Using WebAssembly to run, extend and secure your app

Niels Tanis
Sr. Principal Security Researcher

VERACODE

Who am I?

- Niels Tanis
- Sr. Principal Security Researcher
  - Background .NET Development, Pentesting/ethical hacking, and software security consultancy
  - Research on static analysis for .NET apps
  - Enjoying Rust!
- Microsoft MVP – Developer Technologies

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Agenda

- Introduction
- WebAssembly 101
- Running on WebAssembly
- Extending with WebAssembly
- Securing with WebAssembly
- Conclusion
- Q&A

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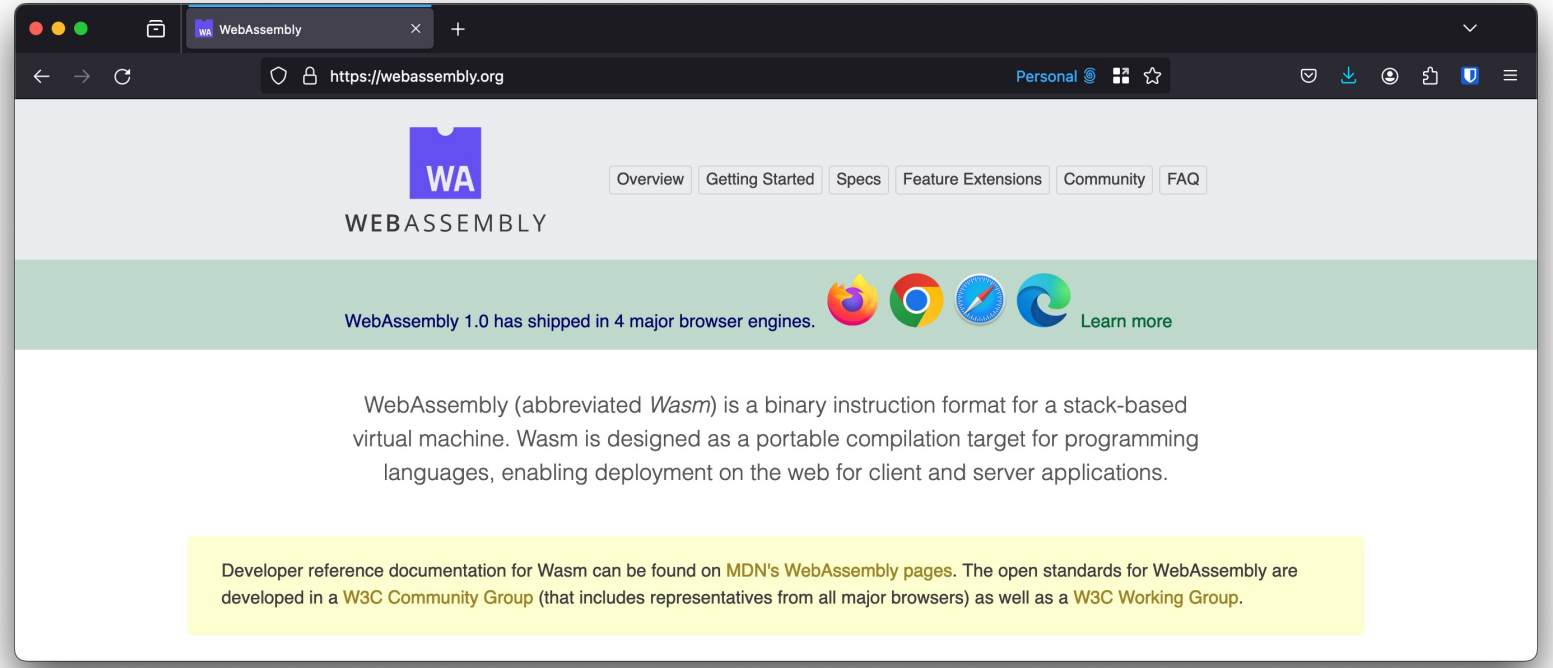
WebAssembly



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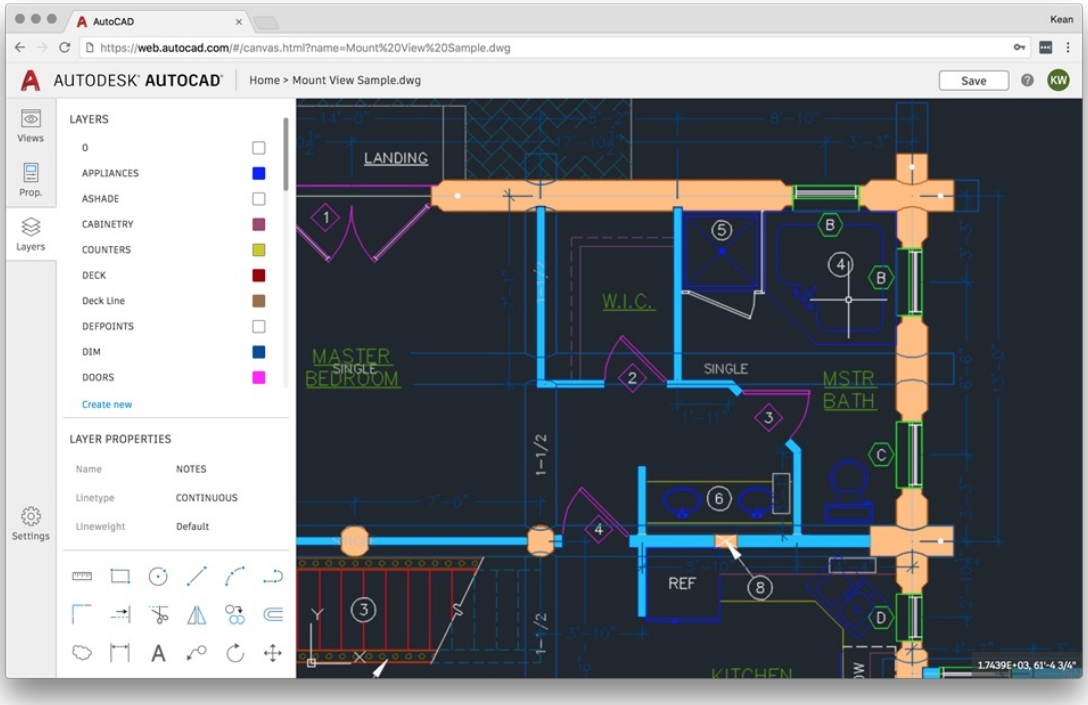
WebAssembly - AutoCAD



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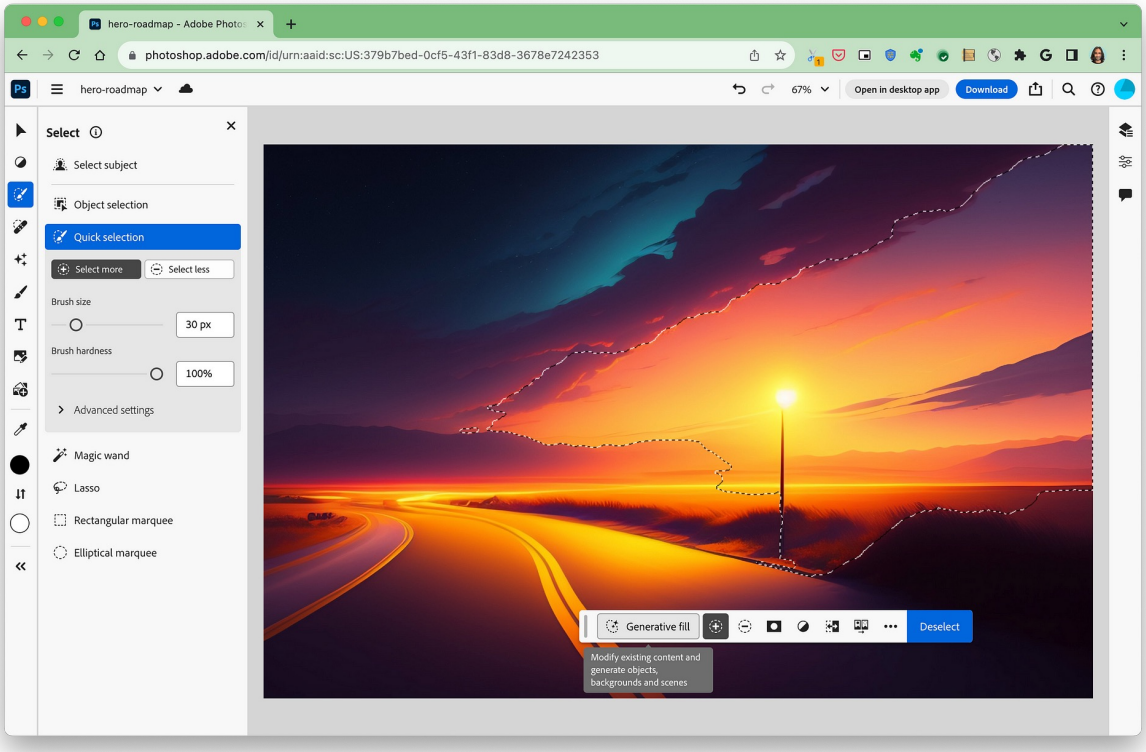
WebAssembly - Photoshop



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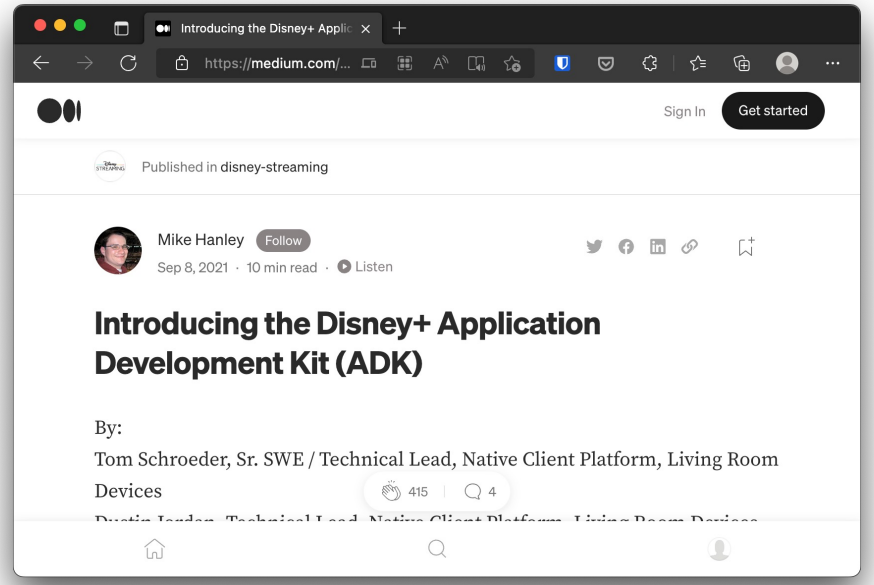
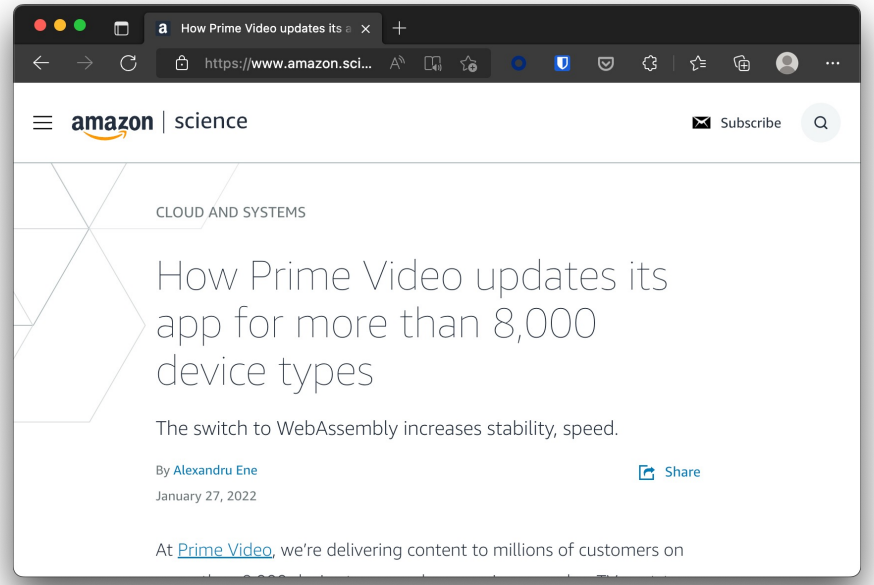
WebAssembly - SDK's





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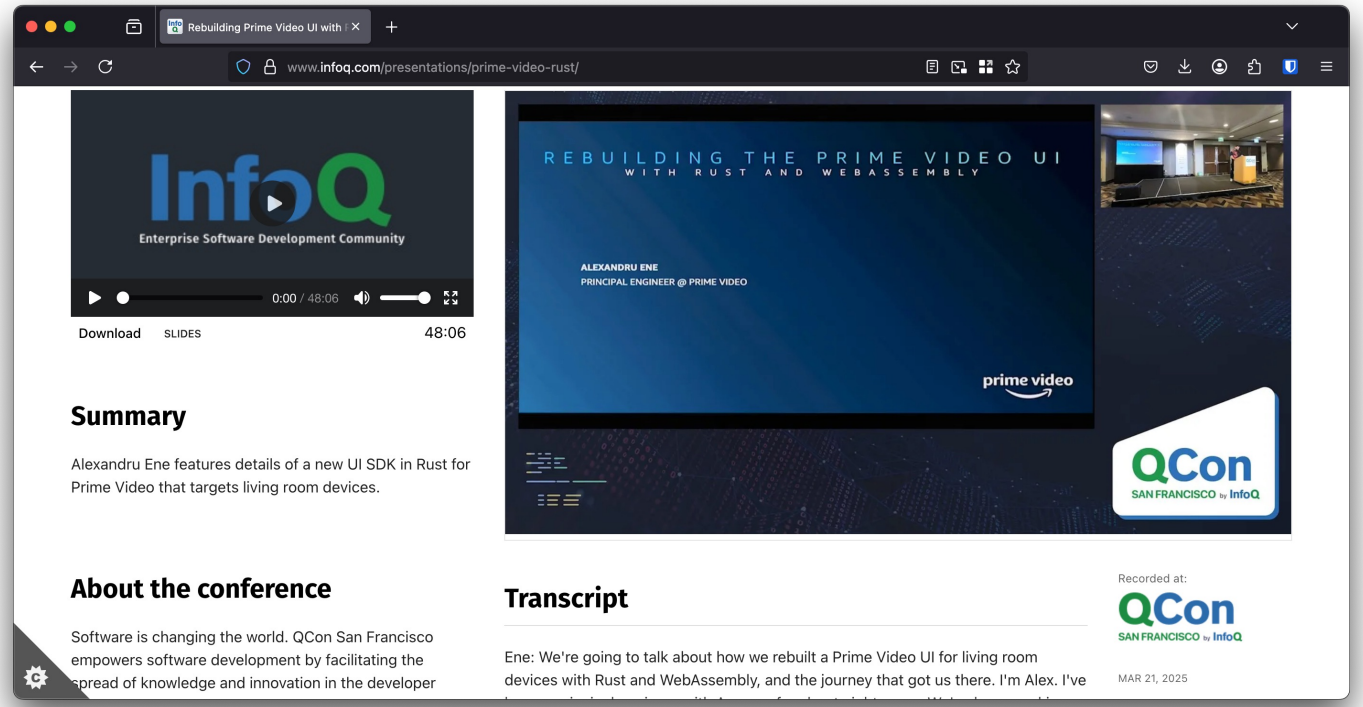
Prime Video UI - Rust & WASM



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WebAssembly – Do you use it?

