An Introduction to WebAssembly

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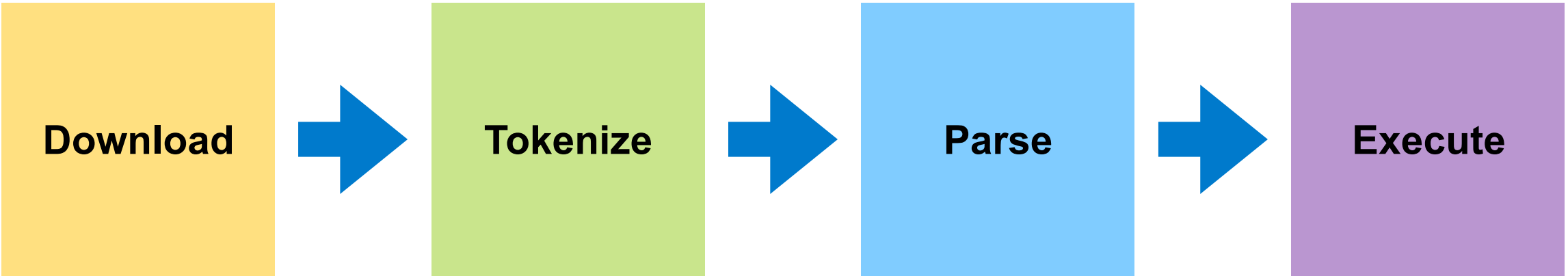
What is WebAssembly?

(Hint. It's a solution to a problem.)

WTH, JavaScript?

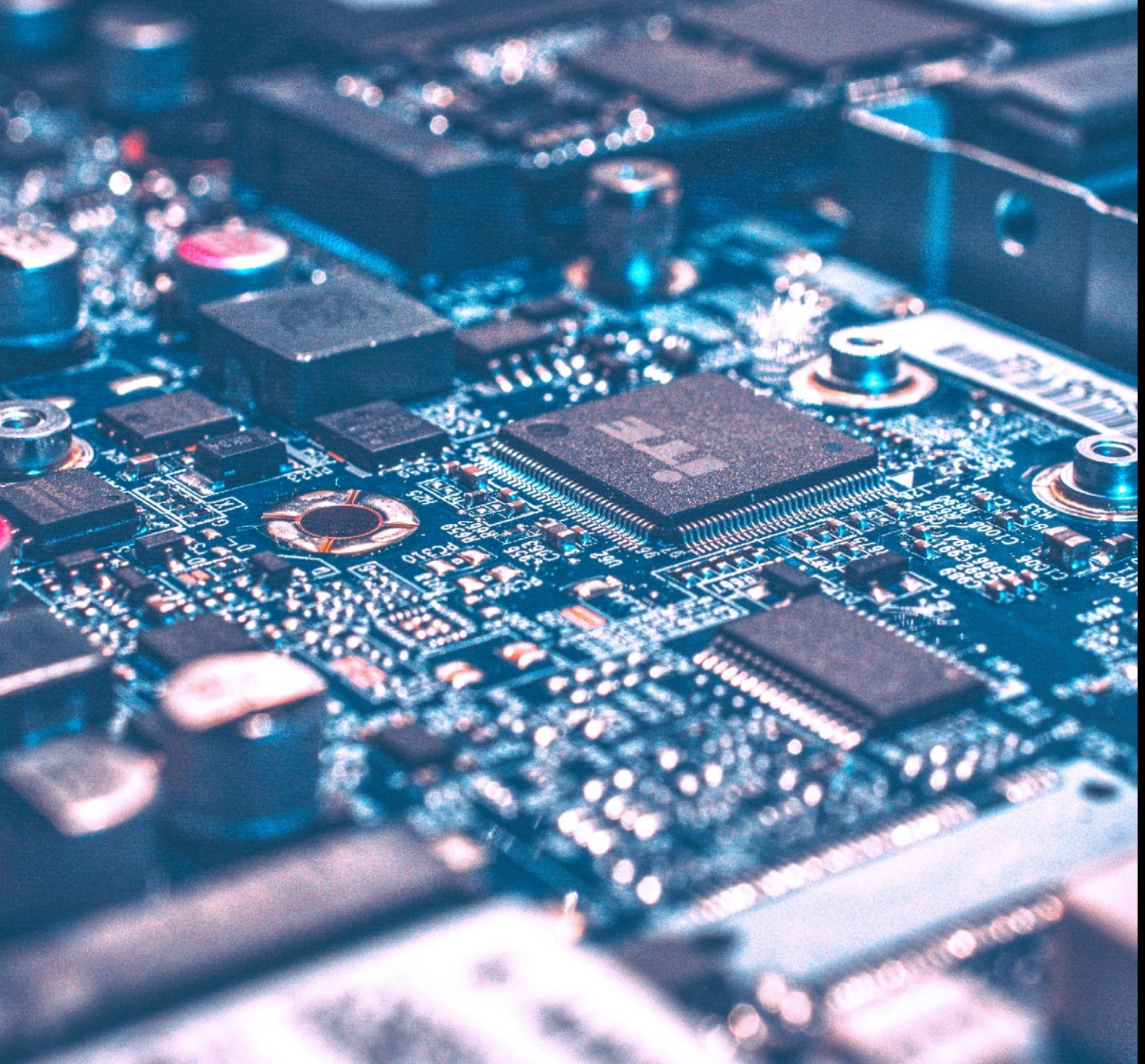
```
[] == ![]; // → true

NaN === NaN; // → false

Number.MIN_VALUE > 0; // → true

parseInt("firetruck"); // → NaN
parseInt("firetruck", 16); // → 15

console.log.call.call.call.call
  .call.apply(a => a, [1, 2]);

Math.min() > Math.max(); // → true
```

