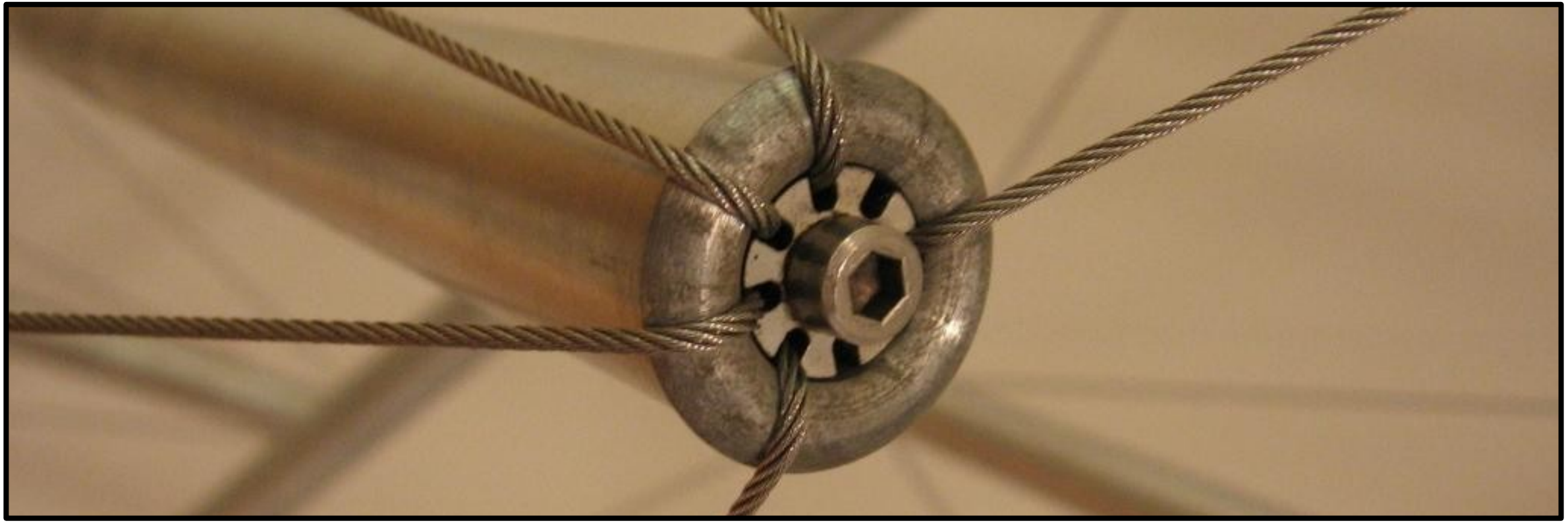
WebAssembly

Julian Arz - 21.10.2022



What is WebAssembly?

WebAssembly is a portable binary format.

It lets you run languages other than JavaScript in the browser.