- Does your organization use WASM?
- Which main tech stacks used?
- WASM for what kind of apps?
  - Mobile
  - Cloud Native
  - Other…

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WebAssembly Design

- **Be fast, efficient, and portable**
  - Executed in near-native speed across different platforms
- **Be readable and debuggable**
  - In low-level bytecode but also human readable
- **Keep secure**
  - Run on sandboxed execution environment
- **Don't break the web**
  - Ensure backwards compatibility

WebAssembly

- Binary instruction format for stack-based virtual machine similar to .NET CLR running MSIL or JVM running bytecode
- Designed as a portable compilation target
- The security model of WebAssembly:
  - Protect users from buggy or malicious modules
  - Provide developers with useful primitives and mitigations for developing safe applications

WebAssembly Type System

- WebAssembly's type only supports:
  - `i32 (32-bit integer)`
  - `i64 (64-bit integer)`
  - `f32 (32-bit float)`
  - `f64 (64-bit float)`

- No strings, no objects, no complex data types.
- Basic operations on numerical values.

WebAssembly Stack Based VM

- In a stack-based VM, operations primarily manipulate a last-in-first-out (LIFO) stack of values, rather than working with named registers as in register-based architectures.

WebAssembly Stack Based VM

- WebAssembly maintains an operand stack during execution:
  - Values are pushed onto the stack by instructions
  - Operations pop their operands from the stack
  - Results are pushed back onto the stack
  - The stack is separate from linear memory and is not directly accessible

Code some WebAssembly

Let’s create some WAT!

http://github.com/nielstanis/secappdev25wasm

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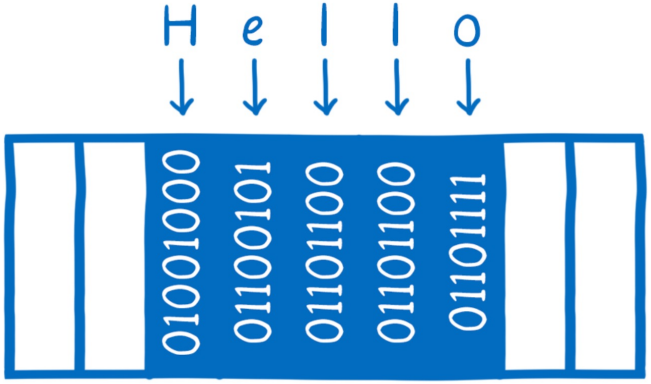
WebAssembly Memory

- Isolated per WASM module
- A contiguous, mutable array of uninterpreted bytes



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Code some WebAssembly

Let’s work with some Memory!

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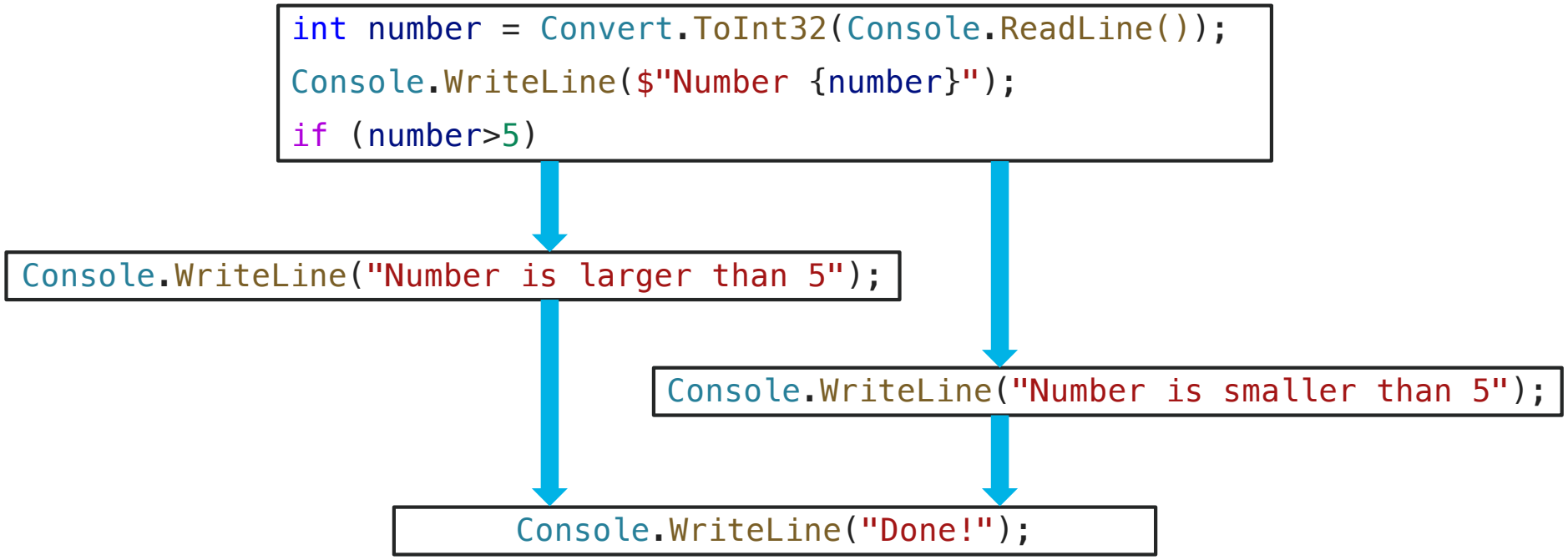
WebAssembly Control-Flow Integrity

- Control-Flow Integrity (CFI) ensures that program execution follows only valid paths as defined by the program's source code.
- In traditional native code, attackers can exploit memory vulnerabilities to hijack execution flow:
  - Redirecting it to malicious code
  - Chaining together existing code fragments in unintended ways (like Return-Oriented Programming attacks).

CFI Example


```
int number = Convert.ToInt32(Console.ReadLine());
Console.WriteLine($"Number {number}");
if (number>5)
{
        Console.WriteLine("Number is larger than 5");
}
else
{
        Console.WriteLine("Number is smaller than 5");
}
Console.WriteLine("Done!");
```

CFI Example



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CFI: Structured Control-Flow Only

- No arbitrary jump instructions (no goto, jmp or equivalent)
- All branches have explicit, validated targets within the same function
- No ability to jump to arbitrary memory addresses
- All control flow is validated before execution

CFI: Protected Function Calls


```
(module
  (func $safe_function (param i32) (result i32)
    local.get 0
    i32.const 1
    i32.add
  )

  (func $caller (param i32) (result i32)
    local.get 0
    call $safe_function  ;; Direct call - target validated at compile time
  )
)
```

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CFI: Indirect Calls

- Function table entries are validated at module instantiation
- Runtime checks ensure the target index is within table bounds
- Runtime type checking ensures the called function matches the expected signature
- The table is protected from direct memory manipulation

Code some WebAssembly

Indirect calling!

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CFI: Indirect Calls


```
(module
  (table 2 funcref)
  (func $f1 (result i32)
    i32.const 42)
  (func $f2 (result i32)
    i32.const 13)
  (elem (i32.const 0) $f1 $f2)
  (type $return_i32 (func (result i32)))
  (func (export "callByIndex") (param $i i32) (result i32)
    local.get $i
    call_indirect (type $return_i32))
)
```

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CFI: Separation of Code and Data

- Code sections cannot be modified at runtime
- Linear memory (accessible data) cannot contain executable code
- No instruction exists to convert data to code No self-modifying code capabilities

RLBox

RLBox

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RLBox in Firefox

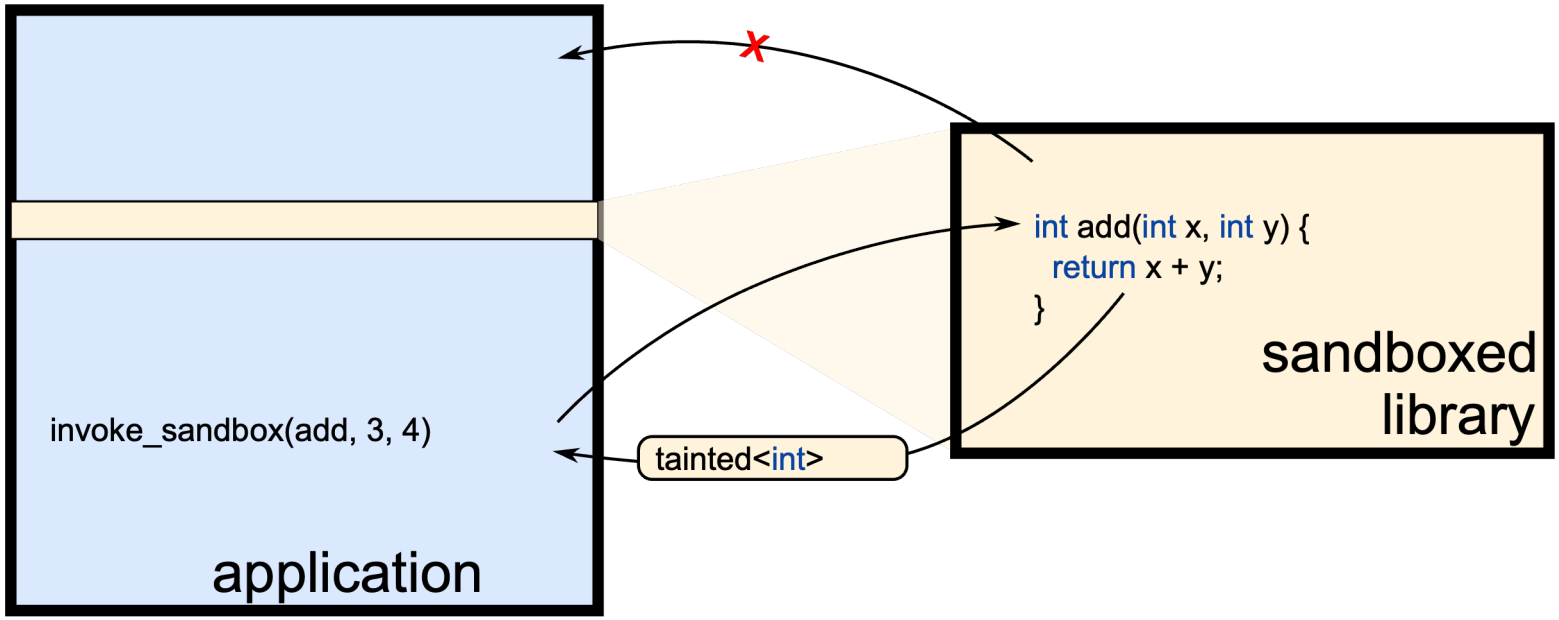
- RLBox uses **WebAssembly as an intermediate compilation target** for creating sandboxed versions of third-party C/C++ libraries.

- Rather than running WebAssembly code directly, RLBox employs a unique "**WebAssembly and Back Again**" approach.

RLBox in Firefox

- RLBox considers all values that originate in the sandbox as untrusted and "taints" them.
- Tainted values are essentially opaque values that cannot be used directly by the application code.
- RLBox's type system marks all data coming out of the sandbox as "tainted" and ensures, through compiler errors, that developers sanitize potentially unsafe data before using it.

RLBox in Firefox



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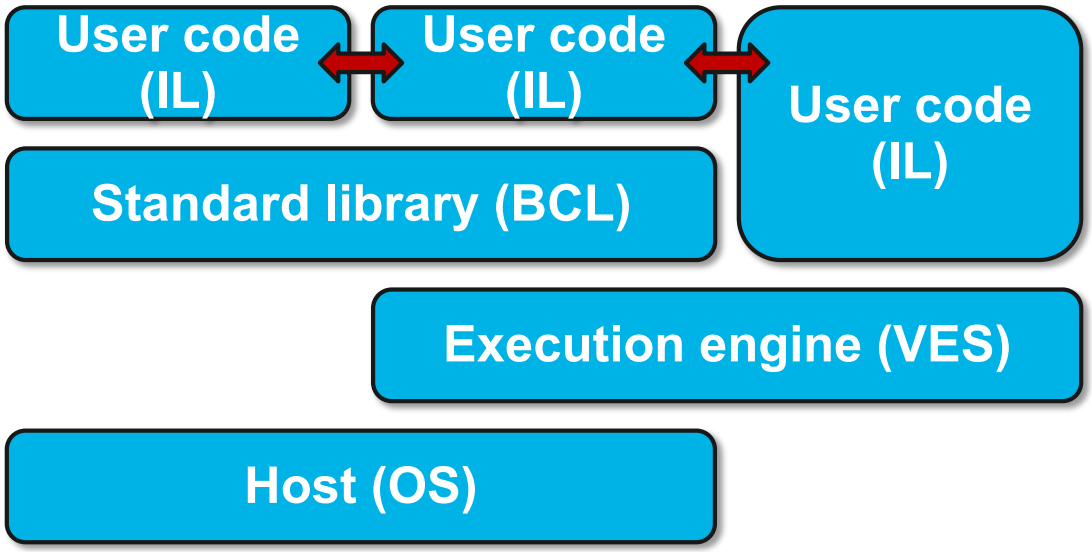
RLBox in Firefox

- RLBox is currently deployed in Firefox to isolate five different modules:
  - Graphite – Font rendering engine - Firefox 95
  - Hunspell – Spell checker – Firefox 95
  - Ogg - Multimedia container format – Firefox95
  - Expat - XML parser – Firefox 96
  - Woff2 – Web font compression format - Firefox 96

Running .NET on WebAssembly



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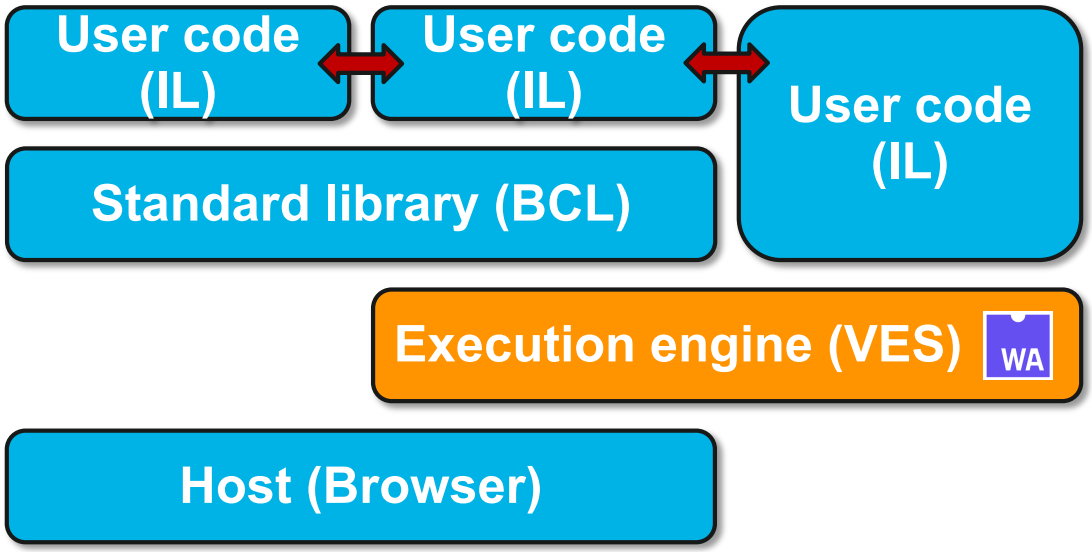
Running .NET on WebAssembly