So Many Choices


Download
Tokenize
Parse
Execute

What If You Could Compile Code for the Browser?

WA



10100000 00000000
10100010 00000000
10001010 10000101
11000100 00100000
11011101 11110000
11001000 01110000
00000101 01001100
00000111 00000010
10111000 11101000
01001100 00000100
00000010

Address	Binary	Hex	Assembly
0200	10100000 00000000	A0 00	LDY #$00
0202	10100010 00000000	A2 00	LDX #$00
0204	10001010	8A	LOOP2 TXA
0205	10000101 11000100	85 C4	STA $00C4
0207	00100000 11011101 11110000	20 22 F0	LOOP1 JSR SCAN
020A	11001000	C8	INY
020B	01110000 00000101	70 05	BVS RESET
020D	01001100 00000111 00000010	4C 07 02	JMP LOOP1
0210	10111000	B8	RESET CLV
0211	11101000	E8	INX
0212	01001100 00000100 00000010	4C 04 02	JMP LOOP2

In the 1950's von Neumann was employed as a consultant to review proposed and ongoing advanced technology projects. One day a week, von Neumann "held court" at 590 Madison Avenue, New York. On one of these occasions in 1954 he was confronted with the FORTRAN concept; John Backus remembered von Neumann being unimpressed and that he asked "why would you want more than machine language?" Frank Beckman, who was also present, recalled that von Neumann dismissed the whole development as "but an application of the idea of Turing's `short code'." Donald Gilles, one of von Neumann's students at Princeton, and later a faculty member at the University of Illinois, recalled in the mid-1970's that the graduates students were being "used" to hand assemble programs into binary for their early machine (probably the IAS machine). He took time out to build an assembler, but when von Neumann found out about he was very angry, saying (paraphrased), "It is a waste of a valuable scientific computing instrument to use it to do clerical work." (source: [John von Neuman and von Neumann Architecture for Computers (1945)])

