



Bringing the Web Up to Speed with WebAssembly

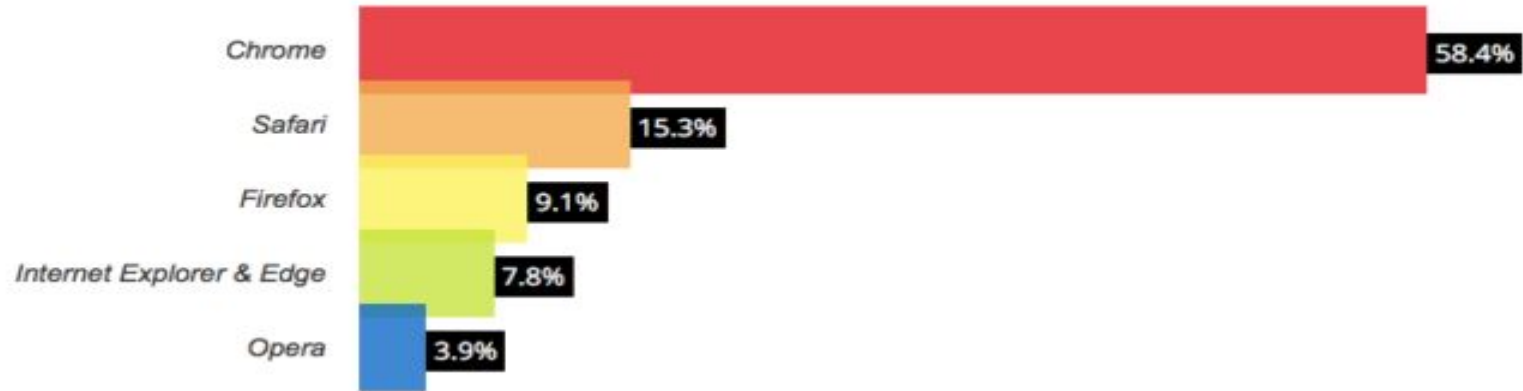
Matthew Furlong, Drew Davis, Ayush
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An Open Standard



Web Browser Market Share

[View Monthly Trends](#)

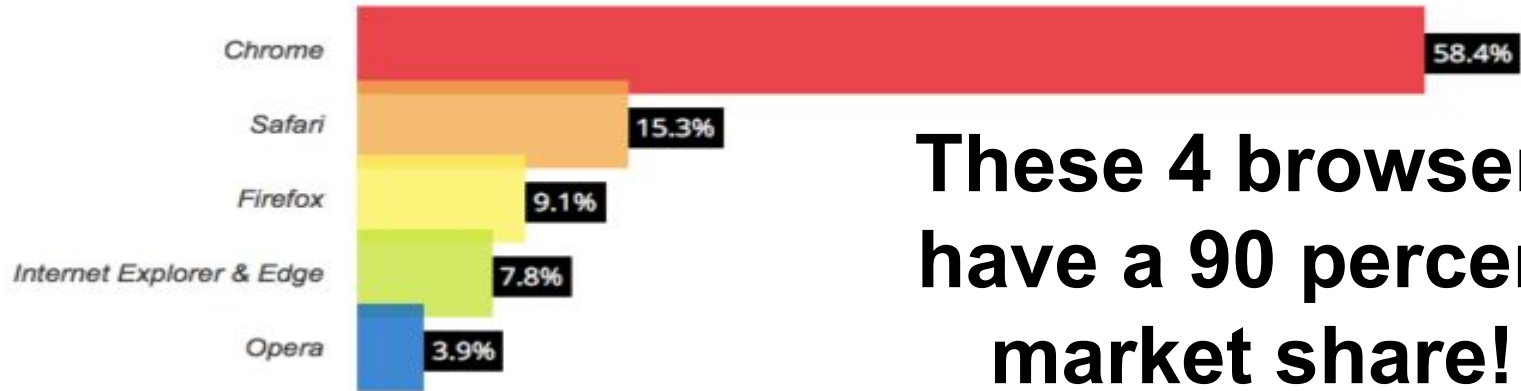


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**These 4 browsers
have a 90 percent
market share!**

Outline

1. **Introduction and Motivation**
2. Overview and Execution
3. Validation
4. Binary Format & Embedding
5. Evaluation

The Web

- “The most ubiquitous application platform ever.”

