black hat
ASIA 2023

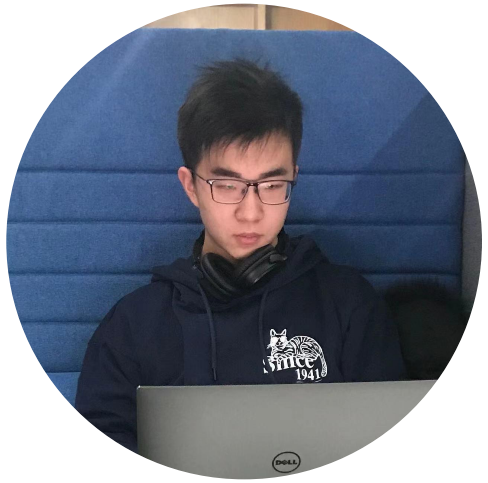
MAY 11-12

BRIEFINGS

Attacking the WebAssembly Compiler of WebKit

Zong Cao(@P1umer)   Zheng Wang(@xmzyshypnc)

Who are we



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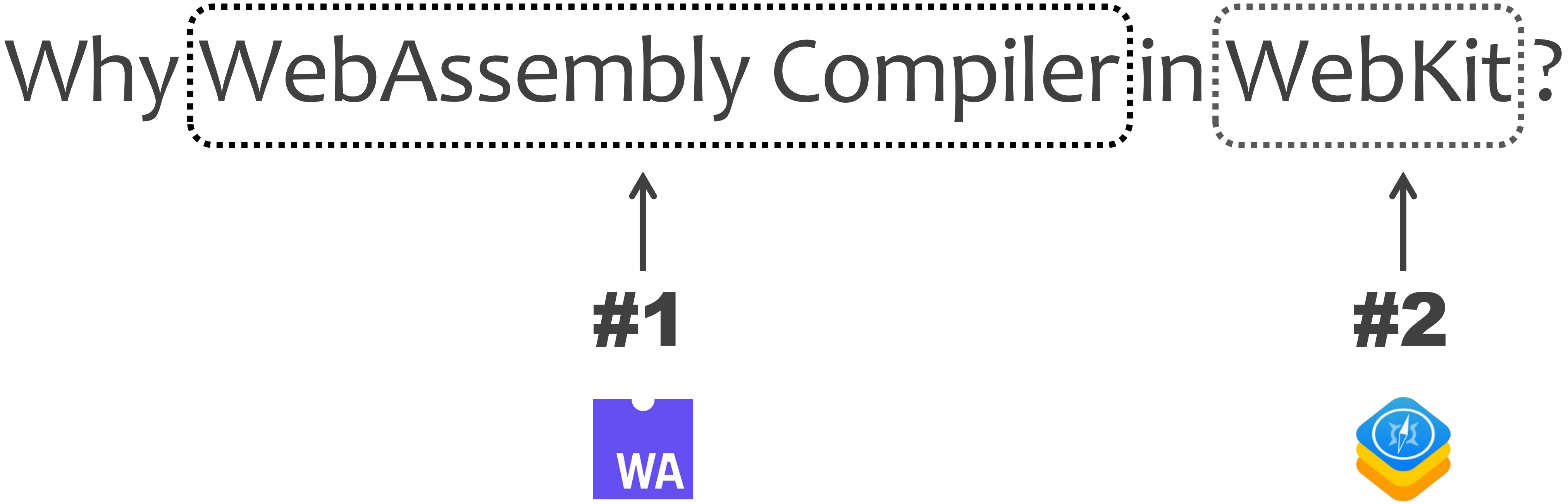
Why WebAssembly Compiler in WebKit ?



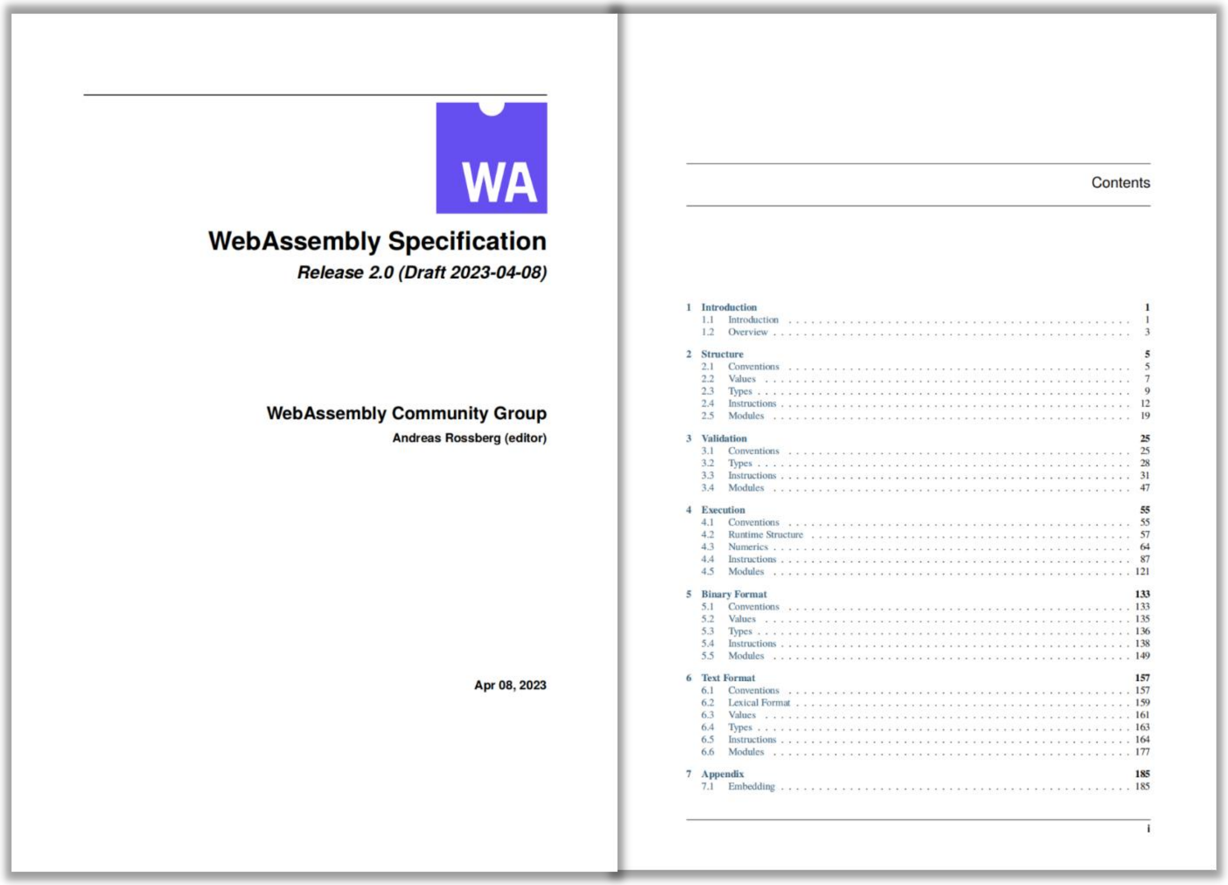
Why WebAssembly Compiler in WebKit?

#1

#2

WASM Compiler in WebKit #1

- New features from WebAssembly 2.0 specs
  - Wasm 2.0 compatibility roadmap



WA

WebAssembly Specification

Release 2.0 (Draft 2023-04-08)

WebAssembly Community Group

Andreas Rossberg (editor)

Apr 08, 2023

Contents

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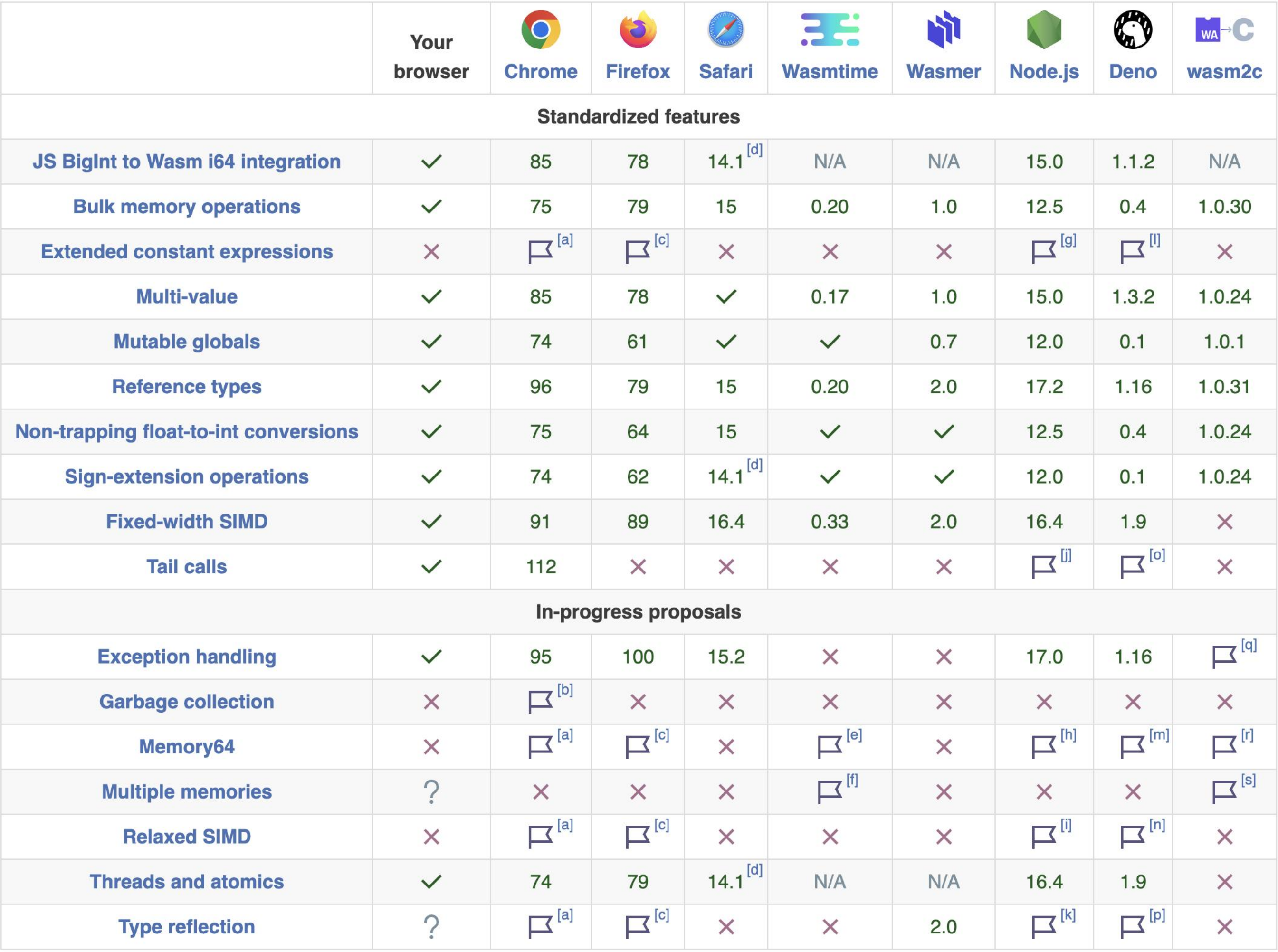
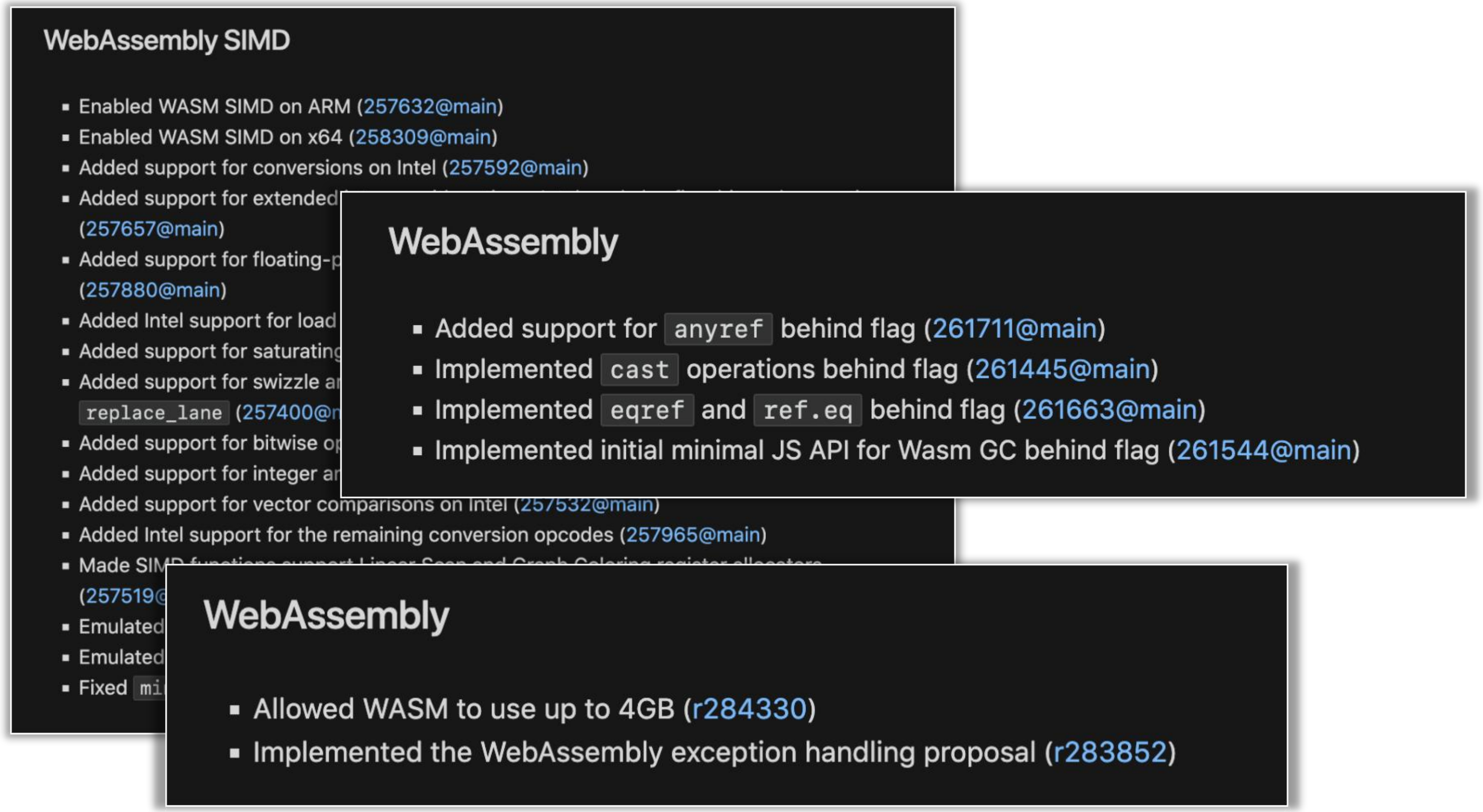


	Your browser	Chrome	Firefox	Safari	Wasmtime	Wasmer	Node.js	Deno	wasm2c
Standardized features									
JS BigInt to Wasm i64 integration	✓	85	78	14.1[d]	N/A	N/A	15.0	1.1.2	N/A
Bulk memory operations	✓	75	79	15	0.20	1.0	12.5	0.4	1.0.30
Extended constant expressions	✗	⚐[a]	⚐[c]	✗	✗	✗	⚐[g]	⚐[l]	✗
Multi-value	✓	85	78	✓	0.17	1.0	15.0	1.3.2	1.0.24
Mutable globals	✓	74	61	✓	✓	0.7	12.0	0.1	1.0.1
Reference types	✓	96	79	15	0.20	2.0	17.2	1.16	1.0.31
Non-trapping float-to-int conversions	✓	75	64	15	✓	✓	12.5	0.4	1.0.24
Sign-extension operations	✓	74	62	14.1[d]	✓	✓	12.0	0.1	1.0.24
Fixed-width SIMD	✓	91	89	16.4	0.33	2.0	16.4	1.9	✗
Tail calls	✓	112	✗	✗	✗	✗	⚐[j]	⚐[o]	✗
In-progress proposals									
Exception handling	✓	95	100	15.2	✗	✗	17.0	1.16	⚐[q]
Garbage collection	✗	⚐[b]	✗	✗	✗	✗	✗	✗	✗
Memory64	✗	⚐[a]	⚐[c]	✗	⚐[e]	✗	⚐[h]	⚐[m]	⚐[r]
Multiple memories	?	✗	✗	✗	⚐[f]	✗	✗	✗	⚐[s]
Relaxed SIMD	✗	⚐[a]	⚐[c]	✗	✗	✗	⚐[i]	⚐[n]	✗
Threads and atomics	✓	74	79	14.1[d]	N/A	N/A	16.4	1.9	✗
Type reflection	?	⚐[a]	⚐[c]	✗	✗	2.0	⚐[k]	⚐[p]	✗

WASM Compiler in WebKit #2

- **Shared** security implications
- **Active** on WASM 2.0



WebAssembly SIMD

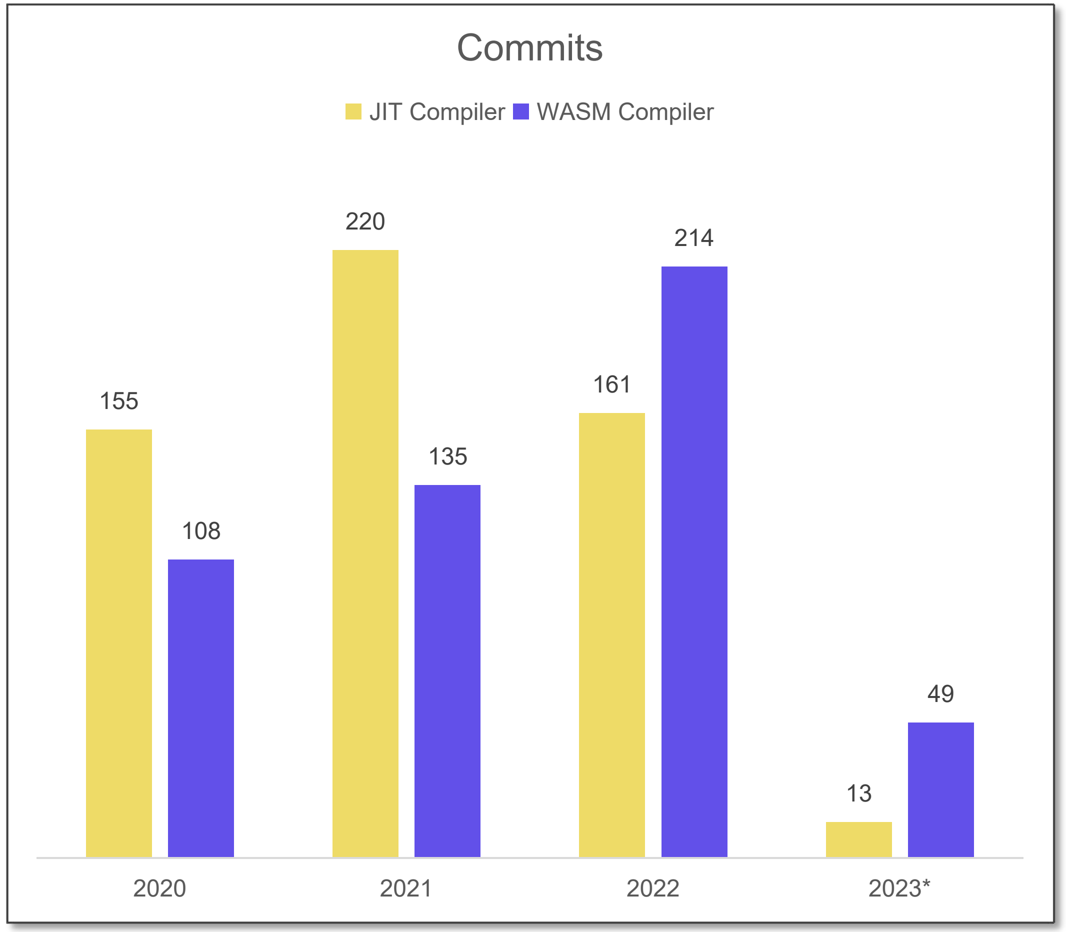
- Enabled WASM SIMD on ARM (257632@main)
- Enabled WASM SIMD on x64 (258309@main)
- Added support for conversions on Intel (257592@main)
- Added support for extended
  (257657@main)
- Added support for floating-p
  (257880@main)
- Added Intel support for load
- Added support for saturating
- Added support for swizzle ar
  `replace_lane` (257400@m
- Added support for bitwise op
- Added support for integer ar
- Added support for vector comparisons on Intel (257532@main)
- Added Intel support for the remaining conversion opcodes (257965@main)
- Made SIMD functions support Linear Scan and Graph Coloring register allocators
  (257519@
- Emulated
- Emulated
- Fixed `mi

WebAssembly

- Added support for `anyref` behind flag (261711@main)
- Implemented `cast` operations behind flag (261445@main)
- Implemented `eqref` and `ref.eq` behind flag (261663@main)
- Implemented initial minimal JS API for Wasm GC behind flag (261544@main)

WebAssembly

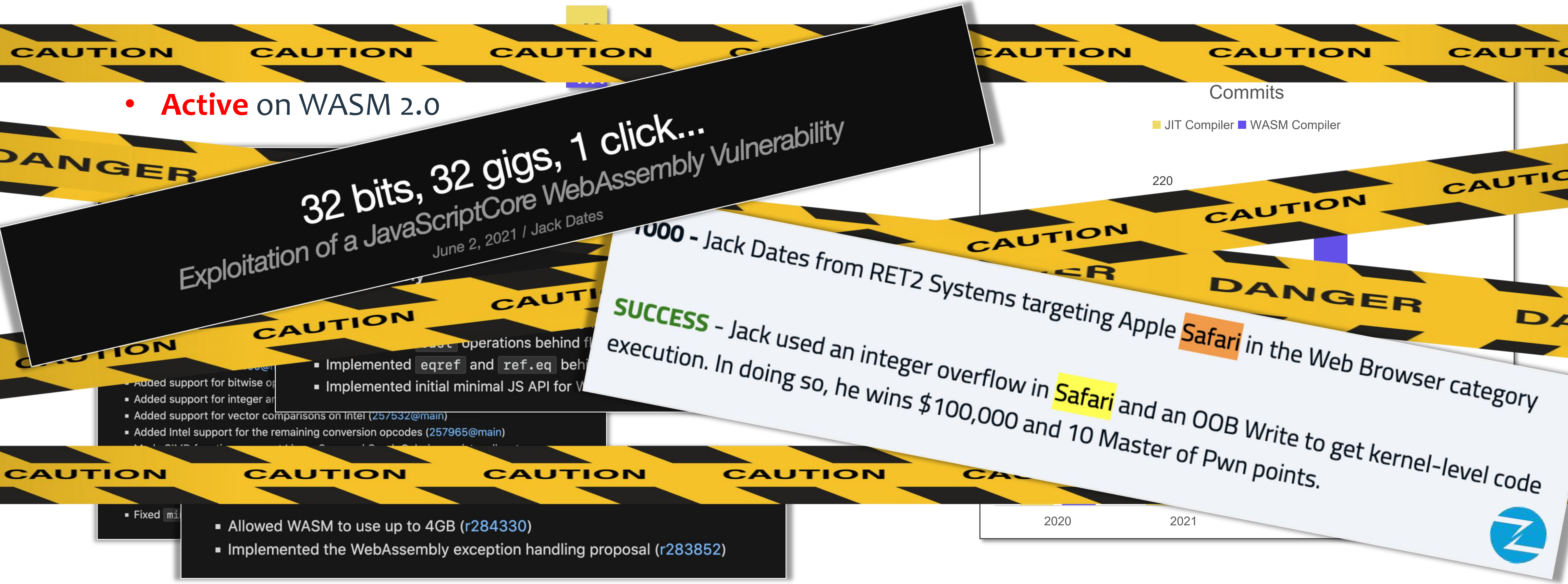
- Allowed WASM to use up to 4GB (r284330)
- Implemented the WebAssembly exception handling proposal (r283852)



2023*: 2023.1.1~2023.5.1
Command: git log --pretty=oneline --since=202{n}.1.1 --before=202{n}.12.31 -- ./{dir} |wc -l

WASM Compiler in WebKit #2

- **Active** on WASM 2.0



32 bits, 32 gigs, 1 click...