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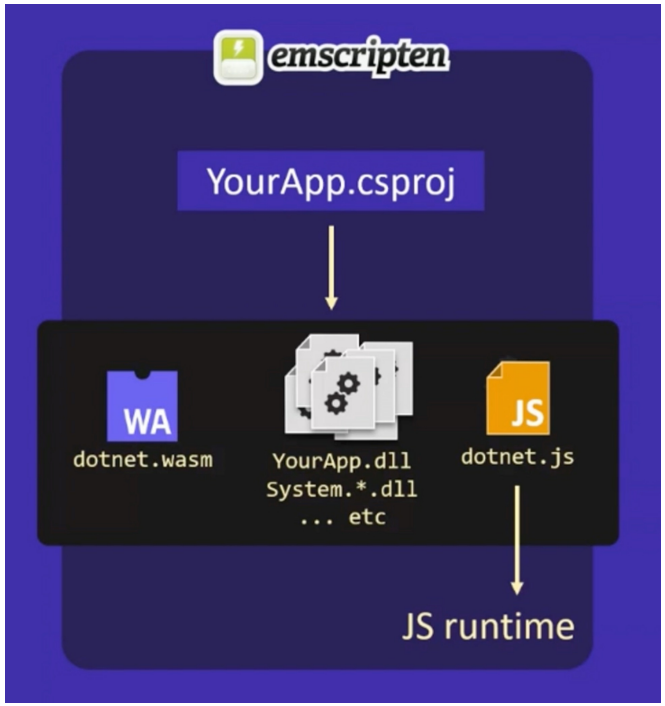
Blazor WebAssembly



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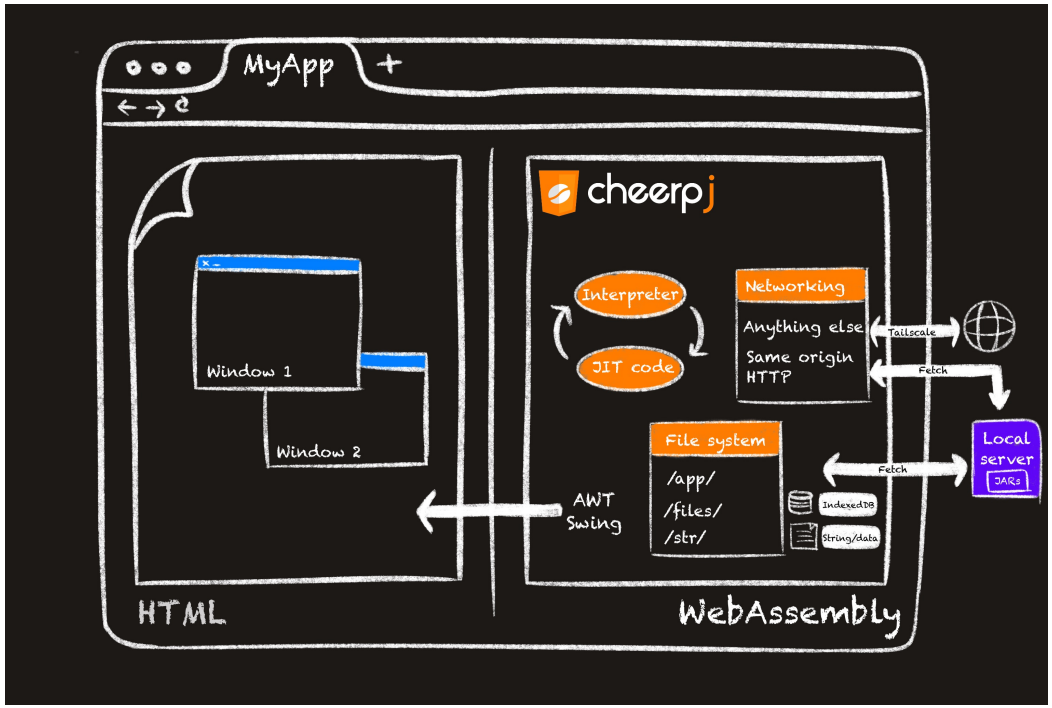
JVM on WASM with CheerpJ

The magic behind CheerpJ is Cheerp, which was used for compiling full Java SE 8 and Java SE 11 runtimes based on OpenJDK.



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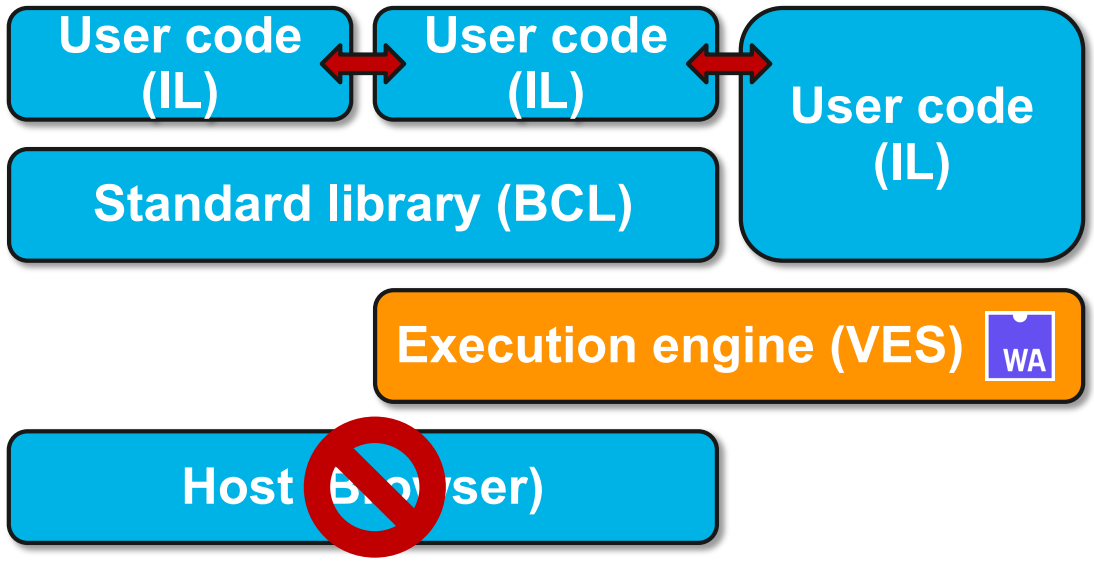
Running .NET on WebAssembly



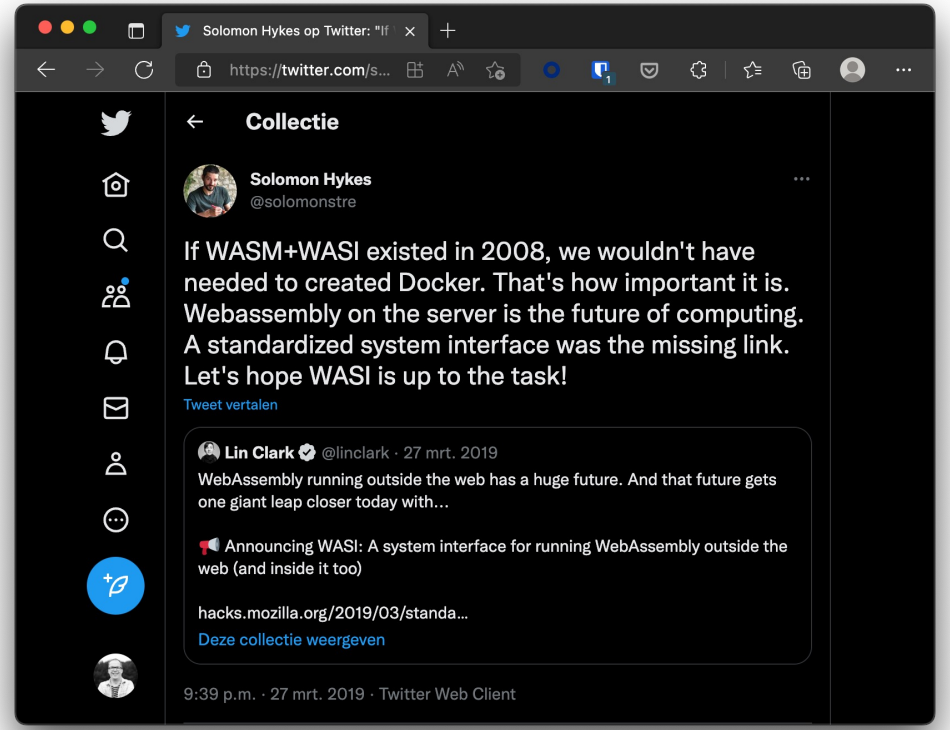
WebAssembly System Interface WASI

- Introduced in March 2019 by Bytecode Alliance
- WasmTime implementation as reference
- POSIX inspired, engine-independent, non-Web system-oriented API for WebAssembly

WebAssembly System Interface WASI

- Strong sandbox with Capability Based Security
- Right now, supports e.g. FileSystem actions, Sockets, CLI and HTTP at version 0.2
- Future support for promise/async and streams
- Anyone recall .NET Standard? ☺

Docker vs WASM & WASI



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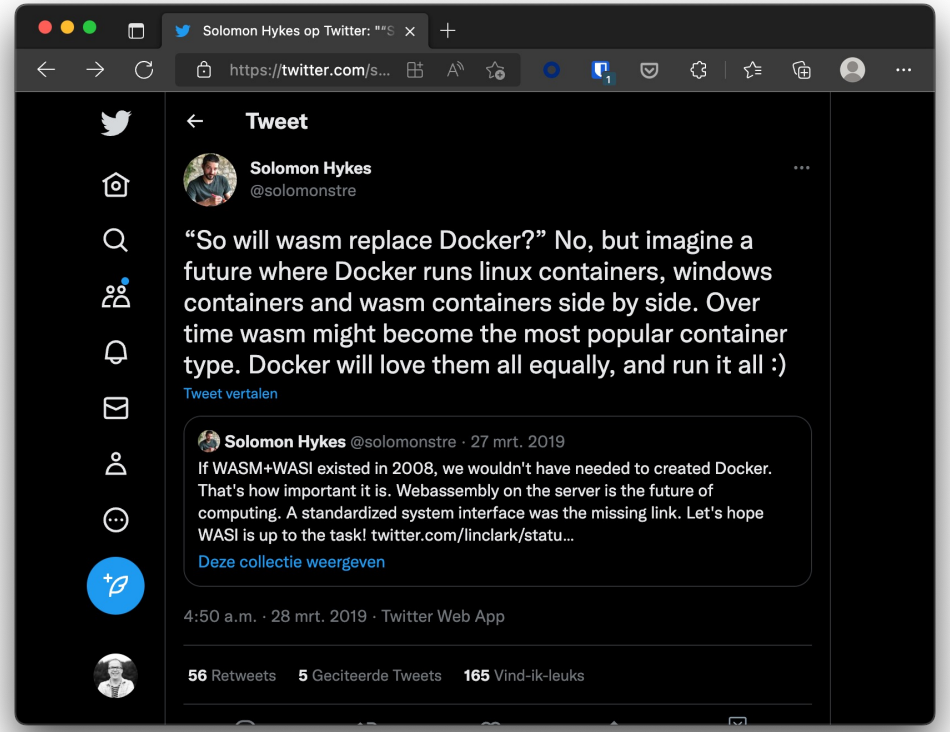
Docker vs WASM & WASI



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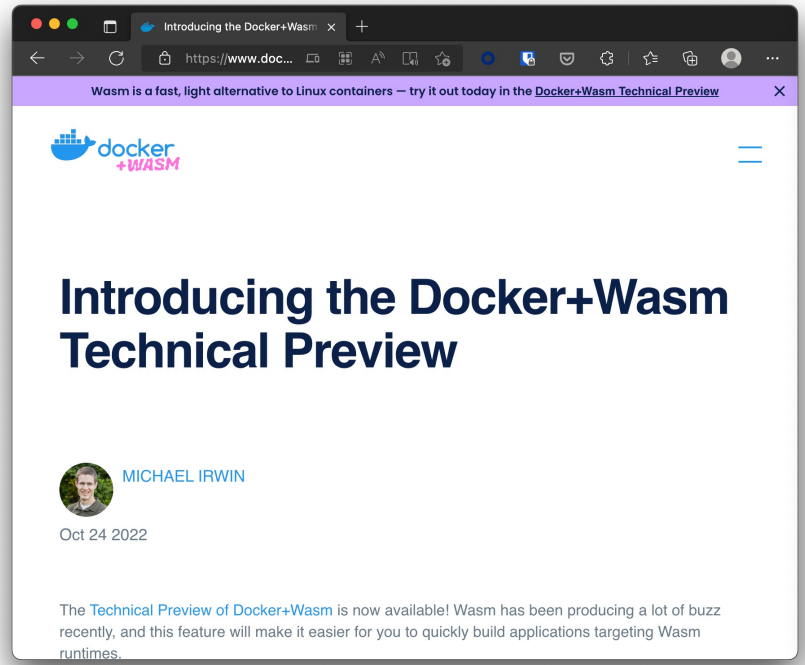
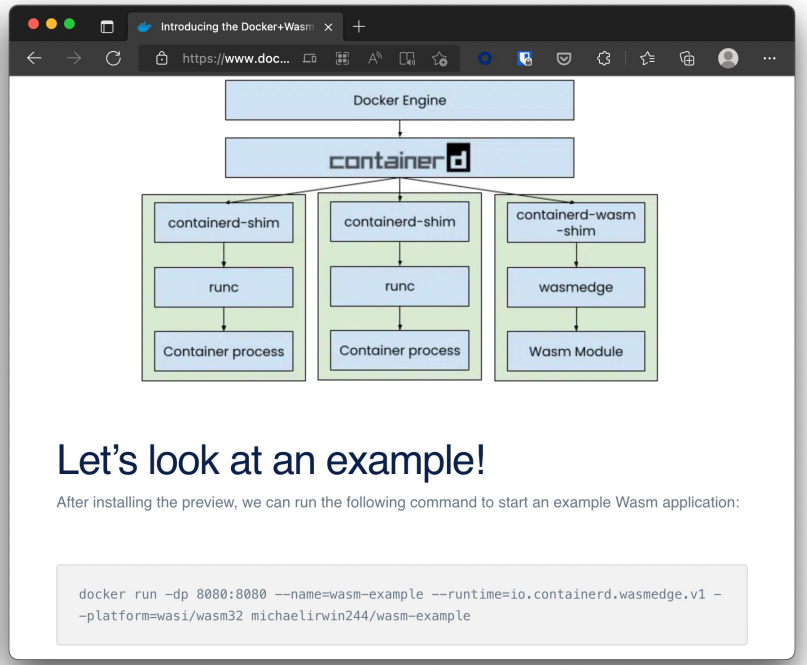
Docker & WASM





