Hit the Bullseye: Detecting Browser Exploits Abusing the X Memory in WebAssembly

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About Us

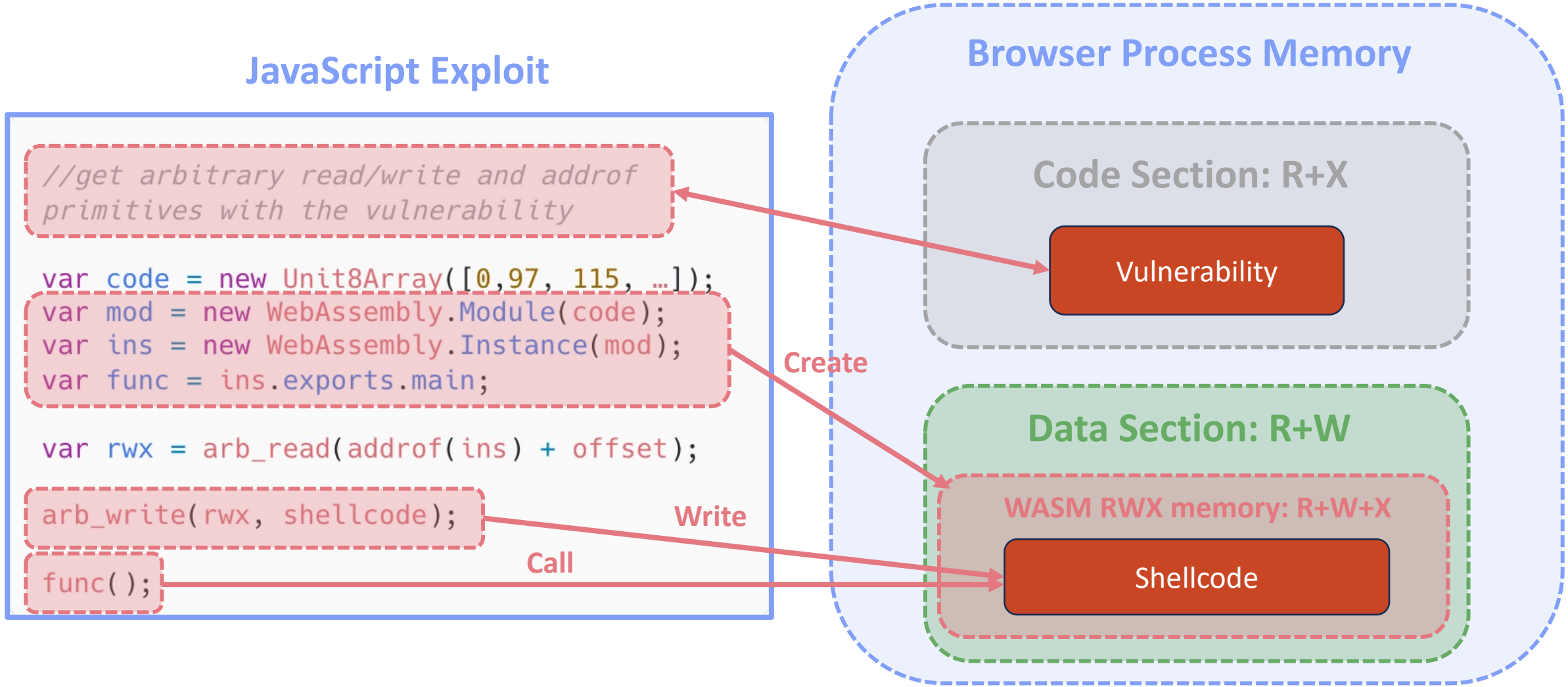
- Security Researchers from Palo Alto Networks
  - Tao Yan (@Ga1ois)
  - Edouard Bochin
- Vulnerability researchers
  - Multiple times for MSRC Top 10 Researchers
- Pwn2Own winner
- Conference speakers
  - Black Hat, CanSecWest, Blue Hat, POC, HITCON, Recon, etc
- Patent inventors
  - New defense and detection techniques

Agenda

- Background & Introduction
- V8 WebAssembly Engine Internals
- WASMGuard
- Demo
- Summary

Background & Introduction

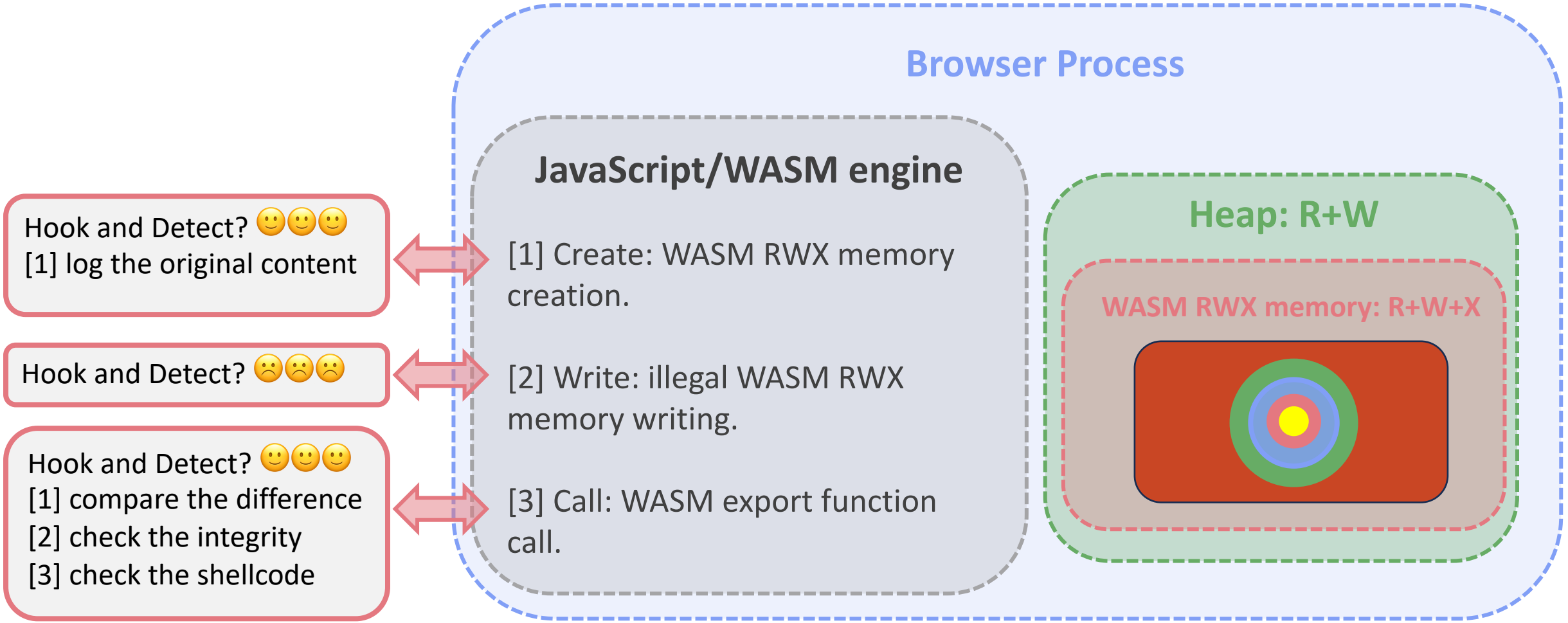
Exploits abusing the X memory in WebAssembly



How popular is it and why?

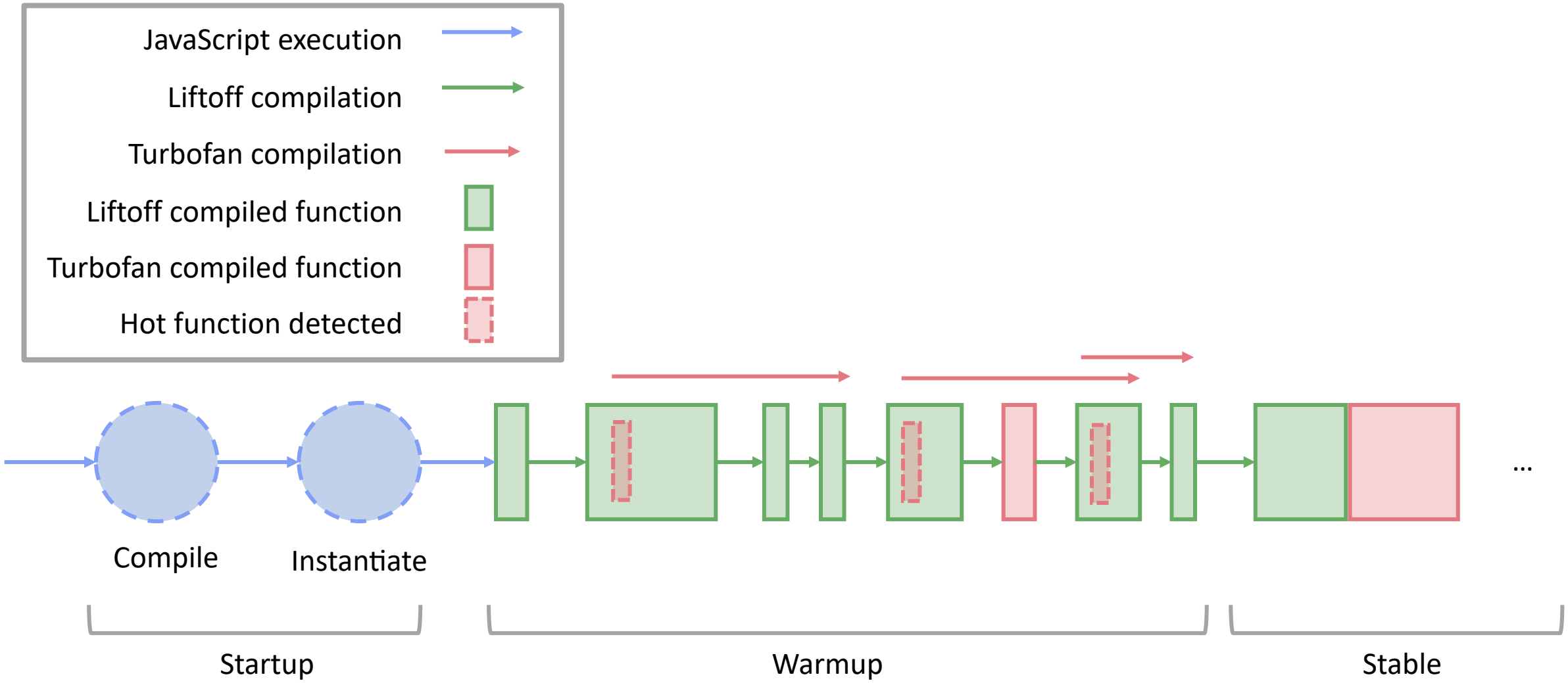
- Statistics of the past 3 years
  - **29** WASM Vs **3** ROP in **32** publicly disclosed exploits (including 0 days, n days, exploits used in Pwn2Own, etc)
- Simple, effective and stable
  - An existing RWX memory region, exploit-friendly in born
  - A perfect way to bypass DEP / NX
- Mitigation
  - There is a WASM_MEMORY_PROTECTION flag
    - But easy to be bypassed after getting arbitrary read & write primitives
  - V8 sandbox
    - Efficient but could be bypassed (Example with WASM Globals)
  - Mitigation != Detection