Exploitation of a JavaScriptCore WebAssembly Vulnerability

June 2, 2021 / Jack Dates

- operations behind fl
- Implemented `eqref` and `ref.eq` behi
- Implemented initial minimal JS API for W

- Added support for bitwise op
- Added support for integer ar
- Added support for vector comparisons on Intel (257532@main)
- Added Intel support for the remaining conversion opcodes (257965@main)
- Fixed `mi`

- Allowed WASM to use up to 4GB (r284330)
- Implemented the WebAssembly exception handling proposal (r283852)

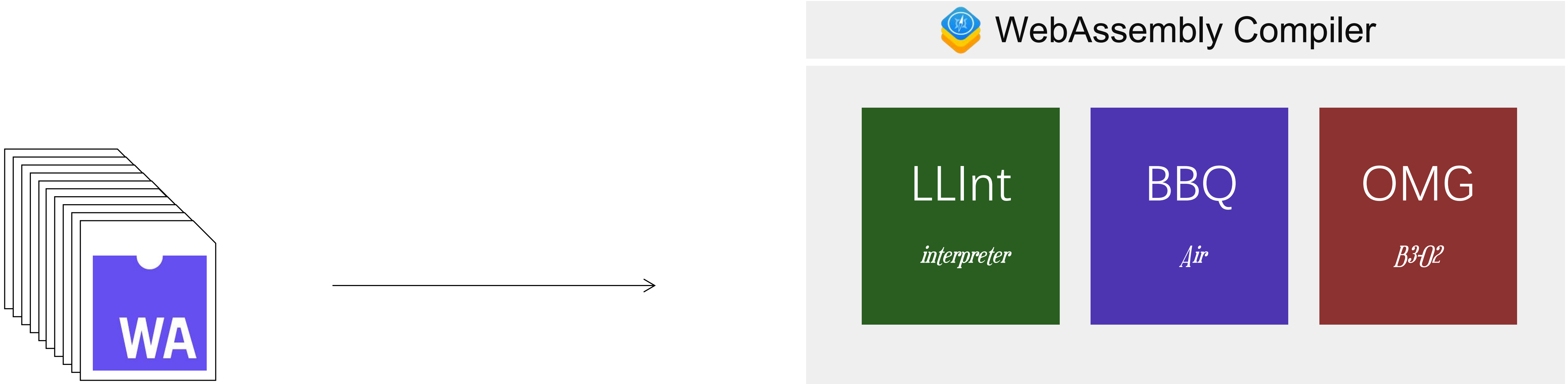
1000 - Jack Dates from RET2 Systems targeting Apple Safari in the Web Browser category

SUCCESS - Jack used an integer overflow in Safari and an OOB Write to get kernel-level code execution. In doing so, he wins $100,000 and 10 Master of Pwn points.

➢ https://www.zerodayinitiative.com/blog/2021/4/2/pwn2own-2021-schedule-and-live-results

Fuzzing WebAssembly Compiler in WebKit

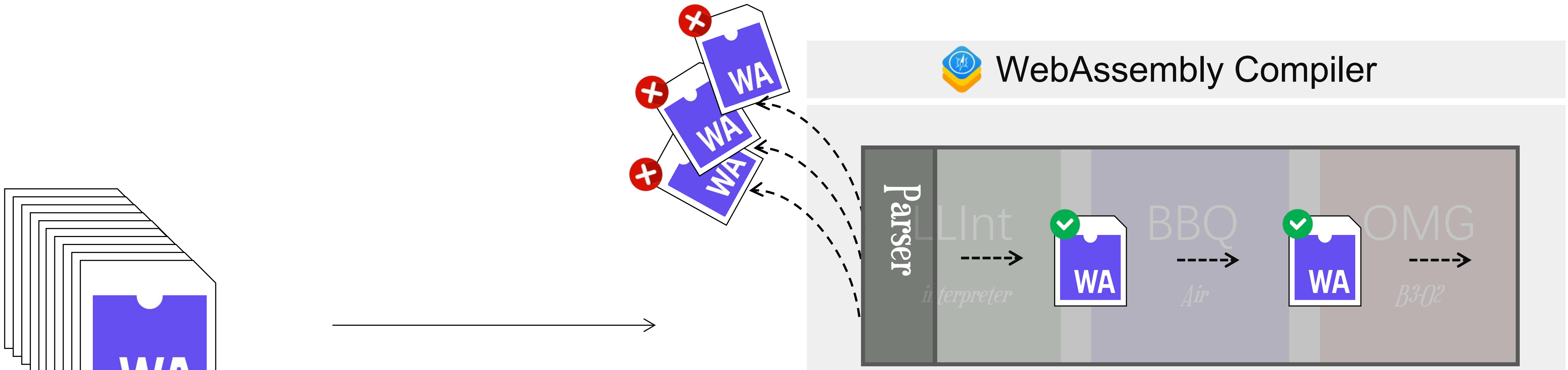
Fuzzing Overview



- **LLInt**: Low Level Interpreter
- **BBQ:** Build Bytecode Quickly
- **OMG:** Optimized Machine-code Generator

Fuzzing Overview

Main challenge: how to make the fuzzer generate semi-well-formed samples



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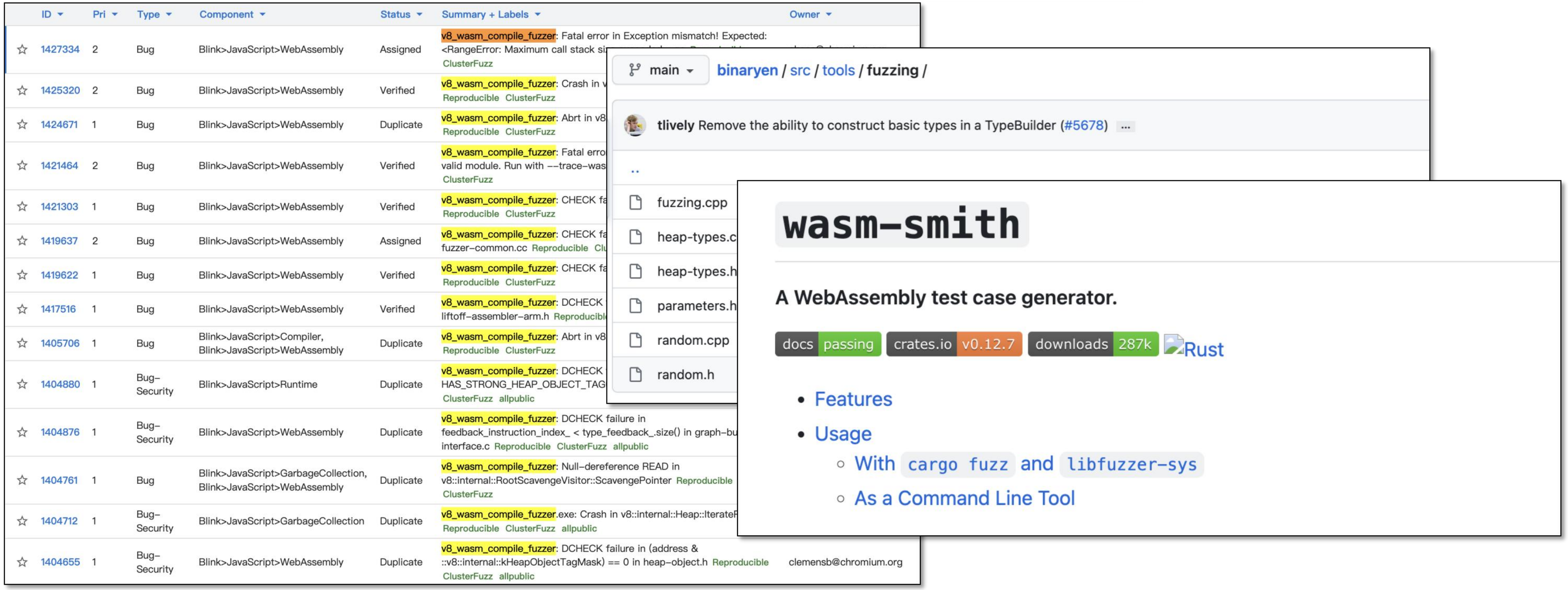


	ID	Pri	Type	Component	Status	Summary + Labels	Owner
☆	1427334	2	Bug	Blink>JavaScript>WebAssembly	Assigned	v8_wasm_compile_fuzzer: Fatal error in Exception mismatch! Expected: <RangeError: Maximum call stack si ClusterFuzz	
☆	1425320	2	Bug	Blink>JavaScript>WebAssembly	Verified	v8_wasm_compile_fuzzer: Crash in v Reproducible ClusterFuzz	
☆	1424671	1	Bug	Blink>JavaScript>WebAssembly	Duplicate	v8_wasm_compile_fuzzer: Abrt in v8 Reproducible ClusterFuzz	
☆	1421464	2	Bug	Blink>JavaScript>WebAssembly	Verified	v8_wasm_compile_fuzzer: Fatal erro valid module. Run with --trace-was ClusterFuzz	
☆	1421303	1	Bug	Blink>JavaScript>WebAssembly	Verified	v8_wasm_compile_fuzzer: CHECK fa Reproducible ClusterFuzz	
☆	1419637	2	Bug	Blink>JavaScript>WebAssembly	Assigned	v8_wasm_compile_fuzzer: CHECK fa fuzzer-common.cc Reproducible Clu	
☆	1419622	1	Bug	Blink>JavaScript>WebAssembly	Verified	v8_wasm_compile_fuzzer: CHECK fa Reproducible ClusterFuzz	
☆	1417516	1	Bug	Blink>JavaScript>WebAssembly	Verified	v8_wasm_compile_fuzzer: DCHECK liftoff-assembler-arm.h Reproducibl	
☆	1405706	1	Bug	Blink>JavaScript>Compiler, Blink>JavaScript>WebAssembly	Duplicate	v8_wasm_compile_fuzzer: Abrt in v8 Reproducible ClusterFuzz	
☆	1404880	1	Bug-Security	Blink>JavaScript>Runtime	Duplicate	v8_wasm_compile_fuzzer: DCHECK HAS_STRONG_HEAP_OBJECT_TAG ClusterFuzz allpublic	
☆	1404876	1	Bug-Security	Blink>JavaScript>WebAssembly	Duplicate	v8_wasm_compile_fuzzer: DCHECK failure in feedback_instruction_index_ < type_feedback_.size() in graph-bu interface.c Reproducible ClusterFuzz allpublic	
☆	1404761	1	Bug	Blink>JavaScript>GarbageCollection, Blink>JavaScript>WebAssembly	Duplicate	v8_wasm_compile_fuzzer: Null-dereference READ in v8::internal::RootScavengeVisitor::ScavengePointer Reproducible ClusterFuzz	
☆	1404712	1	Bug-Security	Blink>JavaScript>GarbageCollection	Duplicate	v8_wasm_compile_fuzzer.exe: Crash in v8::internal::Heap::IterateR Reproducible ClusterFuzz allpublic	
☆	1404655	1	Bug-Security	Blink>JavaScript>WebAssembly	Duplicate	v8_wasm_compile_fuzzer: DCHECK failure in (address & ::v8::internal::kHeapObjectTagMask) == 0 in heap-object.h Reproducible ClusterFuzz allpublic	clemensb@chromium.org

main ▾ binaryen / src / tools / fuzzing /

tlively Remove the ability to construct basic types in a TypeBuilder (#5678) …

..

- fuzzing.cpp
- heap-types.c
- heap-types.h
- parameters.h
- random.cpp
- random.h

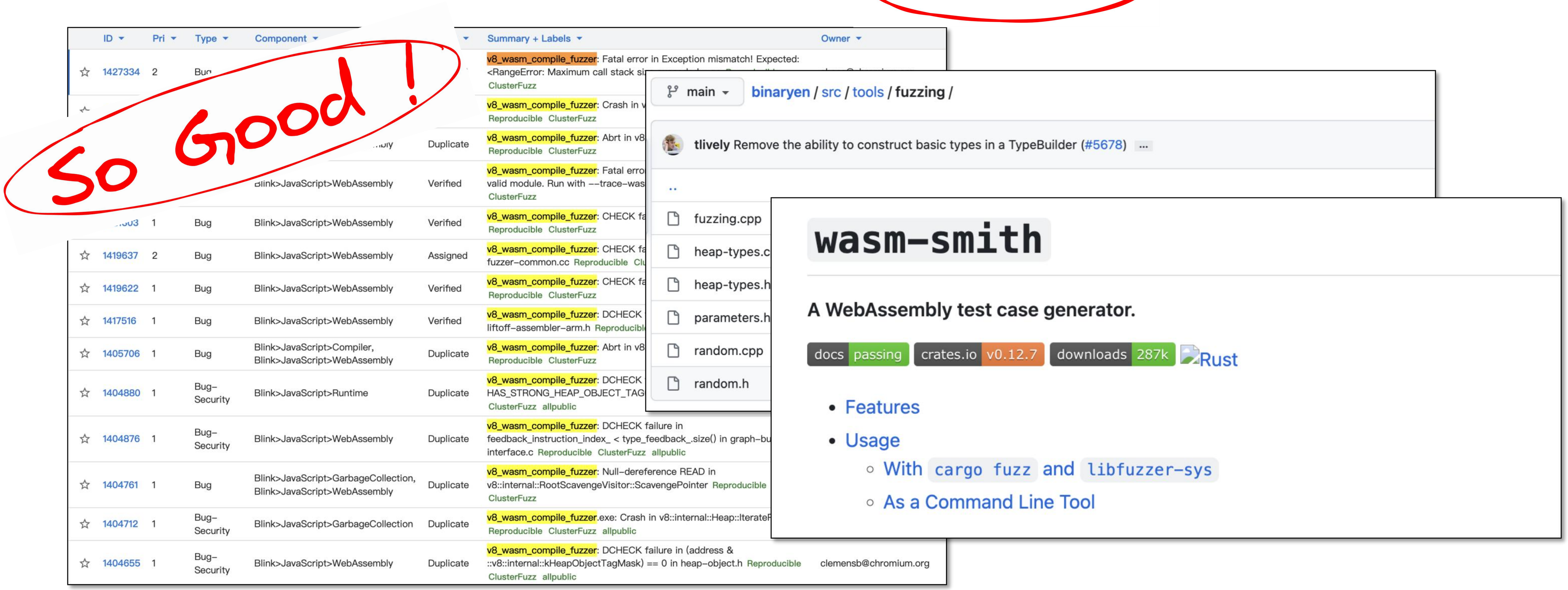
wasm-smith

A WebAssembly test case generator.

- Features
- Usage
  - With `cargo fuzz` and `libfuzzer-sys`
  - As a Command Line Tool

Fuzzing Overview

Main challenge: how to make the fuzzer generate semi-well-formed samples



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303	1	Bug	Blink>JavaScript>WebAssembly	Verified	v8_wasm_compile_fuzzer: CHECK fa Reproducible ClusterFuzz	
1419637	2	Bug	Blink>JavaScript>WebAssembly	Assigned	v8_wasm_compile_fuzzer: CHECK fa fuzzer-common.cc Reproducible Clu	
1419622	1	Bug	Blink>JavaScript>WebAssembly	Verified	v8_wasm_compile_fuzzer: CHECK fa Reproducible ClusterFuzz	
1417516	1	Bug	Blink>JavaScript>WebAssembly	Verified	v8_wasm_compile_fuzzer: DCHECK liftoff-assembler-arm.h Reproducibl	
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- random.h

wasm-smith

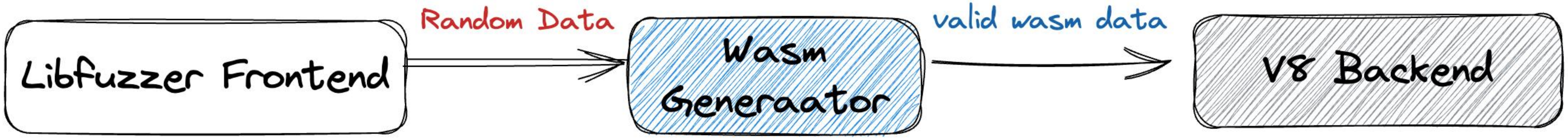
A WebAssembly test case generator.

docs passing | crates.io v0.12.7 | downloads 287k | Rust

- Features
- Usage
  - With `cargo fuzz` and `libfuzzer-sys`
  - As a Command Line Tool

Our Approach: Inspiration

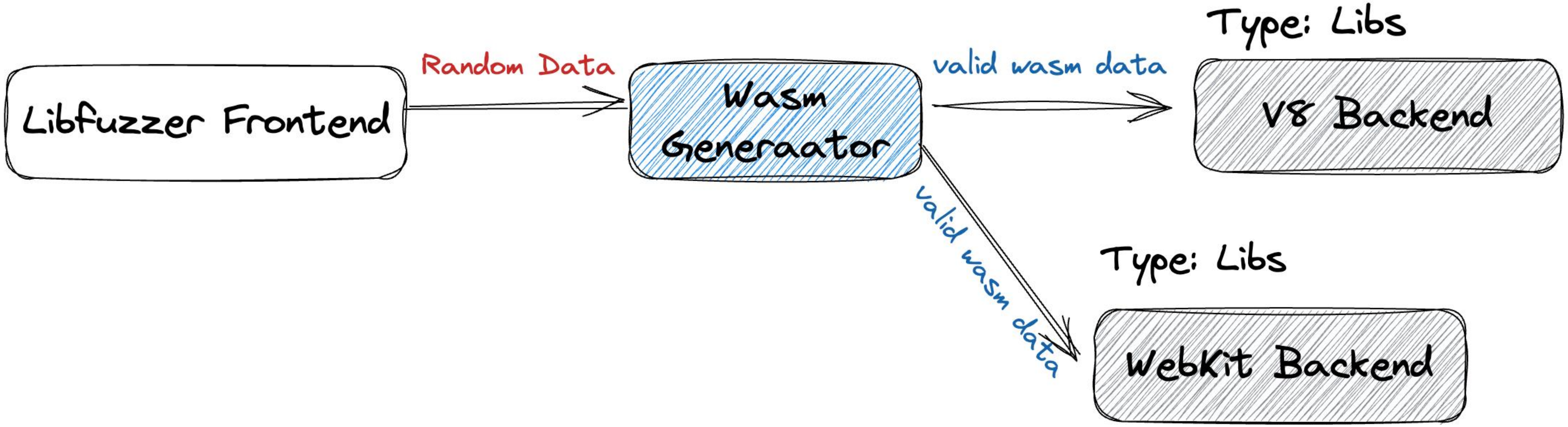
- *v8_wasm_compile_fuzzer*: 3 parts with strong binding



- ➢ **LibFuzzer Frontend**: Generate random data
- ➢ **Wasm Generator:** Convert ramdom data to valid & general wasm module
- ➢ **V8 Backend:** Embeded V8 as harness

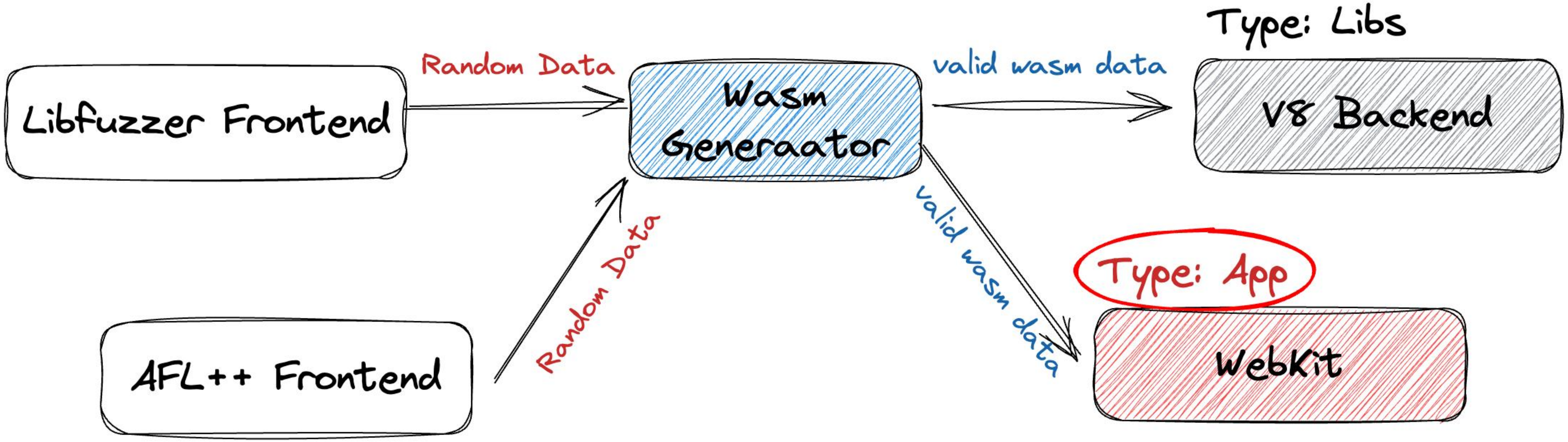
Our Approach: Inspiration

- **Original idea:** Port WebKit backend, but there are some issues:
    - Code complexity
    - Integration effort



