Part 2:
Introduction to Wasabi

Dynamic Analysis Frameworks

- New platform → Need for dynamic analysis tools


Correctness


Performance


Security

- Framework as a basis

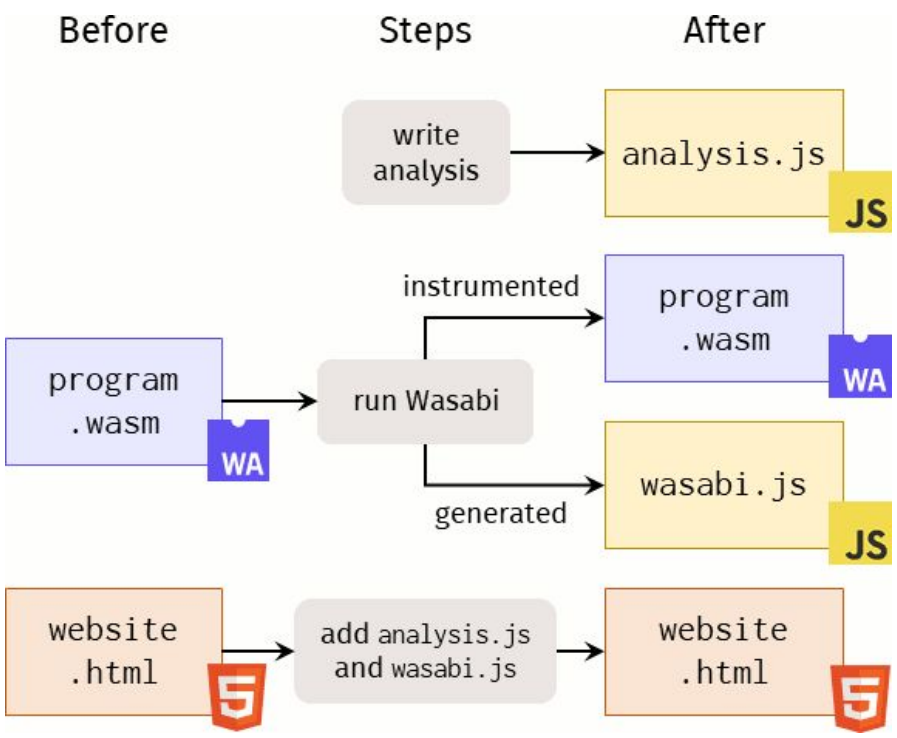
	Pin	Valgrind	RoadRunner	Jalangi	Wasabi
Platform	x86-64		JVM	JavaScript	WebAssembly
Instrumentation	native binaries		byte code	source code	binary code
Analysis Language	C/C++		Java	JavaScript	JavaScript

Wasabi:
Dynamic Analysis Framework for WebAssembly

- Observe any operation
- Analysis API in JavaScript
- Static, binary instrumentation
  - Why binary? Why static?
    - Different producers of WebAssembly
    - Source code not always available
    - Static instrumentation is reliable
- Open source: http://wasabi.software-lab.org

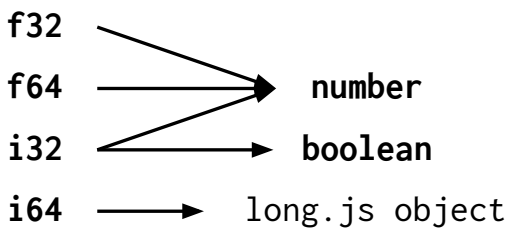
Wasabi

Instrument and Analyze



Analysis API: Overview

- Every instruction can be observed
  - Location, inputs, outputs
- Grouping of similar instructions
  - Similar instructions have a single API hook
  - 23 hooks instead of >100
- Statically pre-computed information
  - E.g., resolve relative branch targets
- Type mapping:
  - WebAssembly → JavaScript



Example Analysis: Detecting Cryptominers

- Dynamic analysis to identify cryptomining code
- 11-line re-implementation of Wang et al. [ESORICS'18]
- Gather instruction profile
- No manual instrumentation

```
let inst = {};
Wasabi.binary = function(loc, op, args) {
  switch (op) {
    case "i32.add":
    case "i32.and":
    case "i32.shl":
    case "i32.shr_u":
    case "i32.xor":
      inst[op] = (inst[op] || 0)+1;
  }
};
```

