  var greaterThan = SIMD.float32x4.greaterThan(a, b);
  return SIMD.float32x4.select(a, b, greaterThan);
}
```

Implementations

How does the VM optimize for SIMD?

1. Unboxing
    a. Boxed -> allocated in memory
    b. Unboxed -> in CPU memory (in registers)

2. Replacing method calls with inlined machine instructions
    a. Allows values to remain unboxed (in registers)
    b. Avoids method call overhead

Firefox implementation status

- Interpreter support:
  - In Nightly since early 2014. No flags needed
- IonMonkey:
  - Support has been prototyped for x86
  - Missing ARM port of register allocator
  - Ongoing refactoring of a generic register allocator before landing the JIT compiler support
  - Reuse work done for OdinMonkey
- OdinMonkey (for asm.js):
  - Current focus
  - Full x86 support planned for end of August in Nightly

Chrome/V8 implementation status

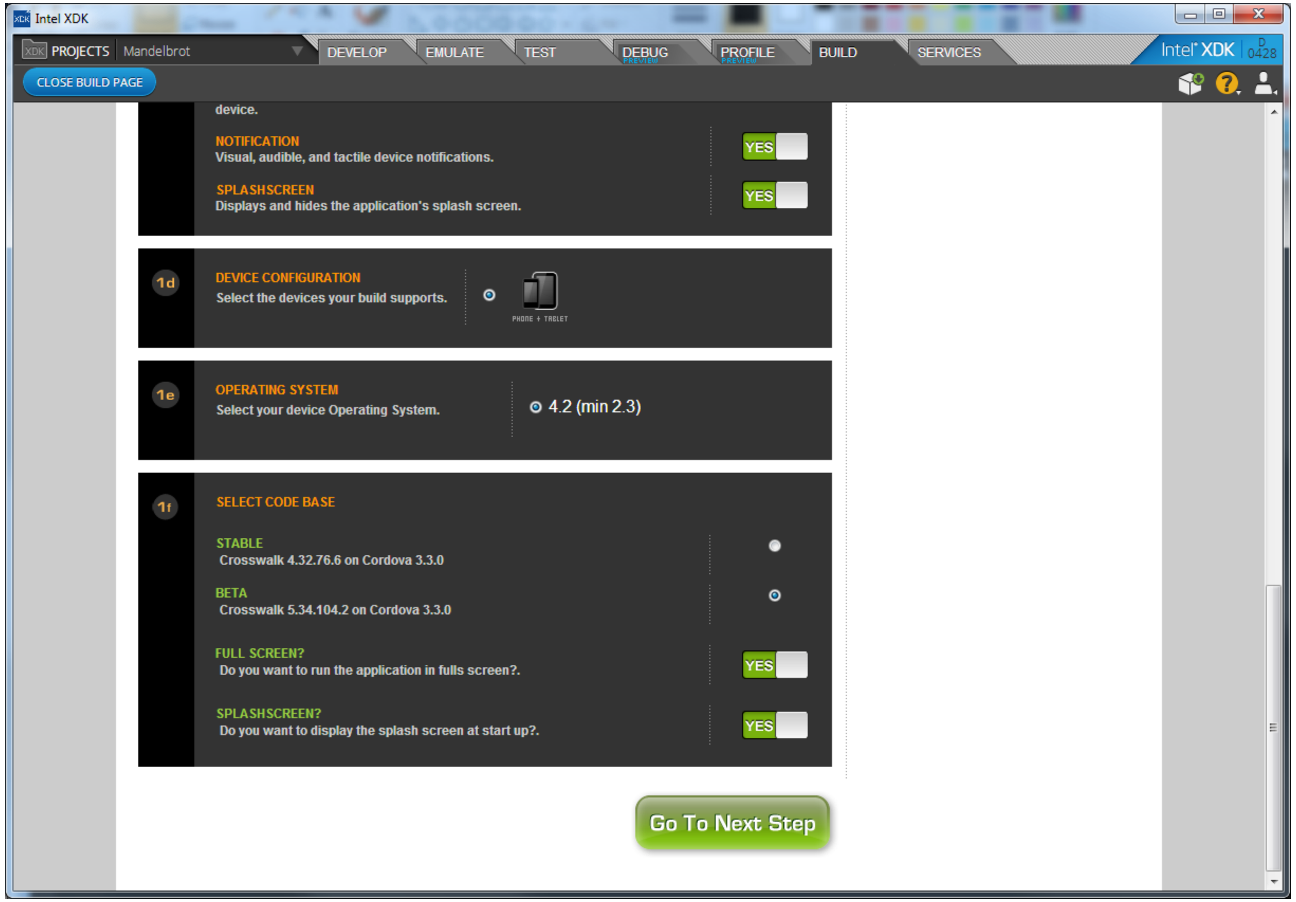
- Code is also hosted in Crosswalk Runtime fork:
    - https://github.com/crosswalk-project/v8-crosswalk
- Full implementation for polyfill spec:
    - Optimized implementation for ia32 and x64 (full-codegen and crankshaft)
    - Runtime support for ARM/NEON (full-codegen)
- Patches available for:
    - Chrome 34, 35, 36
    - Rebasing for Chrome 37 in progress

Emscripten implementation status

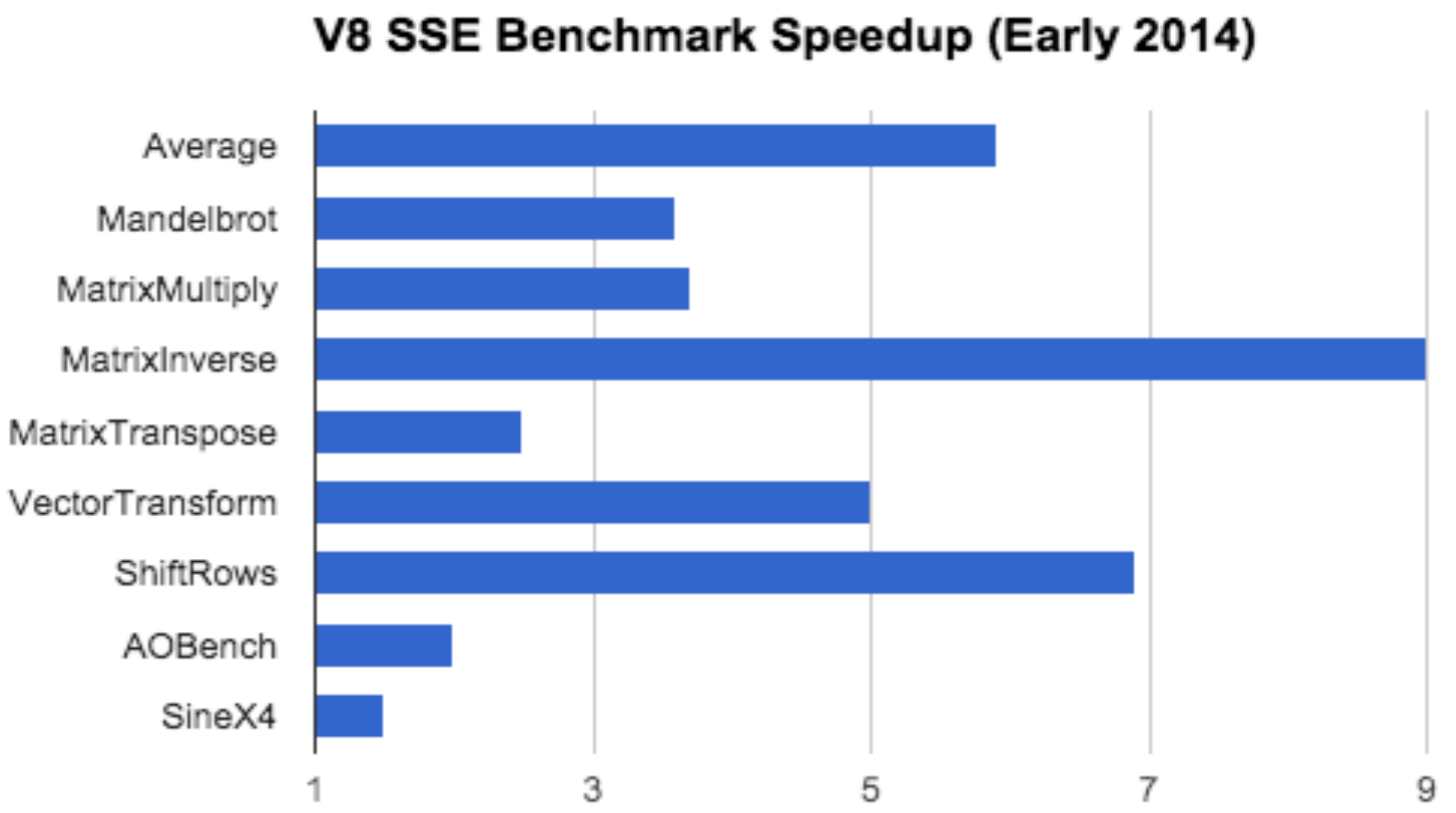
- Supports both the JS and fastcomp ‘backends’
- Supports SIMD.float32x4 and SIMD.int32x4 operations for LLVM vector types:
  - <4 x i32> and <4 x float> LLVM vector types supported
  - Code generated by Loop Vectorizer and SLP Vectorizer
  - Code generated from use of ext_vector_type and vector_size attributes
- Supports a few C++ intrinsics:
  - Most of _mm_<op>_ps (_mm_add_ps, _mm_sub_ps, ...)