Detecting the exploitation technique



V8 WebAssembly Engine Internals

V8 WebAssembly compilation pipeline



WebAssembly: Past and Future (Ben Titzer, Google, V8 WebAssembly team lead) 2019 : https://youtu.be/nRArrwEjccI?si=wgN0xcXALC28chRh

WebAssembly RWX Memory Allocation

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
})();
```

V8 internals

```
void WebAssemblyModule(
  const v8::FunctionCallbackInfo<v8::Value>& args);
```

```
MaybeHandle<WasmModuleObject>
WasmEngine::SyncCompile(Isolate* isolate, WasmFeatures
enabled, ErrorThrower* thrower, ModuleWireBytes bytes);
```

```
std::shared_ptr<NativeModule> CompileToNativeModule(
Isolate* isolate,...);
```

```
std::shared_ptr<NativeModule>
WasmEngine::NewNativeModule(Isolate* isolate, ...);
```

WASM RWX memory

0x42a81be9000	Int 3
0x42a81be9001	Int 3
0x42a81be9002	Int 3
0x42a81be9003	Int 3
0x42a81be9004	Int 3
0x42a81be9005	Int 3
0x42a81be9006	Int 3
0x42a81be9007	Int 3
0x42a81be9008	Int 3
0x42a81be9009	Int 3
.	.
.	.
.	.

WebAssembly jump tables creation

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
})();
```

V8 internals

```
void NativeModule::AddCodeSpaceLocked(base::AddressRegion
region){
  ...
  JumpTableAssembler::GenerateFarJumpTable(...);
  ...
  InitializeJumpTableForLazyCompilation(...);
}
```

```
void NativeModule::InitializeJumpTableForLazyCompilation(
    uint32_t num_wasm_functions) {
  ...
  JumpTableAssembler::GenerateLazyCompileTable(...);

  JumpTableAssembler::InitializeJumpsToLazyCompileTable(...);
}
```

WASM RWX memory

0x42a81be9000	int 3
0x42a81be9002	int 3
0x42a81be9003	int 3
0x42a81be9004	int 3
0x42a81be9005	int 3
0x42a81be9006	int 3
0x42a81be9007	int 3
0x42a81be9008	int 3
0x42a81be9009	int 3
0x42a81be900a	int 3
0x42a81be900b	int 3
0x42a81be900c	int 3
0x42a81be900d	int 3
0x42a81be900e	int 3
0x42a81be900f	int 3
0x42a81be9010	int 3
0x42a81be9011	int 3
0x42a81be9012	int 3
…	…

WebAssembly jump tables creation

JavaScript code execution

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    uint32_t num_wasm_functions) {
  ...
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  JumpTableAssembler::InitializeJumpsToLazyCompileTable(...);
}
```

WASM RWX memory

0x42a81be9000	int 3
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…	…
0x42a81be9040	jmp qword ptr[rip+0x2]
…	…
0x42a81be9048	0x7ffff4b0b600
…	…
0x42a81be9150	jmp qword ptr[rip+0x2]
…	…
0x42a81be9158	0x7ffff4609600
…	…
0x42a81be9691	int 3
0x42a81be9692	int 3
0x42a81be9693	int 3
0x42a81be9694	int 3
0x42a81be9695	int 3
0x42a81be9696	int 3
0x42a81be9697	int 3
…	…

Far Jump Table

WebAssembly jump tables creation

JavaScript code execution

```
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const buffer = await response.arrayBuffer();
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```