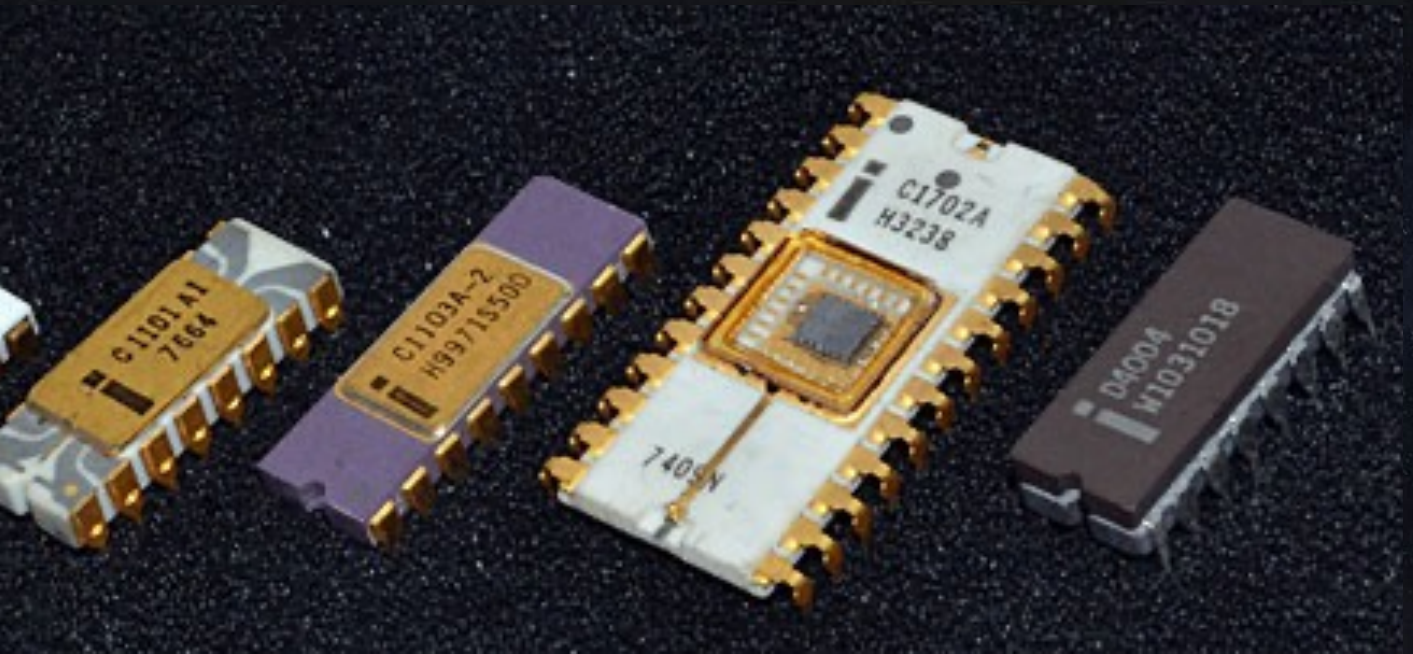
	LDY #$00	0200	A0 00
	LDX #$00	0202	A2 00
LOOP2	TXA	0204	8A
	STA $00C4	0205	85 C4
LOOP1	JSR SCAN	0207	20 22 F0
	INY	020A	C8
	BVS RESET	020B	70 05
	JMP LOOP1	020D	4C 07 02
RESET	CLV	0210	B8
	INX	0211	E8
	JMP LOOP2	0212	4C 04 02

```
int x = 0;
int y = 0;

for (x=0;x<12;x++)
{
  for (y=0;y<12;y++)
  {
    scan(x, y);
  }
}
```

