Deobfuscation in the Age of Agentic Reverse Engineering

Tim Blazytko

@mr_phrazer
synthesis.to
tim@blazytko.to

Nicolò Altamura

@nicolodev
nicolo.dev
altamura@nicolo.dev

About Us

- Tim Blazytko
  - independent trainer & consultant
  - PhD in binary program analysis & reverse engineering
  - focus on (de)obfuscation & automation

- Nicolò Altamura
  - security engineer at emproof
  - reverse engineering & program analysis
  - code deobfuscation by night

deobfuscation needs to **catch up**

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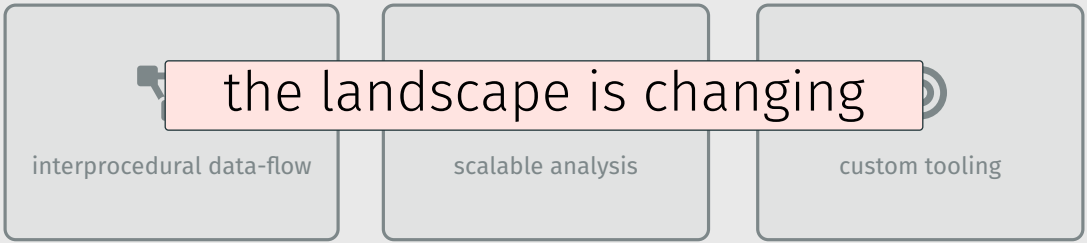
interprocedural data-flow

scalable analysis

custom tooling

deobfuscation needs to **catch up**

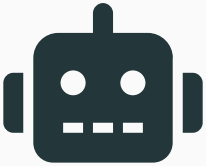


Today

Agentic Reverse Engineering

Agentic deobfuscation at scale

Anti-agentic obfuscation



Agentic Reverse Engineering

A Shift in Reverse Engineering

manual

disassembler

+ analyst

A Shift in Reverse Engineering

manual

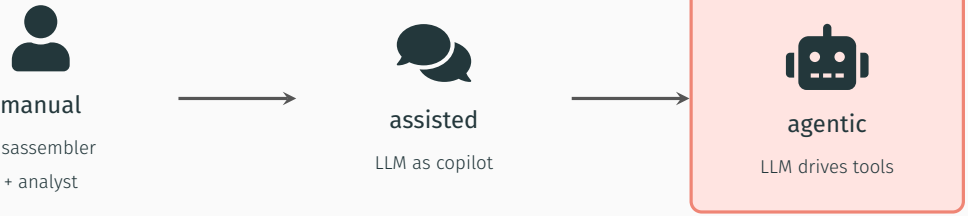
disassembler

+ analyst

assisted

LLM as copilot

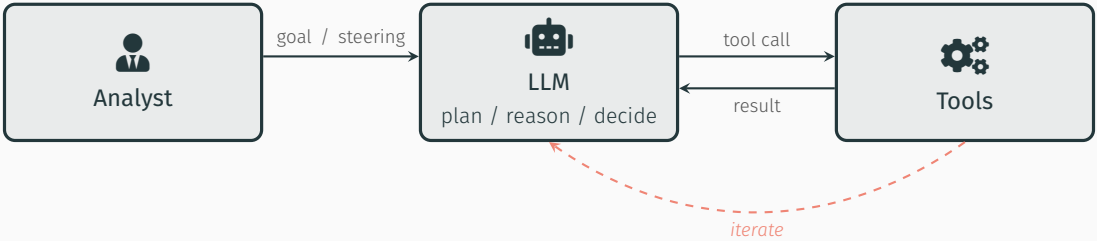
A Shift in Reverse Engineering



A Shift in Reverse Engineering

The Agent Loop

The Agent Loop



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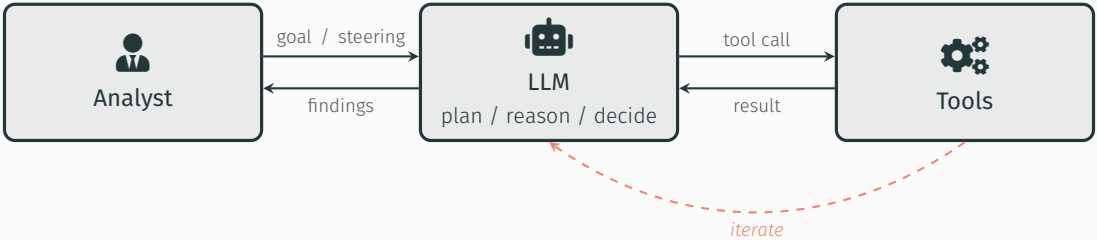

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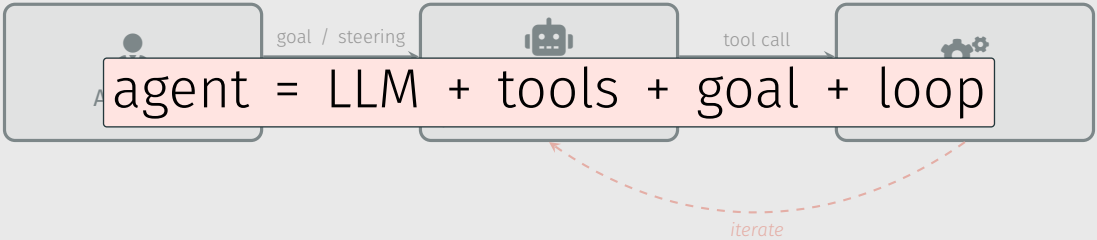
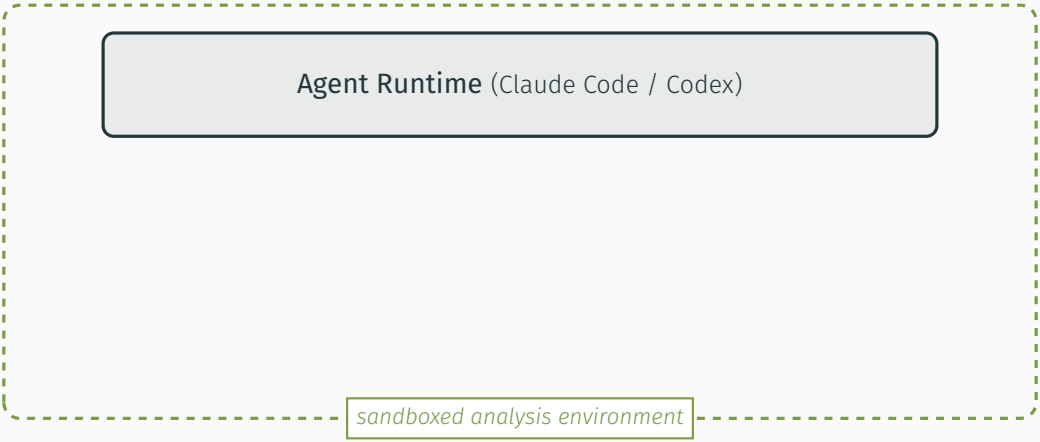


Our Analysis Environment



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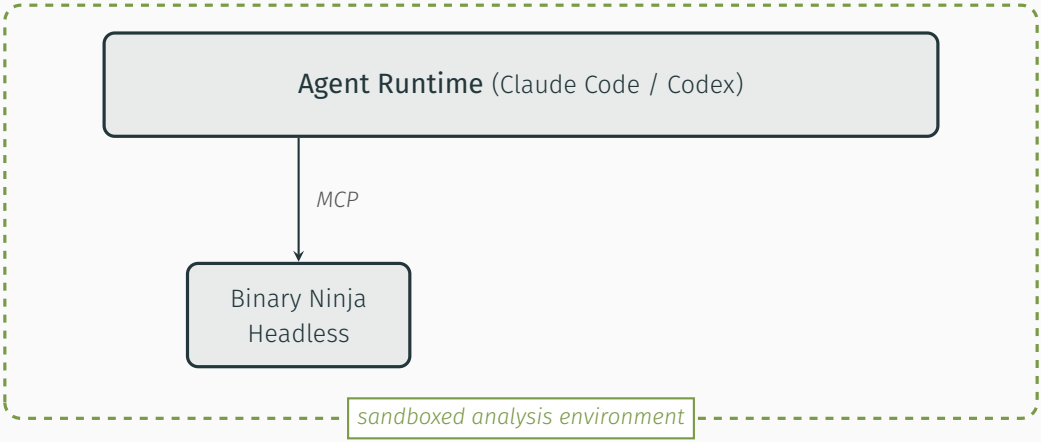

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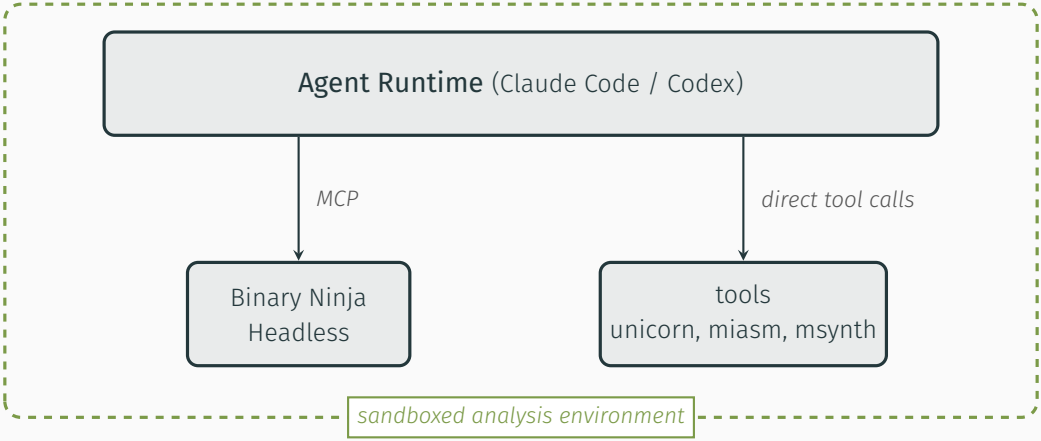

Agentic Deobfuscation at Scale

Experiment Setup

- experiments run in **May/June 2026**
- **frontier models**: Codex (GPT-5.5) & Claude Code (Opus 4.8)
- the agent was given **problem-specific tooling**, frameworks & examples
- workflow **guided** by a **seasoned reverse engineer**

Case Study

Virtual Machines

Virtual Machine

```
mov ecx, [esp+4]
xor eax, eax
mov ebx, 1

__secret_ip:
  mov  edx, eax
  add  edx, ebx
  mov  eax, ebx
  mov  ebx, edx
  loop __secret_ip

mov eax, ebx
ret
```