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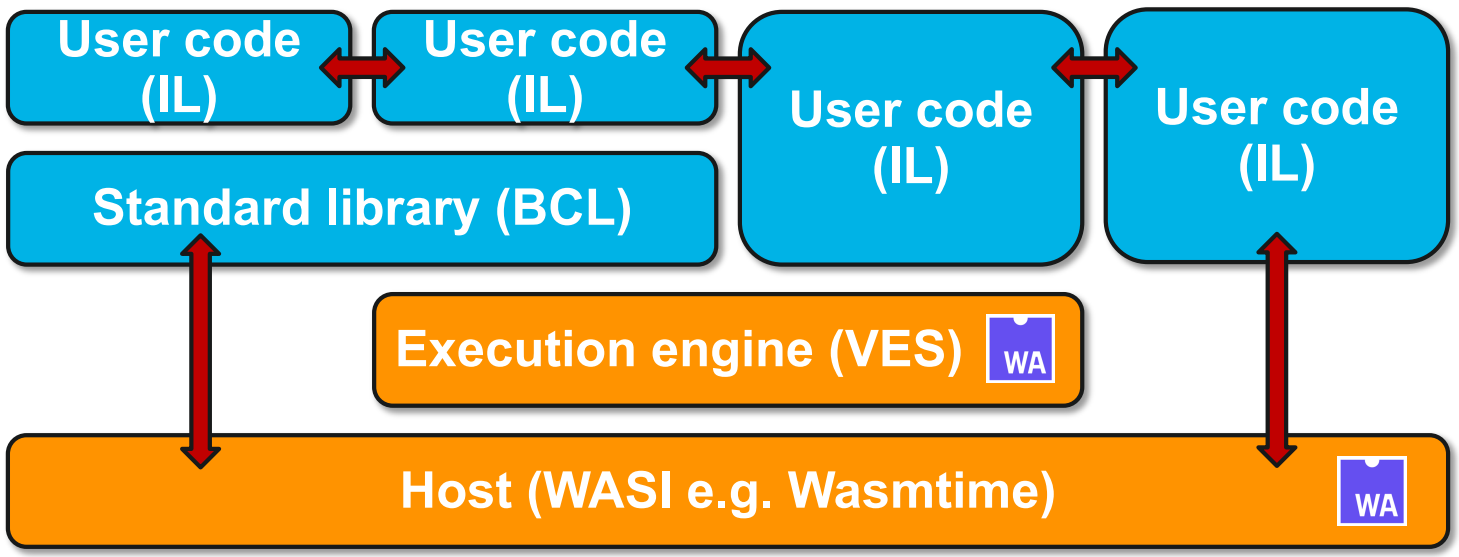
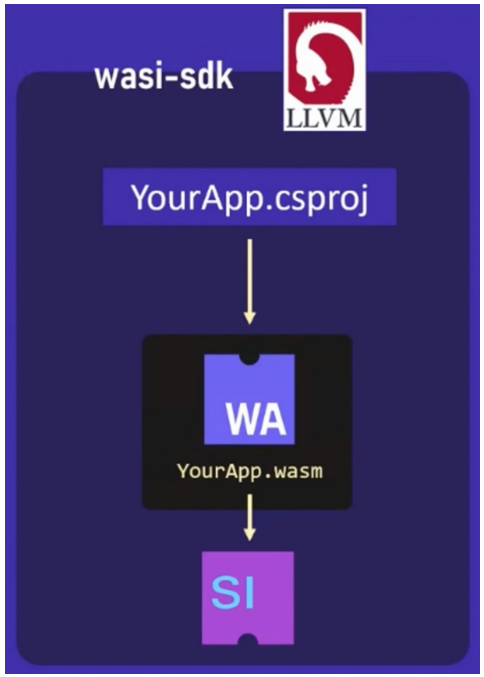
WebAssembly System Interface WASI



Experimental WASI SDK for .NET



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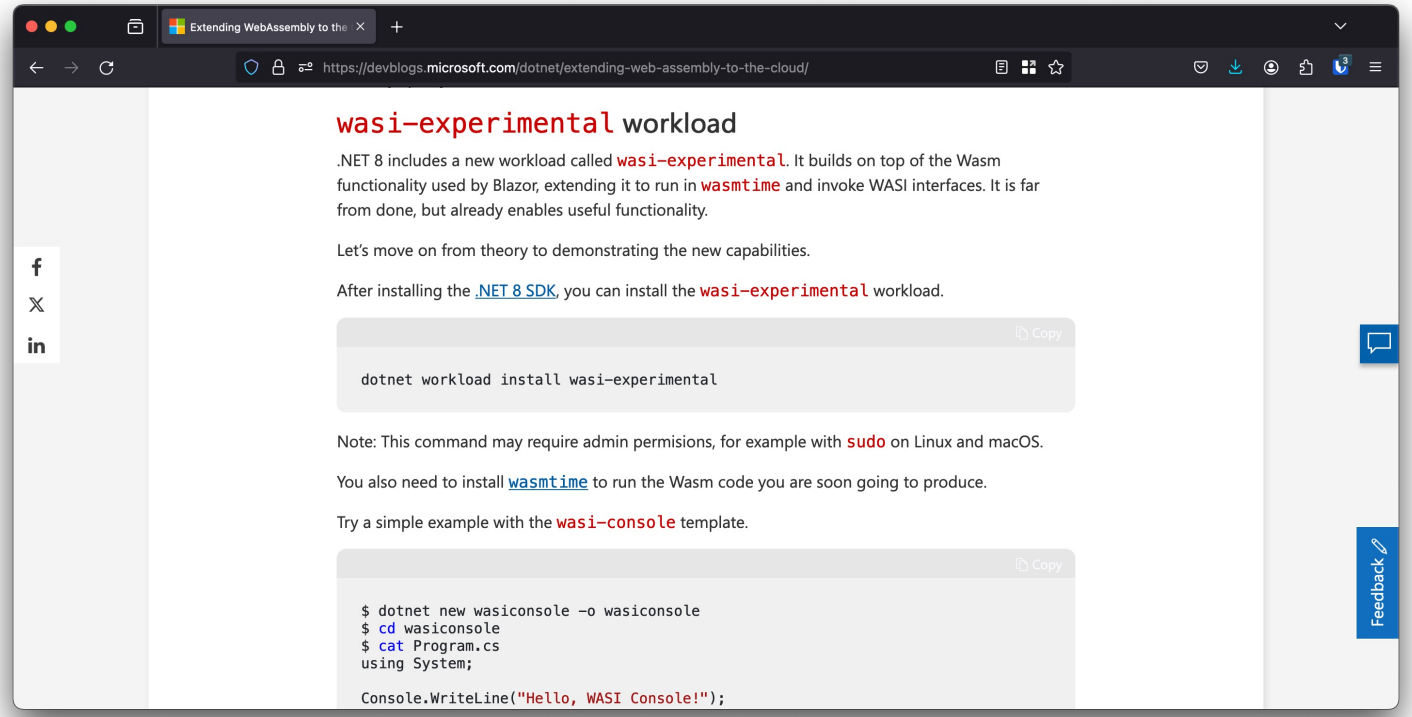
.NET 8 WASI-Experimental



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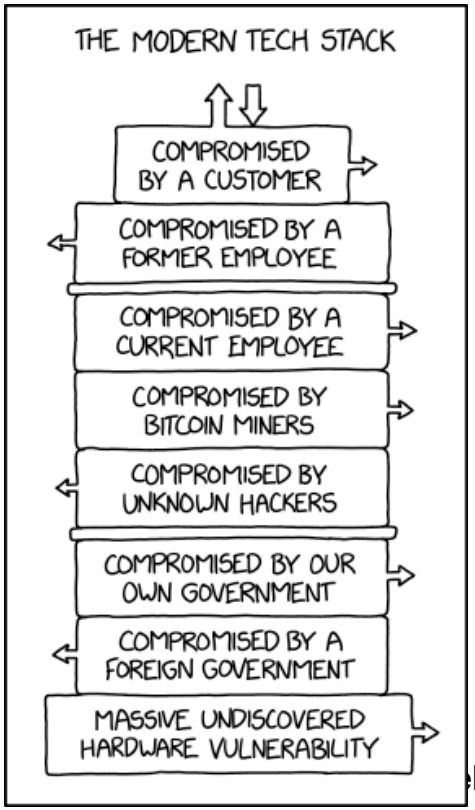
Extending .NET with WASM

- WasmTime.NET NuGet package
- Can run WASM inside of any .NET application
- Extend with Rust based WASM module
- Limit capabilities
- Demo time!

Trusted Computing - XKCD 2166



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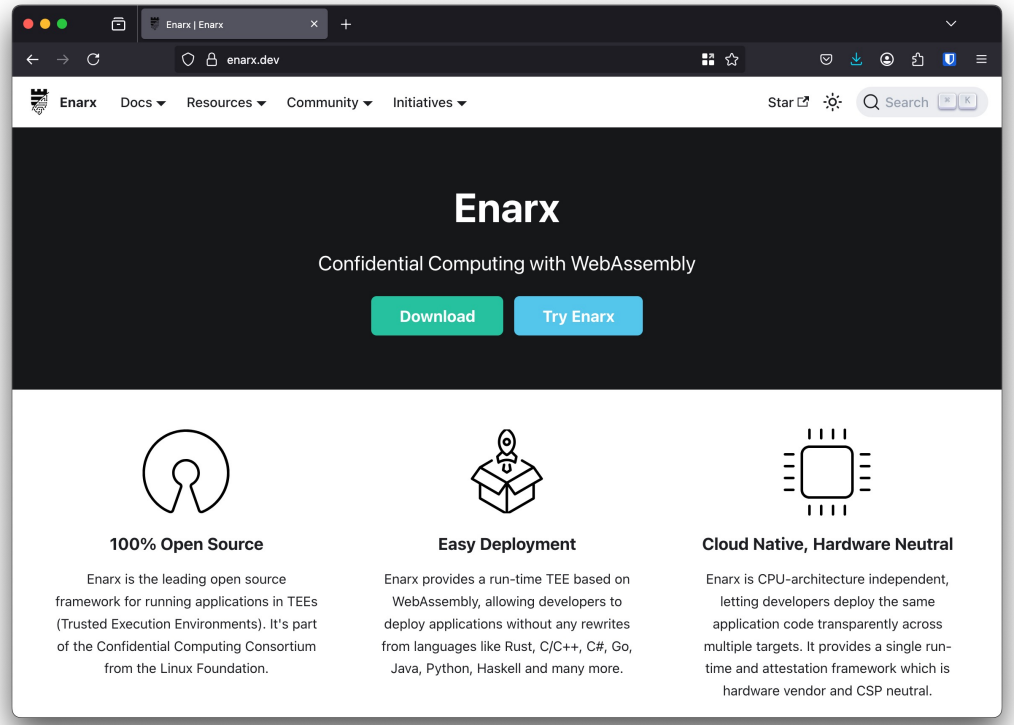
Enarx



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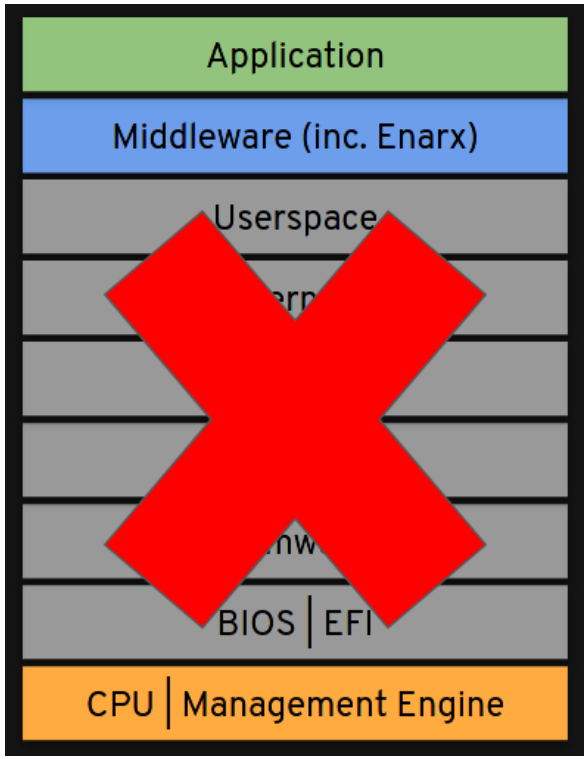
Enarx Threat Model

- Don’t trust the host
- Don’t trust the host owner
- Don’t trust the host operator
- Hardware cryptographically verified
- Software audited and cryptographically verified



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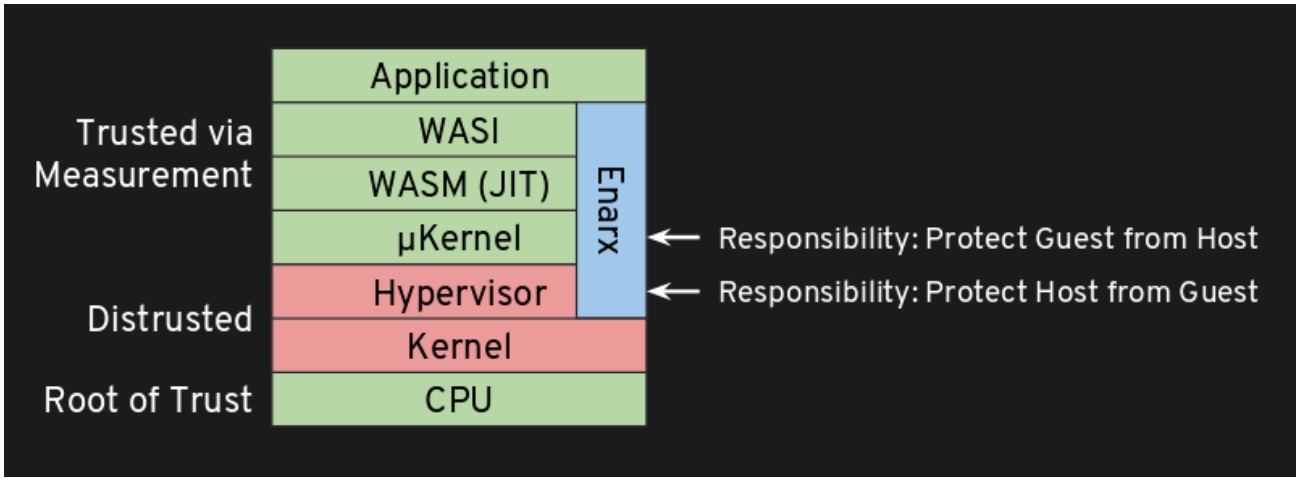
Enarx

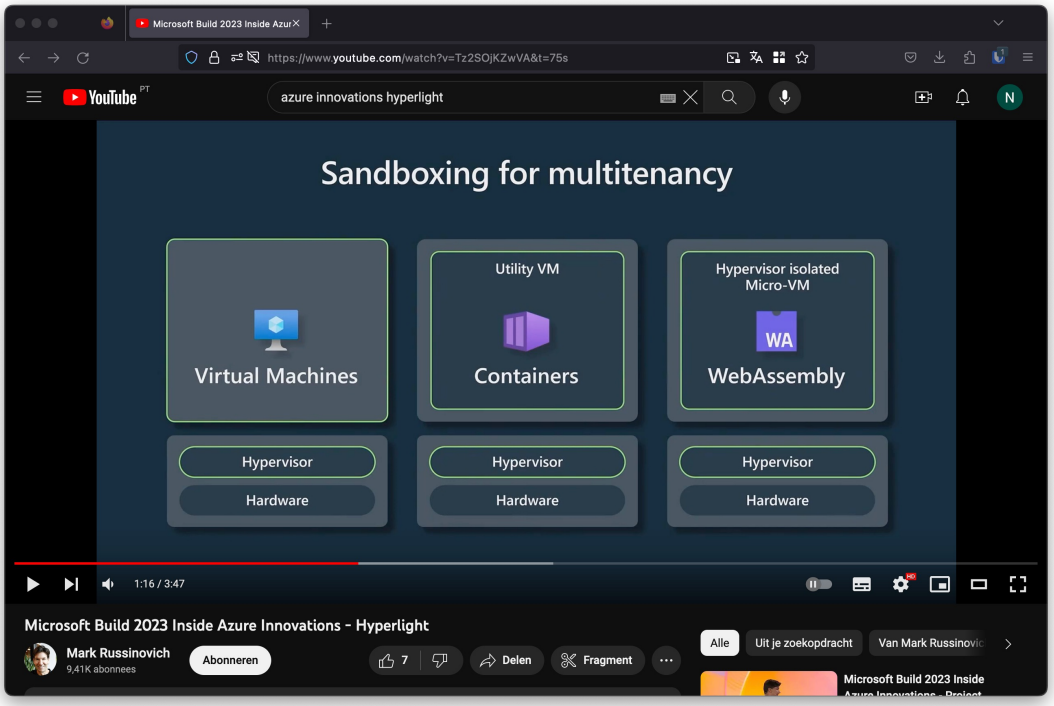
- Leverages Trusted Execution Environment (TEE) direct on processor
  - AMD's SEV, Intel's SGX and IBM's PEF
- Attestation of hardware and Enarx runtime