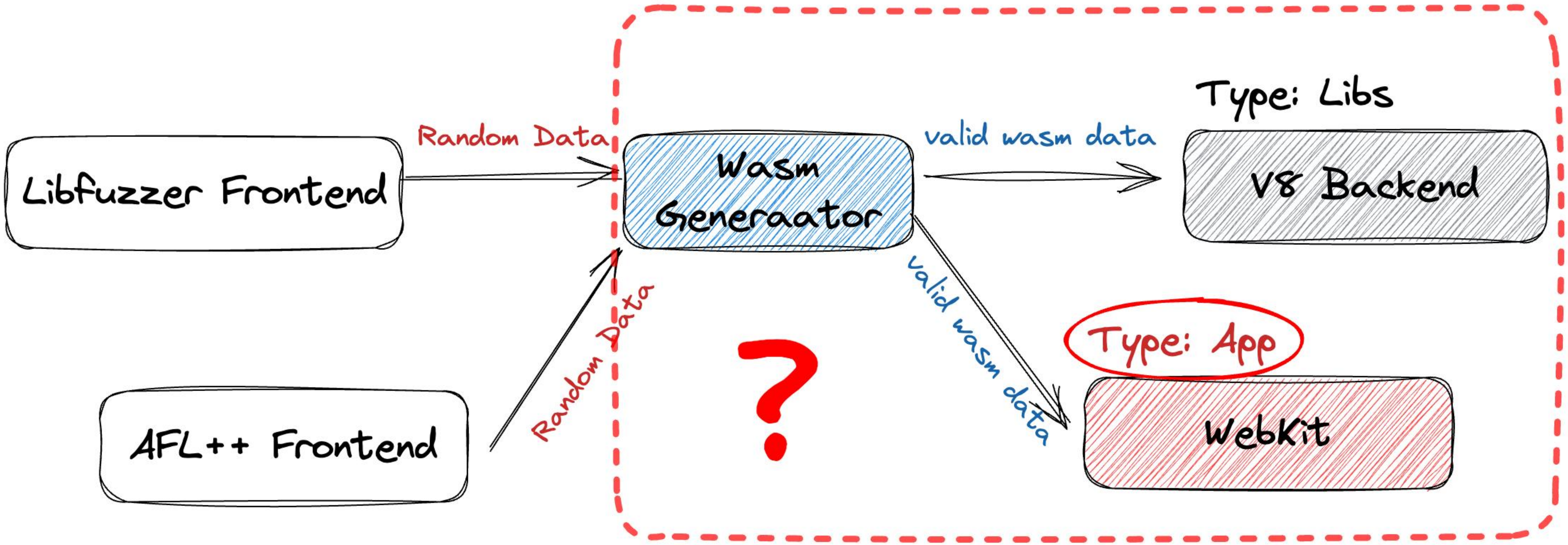
Our Approach: Inspiration

- Use AFL++ for complete WebKit application fuzzing
- Goal shifts: Port WebKit to *wasm_compile_fuzzer* ⇨ enable AFL++ with wasm generator



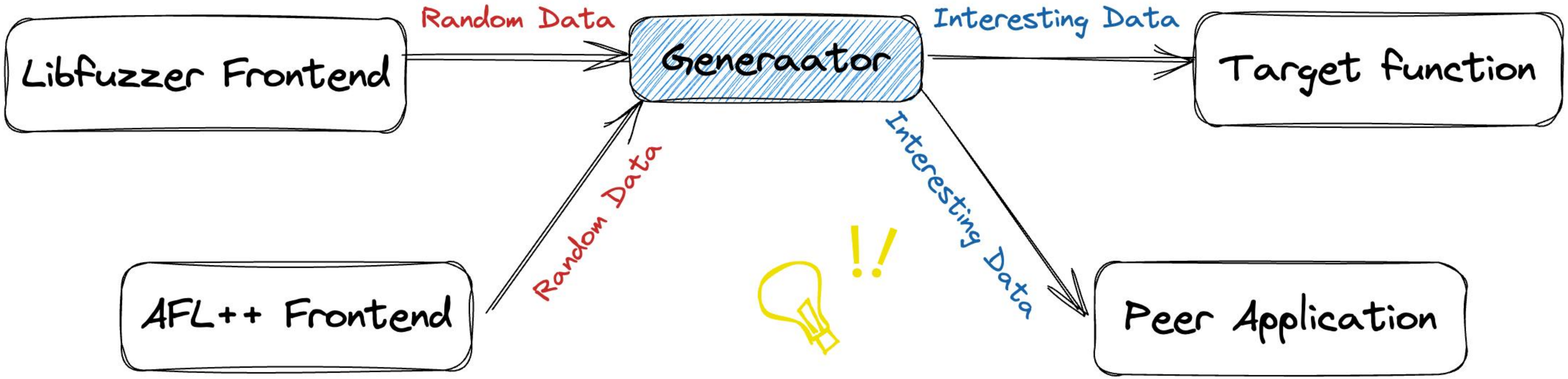
Our Approach: Inspiration

- **Generator Reuse:** not only between V8 & WebKit



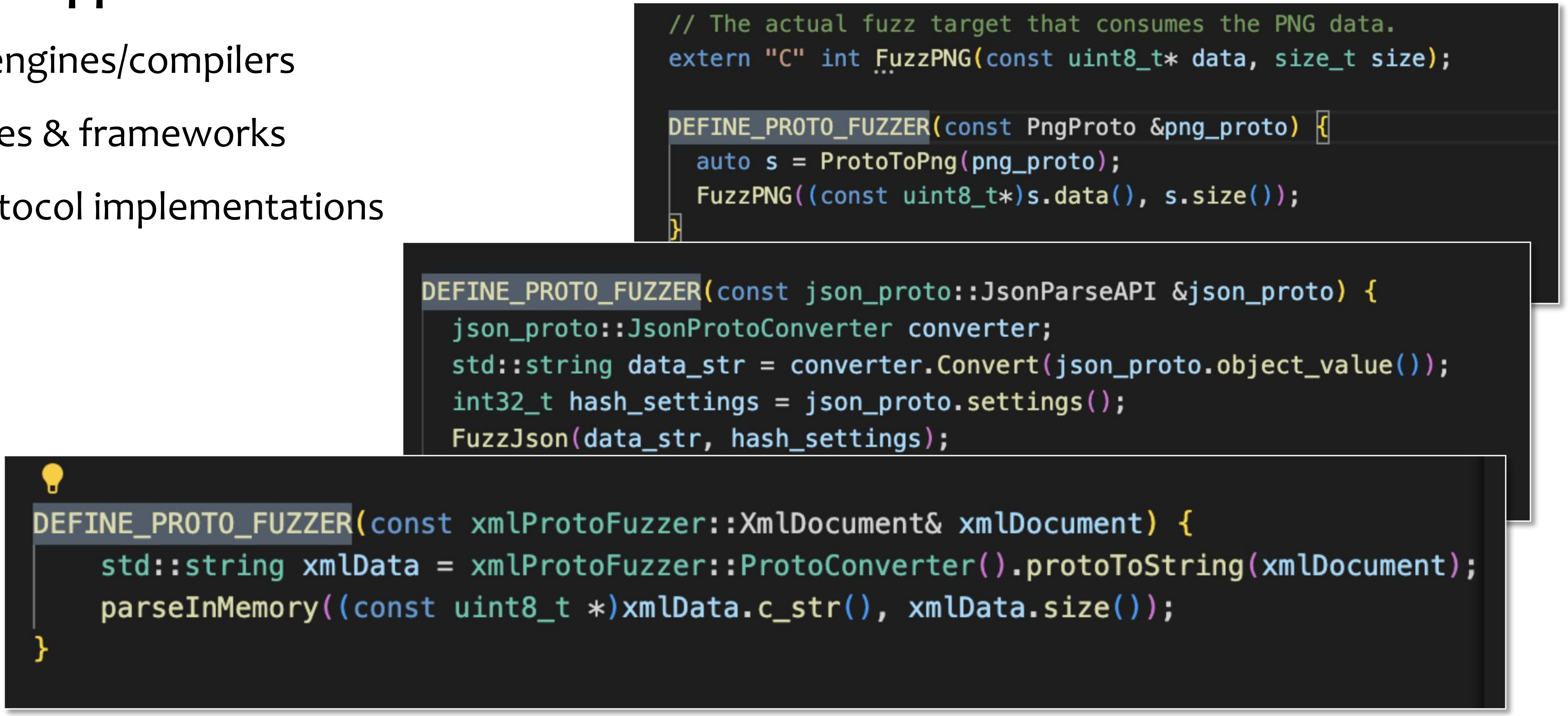
Our Approach: Inspiration

- **Generator Reuse:** applicable across peer-applications



Our Approach: Inspiration

- **Where are Peer Applications?**
  - Different JS engines/compilers
  - Similar libraries & frameworks
  - Different protocol implementations



```
// The actual fuzz target that consumes the PNG data.
extern "C" int FuzzPNG(const uint8_t* data, size_t size);

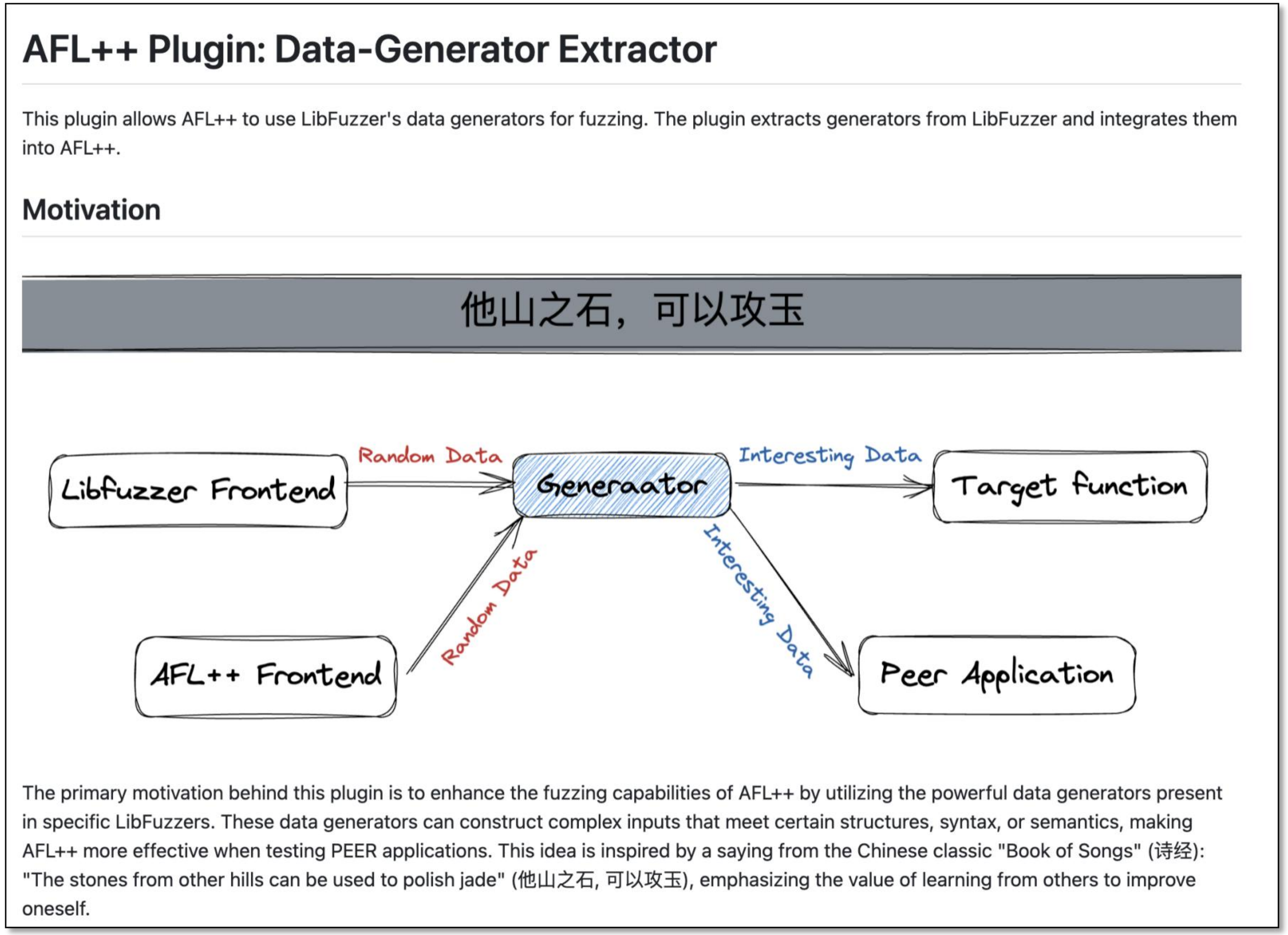
DEFINE_PROTO_FUZZER(const PngProto &png_proto) {
  auto s = ProtoToPng(png_proto);
  FuzzPNG((const uint8_t*)s.data(), s.size());
}
```

```
DEFINE_PROTO_FUZZER(const json_proto::JsonParseAPI &json_proto) {
  json_proto::JsonProtoConverter converter;
  std::string data_str = converter.Convert(json_proto.object_value());
  int32_t hash_settings = json_proto.settings();
  FuzzJson(data_str, hash_settings);
```

```
DEFINE_PROTO_FUZZER(const xmlProtoFuzzer::XmlDocument& xmlDocument) {
    std::string xmlData = xmlProtoFuzzer::ProtoConverter().protoToString(xmlDocument);
    parseInMemory((const uint8_t *)xmlData.c_str(), xmlData.size());
}
```

Our Approach: AFL++ Extractor

- An AFL++ plugin with:
  - **Concise** code
  - **Easy** usage
  - **Remarkable** results



AFL++ Plugin: Data-Generator Extractor

This plugin allows AFL++ to use LibFuzzer's data generators for fuzzing. The plugin extracts generators from LibFuzzer and integrates them into AFL++.

Motivation

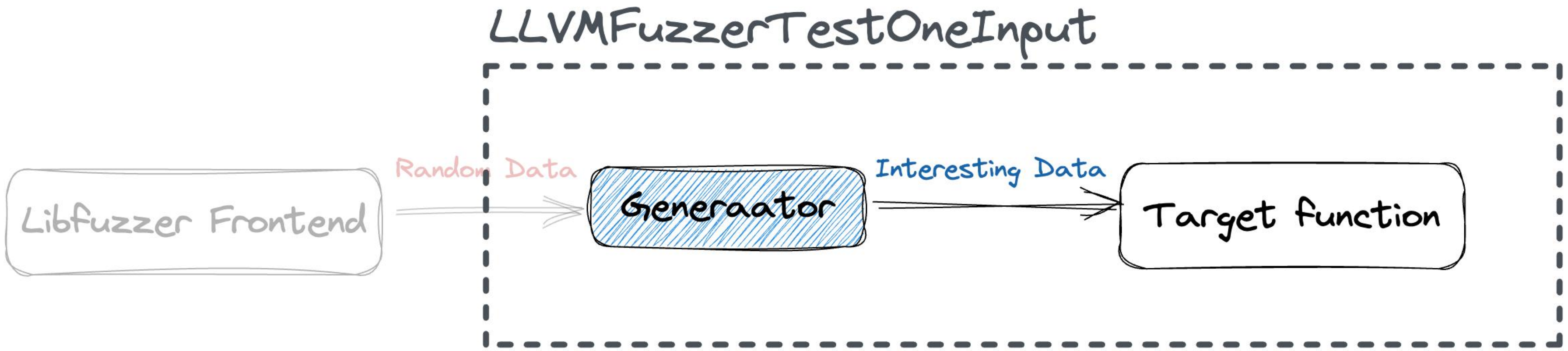
他山之石，可以攻玉

The primary motivation behind this plugin is to enhance the fuzzing capabilities of AFL++ by utilizing the powerful data generators present in specific LibFuzzers. These data generators can construct complex inputs that meet certain structures, syntax, or semantics, making AFL++ more effective when testing PEER applications. This idea is inspired by a saying from the Chinese classic "Book of Songs" (诗经): "The stones from other hills can be used to polish jade" (他山之石, 可以攻玉), emphasizing the value of learning from others to improve oneself.

➢ **GitHub:** https://github.com/P1umer/AFLplusplus-Extractor/tree/libfuzzer_extractor/utils/aflpp_extractor

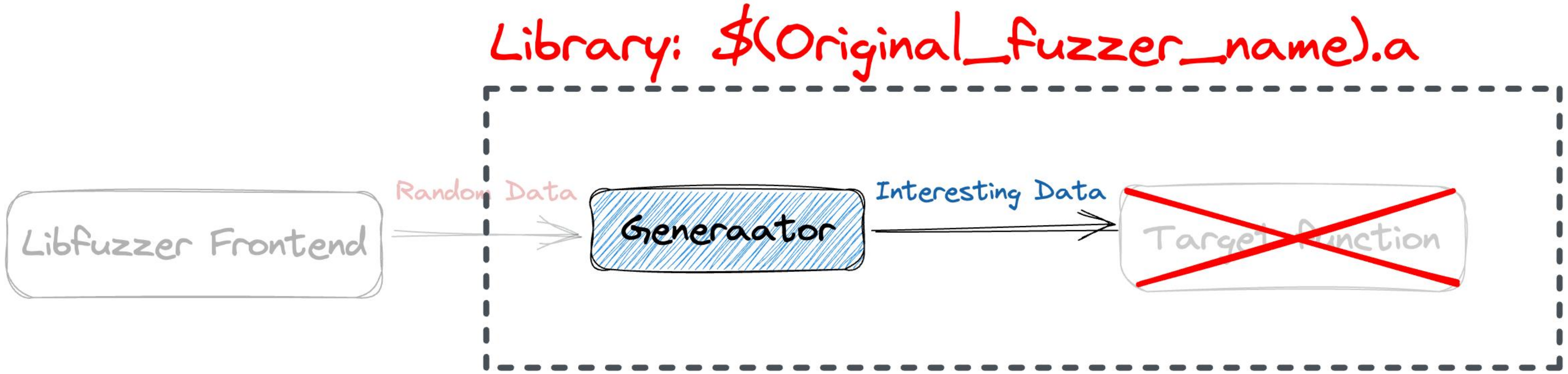
Our Approach: AFL++ Extractor

1. LibFuzzer divided into Generator and Harness logically



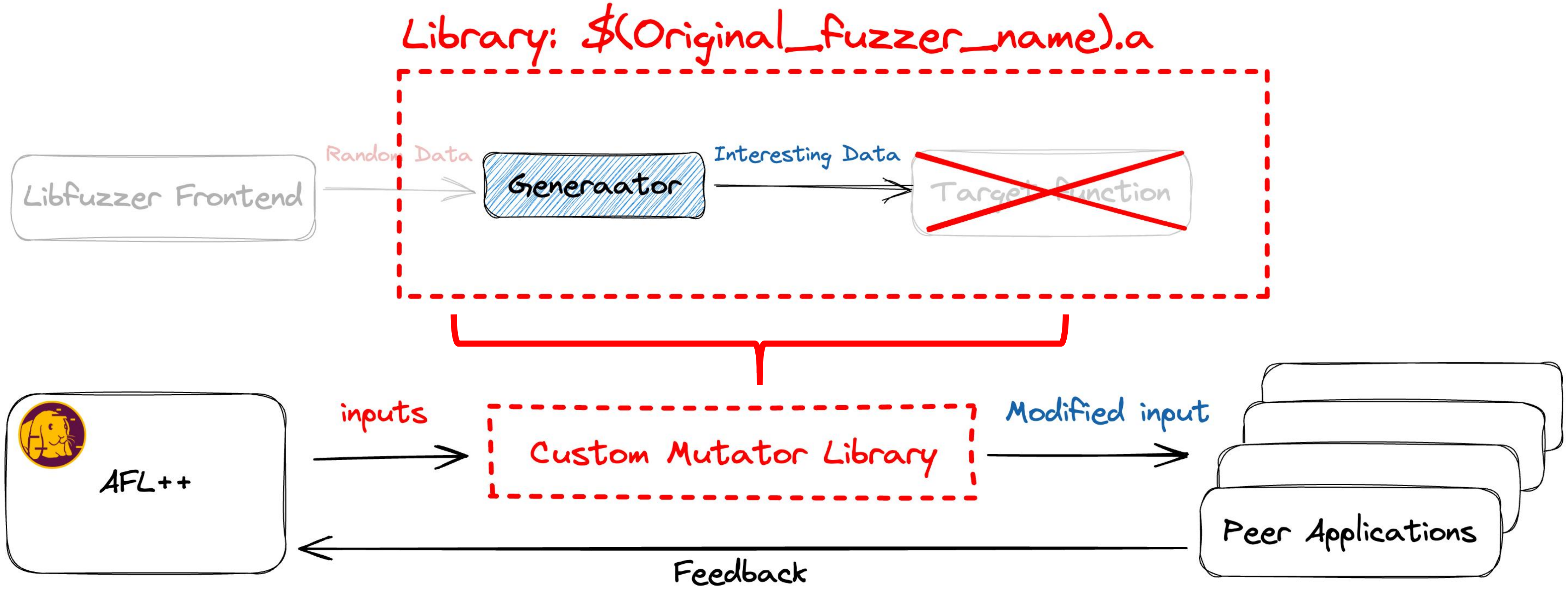
Our Approach: AFL++ Extractor

2. Remove the invocation of the target functions via patching.



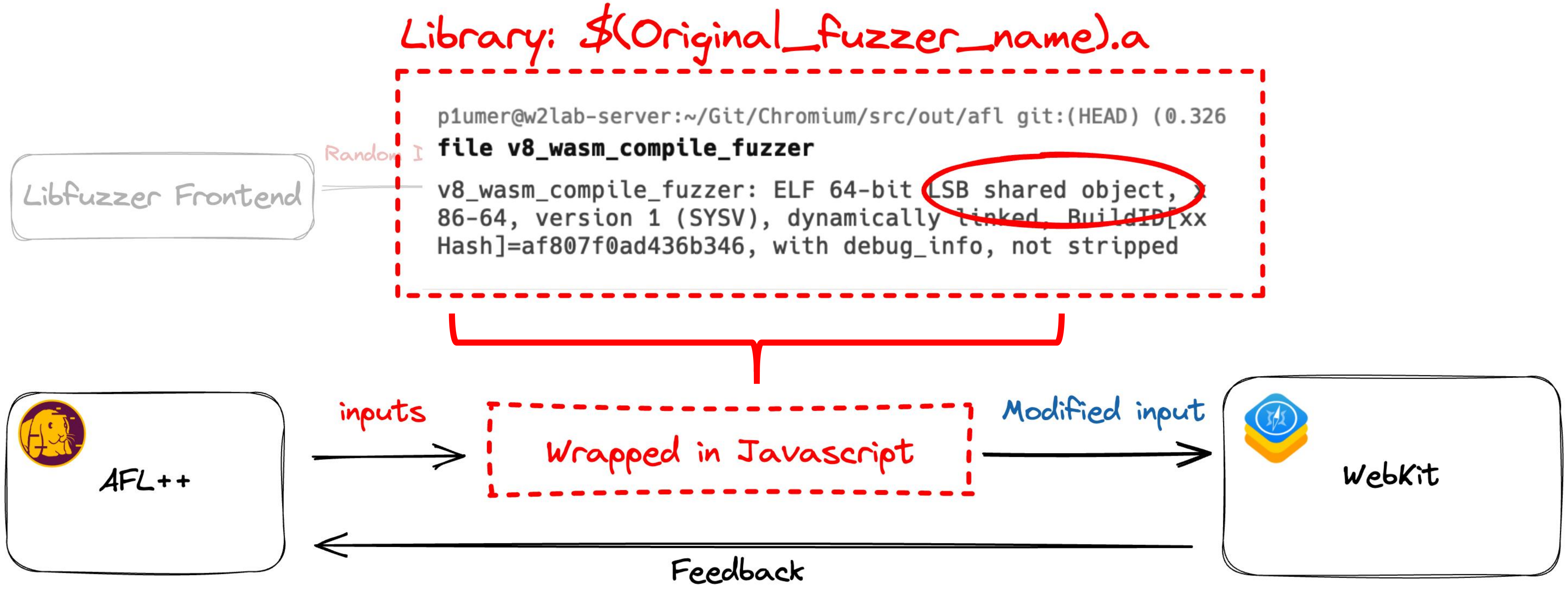
Our Approach: AFL++ Extractor

3. Compile libfuzzer into a shared library using ***afl-cc*** modified by AFL++ Extractor
   - Make an AFL++ custom mutator based on this shared library