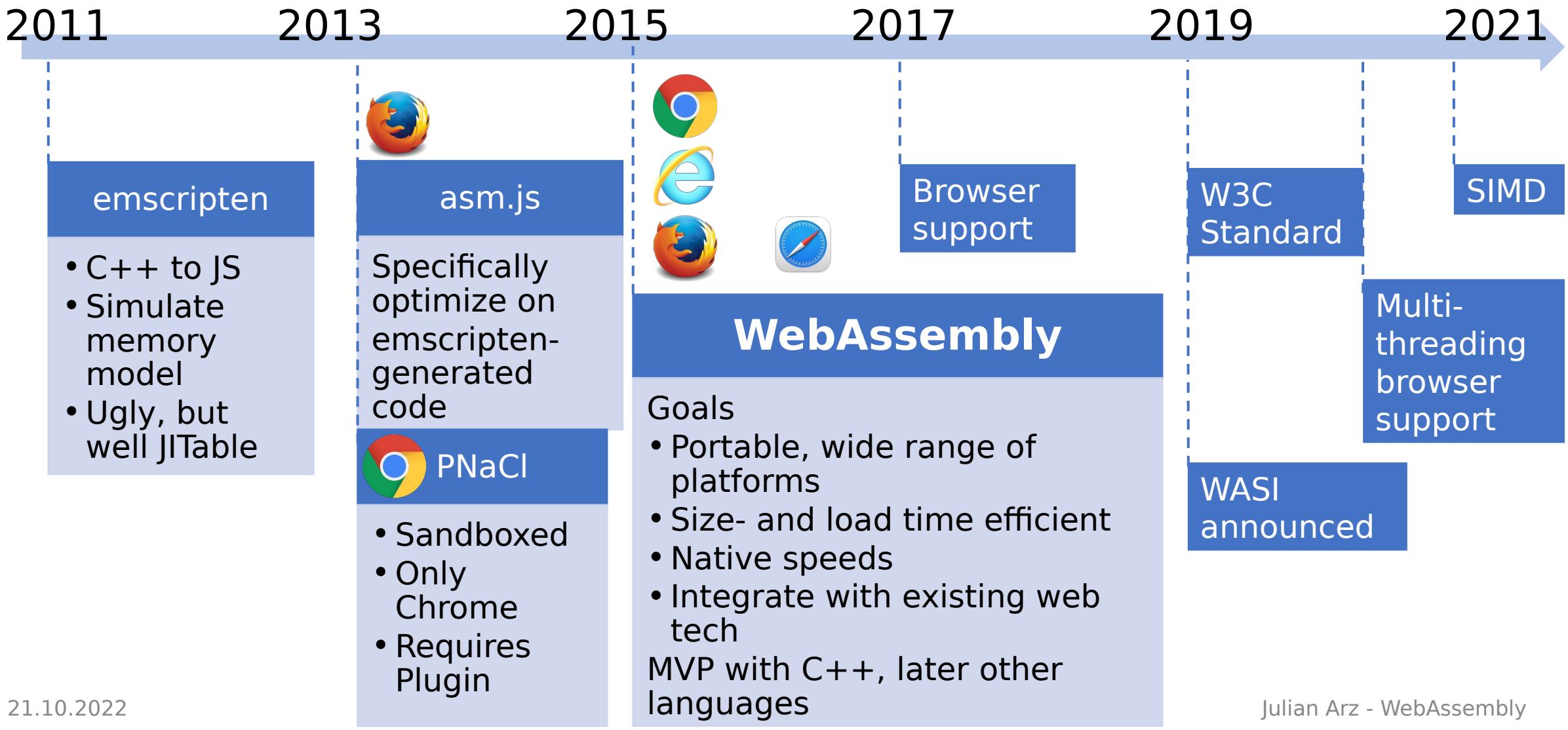
But also:

WebAssembly is not assembly, and it is also not (only) for the web.

Topics

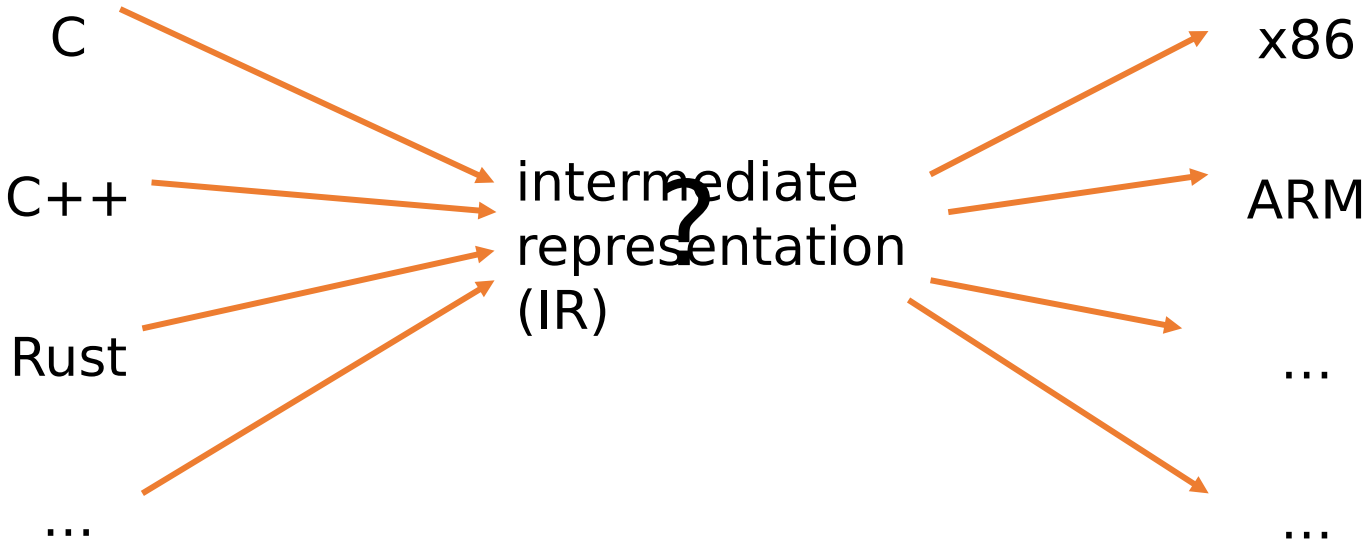
- History & Goals
- Demo
- Use cases
- Languages