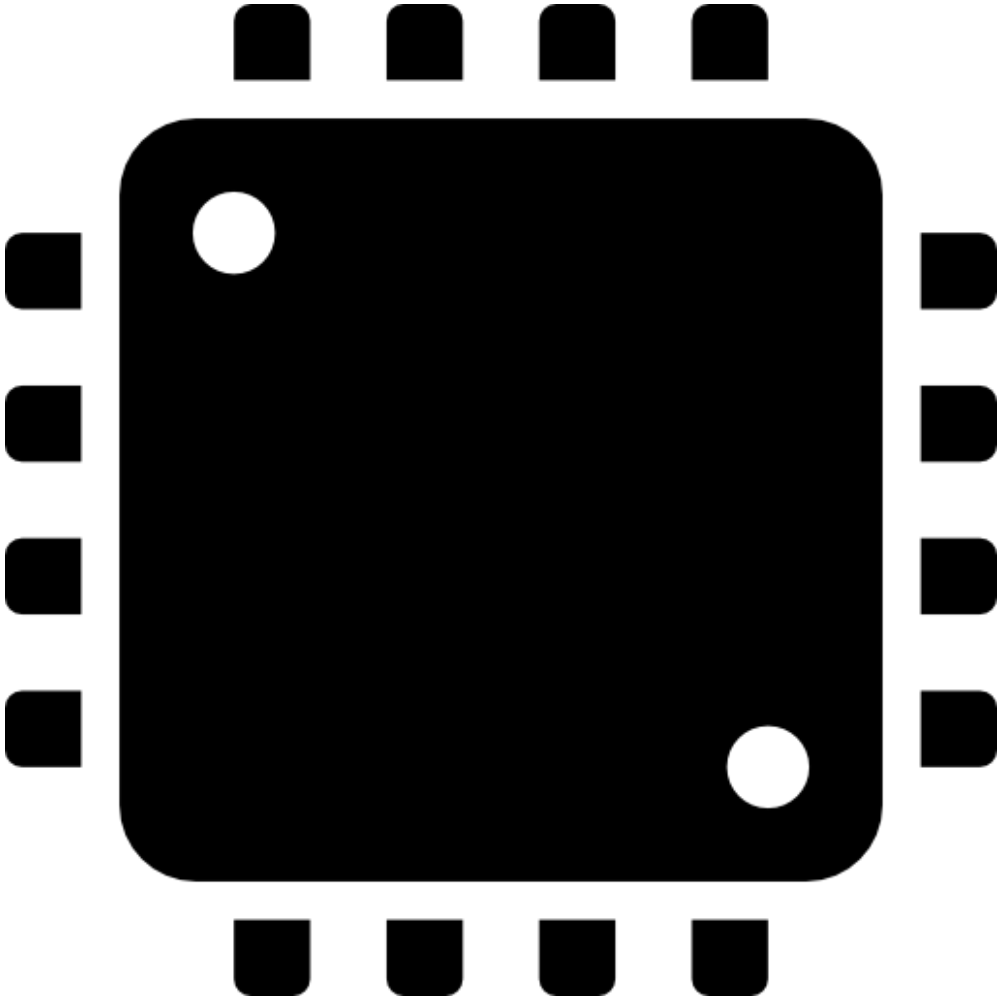
```
10100000 00000000
10100010 00000000
10001010 10000101
11000100 00100000
11011101 11110000
11001000 01110000
00000101 01001100
00000111 00000010
10111000 11101000
01001100 00000100
     00000010
```

6502AD
4585 S

XILINX
HKb2bsita.com


C1101A1
7664
C1103A-2
H9971550D
C1702A
H323S
D4004
W1031018
7404N

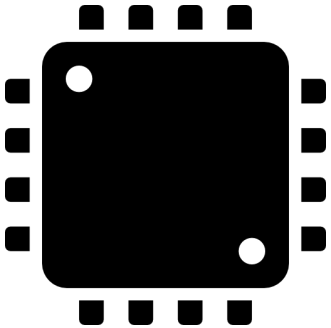
D5061
3001
8231946
MICROCODE ©
1985 INTERGRAPH
INTERGRAPH
C322C3Q
F307009B
8944 USA
PMC
SMC
intel
StrongARM
21281-EB
MOXA
MOXA ART
C-BGA292-V0C
D4C2T-014
0937-UMC-CE-AS-CE
TZIK01140515 (FS)
RoHS
AMD
R80286-12/S
8741HP
INTEL 1982
MOTOROLA
750
QLOGIC
ISP4022 2406040
SSSF8847.1 D0715
DTP704F084
TAIWAN
Raritan
SIEMENS
SAB
80286-R
BROADCOM
BCM8603KPBG
HA0716 P13
819010 P2
A5
DS89C420
MCS
0119A2
075AB
ES
MC68000L8
GN78331
SIEMENS
SAB
82258-R
Agilent
N2530/SP2.0E
ARM710 POWERED
0710KU200 JAPAN



How Virtual Machines Work

```
int x = 0;
int y = 0;

for (x=0;x<12;x++)
{
  for (y=0;y<12;y++)
  {
    scan(x, y);
  }
}
```

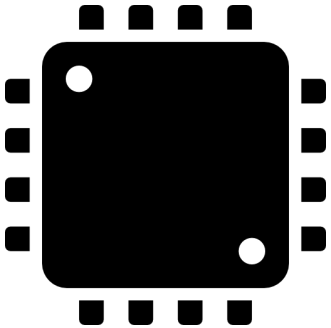
```
CA FE BA BE 00 00 00 31 00
13 07 00 10 07 00 11 01 00
07 63 6F 6E 76 65 72 74 01
00 3A 28 4C 6A 61 76 61 2F
6C 61 6E 67 2F 49 74 65 72
61 62 6C 65 3B 4C 6A 61 76
61 2F 6C 61 6E 67 2F 4F 62
6A 65 63 74 3B 29 4C 6A 61
76 61 2F 6C 61 6E 67 2F 4F
62 6A 65 63 74 3B 01 00 0A
45 78 63 65 70 74 69 6F 6E
73 07 00 12 01 00 09 53 69
```