V8 internals

```
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region){
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  ...
  InitializeJumpTableForLazyCompilation(...);
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```
void NativeModule::InitializeJumpTableForLazyCompilation(
    uint32_t num_wasm_functions) {
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  JumpTableAssembler::GenerateLazyCompileTable(...);

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```
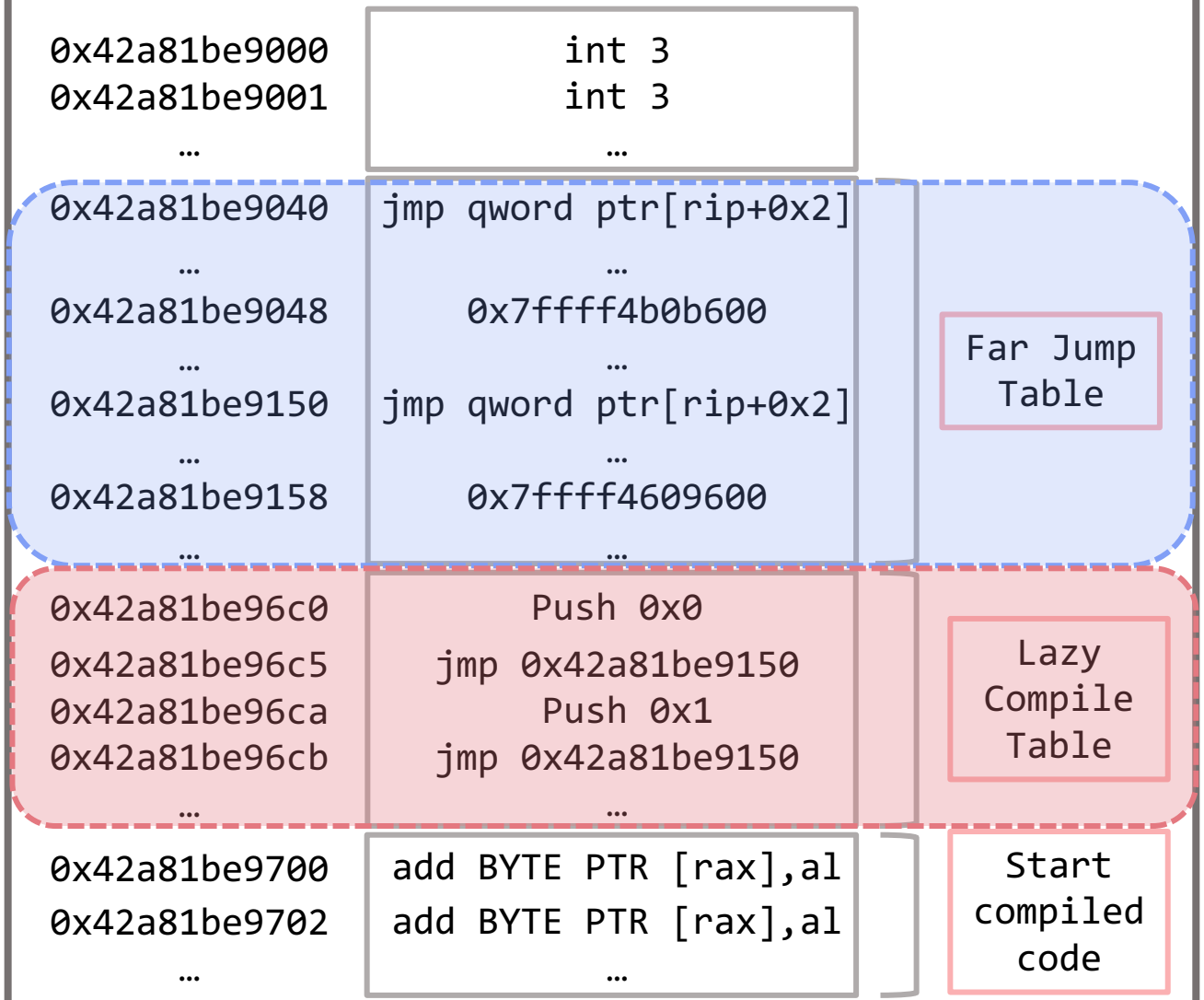

WASM RWX memory



WebAssembly jump tables creation

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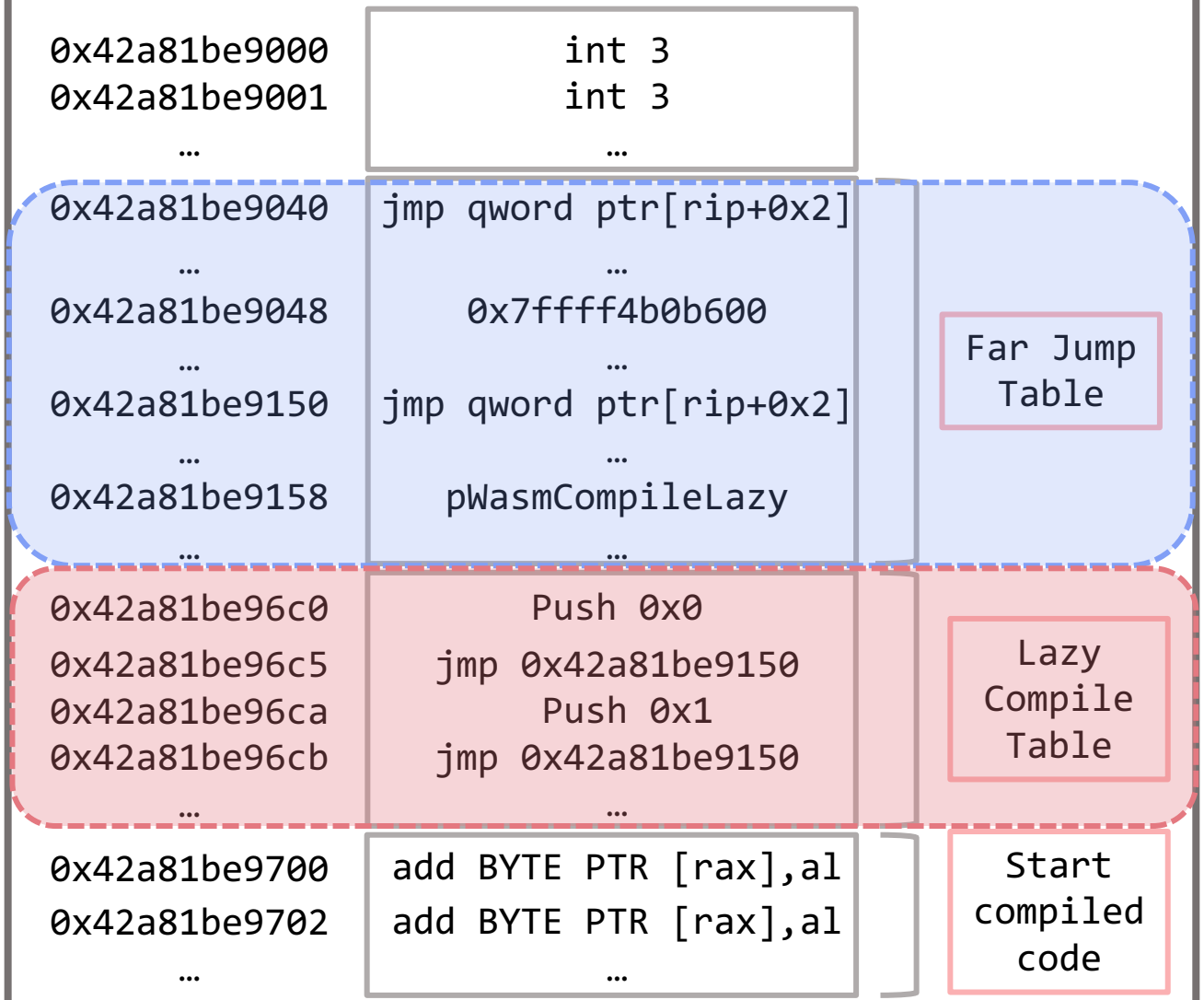
WASM RWX memory



WebAssembly jump tables creation

JavaScript code execution

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const result = instance.exports.main();
console.log(result);
})();
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V8 internals

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void NativeModule::AddCodeSpaceLocked(base::AddressRegion
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    uint32_t num_wasm_functions) {
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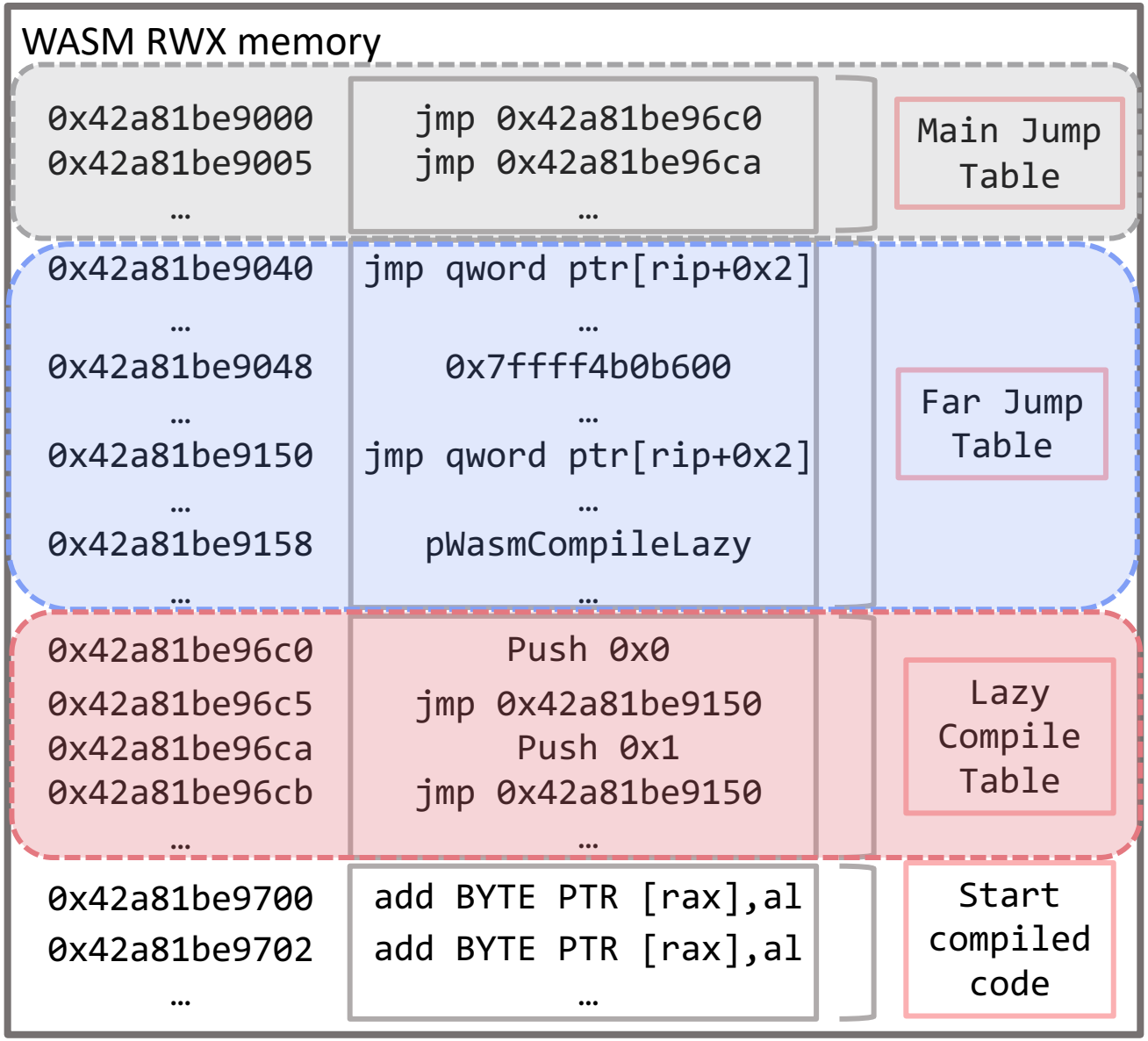
WASM RWX memory



WebAssembly Module Instantiation

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
})();
```

```
(async () => {
  const module = await WebAssembly.compileStreaming(
    fetch('../out/main.wasm'));
  const instance = await WebAssembly.instantiate(module);
  const result = instance.exports.main();
  console.log(result);
})();
```

```
(async () => {
const fetchPromise = fetch('../out/main.wasm');
const { instance } = await
WebAssembly.instantiateStreaming(fetchPromise);
const result = instance.exports.main();
console.log(result);
})();
```

There are different ways to instantiate a WebAssembly Module :

- WebAssembly.Instance()
- WebAssembly.instantiate(module)
- WebAssembly.instantiateStreaming()

But all of them are calling the same low level WebAssembly engine internal function v8::internal::wasm::InstantiateToInstanceObject.

WebAssembly Module Instantiation

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
})();
```

V8 internals

```
MaybeHandle<WasmInstanceObject> InstantiateToInstanceObject(
    Isolate* isolate, ErrorThrower* thrower,
    Handle<WasmModuleObject> module_object, MaybeHandle<JSReceiver>
      imports, MaybeHandle<JSArrayBuffer> memory_buffer);
```

```
MaybeHandle<WasmInstanceObject> InstanceBuilder::Build()
```

WASM RWX memory

0x42a81be9000	jmp 0x42a81be96c0	Main Jump Table
0x42a81be9005	jmp 0x42a81be96ca	
…	…	
0x42a81be9040	jmp qword ptr[rip+0x2]	Far Jump Table
…	…	
0x42a81be9048	0x7ffff4b0b600	
…	…	
0x42a81be9150	jmp qword ptr[rip+0x2]	
…	…	
0x42a81be9158	pWasmCompileLazy	
…	…	
0x42a81be96c0	Push 0x0	Lazy Compile Table
0x42a81be96c5	jmp 0x42a81be9150	
0x42a81be96ca	Push 0x1	
0x42a81be96cb	jmp 0x42a81be9150	
…	…	
0x42a81be9700	add BYTE PTR [rax],al	Start compiled code
0x42a81be9702	add BYTE PTR [rax],al	
…	…	

WebAssembly Module Instantiation

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
})();
```

V8 internals

```
class WasmInstanceObject {
 public:
  Tagged<WasmModuleObject> module_object;
  Tagged<JSObject> exports_object;
  Tagged<Context> native_context;
  Tagged<FixedArray> memory_objects;
  ...
  Tagged<FixedArray> indirect_function_tables;
  ...
  Tagged<FixedArray> wasm_internal_functions;
  ...
  Address stack_limit_address;
  Address real_stack_limit_address;
  ...
  uint32_t indirect_function_table_size;
  Address jump_table_start;
  ...
};
```