The Web

- “The most ubiquitous application platform ever.”
- Yet Javascript is the only natively supported programming language on the web...

```
> typeof NaN           > true==1
< "number"            < true
> 9999999999999999999 > true===1
< 1000000000000000000 < false
> 0.5+0.1==0.6        > (!+[[]]+[![]]).length
< true                < 9
> 0.1+0.2==0.3        > 9+"1"
< false               < "91"
> Math.max()           > 91-"1"
< -Infinity           < 90
> Math.min()           > []==0
< Infinity            < true
> []+[]
< ""
> []+{}
< "[object Object]"
> {}+[]
< 0
> true+true+true===3
< true
> true-true
< 0
```



Away from Javascript...

- Web applications are more demanding than ever
 - 3D Visualization
 - Audio and Video software
 - Games
- Many developers don't want to use Javascript

... and Onto WebAssembly!

- A low-level, language independent bytecode for the Web

... and Onto WebAssembly!

- A low-level, language independent bytecode for the Web
- Goals
 - Safe
 - Fast
 - Portable
 - Compact

Previous Work on Bytecode for the Web

- Microsoft's ActiveX
- Native Client and Portable Native Client
- asm.js

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WebAssembly is the first solution for low-level code on the Web that provides safety, speed, portability, and small code sizes.

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Overview

- A binary code format, not a language
- Basic language features
 - Modules
 - Functions
 - Instructions
 - Traps
 -

Overview

- New Language features
 - Linear memory (also known as flat memory)
 - Endiannes
 - Little endian
 - Structured Control Flow
 - Eliminates problems caused by simply jumps
 - Blocks execute like function calls
 - Function calls

Overview

- Determinism
 - Design semantics tries to minimize non determinism due to corner cases.
 - Implementation dependent behavior
 - NaNs
 - Resource Exhaustion
 - Host Functions

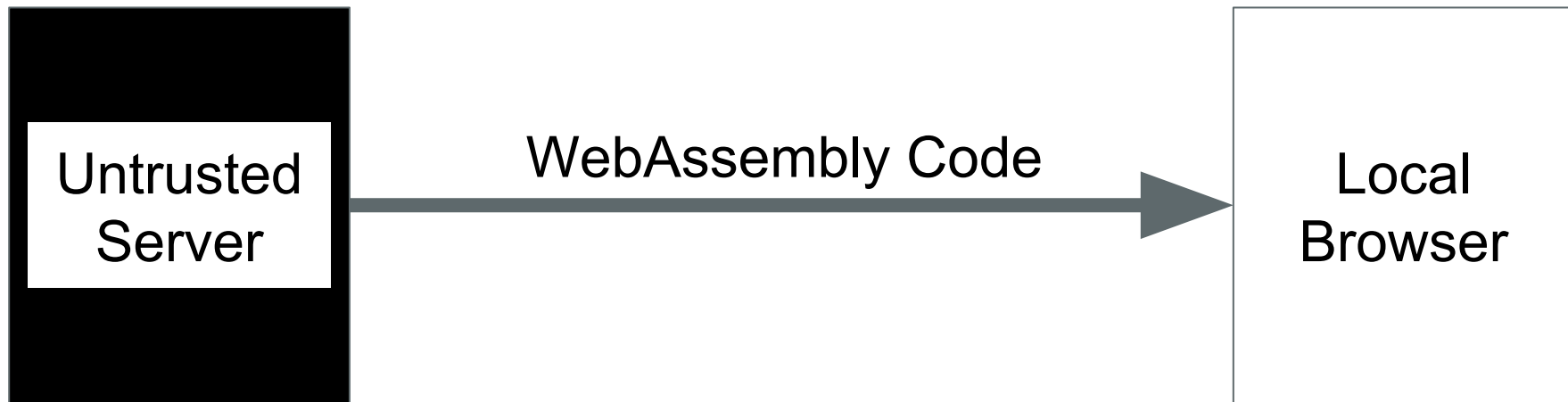
Execution

- Uses a global store object (like Windows in Browsers)
- Stores and Runtime objects representation
- Reduction Rules

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Validation



Validation

- Defined as a simple *type system*
- Efficiently checkable in a single linear pass

Validation

- Typing Rules
 - Ensure that the type is correct
- Soundness
 - Typing rules cover behavior
 - Guarantees memory addresses

(contexts) $C ::= \{\text{func } tf^*, \text{global } tg^*, \text{table } n^?, \text{memory } n^?, \text{local } t^*, \text{label } (t^*)^*, \text{return } (t^*)^?\}$

