SIMD in JavaScript via C++ and Emscripten

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Agenda

- Motivation
- Background/History
- SIMD.JS
- Emscripten
- Compiling SIMD C++ code to SIMD.JS JavaScript code
- Benchmark Results
- Summary

SIMD: Single Instruction, Multiple Data

Scalar Operation

$$A_x + B_x = C_x$$
$$A_y + B_y = C_y$$
$$A_z + B_z = C_z$$
$$A_w + B_w = C_w$$

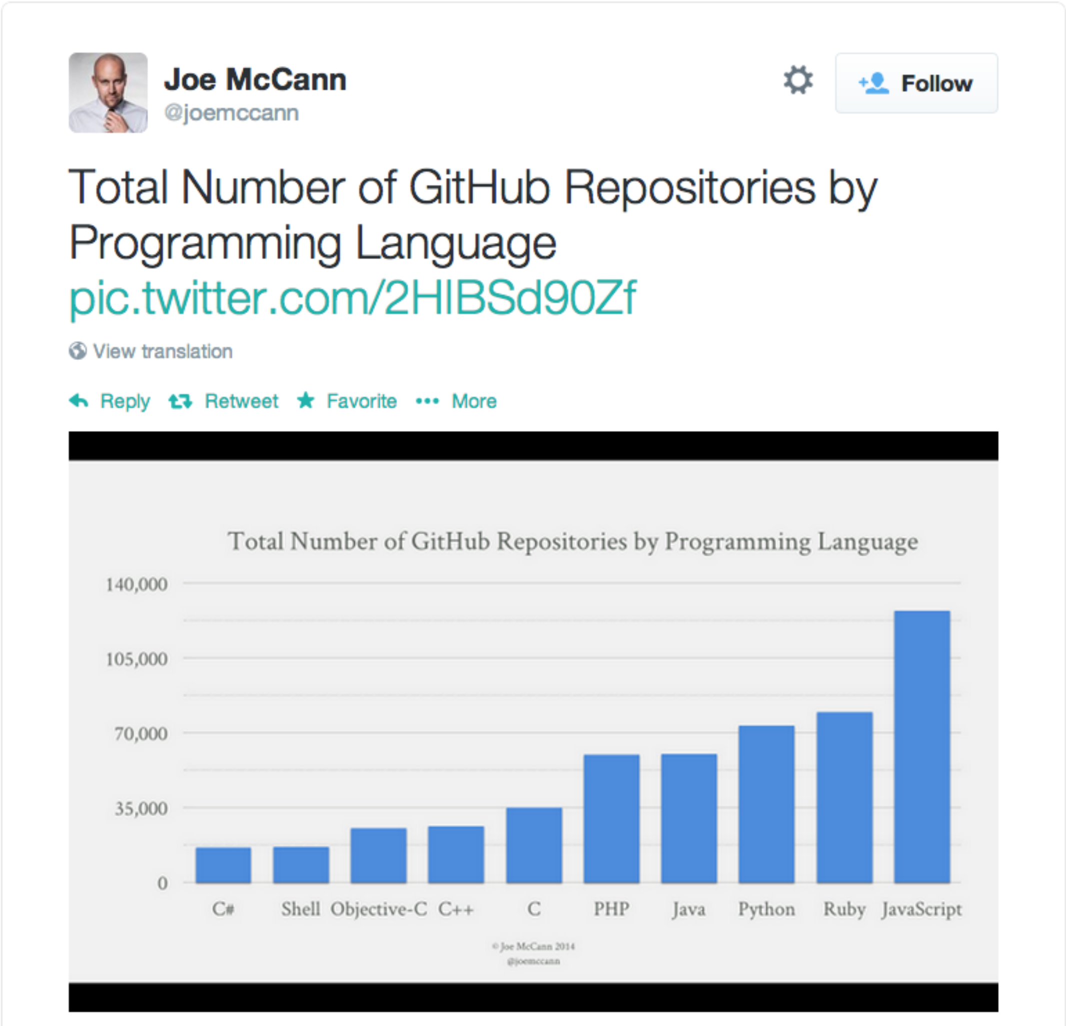
SIMD Operation of Vector Length 4

$$\begin{bmatrix} A_x \\ A_y \\ A_z \\ A_w \end{bmatrix} + \begin{bmatrix} B_x \\ B_y \\ B_z \\ B_w \end{bmatrix} = \begin{bmatrix} C_x \\ C_y \\ C_z \\ C_w \end{bmatrix}$$