  - Most of _mm_<op>_epi32 (_mm_add_epi32, _mm_sub_epi32, ...)
- No support for x4 arrays, yet

Intel Crosswalk implementation status

- Crosswalk 5,6,7: Full support for polyfill spec
- Crosswalk 8: In progress
- Available via Intel’s XDK build feature
- Optimized for ia32 and x64
- Functional for ARM/NEON



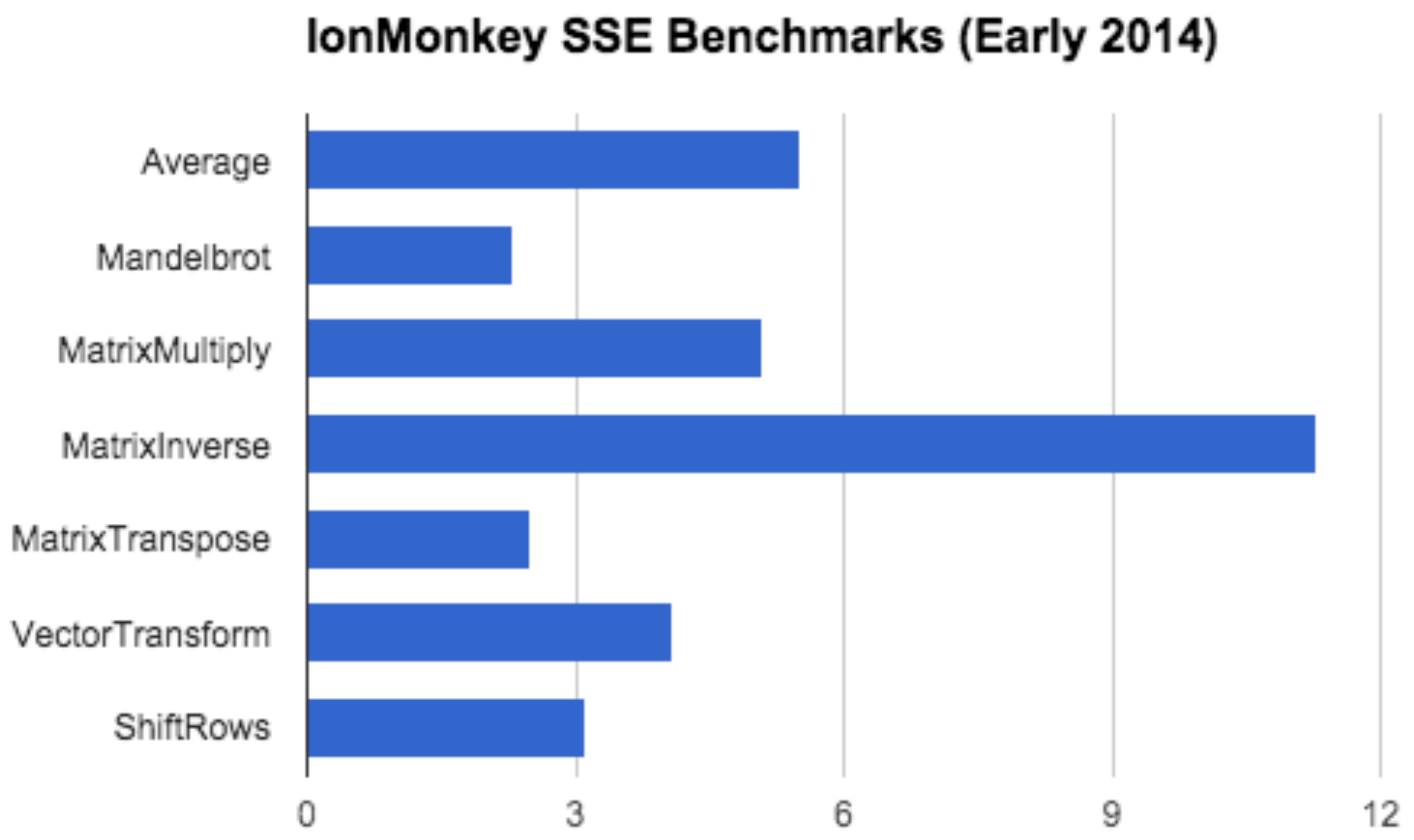
V8 SSE Benchmarks (Early 2014)



V8 SSE Benchmarks (Early 2014)

Benchmark	Scalar Time (us)	SIMD Time (us)	Speedup
Average	208	35	5.9
Mandelbrot	393167	109158	3.6
MatrixMultiply	74	20	3.7
MatrixInverse	189	21	9.0
MatrixTranspose	1037	408	2.5
VectorTransform	30	6	5
ShiftRows	6067	880	6.9
AOBench	1488	736	2.0
SineX4	9538	6568	1.5