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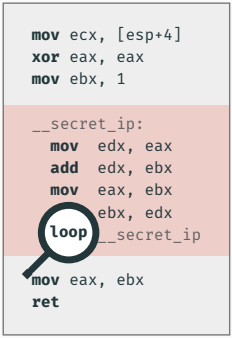
Virtual Machine



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mov eax, ebx
ret
```

made-up instruction set

```
__bytecode:    vld  r1
  vld  r0      vpop r2
  vpop r1      vldi #1
  vld  r2      vld  r3
  vld  r1      vsub r3
  vadd r1      vld  #0
  vld  r2      veq  r3
  vpop r0      vbr0 #-0E
```

Virtual Machine

```
mov ecx, [esp+4]
xor eax, eax
mov ebx, 1

__secret_ip:
  push __bytecode
  call vm_entry



mov eax, ebx
ret
```

made-up instruction set

```
__bytecode:
  db 54 68 69 73 20 64 6f
  db 65 73 6e 27 74 20 6c
  db 6f 6f 6b 20 6c 69 6b
  db 65 20 61 6e 79 74 68
  db 69 6e 67 20 74 6f 20
  db 6d 65 2e de ad be ef
```

Virtual Machine

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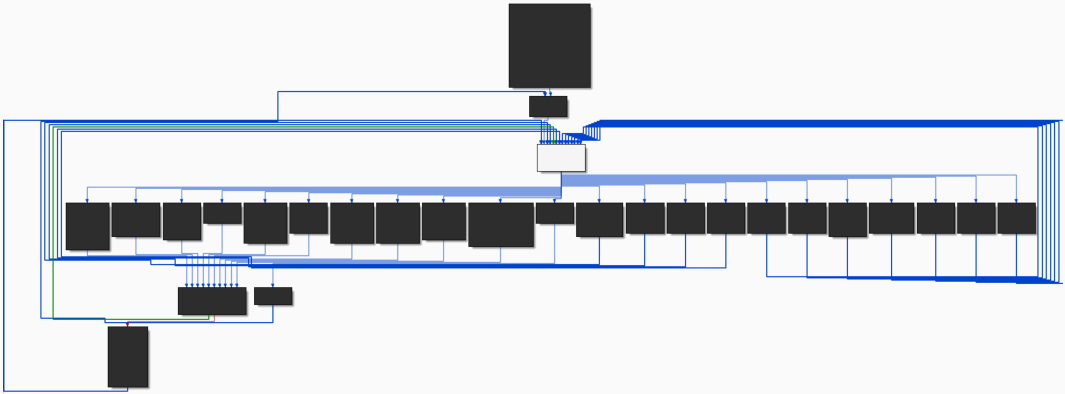
  db 65 20 61 6e 79 74 68
  d   e 67 20 74 6f 20
  d   5 2e de ad be ef
```

Simple VM

VM Architecture



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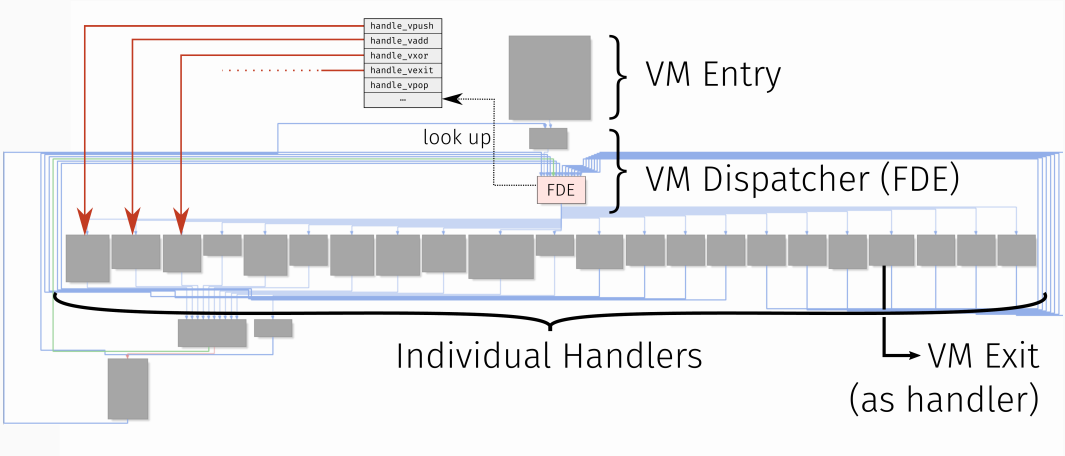

VM Deobfuscation: Reconstruct High-Level Code from Bytecode

understand the VM structure

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understand the VM structure $\rightarrow$ **write a VM disassembler**

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```
0a 01 02  0b 01 05
```

VM Deobfuscation: Reconstruct High-Level Code from Bytecode

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0a 01 02  0b 01 05
```

```
add
```

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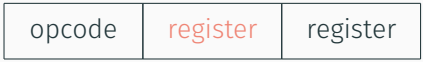
understand the VM structure → **write a VM disassembler** → reconstruct high-level code




```
0a 01 02  0b 01 05
```

```
add r1
```

VM Deobfuscation: Reconstruct High-Level Code from Bytecode

understand the VM structure → **write a VM disassembler** → reconstruct high-level code


```
0a 01 02  0b 01 05
```

```
add r1, r2
```

VM Deobfuscation: Reconstruct High-Level Code from Bytecode

understand the VM structure → **write a VM disassembler** → reconstruct high-level code


```
0a 01 02  0b 01 05
```

```
add r1, r2
mul
```

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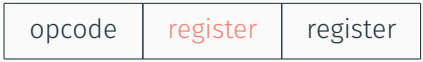
understand the VM structure → **write a VM disassembler** → reconstruct high-level code

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VM Deobfuscation: Reconstruct High-Level Code from Bytecode

understand the VM structure → **write a VM disassembler** → reconstruct high-level code


```
0a 01 02  0b 01 05
```

```
add r1, r2
mul r1, r5
```

→ high-level: `(r1 + r2) * r5`

Agentic VM Deobfuscation

Given the obfuscated function `f`, deobfuscate it and reconstruct the high-level code.

Agentic VM Deobfuscation

Given the obfuscated function `f`, deobfuscate it and reconstruct the high-level code.

- discovered the VM architecture
- recovered the handler semantics
- wrote a VM disassembler
- reconstructed the high-level code:

```
uint64_t f(uint64_t r1, uint64_t r2, uint64_t r5)
  { return (r1 + r2) * r5; }
```

Agentic VM Deobfuscation

Given the obfuscated function `f`, deobfuscate it and reconstruct the high-level code.

- discovered the VM architecture
- recover
- wrote a VM disassembler
- reconstructed the high-level code:

essentially a one-shot

```
uint64_t f(uint64_t r1, uint64_t r2, uint64_t r5)
  { return (r1 + r2) * r5; }
```

Commercial VM Obfuscator

Production-Grade Hardening

decentralized dispatch

cannot enumerate handlers

Production-Grade Hardening

decentralized dispatch

cannot enumerate handlers

handler duplication

thousands of diversified handlers

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decentralized dispatch

cannot enumerate handlers

handler duplication

thousands of diversified handlers

bytecode encryption

control-flow-dependent rolling key

Production-Grade Hardening

decentralized dispatch

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handler duplication

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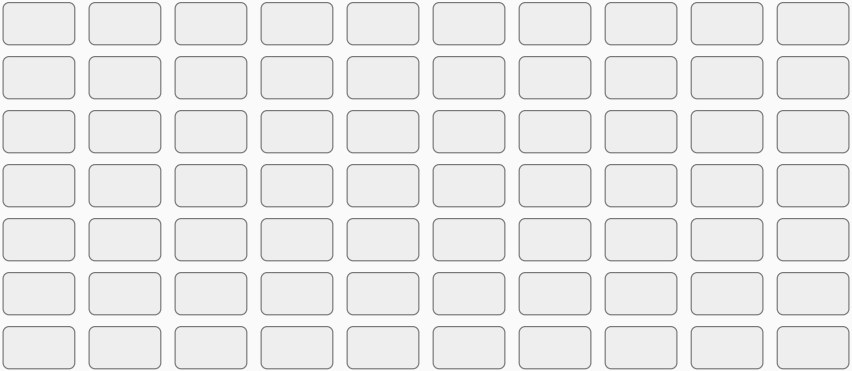
bytecode encryption

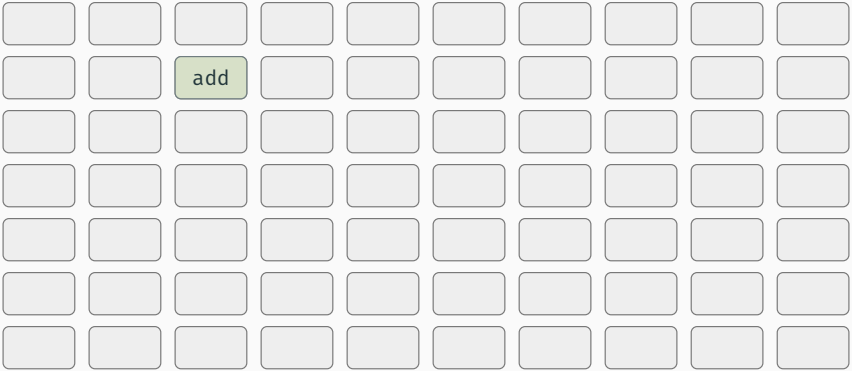
control-flow-dependent rolling key

enforces **large-scale automation** and **following the execution flow**

Handler Duplication



Handler Duplication



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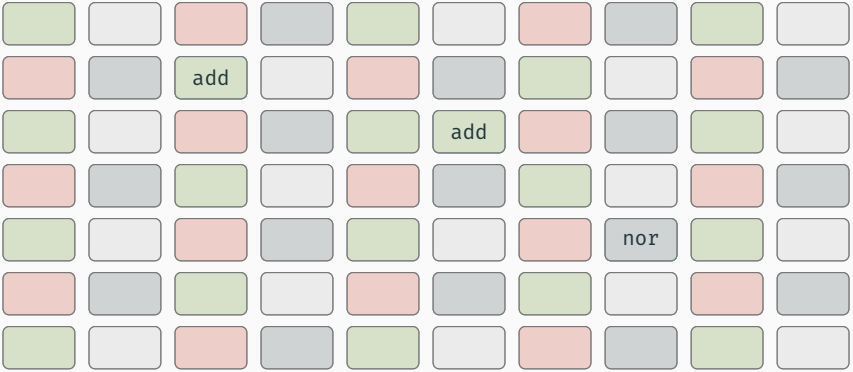
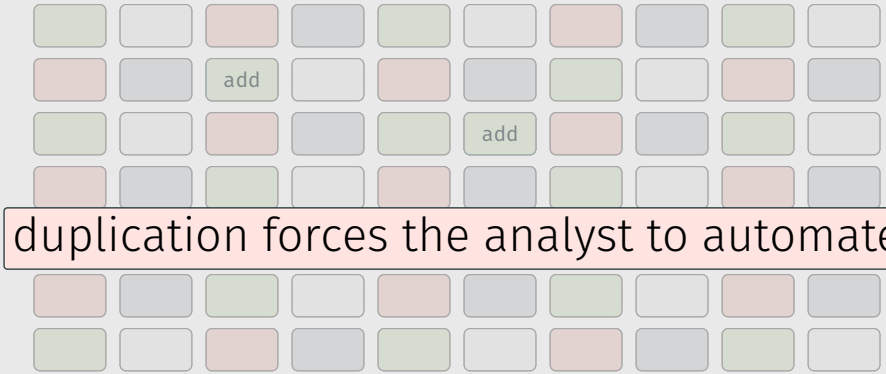