WASM RWX memory

0x42a81be9000	jmp 0x42a81be96c0	Main Jump Table
0x42a81be9005	jmp 0x42a81be96ca	
…	…	
0x42a81be9040	jmp qword ptr[rip+0x2]	Far Jump Table
…	…	
0x42a81be9048	0x7ffff4b0b600	
…	…	
0x42a81be9150	jmp qword ptr[rip+0x2]	
…	…	
0x42a81be9158	pWasmCompileLazy	
…	…	
0x42a81be96c0	Push 0x0	Lazy Compile Table
0x42a81be96c5	jmp 0x42a81be9150	
0x42a81be96ca	Push 0x1	
0x42a81be96cb	jmp 0x42a81be9150	
…	…	
0x42a81be9700	add BYTE PTR [rax],al	Start compiled code
0x42a81be9702	add BYTE PTR [rax],al	
…	…	

Processing export functions

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
})();
```

V8 internals

```
void InstanceBuilder::ProcessExports(Handle<WasmInstanceObject>
instance);
```

```
Handle<JSFunction> WasmInternalFunction::GetOrCreateExternal(
    Handle<WasmInternalFunction> internal)
```

```
Handle<WasmExportedFunction> WasmExportedFunction::New(
    Isolate* isolate, Handle<WasmInstanceObject> instance,
    Handle<WasmInternalFunction> internal, int func_index, int arity,
    Handle<Code> export_wrapper);
```

V8 internal classes

```
class WasmExportedFunction : public
JSFunction {
  SharedFunctionInfo shared_function_info;
  ...
}
```

```
class SharedFunctionInfo
{
 public:
   Tagged<String> Name;
   Tagged<Object> function_data;
   Tagged<HeapObject> script;
 ...
}
```

```
class WasmExportedFunctionData
{
 public:
  Tagged<WasmInternalFunction> internal;
  Tagged<Code> wrapper_code;
  Tagged<WasmInstanceObject> instance;
  int function_index;
  FunctionSig* signature;
  int wrapper_tiering_budget;
  ...
};
```

WebAssembly export functions call

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
})();
```

V8 internals

```
void Builtins_GenericJSToWasmWrapper(
  JSFunction rdi, ...)
```

WASM RWX memory

WebAssembly export functions call

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
})();
```

V8 internals

```
void Builtins_WasmCompileLazy();

bool CompileLazy(...);

WasmCode* NativeModule::PublishCodeLocked(
    std::unique_ptr<WasmCode> owned_code);

void NativeModule::PatchJumpTableLocked(const
CodeSpaceData& code_space_data, uint32_t
slot_index, Address target);
```

WASM RWX memory

0x42a81be9000	jmp 0x42a81be96c0	Main Jump Table
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…	…	
0x42a81be9040	jmp qword ptr[rip+0x2]	Far Jump Table
…	…	
0x42a81be9048	0x7ffff4b0b600	
…	…	
0x42a81be9150	jmp qword ptr[rip+0x2]	
…	…	
0x42a81be9158	pWasmCompileLazy	
…	…	
0x42a81be96c0	Push 0x0	Lazy Compile Table
0x42a81be96c5	jmp 0x42a81be9150	
0x42a81be96ca	Push 0x1	
0x42a81be96cb	jmp 0x42a81be9150	
…	…	
0x42a81be9700	add BYTE PTR [rax],al	Start compiled code
0x42a81be9701	add BYTE PTR [rax],al	
…	…	

WebAssembly export functions call

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
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console.log(result);
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…	…	
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…	…	
0x42a81be9048	0x7ffff4b0b600	
…	…	
0x42a81be9150	jmp qword ptr[rip+0x2]	
…	…	
0x42a81be9158	pWasmCompileLazy	
…	…	
0x42a81be96c0	Push 0x0	Lazy Compile Table
0x42a81be96c5	jmp 0x42a81be9150	
0x42a81be96ca	Push 0x1	
0x42a81be96cb	jmp 0x42a81be9150	
…	…	
0x42a81be9700	push rbp	Start compiled code
0x42a81be9701	mov rbp, rsp	
…	…	

WebAssembly export functions call

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
})();
```

V8 internals

```
void Builtins_WasmCompileLazy();

bool CompileLazy(...);

WasmCode* NativeModule::PublishCodeLocked(
    std::unique_ptr<WasmCode> owned_code);

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CodeSpaceData& code_space_data, uint32_t
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0x42a81be96ca	Push 0x1	
0x42a81be96cb	jmp 0x42a81be9150	
…	…	
0x42a81be9700	push rbp	Start compiled code
0x42a81be9701	mov rbp, rsp	
…	…	

WebAssembly export functions optimization

JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
for (let i = 0; i < 0x10000; i++){result;}
})();
```

V8 internals

```
void Runtime_WasmCompileWrapper(...);
```

```
void ReplaceWrapper(Isolate* isolate,
Handle<WasmInstanceObject> instance, int
function_index, Handle<Code> wrapper_code);
```

V8 internal classes

```
class WasmExportedFunction : public
JSFunction {
  SharedFunctionInfo shared_function_info;
  ...
}
```

```
class SharedFunctionInfo
{
 public:
   Tagged<String> Name;
   Tagged<Object> function_data;
   Tagged<HeapObject> script;
 ...
}
```

```
class WasmExportedFunctionData
{
 public:
  Tagged<WasmInternalFunction> internal;
  Tagged<Code> wrapper_code;
  Tagged<WasmInstanceObject> instance;
  int function_index;
  FunctionSig* signature;
  int wrapper_tiering_budget;
  ...
};
```

WebAssembly export functions optimization

JavaScript code execution

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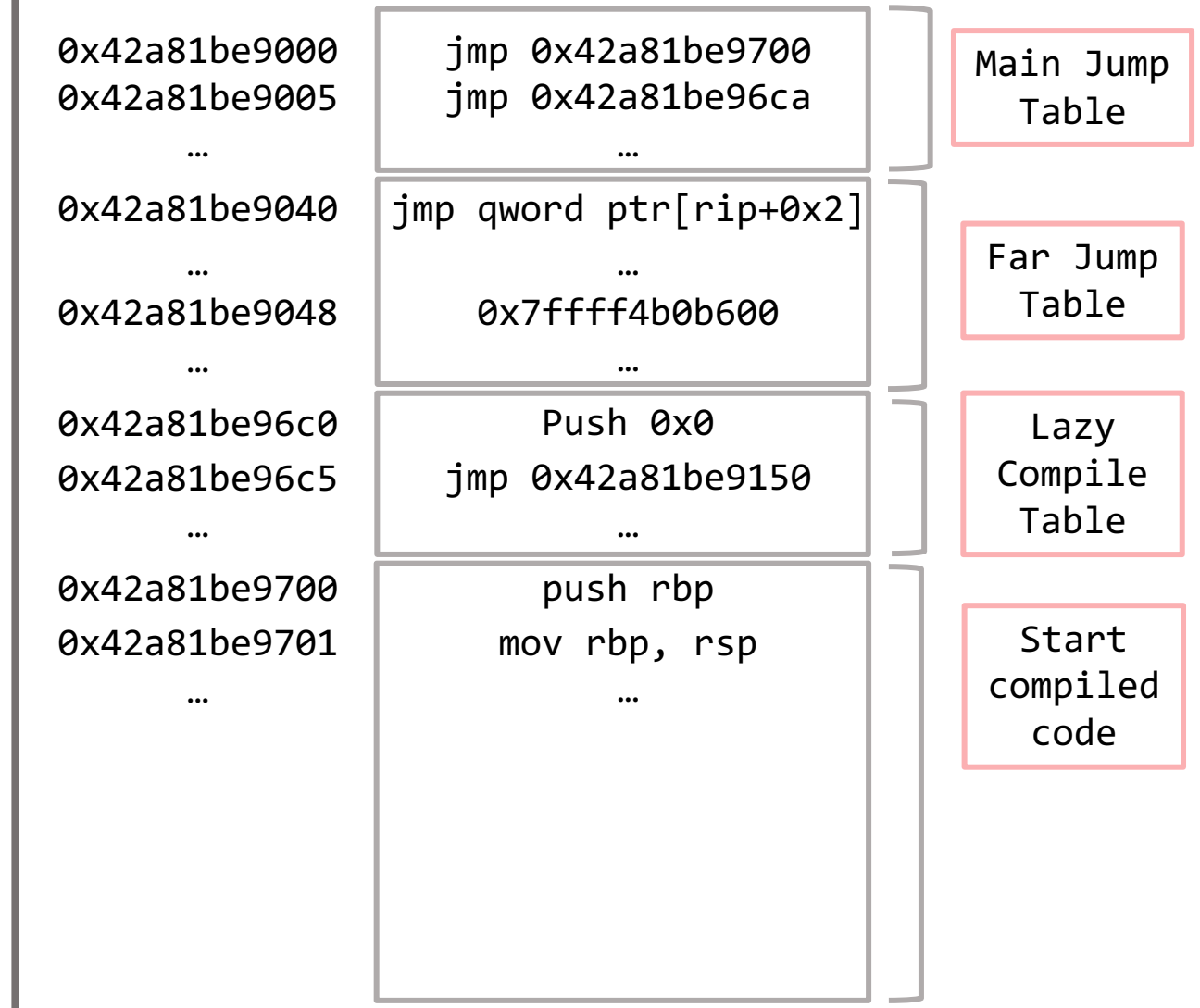
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
for (let i = 0; i < 0x10000; i++){result;}
})();
```

V8 internals