How WebAssembly Works

```
int x = 0;
int y = 0;

for (x=0;x<12;x++)
{
  for (y=0;y<12;y++)
  {
    scan(x, y);
  }
}
```

```
00 61 73 6D 01 00 00 00 01
10 03 60 01 7F 00 60 01 7F
01 7F 60 02 7F 7F 01 7F 02
15 01 08 66 69 7A 7A 62 75
7A 7A 08 63 61 6C 6C 62 61
63 6B 00 00 03 03 02 01 02
07 0C 01 08 66 69 7A 7A 62
75 7A 7A 00 01 0A 44 02 39
00 20 00 41 0F 10 02 04 40
41 7D 10 00 41 7D 0F 0B 20
00 41 05 10 02 04 40 41 7E
10 00 41 7E 0F 0B 20 00 41
```



WebAssembly in the Browser

Browser

CSS

```
.effort {
  display: none
}
```

HTML

```
<html>
  ...
</html>
```

WASM

```
00 61 73 6D 01 00 00
00 01 10 03 60 01 7F
00 60 01 7F 01 7F 60
02 7F 7F 01 7F 02 15
01 08 66 69 7A 7A 62
75 7A 7A 08 63 61 6C
6C 62 61 63 6B 00 00
03 03 02 01 02 07 0C
01 08 66 69 7A 7A 62
75 7A 7A 00 01 0A 44
02 39 00 20 00 41 0F
10 02 04 40 41 7D 10
00 41 7D 0F 0B 20 00
41 05 10 02 04 40 41
7E 10 00 41 7E 0F 0B
20 00 41 03 10 02 04
40 41 7F 10 00 41 7F
0F 0B 20 00 10 00 20
```

JavaScript

```
return fetch('foo.wasm')
  .then(r => {
    return r.arrayBuffer()
  })
  .then(bytes => {
    return WebAssembly.instantiate(bytes)
  })
```

WA

JS

A Simple WebAssembly Module

```
00 61 73 6D 01 00 00
00 01 10 03 60 01 7F
00 60 01 7F 01 7F 60
02 7F 7F 01 7F 02 15
01 08 66 69 7A 7A 62
75 7A 7A 08 63 61 6C
6C 62 61 63 6B 00 00
03 03 02 01 02 07 0C
01 08 66 69 7A 7A 62
75 7A 7A 00 01 0A 44
02 39 00 20 00 41 0F
10 02 04 40 41 7D 10
00 41 7D 0F 0B 20 00
41 05 10 02 04 40 41
7E 10 00 41 7E 0F 0B
20 00 41 03 10 02 04
40 41 7F 10 00 41 7F
0F 0B 20 00 10 00 20
```

```
(module

  (export "add" (func $add))

  (func $add (param $a i32) (param $b i32) (result i32)
    get_local $a
    get_local $b
    i32.add
  )
)
```

WebAssembly is Stack-based

```
(module

  (export "add" (func $add))

  (func $add (param $a i32) (param $b i32) (result i32)
    get_local $a
    get_local $b
    i32.add
  )
)
```

Stack

Push an Argument

```
(module

  (export "add" (func $add))

  (func $add (param $a i32) (param $b i32) (result i32)
    get_local $a
    get_local $b
    i32.add
  )
)
```

5

Stack

Push Another Argument

```
(module

  (export "add" (func $add))

  (func $add (param $a i32) (param $b i32) (result i32)
    get_local $a
    get_local $b
    i32.add
  )
)
```

10

5

Stack

Pop the Arguments

```
(module

  (export "add" (func $add))

  (func $add (param $a i32) (param $b i32) (result i32)
    get_local $a
    get_local $b
    i32.add
  )
)
```

10

5

Stack

Add & Push

```
(module

  (export "add" (func $add))

  (func $add (param $a i32) (param $b i32) (result i32)
    get_local $a
    get_local $b
    i32.add
  )
)
```

15

Stack

Instantiating Modules

```
fetch('sample.wasm')
  .then(response => response.arrayBuffer())
  .then(bytes => WebAssembly.instantiate(bytes))
  .then(module => {
    let x = module.instance.exports.add(5, 10)
  })
```

