EMSCRIPTEN - COMPILING LLVM BITCODE TO JAVASCRIPT (?!)

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JavaScript..? At the **LLVM** developer's conference..?

Everything compiles into LLVM bitcode

The web is **everywhere**, and runs **JavaScript**

Compiling LLVM bitcode to JavaScript lets us run
~ **everything, everywhere**

THIS WORKS TODAY!

Game engines like **Unreal Engine 3**

Programming languages like **Lua**

Libraries too: like **Bullet**

Of course, usually **native** builds are best

But imagine, for example, that you wrote a new feature in clang and want to let people give it a quick test

Build once to JS, and **just give people a URL**

(and that's **not** theoretical)

OK, **HOW** DOES THIS WORK?

LLVM VS. JAVASCRIPT

Random (unrelated) code samples from each:

```
%r = load i32* %p
%s = shl i32 %r, 16
%t = call i32 @calc(i32 %r, i32 %s)
br label %next
```

```
var x = new MyClass('name', 5).chain(function(arg) {
  if (check(arg)) doMore({ x: arg, y: [1,2,3] });
  else throw 'stop';
});
```

What could be more different? ;)

NUMERIC TYPES

LLVM	i8, i16, i32, float, double
JS	double

PERFORMANCE MODEL

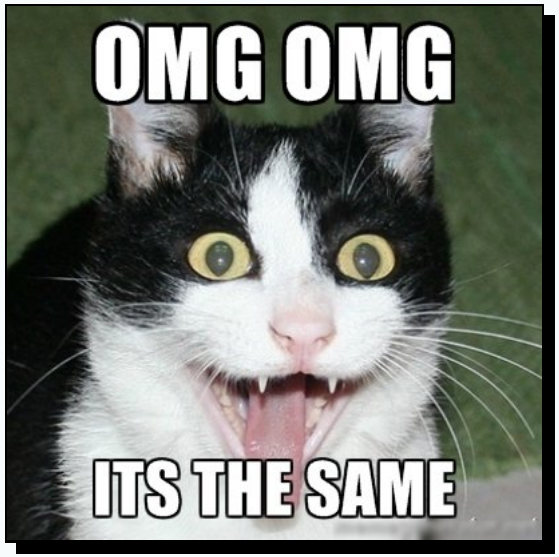
LLVM	types and ops map ~1:1 to CPU
JS	virtual machine (VM), just in time (JIT) compilers w/ type profiling, garbage collection, etc.

CONTROL FLOW

LLVM	Functions, basic blocks & branches
JS	Functions, ifs and loops - no goto!

VARIABLES

LLVM	Local vars have function scope
JS	Local vars have function scope



Ironic, actually - many wish JS had **block** scope, like most languages...

OK, HOW DO WE GET AROUND THESE ISSUES?

```
// LLVM IR
define i32 @func(i32* %p) {
  %r = load i32* %p
  %s = shl i32 %r, 16
  %t = call i32 @calc(i32 %r, i32 %s)
  ret i32 %t
}
```

⇒ Emscripten ⇒

```
// JS
function func(p) {
  var r = HEAP[p];
  return calc(r, r << 16);
}
```

Almost direct mapping in many cases

Another example:

```
float array[5000]; // C++
int main() {
  for (int i = 0; i < 5000; ++i) {
    array[i] += 1.0f;
  }
}
```

⇒ Emscripten ⇒

```
var g = Float32Array(5000); // JS
function main() {
  var a = 0, b = 0;
  do {
    a = b << 2;
    g[a >> 2] = +g[a >> 2] + 1.0;
    b = b + 1 | 0;
  } while ((b | 0) < 5000);
}
```

(this "style" of code is a subset of JS called **asm.js**)

