Part 1:
Introduction to WebAssembly

What is WebAssembly?

Bringing the Web up to Speed with WebAssembly

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Abstract

The maturation of the Web platform has given rise to sophisticated and demanding Web applications such as interactive 3D visualization, audio and video software, and games. With that, efficiency and security of code on the Web has become more important than ever. Yet JavaScript as the only built-in language of the Web is not well-equipped to meet these

device types. By historical accident, JavaScript is the only natively supported programming language on the Web, its widespread usage unmatched by other technologies available only via plugins like ActiveX, Java or Flash. Because of JavaScript's ubiquity, rapid performance improvements in modern VMs, and perhaps through sheer necessity, it has become a compilation target for other languages. Through Emscripten [43], even C and C++ programs can be compiled to

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WEBASSEMBLY

Overview | Getting Started | Docs | Spec | Community | Roadmap | FAQ

WebAssembly 1.0 has shipped in 4 major browser engines. Learn more

WebAssembly (abbreviated *Wasm*) is a binary instruction format for a stack-based virtual machine. Wasm is designed as a portable target for compilation of high-level languages like C/C++/Rust, enabling deployment on the web for client and server applications.

Haas et al., PLDI 2017

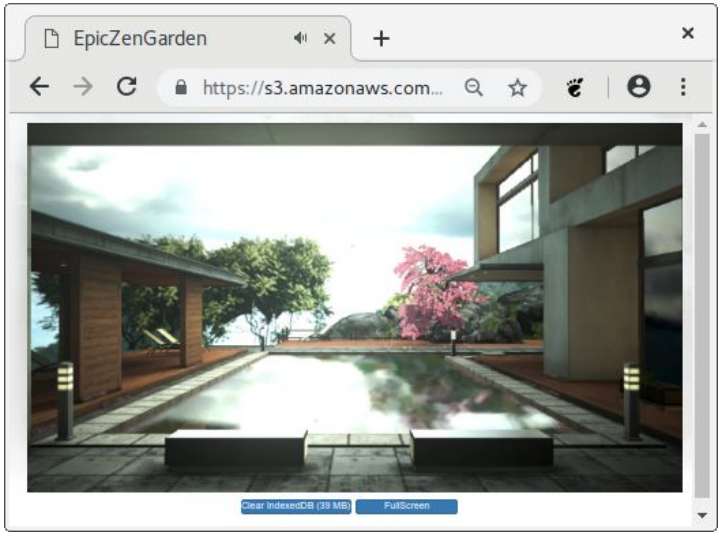
https://webassembly.org/

What is WebAssembly?

- “Byte code for the web”
  - Very rough idea: “JVM, without 3rd party plugins, directly in the browser”
  - Lower-level than JavaScript
- Fast
  - Compact binary format → quicker to parse
  - Instructions map closely to common hardware
  - Linear memory, no garbage collector
- Safe
  - Typed, separated code and data, modules, ...
- Portable
  - Support by all 4 major browsers, x86/ARM

Use Cases

- Designed as compilation target
  - For low-level languages
  - From C, C++ with Emscripten
  - Rust, Go, …
- Application domains
  - Audio/video processing, codecs, e.g., AV1
  - Compression, e.g., Brotli
  - Games, simulations, e.g., Unreal Engine 4
  - Language runtimes, e.g., Blazor (C#)
  - Complex web applications, e.g., AutoCAD



https://s3.amazonaws.com/mozilla-games/ZenGarden/EpicZenGarden.html

Binary and Text Format

WebAssembly Code Explorer

```
0x00000000  00 61 73 6D 01 00 00 00 01 07 01 60 02 7F 7F 01   .asm.......`....
0x00000010  7F 03 02 01 00 07 07 01 03 61 64 64 00 00 0A 09   .........add....
0x00000020  01 07 00 20 00 20 01 6A 0B 00 1C 04 6E 61 6D 65   ... . .j....name
0x00000030  01 06 01 00 03 61 64 64 02 0D 01 00 02 00 03 6C   .....add.......l
0x00000040  68 73 01 03 72 68 73                              hs..rhs
```

```
(module
  (type $type0 (func (param i32 i32) (result i32)))
  (export "add" (func $func0))
  (func $func0 (param $var0 i32) (param $var1 i32) (result i32)
    get_local $var0
    get_local $var1
    i32.add
  )
)
```

https://webassembly.studio/

Text Format: Overview

- Syntax: S-expressions
- 1 file = 1 module
- 1 module : n sections
  - Types
  - Imports/Exports
  - Functions
  - Globals
  - Data

```
(module
  (type $t0 (func (param i32 i32) (result i32)))
  ...
  (import "env" "b" (func $env.b (type $t4)))
  ...
  (func $f7 (param i32 i32) (result i32)
    (local $l0 i32) ...
    get_global $g2
    i32.const 48
    i32.add
    set_global $g2
    ...
    i32.load
    ...
  (global $g2 (mut i32))
  (export "h" (func $h))
  (data (i32.const 1152) "Hello, world!")
)
```