OK

```
WebAssembly.instantiateStreaming(fetch('sample.wasm')
)
  .then(module => {
    let x = module.instance.exports.add(5, 10)
```

Way Better

Instantiating Modules

```
fetch('sample.wasm')
  .then(response => response.arrayBuffer())
  .then(bytes => WebAssembly.instantiate(bytes))
  .then(module => {
    let x = module.instance.exports.add(5, 10)
  })
```

OK

```
WebAssembly.instantiateStreaming(fetch('sample.wasm')
)
  .then(module => {
    let x = module.instance.exports.add(5, 10)
```

Way Better

Using the Modules

```
fetch('sample.wasm')
  .then(response => response.arrayBuffer())
  .then(bytes => WebAssembly.instantiate(bytes))
  .then(module => {
    let x = module.instance.exports.add(5, 10)
  })
```

OK

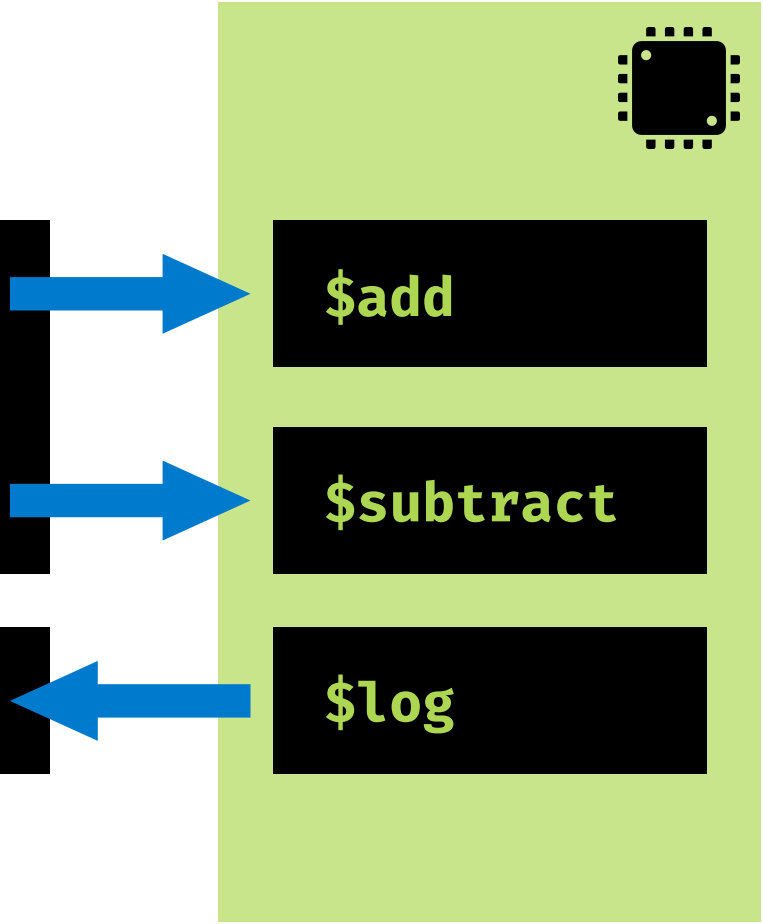
```
WebAssembly.instantiateStreaming(fetch('sample.wasm')
)
  .then(module => {
    let x = module.instance.exports.add(5, 10)
```

Way Better

Importing & Exporting Functions

```
let x = module.instance.exports.add(5, 10)
let y = module.instance.exports.subtract(x, 10)
```

```
let logCallback = x ⇒ console.log(x)
```



Importing & Exporting Functions

JS

.add

```
(export "add" (func $add))

(func $add (param $a i32) (param $b i32) (result i32)
  (i32.add (get_local $a) (get_local $b))
)
```

.subtract

```
(export "subtract" (func $sub))

(func $subtract (param $a i32) (param $b i32) (result i32)
  (i32.sub (get_local $a) (get_local $b))
)
```

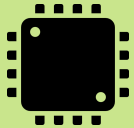
.js.log

```
(import "js" "log" (func $log) (param i32))
```

Instantiating Modules with Imports

```
let logCallback = x ⇒ console.log(x)

let imports = {
  js : {
    log : logCallback
  }
}

WebAssembly.instantiateStreaming(fetch('sample.wasm'), imports)
  .then(module ⇒ {
    // use webassembly module
```