History: C++ in Browser



LLVM

- Compiler for C/C++, later also Rust. Today a lot more.



Demo

Hello World

Heron

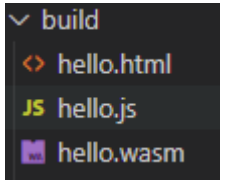
Labyrinth

Demo: Hello World

```c
#include <stdio.h>

int main() {
    printf("Hello WebAssembly!");
}
```

```
$ emcc hello.cpp -o hello.html
```



Text

```
(import "wasi_snapshot_preview1" "fd_close" (func (;0;) (type 0)))
(import "wasi_snapshot_preview1" "fd_read" (func (;1;) (type 10)))
(import "wasi_snapshot_preview1" "fd_write" (func (;2;) (type 10)))
(import "env" "__cxa_atexit" (func (;3;) (type 3)))
(import "env" "abort" (func (;4;) (type 6)))
(import "wasi_snapshot_preview1" "environ_sizes_get" (func (;5;) (type 2)))
(import "wasi_snapshot_preview1" "environ_get" (func (;6;) (type 2)))
(import "env" "strftime_l" (func (;7;) (type 9)))
(import "env" "emscripten_resize_heap" (func (;8;) (type 0)))
(import "env" "emscripten_memcpy_big" (func (;9;) (type 3)))
(import "env" "setTempRet0" (func (;10;) (type 4)))
(import "wasi_snapshot_preview1" "fd_seek" (func (;11;) (type 9)))
```

WebAssembly has no library, imports everything from environment -> **portability**

Demo: Heron

```cpp
extern "C" {
    double heron(const double number) {
        double x = 42.0;
        for (int i = 0; i < 1000; ++i) {
            x = (x + number / x) / 2.0;
        }
        return x;
    }
}
```

optimize for size, dce

```
$ emcc heron.cpp --no-entry -Os -s EXPORTED_FUNCTIONS=[_heron] -o heron.wasm
```

heron.wasm

no main method

make it callable from JS

Call from JS:

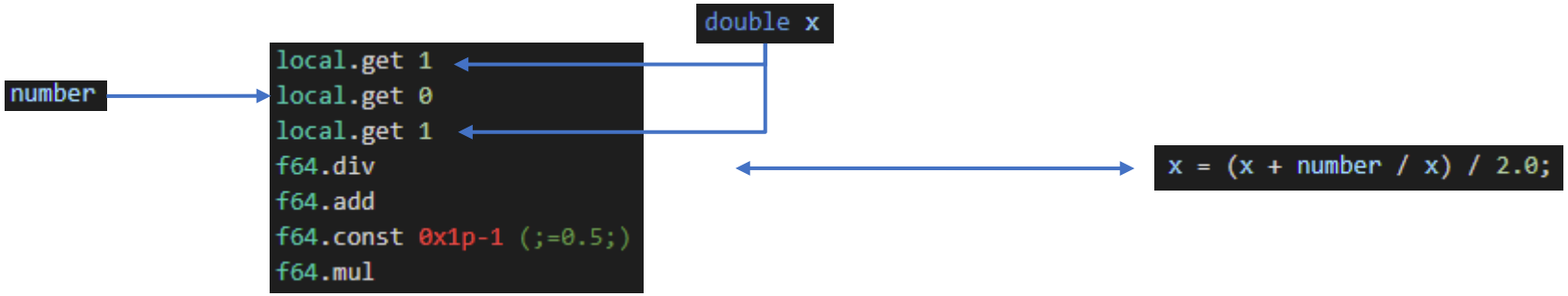
Browser API →

```js
WebAssembly.instantiateStreaming(fetch("heron.wasm")).then((obj) => {
    heron = obj.instance.exports.heron;
});

computeButton.onclick = function (event) {
    const value = parseFloat(input.value);
    const result = heron(value);
    outputDiv.innerHTML = result;
};
```