JS AS A COMPILATION TARGET

JS began as a slow interpreted language

Competition ⇒ **type-specializing** JITs

Those are very good at **statically typed** code

LLVM compiled through Emscripten is **exactly that**,
so it can be fast

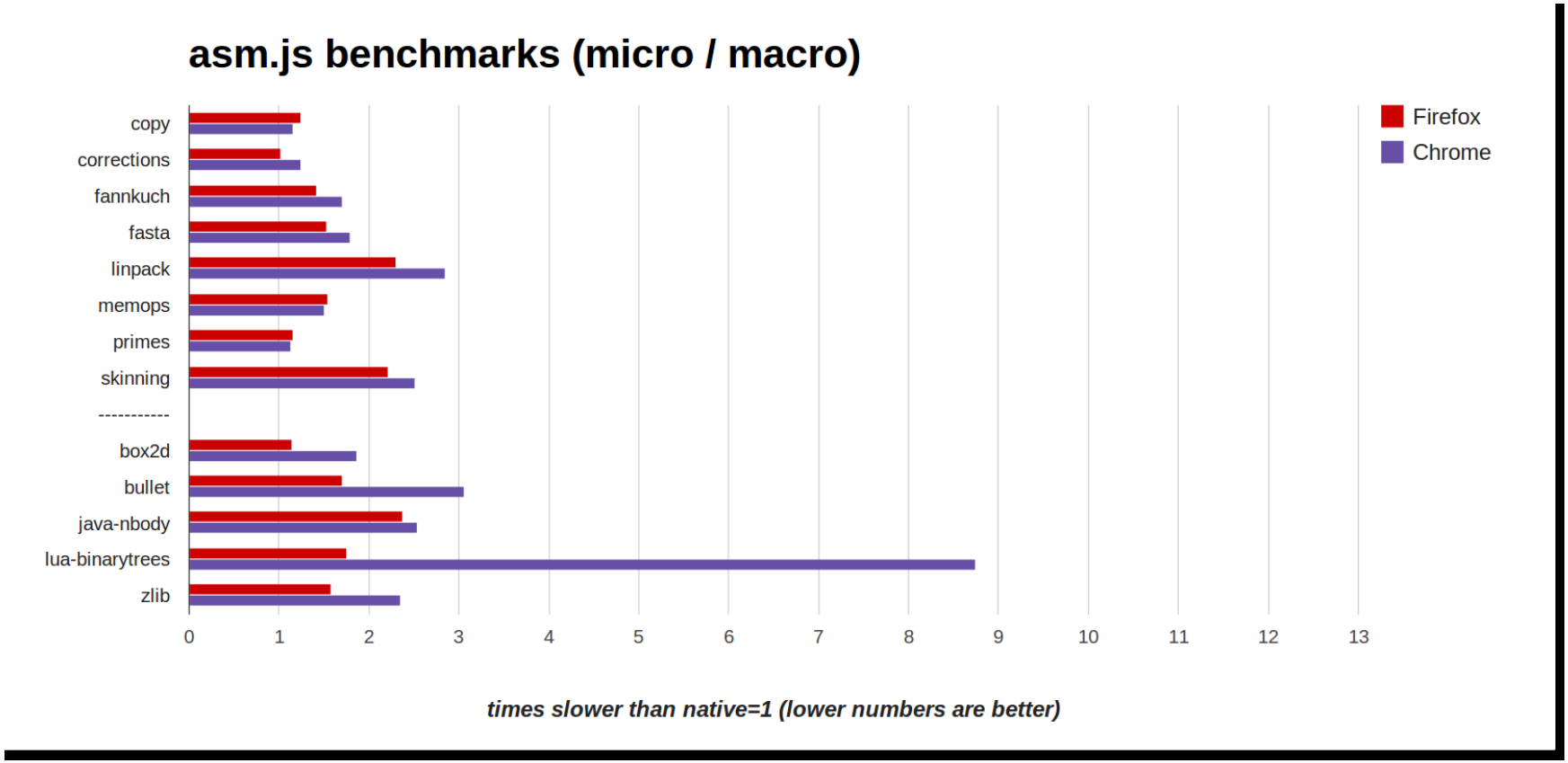
SPEED: MORE DETAIL

`(x+1)|0` ⇒ 32-bit integer + in modern JS VMs

Loads in LLVM IR become **reads** from typed array in JS, which become **reads** in machine code