Our Approach: AFL++ Extractor

✓ Apply **AFL++ Extractor** to *v8_wasm_compile_fuzzer*



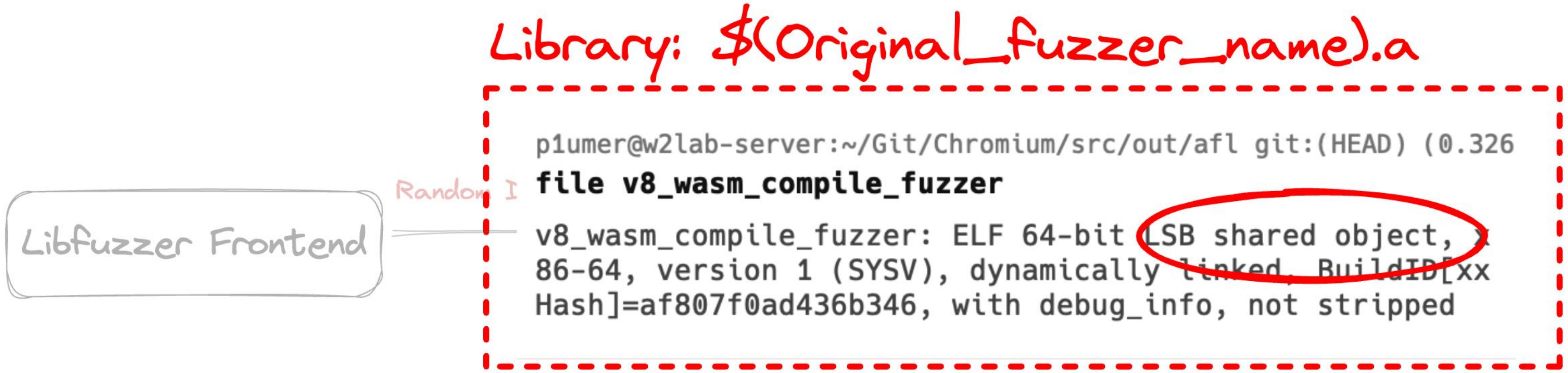
```
p1umer@w2lab-server:~/Git/Chromium/src/out/afl git:(HEAD) (0.326
file v8_wasm_compile_fuzzer
v8_wasm_compile_fuzzer: ELF 64-bit LSB shared object, x
86-64, version 1 (SYSV), dynamically linked, BuildID[xx
Hash]=af807f0ad436b346, with debug_info, not stripped
```

Our Approach: AFL++ Extractor

✓ Apply **AFL++ Extractor** to *v8_wasm_compile_fuzzer*

Optimize:

- Persistent mode
- Shared memory fuzzing
- Features update
- Different options



Library: $(Original_fuzzer_name).a

```
p1umer@w2lab-server:~/Git/Chromium/src/out/afl git:(HEAD) (0.326
file v8_wasm_compile_fuzzer
v8_wasm_compile_fuzzer: ELF 64-bit LSB shared object, x
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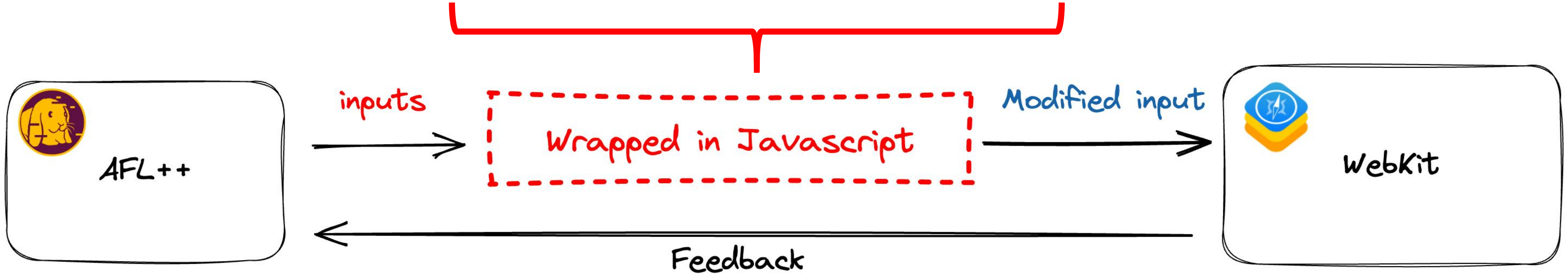
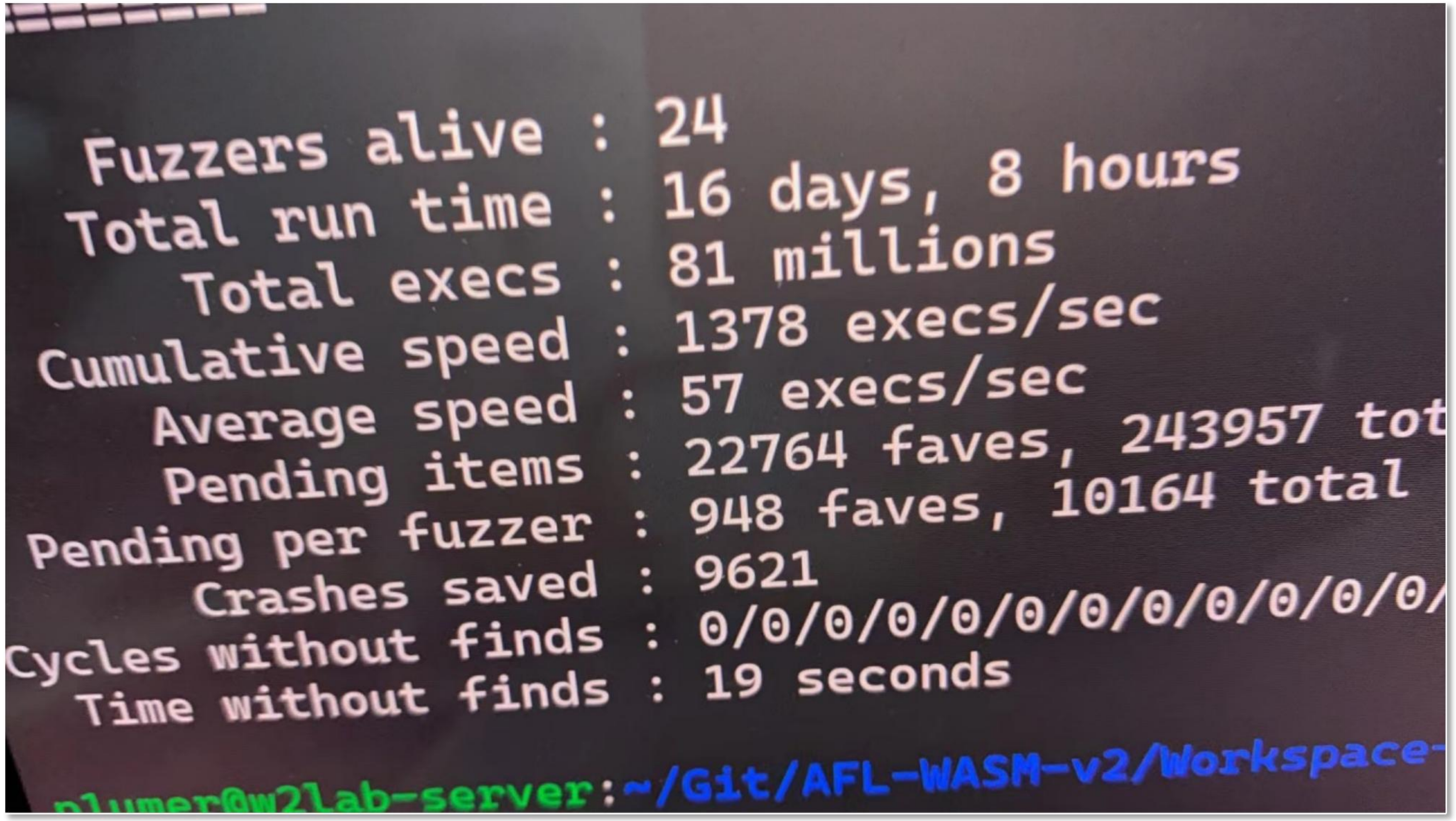


Result

- 13 Security-Related Issues
- 4 CVEs & Acknowledgements
- 3 Tiers of Pipeline
- 2 arch: x64 + arm64

Still Progressing ...

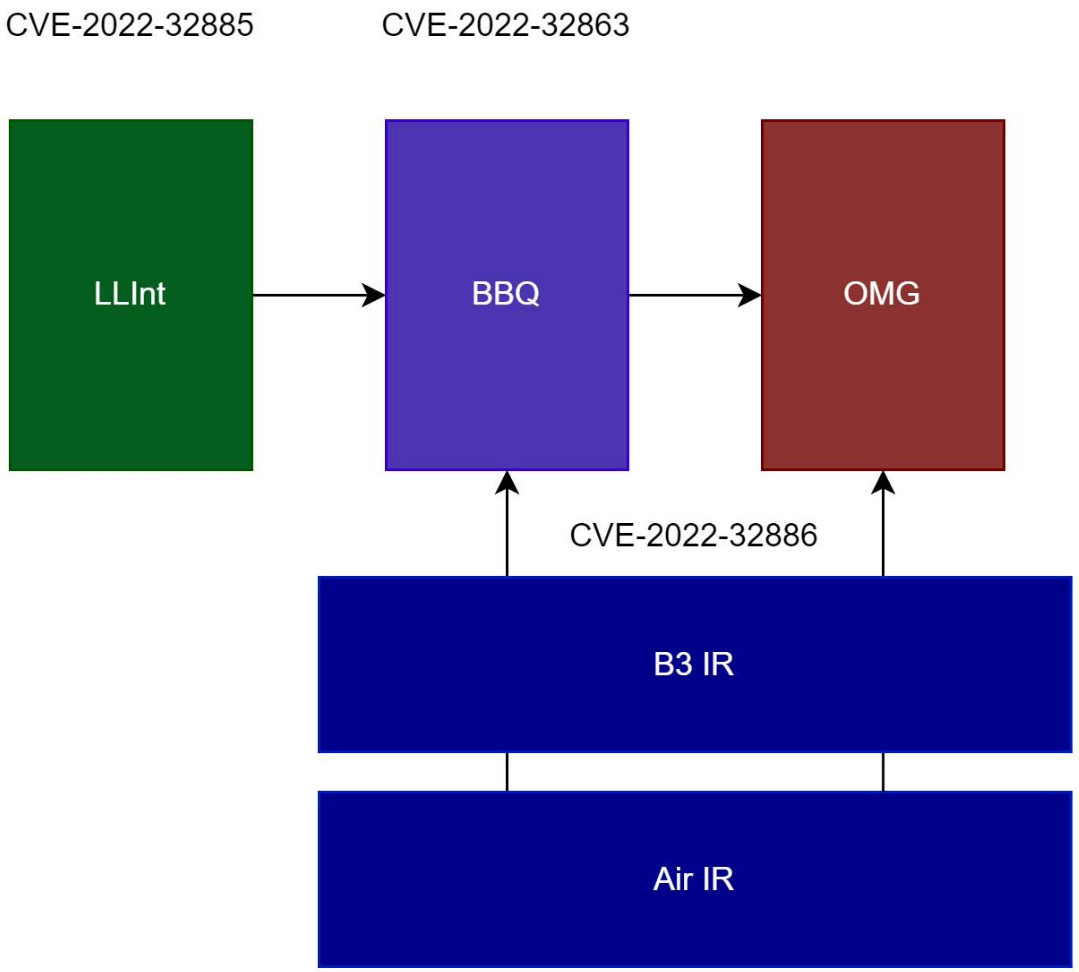


```
       Fuzzers alive : 24
      Total run time : 16 days, 8 hours
         Total execs : 81 millions
    Cumulative speed : 1378 execs/sec
       Average speed : 57 execs/sec
       Pending items : 22764 faves, 243957 tot
   Pending per fuzzer : 948 faves, 10164 total
       Crashes saved : 9621
 Cycles without finds : 0/0/0/0/0/0/0/0/0/0/0/0/
   Time without finds : 19 seconds
plumer@w2lab-server:~/Git/AFL-WASM-v2/Workspace-
```

Cases Study

WebKit Wasm Compilers

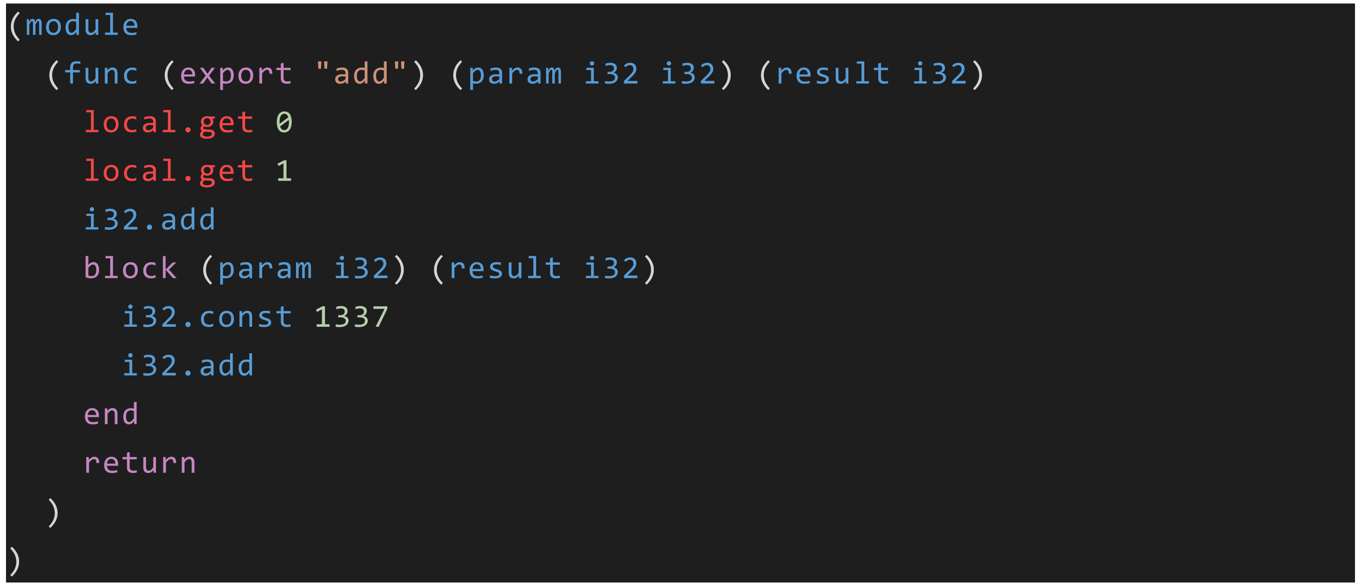
1. **LLInt** : Interpreter
2. **B3 and Air** : Low-level optimizer, IRGenerator
3. **BBQ** : Fast in compiling
4. **OMG** : Fast in executing



WebKit Wasm Compilers

LLInt Interpreter

- ➢ Parse
- ➢ Bytecode Generation
- ➢ Execute



```
(module
  (func (export "add") (param i32 i32) (result i32)
    local.get 0
    local.get 1
    i32.add
    block (param i32) (result i32)
      i32.const 1337
      i32.add
    end
    return
  )
)
```

LLInt/WebAssembly.asm

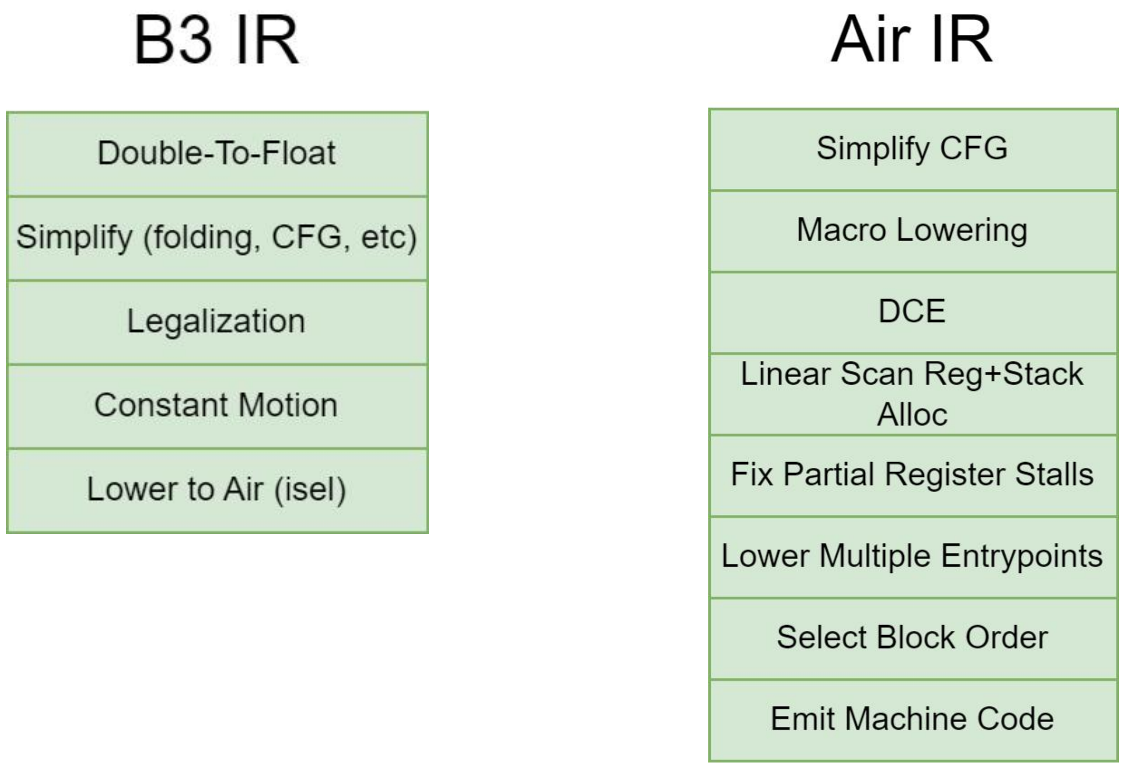
```
wasmOp(i32_add, WasmI32Add, macro(ctx)
    mloadi(ctx, m_lhs, t0)
    mloadi(ctx, m_rhs, t1)
    addi t0, t1, t2
    returni(ctx, t2)
end)
```

➢ src: JavaScriptCore/llint/WebAssembly.asm

WebKit Wasm Compilers

BBQ

- BBQ omits many optimizations in the B3 compiler



B3 IR

Double-To-Float

Simplify (folding, CFG, etc)

Legalization

Constant Motion

Lower to Air (isel)

Air IR

Simplify CFG

Macro Lowering

DCE

Linear Scan Reg+Stack Alloc

Fix Partial Register Stalls

Lower Multiple Entrypoints

Select Block Order

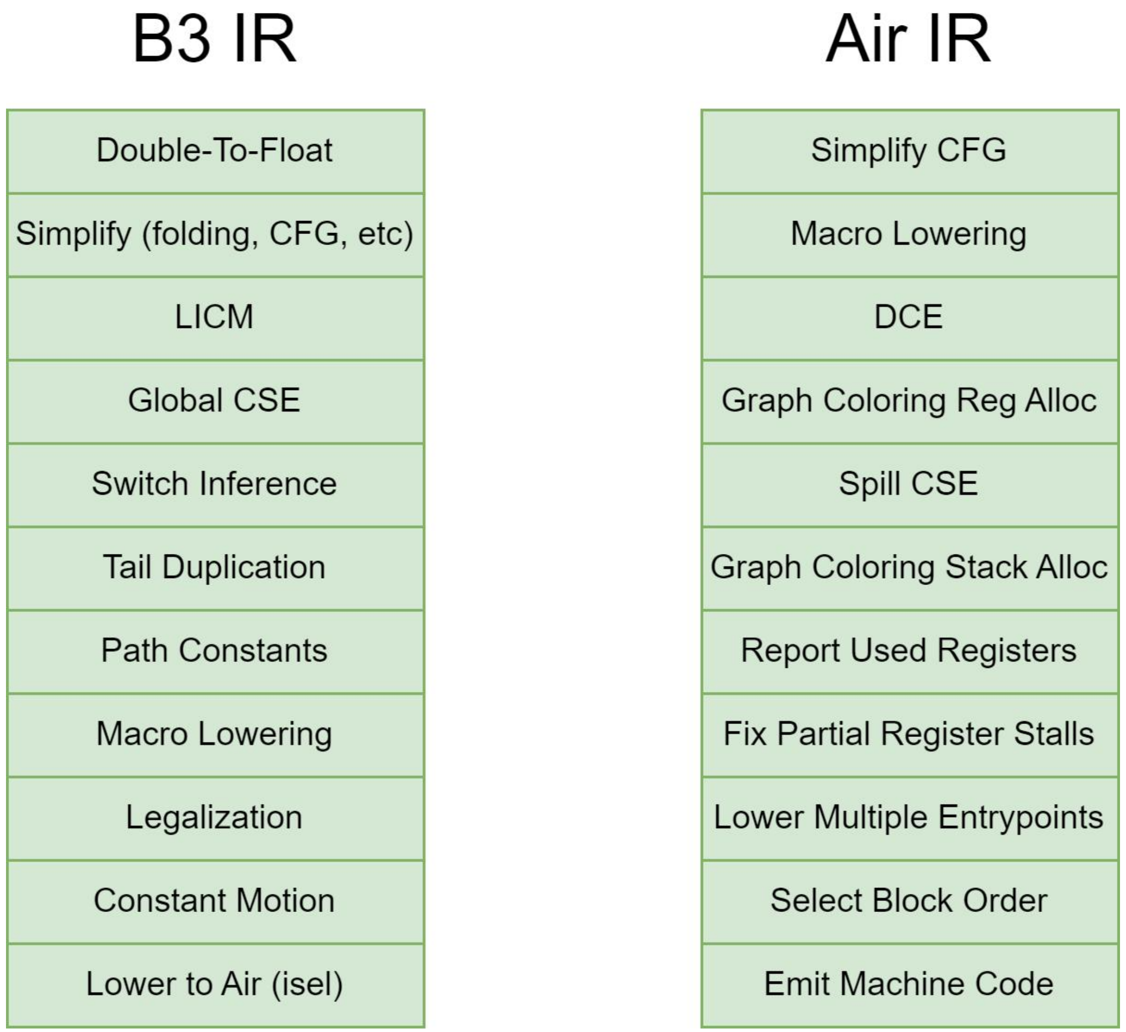
Emit Machine Code

➢ Ref: 《All About JavaScriptCore's Many》 - Filip Pizlo

WebKit Wasm Compilers

OMG

- OMG uses as many optimizations as possible to generate code that executes quickly.



B3 IR

- Double-To-Float
- Simplify (folding, CFG, etc)
- LICM
- Global CSE
- Switch Inference
- Tail Duplication
- Path Constants
- Macro Lowering
- Legalization
- Constant Motion
- Lower to Air (isel)

Air IR

- Simplify CFG
- Macro Lowering
- DCE
- Graph Coloring Reg Alloc
- Spill CSE
- Graph Coloring Stack Alloc
- Report Used Registers
- Fix Partial Register Stalls
- Lower Multiple Entrypoints
- Select Block Order
- Emit Machine Code

➢ Ref: 《All About JavaScriptCore's Many》 - Filip Pizlo

CVE-2022-32863

Vulnerability analysis

- Vulnerability exists in the **BBQ Air.**
- Inappropriate implementation in Wasm stackoverflow check
- Type Confusion of **JSWebAssemblyInstance**

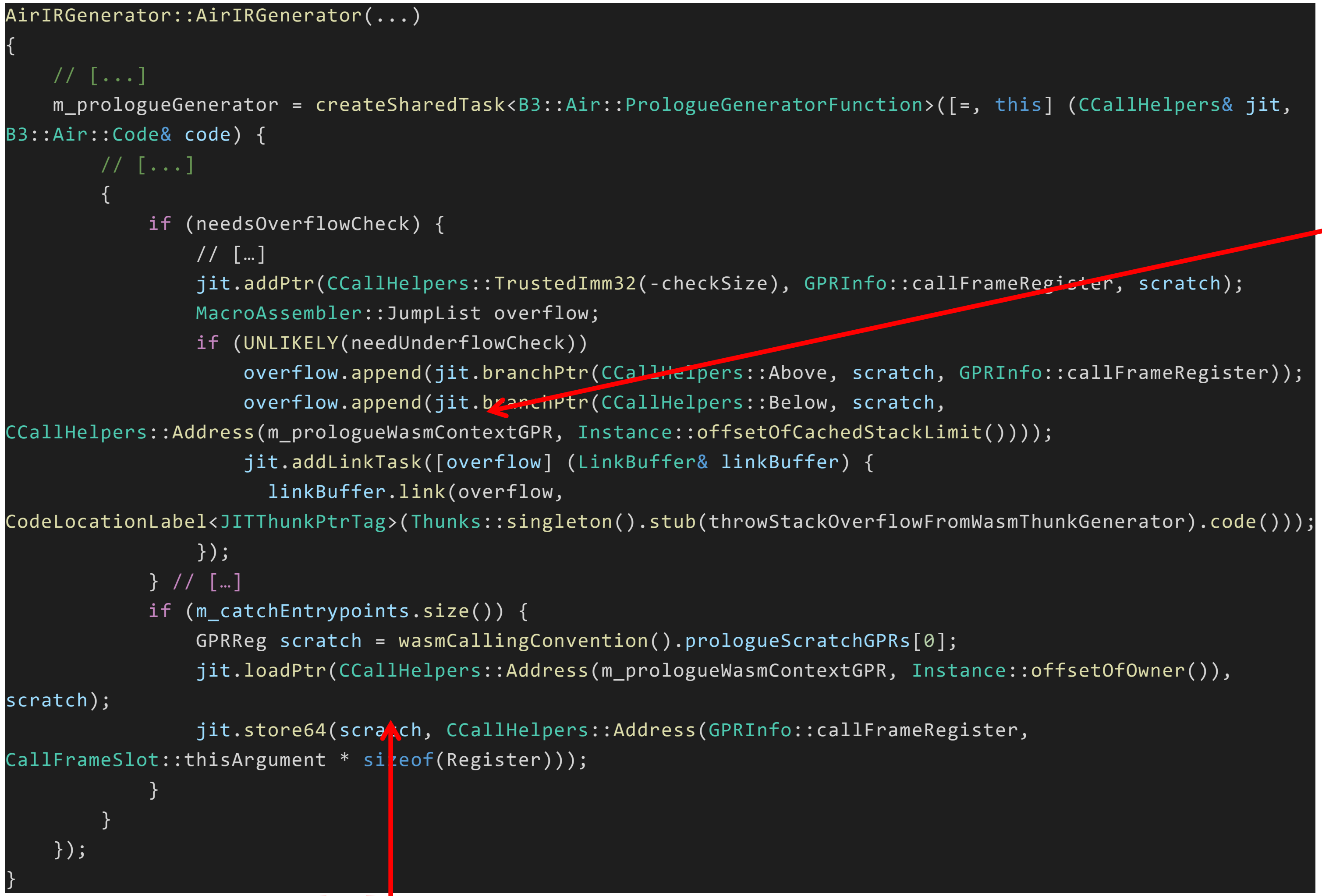
CVE-2022-32863

Vulnerability analysis

[0] : Calculate rsp(in x86_64)
by rbp

[1] : Init |this| slot in call frame

Uninitialized Value !