Demo: Heron

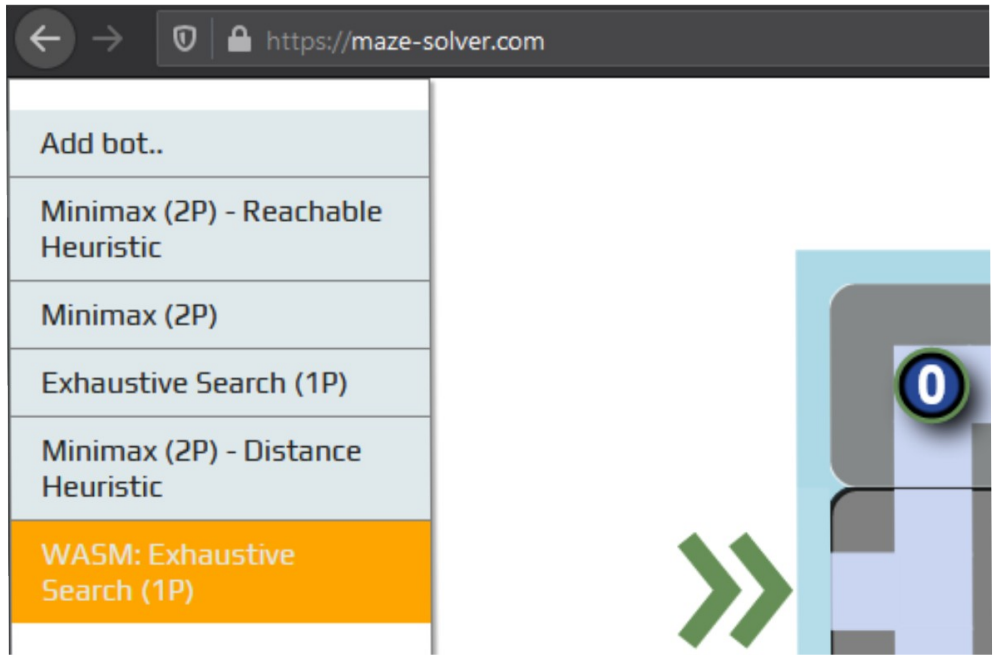
Code: Reverse Polish Notation (stack machine semantics)



It‘s not JavaScript, but is also not assembly!

Close to assembly, allows compiling while downloading

Demo: Labyrinth



- Hello World & simple functions: easy
- Pass / return complex data types: tricky

My first experiences (around 2019):