Text Format: Instructions

- Code is organized in functions
  - No OOP: no objects or methods
- Globals, per-function locals
- Stack machine
- 4 types: i32, i64, f32, f64
- Linear, unmanaged memory
  - 32-bit addresses

```
(module
  (type $t0 (func (param i32 i32) (result i32)))
  ...
  (import "env" "b" (func $env.b (type $t4)))
  ...
  (func $f7 (param i32 i32) (result i32)
    (local $l0 i32) ...
    get_global $g2
    i32.const 48
    i32.add
    set_global $g2
    ...
    i32.load
    ...
  (global $g2 (mut i32))
  (export "h" (func $h))
  (data (i32.const 1152) "Hello, world!")
)
```

Structured Control-Flow

- Well-nested blocks
  - Branches (`br`) reference blocks by numerical *label*
- Block types: block, if, loop

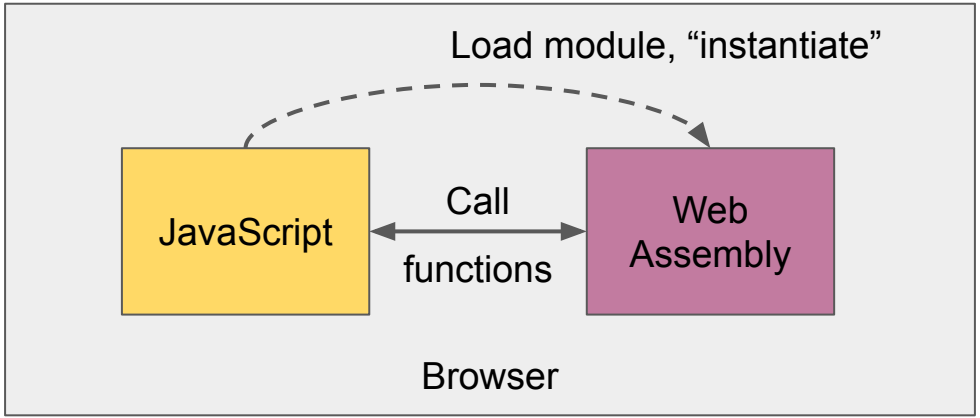
```
block
  ...
  br_if 0
  ...
end
...
```

```
;; infinite loop
loop
  ...
  br 0
end
...
```

```
i32.const 0
if
  ...
else
  ...
end
...
```

Host Embedding

- WebAssembly itself is agnostic of its *host*
  - No functions defined by default
  - No system calls/IO routines by default
- Most common embedding: web browsers



WebAssembly API in JavaScript

```
1   let importObject = {
2       env: {
3           print: function(s) {
4               console.log(s);
5           },
6       }
7   };
8
9   fetch("hello.wasm")
10      .then(response => response.arrayBuffer())
11      .then(buffer => WebAssembly.instantiate(buffer, importObject))
12      .then(object => {
13          let inputs = ...;
14          let result = object.instance.exports.somefun(inputs);
15          ...
16      });
```

WebAssembly API in JavaScript

- WebAssembly global object
- Usual lifecycle:
  - Load .wasm file with fetch()
  - Instantiate the file = compile and provide imports
  - Call exported functions on the instance
- Instantiation methods
  - Blocking: `new WebAssembly.Instance(...)`
  - Async: `await WebAssembly.instantiate(buffer, imports)`
  - Streaming: `await WebAssembly.instantiateStreaming(fetch(...), imports)`

Tooling and Documentation

- Emscripten: C → WebAssembly compiler
  - https://emscripten.org/
- WebAssembly Binary Toolkit
  - https://github.com/WebAssembly/wabt
  - wat2wasm
  - wasm2wat
  - wasm-objdump
- WebAssembly Specification
  - https://webassembly.github.io/spec/
  - E.g., instructions: https://webassembly.github.io/spec/core/bikeshed/index.html#instructions

Setup for Hands-On Tasks

- Download VirtualBox https://www.virtualbox.org/
- Copy or download VM image
  - USB stick
  - http://wasabi.software-lab.org/tutorial-pldi2019/
- “Import Appliance”
- $ cd ~/tutorial/wasabi/

  $ git pull

  $ cd ./tutorial/

Task 0.1: A Minimal WebAssembly Program

- Goals
  - Understand the text format
  - Convert between text and binary format
  - Embed a WebAssembly binary in a website
  - Run it in the browser
- Prerequisites
  - WebAssembly Binary Toolkit: https://github.com/WebAssembly/wabt
- Instructions
  - See README in https://github.com/danleh/wasabi/tree/master/tutorial/task0/1-hello

Task 0.2: Addition in WebAssembly

- Goals
  - Write a more useful function in WebAssembly
  - How to call WebAssembly functions from JavaScript
  - Bonus: WebAssembly i32 != JavaScript number
- Prerequisites
  - WebAssembly Binary Toolkit: https://github.com/WebAssembly/wabt
- Instructions
  - See README in https://github.com/danleh/wasabi/tree/master/tutorial/task0/2-add

Task 0.3: Compiling C to WebAssembly

- Goals
  - Learn about Emscripten
  - Compile C code to WebAssembly + HTML harness with Emscripten
  - See that you can “run C code in the browser”
- Prerequisites
  - Emscripten: https://emscripten.org/docs/getting_started/downloads.html
- Instructions
  - See README in https://github.com/danleh/wasabi/tree/master/tutorial/task0/3-hello-c