Typing Instructions

$C \vdash e^* : tf$

$$\frac{}{C \vdash t.\text{const } c : \epsilon \rightarrow t} \quad \frac{}{C \vdash t.\text{unop} : t \rightarrow t} \quad \frac{}{C \vdash t.\text{binop} : t t \rightarrow t} \quad \frac{}{C \vdash t.\text{testop} : t \rightarrow i32} \quad \frac{}{C \vdash t.\text{relop} : t t \rightarrow i32}$$

$$\frac{t_1 \neq t_2 \quad sx^? = \epsilon \Leftrightarrow (t_1 = \text{in} \wedge t_2 = \text{in}' \wedge |t_1| < |t_2|) \vee (t_1 = \text{fn} \wedge t_2 = \text{fn}')}{C \vdash t_1.\text{convert } t_2.sx^? : t_2 \rightarrow t_1} \quad \frac{t_1 \neq t_2 \quad |t_1| = |t_2|}{C \vdash t_1.\text{reinterpret } t_2 : t_2 \rightarrow t_1}$$

$$\frac{}{C \vdash \text{unreachable} : t_1^? \rightarrow t_2^?} \quad \frac{}{C \vdash \text{nop} : \epsilon \rightarrow \epsilon} \quad \frac{}{C \vdash \text{drop} : t \rightarrow \epsilon} \quad \frac{}{C \vdash \text{select} : t t i32 \rightarrow t}$$

$$\frac{tf = t_1^n \rightarrow t_2^m \quad C, \text{label } (t_2^m) \vdash e^* : tf}{C \vdash \text{block } tf \text{ end} : tf} \quad \frac{tf = t_1^n \rightarrow t_2^m \quad C, \text{label } (t_1^?) \vdash e^* : tf}{C \vdash \text{loop } tf \text{ end} : tf}$$

$$\frac{tf = t_1^n \rightarrow t_2^m \quad C, \text{label } (t_2^m) \vdash e_1^* : tf \quad C, \text{label } (t_2^m) \vdash e_2^* : tf}{C \vdash \text{if } tf \text{ else } e_2^* \text{ end} : t_1^n i32 \rightarrow t_2^m}$$

$$\frac{C_{\text{label}(i)}(i) = t^*}{C \vdash \text{br } i : t_1^? t^* \rightarrow t_2^?} \quad \frac{C_{\text{label}(i)}(i) = t^*}{C \vdash \text{br.if } i : t^* i32 \rightarrow t^*} \quad \frac{(C_{\text{label}(i)}(i) = t^*)^+}{C \vdash \text{br.table } i^+ : t_1^? t^* i32 \rightarrow t_2^?}$$

$$\frac{C_{\text{return}} = t^*}{C \vdash \text{return} : t_1^? t^* \rightarrow t_2^?} \quad \frac{C_{\text{func}(i)} = tf}{C \vdash \text{call } i : tf} \quad \frac{tf = t_1^? \rightarrow t_2^? \quad C_{\text{table}} = n}{C \vdash \text{call.indirect } tf : t_1^? i32 \rightarrow t_2^?}$$

$$\frac{C_{\text{local}(i)}(i) = t}{C \vdash \text{get.local } i : \epsilon \rightarrow t} \quad \frac{C_{\text{local}(i)}(i) = t}{C \vdash \text{set.local } i : t \rightarrow \epsilon} \quad \frac{C_{\text{local}(i)}(i) = t}{C \vdash \text{tee.local } i : t \rightarrow t} \quad \frac{C_{\text{global}(i)}(i) = \text{mut}^? t}{C \vdash \text{get.global } i : \epsilon \rightarrow t} \quad \frac{C_{\text{global}(i)}(i) = \text{mut}^? t}{C \vdash \text{set.global } i : t \rightarrow \epsilon}$$

$$\frac{C_{\text{memory}} = n \quad 2^a \leq (|tp| <)^? |t| \quad (tp.sx)^? = \epsilon \vee t = \text{im}}{C \vdash t.\text{load } (tp.sx)^? a o : i32 \rightarrow t} \quad \frac{C_{\text{memory}} = n \quad 2^a \leq (|tp| <)^? |t| \quad tp^? = \epsilon \vee t = \text{im}}{C \vdash t.\text{store } tp^? a o : i32 t \rightarrow \epsilon}$$

$$\frac{C_{\text{memory}} = n}{C \vdash \text{current.memory} : \epsilon \rightarrow i32} \quad \frac{C_{\text{memory}} = n}{C \vdash \text{grow.memory} : i32 \rightarrow i32}$$

$$\frac{}{C \vdash \epsilon : \epsilon \rightarrow \epsilon} \quad \frac{C \vdash e_1^* : t_1^? \rightarrow t_2^? \quad C \vdash e_2 : t_2^? \rightarrow t_3^?}{C \vdash e_1^* e_2 : t_1^? \rightarrow t_3^?} \quad \frac{C \vdash e^* : t_1^? \rightarrow t_2^?}{C \vdash e^* : t^* t_1^? \rightarrow t^* t_2^?}$$