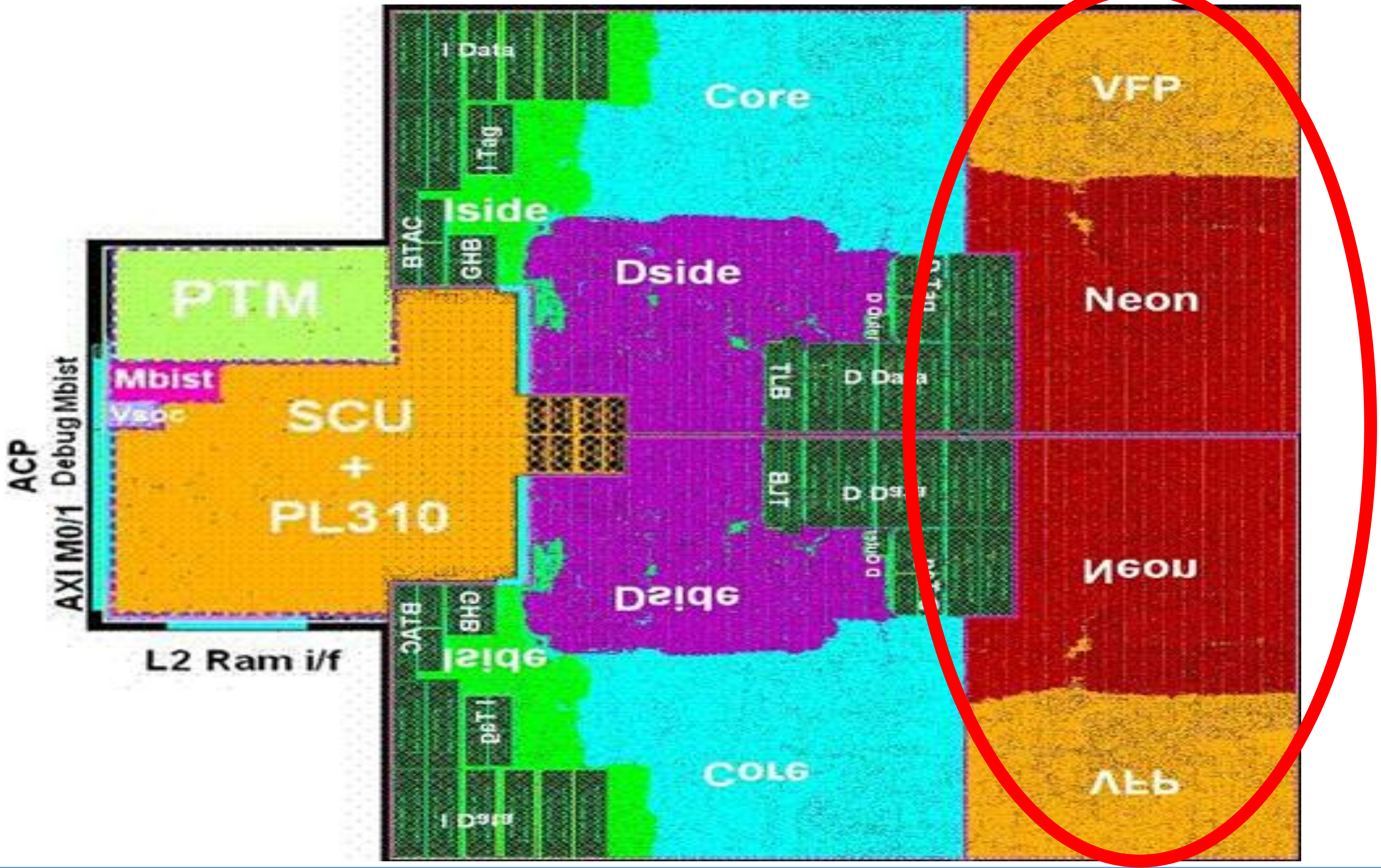
Intel® Architecture currently has SIMD operations of vector length 4, 8, 16

JavaScript’s Popularity and Use on the Rise!

- Games (Unreal, Unity) (via Emscripten/asm.js)
- Hybrid HTML5/JS apps for cross platform apps on mobile devices
- Pure HTML5/JS apps on ChromeOS/FirefoxOS/Tizen
- Standalone desktop JavaScript apps via NW.js (formerly node-webkit) (Intel XDK)
- Full featured browser based apps (Google Docs/maps, Office 365, …)
- Server side logic via node.js/io.js