```
CompilationExecutionResult ExecuteCompilationUnits(...);
  void CompilationStateImpl::SchedulePublishCompilationResults(...);
    void CompilationStateImpl::PublishCompilationResults(...);
      WasmCode* NativeModule::PublishCode(...)
        WasmCode* NativeModule::PublishCodeLocked(
            std::unique_ptr<WasmCode> owned_code);
          void NativeModule::PatchJumpTableLocked(const
          CodeSpaceData& code_space_data, uint32_t
          slot_index, Address target);
```

WASM RWX memory



WebAssembly export functions optimization

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for (let i = 0; i < 0x10000; i++){result;}
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            std::unique_ptr<WasmCode> owned_code);
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```
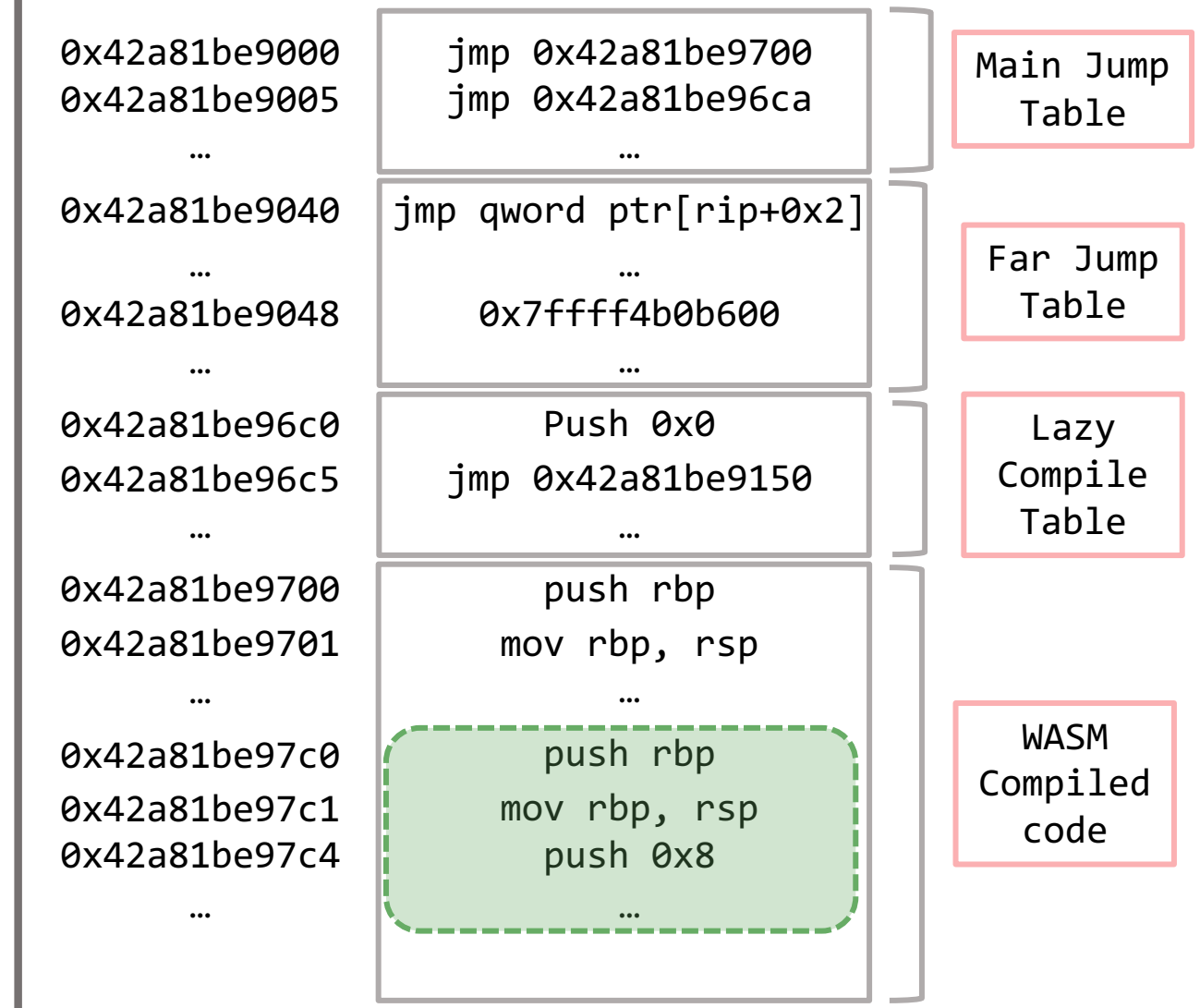

WASM RWX memory



WebAssembly export functions optimization

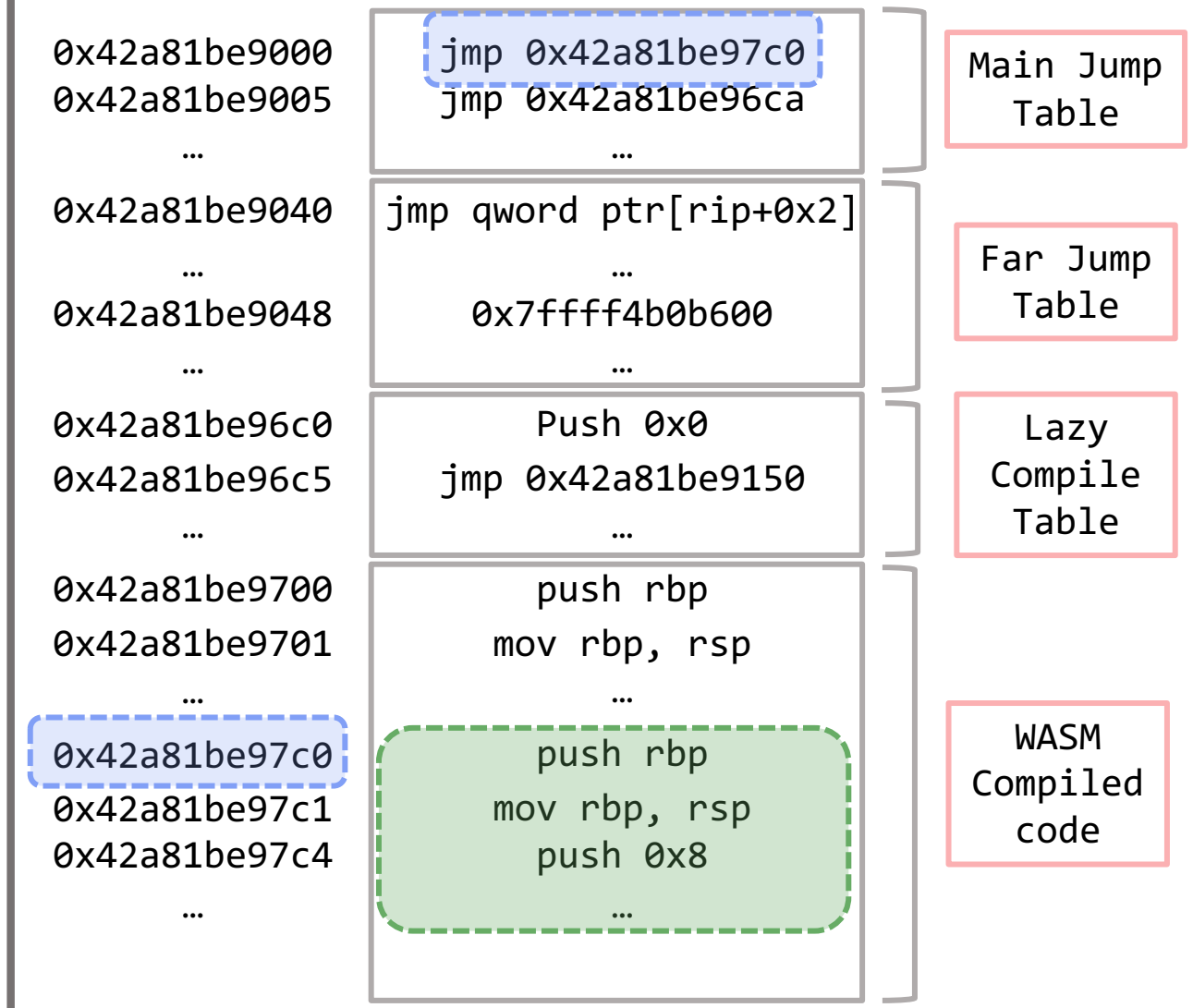
JavaScript code execution

```
(async () => {
const response = await fetch('main.wasm');
const buffer = await response.arrayBuffer();
const module = new WebAssembly.Module(buffer);
const instance = new WebAssembly.Instance(module);
const result = instance.exports.main();
console.log(result);
for (let i = 0; i < 0x10000; i++){result;}
})();
```

V8 internals

