WA

WEBASSEMBLY

What is WebAssembly

> WebAssembly (abbreviated Wasm) is a binary instruction format for a stack-based virtual machine. Wasm is designed as a portable compilation target for programming languages, enabling deployment on the web for client and server applications.

What is WebAssembly? (cont.)

- Stack-based virtual machine (similar to the JVM or the CIL of .NET)
  - Non object-oriented (only supports simple datatypes)
  - Linear memory - memory is just an `ArrayBuffer` (no GC)
- Compilation target of compiled programming languages
- Sandboxed execution environment
  - Host interaction via imports/exports
  - security checks applied
- W3C standard (1.0)

How to run?

- Built-in browser support: https://caniuse.com/?search=wasm

Chrome	Edge *	Safari	Firefox	Opera	IE	Chrome for Android	Safari on iOS *	Samsung Internet	Opera Mini *	Opera Mobile *	UC Browser for Android	Android Browser *	Firefox for Android	QQ Browser	Baidu Browser	KaiOS Browser
			2-46													
4-50	12-14		[1] 47-51	10-37												
[2] 51-56	[3] 15	3.1-10.1	[4] 52	[2] 38-43			3.2-10.3	4-6.4								
57-124	16-124	11-17.4	53-125	44-108	6-10		11-17.4	7.2-23		12-12.1		2.1-4.4.4				[1] 2.5
125	125	17.5	126	109	11	124	17.5	24	all	80	15.5	124	125	14.9	13.52	3.1
126-128		17.6-TP	127-129				17.6									

- Built-in *node.js* support
- Dedicated / stand-alone interpreters (see later)

Which languages can compile to WASM?

- C/C++ `emscripten`
- Rust *built-in*
- Go *built-in*, `TinyGo`
- C# `Blazor`, `Uno` / F# *community*
- Kotlin *built-in*
- AssemblyScript *native*
- Dart/Flutter *built-in*
- Swift *community*
- Zig *built-in*
- Nim (via generated C-Code)
- ...

Why WASM?

- Performance
- Re-use existing (C/C++) code bases
- Hide implementation details (better then JS obfuscation)

Use Case #1: Web Apps

- Re-use existing code bases in browser apps
- Use WASM to provide calculation intense parts of an app
  - signal processing (images, video, audio)
  - Complex calculations (i.e. graphics, 3d models)
  - Weather simulation
  - Games (of course 😃)
- In use today:
  - Jupyter Notebooks (running full Python interpreter on WASM incl. numpy, ...)
  - Photoshop/Lightroom browser apps (Adobe)
  - Figma
  - TinkerCAD
  - ...

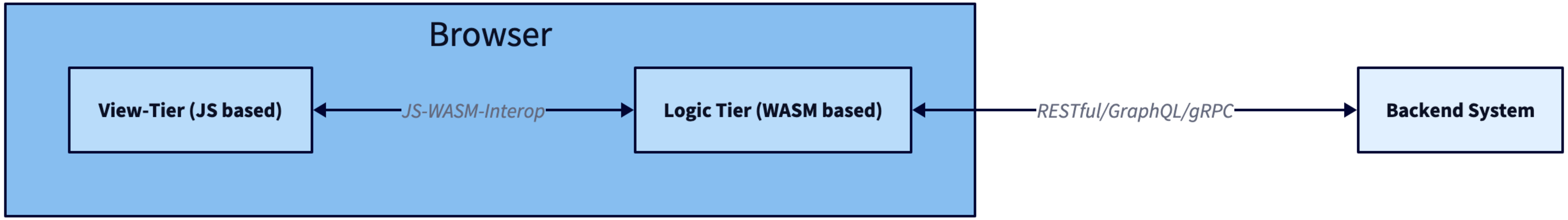
Downsides (Web Apps)

- No built-in API for DOM manipulations
  - Needs JS interaction hooks (slow)
  - Will be refined in upcomining standards draft
- "Fat" binaries
  - No GC built-in -- languages need to ship a custom GC as part of the module
  - No standard lib - languages need to package everything they need

WebAssembly 2.0 (draf) will address some of these with

- reference types
- optional GC to be used to cleanup WebAssembly memory

3-tier web app architecture



WASI - WebAssembly System Interface

- Own spec building on WebAssembly specs
- Same VM/assembly code
- Specs for types/functions that interact with the underlying OS
    - Filesystem
    - I/O streams
- Very early draft (current spec is named "preview1", "preview2" is in dev)

Use Case #2: Backend Apps/Serverless/FaaS

- Write portable backend apps/functions targetting WASM/WASI
  - Use any language that can compile to WASM/WASI
- Different VM implementations: wasmtime, WAMR, WasmEdge, wazero, Wasmer, wasmi, wasm3
- Kubernetes devs work on providing k8s for WASM (instead of Containers): FaaS

Downsides (Backend Apps)

- WASI specs early drafts
- Lots of features missing (i.e. direct network access)
- Area of active development

How does a virtual stack machine work

- operands are pushed onto a stack
- Operations pop operands off the stack and push the result back onto the stack
- Function arguments and return values are also passed via the stack

How does a virtual stack machine work (cont.)