More Silicon Dedicated to Vector Processing

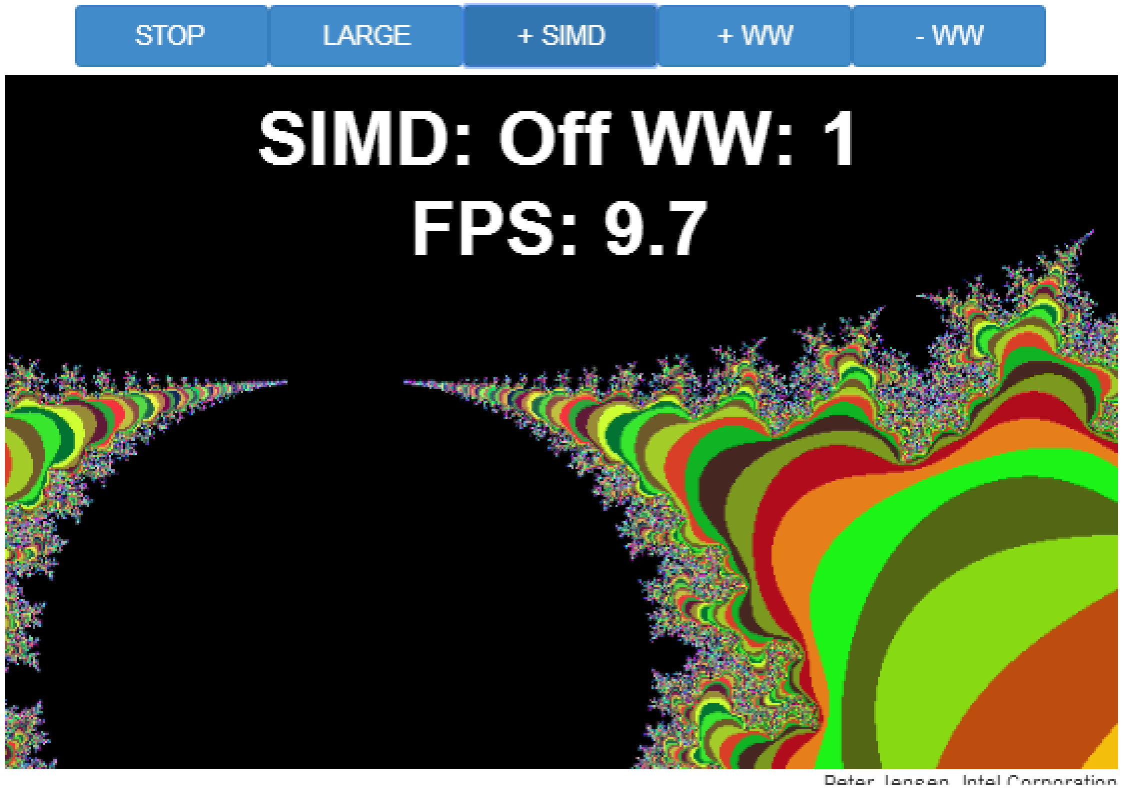


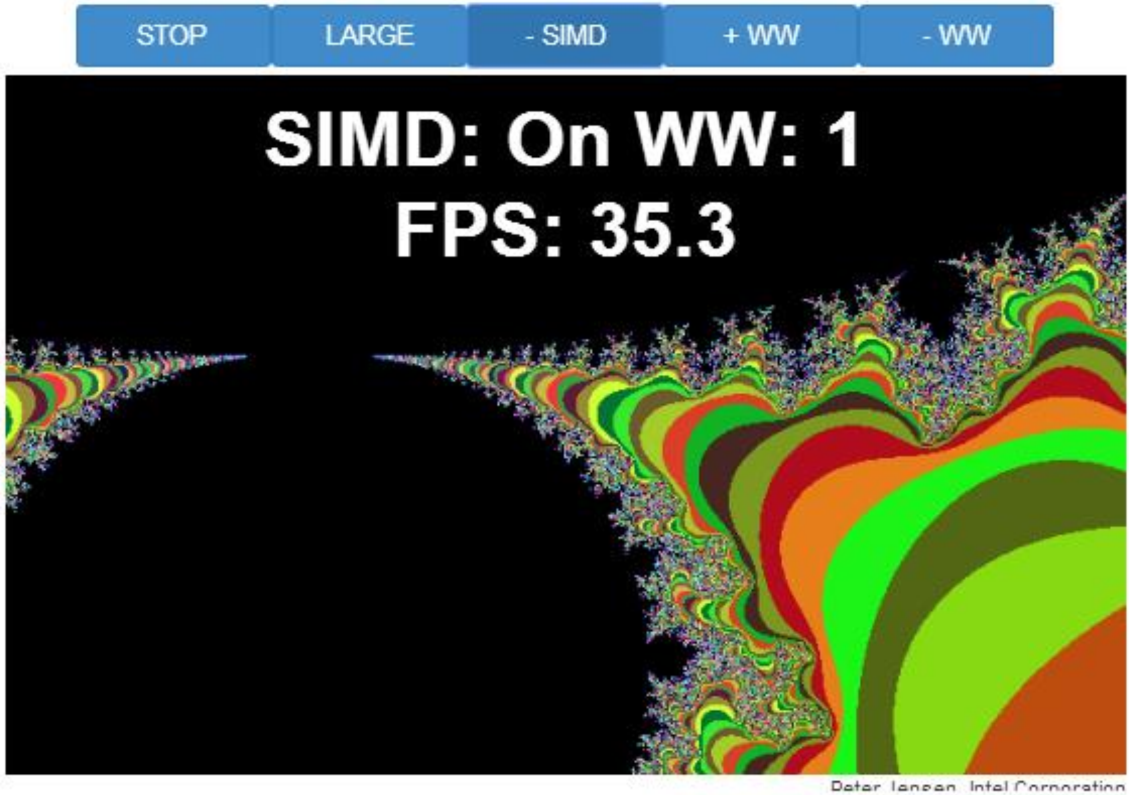
Hardware/Software Gap

- SIMD instructions are an increasingly larger portion of instruction set architectures of newer CPUs
- Currently, it's not possible to utilize these powerful instructions from JavaScript programs