Start Function



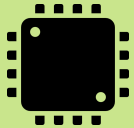
$main

$add

$subtract

```
(export "add" (func $add))
(export "subtract" (func $sub))

(start $main)

(func $main
  ;; do stuff
)

(func $add (param $a i32) (param $b i32) (result i32)
  (i32.add (get_local $a) (get_local $b))
)

(func $subtract (param $a i32) (param $b i32) (result i32)
  (i32.sub (get_local $a) (get_local $b))
)
```

Start Function



$main

$add

$subtract

```
(export "add" (func $add))
(export "subtract" (func $sub))

(start $main)

(func $main
  ;; do stuff
)

(func $add (param $a i32) (param $b i32) (result i32)
  (i32.add (get_local $a) (get_local $b))
)

(func $subtract (param $a i32) (param $b i32) (result i32)
  (i32.sub (get_local $a) (get_local $b))
)
```

It's All Numbers

Shared Memory

```
(module

  (import "js" "memory"
    (memory 1)
  )

  (data (i32.const 0) 13)

  (start $main)

  (func $main
    i32.const 1    ;; position 1
    i32.const 23   ;; value of 23
    i32.store8     ;; store it
  )
)
```

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Shared Memory

```
(module

  (import "js" "memory"
    (memory 1)
  )

  (data (i32.const 0) 13)

  (start $main)

  (func $main
    i32.const 1    ;; position 1
    i32.const 23   ;; value of 23
    i32.store8     ;; store it
  )
)
```

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Shared Memory

```
(module

  (import "js" "memory"
    (memory 1)
  )

  (data (i32.const 0) 13)

  (start $main)

  (func $main
    i32.const 1    ;; position 1
    i32.const 23   ;; value of 23
    i32.store8     ;; store it
  )
)
```

13	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Shared Memory

```
(module

  (import "js" "memory"
    (memory 1)
  )

  (data (i32.const 0) 13)

  (start $main)

  (func $main
    i32.const 1    ;; position 1
    i32.const 23   ;; value of 23
    i32.store8     ;; store it
  )
)
```

13	23	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Shared Memory

```
let memory =
  new WebAssembly.Memory({ initial: 1 })

let imports = { js: { memory: memory } }

WebAssembly.instantiateStreaming(
  fetch('sample.wasm'), imports)
    .then(module => {

      let shared =
        new Uint8Array(memory.buffer)

      shared[0] // fetches 13
      shared[1] // fetches 23

      // stores 42 at position 3
      shared[3] = 42
 }))
```

13	23	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Shared Memory

```
let memory =
  new WebAssembly.Memory({ initial: 1 })

let imports = { js: { memory: memory } }

WebAssembly.instantiateStreaming(
  fetch('sample.wasm'), imports)
    .then(module => {

      let shared =
        new Uint8Array(memory.buffer)

      shared[0] // fetches 13
      shared[1] // fetches 23

      // stores 42 at position 3
      shared[3] = 42
 }))
```

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Shared Memory

```
let memory =
  new WebAssembly.Memory({ initial: 1 })

let imports = { js: { memory: memory } }

WebAssembly.instantiateStreaming(
  fetch('sample.wasm'), imports)
    .then(module => {

      let shared =
        new Uint8Array(memory.buffer)

      shared[0] // fetches 13
      shared[1] // fetches 23

      // stores 42 at position 3
      shared[3] = 42
 }))
```

13	23	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Shared Memory

```
let memory =
  new WebAssembly.Memory({ initial: 1 })

let imports = { js: { memory: memory } }

WebAssembly.instantiateStreaming(
  fetch('sample.wasm'), imports)
    .then(module => {

      let shared =
        new Uint8Array(memory.buffer)

      shared[0] // fetches 13
      shared[1] // fetches 23

      // stores 42 at position 3
      shared[3] = 42
 }))
```

13	23	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Shared Memory

```
let memory =
  new WebAssembly.Memory({ initial: 1 })

let imports = { js: { memory: memory } }

WebAssembly.instantiateStreaming(
  fetch('sample.wasm'), imports)
    .then(module => {

      let shared =
        new Uint8Array(memory.buffer)

      shared[0] // fetches 13
      shared[1] // fetches 23

      // stores 42 at position 3
      shared[3] = 42
 }))
```