```
CompilationExecutionResult ExecuteCompilationUnits(...);
  void CompilationStateImpl::SchedulePublishCompilationResults(...);
    void CompilationStateImpl::PublishCompilationResults(...);
      WasmCode* NativeModule::PublishCode(...)
        WasmCode* NativeModule::PublishCodeLocked(
            std::unique_ptr<WasmCode> owned_code);
          void NativeModule::PatchJumpTableLocked(const
          CodeSpaceData& code_space_data, uint32_t
          slot_index, Address target);
```

WASM RWX memory



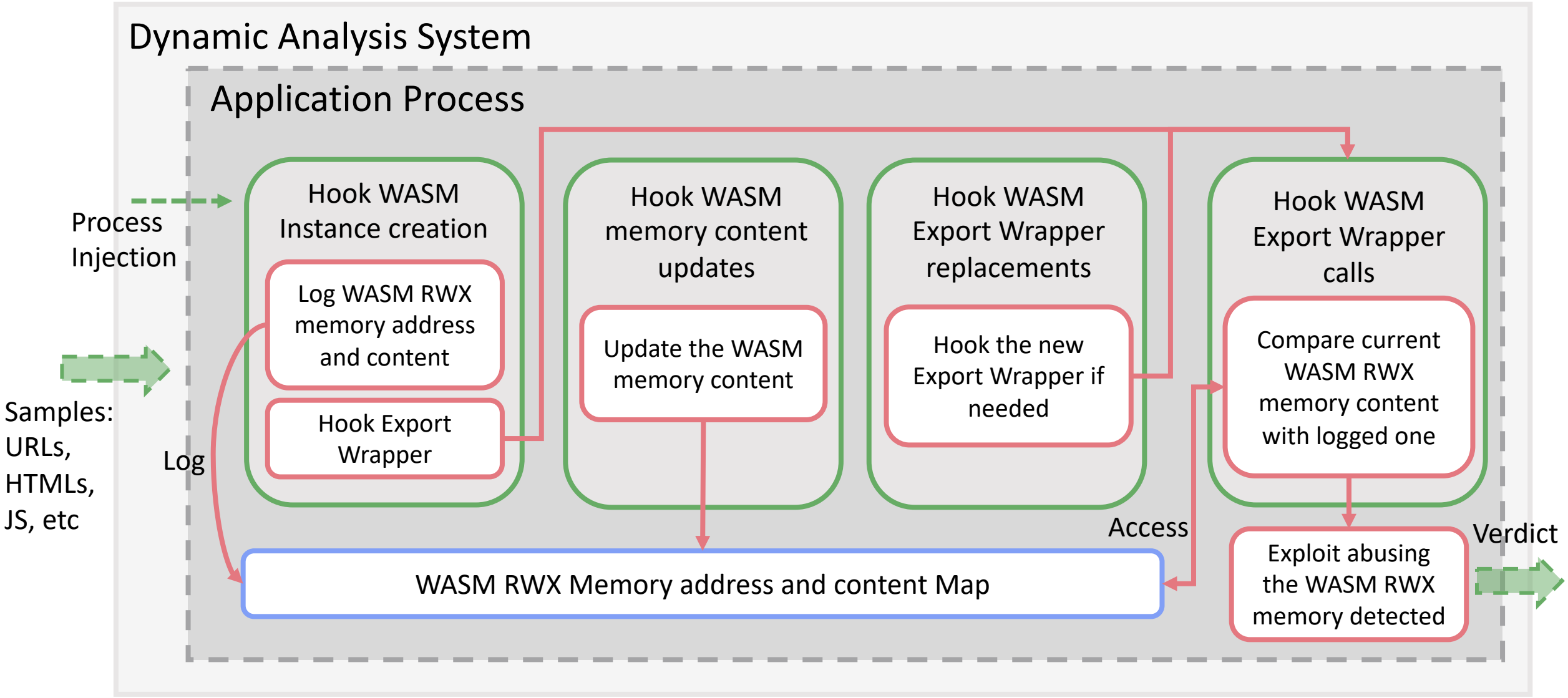
WASMGuard

What is WASMGuard ?

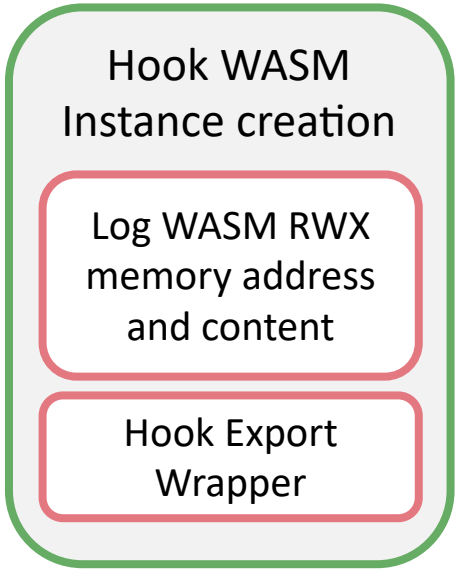
- Hook-based system for runtime detection of browser exploits abusing WASM RWX memory based on 3 detection mechanisms :
  - Detecting illegal content changes in WebAssembly RWX memory by monitoring legitimate ones;
  - Checking the integrity of WebAssembly RWX memory;
  - Detecting shellcode in the WebAssembly RWX memory;

- These mechanisms can be used independently or together to maximize detection efficiency

Detecting illegal content changes by monitoring legitimate ones



Detecting illegal content changes by monitoring legitimate ones



- Hooking v8::internal::wasm::InstantiateToInstanceObject;

```
void* hooked_InstantiateToInstanceObject(…) {
    ins = org_InstantiateToInstanceObject(…);
    rwx_mem_addr = ins->jmp_table_start;
    rwx_mem_cont = read_mem(rwx_mem_addr, …);
    update_rwx_mem(rwx_mem_addr, rwx_mem_cont, rwx_mem_map_logged);
    ret = ins;
}
```

- Hooking v8::internal::WasmExportedFunction::New;

```
void* hooked_WasmExportedFunction_New(…, Code export_wrapper) {
    JSToWasmWrapper_addr = export_wrapper->instruction_start;
    if (not_hooked(JSToWasmWrapper_addr))
        hook_function(JSToWasmWrapper_addr);
    ret = org_ WasmExportedFunction_New(…, export_wrapper);
}
```

Detecting illegal content changes by monitoring legitimate ones

Hook WASM memory content updates

Update the WASM memory content

- Hooking v8::internal::wasm::NativeModule::PublishCodeLocked;

```
void* hooked_PublishCodeLocked(..., WasmCode wasm_code) {
    rwx_mem_addr = get_base_address(wasm_code->instruction_start);
    rwx_mem_cont = read_mem(rwx_mem_addr, …);
    update_rwx_mem(rwx_mem_addr, rwx_mem_cont, rwx_mem_map_logged);
    ret = org_PublishCodeLocked(..., wasm_code);
}
```

- Hooking v8::internal::wasm::NativeModule::PatchJumpTableLocked;

```
void hooked_PatchJumpTableLocked(…, Address target) {
    rwx_mem_addr = get_base_address(target);
    rwx_mem_cont = read_mem(rwx_mem_addr, …);
    update_rwx_mem(rwx_mem_addr, rwx_mem_cont, rwx_mem_map_logged);
    ret = org_PatchJumpTableLocked(…, target);
}
```

Detecting illegal content changes by monitoring legitimate ones

Hook WASM Export Wrapper replacements

Hook the new Export Wrapper if needed

- Hooking v8::internal::(anonymous namespace)::ReplaceWrapper;

```
void hooked_ReplaceWrapper(…, Code wrapper_code) {
    JSToWasmWrapper_addr = wrapper_code->instruction_start;
    if (not_hooked(JSToWasmWrapper_addr))
        hook_function(JSToWasmWrapper_addr);
    ret = org_ReplaceWrapper(…, wrapper_code);
}
```

Detecting illegal content changes by monitoring legitimate ones

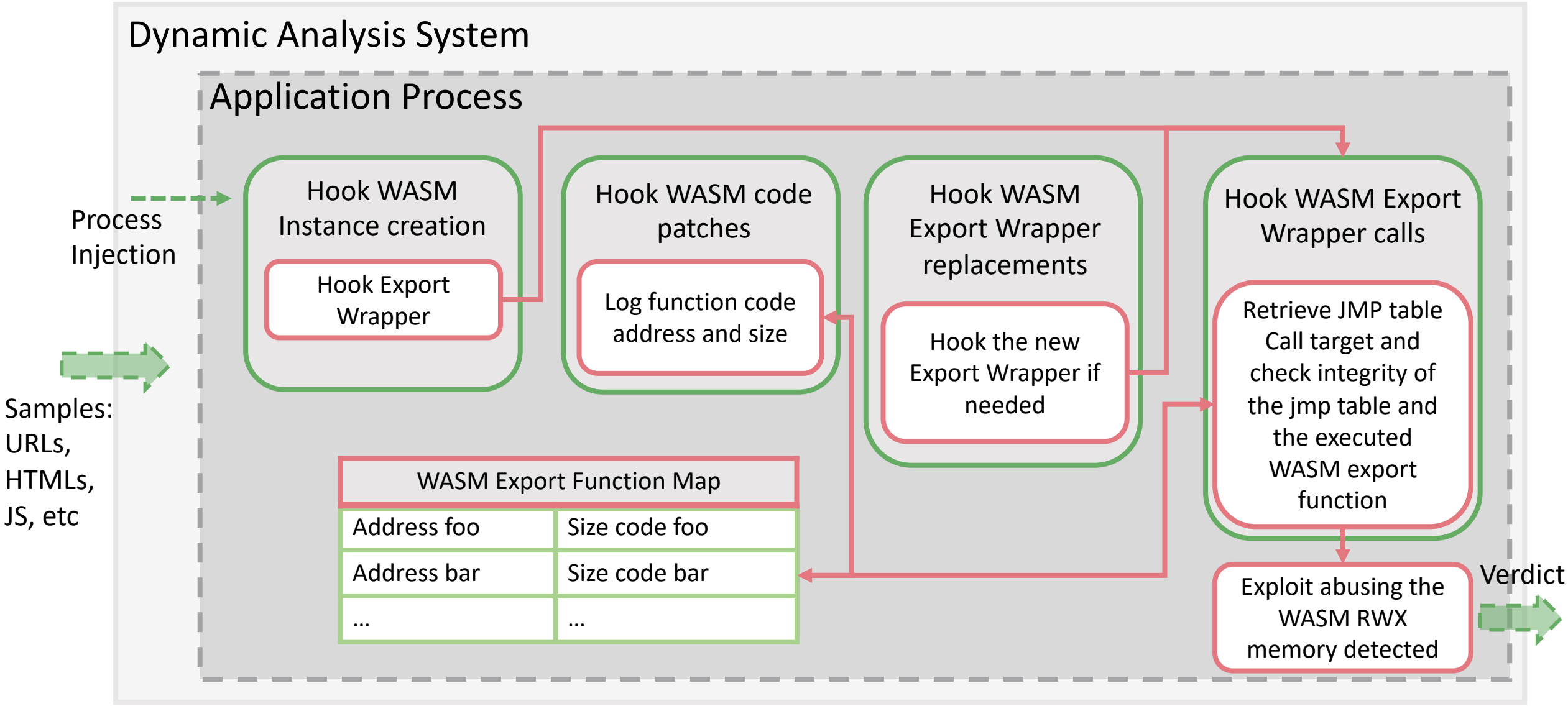
Hook WASM Export Wrapper calls

Compare current WASM RWX memory content with logged one

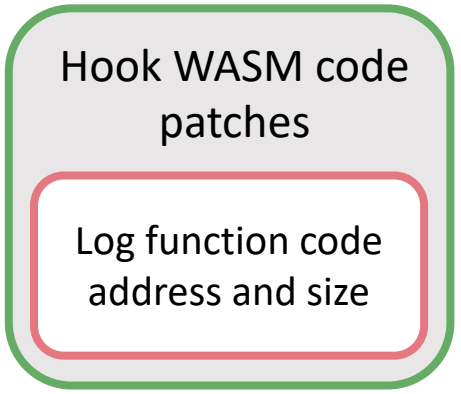
- Hooking Builtins_*JSToWasmWrapper;