SIMD.JS/Emscripten will bridge this gap

Demo - Mandelbrot

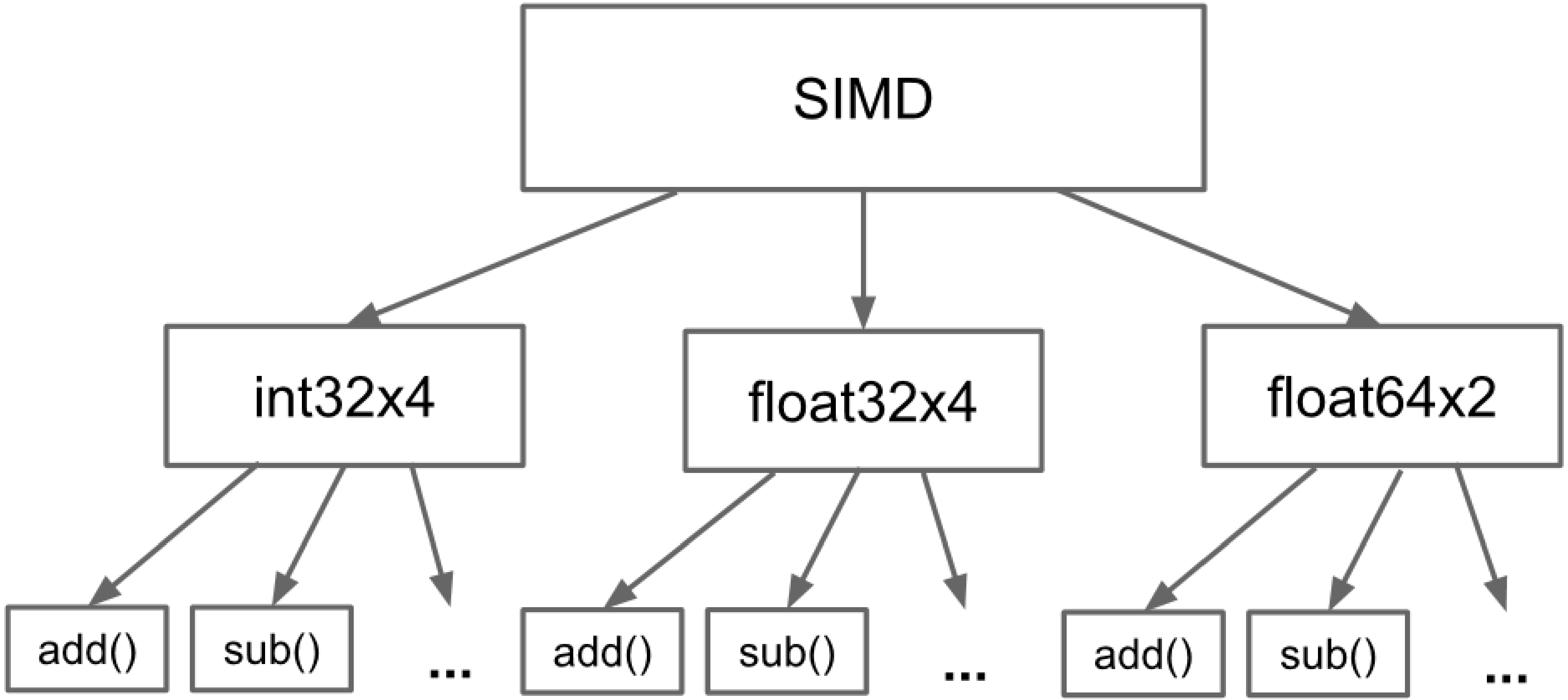




SIMD.JS/Emscripten – Background/History

- **Intel/Mozilla/Google/Microsoft/ARM collaboration!**
- Started mid-2013
- Initial polyfill spec by John McCutchan (Google's Dart VM team)
- Prototypes for Chromium, Firefox
- **Available in Intel's Crossswalk web-runtime (for hybrid HTML5 apps) TODAY!**
- Emscripten (C++ -> JavaScript compiler) now generates SIMD.JS code from LLVM vector operations and from a subset of x86 SIMD intrinsics
- **Standardization (TC39) underway for inclusion of SIMD.JS in EcmaScript 7**

SIMD.JS – Object Hierarchy



SIMD.JS – API Details

Lane accessors, mutators:

- **Accessors:** x, y, z, w
- **Mutators:** withX, withY, withZ, withW

Operators:

- **Arithmetic:** abs, neg, add, sub, mul, div, reciprocal, reciprocalSqrt, sqrt
- **Shuffle:** swizzle (1 operand), shuffle (2 operands)
- **Logical:** and, or, xor, not
- **Comparison:** equal, greaterThan, LessThan
- **Shifts:** shiftRightLogicalByScalar, shiftRightArithmeticByScalar, shiftLeftByScalar
- **Conversion:** fromInt32x4, fromInt32x4Bits, etc.
- **Min/Max:** min, minNum, max, maxNum

SIMD.JS – Example Usage - Mandelbrot

Scalar

```
//
// z(i+1) = z(i)^2 + c
// terminate when |z|^2 > 4.0
// returns 1 iteration count
//
function mandelx1 (c_re, c_im) {
  var z_re = c_re, z_im = c_im, i;


  for (i = 0; i < max_iterations; ++i) {
    var z_re2 = z_re*z_re;
    var z_im2 = z_im*z_im;

    if (z_re2 + z_im2 > 4.0) {
      // iteration has diverged
      break;
    }
    var new_re = z_re2 - z_im2;
    var new_im = 2.0 * z_re * z_im;
    z_re = c_re + new_re;
    z_im = c_im + new_im;

  }
  return i;
}
```

SIMD

```
function mandelx4(c_re4, c_im4) {
  var z_re4  = c_re4,
      z_im4  = c_im4,
      four4  = SIMD.float32x4.splat (4.0),
      two4   = SIMD.float32x4.splat (2.0),
      count4 = SIMD.int32x4.splat (0),
      one4   = SIMD.int32x4.splat (1),
      i, z_re24, z_im24, mi4, new_re4, new_im4;

  for (i = 0; i < max_iterations; ++i) {
    z_re24 = SIMD.float32x4.mul (z_re4, z_re4);
    z_im24 = SIMD.float32x4.mul (z_im4, z_im4);
    mi4 = SIMD.float32x4.greaterThan(SIMD.float32x4.add (z_re24, z_im24), four4);
    if (SIMD.int32x4.allTrue()) {
      // all 4 values have diverged
      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.JS – Focus

Initial focus on architecture overlap (128-bit vectors)

- Well defined NaN handling
- Well defined float32 -> int32 conversions
- Well defined shift handling for shift counts > 32
- Precision of reciprocalSqrt – left undefined

Architecture specific extensions are in the works, for example

- Fma (NEON, AVX)
- Vector shifts (NEON)

Emscripten - Basics

- Brainchild of Mozilla's Alon Zakai
- Compiles C/C++ to JavaScript
- Uses clang/LLVM for C/C++ front-end and optimizer framework
- Models memory with JS TypedArrays
- Generates the asm.js subset of JavaScript
- Tools available to create bindings between handwritten JS and Emscripten generated JS (webidl_binder)
- Several large C/C++ applications/games have been ported to the web platform (e.g., Unity, Unreal, box2D)

Emscripten – C/C++ -> JS Memory Modelling

- Views over the same memory (buffer) for basic C/C++ types
- C/C++ pointers used as indices to access elements of these arrays

```
var buffer = new ArrayBuffer(TOTAL_MEMORY);
HEAP8 = new Int8Array(buffer);
HEAP16 = new Int16Array(buffer);
HEAP32 = new Int32Array(buffer);
HEAPU8 = new Uint8Array(buffer);
HEAPU16 = new Uint16Array(buffer);
HEAPU32 = new Uint32Array(buffer);
HEAPF32 = new Float32Array(buffer);
HEAPF64 = new Float64Array(buffer);
```

Emscripten – Generated Code Example