13	23	0	42
0	0	0	0
0	0	0	0
0	0	0	0

Storing Strings

```
(module

  (import "js" "memory"
    (memory 1)
  )

  (data (i32.const 0) "👋🌍\00")

  (export "hello" (func $hello))

  (func $hello (result i32)
    i32.const 0
  )
)
```

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Storing Strings

```
(module

  (import "js" "memory"
    (memory 1)
  )

  (data (i32.const 0) "👋🌍\00")

  (export "hello" (func $hello))

  (func $hello (result i32)
    i32.const 0
  )
)
```

240	159	145	139
240	159	143	187
240	159	140	142
0	0	0	0

Storing Strings

```
(module

  (import "js" "memory"
    (memory 1)
  )

  (data (i32.const 0) "👋🌍\00")

  (export "hello" (func $hello))

  (func $hello (result i32)
    i32.const 0
  )
)
```

240	159	145	139
240	159	143	187
240	159	140	142
0	0	0	0

Using Stored Strings

```
let decoder = new TextDecoder('utf8')

let memory =
  new WebAssembly.Memory({ initial: 1 })

let position =
  module.instance.exports.hello()

let shared =
  new Uint8Array(memory.buffer, position)

let index = shared.indexOf(0)

let bytes = shared
if (index !== -1)
  bytes = shared.slice(0, index)

let string = decoder.decode(bytes)
```

240	159	145	139
240	159	143	187
240	159	140	142
0	0	0	0

Other Stuff

Locals

```
(func $foo
  (result i32)

  (local $n i32)

  i32.const 42
  set_local $n

  get_local $n

  tee_local $n
)
```

Globals

```
(global $n
  (import
    "js"
    "global")
  (mut i32))

(func $foo
  (result i32)

  i32.const 42
  set_global $n

  get_global $n
)
```

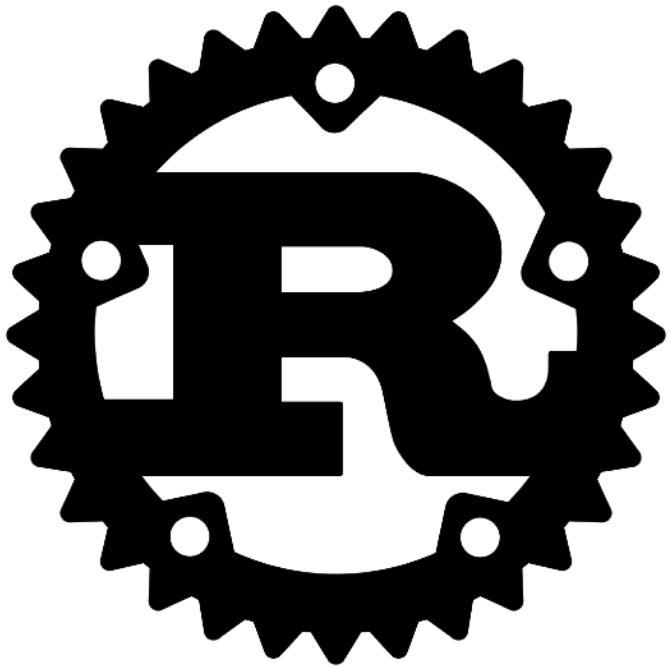
S-Expressions

```
(func $foo
  (result i32)

  (i32.add
    (i32.const 5)
    (i32.const 10)
  )

)
```

Tables

```
(table 3 anyfunc)

(elem (i32.const 0)
  $foo)

(elem (i32.const 1)
  $bar $baz)

(func $foo)
(func $bar)
(func $baz)
```

Other Languages



Awesome Wasm Languages

https://github.com/appcypher/awesome-wasm-langs

Demo

Resources

- WebAssembly.org - official site for WebAssembly
- Mozilla Developer Network Documentation - JavaScript side of things
- WebAssembly Binary Toolkit - command-line assembler and disassembler
- WebAssembly Toolkit for VSCode - assembly code highlighter and assembler
- Rust - has built-in support for WebAssembly
- Emscripten - LLVM bitcode to WebAssembly
- Awesome Wasm Languages - .NET, Elixir, Go, Java, Python, et al.
- Awesome Wasm - curated list of awesome WebAssembly things

github.com/guyroyse/intro-to-webassembly

github.com/guyroyse/wasm-fizzbuzz

Guy Royse

Engineering Manager

ScriptDrop

guyroyse

code.guy.dev

guy.dev

Thanks!

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