`2 + 3`

```
i32.const 2
i32.const 3
i32.add
```

How does a virtual stack machine work (cont.)

`2 + 3`

```
i32.const 2
i32.const 3
i32.add
```

... or equivalent as *S-expressions*

```
(i32.add
    (i32.const 2)
    (i32.const 3)
)
```

How does it look like?

```
(module
    ;; Define a function fib to calculate the n-th fibonacci number in a resource wasting way.
    (func $fib (export "fib") (param i64) (result i64)
        ;; Calculate param < 3
        (i64.lt_u
            (local.get 0)
            (i64.const 3)
        )

        ;; If result of comparison is true (!= 0)...
        (if (result i64)
            (then
                ;; ... then put 1 on the stack ...
                i64.const 1
            )
            (else
                ;; ... otherwise compute fib(param - 1) + fib(param - 2)
                ;; and leave the result on the stack
                (i64.add
                    (call $fib
                        (i64.sub
                            (local.get 0)
                            (i64.const 1)
                        )
                    )

                    (call $fib
                        (i64.sub
                            (local.get 0)
                            (i64.const 2)
                        )
                    )
                )
            )
        )
    )
)
```

Hello, WASI

```
(module
    ;; Import the required fd_write WASI function which will write the given io vectors to stdout
    ;; The function signature for fd_write is:
    ;; (File Descriptor, *iovs, iovs_len, *nwritten) -> Returns 0 on success, nonzero on error
    (import "wasi_snapshot_preview1" "fd_write" (func $fd_write (param i32 i32 i32 i32) (result i32)))

    ;; Reserve 1 page of memory (=64Kb) and export it
    (memory 1)
    (export "memory" (memory 0))

    ;; Write 'hello world\n' to memory at an offset of 8 bytes
    (data (i32.const 8) "hello world\n")

    (func (export "_start")
        ;; Creating a new io vector within linear memory
        (i32.store (i32.const 0) (i32.const 8))  ;; iov.iov_base - This is a pointer to the start of the 'hello world\n' string
        (i32.store (i32.const 4) (i32.const 12))  ;; iov.iov_len - The length of the 'hello world\n' string

        (call $fd_write
            (i32.const 1) ;; file_descriptor - 1 for stdout
            (i32.const 0) ;; *iovs - The pointer to the iov array, which is stored at memory location 0
            (i32.const 1) ;; iovs_len - We're printing 1 string stored in an iov - so one.
            (i32.const 20) ;; nwritten - A place in memory to store the number of bytes written
        )
        drop ;; Discard the number of bytes written from the top of the stack
    )
)
```

How fast is WASM?

Very simple CPU-intensive benchmark:

```
// Javascript
function fib (x) {
    if (x === 0) return 0;
    if (x < 2) return 1;
    return fib(x-1) + fib(x-2);
}
```

```
// C
unsigned long long fib(const unsigned long long x) {
    if (x == 0) return 0;
    if (x < 3) return 1;
    return fib(x-1) + fib(x - 2);
}
```

How fast is WASM? (cont.)

Implementation	Time for `fib(45)` [s]	Size of the binary [kB]	env
JavaScript	6.3	0.2	node v22
C (native; unoptimized)	4.6	33	macOS
C (native; optimized)	2.0	33	macOS
C (WASM; unoptimized)	9.3	(59 + 13) = 72	node v22
C (WASM; optimized)	2.7	(12 + 6.3) = 18.3	node v22
WASM (handwritten)	4.7	0.06	wasmtime

How fast is WASM? (cont.)

Implementation	Time for `fib(45)` [s]	Size of the binary [kB]	env
Go (native)	2.4	2,000	macOS
Go (WASM)	12.2	2,100	node v22 w/ custom JS
Go (WASM)	47.2	2,100	wasmtime
TinyGo (WASM)	2.9	603	node v22 w/ custom JS
TinyGo (WASM)	2.8	603	wasmtime

```
function fib (x) {
    if (x < 2) return x;
    let a = 0, b = 1;
    for (let i = 2; i <= x; i++) {
        const tmp = a + b; a = b; b = tmp;
    }
    return b;
}
```

Implementation	Time for `fib(45)` [s]
JavaScript	6.3
C (native; optimized)	2.0
JavaScript (dynamic programming; bottom up)	0.05

Live Demo

Stuff to check out

- https://webassembly.org
- https://developer.mozilla.org/en-US/docs/WebAssembly
- https://wasi.dev
- https://www.cncf.io/blog/2024/03/12/webassembly-on-kubernetes-from-containers-to-wasm-part-01/