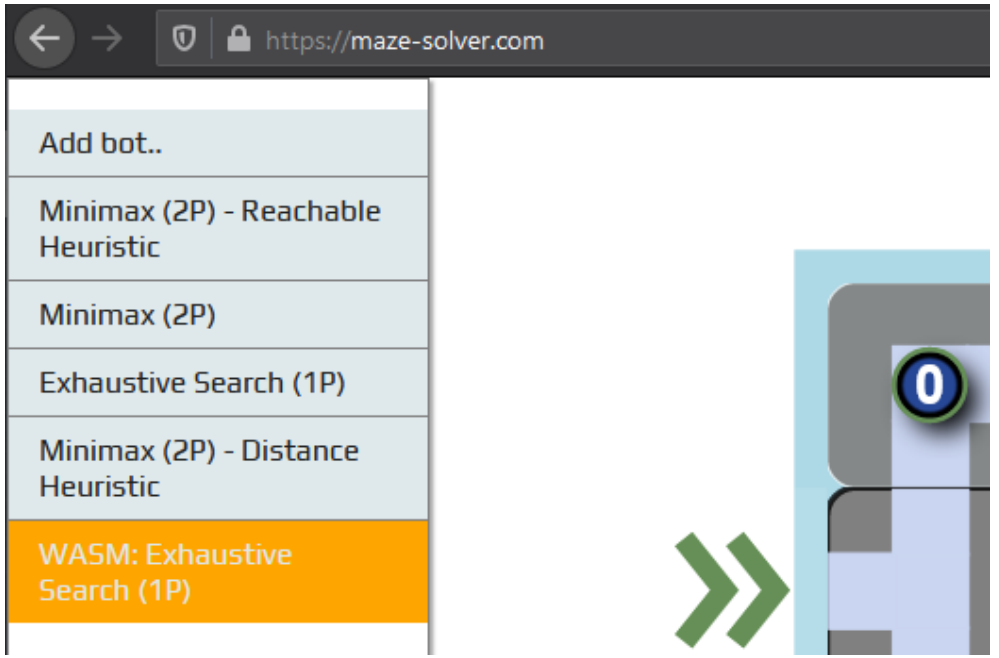
- No clear guidelines, bad documentation, no debugging capabilities
- Also a C++ - issue. Go is better. Maybe Rust best?

Today (2022):

- Better documentation, both Chrome and Firefox have debuggers

Demo: Labyrinth

- Opens new possibilities
- Choose the right tool for the job



Why new Standard? Limitations of JS

- Dynamic typing: optimizer has to check types at runtime
- JIT introduces overhead & requires a few cycles to warm up
- Entire script has to be downloaded before parsing can begin
- GC introduces overhead & unpredictable slowdowns

How does WebAssembly relate to...

… JavaScript?

- Goal: complement of JS, not replacement
- Releases feature pressure from JS (e.g. SIMD, multi-threading, …)
- Use cases: high performance, low start-up