Typing Modules

$$\frac{tf = t_1^? \rightarrow t_2^? \quad C, \text{local } t_1^? t^*, \text{label } (t_2^?), \text{return } (t_2^?) \vdash e^* : \epsilon \rightarrow t_2^?}{C \vdash \text{ex}^* \text{func } tf \text{ local } t^* e^* : \text{ex}^* tf} \quad \frac{tg = \text{mut}^? t \quad C \vdash e^* : \epsilon \rightarrow t \quad \text{ex}^* = \epsilon \vee tg = t}{C \vdash \text{ex}^* \text{global } tg \text{ e}^* : \text{ex}^* tg}$$

$$\frac{(C_{\text{func}(i)} = tf)^n}{C \vdash \text{ex}^* \text{table } n \text{ im}^n : \text{ex}^* n} \quad \frac{}{C \vdash \text{ex}^* \text{memory } n : \text{ex}^* n}$$

$$\frac{}{C \vdash \text{ex}^* \text{func } tf \text{ im} : \text{ex}^* tf} \quad \frac{tg = t}{C \vdash \text{ex}^* \text{global } tg \text{ im} : \text{ex}^* tg} \quad \frac{}{C \vdash \text{ex}^* \text{table } n \text{ im} : \text{ex}^* n} \quad \frac{}{C \vdash \text{ex}^* \text{memory } n \text{ im} : \text{ex}^* n}$$

$$\frac{(C_i \vdash f : \text{ex}_i^? tf)^* \quad (C_i \vdash \text{glob}_i : \text{ex}_i^? tg_i)_i^* \quad (C \vdash \text{tab} : \text{ex}_i^? n)^? \quad (C \vdash \text{mem} : \text{ex}_i^? n)_i^?}{(C_i = \{\text{global } tg_i^{i-1}\})_i^* \quad C = \{\text{func } tf^*, \text{global } tg^*, \text{table } n^?, \text{memory } n^?\} \quad \text{ex}_i^* \text{ ex}_i^* \text{ ex}_i^* \text{ ex}_i^* \text{ distinct}} \quad \vdash \text{module } f^* \text{ glob}^* \text{ tab}^? \text{ mem}^?$$

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Binary Format

- Code transmitted across web as a binary encoding
 - Binary code organized by entities
 - Streaming compilation
 - Parallelized compilation
 - Instructions - one-byte opcodes
 - Integral numbers - LEB128 format

Embedding

- WebAssembly is designed to be embedded into an execution environment
- Therefore, does not define:
 - How programs are loaded into execution environment
 - How I/O is performed