```
for (uint32_t j = 0, l = length;
     j < l;
     j = j + 4) {
  sum = sum + *(a++);
}
```

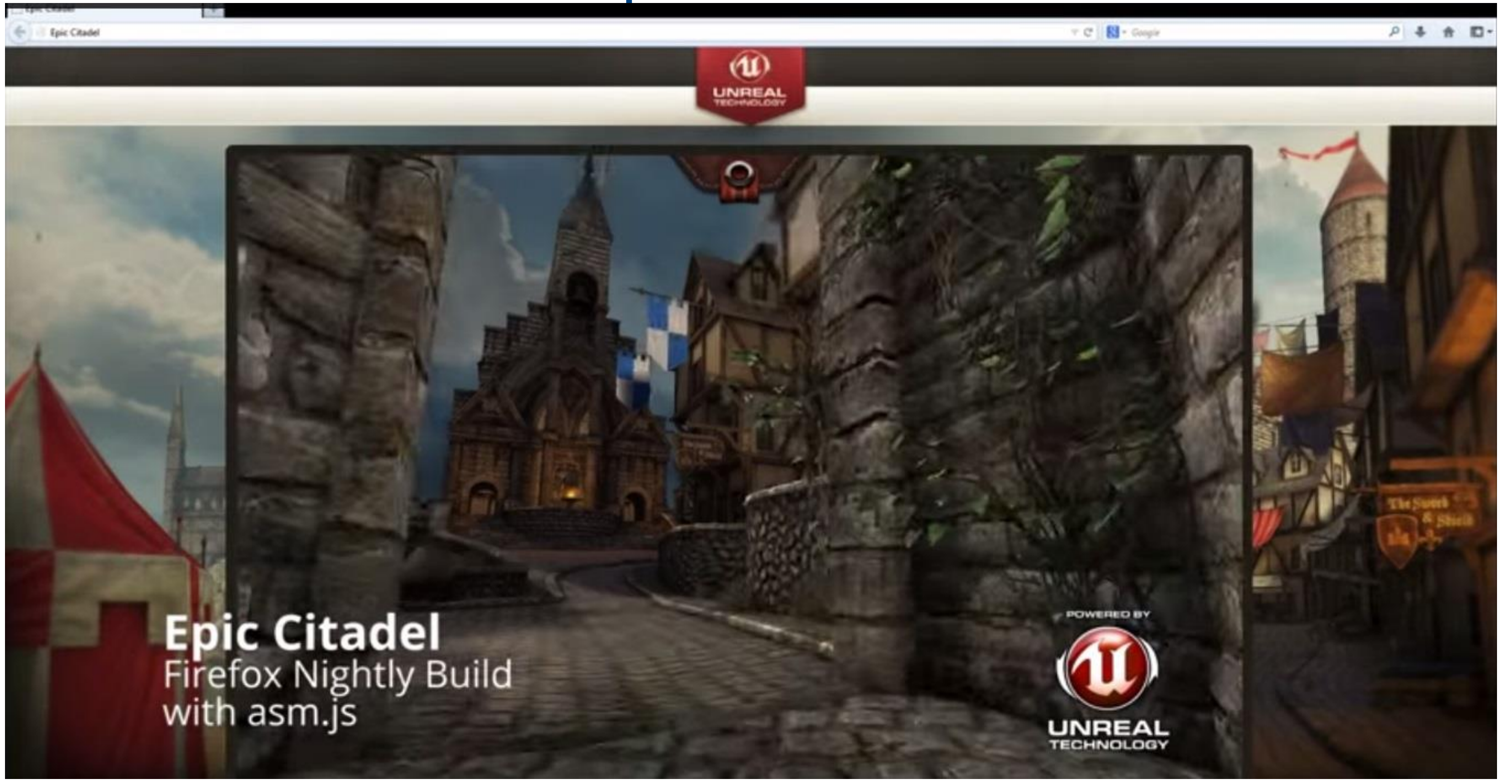
```
while (1) {
 $add = $sum$04 + +HEAPF32[$a$addr$06 >> 2];
 $j$05 = $j$05 + 4 | 0;
 if (!($j$05 >>> 0 < $length >>> 0)) {
  $sum$0$lcssa = $add;
  break;
 } else {
  $a$addr$06 = $a$addr$06 + 4 | 0;
  $sum$04 = $add;
 }
}
```

- Unary '+' (+expr) used as hint to JIT compiler to indicate number
- Bitwise-Or zero (expr|0) used to indicate 32-bit signed int
- Unsigned shift right (>>>) used to indicate 32-bit unsigned int
- Addresses are byte addresses. Need to shift right by 2 to get the right index

Type hints and no dynamic allocations allow JIT compilers to generate very efficient code QUICKLY!

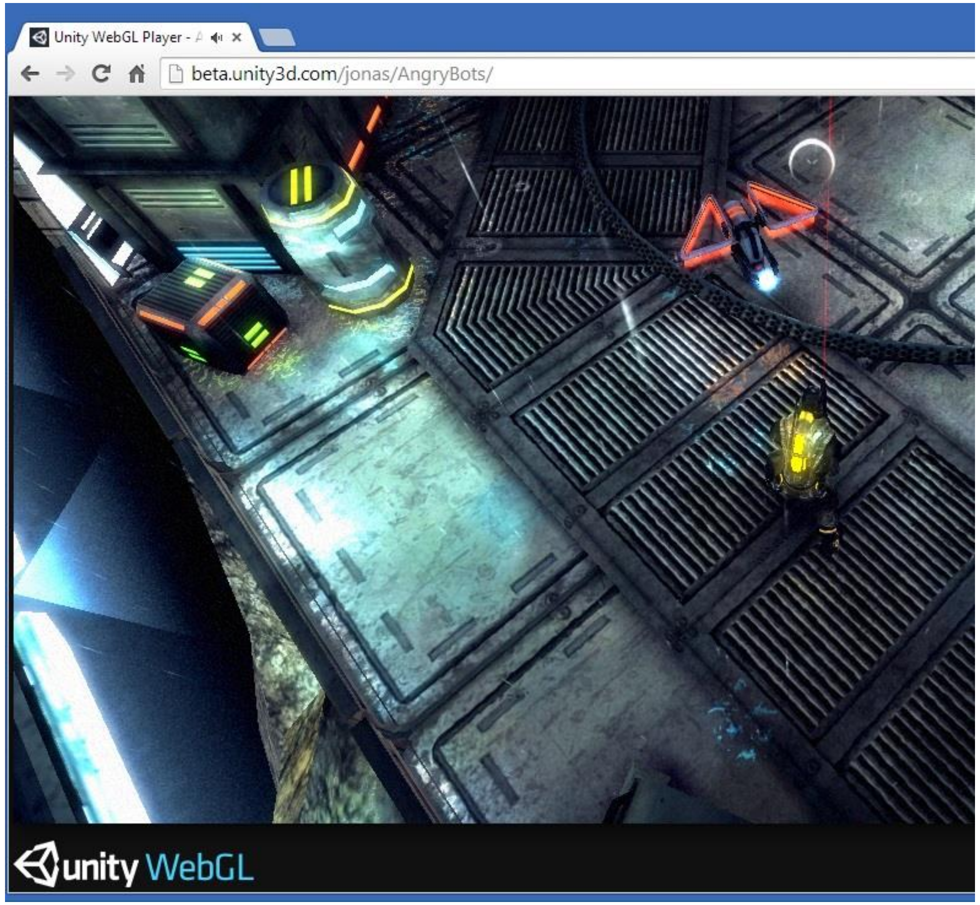
Emscripten – Showcase Uses

Epic Unreal



- Over a million lines of C++ code ported to JS
- 4 days to port!

Unity



SIMD.JS and Emscripten – A Perfect Match!

- Performance critical C/C++ code uses SIMD to get acceptable performance
  - Games, physics, image manipulation, video encoding/decoding, signal processing, etc.
- SIMD.JS enables Emscripten to fully utilize these highly optimized C/C++ code sequences

Emscripten – Compiling SIMD C/C++ Code

$ emcc –O2 –g average-intrin.c

C code with x86 intrinsics