~12,000 diversified handlers · ~30 families

Handler Duplication



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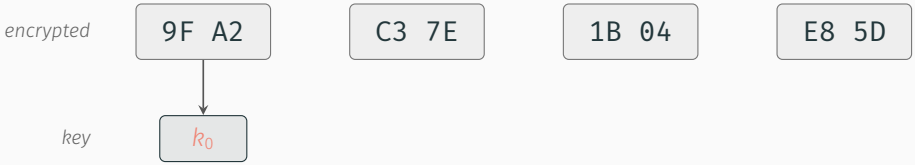
Control-Flow-Sensitive Bytecode Encryption

encrypted

Control-Flow-Sensitive Bytecode Encryption



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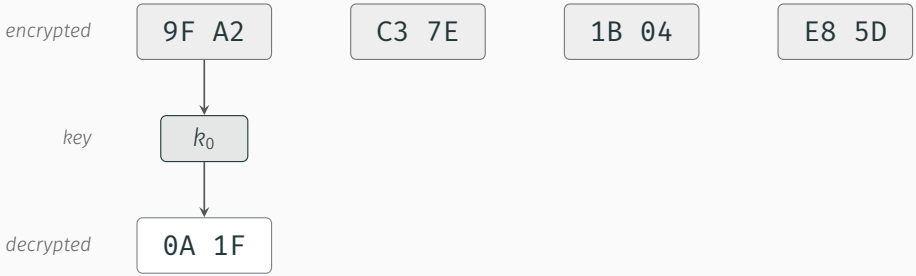

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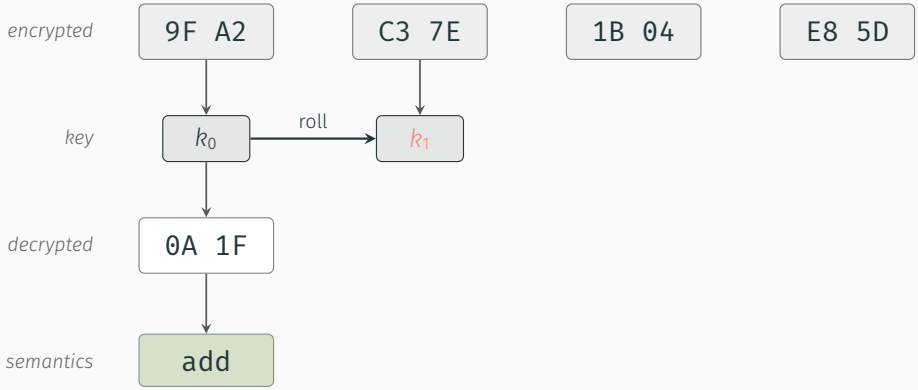

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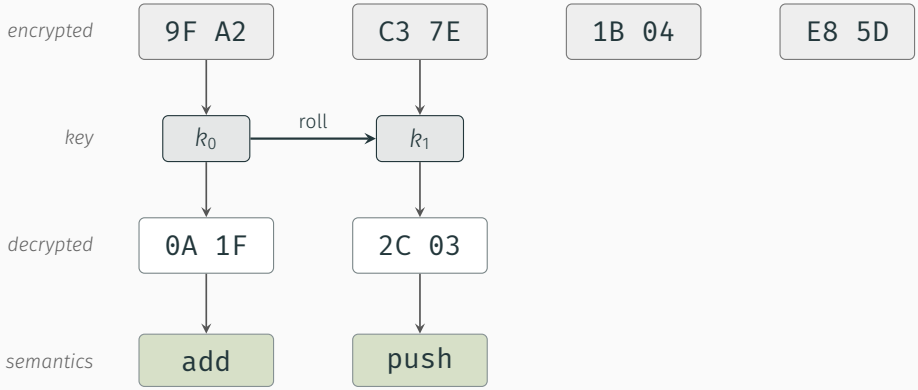

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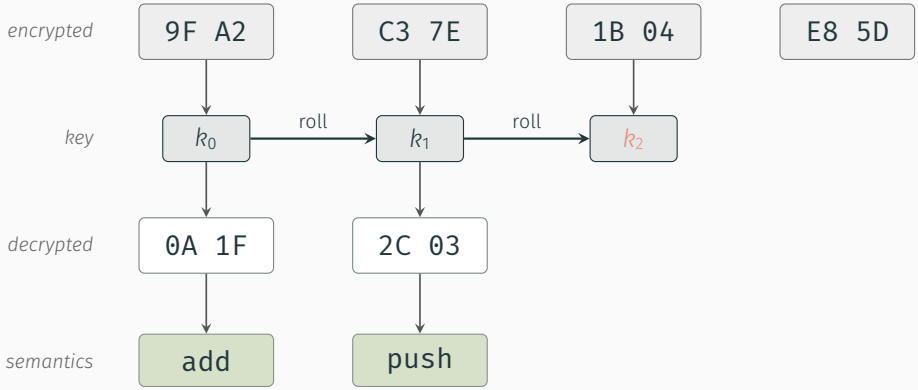

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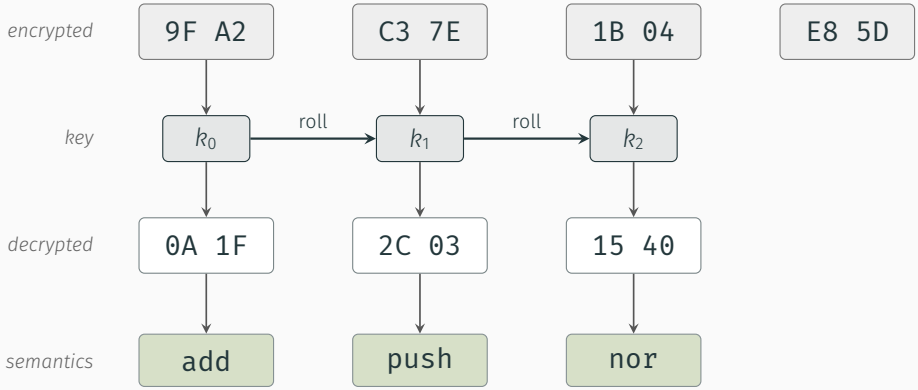

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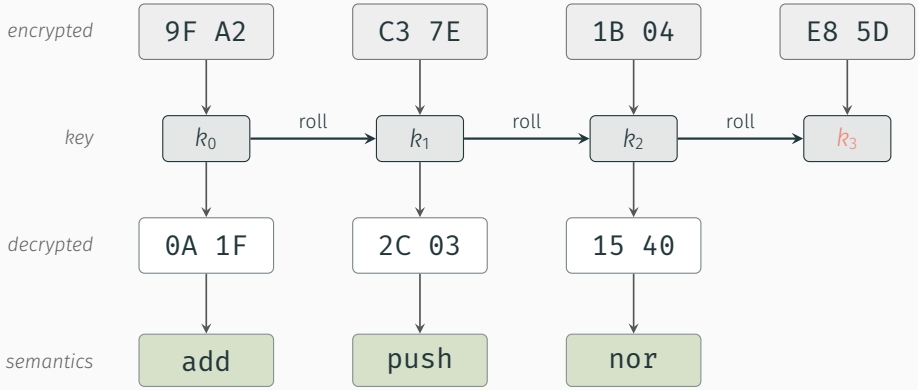

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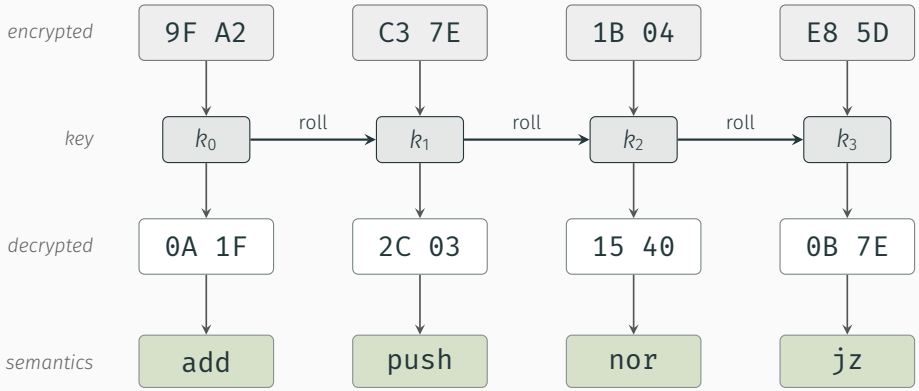

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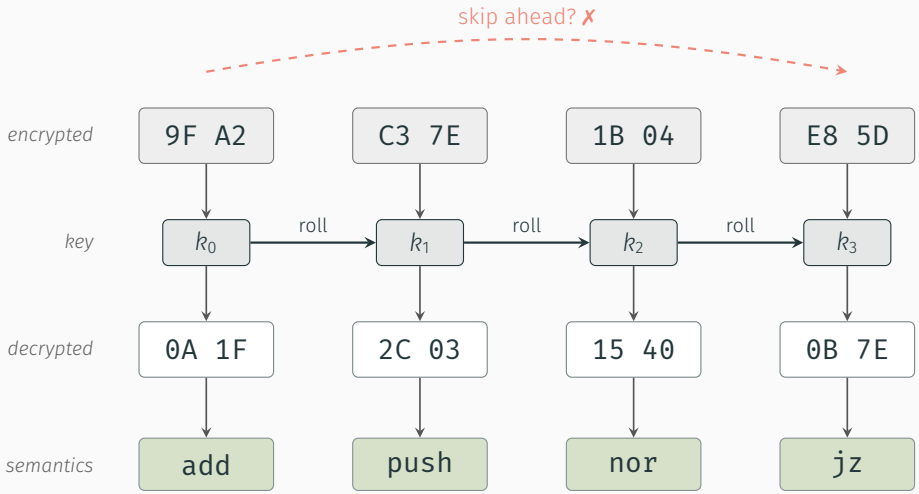