```
void hooked_JSToWasmWrapper(JSFunction js_func, …) {
    rwx_mem_addr = js_func->shared_function_info->function_data->instance->jmp_table_start;
    rwx_mem_cont = read_mem(rwx_mem_addr, …);
    verdict = compare_rwx_mem(rwx_mem_addr, rwx_mem_cont, rwx_mem_map_logged);
    if (verdict) output_result(…);
    else ret = org_ JSToWasmWrapper(js_func, …);
}
```

Checking the integrity of WebAssembly RWX memory



Checking the integrity of WebAssembly RWX memory



- Hooking v8::internal::wasm::NativeModule::PublishCodeLocked;

```
void hooked_PublishCodeLocked(..., WasmCode wasm_code) {
    func_addr = wasm_code->instructions_ ;
    func_size = wasm_code->instructions_size_;
    update_export_functions_map(func_addr, func_size, export_functions_map);
    ret = org_PublishCodeLocked(wasm_code);
}
```

Checking the integrity of WebAssembly RWX memory

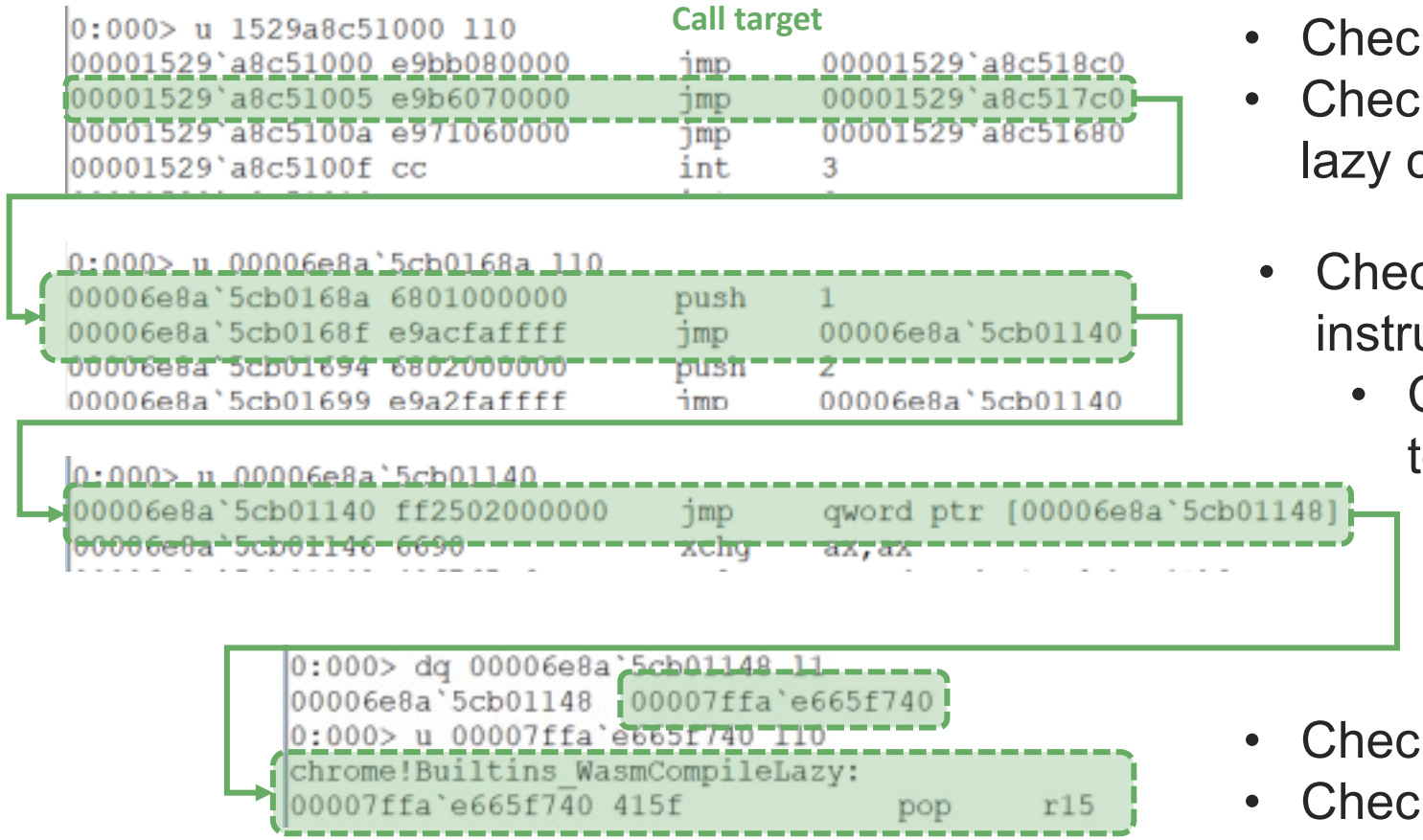
Hook WASM Export Wrapper calls

Retrieve JMP table Call target and check integrity of the jmp table and the executed WASM export function

- Hooking Builtins_*JSToWasmWrapper;