Outline

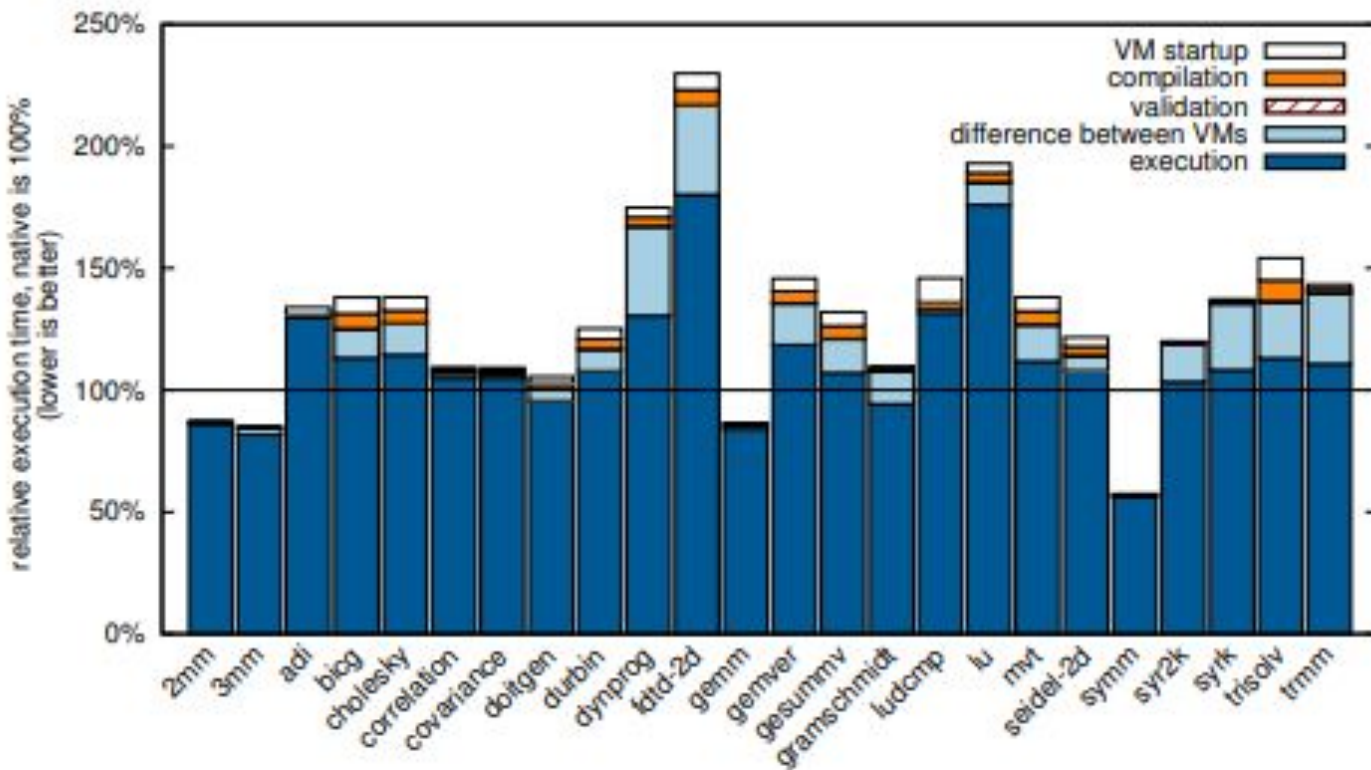
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Implementation

- Lots of different JavaScript engines
 - V8 (Chrome), SpiderMonkey (Mozilla), Chakra (Edge)
- Developed independent implementations for each browser
 - On-the-fly validation (as fast as 1 GB/s)
 - SSA (V8 and SpiderMonkey) → direct-to-SSA in a single pass
- Other Optimizations
 - Bounds Check - Constant-fold memsize - offset
 - Parallel Compilation (5-6x improvement)
 - Compiled code caching (memoization)