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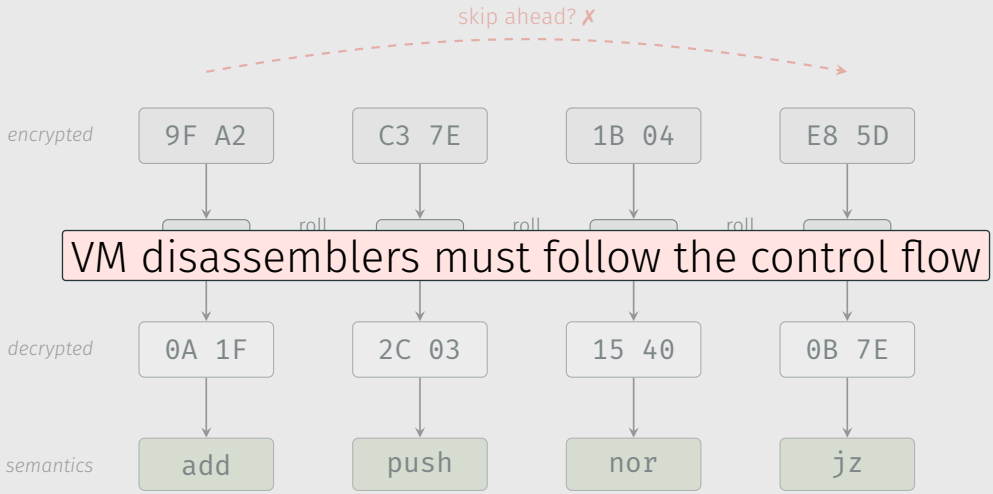

Agentic VM Deobfuscation Attempt

Given the obfuscated function `f`, deobfuscate it and reconstruct the high-level code.

Agentic VM Deobfuscation Attempt

Given the obfuscated function `f`, deobfuscate it and reconstruct the high-level code.

producing nothing usable after several hours of work

exploration /
path discovery

entry → vmexit

Deobfuscation of Commercial VM Obfuscators

exploration / path discovery

entry → vmexit

→

handler semantics

lift each handler

Deobfuscation of Commercial VM Obfuscators

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per-handler artifacts

VM disassembly

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entry → vmexit

→

handler semantics

lift each handler

→

per-handler artifacts

VM disassembly

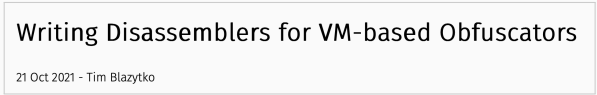
→

reconstruction

original code

common approaches: symbolic execution, LLVM-based lifting

Agentic Setup & Resources

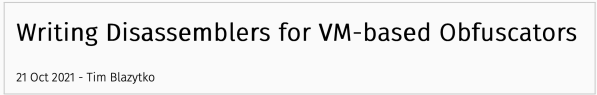


knowledge

how to write a symbolic-execution-based VM disassembler

`synthesis.to/2021/10/21/vm_based_obfuscation.html`

Agentic Setup & Resources



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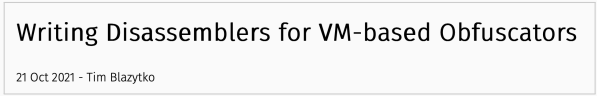
scripts templates for SE-based disassemblers (from the blog post)

Agentic Setup & Resources



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scripts

templates for SE-based disassemblers (from the blog post)

tools

unicorn → emulation

miasm → symbolic execution

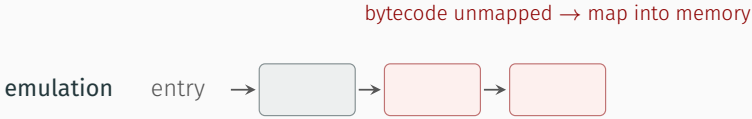
msynth → MBA simplification

Agentic Deobfuscation Workflow

emulation entry →

Agentic Deobfuscation Workflow

Agentic Deobfuscation Workflow



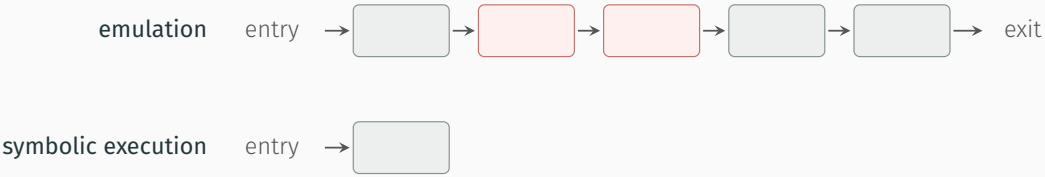
Agentic Deobfuscation Workflow

Agentic Deobfuscation Workflow

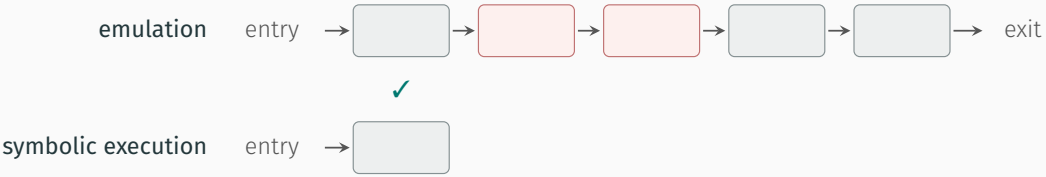
Agentic Deobfuscation Workflow

emulation as ground truth

Agentic Deobfuscation Workflow



Agentic Deobfuscation Workflow



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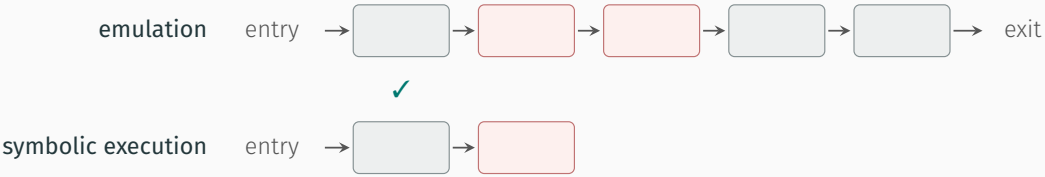

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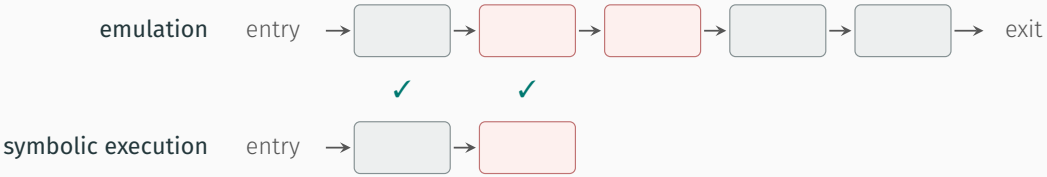

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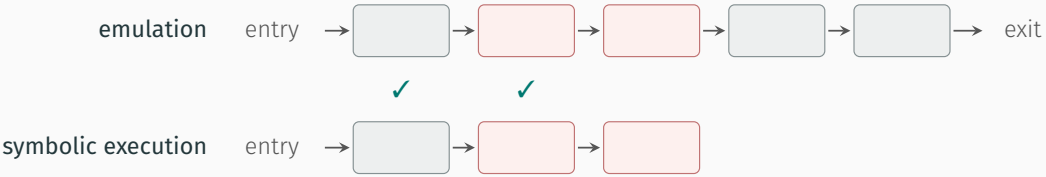
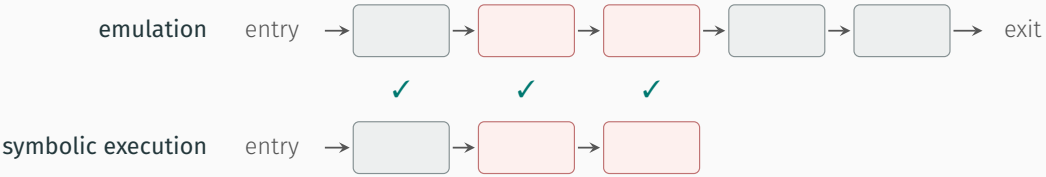
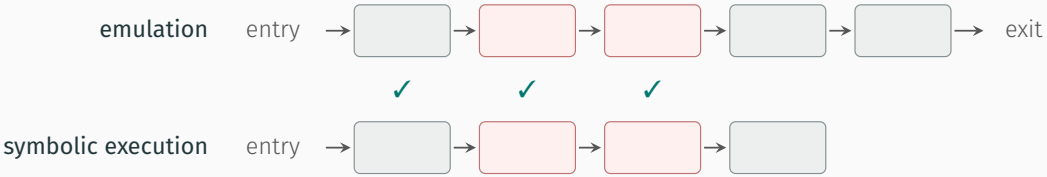