```
void hooked_JSToWasmWrapper(JSFunction js_func, …) {
    func_call_target = js_func->shared_function_info->function_data->internal_function->call_target;
    jmp_table_entry = get_jmp_table_entry_from_call_target(func_call_target);
    verdict = check_jmp_table_integrity(jmp_table_entry);
    if (verdict) output_result(…);
    else{
      func_addr = get_func_addr_from_jmp_table_entry(jmp_table_entry);
      verdict = check_func_addr_integrity(func_addr, export_functions_map);
      if (verdict) output_result(…);
      else{
        func_size = get_func_size(func_addr, export_functions_map);
        code = read_mem(func_addr, func_size);
        verdict = check_code_integrity(code);
        if (verdict) output_result(…);
        else ret = org_JSToWasmWrapper(js_func, …);
      }
   }
}
```

Checking the integrity of the first call to a WASM export function

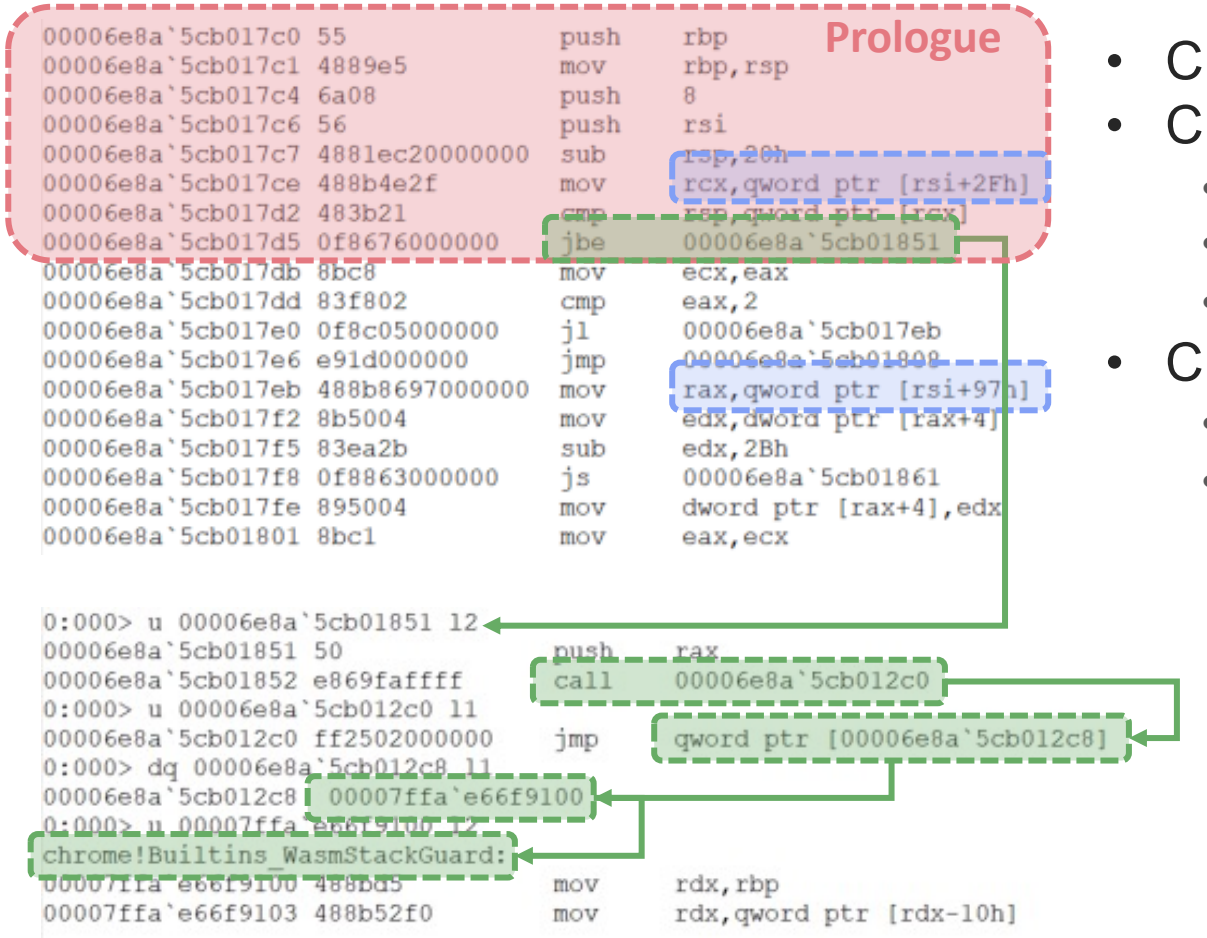


- Check the integrity of the jmp instruction;
- Check that the address to jump to is pointing to lazy compile table;

- Check the integrity of the push and jmp instructions;
  - Check that the address to jump to is pointing to the far jump table;

- Check the integrity of the jmp instruction;
- Check that the address to jump to is the address of the WasmCompileLazy function;

Checking the integrity of the call to a Liftoff compiled WASM export function



- Checking the integrity of Liftoff **prologue** instructions;
- Checking the V8 internal structure usages:
  - rsi = **WasmInstanceObject**
  - rsi+0x2f = WasmInstanceObject->**stack_limit_address**
  - rsi+0x97 = WasmInstanceObject->**tiering_budget_array**
- Checking the V8 internal function calls:
  - WasmStackGuard;
  - WasmTriggerTierUp;

Checking the integrity of the call to a Turbofan compiled WASM export function

- We apply the **same logic as Liftoff integrity checks** for Turbofan JIT compiled code BUT:
  - Turbofan can **get rid of the prologue**;
  - Turbofan can **get rid of the structures' access**;
  - Turbofan can **get rid of the internal function calls**;
- It doesn't really matter since it never happens in any existing exploit.
- But if the adversary knows our method and try to call a Turbofan compiled WASM export function to bypass our detection, we still could compute **function content hash** to ensure the integrity of the code.

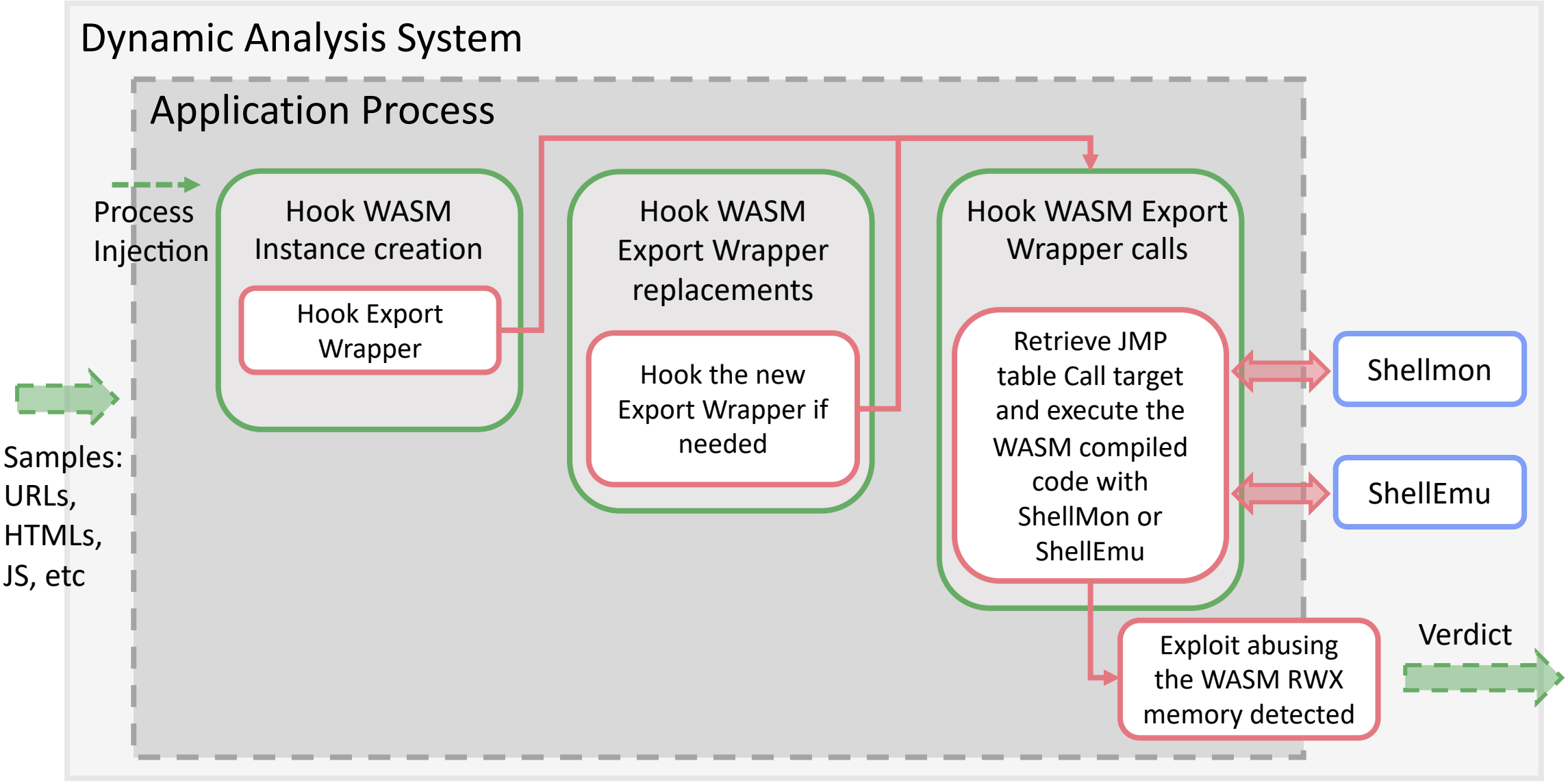
Checking the integrity of the call to a Turbofan compiled WASM export function

Example of **JIT compiled** WASM code implementing a simple addition:

```
00005fab`459e16c0 55              push    rbp
00005fab`459e16c1 4889e5          mov     rbp,rsp
00005fab`459e16c4 6a08            push    8
00005fab`459e16c6 56              push    rsi
00005fab`459e16c7 4881ec10000000  sub     rsp,10h
00005fab`459e16ce 488b4e2f        mov     rcx,qword ptr [rsi+2Fh]
00005fab`459e16d2 483b21          cmp     rsp,qword ptr [rcx]
00005fab`459e16d5 0f8620000000    jbe     00005fab`459e16fb
00005fab`459e16db 8d0c02          lea     ecx,[rdx+rax]
00005fab`459e16de 488b9e97000000  mov     rbx,qword ptr [rsi+97h]
00005fab`459e16e5 8b7b08          mov     edi,dword ptr [rbx+8]
00005fab`459e16e8 83ef1e          sub     edi,1Eh
00005fab`459e16eb 0f8819000000    js      00005fab`459e170a
00005fab`459e16f1 897b08          mov     dword ptr [rbx+8],edi
00005fab`459e16f4 8bc1            mov     eax,ecx
00005fab`459e16f6 488be5          mov     rsp,rbp
00005fab`459e16f9 5d              pop     rbp
00005fab`459e16fa c3              ret
```

```
00005fab`459e1740 55              push    rbp
00005fab`459e1741 4889e5          mov     rbp,rsp
00005fab`459e1744 6a08            push    8
00005fab`459e1746 56              push    rsi
00005fab`459e1747 03c2            add     eax,edx
00005fab`459e1749 488be5          mov     rsp,rbp
00005fab`459e174c 5d              pop     rbp
00005fab`459e174d c3              ret
```

Detecting shellcode in the WASM RWX memory region



Detecting shellcode in the WASM RWX memory region

Hook WASM Export Wrapper calls

Retrieve JMP table Call target and execute the WASM compiled code with ShellMon or ShellEmu

- Hooking Builtins_*JSToWasmWrapper;

```
void hooked_JSToWasmWrapper(JSFunction js_func, …) {
    func_call_target = js_func->shared_function_info->function_data->internal_function->call_target;
    rwx_mem_addr = get_mem_region_base_address(func_call_target);
    rwx_mem_size = get_mem_region_size(rwx_mem_addr);
    code = read_mem(func_call_target, (rwx_mem_size-(func_call_target-rwx_mem_addr));
    sm_verdict = shellmon(code);
    se_verdict = shellemu(code);
    if (sm_verdict or se_verdict) output_result(…);
    else ret = org_JSToWasmWrapper(js_func, …);
}
```

ShellMon

- ShellMon is a shellcode detection system taking as an input a piece of bytecode, executing it in the memory and monitoring its behaviors in a lightweight sandbox.
- Main features:
  - Determine shellcode entry point;
  - Use its fast and minimalist hook engine to trace sensible Windows API calls;

ShellEmu

- Shellcode detection tool based on Qiling emulation Engine.
- Main features:
  - ASM level detection:
    - TEB/PEB Structures access
    - DLLs access: export table, name table, function table, etc.
    - GetPC techniques: Call/Pop, FPU instructions, x64 LEA/Relative addressing, etc.
    - Self decoding
  - API level detection:
    - Sensible Windows API calls

Demo

Summary

- Three exploitation detection mechanisms focusing the WASM RWX memory in WASMGuard.
- The ideas also work for other RWX memory focused DEP/NX bypass techniques.
- The exploitation technique focused exploit detection mechanism rocks!
- A lot more research focusing on the detection of exploitation techniques are needed.

Q&A

References

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- [3] Loading WebAssembly modules efficiently (Mathias Bynens) 2018: https://web.dev/loading-wasm/