Enarx

- Each execution:
  - Attestation: Enarx checks that the host to which you're planning to deploy is a genuine TEE instance.
  - Packaging: Once the attestation is complete and the TEE instance verified, the Enarx management component encrypts the application, along with any required data.
  - Provisioning: Enarx then sends the application and data along to the host for execution in the Enarx Keep.
- TEE provides: Data Confidentiality, Data Integrity, Code Integrity

Project Hyperlight



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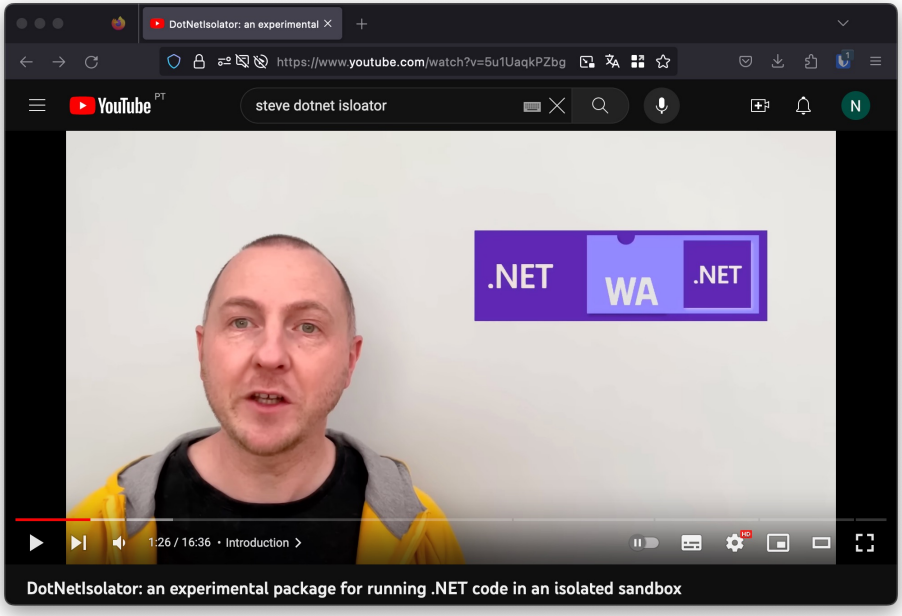
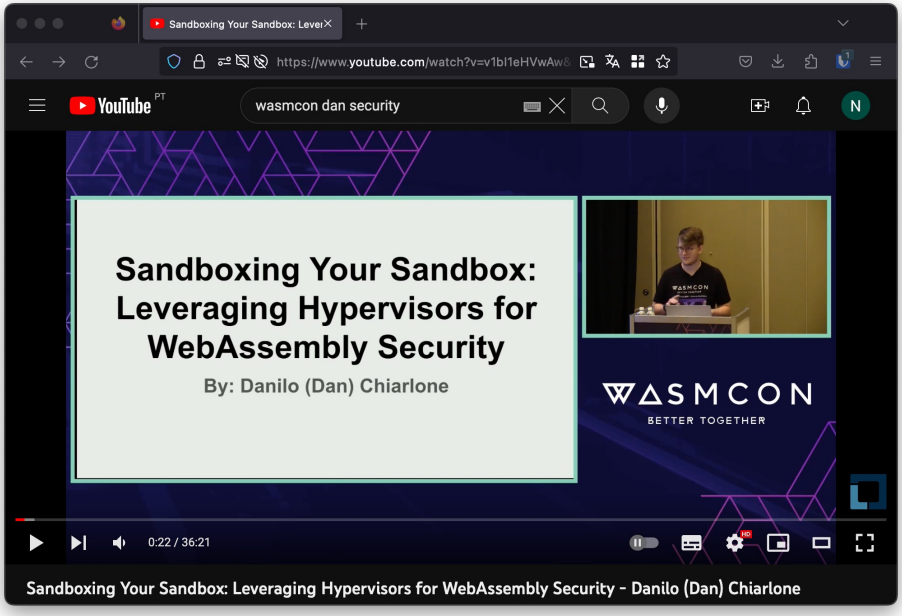
DotNetIsolator & Project Hyperlight





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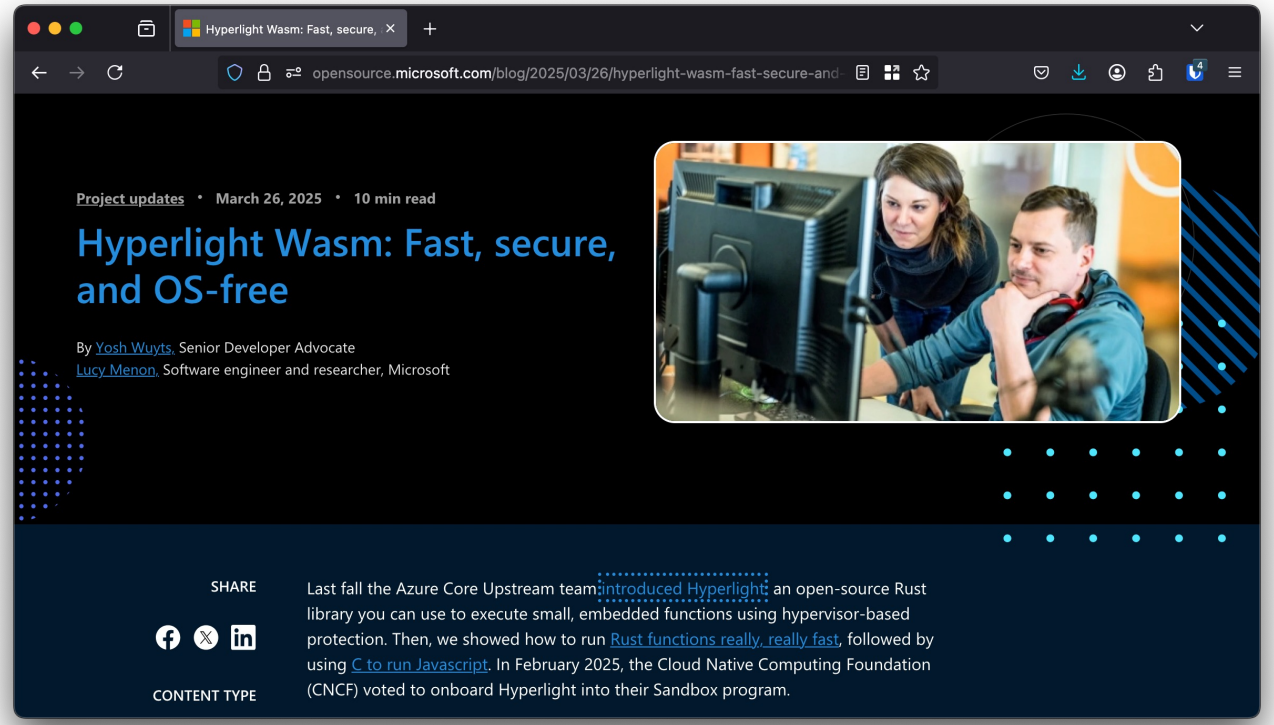
Hyperlight CNCF Sandbox



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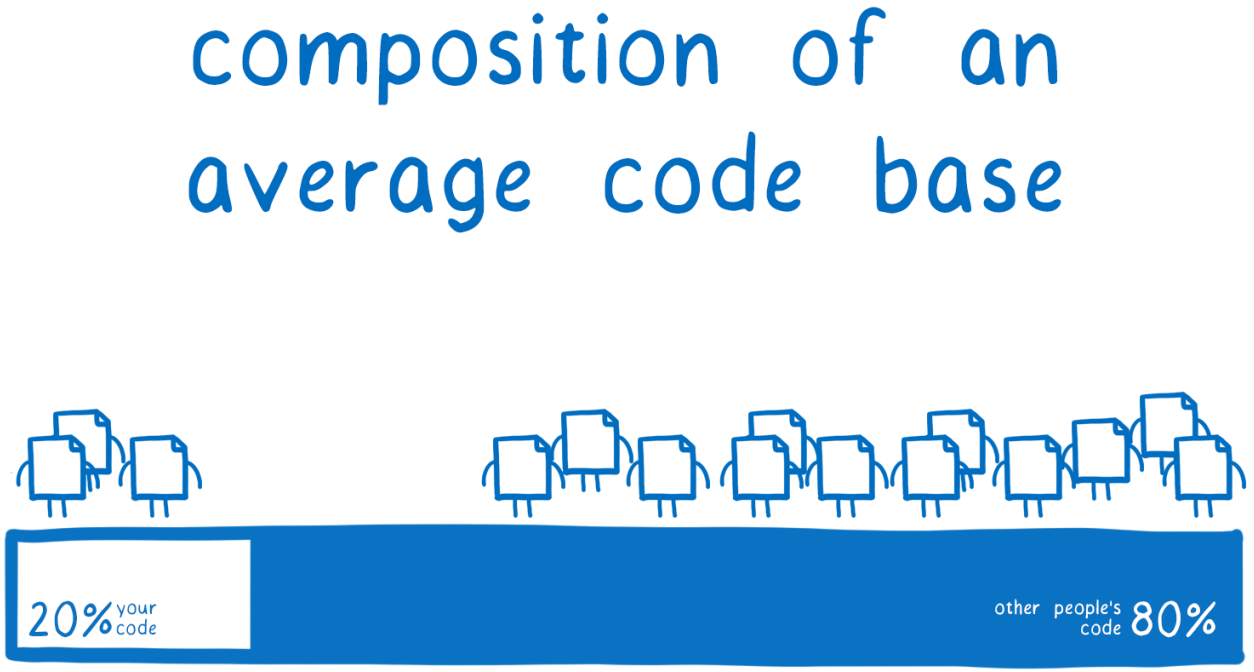
WASM – What's next?



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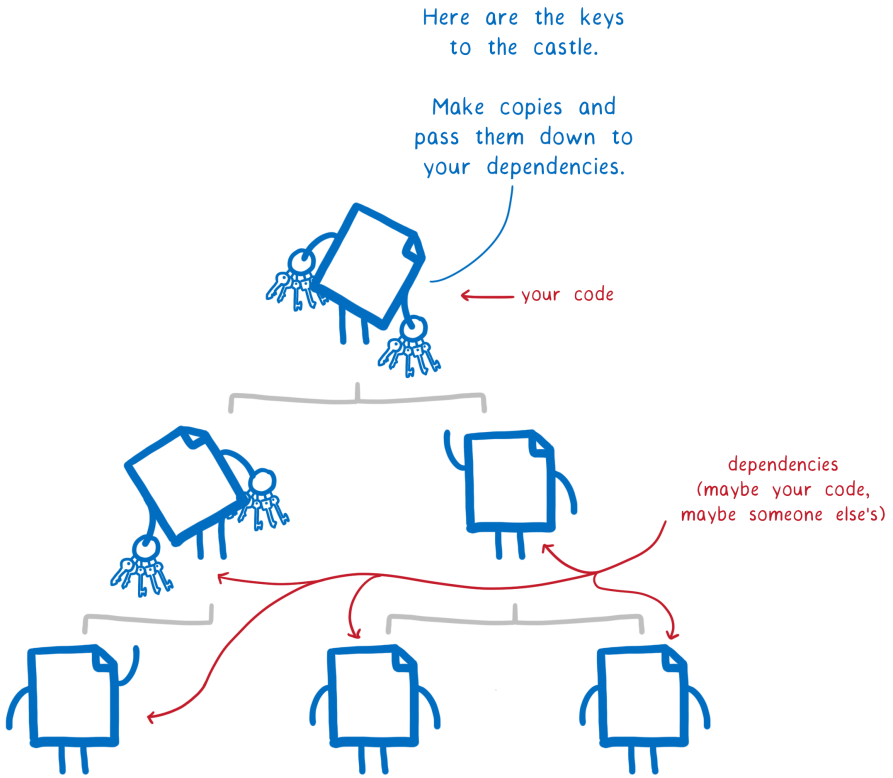
Dependencies



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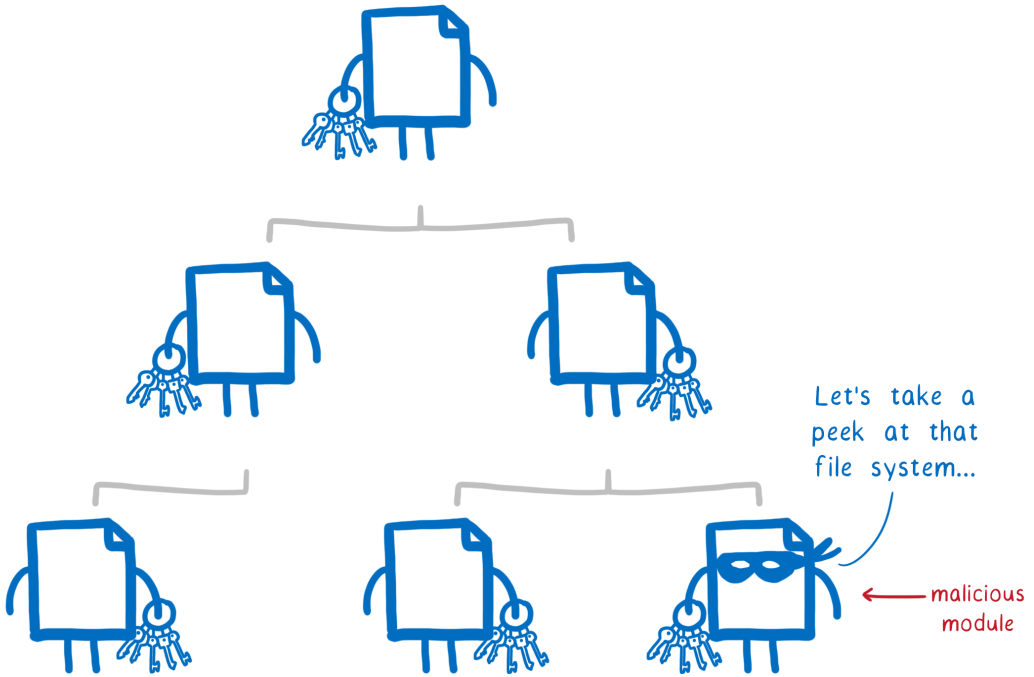
Malicious module