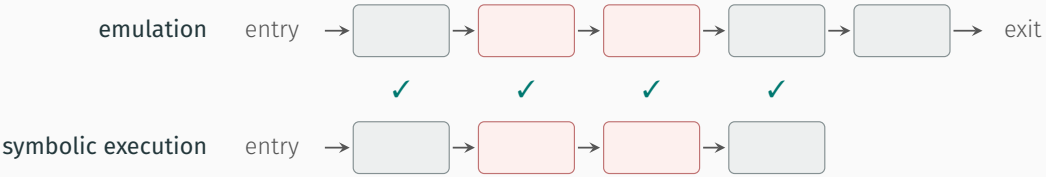
Agentic Deobfuscation Workflow



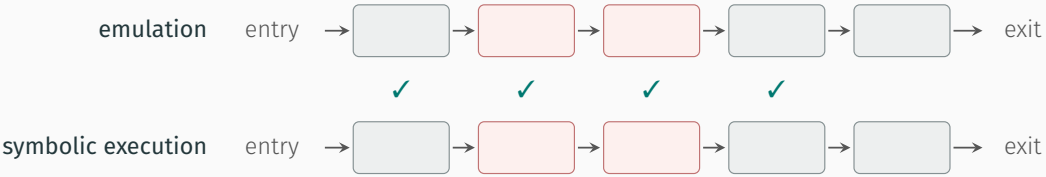
Agentic Deobfuscation Workflow



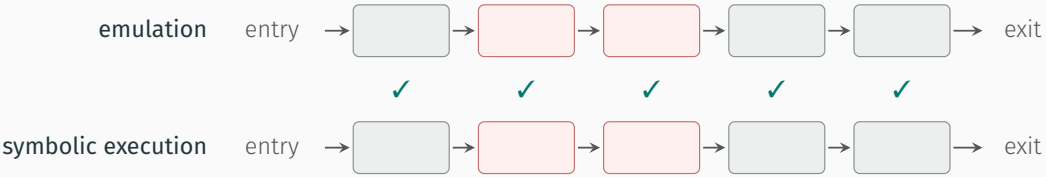
Agentic Deobfuscation Workflow



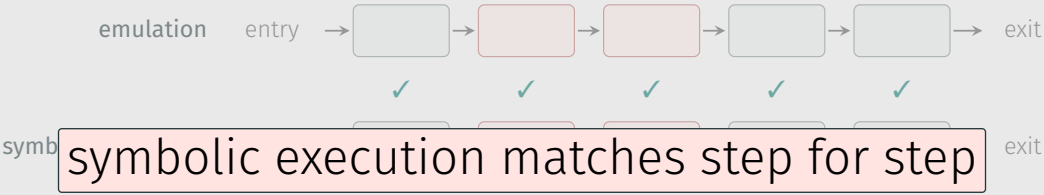
Agentic Deobfuscation Workflow



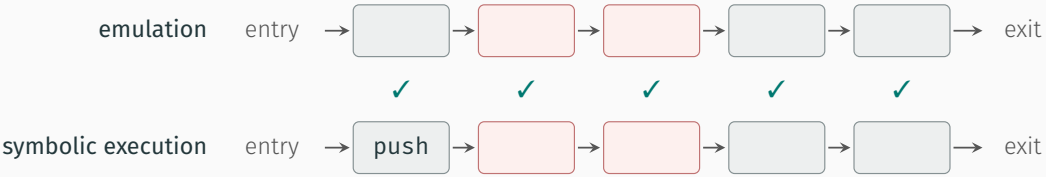
Agentic Deobfuscation Workflow



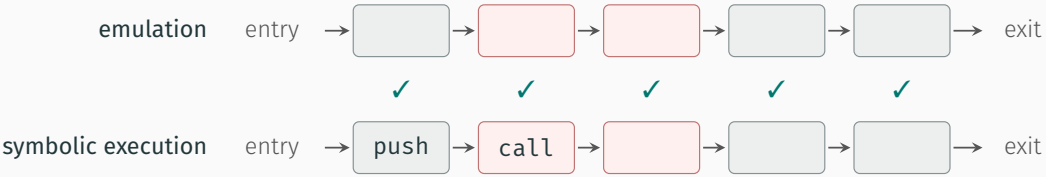
Agentic Deobfuscation Workflow



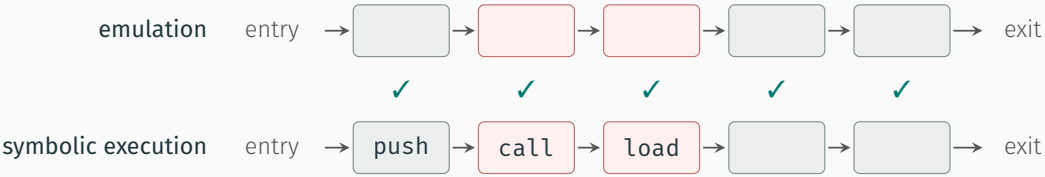
Agentic Deobfuscation Workflow



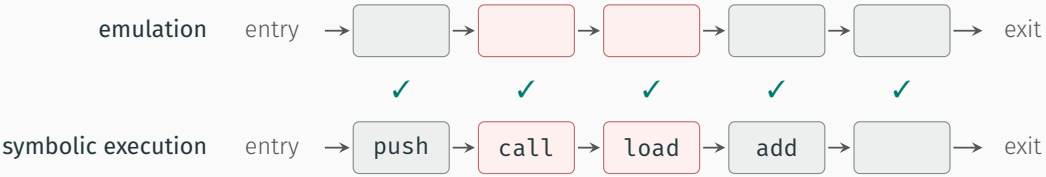
Agentic Deobfuscation Workflow



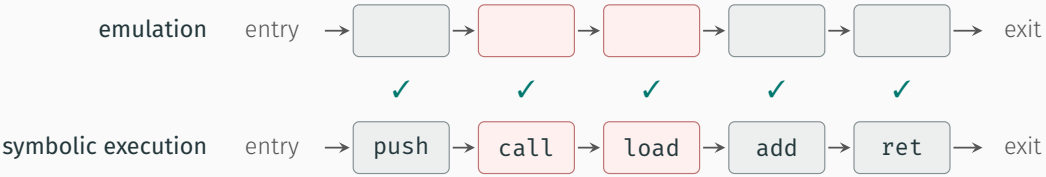
Agentic Deobfuscation Workflow



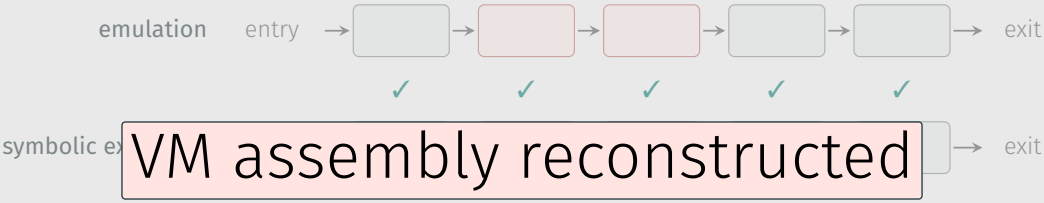
Agentic Deobfuscation Workflow



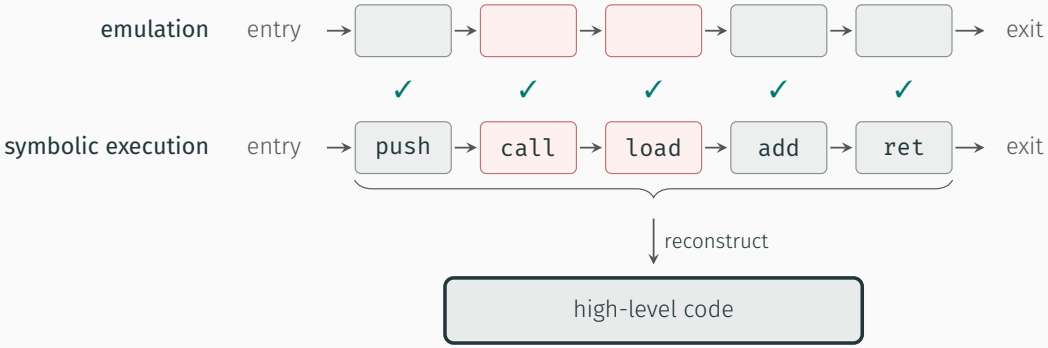
Agentic Deobfuscation Workflow



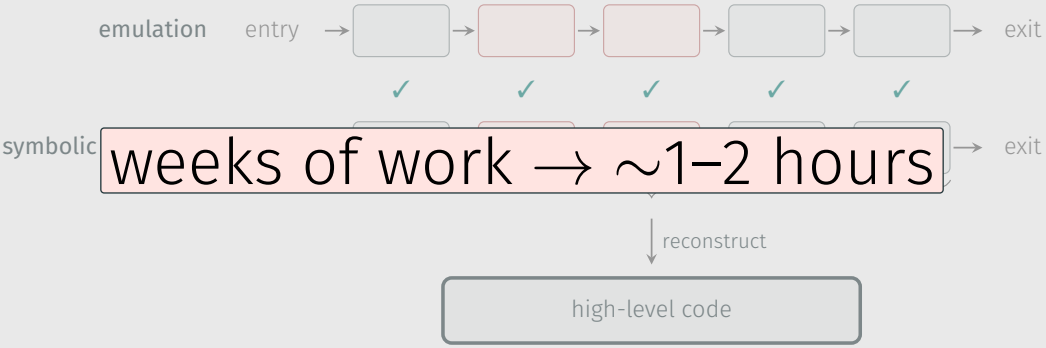
Agentic Deobfuscation Workflow



Agentic Deobfuscation Workflow



Agentic Deobfuscation Workflow

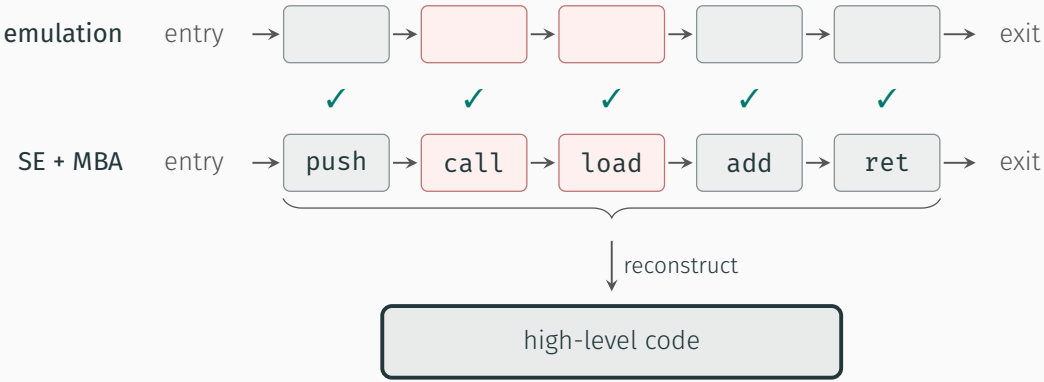


Anti Cheat

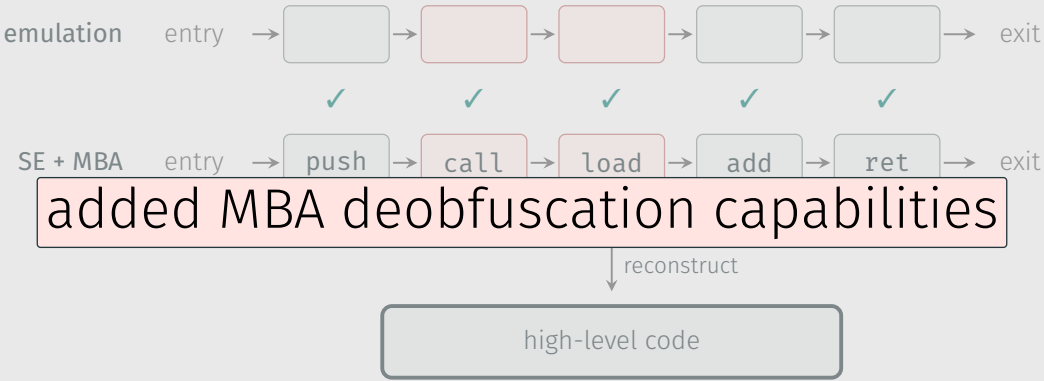
Kernel-Level Anti-Cheat

- custom in-house VM
- direct-threaded dispatch
- rolling-key bytecode encryption
- MBA-obfuscated handlers