```
float averageIntrin(float *a,
                    uint32_t length) {
  __m128 sumx4 = _mm_set_ps1(0.0);
  for (uint32_t j = 0, l = length;
       j < l; j = j + 4) {
    sumx4 = _mm_add_ps(
              sumx4, _mm_loadu_ps(&(a[j])));
  }
  float mSumx4[4];
  _mm_storeu_ps(mSumx4, sumx4);
  return (mSumx4[0] + mSumx4[1] +
          mSumx4[2] + mSumx4[3])/length;
}
```

asm.js code with SIMD.JS (for loop)

```
while (1) {
 $add$i = SIMD_float32x4_add(
           $sumx4$010,
           SIMD_float32x4_load(
            buffer, $a + ($j$09 << 2) | 0));
 $j$09 = $j$09 + 4 | 0;
 if (!($j$09 >>> 0 < $length >>> 0)) {
  $sumx4$0$lcssa = $add$i;
  break;
 } else $sumx4$010 = $add$i;
}
```

Benchmarks

- Handwritten JavaScript benchmark kernels:
  - Average, Mandelbrot, MatrixMultiplication, VertexTransform, MatrixTranspose, MatrixInverse
  - Vector/Matrix math important for game/physics
  - Kernels for both scalar and SIMD implementations
  - Measure speedup (SIMD/scalar)
- Manually converted to C++
- Automatically compiled back to JavaScript with Emscripten
- JavaScript code executed with both Chromium and Firefox SIMD prototypes
- Native clang/LLVM compiler used to compile C++ code

Benchmarks – Handwritten JavaScript

Scalar JavaScript

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

SIMD JavaScript

```
function simdAverage(n) {
  for (var i = 0; i < n; ++i) {
    var sum4 = SIMD.float32x4.splat(0.0);
    for (var j = 0; j < a.length / 4; ++j) {
      sum4 = SIMD.float32x4.add(sum4, SIMD.float32x4.load(a, j << 2));
    }
  }
  return (sum4.x + sum4.y + sum4.z + sum4.w)/a.length;
}
```

Benchmarks – Handwritten C++

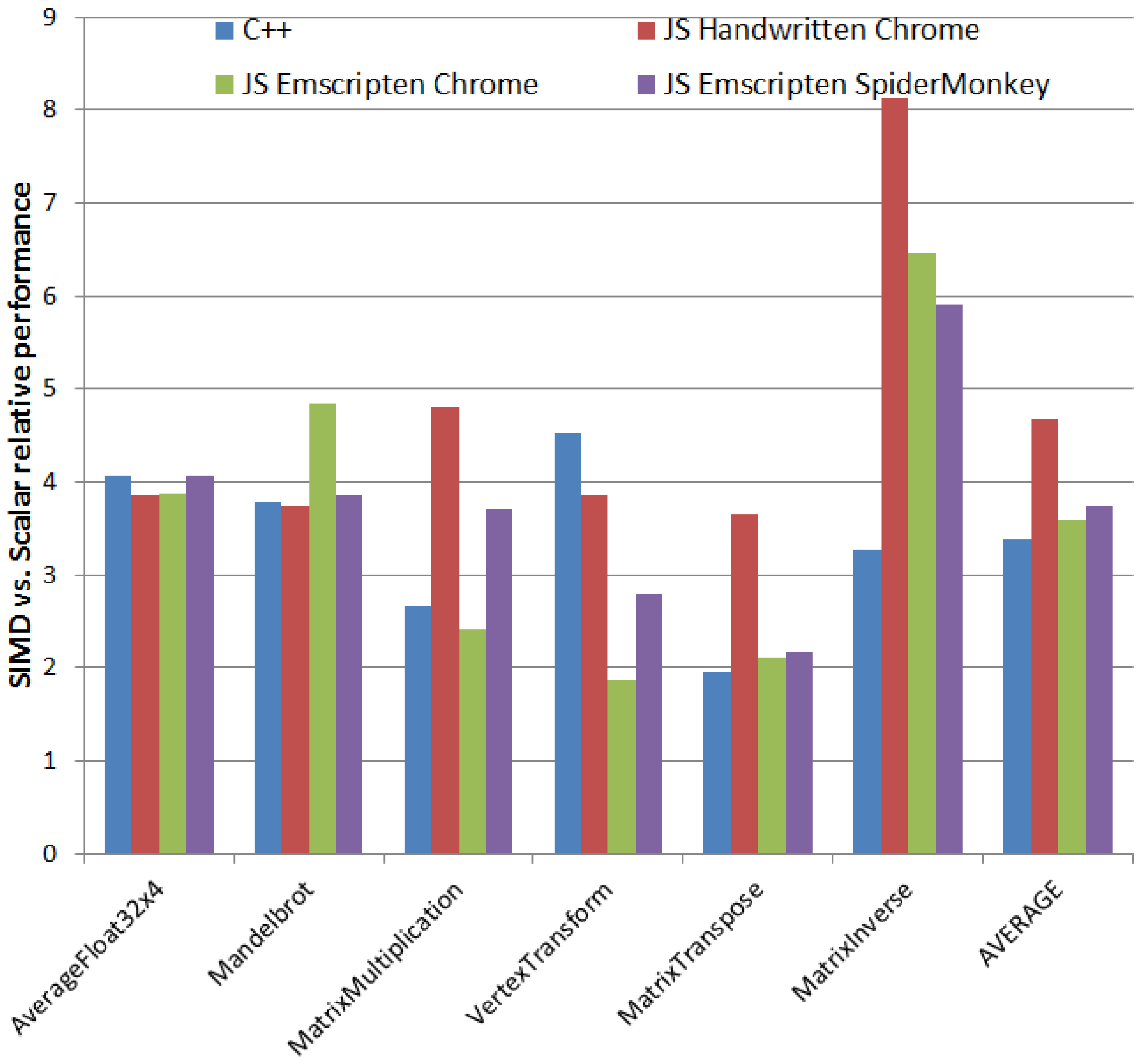
Scalar C++