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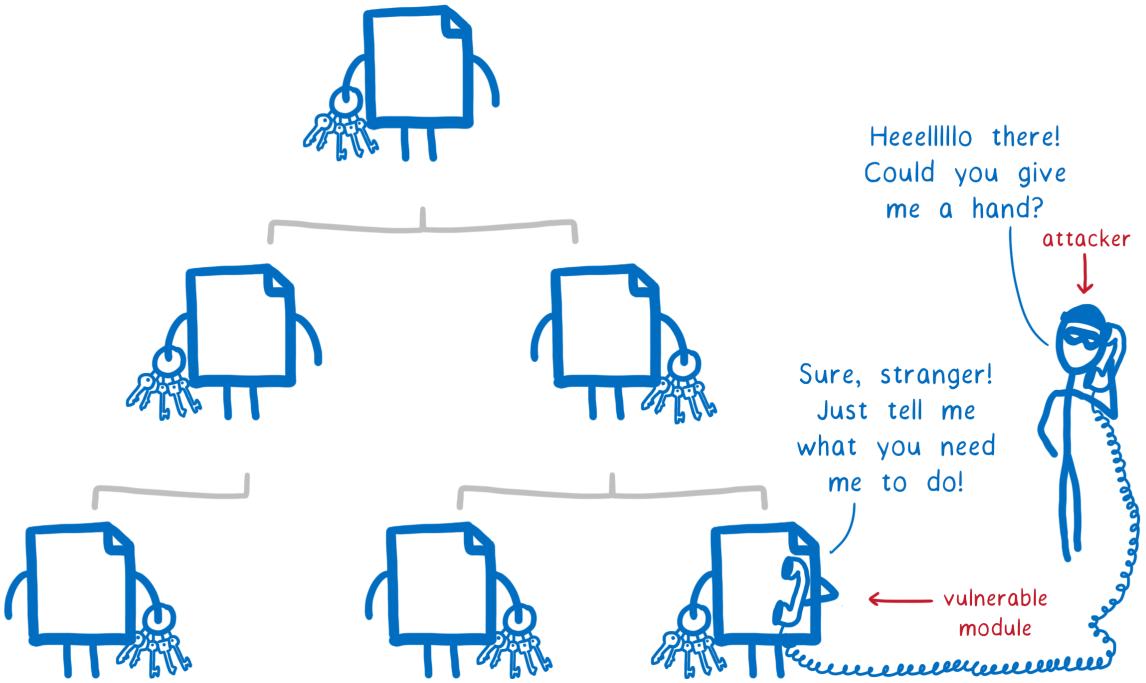
Vulnerable module



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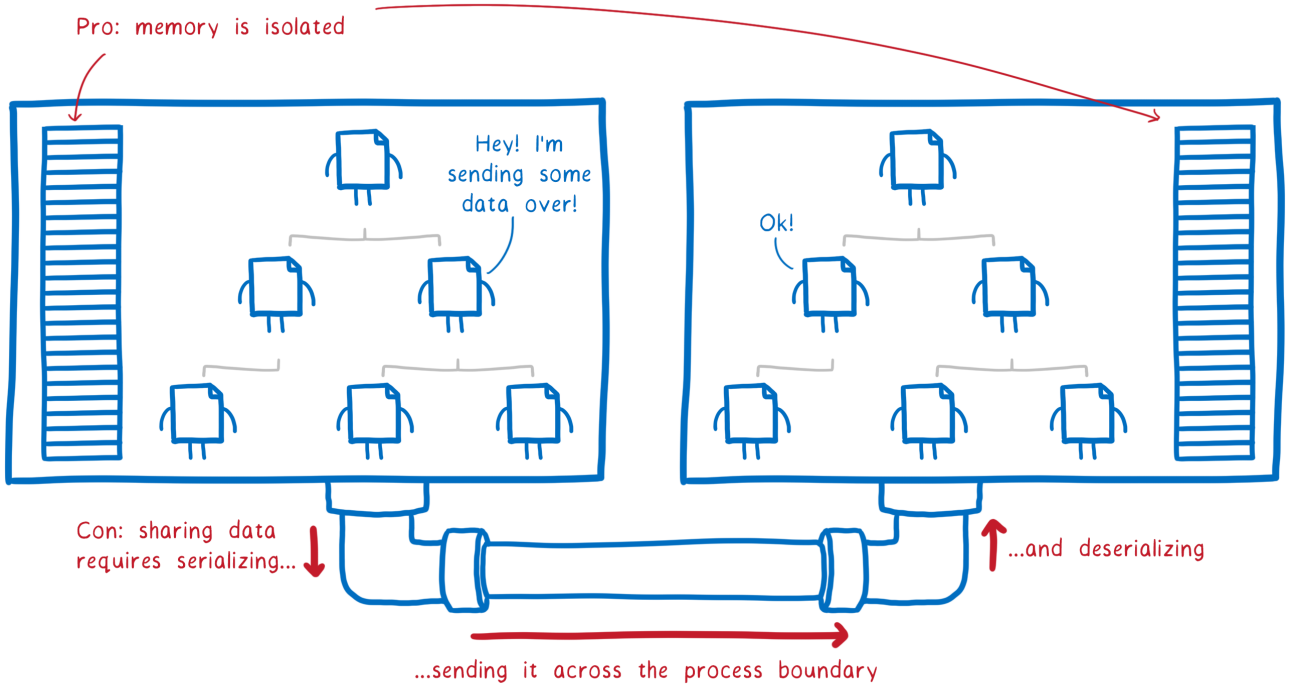
Process Isolation



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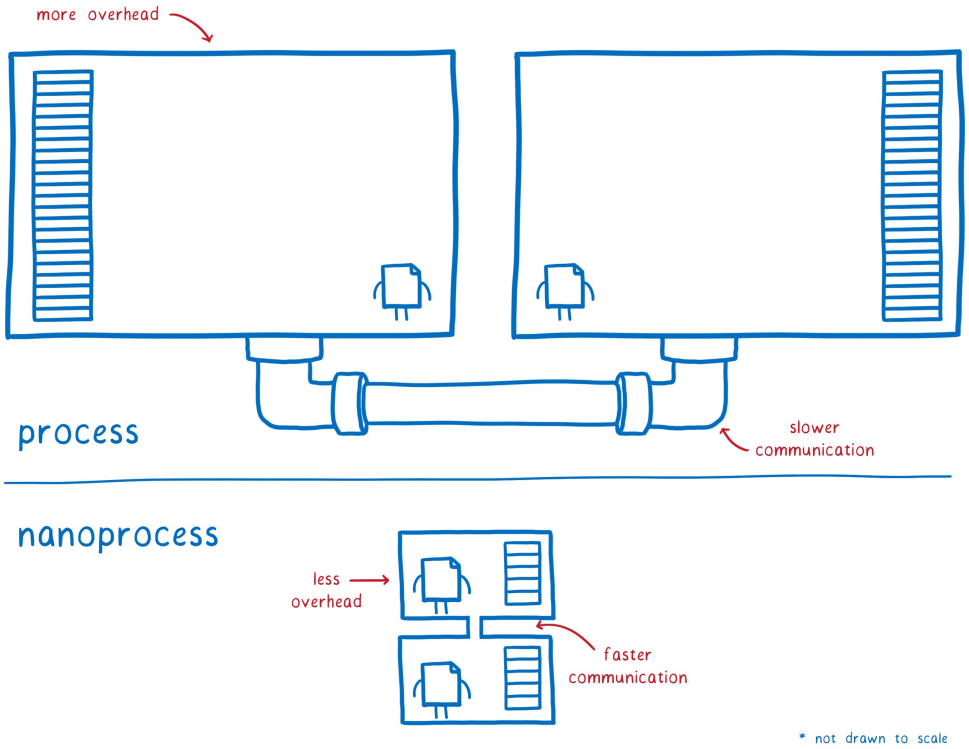
WebAssembly Nano-Process



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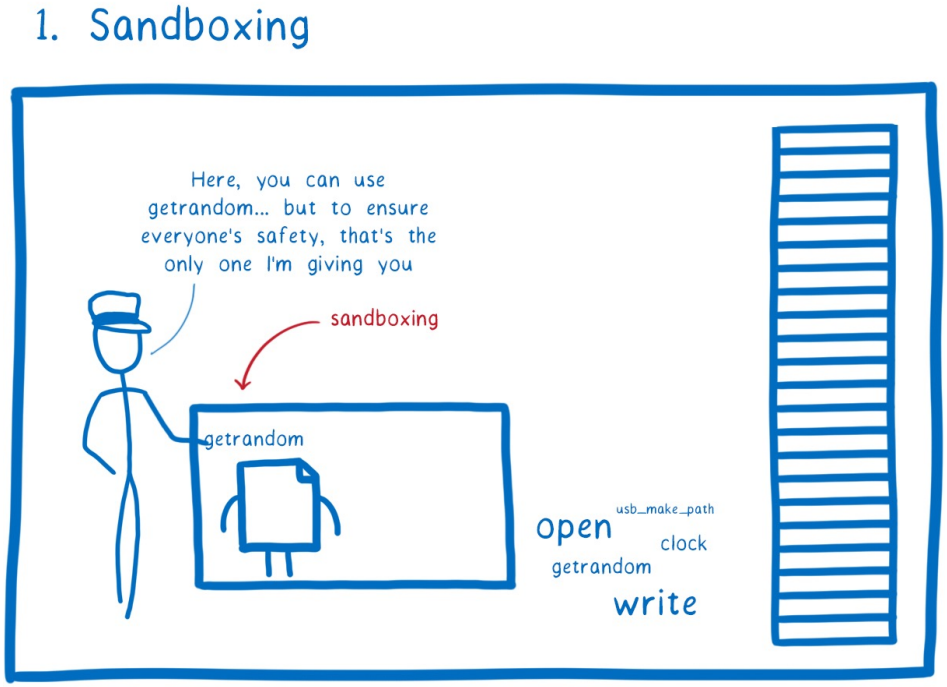
WebAssembly Nano-Process



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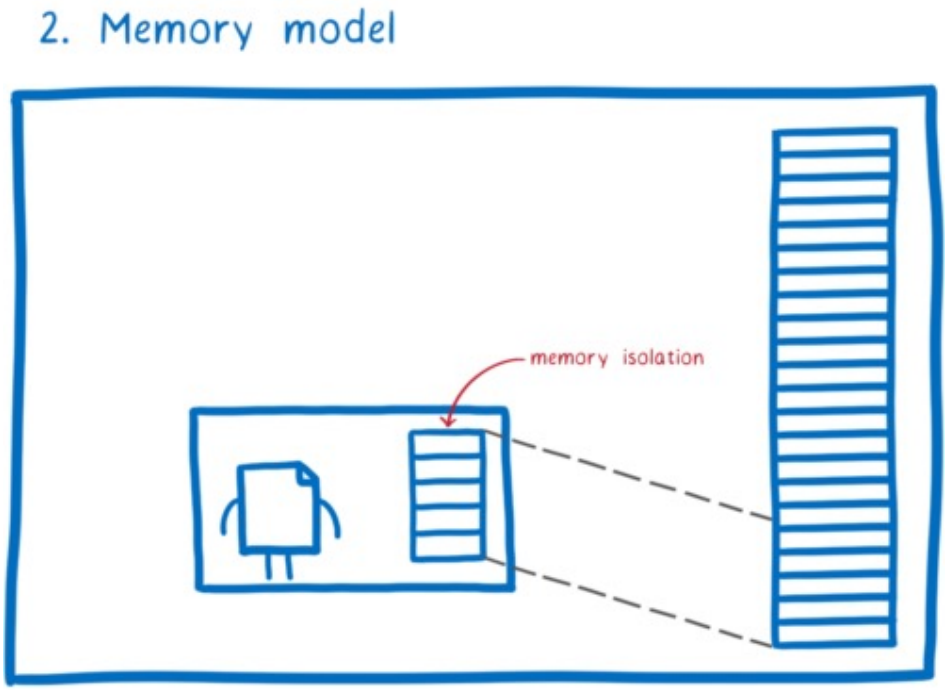
WebAssembly Nano-Process



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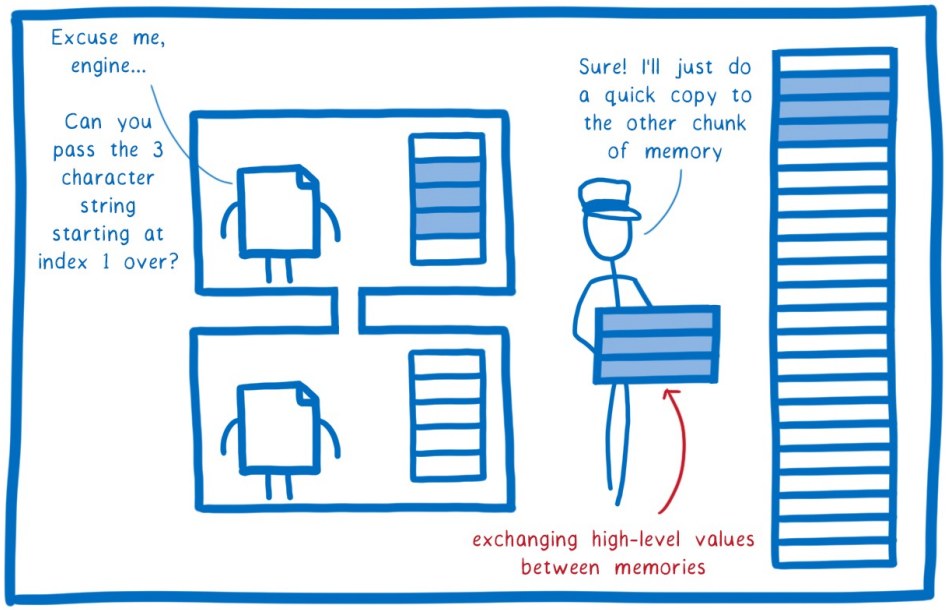
WebAssembly Nano-Process