Agentic Deobfuscation Workflow



Agentic Deobfuscation Workflow



Deobfuscation of the Anti-Cheat VM

shared VM interpreter

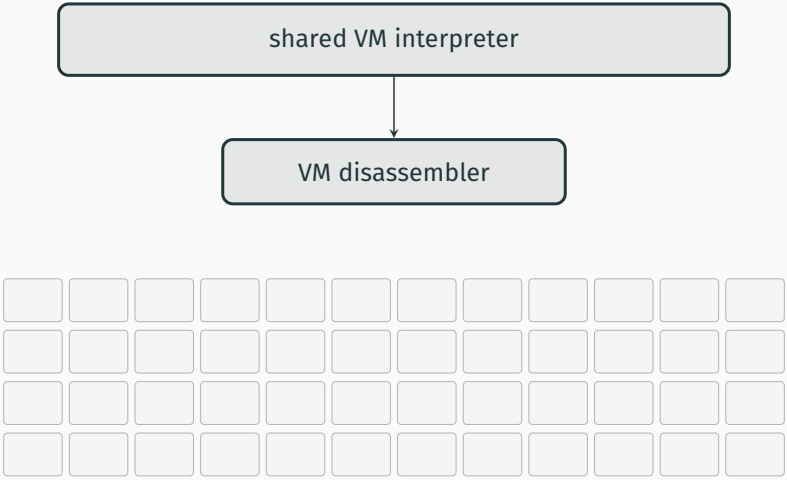
Deobfuscation of the Anti-Cheat VM

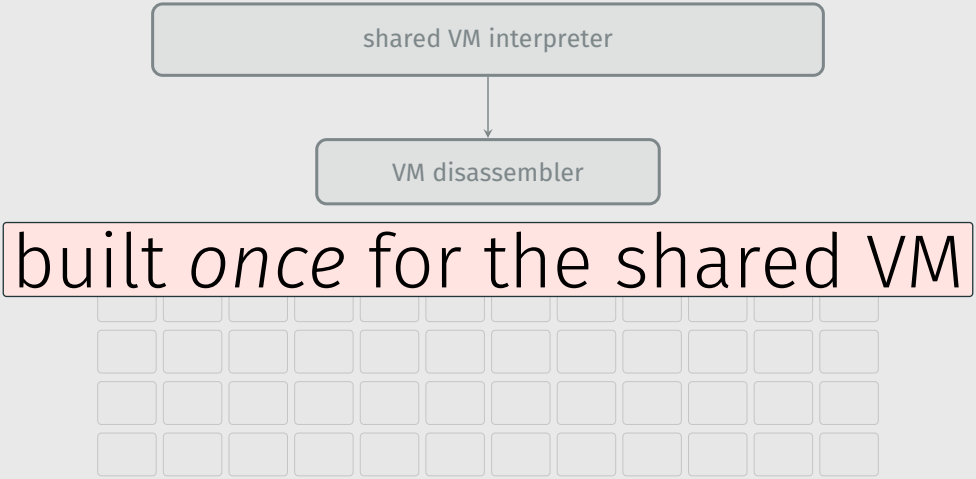
shared VM interpreter

shared VM interpreter

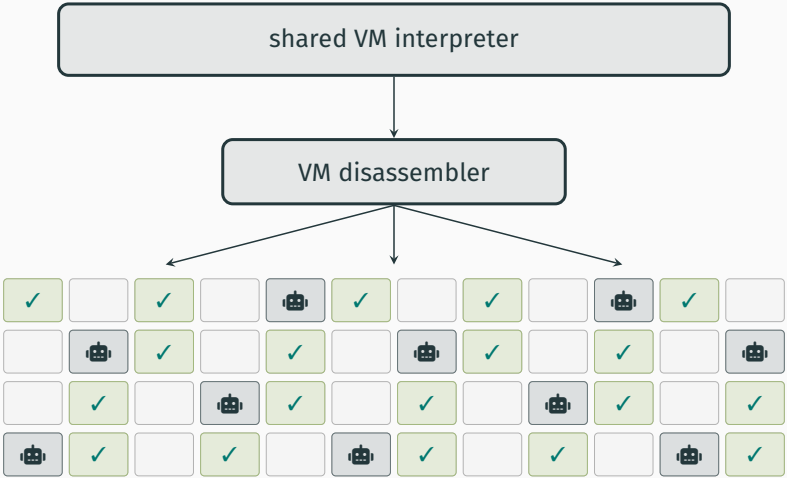
shared by 1,023 VM-entry stubs

Deobfuscation of the Anti-Cheat VM

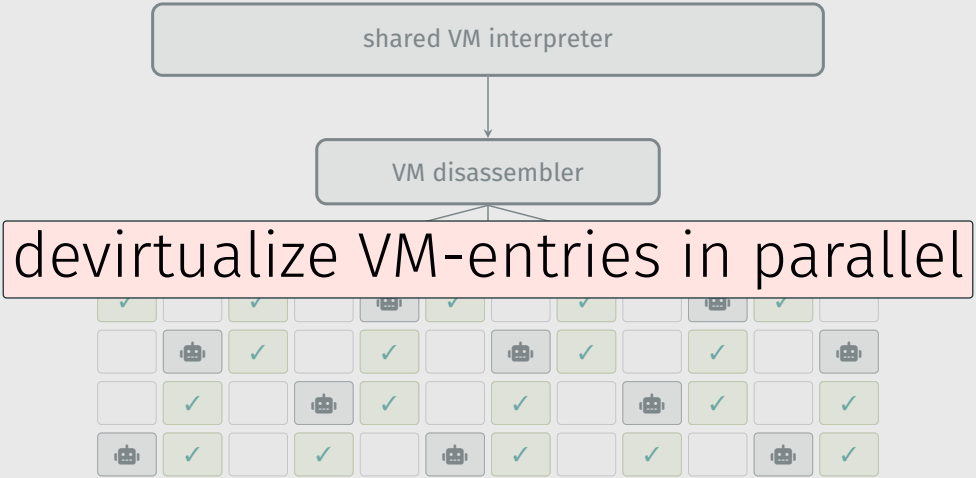



shared VM interpreter
VM disassembler
built *once* for the shared VM

Deobfuscation of the Anti-Cheat VM



Deobfuscation of the Anti-Cheat VM



Analysis Results: Most of the Driver Recovered

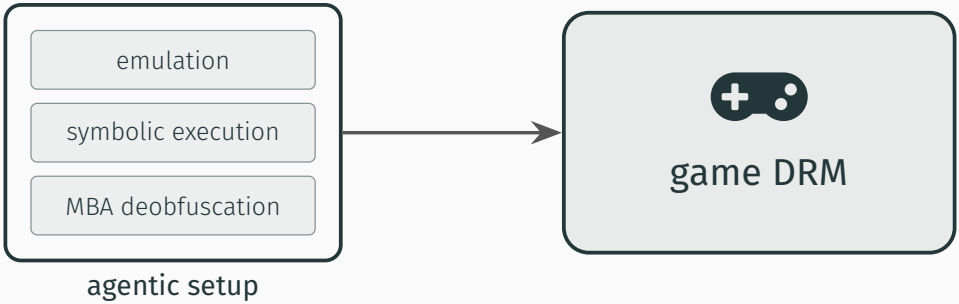
- ✓ process & cross-process memory monitoring
- ✓ physical-memory integrity scanning
- ✓ hypervisor, timing & anti-VM checks
- ✓ API-hook & tampering detection
- ✓ enforcement: telemetry + forced bugcheck

Anti-Cheat Reconstruction

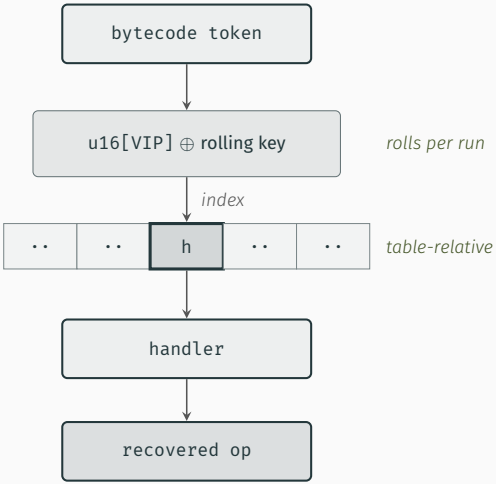
```
/*============================================================================================
 *  [redacted] --  Reconstructed [redacted] Anti-Cheat [redacted] kernel driver
 *
 *  This is a CLEAN-ROOM, DE-OBFUSCATED C reconstruction of the driver's architecture and core
 *  functionality, recovered by reverse-engineering the original sample (a custom direct-threaded
 *  VM, [redacted]. It is NOT byte-equivalent and is NOT the original source: it is an independent,
 *  readable approximation that mirrors the original's structure, subsystems, data layouts and
 *  control flow, with the virtual machine entirely lowered to plain C.
 *
 *  Throughout, comments of the form  [orig: 0x140xxxxxx / sub_xxxx]  cite the address/function in
 *  the original binary that a given construct was reconstructed from, and  [sess N]  cites the
 *  analysis session that established it. See the companion 00_STATE.md and 14..18_*.md writeups.
 *
 *  Identity:  [redacted]
 *  Nature:    Windows x86-64 kernel-mode anti-cheat driver. Callback/system-thread driven (NOT
 *             IOCTL-command driven: all IRP major handlers are trivial STATUS_SUCCESS completers).
 *             Policy and target identities are DATA-DRIVEN from an external config (.ini) and a
 *             user-mode service; this driver is the detection/enforcement MACHINERY.
 *============================================================================================*/
```

Game DRM

Game DRM: Highest-Tier Target

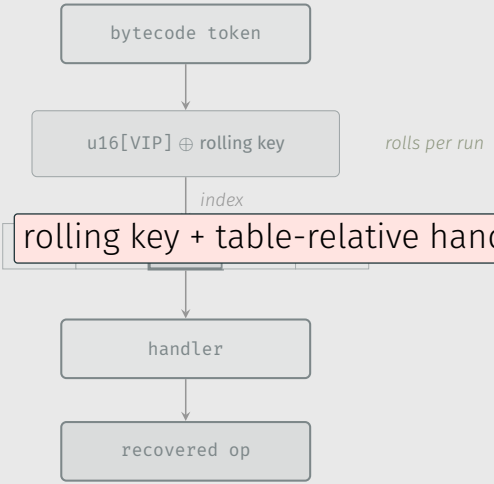


VM in an Older Game Title



- ✓ VM architecture fully reverse-engineered
- ✓ executed path devirtualized end-to-end
- ✓ recovered the license/integrity crypto core