```
static float nonSimdAverageKernel32() {
  float sum = 0.0;
  for (uint32_t j = 0, l = length; j < l; ++j) {
    sum += a[j];
  }
  return sum/length;
}
```

SIMD C++

```
static float simdAverageKernel() {
  __m128 sumx4 = _mm_set_ps1(0.0);
  for (uint32_t j = 0, l = length; j < l; j = j + 4) {
    sumx4 = _mm_add_ps(sumx4, _mm_loadu_ps(&(a[j])));
  }
  Base::Lanes<__m128, float> lanes(sumx4);
  return (lanes.x() + lanes.y() + lanes.z() + lanes.w())/length;
}
```

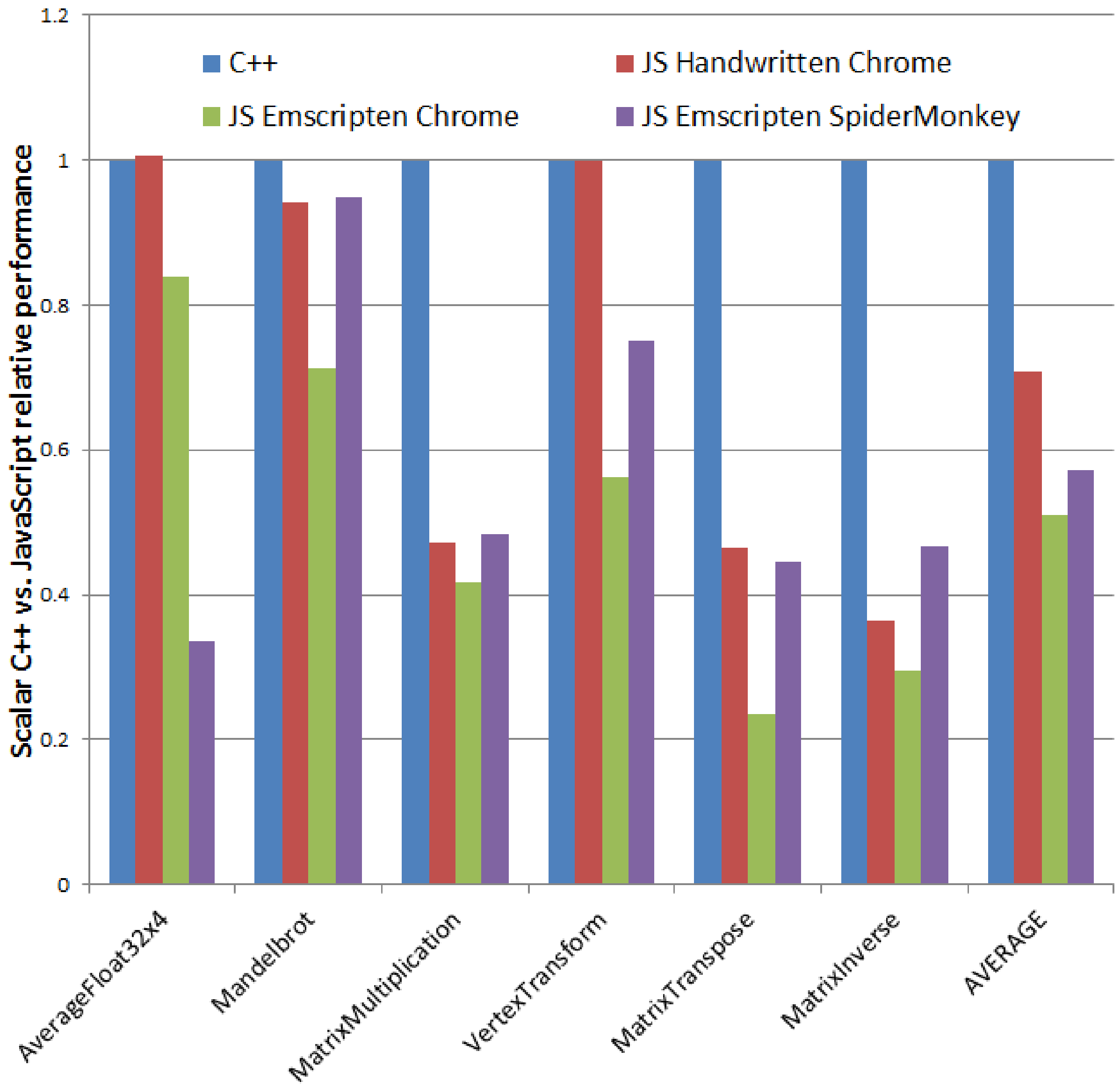
Benchmark Results – SIMD vs. Scalar Speedups



Observations:

- **Average speedups are in the expected ~4x range**
- Higher speedups for 'JS Handwritten Chrome' is due to slow scalar kernel (64-bit FP operations
- Super linear speedups for MatrixInverse most likely due to slower scalar kernel as well.

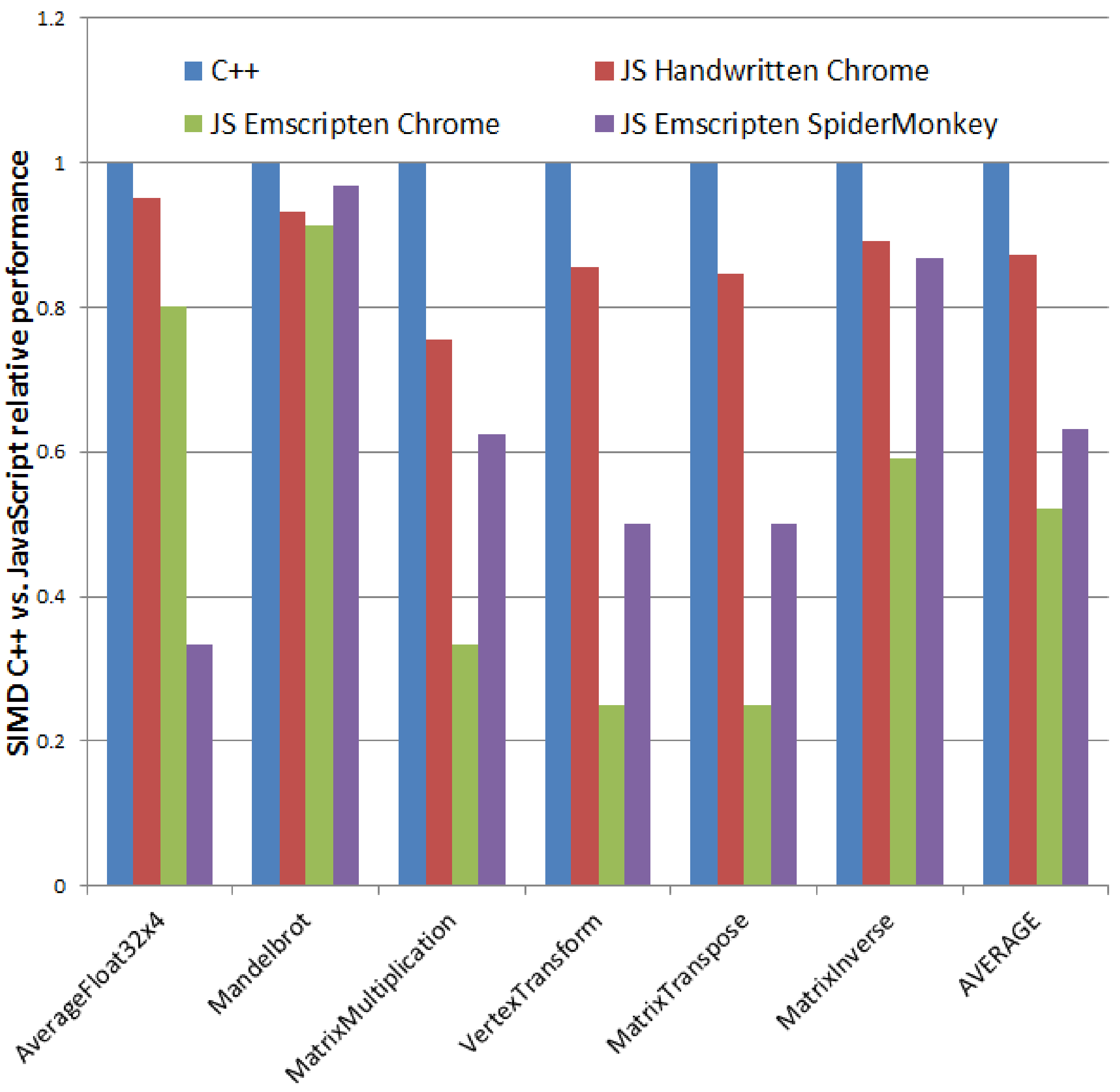
Benchmark Results – Scalar C++ vs. Scalar JS



Observations:

- **Average JS performance is roughly 60% of native C++**
- Handwritten JS code is slightly faster than Emscripten generated JS
- SpiderMonkey/OdinMonkey is slightly faster than Chromium on Emscripten generated JS
- Chromium has 'slow JIT' overhead that OdinMonkey doesn't

Benchmark Results – SIMD C++ vs. SIMD JS



Observations:

- Handwritten JS performance is ~85% of native C++ on Chromium!
- Emscripten generated JS performance is ~60% of native C++ on both Chromium and OdinMonkey
- C++/JS performance for SIMD code is roughly the same as it is for Scalar code

Summary

SIMD.JS bridges the hardware/software gap for JavaScript programs

SIMD.JS makes ~4x speedup of performance critical code possible

Emscripten now compiles SIMD C++ vector code

The performance gap between native C/C++ code and JavaScript code keeps getting smaller

HTML5/JavaScript is rapidly becoming a viable cross platform

THANK YOU

References

SIMD.JS polyfill/spec and handwritten JS benchmarks:

- https://github.com/johnmccutchan/ecmascript_simd

Emscripten:

- https://github.com/kripken/emscripten/wiki

C++ benchmarks:

- https://github.com/PeterJensen/benchcpp

This Presentation:

- https://github.com/PeterJensen/wpmvp2015