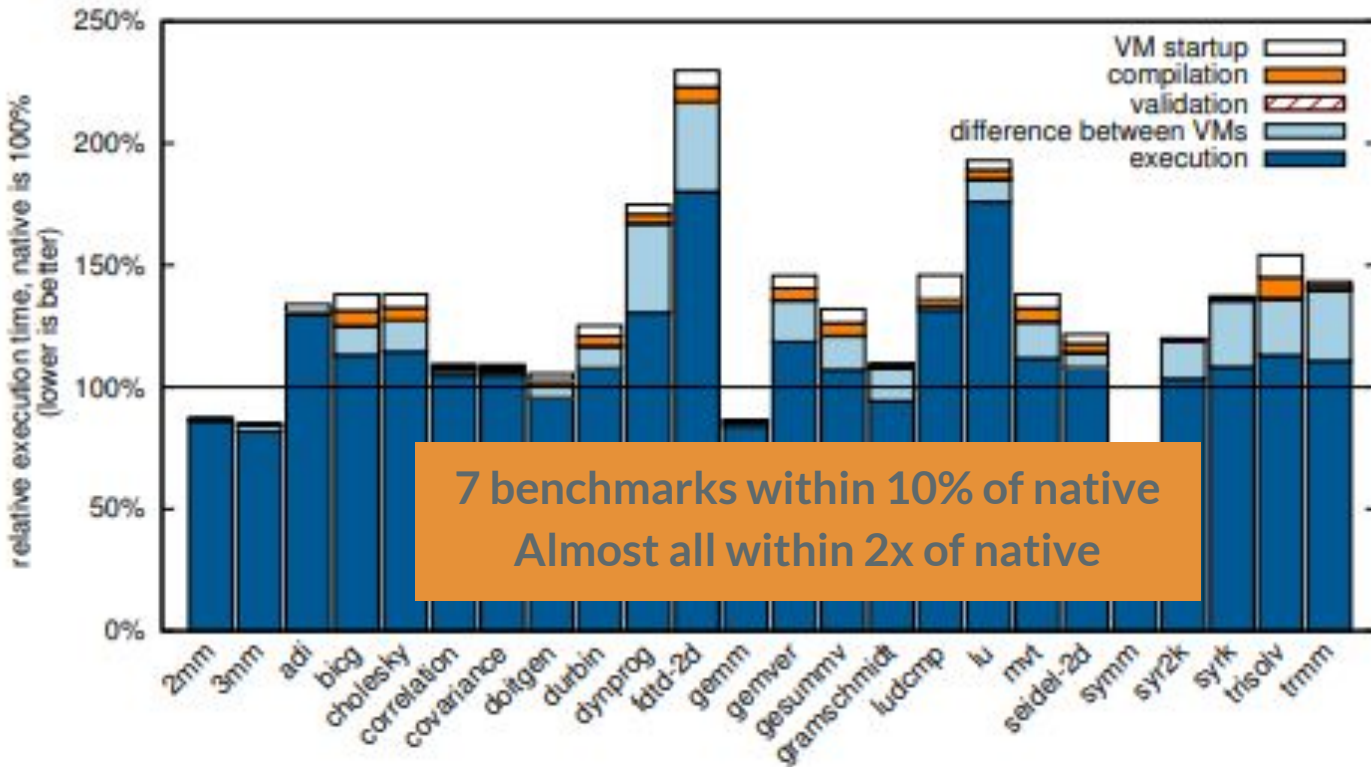
Measurements

Execution time of PolyBenchC benchmarks on Webassembly normalized to native code



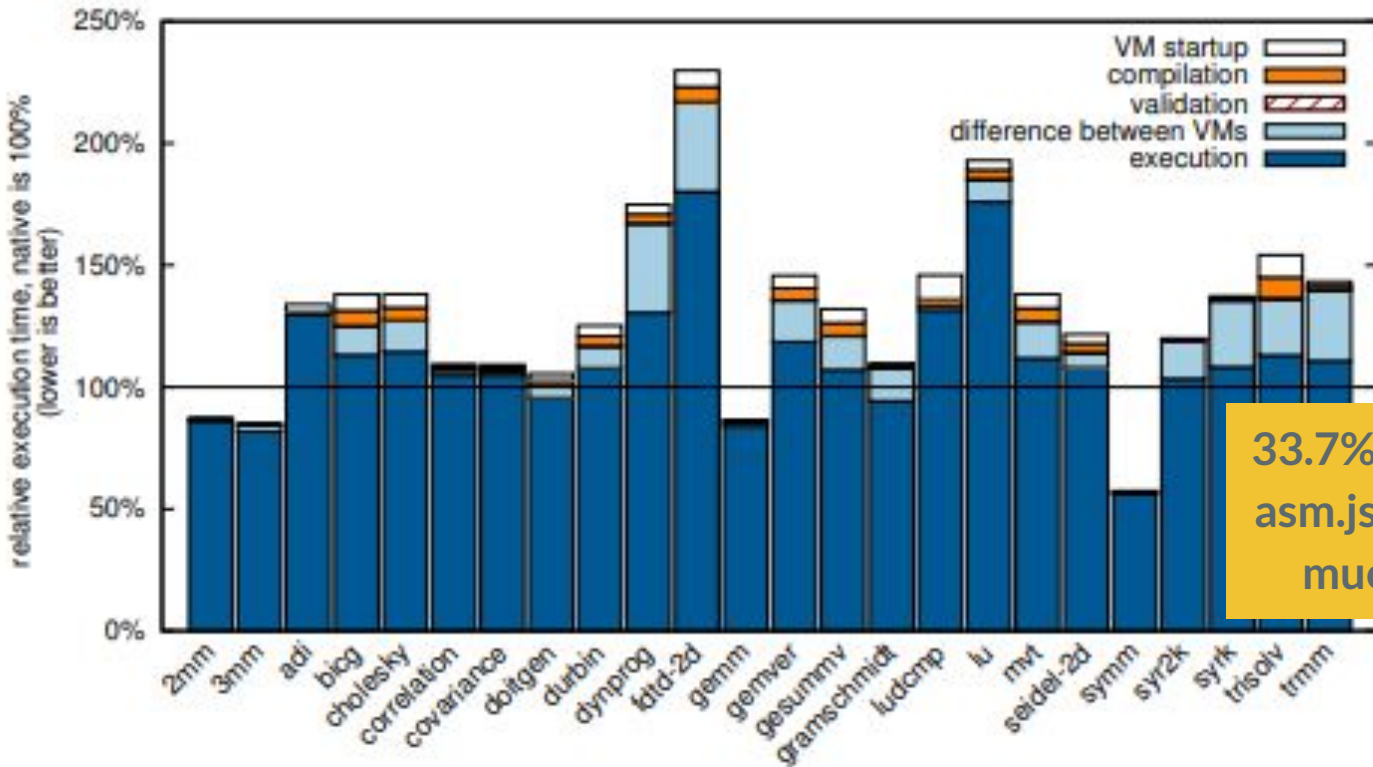