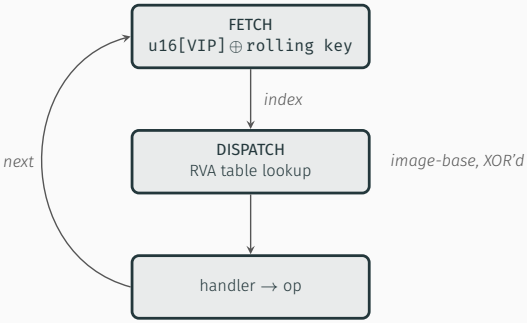
VM in an Older Game Title



rolling key + table-relative handlers ⇒ recovered by emulation

- ✓ VM architecture fully reverse-engineered
- ✓ recovered the license/integrity crypto core

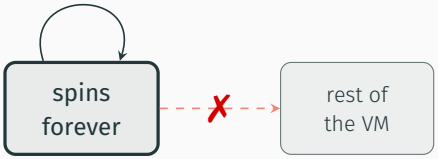
VM in a Recent Game Title



- ✓ VM architecture understood
- ✓ decode & dispatch recovered
- ✗ can't analyze the bytecode
- ✗ requires runtime state
- ✗ stalls under emulation

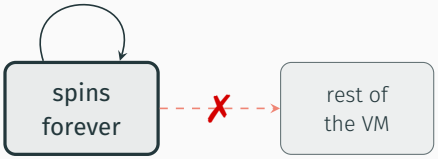
VM in a Recent Game Title: Analysis Walls

anti-emulation loop



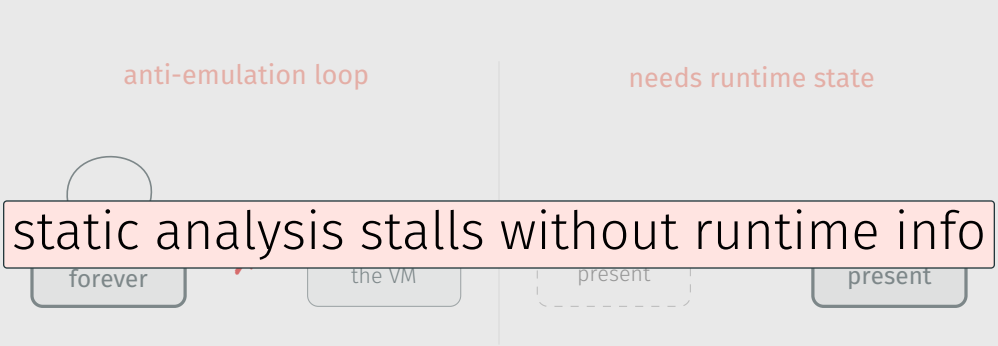
VM in a Recent Game Title: Analysis Walls

anti-emulation loop



needs runtime state

VM in a Recent Game Title: Analysis Walls



Summary: Agentic Virtual Machine Deobfuscation

✓ **simple VM** — essentially a one-shotted

✓ **commercial VM** — full devirtualization in hours

✓ **anti-cheat** — devirtualized the majority of ∼1,000 VM-entries in parallel

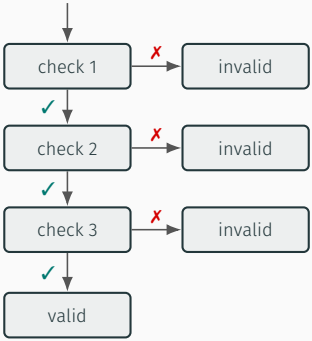
✓ **game DRM** — VM architectures understood; older VM path devirtualized

✗ **game DRM** — stalls under emulation and misses runtime information

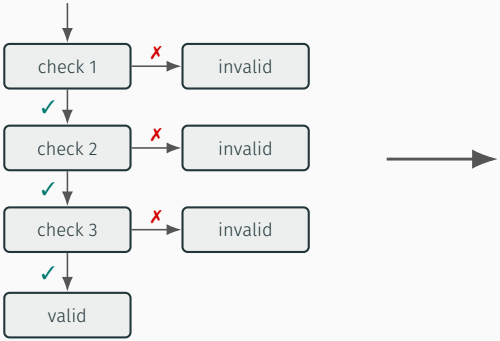
Case Study

Control-Flow Deflattening

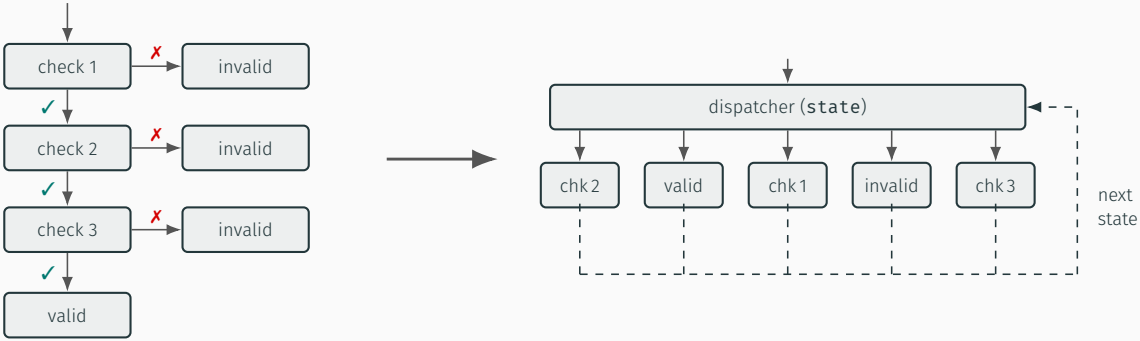
Control-Flow Flattening

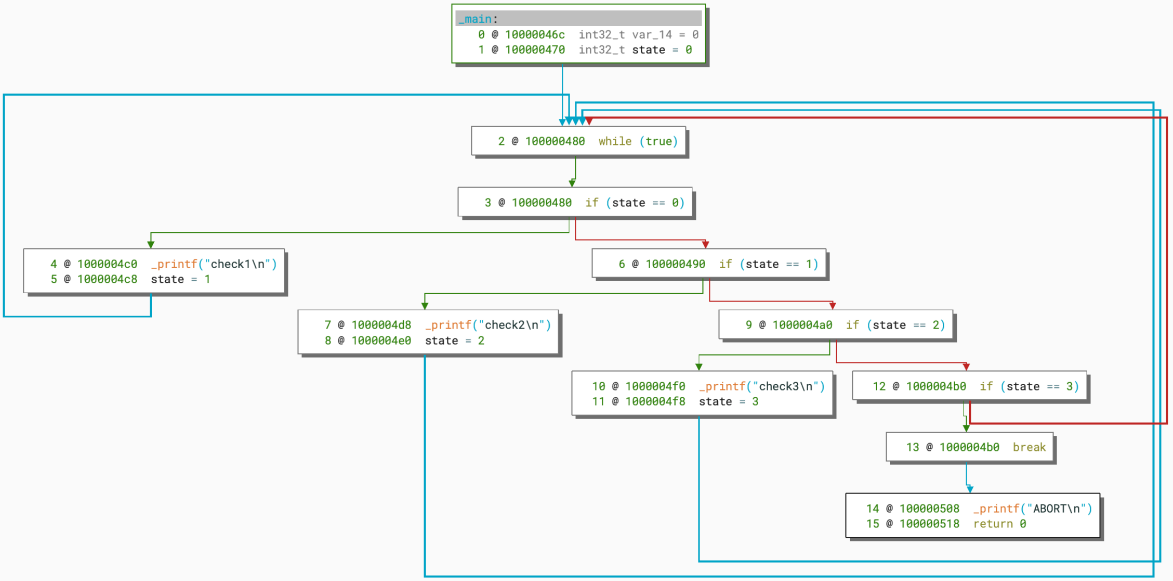


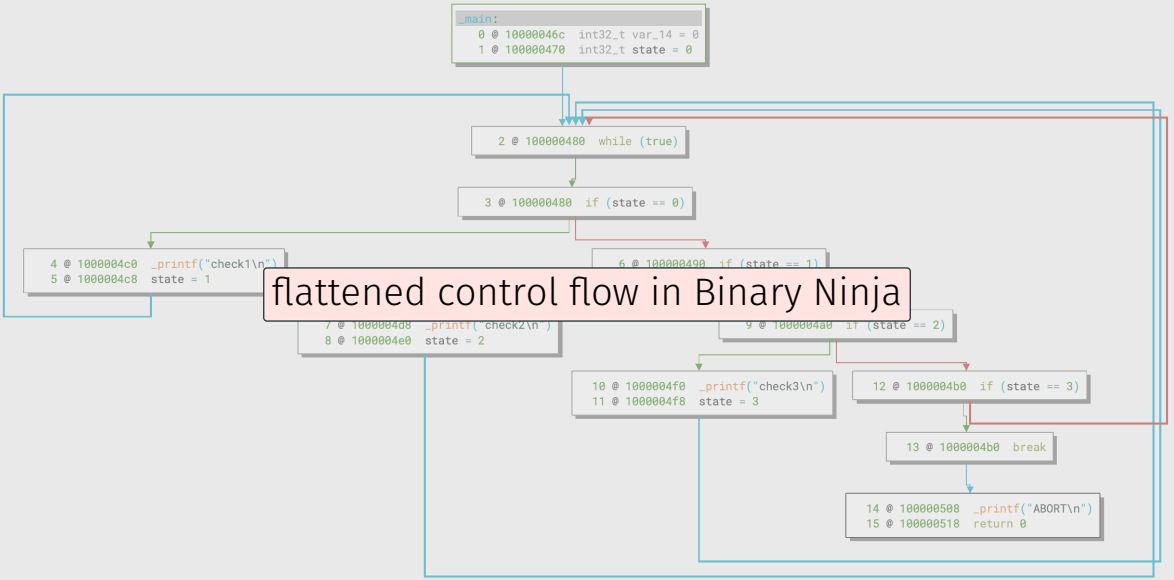
Control-Flow Flattening



Control-Flow Flattening




_main:
0 @ 10000046c int32_t var_14 = 0
1 @ 100000470 int32_t state = 0
2 @ 100000480 while (true)
3 @ 100000480 if (state == 0)
4 @ 1000004c0 _printf("check1\n")
5 @ 1000004c8 state = 1
6 @ 100000490 if (state == 1)
7 @ 1000004d8 _printf("check2\n")
8 @ 1000004e0 state = 2
9 @ 1000004a0 if (state == 2)
10 @ 1000004f0 _printf("check3\n")
11 @ 1000004f8 state = 3
12 @ 1000004b0 if (state == 3)
13 @ 1000004b0 break
14 @ 100000508 _printf("ABORT\n")
15 @ 100000518 return 0