3. Interface Types



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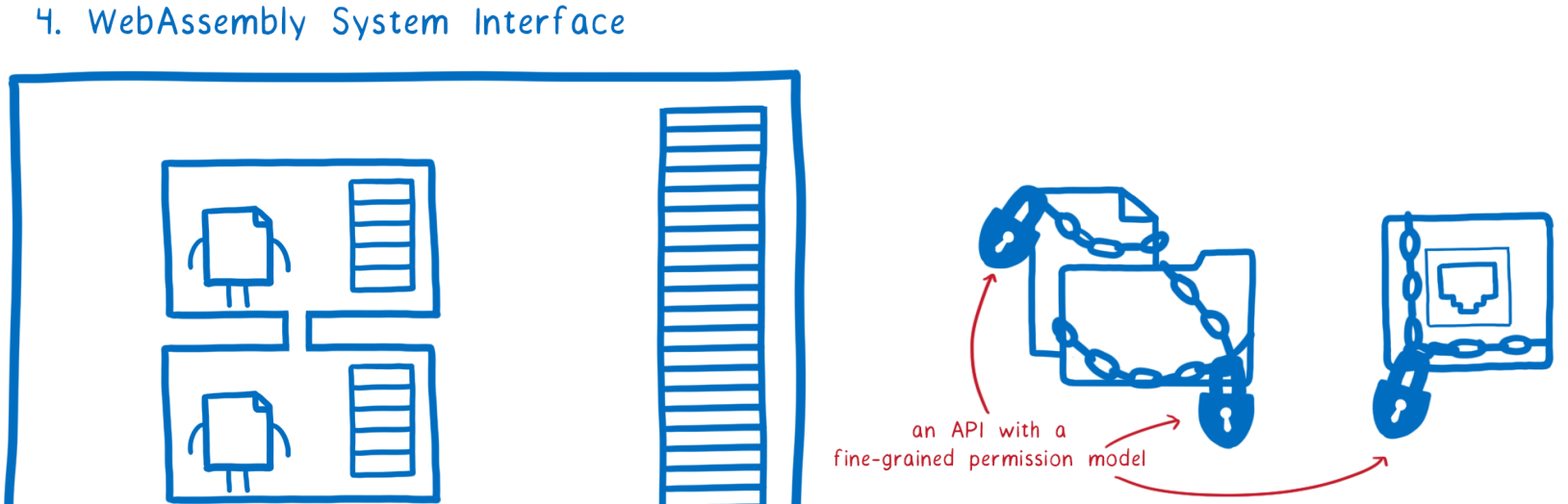
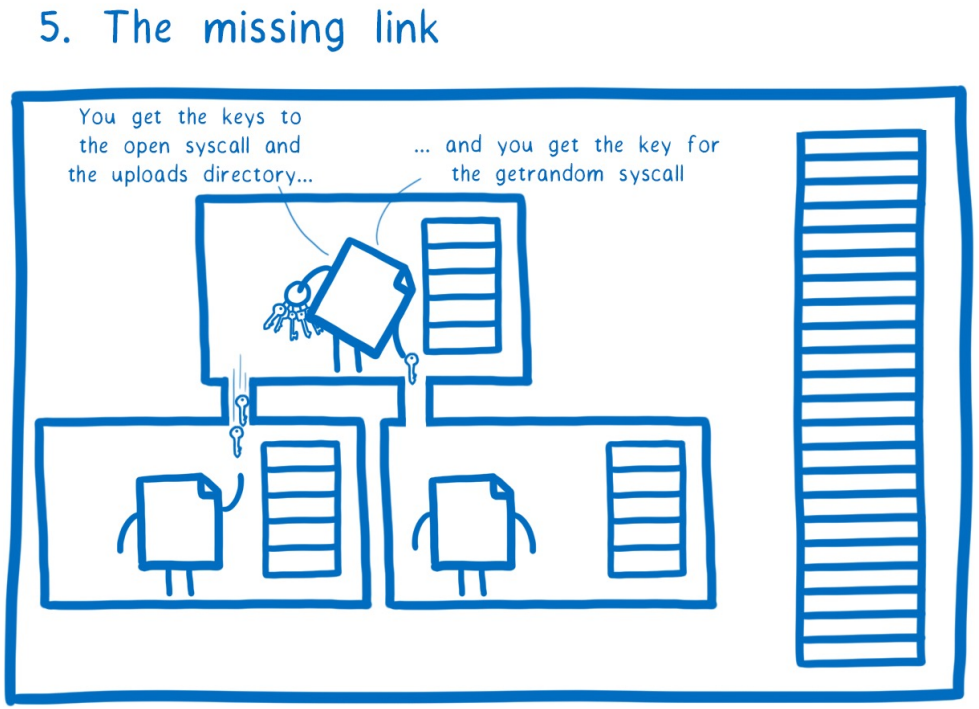
WebAssembly Nano-Process



WebAssembly Nano-Process



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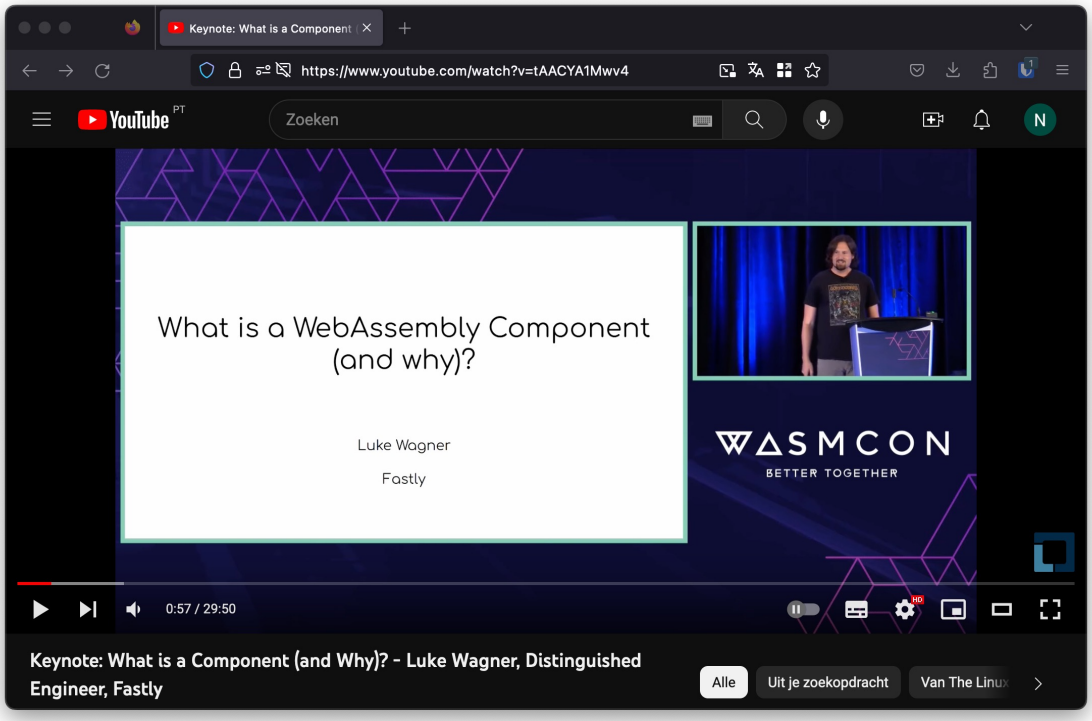
WebAssembly Component Model



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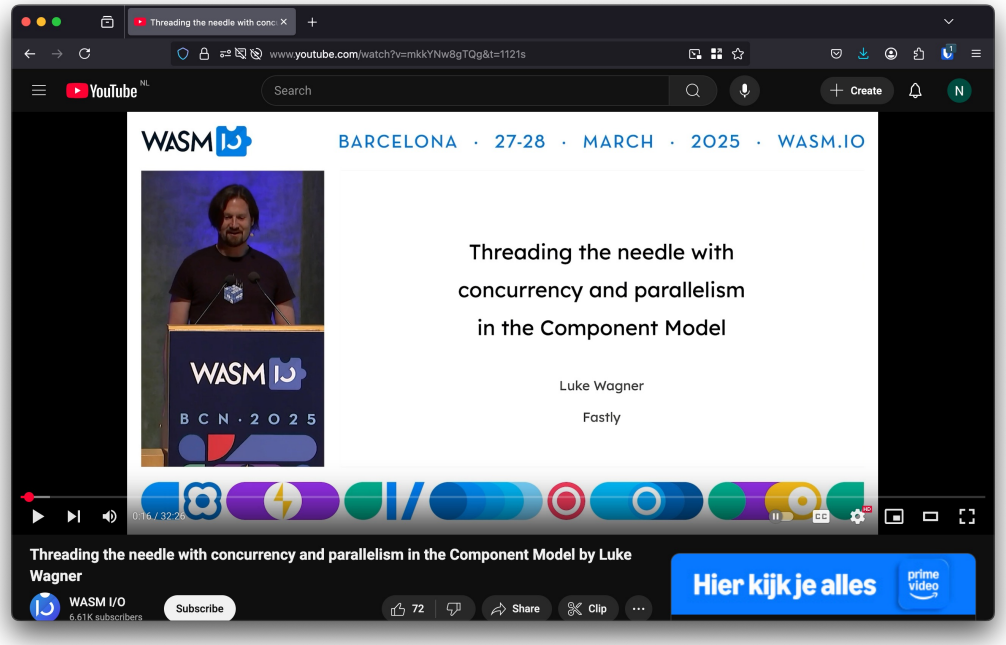
WebAssembly Component Model



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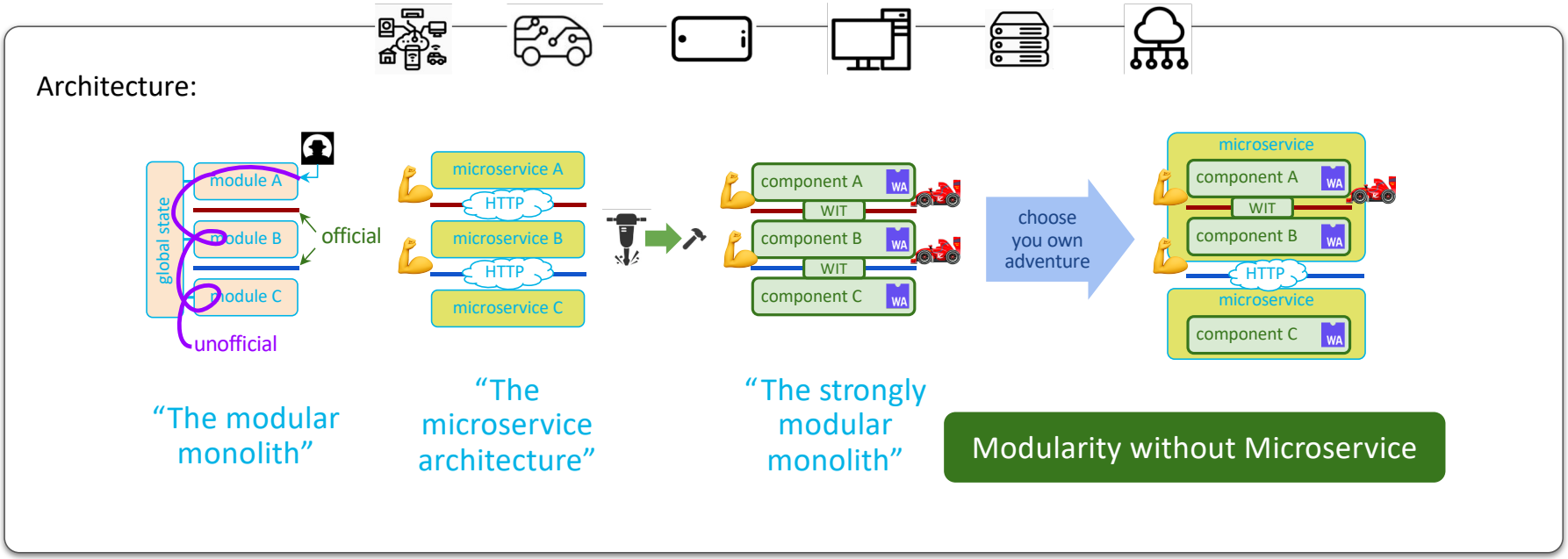
WASI 0.3

?



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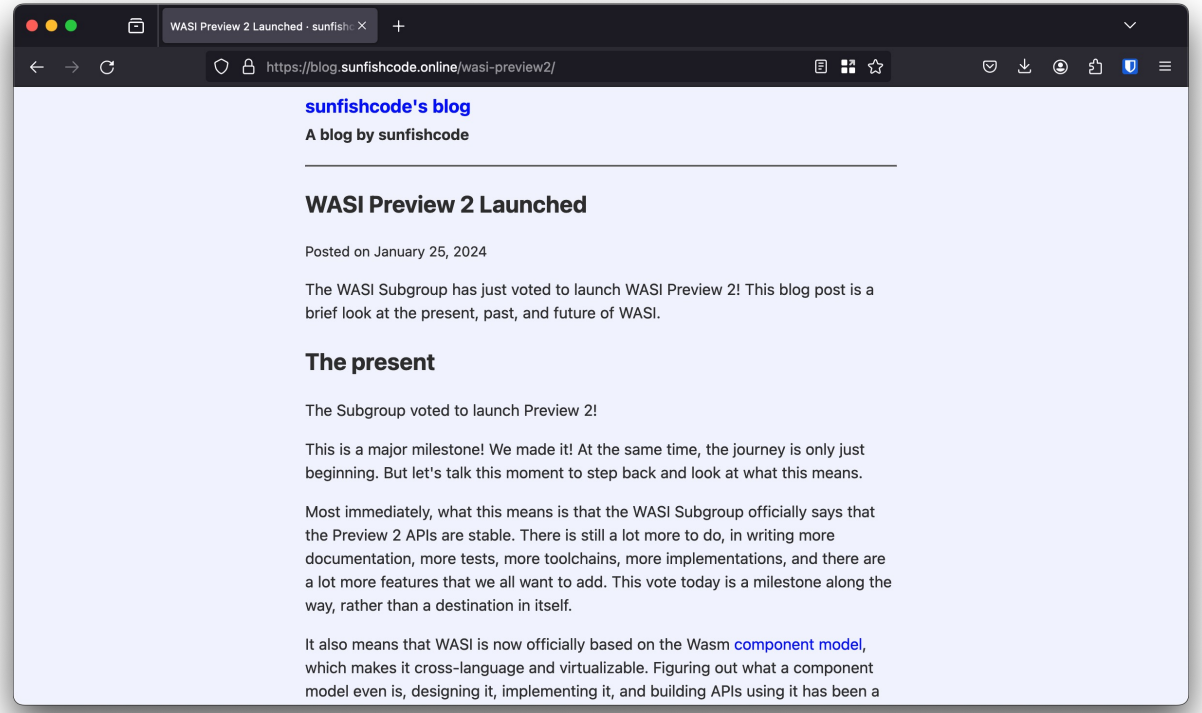
WASI Preview 2 (0.2)



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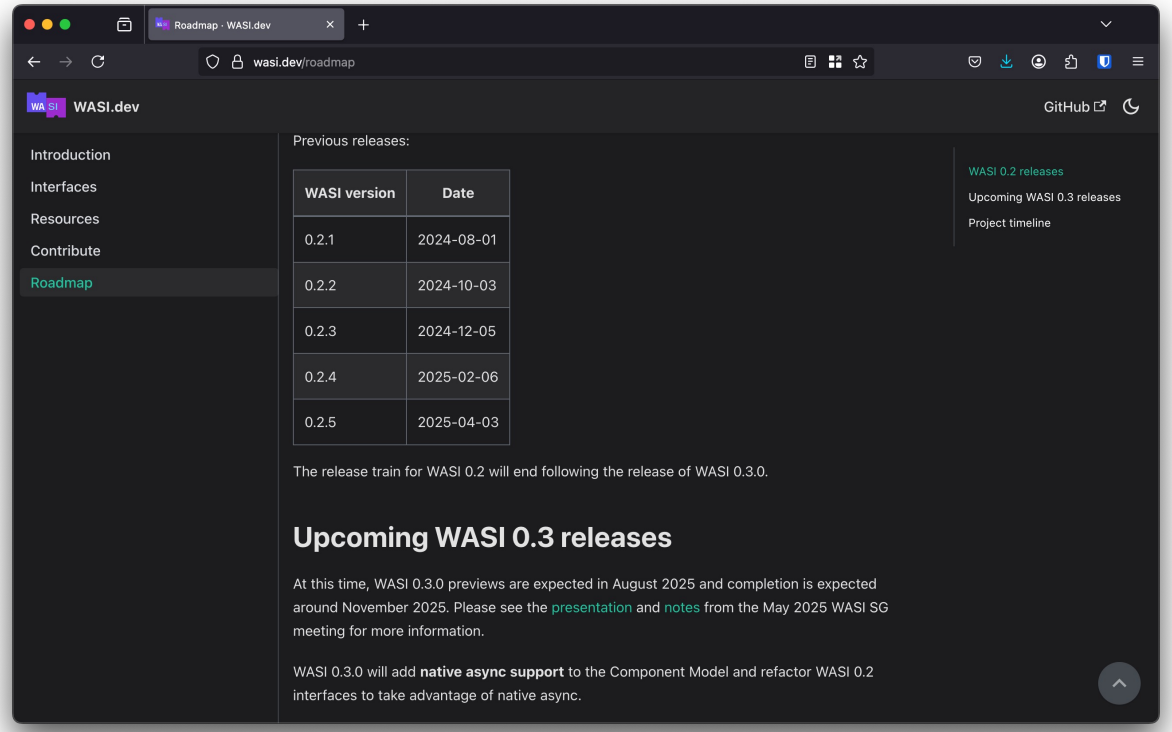
WASI 0.3