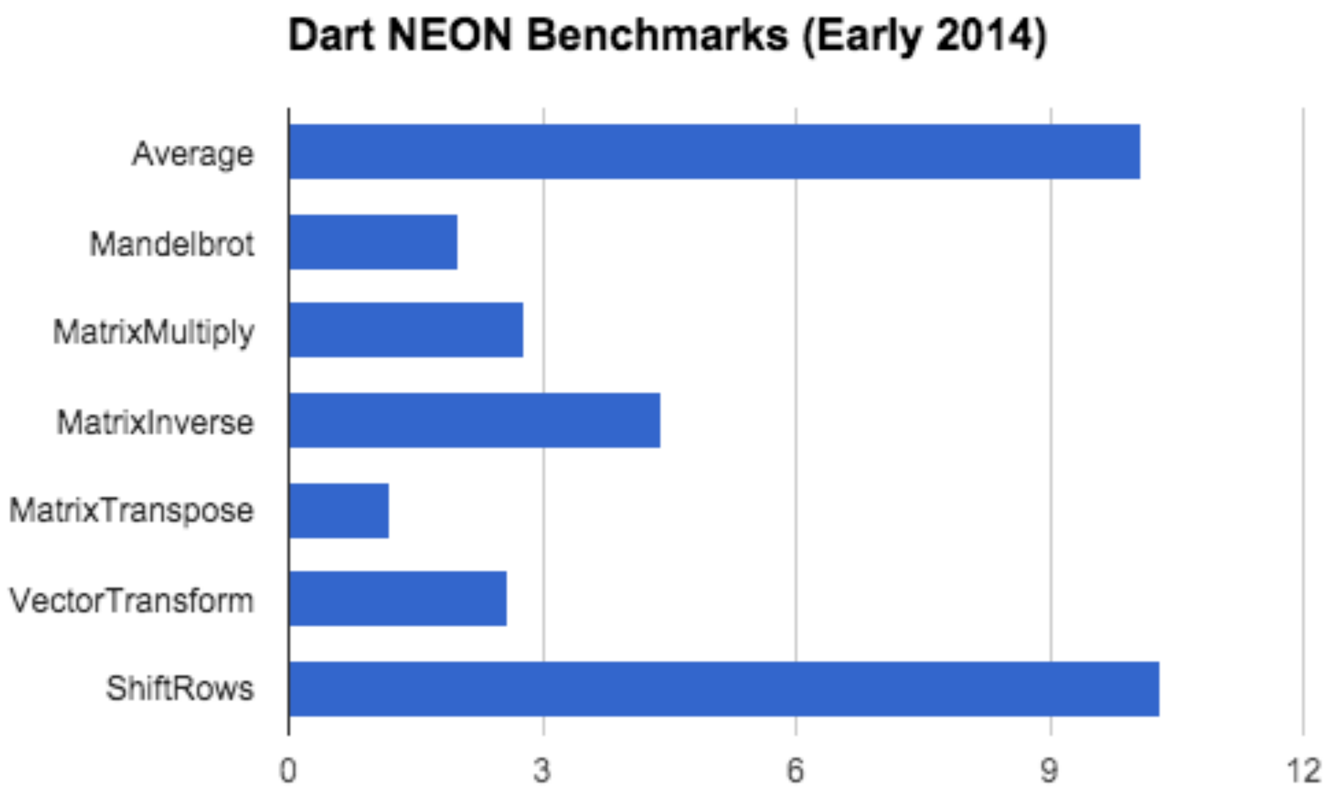
SpiderMonkey SSE Benchmarks (Early 2014)



SpiderMonkey SSE Benchmarks (Early 2014)

Benchmark	Scalar Time (us)	SIMD Time (us)	Speedup
Average	116	21	5.5
Mandelbrot	346333	152357	2.3
MatrixMultiply	97	19	5.1
MatrixInverse	294	26	11.3
MatrixTranspose	1237	488	2.5
VectorTransform	33	8	4.1
ShiftRows	6067	1956	3.1

Dart VM* NEON Benchmarks (Early 2014)



Dart VM* NEON Benchmarks (Early 2014)

Benchmark	Scalar Time (us)	SIMD Time (us)	Speedup
Average	1832	180	10.1
Mandelbrot	1806	892333	2.0
MatrixMultiply	630	224	2.8
MatrixInverse	1506	345	4.4
MatrixTranspose	6335	5488	1.2
VectorTransform	175	67	2.6
ShiftRows	33148	3219	10.3

Why fixed width and not variable width vectors?