```
AirIRGenerator::AirIRGenerator(...)
{
    // [...]
    m_prologueGenerator = createSharedTask<B3::Air::PrologueGeneratorFunction>([=, this] (CCallHelpers& jit,
B3::Air::Code& code) {
        // [...]
        {
            if (needsOverflowCheck) {
                // […]
                jit.addPtr(CCallHelpers::TrustedImm32(-checkSize), GPRInfo::callFrameRegister, scratch);
                MacroAssembler::JumpList overflow;
                if (UNLIKELY(needUnderflowCheck))
                    overflow.append(jit.branchPtr(CCallHelpers::Above, scratch, GPRInfo::callFrameRegister));
                    overflow.append(jit.branchPtr(CCallHelpers::Below, scratch,
CCallHelpers::Address(m_prologueWasmContextGPR, Instance::offsetOfCachedStackLimit())));
                    jit.addLinkTask([overflow] (LinkBuffer& linkBuffer) {
                      linkBuffer.link(overflow,
CodeLocationLabel<JITThunkPtrTag>(Thunks::singleton().stub(throwStackOverflowFromWasmThunkGenerator).code()));
                });
            } // […]
            if (m_catchEntrypoints.size()) {
                GPRReg scratch = wasmCallingConvention().prologueScratchGPRs[0];
                jit.loadPtr(CCallHelpers::Address(m_prologueWasmContextGPR, Instance::offsetOfOwner()),
scratch);
                jit.store64(scratch, CCallHelpers::Address(GPRInfo::callFrameRegister,
CallFrameSlot::thisArgument * sizeof(Register)));
            }
        }
    });
}
```

[0]

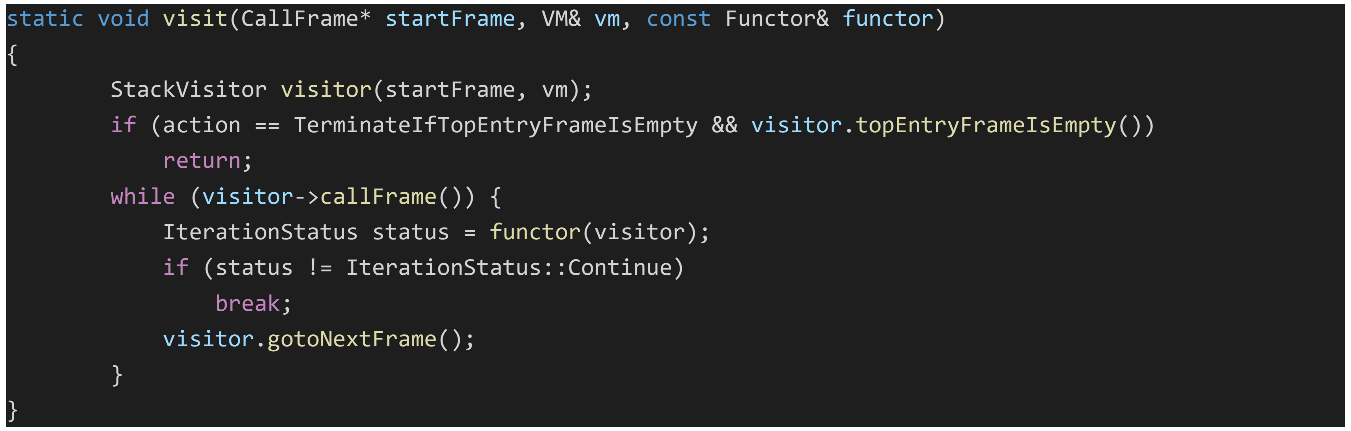
[1]

➢ src: JavaScriptCore/wasm/WasmAirIRGenerator.cpp

CVE-2022-32863

How to trigger

1. Exception handler exists in wasm code
2. Hit a StackOverflow exception :
   operationWasmToJSException
   ->genericUnwind
    ->Interpreter::unwind
     ->StackVisitor::visit



```
static void visit(CallFrame* startFrame, VM& vm, const Functor& functor)
{
        StackVisitor visitor(startFrame, vm);
        if (action == TerminateIfTopEntryFrameIsEmpty && visitor.topEntryFrameIsEmpty())
            return;
        while (visitor->callFrame()) {
            IterationStatus status = functor(visitor);
            if (status != IterationStatus::Continue)
                break;
            visitor.gotoNextFrame();
        }
}
```

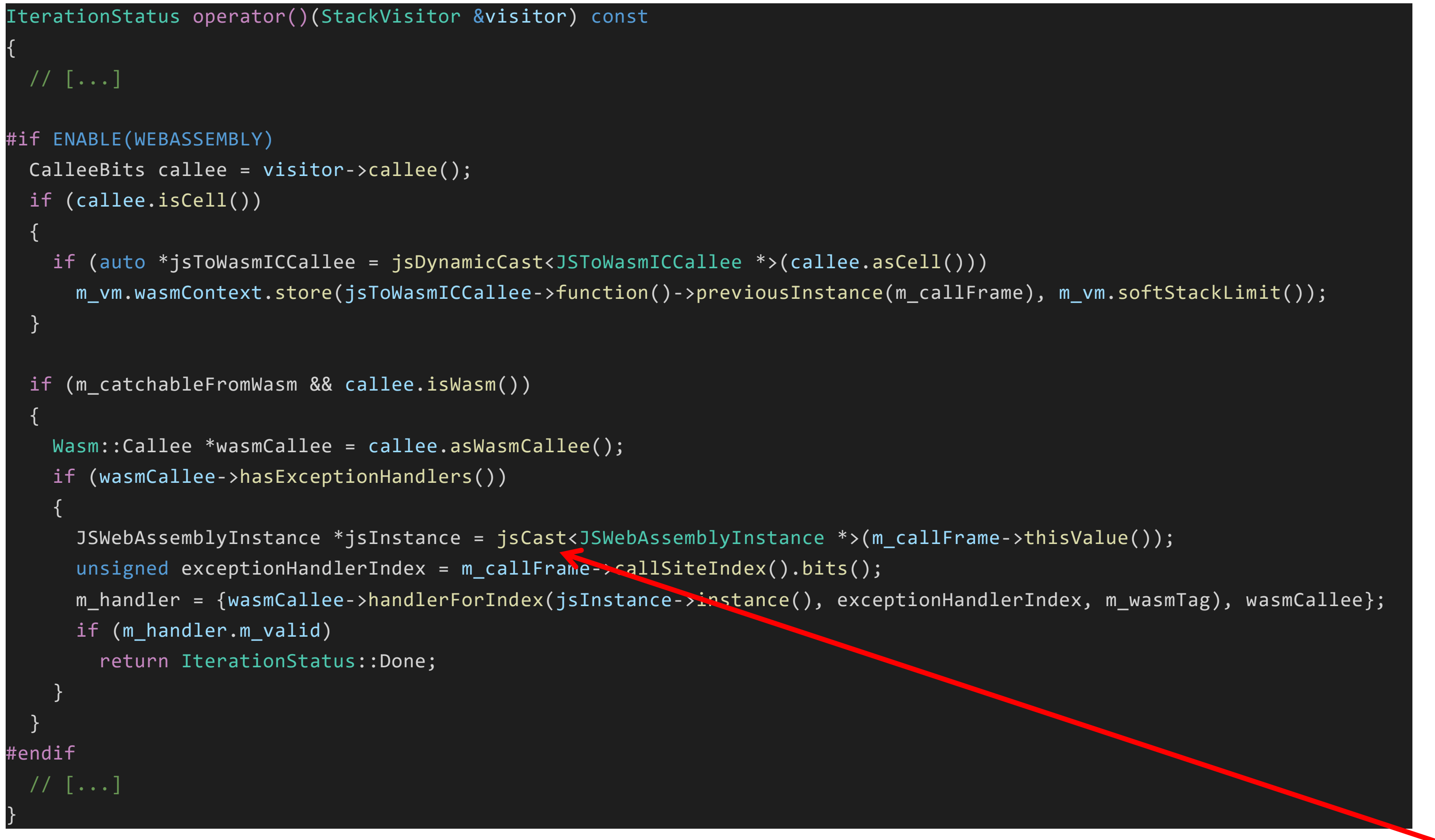
➢ src: JavaScriptCore/interpreter/StackVisitor.h

CVE-2022-32863

Vulnerability analysis

Fetch |**this**| as jsInstance

Type confusion happened



```
IterationStatus operator()(StackVisitor &visitor) const
{
  // [...]

#if ENABLE(WEBASSEMBLY)
  CalleeBits callee = visitor->callee();
  if (callee.isCell())
  {
    if (auto *jsToWasmICCallee = jsDynamicCast<JSToWasmICCallee *>(callee.asCell()))
      m_vm.wasmContext.store(jsToWasmICCallee->function()->previousInstance(m_callFrame), m_vm.softStackLimit());
  }

  if (m_catchableFromWasm && callee.isWasm())
  {
    Wasm::Callee *wasmCallee = callee.asWasmCallee();
    if (wasmCallee->hasExceptionHandlers())
    {
      JSWebAssemblyInstance *jsInstance = jsCast<JSWebAssemblyInstance *>(m_callFrame->thisValue());
      unsigned exceptionHandlerIndex = m_callFrame->callSiteIndex().bits();
      m_handler = {wasmCallee->handlerForIndex(jsInstance->instance(), exceptionHandlerIndex, m_wasmTag), wasmCallee};
      if (m_handler.m_valid)
        return IterationStatus::Done;
    }
  }
#endif
  // [...]
}
```

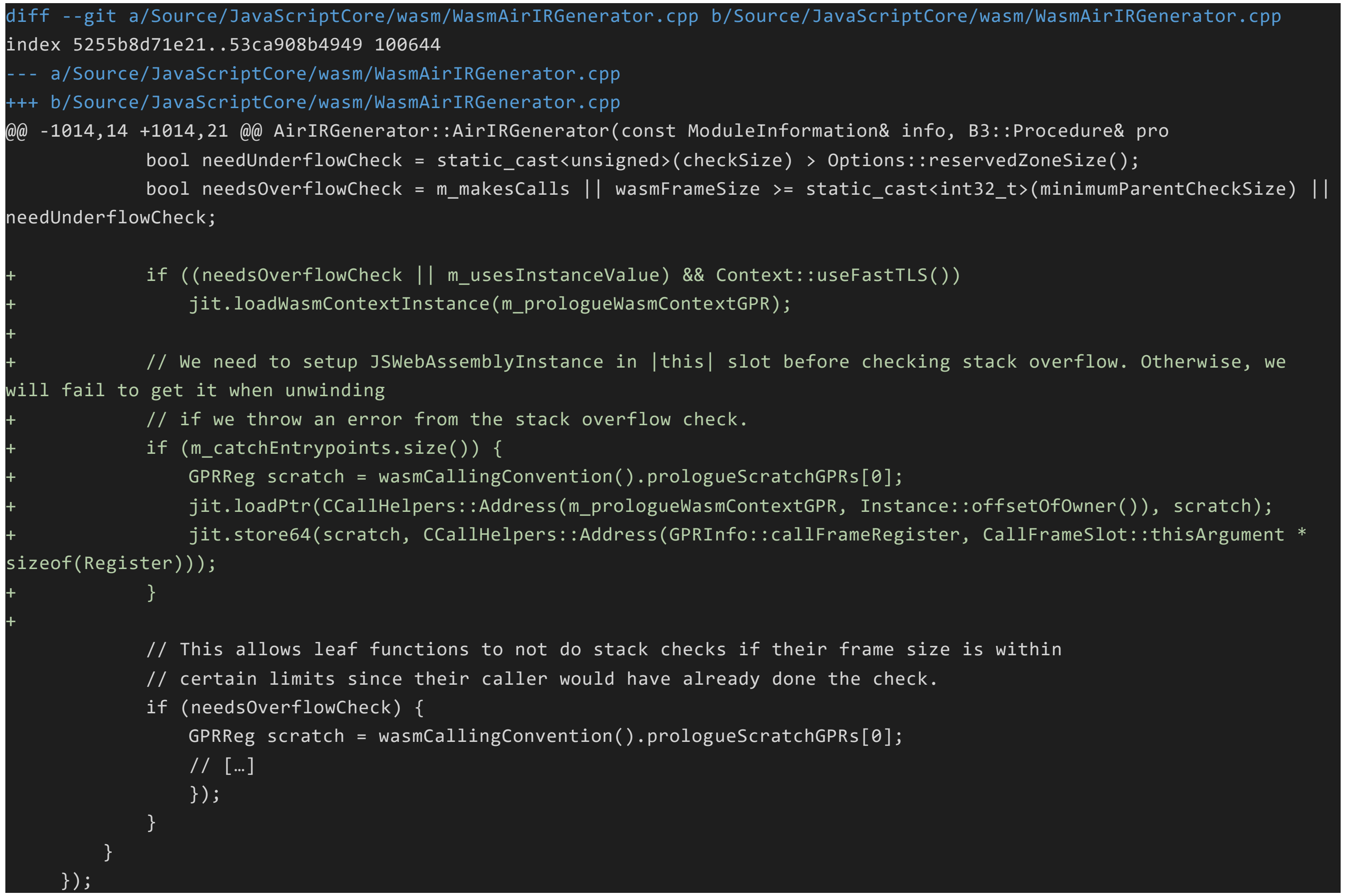
[2]

➢ src: JavaScriptCore/interpreter/Interpreter.cpp

CVE-2022-32863

Patch

- Setup wasm stack **|this|** first if there is exception handler in wasm code



```
diff --git a/Source/JavaScriptCore/wasm/WasmAirIRGenerator.cpp b/Source/JavaScriptCore/wasm/WasmAirIRGenerator.cpp
index 5255b8d71e21..53ca908b4949 100644
--- a/Source/JavaScriptCore/wasm/WasmAirIRGenerator.cpp
+++ b/Source/JavaScriptCore/wasm/WasmAirIRGenerator.cpp
@@ -1014,14 +1014,21 @@ AirIRGenerator::AirIRGenerator(const ModuleInformation& info, B3::Procedure& pro
             bool needUnderflowCheck = static_cast<unsigned>(checkSize) > Options::reservedZoneSize();
             bool needsOverflowCheck = m_makesCalls || wasmFrameSize >= static_cast<int32_t>(minimumParentCheckSize) ||
needUnderflowCheck;