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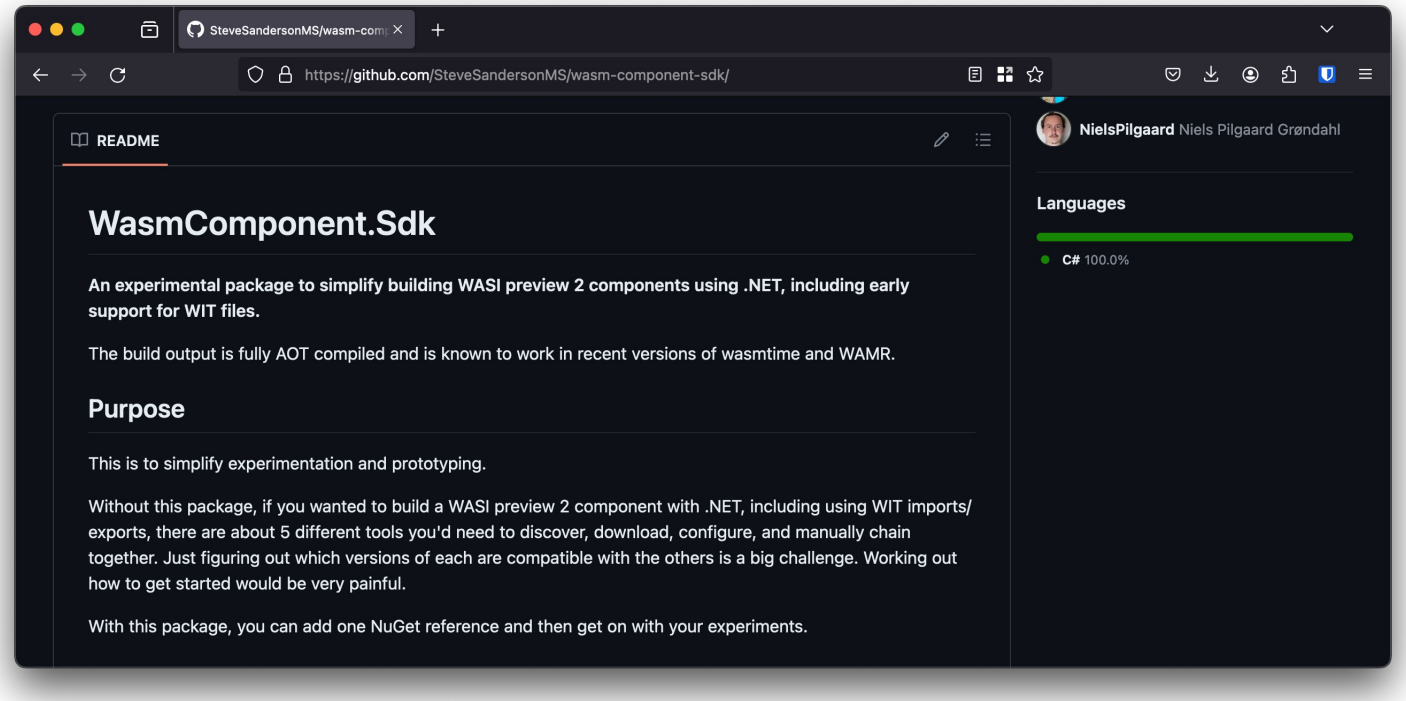
WasmComponent.SDK



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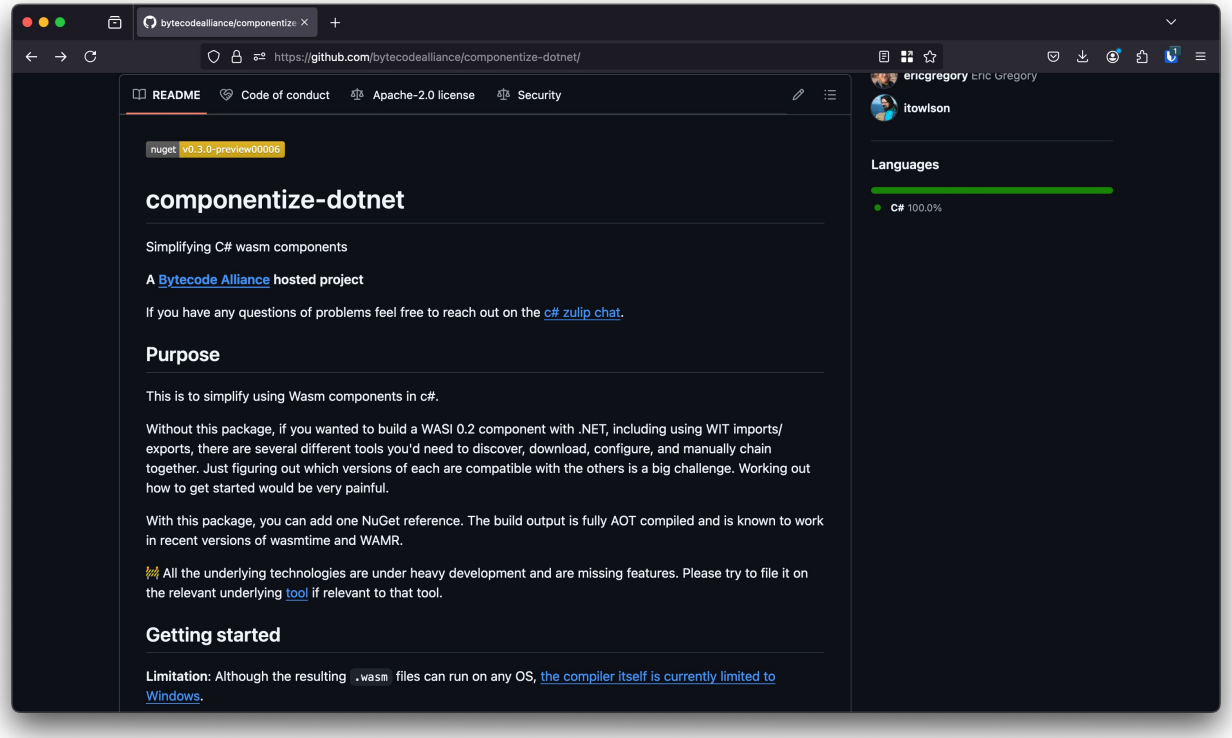
componentize-dotnet



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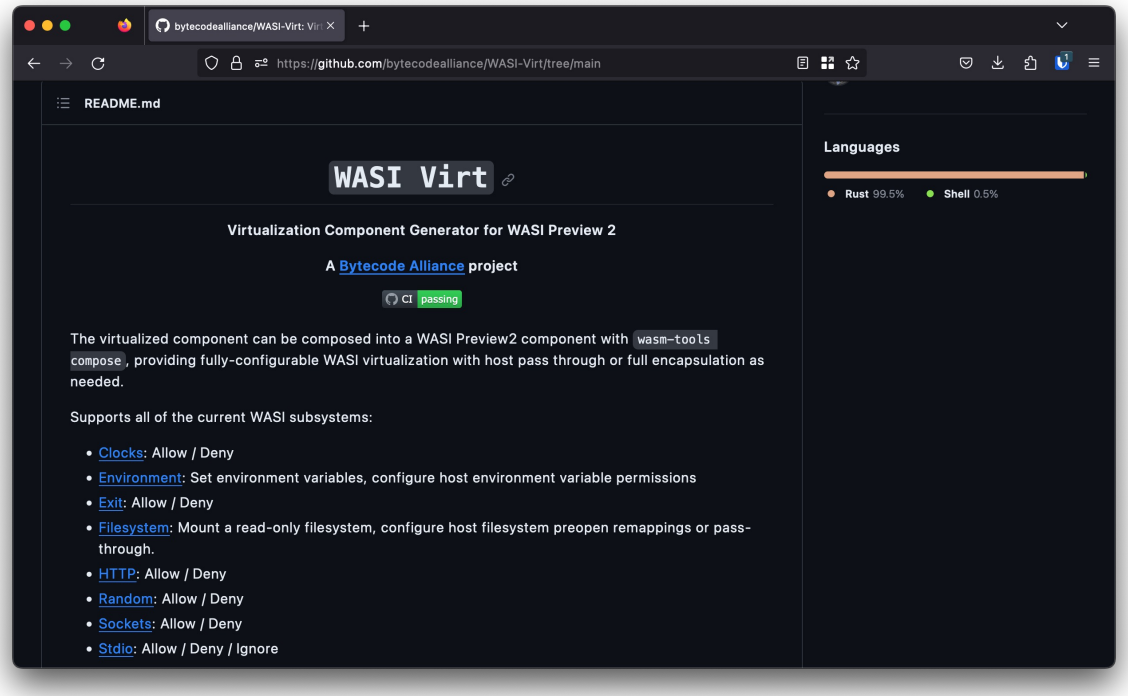
WASI Virt



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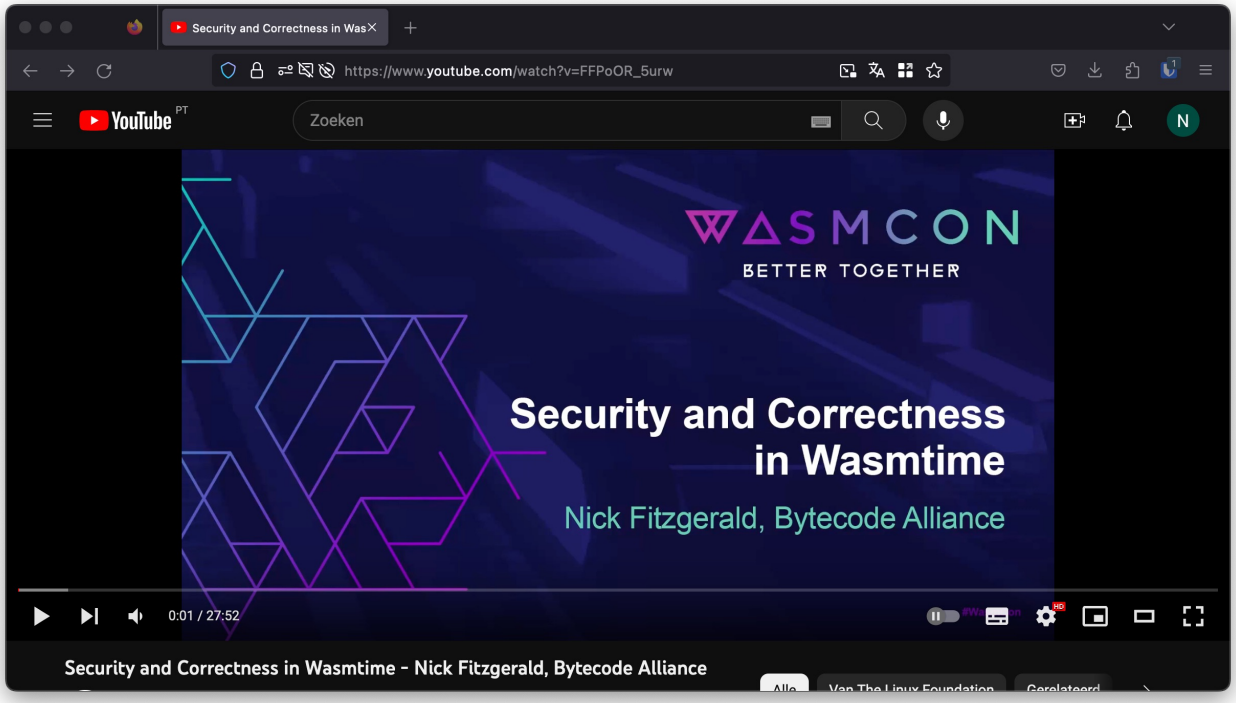
Runtimes and Security

- Most security research published focusses on correctness of WASM runtimes/VM's

- Bytecode Alliance Blogpost:
  - "Security and Correctness in Wasmtime"
  - Written in Rust → Using all it's LangSec features
  - Continues Fuzzing & formal verification
  - Security process & vulnerability disclosure

Runtimes and Security



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WebAssembly Lineair Memory

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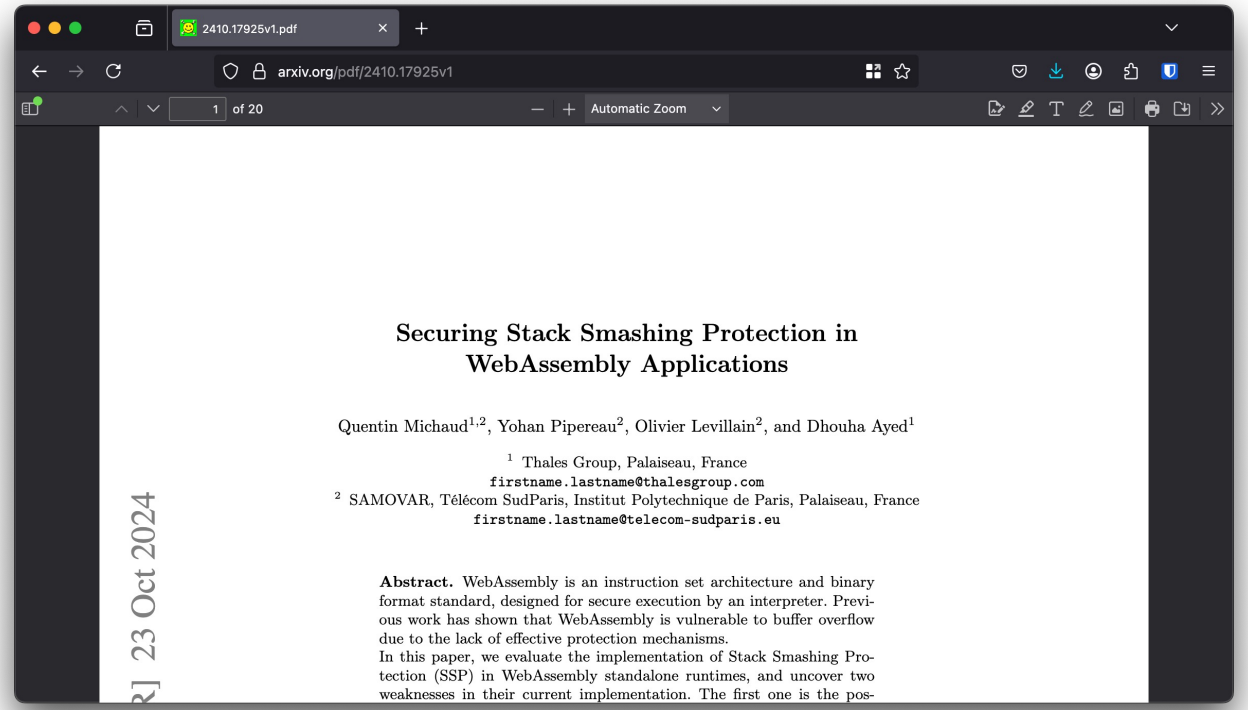
WebAssembly Lineair Memory



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Conclusion

- WebAssembly has a lot of potential to be used to run, extend, and secure your applications!
- Its as secure as the WebAssembly runtime implementation!
- WASI 0.2 big milestone; tooling in progress!
- WASI 0.3 due in August 2025
- Cloud Native ❤️ WebAssembly

Merci! Bedankt! Thanks!

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