- Practicality
    - Stream processing and auto vectorization have limited use cases
    - Variable width vectors cannot efficiently implement
        - Matrix multiplication
        - Matrix inversion
        - Vector transform
        - ....
- Portable performance
    - 128-bit is the only vector width supported by all architectures

Why fixed width and not variable width vectors (continued)?

- C/C++ code is usually written using intel _mm_ intrinsics.
  - JavaScript as a C/C++ compilation target needs fixed width vectors
- Abstraction
  - Stream processors can be built in software on top of SIMD-128
- Observable state will be different for different architectures, e.g., if SIMD.float32xN was introduced, this code:

```
for (var i = 0; i < M; i += SIMD.float32xN.size) {
  sum = SIMD.float32xN.add(sum, input[i]);
}
```

would cause bits in memory to be different for different architectures.

SIMD in JavaScript Miscellaneous

- Result of ‘typeof’:
  - “float32x4”, “float64x2”, “int32x4”
- Result of SIMD.float32x4(1,2,3,4).toString():
  - “float32x4(1,2,3,4)"
- Implicit type conversions kept to a minimum:
  - 1 + <float32x4>:
    - Apply .toString() to <float32x4> and concatenate
  - SIMD.float32x4.add(1,<float32x4>)
    - TypeError

SIMD in JavaScript Planned Features

- SIMD and value objects/types:
  - float32x4 and friends will be value objects
  - Overloaded operators (+,-,...) will be mapped to SIMD.<type>.<op> equivalents (.add(), .sub(), ...)

- Additional data types (int8x16 and int16x8)
  - Looking at VP9 encode/decode for justification

SIMD in JavaScript Planned Features

- Feature detection:
  - Fine grained feature detection
    - Something like: SIMD.optimized.<feature>
  - There are arch differences that will need exposure!
    - Two vector shuffle (Useful for 4x4 matrix transpose)
    - .signmask for NEON
    - Algorithm specific instructions where no overlap/equivalent exists
  - Inlined scalar fallbacks can help minimize performance hit across ISAs

Stage 1 Ready?

- ✓ Identified “champion” who will advance the addition
- ✓ Prose outlining the problem or need and the general shape of a solution
- ✓ Illustrative examples of usage
- ✓ High-level API
- ✓ Discussion of key algorithms, abstractions and semantics
- ✓ Identification of potential “cross-cutting” concerns and implementation challenges/complexity

Wrap up

Wrap Up

Concrete implementation, accelerating real world algorithms.

- SSE*
  - V8
  - SpiderMonkey
  - Intel’s Crosswalk HTML5 runtime
- NEON
  - SpiderMonkey (In progress)
  - Dart VM*

Future Work

- SIMD-256 and SIMD-512 extensions
  - No NEON support
    - ARM64 did not extend vector width
    - Can lower SIMD-256 and SIMD-512 operations on to SIMD-128
  - Relevant for server side
  - Lower priority

Questions!

References

Polyfill repository
https://github.com/johnmccutchan/ecmascript_simd

Published Paper on Dart + JS prototype implementations
John McCutchan, Haitao Feng, Nicholas Matsakis, Zachary Anderson, Peter Jensen (2014) A SIMD Programming Model for Dart, JavaScript, and Other Dynamically Typed Scripting Languages, Proceedings of the 2014 Workshop on Programming models for SIMD/Vector processing
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HTML5 Developer Conference Presentation (May 2014)
http://peterjensen.github.io/html5-simd/html5-simd.html#/

Wikipedia
http://en.wikipedia.org/wiki/SIMD