+            if ((needsOverflowCheck || m_usesInstanceValue) && Context::useFastTLS())
+                jit.loadWasmContextInstance(m_prologueWasmContextGPR);
+
+            // We need to setup JSWebAssemblyInstance in |this| slot before checking stack overflow. Otherwise, we
will fail to get it when unwinding
+            // if we throw an error from the stack overflow check.
+            if (m_catchEntrypoints.size()) {
+                GPRReg scratch = wasmCallingConvention().prologueScratchGPRs[0];
+                jit.loadPtr(CCallHelpers::Address(m_prologueWasmContextGPR, Instance::offsetOfOwner()), scratch);
+                jit.store64(scratch, CCallHelpers::Address(GPRInfo::callFrameRegister, CallFrameSlot::thisArgument *
sizeof(Register)));
+            }
+
             // This allows leaf functions to not do stack checks if their frame size is within
             // certain limits since their caller would have already done the check.
             if (needsOverflowCheck) {
                 GPRReg scratch = wasmCallingConvention().prologueScratchGPRs[0];
                 // […]
                 });
             }
         }
     });
```

➢ Fix: e49129f82a16a9b5ef9c951e1743a33057d07d12

CVE-2022-32885

- Vulnerability exists in the LLInt Parser.
- Inappropriate implementation on parsing delegate bytecode
- Break the stack frame balance/StackOverflow

CVE-2022-32885

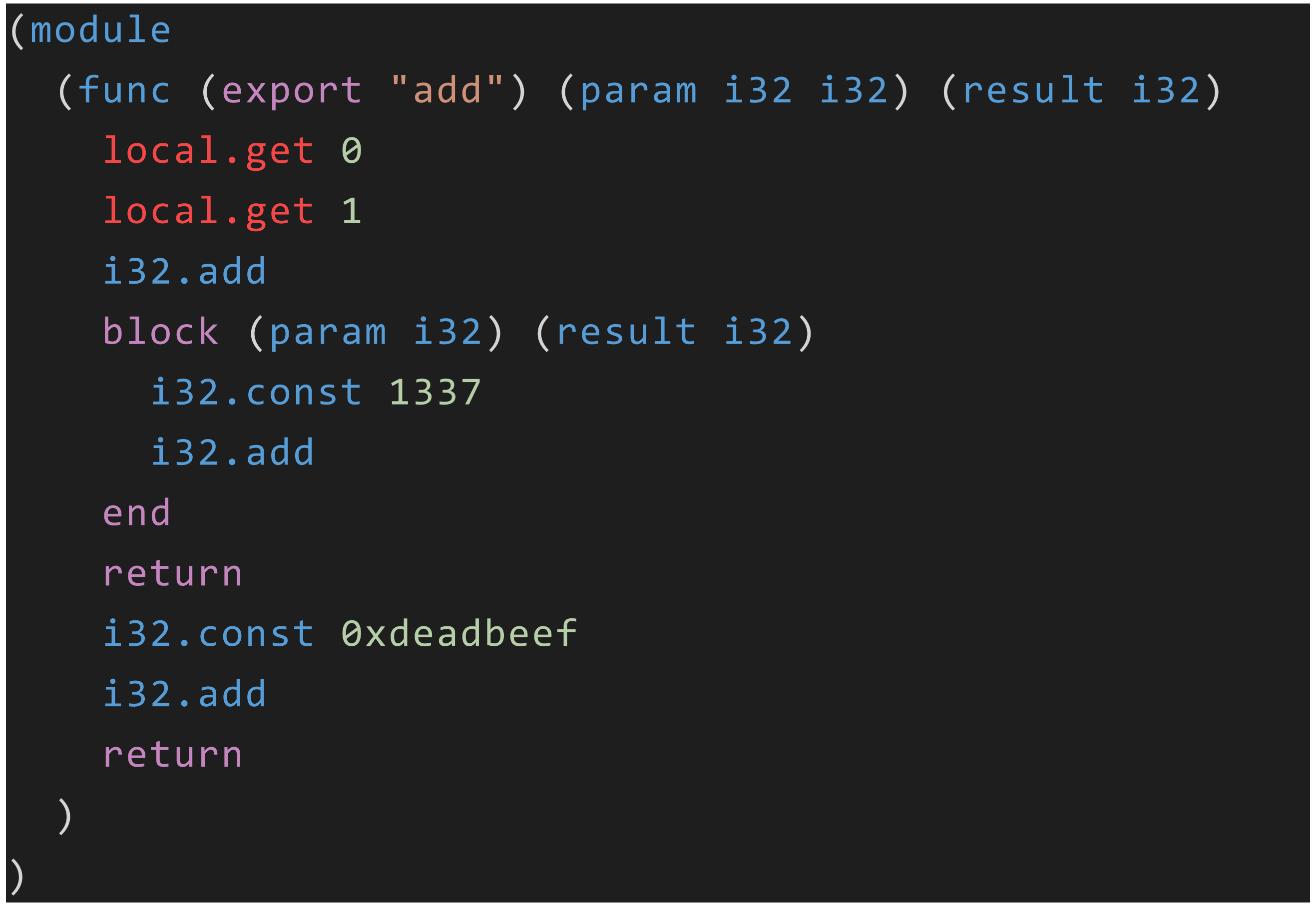
LLInt Parser Overview

- **Wasm function** : Highly-structured
- **m_expressionStack** : Track the value of expressions
- **m_controlStack** : Stack of expression stacks
- **enclosedExpressionStack** : Store parsed expressions

CVE-2022-32885

Unreachable in Wasm

- The code located behind **Br/Brtable/Return**

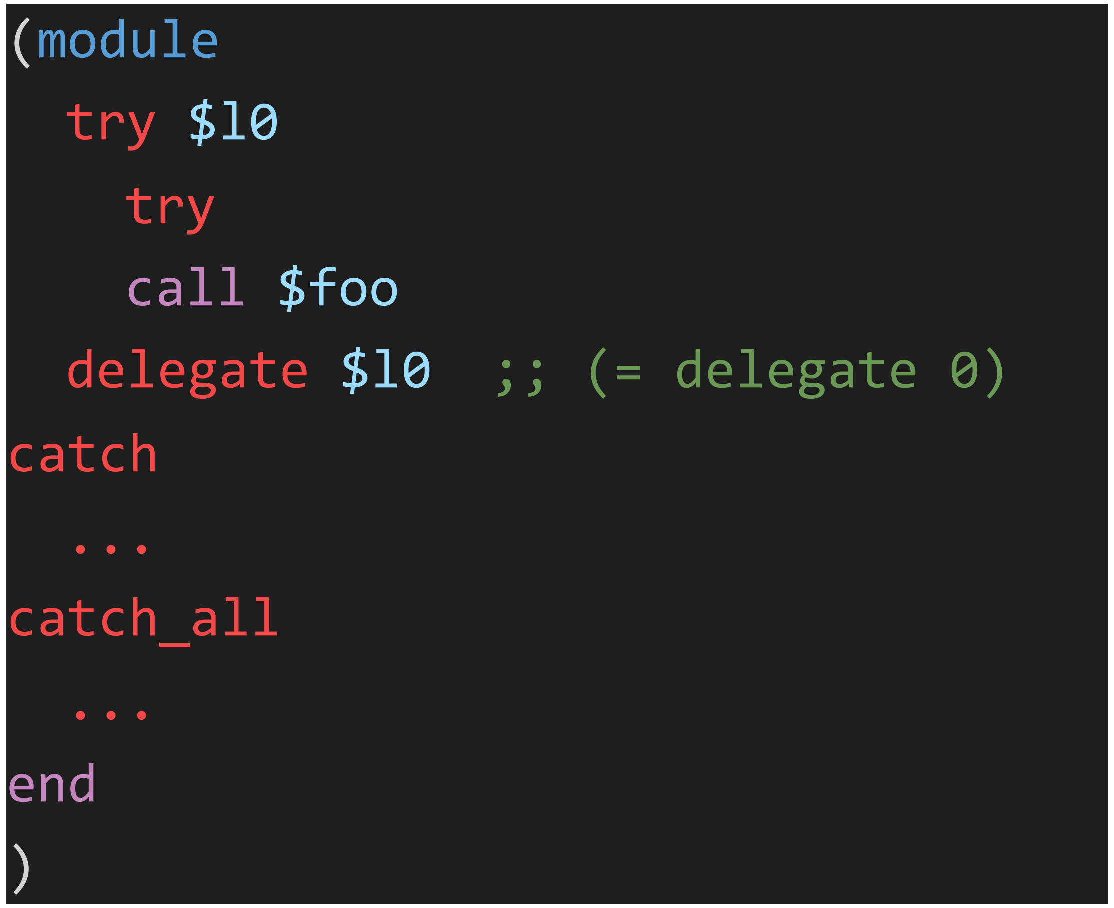


```
(module
  (func (export "add") (param i32 i32) (result i32)
    local.get 0
    local.get 1
    i32.add
    block (param i32) (result i32)
      i32.const 1337
      i32.add
    end
    return
    i32.const 0xdeadbeef
    i32.add
    return
  )
)
```

CVE-2022-32885

Delegate in Wasm

- **Delegate(label_x) :** handle over exception handling to label_x



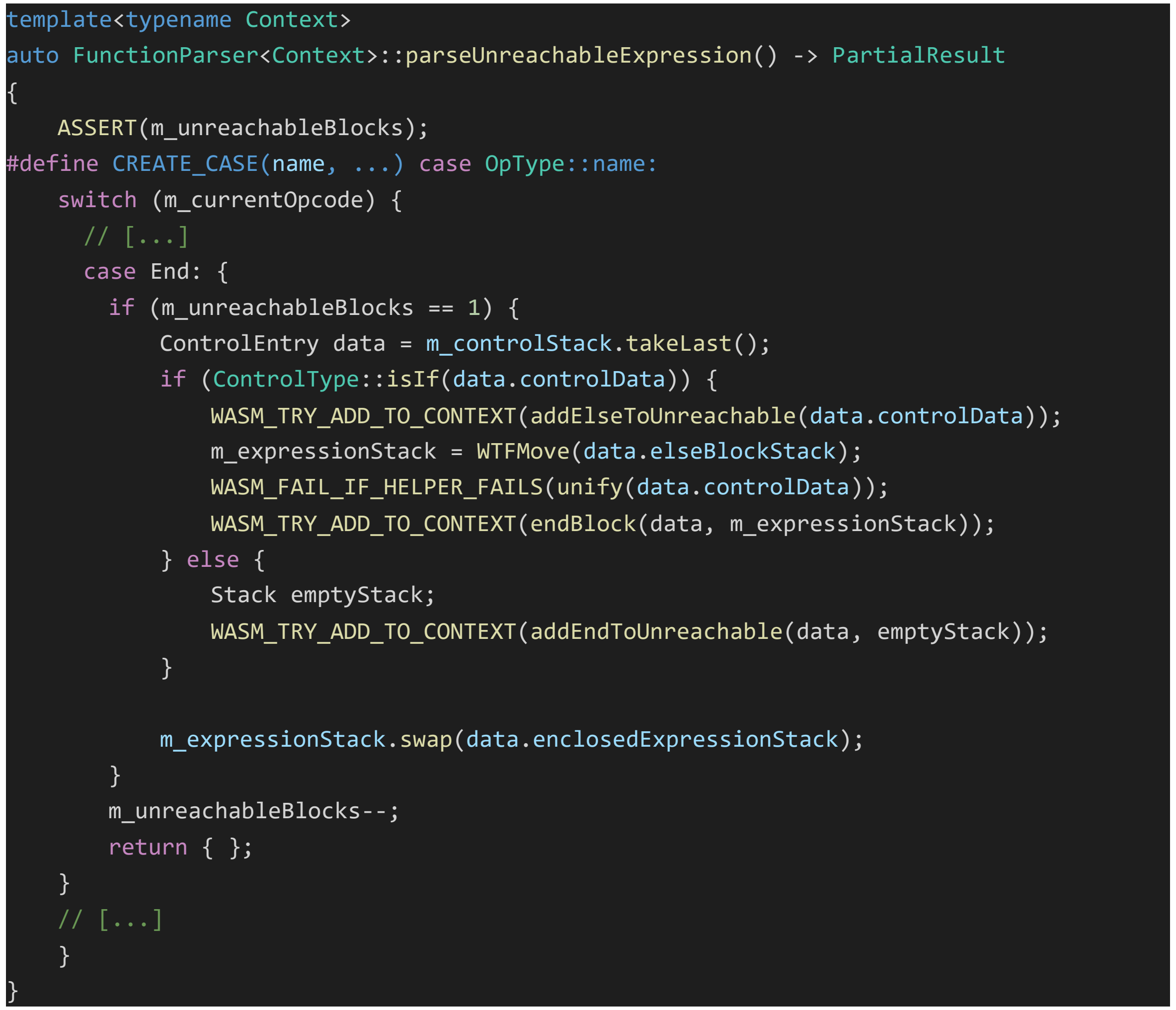
```
(module
  try $l0
    try
    call $foo
  delegate $l0  ;; (= delegate 0)
catch
  ...
catch_all
  ...
end
)
```

➢ Ref: wasm exception-handling

CVE-2022-32885

Vulnerability analysis

- **parseUnreachableExpression:** parse expressions when encountering unreachable blocks



```
template<typename Context>
auto FunctionParser<Context>::parseUnreachableExpression() -> PartialResult
{
    ASSERT(m_unreachableBlocks);
#define CREATE_CASE(name, ...) case OpType::name:
    switch (m_currentOpcode) {
      // [...]
      case End: {
        if (m_unreachableBlocks == 1) {
            ControlEntry data = m_controlStack.takeLast();
            if (ControlType::isIf(data.controlData)) {
                WASM_TRY_ADD_TO_CONTEXT(addElseToUnreachable(data.controlData));
                m_expressionStack = WTFMove(data.elseBlockStack);
                WASM_FAIL_IF_HELPER_FAILS(unify(data.controlData));
                WASM_TRY_ADD_TO_CONTEXT(endBlock(data, m_expressionStack));
            } else {
                Stack emptyStack;
                WASM_TRY_ADD_TO_CONTEXT(addEndToUnreachable(data, emptyStack));
            }

            m_expressionStack.swap(data.enclosedExpressionStack);
        }
        m_unreachableBlocks--;
        return { };
    }
    // [...]
    }
}
```

➢ src: JavaScriptCore/wasm/WasmFunctionParser.h

CVE-2022-32885

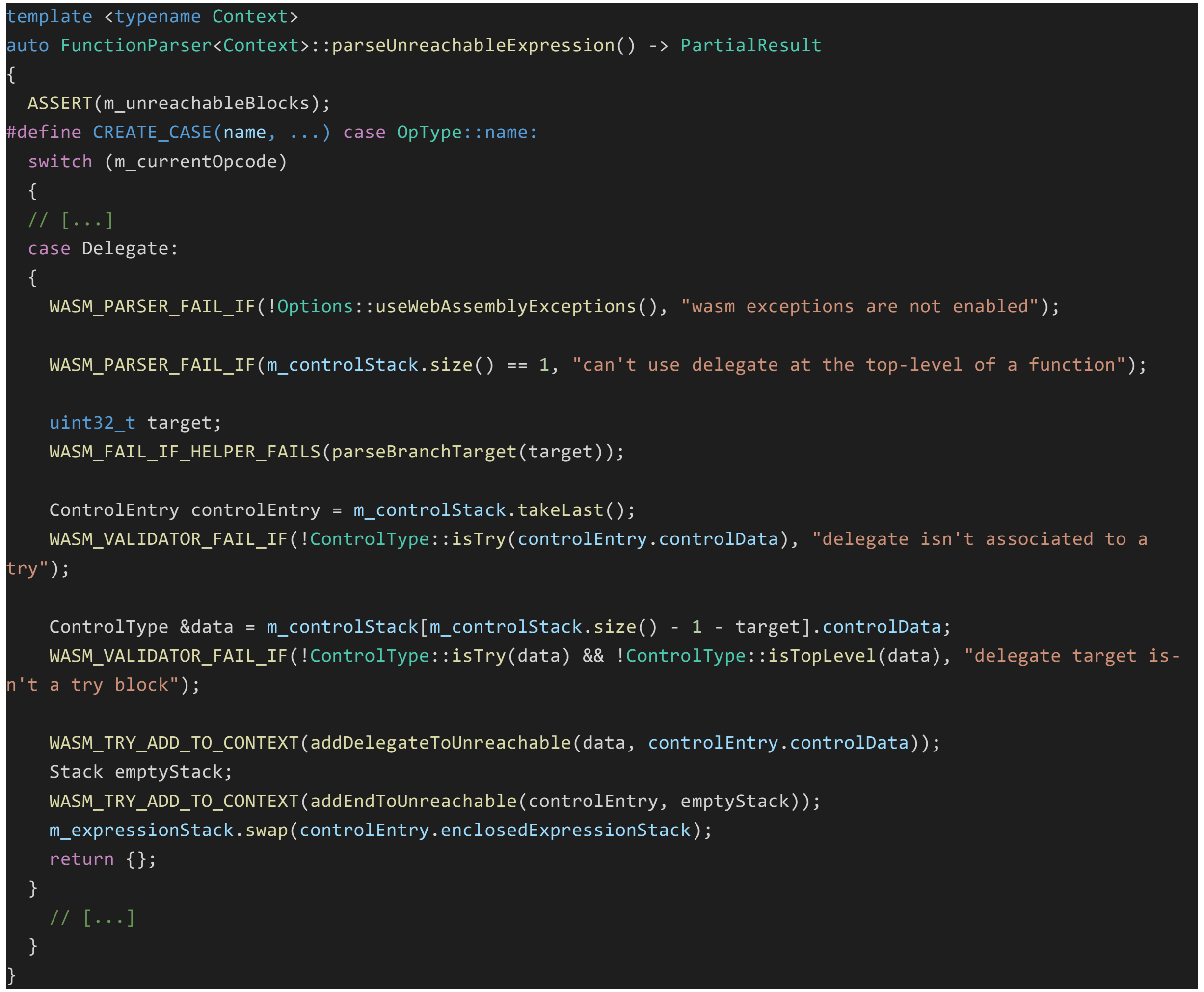
Vulnerability analysis

- Delegate operator should be handled the same way as the End operator :

  try … end

  v.s.

  try … delegate x



```
template <typename Context>
auto FunctionParser<Context>::parseUnreachableExpression() -> PartialResult
{
  ASSERT(m_unreachableBlocks);
#define CREATE_CASE(name, ...) case OpType::name:
  switch (m_currentOpcode)
  {
  // [...]
  case Delegate:
  {
    WASM_PARSER_FAIL_IF(!Options::useWebAssemblyExceptions(), "wasm exceptions are not enabled");

    WASM_PARSER_FAIL_IF(m_controlStack.size() == 1, "can't use delegate at the top-level of a function");

    uint32_t target;
    WASM_FAIL_IF_HELPER_FAILS(parseBranchTarget(target));

    ControlEntry controlEntry = m_controlStack.takeLast();
    WASM_VALIDATOR_FAIL_IF(!ControlType::isTry(controlEntry.controlData), "delegate isn't associated to a
try");

    ControlType &data = m_controlStack[m_controlStack.size() - 1 - target].controlData;
    WASM_VALIDATOR_FAIL_IF(!ControlType::isTry(data) && !ControlType::isTopLevel(data), "delegate target is-
n't a try block");

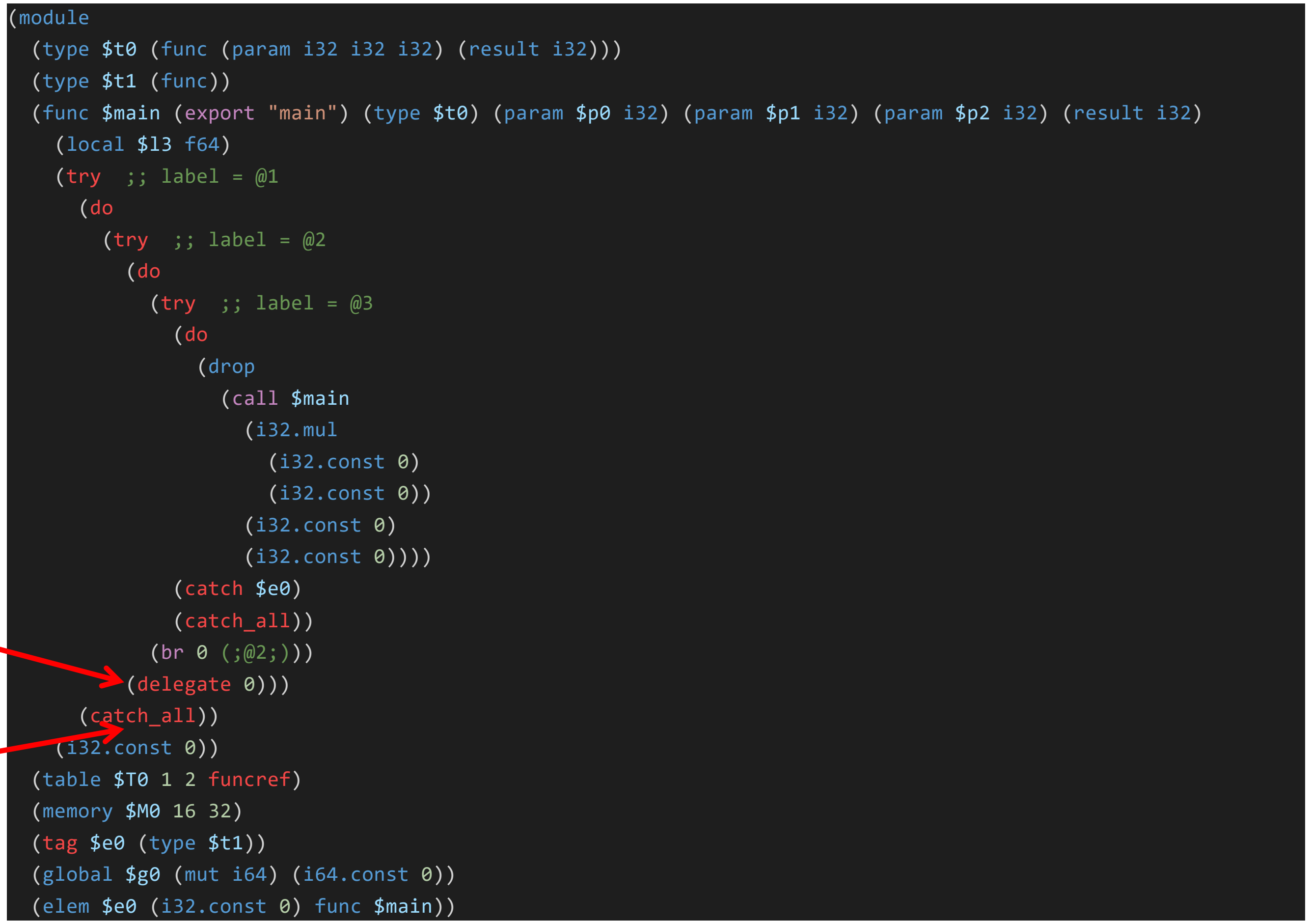
    WASM_TRY_ADD_TO_CONTEXT(addDelegateToUnreachable(data, controlEntry.controlData));
    Stack emptyStack;
    WASM_TRY_ADD_TO_CONTEXT(addEndToUnreachable(controlEntry, emptyStack));
    m_expressionStack.swap(controlEntry.enclosedExpressionStack);
    return {};
  }
    // [...]
  }
}
```

➢ src: JavaScriptCore/wasm/WasmFunctionParser.h

CVE-2022-32885

POC

- Add a Delegate statement after unreachable code.