gaming

virtual / augmented reality

cryptography

CAD

language interpreters

AI / machine learning

scientific computing

VMs

video editing

cryptography

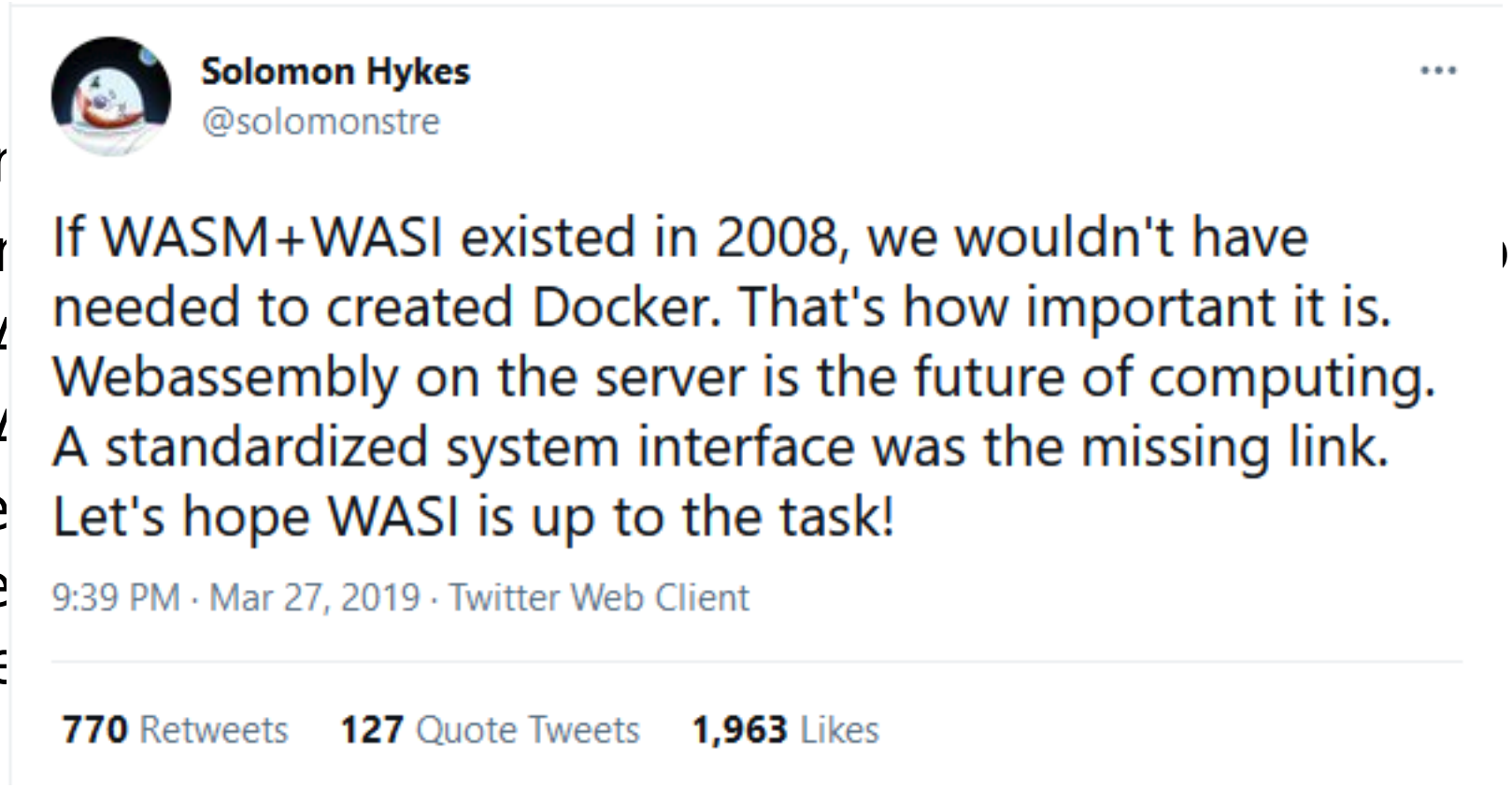
… the JVM?

- Java Applets: heavy-weight, slow startup
- WebAssembly: use existing functionalities of browsers

- WebAssembly is not limited to the Web
  - Runtimes outside of browser: wasmtime, Wasmer, lucet
  - Standardization process − WebAssembly System Interface (WASI)
- Java had a similar goal: „Write once, run anywhere“

… Docker?

- Container
- WebAsser
- Can WebA
- Can WebA
  - Maybe
  - e.g. se
  - Krustle



inary files

Performance

- It depends
- Benchmarks (see Appendix): up to factor 2 to 4 faster, some also slower
  - V8 builds on 10 years of experience
- If raw execution speed is the only criterion: it might not be worth it
- Smaller file size, faster startup, no JIT overhead, no GC
  - predictable performance (same across all browsers)
- Comparing inter-language performance is tricky
  - A programming language does not have a velocity
  - Implementation, language, compiler, runtime, hardware
  - Port and compare? Or two independent implementations?
  - C++ has language features tailored to performance

Security

- WebAssembly is designed to be safe
  - Sandboxed, application has to import functionality
  - Heap is separated from rest of memory
  - Multiple other mitigations
- Malicious software harder to detect than JS
  - e.g. in-browser crypto-mining
- Vulnerabilities have been found (language-specific)
  - e.g. stack buffer overflows
  - compromise the attacked web-app (not the host)

Languages

Stable

- C/C++, Rust (both via LLVM)
- Go (WASI with TinyGo)
- C# (Blazor)
- A few more ...

Unstable, but usable

- Python (e.g. pyodide)
- Java?

Languages

Difficult to adopt: dynamic typing, garbage collection

Work in progress: add GC to WebAssembly

- Idea: let host system do GC

But then, how do Python and C# do it?