Analysis API: Memory Operations

- Stack: Manipulation of the value stack
  - const: Constant is pushed onto the stack
  - drop: Top-of-stack value is discarded
  - select: Conditional push of one of two given values
- Heap: Manipulation of global heap values
  - load: Load value from memory
  - store: Store value into memory
- Locals/globals: Manipulation of variables
  - local: Reads and writes of local variables
  - global: Reads and writes of global variables

```
(module
  (func $myfunction (local $locA i32)
    i32.const 7
    set_local $locA
  )
  (start $myfunction)
)
```

Hooks receive: Involved values, memory addresses, and code location

Analysis API: Control Flow

- Branches
  - br, br_if : Unconditional and conditional branch
  - br_table: Branch via lookup table
  - if: Enters block if condition is true

Hooks receive: Branch target(s), condition, and code location

- Function calls
  - call_pre: Just before a function call (at the call site)
  - call_post: Just after a function call (at the call site)
  - return: Just before a function return (in the callee)

Hooks receive: Arguments, return value, function (for direct calls) or function table (for indirect calls), and code location

```
(module
    (func $foo (result i32)
        i32.const 5
    )

    (func $f (local $loc i32)
        call $foo
        set_local $loc
    )

    (start $f)
)
```

Analysis API: Operations

- unary: Operations with a single operand
- binary: Operations with two operands

Hooks receive: Input value(s), output value, and code location

```
(module
    (func $f
        i32.const 3
        i32.const 2
        i32.add
        drop
    )

    (start $f)
)
```

Analysis API: Other Hooks

- Blocks:
  - begin
  - end

  Hooks receive: type of block (function, loops, block, if, else) and code location

- Memory management:
  - memory_grow
  - memory_size

  Hooks receive: Current memory size, delta in size, code location

- Others:
  - start, nop, unreachable

```
(module
    (func $f
        i32.const 3
        i32.const 2
        i32.add
        drop
    )

    (start $f)
)
```

WASM Instructions versus API Hooks

- 0..1 to N mapping from WASM instructions to API hooks
  - Most instructions trigger exactly one hook
  - Some instructions trigger multiple hooks (e.g., if → if + begin of block)
  - Some hooks are triggered without any explicit instruction (e.g., begin of function)

```
(module
    (func $f
        i32.const 3
        i32.const 2
        i32.add
        drop
    )

    (start $f)
)
```

begin hook

const hook

Code Locations

- All hooks receive the corresponding code locations
- Code locations are w.r.t. original binary, not instrumented binary
- Locations consist of two parts:
  - Function index: Unique identifier of a function within a module
  - Instruction index: Sequential order in function body (start at zero)
    - -1 for hooks that do not correspond to any specific instruction in the body

Example:

```
▸ Object { func: 1, instr: -1 } start
▸ Object { func: 1, instr: -1 } begin function
▸ Object { func: 1, instr: 0 } const, value = 42
▸ Object { func: 1, instr: 1 } direct call to func # 0 args = ▸ Array [ 42 ]
```

Static Information

In addition to runtime hooks, Wasabi provides some static information about the analyzed WebAssembly module:

- Functions
- Branch tables
- Global variables

Access this information via `Wasabi.module`

- `Example:`

```
Wasabi.module
▼ {…}
  ▶ exports: Object {  }
  ▼ info: {…}
    ▶ brTables: Array []
    ▶ functions: Array [ {…}, {…} ]
      globals: ""
      start: 1
      tableExportName: null
```

Part 3:
Writing Your Own Wasabi Analyses

Task 1: Your First Wasabi Analysis

- Goal
  - Build and run a very simple analysis on a minimalistic WebAssembly module
- Prerequisite
  - Wasabi installed
    - You have it after the previous tasks
- Once Wasabi is installed:

  See https://github.com/danleh/wasabi/tree/master/tutorial/task1

Task 2: Dynamic Call Graph of a 3D Game

- Goals
  - Apply Wasabi to a larger program, here: WebAssembly port of C game engine
  - Write dynamic call graph analysis, which is often a building block for other analyses
- Prerequisites
  - Wasabi installed
    - You have it after the previous tasks
  - Graphviz
    - For Ubuntu: sudo apt install graphviz
- Instructions
  - See README in https://github.com/danleh/wasabi/tree/master/tutorial/task2

Task 3: Reverse Engineering

- Goals
  - Very simple WebAssembly “reverse engineering”
  - Why dynamic analysis is sometimes useful/easier
- Prerequisites
  - wasm2wat (from WebAssembly Binary Toolkit) or just browser developer tools
  - Wasabi
- Instructions
  - See README in https://github.com/danleh/wasabi/tree/master/tutorial/task3