```
(module
  (type $t0 (func (param i32 i32 i32) (result i32)))
  (type $t1 (func))
  (func $main (export "main") (type $t0) (param $p0 i32) (param $p1 i32) (param $p2 i32) (result i32)
    (local $l3 f64)
    (try  ;; label = @1
      (do
        (try  ;; label = @2
          (do
            (try  ;; label = @3
              (do
                (drop
                  (call $main
                    (i32.mul
                      (i32.const 0)
                      (i32.const 0))
                    (i32.const 0)
                    (i32.const 0))))
              (catch $e0)
              (catch_all))
            (br 0 (;@2;)))
          (delegate 0)))
      (catch_all))
    (i32.const 0))
  (table $T0 1 2 funcref)
  (memory $M0 16 32)
  (tag $e0 (type $t1))
  (global $g0 (mut i64) (i64.const 0))
  (elem $e0 (i32.const 0) func $main))
```

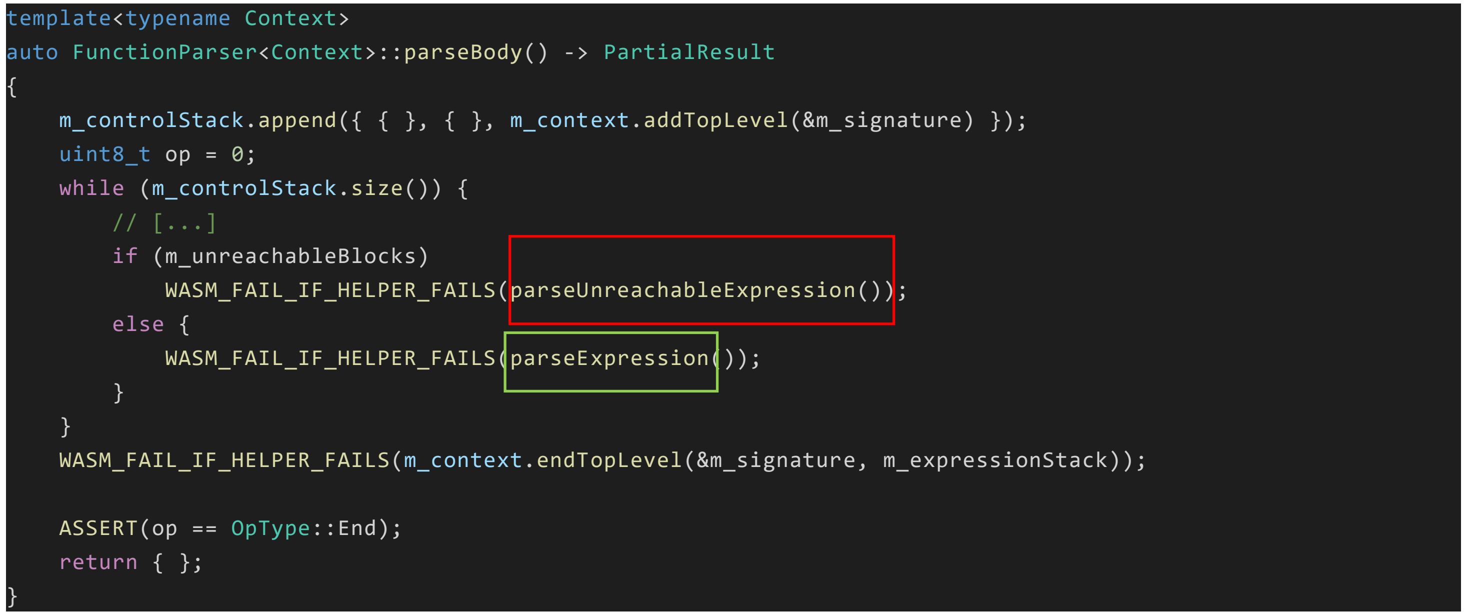
[1]

[2]

CVE-2022-32885

Vulnerability analysis

- parseUnreachableExpression was mistakenly used while parsing the CatchAll operator



```
template<typename Context>
auto FunctionParser<Context>::parseBody() -> PartialResult
{
    m_controlStack.append({ { }, { }, m_context.addTopLevel(&m_signature) });
    uint8_t op = 0;
    while (m_controlStack.size()) {
        // [...]
        if (m_unreachableBlocks)
            WASM_FAIL_IF_HELPER_FAILS(parseUnreachableExpression());
        else {
            WASM_FAIL_IF_HELPER_FAILS(parseExpression());
        }
    }
    WASM_FAIL_IF_HELPER_FAILS(m_context.endTopLevel(&m_signature, m_expressionStack));

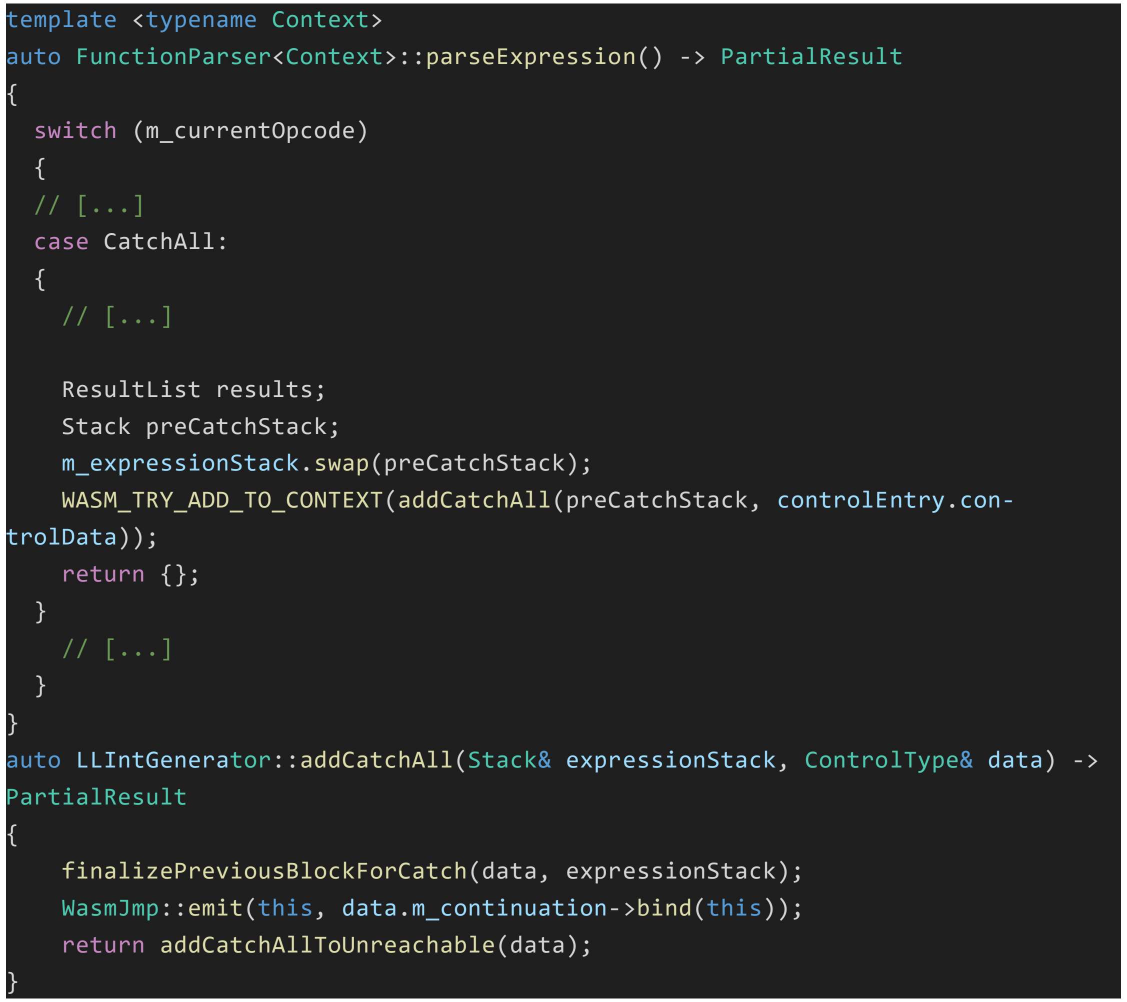
    ASSERT(op == OpType::End);
    return { };
}
```

➢ src: JavaScriptCore/wasm/WasmFunctionParser.h

CVE-2022-32885

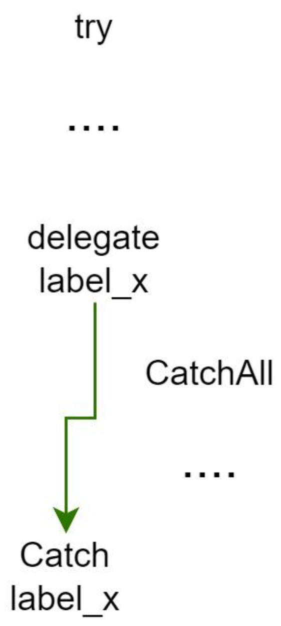
Vulnerability analysis

- In normal case, a pass-jmp instruction will be emitted



```
template <typename Context>
auto FunctionParser<Context>::parseExpression() -> PartialResult
{
  switch (m_currentOpcode)
  {
  // [...]
  case CatchAll:
  {
    // [...]

    ResultList results;
    Stack preCatchStack;
    m_expressionStack.swap(preCatchStack);
    WASM_TRY_ADD_TO_CONTEXT(addCatchAll(preCatchStack, controlEntry.con-
trolData));
    return {};
  }
    // [...]
  }
}
auto LLIntGenerator::addCatchAll(Stack& expressionStack, ControlType& data) ->
PartialResult
{
    finalizePreviousBlockForCatch(data, expressionStack);
    WasmJmp::emit(this, data.m_continuation->bind(this));
    return addCatchAllToUnreachable(data);
}
```



try

....

delegate
label_x

CatchAll

....

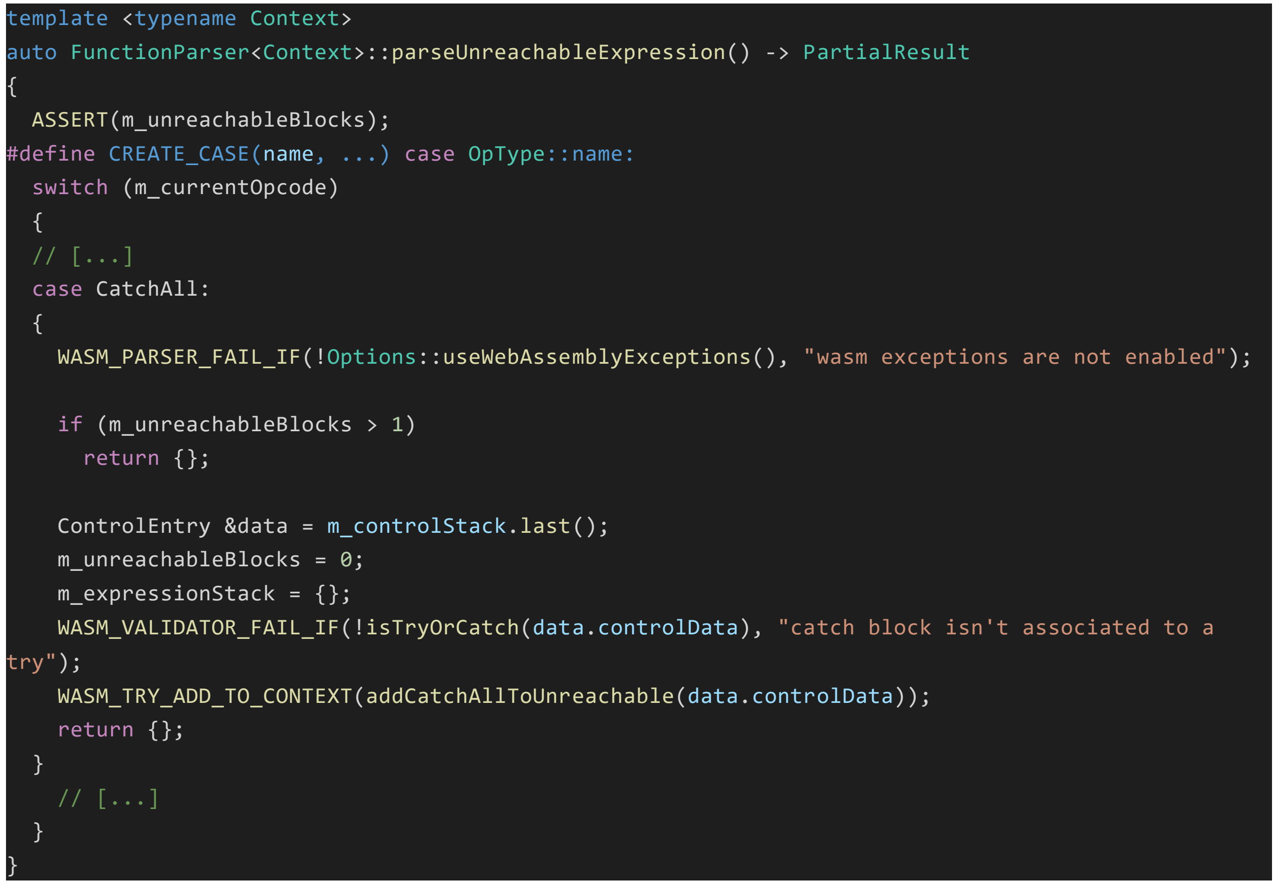
Catch
label_x

➢ src: JavaScriptCore/wasm/WasmFunctionParser.h

CVE-2022-32885

Vulnerability analysis

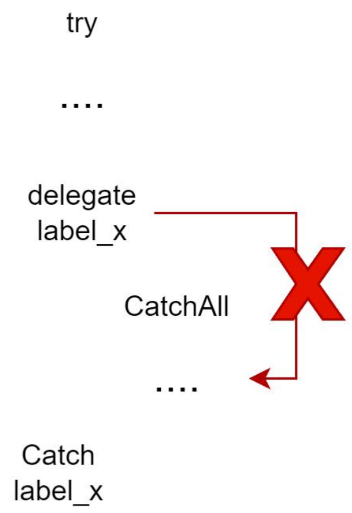
- Under the vulnerability, it won't emit such instruction and will fall into CatchAll's handler code directly



```
template <typename Context>
auto FunctionParser<Context>::parseUnreachableExpression() -> PartialResult
{
  ASSERT(m_unreachableBlocks);
#define CREATE_CASE(name, ...) case OpType::name:
  switch (m_currentOpcode)
  {
  // [...]
  case CatchAll:
  {
    WASM_PARSER_FAIL_IF(!Options::useWebAssemblyExceptions(), "wasm exceptions are not enabled");

    if (m_unreachableBlocks > 1)
      return {};

    ControlEntry &data = m_controlStack.last();
    m_unreachableBlocks = 0;
    m_expressionStack = {};
    WASM_VALIDATOR_FAIL_IF(!isTryOrCatch(data.controlData), "catch block isn't associated to a
try");
    WASM_TRY_ADD_TO_CONTEXT(addCatchAllToUnreachable(data.controlData));
    return {};
  }
    // [...]
  }
}
```

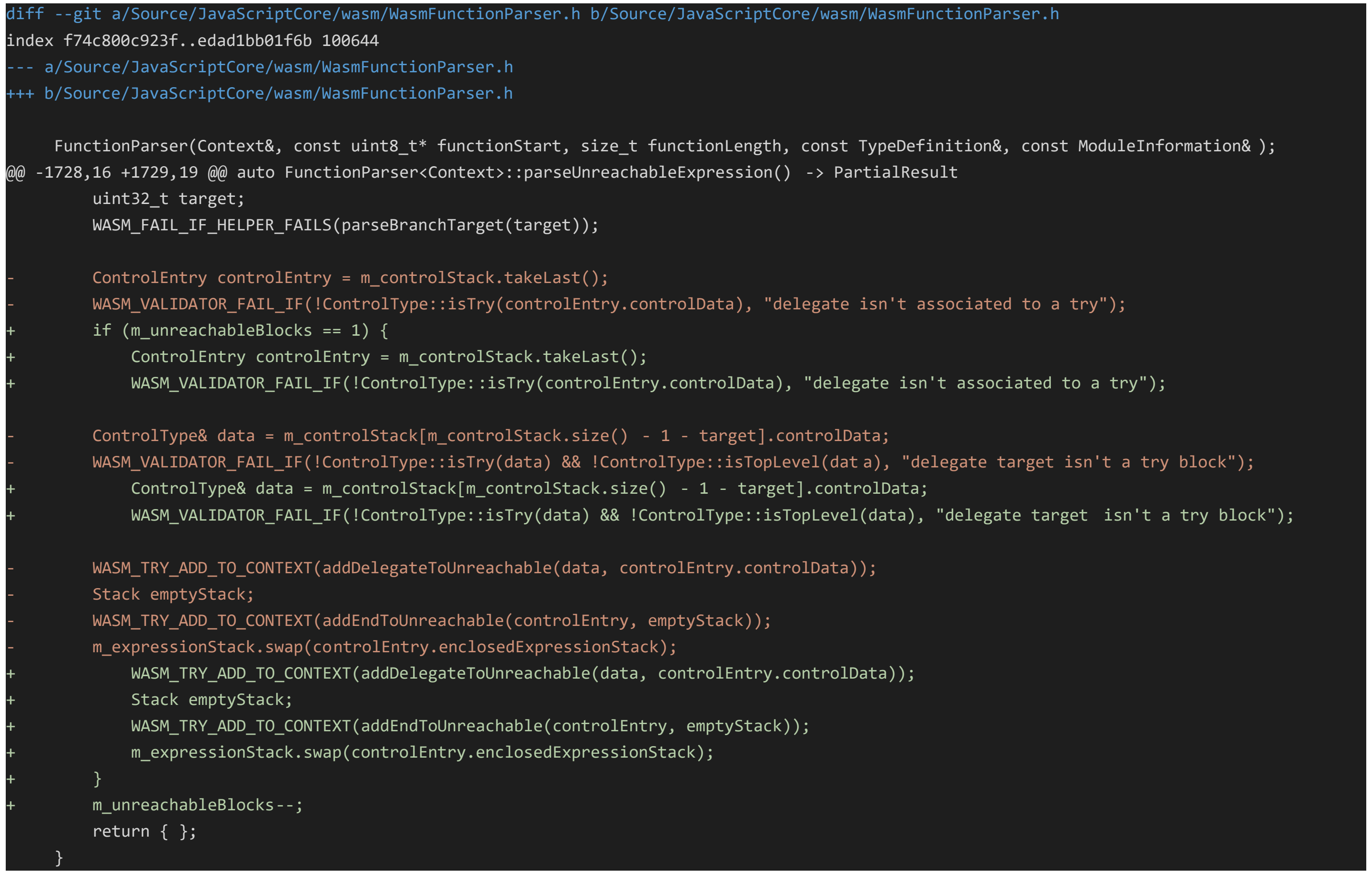


➢ src: JavaScriptCore/wasm/WasmFunctionParser.h

CVE-2022-32885

Patch

- Handle control stack in the same way as the End opcode
- Decrement m_unreachableBlocks in the same way as the End opcode



```
diff --git a/Source/JavaScriptCore/wasm/WasmFunctionParser.h b/Source/JavaScriptCore/wasm/WasmFunctionParser.h
index f74c800c923f..edad1bb01f6b 100644
--- a/Source/JavaScriptCore/wasm/WasmFunctionParser.h
+++ b/Source/JavaScriptCore/wasm/WasmFunctionParser.h

     FunctionParser(Context&, const uint8_t* functionStart, size_t functionLength, const TypeDefinition&, const ModuleInformation& );
@@ -1728,16 +1729,19 @@ auto FunctionParser<Context>::parseUnreachableExpression() -> PartialResult
         uint32_t target;
         WASM_FAIL_IF_HELPER_FAILS(parseBranchTarget(target));

-        ControlEntry controlEntry = m_controlStack.takeLast();
-        WASM_VALIDATOR_FAIL_IF(!ControlType::isTry(controlEntry.controlData), "delegate isn't associated to a try");
+        if (m_unreachableBlocks == 1) {
+            ControlEntry controlEntry = m_controlStack.takeLast();
+            WASM_VALIDATOR_FAIL_IF(!ControlType::isTry(controlEntry.controlData), "delegate isn't associated to a try");

-        ControlType& data = m_controlStack[m_controlStack.size() - 1 - target].controlData;
-        WASM_VALIDATOR_FAIL_IF(!ControlType::isTry(data) && !ControlType::isTopLevel(dat a), "delegate target isn't a try block");
+            ControlType& data = m_controlStack[m_controlStack.size() - 1 - target].controlData;
+            WASM_VALIDATOR_FAIL_IF(!ControlType::isTry(data) && !ControlType::isTopLevel(data), "delegate target  isn't a try block");

-        WASM_TRY_ADD_TO_CONTEXT(addDelegateToUnreachable(data, controlEntry.controlData));
-        Stack emptyStack;
-        WASM_TRY_ADD_TO_CONTEXT(addEndToUnreachable(controlEntry, emptyStack));
-        m_expressionStack.swap(controlEntry.enclosedExpressionStack);
+            WASM_TRY_ADD_TO_CONTEXT(addDelegateToUnreachable(data, controlEntry.controlData));
+            Stack emptyStack;
+            WASM_TRY_ADD_TO_CONTEXT(addEndToUnreachable(controlEntry, emptyStack));
+            m_expressionStack.swap(controlEntry.enclosedExpressionStack);
+        }
+        m_unreachableBlocks--;
         return { };
     }
```

➤ Fix: 27d302ab3481407e8746f57729f0961058235e33

CVE-2022-32886

- BBQ & OMG
- Uninitialized value in callSiteIndex
- Wrong exception handler

CVE-2022-32886

Callsite Index

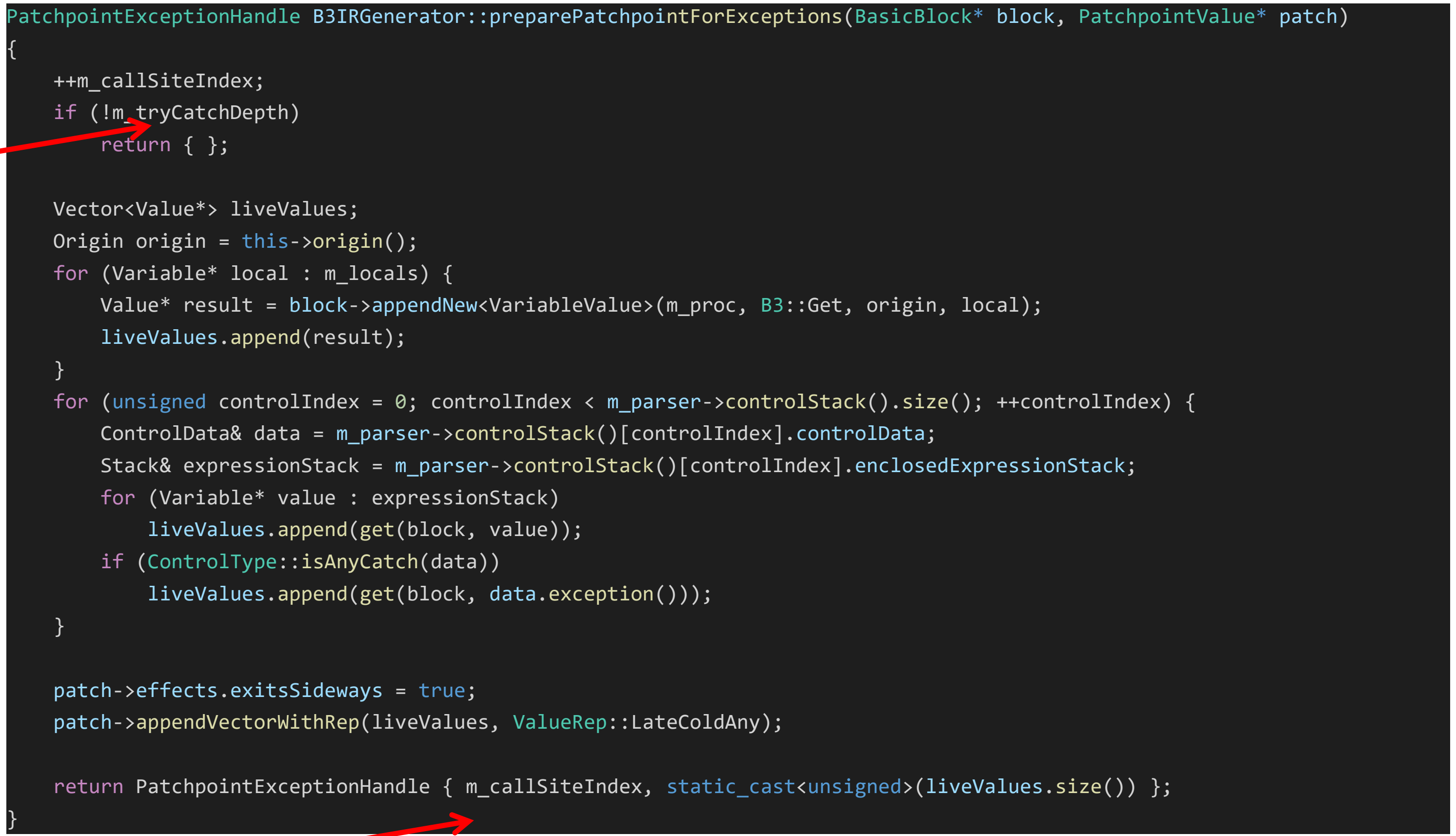
- Used for exception handler
- Store the position of Call/Try/Catch/Throw
- StackMap : keep callsite_index and used_values key-value pair

CVE-2022-32886

Vulnerability analysis

- The handle is initialized only when the call instruction is enclosed within a try-catch block

[1]



```
PatchpointExceptionHandle B3IRGenerator::preparePatchpointForExceptions(BasicBlock* block, PatchpointValue* patch)
{
    ++m_callSiteIndex;
    if (!m_tryCatchDepth)
        return { };