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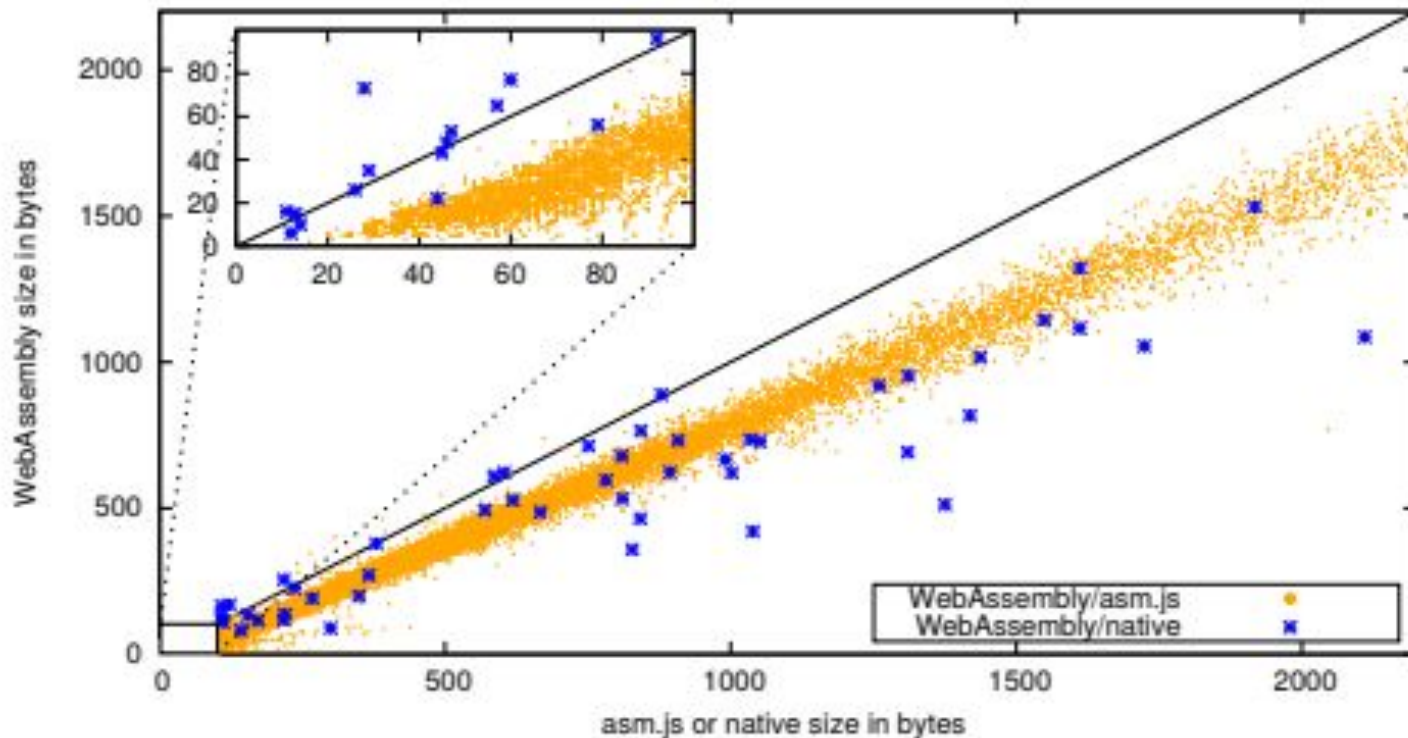
Execution time of PolyBenchC benchmarks on Webassembly normalized to native code



33.7% faster than asm.js (validation much faster)