In general, two options:

- Compile language to WebAssembly, or
- Compile runtime/interpreter to WebAssembly

Languages

- Compile language to WebAssembly, or
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Stable

- C/C++, Rust (both via LLVM)
- Go (WASI with TinyGo)
- C# (Blazor), .NET
- A few more …

Unstable, but usable

- Python (e.g. pyodide)
- Java
  - TeaVM, JWebAssembly
  - CheerpJ
- Some more
  - (Ruby, Swift, PHP, …)

Conclusion

- WebAssembly is a W3C standard for a binary format, designed to be memory-safe, portable, and fast.
- Not only in browser
- Main use cases: portability and performance

- High potential for big impact in web and cloud

Sources

Articles & Presentations

https://hacks.mozilla.org/2017/02/a-cartoon-intro-to-webassembly/
http://kripken.github.io/mloc_emscripten_talk/
https://adlrocha.substack.com/p/adlrocha-can-wasm-become-the-new
https://hacks.mozilla.org/2019/03/standardizing-wasi-a-webassembly-system-interface/

Projects

https://wasmtime.dev/
https://wasmer.io/
https://github.com/bytecodealliance/lucet
https://emscripten.org/
https://blazor.net/

Talks

RustConf 2019: Clark, L. (2019). Closing Keynote https://www.youtube.com/watch?v=IBZFJzGnBoU

Podcasts

In **Software Engineering Daily**: Meyerson, J. (2021, March 23). Suborbital: WebAssembly Infrastructure with Connor Hicks (No. 1226)
In **Software Engineering Daily**: Meyerson, J. (2019, June 20). WebAssembly Compilation with Till Schneidereit (No. 855)
In **Software Architecture Radio**: Stine, M. (2019, March 27). WebAssembly with Brian Sletten (No. 7)
In **CppCast**: Turner, J & Irving, R. (2015, July 9). WebAssembly with JF Bastien (No. 15)
In **CppCast**: Turner, J & Irving, R. (2020, June 11). WebAssembly with Ben Smith (No. 251)

Sources

Misc

https://webassembly.org/docs
https://twitter.com/solomonstre/status/1111004913222324225
https://github.com/appcypher/awesome-wasm-langs
https://madewithwebassembly.com/

Security

https://webassembly.org/docs/security/
Lehmann, Daniel, Johannes Kinder, and Michael Pradel. "Everything old is new again: Binary security of webassembly." 29th {USENIX} Security Symposium ({USENIX} Security 20). 2020.
https://www.virusbulletin.com/virusbulletin/2018/10/dark-side-webassembly/
https://spectrum.ieee.org/tech-talk/telecom/security/more-worries-over-the-security-of-web-assembly

Benchmarks

https://medium.com/@torch2424/webassembly-is-fast-a-real-world-benchmark-of-webassembly-vs-es6-d85a23f8e193
Real world benchmark of GameBoy emulator
- Two ROMs, multiple devices, three browsers, comparing JS vs. WebAssembly
- Desktop: WebAssembly is 67% faster than JS on Chrome, on FF even 11 times faster. Results for mobile show greater speed-up.

https://developers.google.com/web/updates/2019/02/hotpath-with-wasm
Rotating a 16 MP image, JS vs WebAssembly.
- Browsers have different execution speeds in JS (different JS-engines). WebAssembly has same speed across all browsers -> predictable performance
- Measuring one-shot times, not allowing JS to be optimized from the start
- Even in fastest browser WebAssembly is 20% faster than JS

https://surma.dev/things/js-to-asc/
blurring images
- Rust and C - compiled WebAssembly slightly slower than fastest JS-Compiler (TurboFan)
- TurboFan 50times faster than Ignition.

https://medium.com/vacatronics/webassembly-in-go-vs-javascript-a-benchmark-6deb28f24e9d
WebAssembly compiled from Go and C
- is_primrecursive fibonacci: WebAssembly 3times slower than JS
- iterative e: WebAssembly 4times faster than JS

https://dev.to/linkuriousdev/to-wasm-or-not-to-wasm-3803
- n-body-problem: WebAssembly compiled from C, Rust, and AssemblyScript.
- WebAssembly 20% to 50% slower than native, and 20% slower than JS.

https://www.youtube.com/watch?v=aC_QLLilwso
- Calculating prime numbers: C++ native 2 times faster than JS, WebAssembly slightly slower than native. JS warmup is discussed.