    Vector<Value*> liveValues;
    Origin origin = this->origin();
    for (Variable* local : m_locals) {
        Value* result = block->appendNew<VariableValue>(m_proc, B3::Get, origin, local);
        liveValues.append(result);
    }
    for (unsigned controlIndex = 0; controlIndex < m_parser->controlStack().size(); ++controlIndex) {
        ControlData& data = m_parser->controlStack()[controlIndex].controlData;
        Stack& expressionStack = m_parser->controlStack()[controlIndex].enclosedExpressionStack;
        for (Variable* value : expressionStack)
            liveValues.append(get(block, value));
        if (ControlType::isAnyCatch(data))
            liveValues.append(get(block, data.exception()));
    }

    patch->effects.exitsSideways = true;
    patch->appendVectorWithRep(liveValues, ValueRep::LateColdAny);

    return PatchpointExceptionHandle { m_callSiteIndex, static_cast<unsigned>(liveValues.size()) };
}
```

[2]

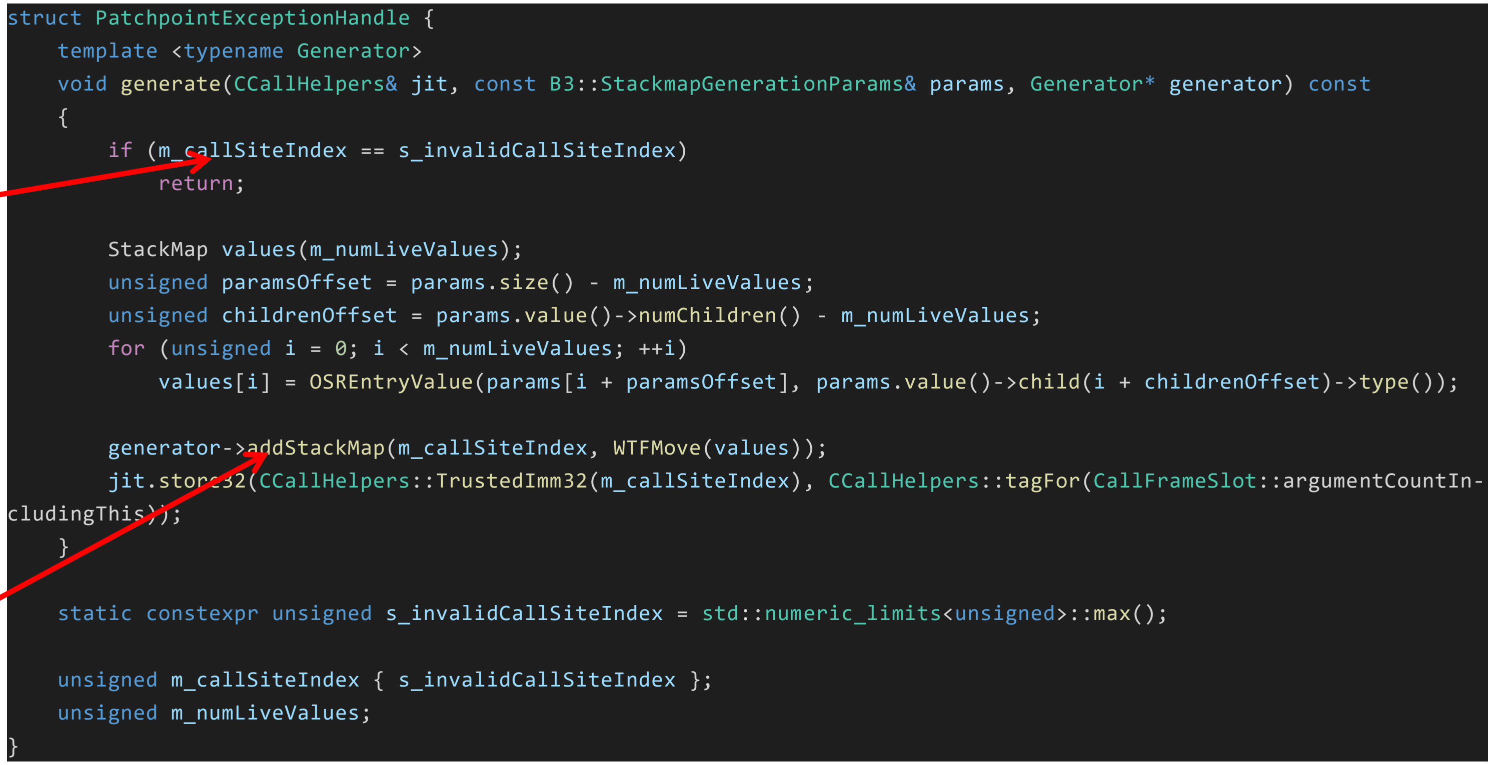
➢ src: JavaScriptCore/wasm/WasmB3IRGenerator.cpp

CVE-2022-32886

Vulnerability analysis

- BBQ and OMG will ultimately call the generate function to get the optimized code

- The generate function omits the storing operation. The callsite index isn't kept neither in slot nor in stack map



```
struct PatchpointExceptionHandle {
    template <typename Generator>
    void generate(CCallHelpers& jit, const B3::StackmapGenerationParams& params, Generator* generator) const
    {
        if (m_callSiteIndex == s_invalidCallSiteIndex)
            return;

        StackMap values(m_numLiveValues);
        unsigned paramsOffset = params.size() - m_numLiveValues;
        unsigned childrenOffset = params.value()->numChildren() - m_numLiveValues;
        for (unsigned i = 0; i < m_numLiveValues; ++i)
            values[i] = OSREntryValue(params[i + paramsOffset], params.value()->child(i + childrenOffset)->type());

        generator->addStackMap(m_callSiteIndex, WTFMove(values));
        jit.store32(CCallHelpers::TrustedImm32(m_callSiteIndex), CCallHelpers::tagFor(CallFrameSlot::argumentCountIn-
cludingThis));
    }

    static constexpr unsigned s_invalidCallSiteIndex = std::numeric_limits<unsigned>::max();

    unsigned m_callSiteIndex { s_invalidCallSiteIndex };
    unsigned m_numLiveValues;
}
```

[3]

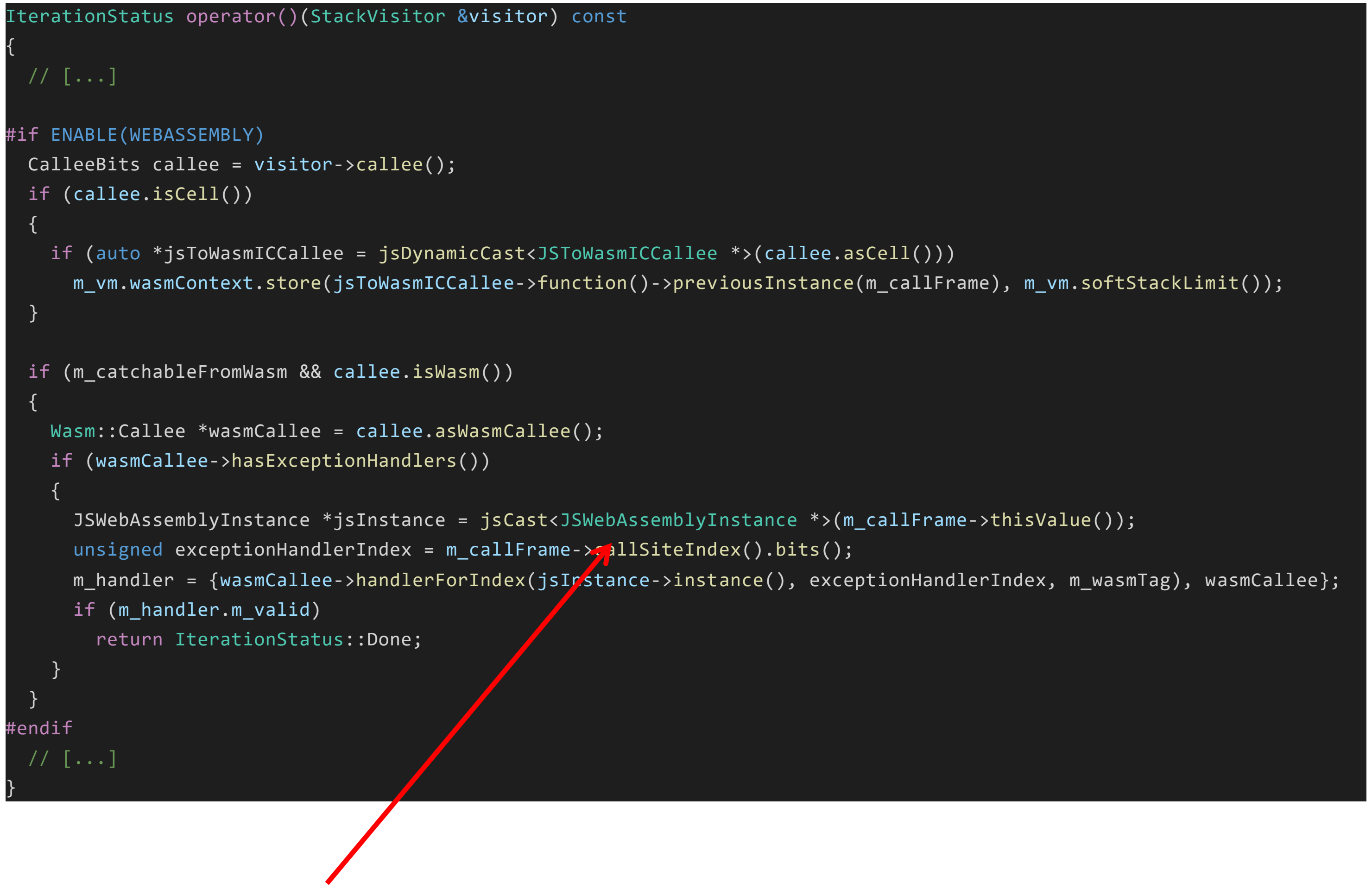
[4]

➢ src: JavaScriptCore/wasm/WasmIRGeneratorHelpers.h

CVE-2022-32886

Vulnerability analysis

- This results in an incorrect handler due to the presence of a dirty value



```
IterationStatus operator()(StackVisitor &visitor) const
{
  // [...]

#if ENABLE(WEBASSEMBLY)
  CalleeBits callee = visitor->callee();
  if (callee.isCell())
  {
    if (auto *jsToWasmICCallee = jsDynamicCast<JSToWasmICCallee *>(callee.asCell()))
      m_vm.wasmContext.store(jsToWasmICCallee->function()->previousInstance(m_callFrame), m_vm.softStackLimit());
  }

  if (m_catchableFromWasm && callee.isWasm())
  {
    Wasm::Callee *wasmCallee = callee.asWasmCallee();
    if (wasmCallee->hasExceptionHandlers())
    {
      JSWebAssemblyInstance *jsInstance = jsCast<JSWebAssemblyInstance *>(m_callFrame->thisValue());
      unsigned exceptionHandlerIndex = m_callFrame->callSiteIndex().bits();
      m_handler = {wasmCallee->handlerForIndex(jsInstance->instance(), exceptionHandlerIndex, m_wasmTag), wasmCallee};
      if (m_handler.m_valid)
        return IterationStatus::Done;
    }
  }
#endif
  // [...]
}
```

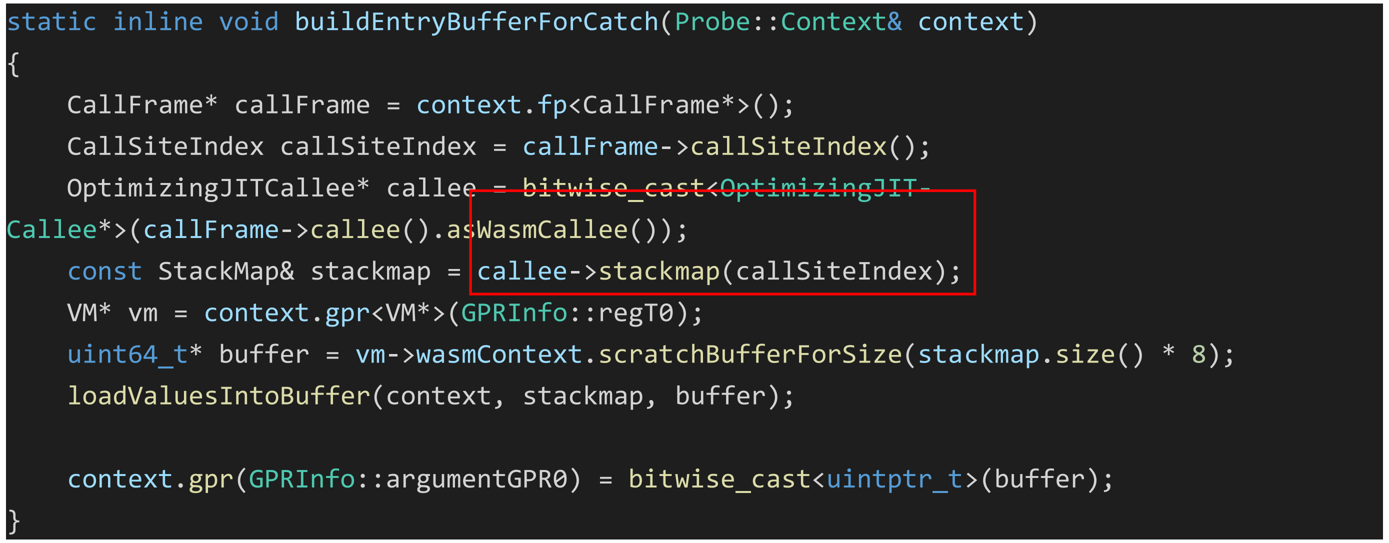
[5]

➢ src: JavaScriptCore/interpreter/Interpreter.cpp

CVE-2022-32886

Vulnerability analysis

- Before executing error-handling code, the stack map is obtained by calling the buildEntryBufferForCatch function.



```
static inline void buildEntryBufferForCatch(Probe::Context& context)
{
    CallFrame* callFrame = context.fp<CallFrame*>();
    CallSiteIndex callSiteIndex = callFrame->callSiteIndex();
    OptimizingJITCallee* callee = bitwise_cast<OptimizingJIT-
Callee*>(callFrame->callee().asWasmCallee());
    const StackMap& stackmap = callee->stackmap(callSiteIndex);
    VM* vm = context.gpr<VM*>(GPRInfo::regT0);
    uint64_t* buffer = vm->wasmContext.scratchBufferForSize(stackmap.size() * 8);
    loadValuesIntoBuffer(context, stackmap, buffer);

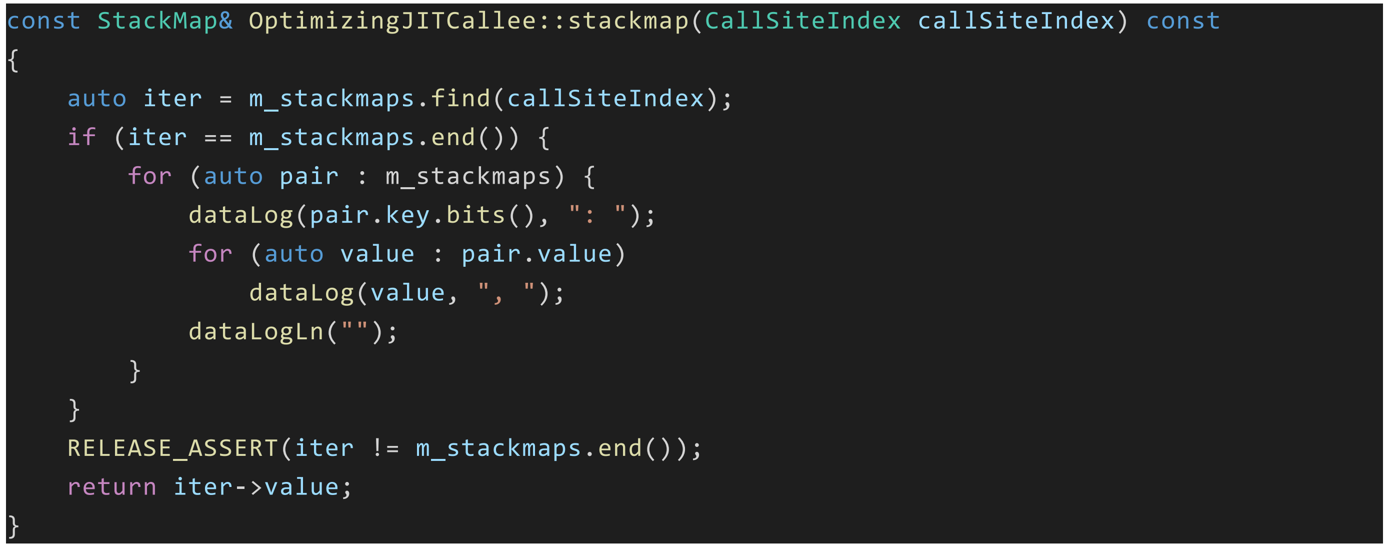
    context.gpr(GPRInfo::argumentGPR0) = bitwise_cast<uintptr_t>(buffer);
}
```

➢ src: JavaScriptCore/wasm/WasmIRGeneratorHelpers.h

CVE-2022-32886

Vulnerability analysis

- Since the key-value pair was not stored, an assert failure is triggered



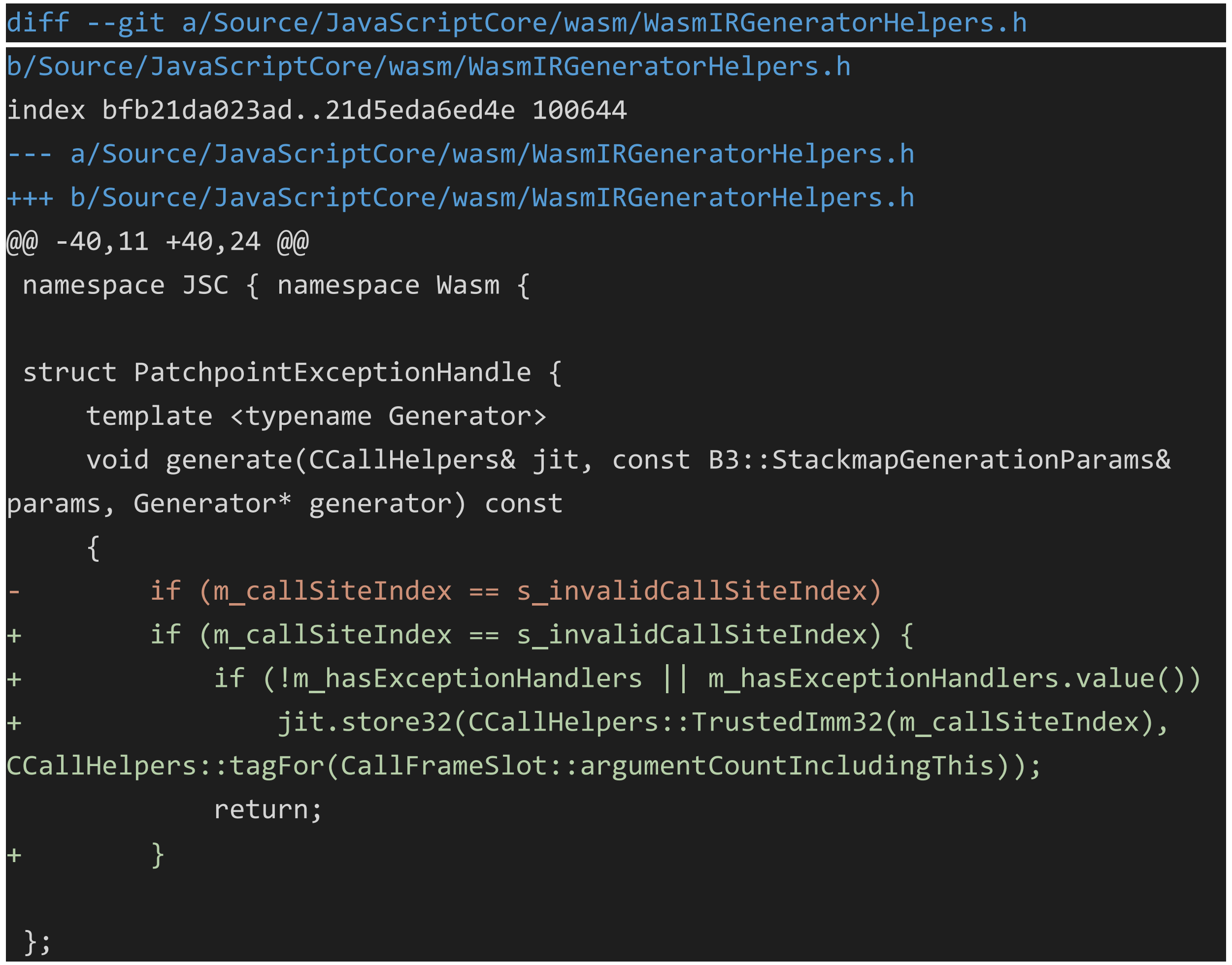
```
const StackMap& OptimizingJITCallee::stackmap(CallSiteIndex callSiteIndex) const
{
    auto iter = m_stackmaps.find(callSiteIndex);
    if (iter == m_stackmaps.end()) {
        for (auto pair : m_stackmaps) {
            dataLog(pair.key.bits(), ": ");
            for (auto value : pair.value)
                dataLog(value, ", ");
            dataLogLn("");
        }
    }
    RELEASE_ASSERT(iter != m_stackmaps.end());
    return iter->value;
}
```

➢ src: JavaScriptCore/wasm/WasmCallee.cpp

CVE-2022-32886

Patch

- Store CallSiteIndex for calls in Air and B3 if there are exception handlers present



```
diff --git a/Source/JavaScriptCore/wasm/WasmIRGeneratorHelpers.h
b/Source/JavaScriptCore/wasm/WasmIRGeneratorHelpers.h
index bfb21da023ad..21d5eda6ed4e 100644
--- a/Source/JavaScriptCore/wasm/WasmIRGeneratorHelpers.h
+++ b/Source/JavaScriptCore/wasm/WasmIRGeneratorHelpers.h
@@ -40,11 +40,24 @@
 namespace JSC { namespace Wasm {

 struct PatchpointExceptionHandle {
     template <typename Generator>
     void generate(CCallHelpers& jit, const B3::StackmapGenerationParams&
params, Generator* generator) const
     {
-        if (m_callSiteIndex == s_invalidCallSiteIndex)
+        if (m_callSiteIndex == s_invalidCallSiteIndex) {
+            if (!m_hasExceptionHandlers || m_hasExceptionHandlers.value())
+                jit.store32(CCallHelpers::TrustedImm32(m_callSiteIndex),
CCallHelpers::tagFor(CallFrameSlot::argumentCountIncludingThis));
             return;
+        }

 };
```

➢ Fix: 97b340447c9fc3e934a8045e059b3fac71e0ab4d

Q & A

Thanks

Feel free to contact us at @P1umer and @xmzyshypnc1 in Twitter