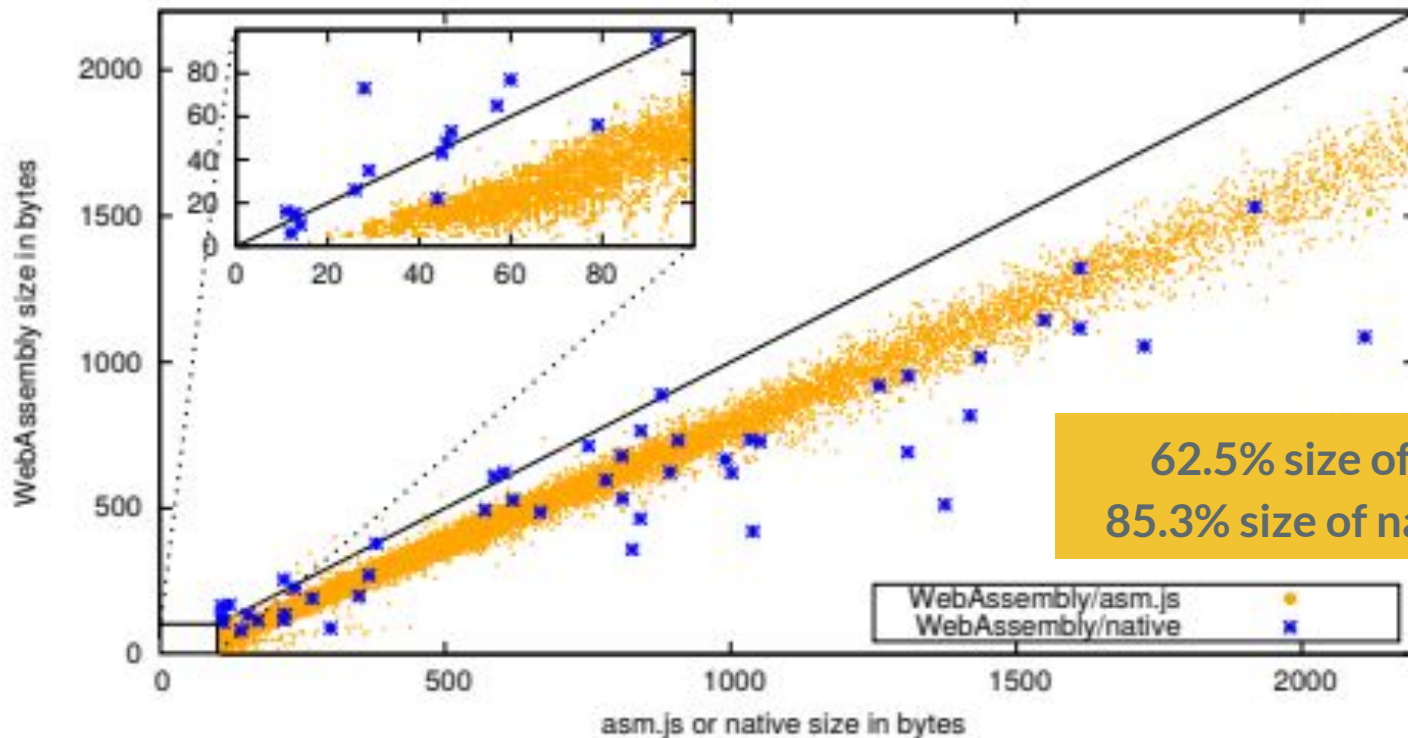
Measurements

Binary size of WebAssembly in comparison to asm.js and native code



Measurements

Binary size of WebAssembly in comparison to asm.js and native code



62.5% size of asm.js
85.3% size of native x86

Evaluation

- Strength
 - Ability to write in any language
 - Faster compilation
 - Compact
 - Fast
- Weaknesses
 - Separate compiler to port each language to WebAssembly

Road Map

- MVP Completed (3 years ago)
- Features in process:
 - Exception handling
 - Threads
 - Garbage Collection
 - Single Instruction Multiple Data instructions
 - Tail Calls

<https://webassembly.org/docs/future-features/>

Community & Current Updates

Understand WebAssembly: Why It Will Change the Web

Dec 19, 2017 -

Why WebAssembly is a game changer for the web—and a source of pride for Mozilla and Firefox

Mar 7, 2017 -

Rust language gets direct WebAssembly compilation

Nov 29, 2017

Making WebAssembly even faster: Firefox's new streaming and tiering compiler

Jan 17, 2018 -

WebAssembly Threads ready to try in Chrome 70

Nov 5, 2018 -

Questions?

Appendix A – Why is WebAssembly faster than asm.js?

- Startup
 - Smaller to download, faster to parse
- CPU features
 - asm.js doesn't have access to CPU features -- slower
-