Emscripten's **memory model** is identical to LLVM's (flat C-like, aliasing, etc.), so can use **all** LLVM opts

BENCHMARKS



(VMs and Emscripten from Oct 28th 2013, run on 64-bit linux)

Open source (MIT/LLVM)

Began in **2010**

Most of the codebase is not the core compiler, but
libraries + toolchain + test suite

LLVM IR ⇛⇛⇛ JS ⇛⇛⇛ JS

Emscripten Compiler

Emscripten Optimizer

Compiler and optimizer written mostly in **JS**

Wait, that's not an LLVM backend..?

3 JS COMPILERS, 3 DESIGNS

Mandreel: **Typical LLVM backend**, uses tblgen, selection DAG (like x86, ARM backends)

Duetto: Processes **LLVM IR** in llvm::Module (like C++ backend)

Emscripten: Processes **LLVM IR** in assembly

EMSCRIPTEN'S CHOICE

JS is such an odd target ⇒ wanted architecture with **maximal flexibility** in codegen

Helped **prototype & test** many approaches

DOWNSIDES TOO

Emscripten currently must do its own legalization (are we doing it wrong? probably...)

OPTIMIZING JS

Emscripten has **3 optimizations** we found are very important for JS

Whatever the best architecture is, it should be able to implement those - let's go over them now

1. RELOOP

```
block0:
  ; code0
  br i1 %cond, label %block0, label %block1

block1:
  ; code1
  br %label block0
```

Without relooping (emulated gotos):

```
var label = 0;
while (1) switch (label) {
  case 0:
    // code0
    label = cond ? 0 : 1; break;
  case 1:
    // code1
    label = 0; break;
}
```

1. RELOOP

```
block0:
  ; code0
  br i1 %cond, label %block0, label %block1

block1:
  ; code1
  br %label block0
```

With relooping:

```
while (1) {
  do {
    // code0
  } while (cond);
  // code1
}
```

1. RELOOP

Relooping allows JS VM to optimize better, as it can **understand** control flow

Emscripten Relooper code is **generic**, written in C++, and used by other projects (e.g., Duetto)

This one seems like it could work in **any** architecture, in an LLVM backend or not

2. EXPRESSIONIZE

```
var a = g(x);
var b = a + y;
var c = HEAP[b];
var d = HEAP[20];
var e = x + y + z;
var f = h(d, e);
FUNCTION_TABLE[c](f);
```

```
FUNCTION_TABLE[HEAP[g(x) + y](h(HEAP[20], x + y + z));
```

2. EXPRESSIONIZE

Improves **JIT time** and **execution speed**: fewer variables ⇒ less stuff for JS engines to worry about

Reduces **code size**

3. REGISTERIZE

```
var a = g(x) | 0; // integers
var b = a + y | 0;
var c = HEAP[b] | 0;
var d = +HEAP[20]; // double
```

```
var a = g(x) | 0;
a = a + y | 0;
a = HEAP[a] | 0;
var d = +HEAP[20];
```

3. REGISTERIZE

Looks like regalloc, but goal is different: Minimize **# of total variables** (in each type), **not** spills

JS VMs will do regalloc, only they know the actual # of registers

Benefits **code size & speed** like expressionize

OPTS SUMMARY

Expressionize & registerize require precise modelling of **JS semantics** (and order of operations is in some cases surprising!)

Is there a nice way to do these opts in an **LLVM backend**, or do we need a JS AST?

Questions: Should Emscripten change how it interfaces with LLVM? What would LLVM like upstreamed?

CONCLUSION

LLVM bitcode can be compiled to **JavaScript** and run in **all browers**, at **high speed**, in a **standards-compliant** way

For more info, see **emscripten.org** - feedback & contributions always welcome

Thank you for listening!