flattened control flow in Binary Ninja

Control-Flow Deflattening Process

Control-Flow Deflattening Process

dispatcher &
state var

locate the
structure

Control-Flow Deflattening Process

dispatcher & state var

locate the structure

enumerate states

state → block map

Control-Flow Deflattening Process

dispatcher & state var

locate the structure

$\longrightarrow$

enumerate states

state $\rightarrow$ block map

$\longrightarrow$

resolve successors

next state per block

Control-Flow Deflattening Process

dispatcher & state var

locate the structure

enumerate states

state → block map

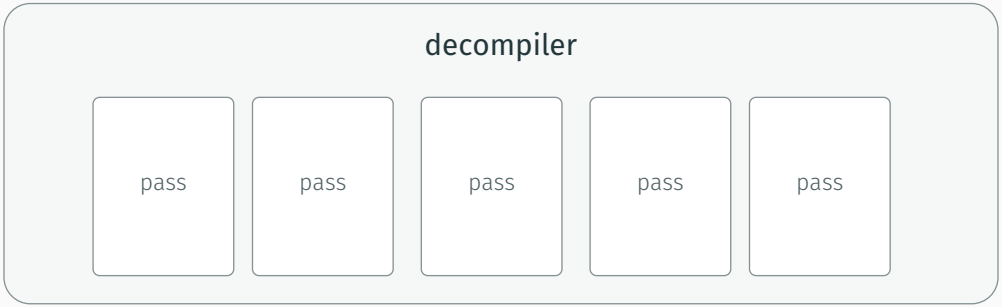
resolve successors

next state per block

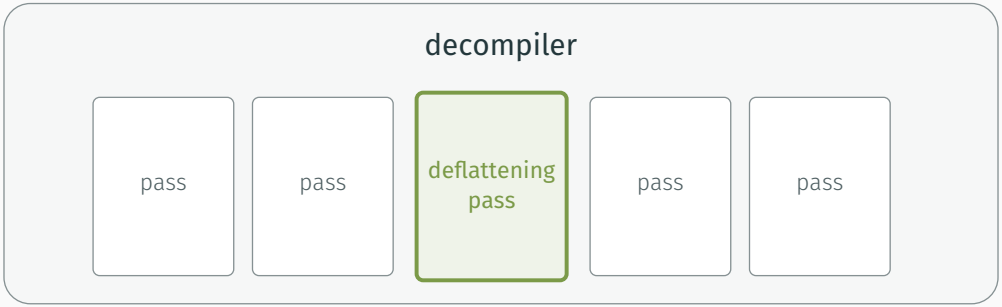
patch

direct edges

Goal: Cleaning Decompiler Output

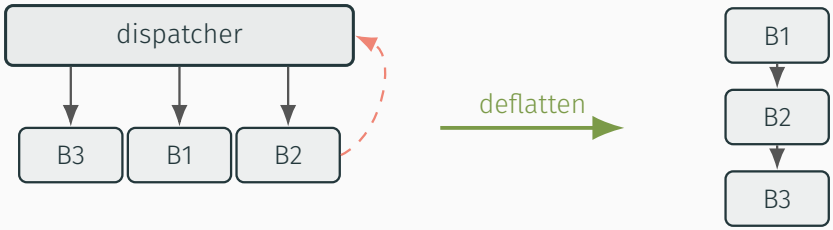


Goal: Cleaning Decompiler Output

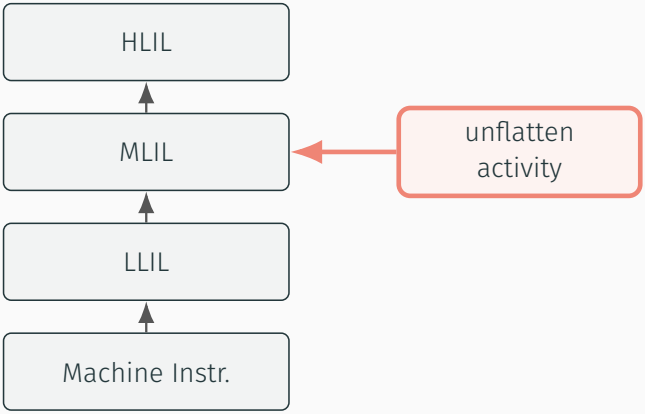


Emotet

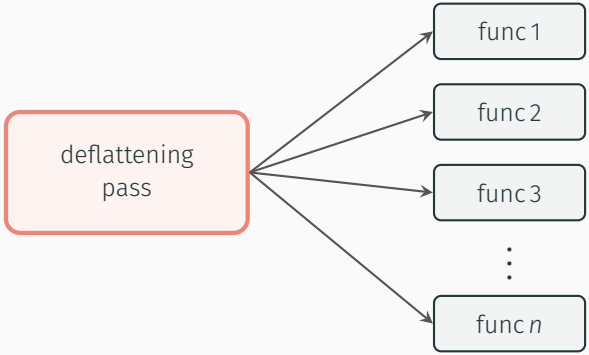
Deflattening Emotet's Obfuscation



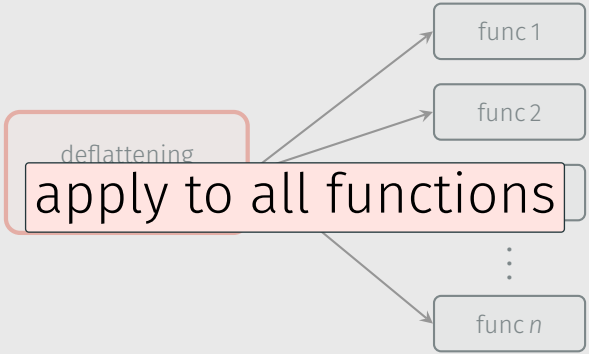
Binary Ninja Workflows

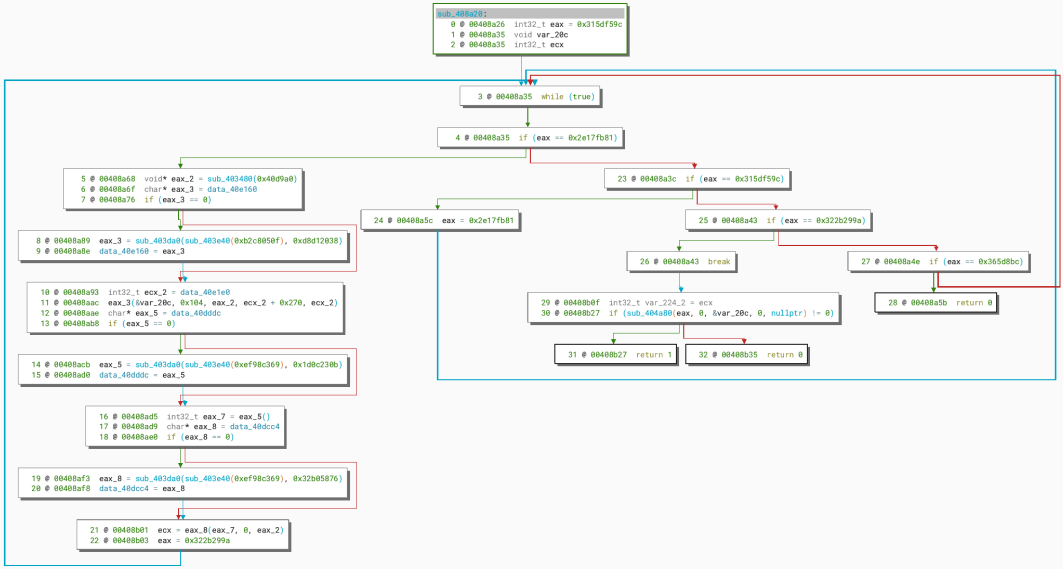


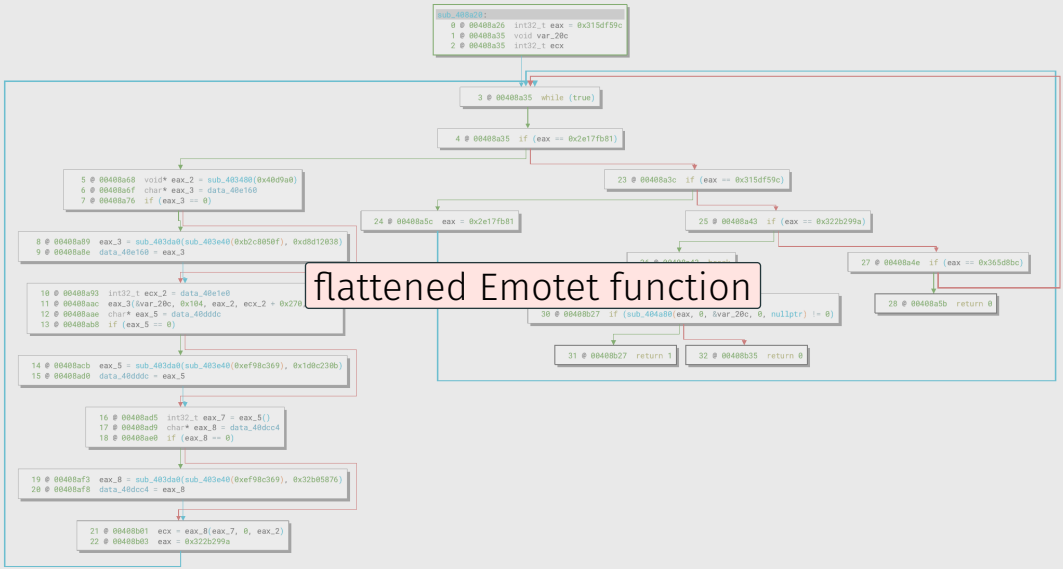
Deflattening pass



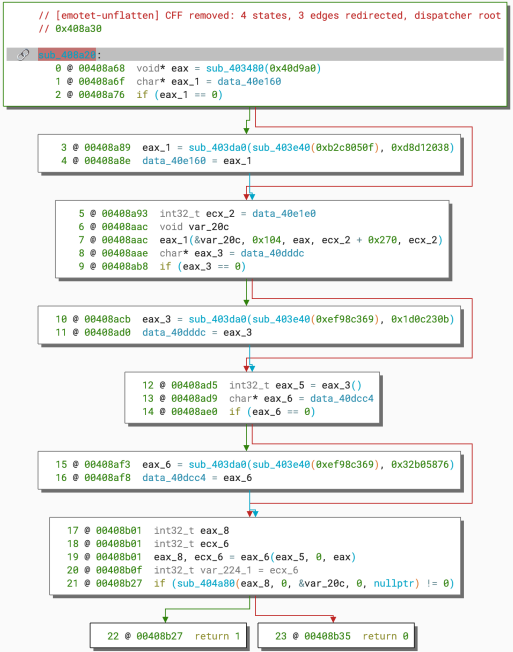
Deflattening pass

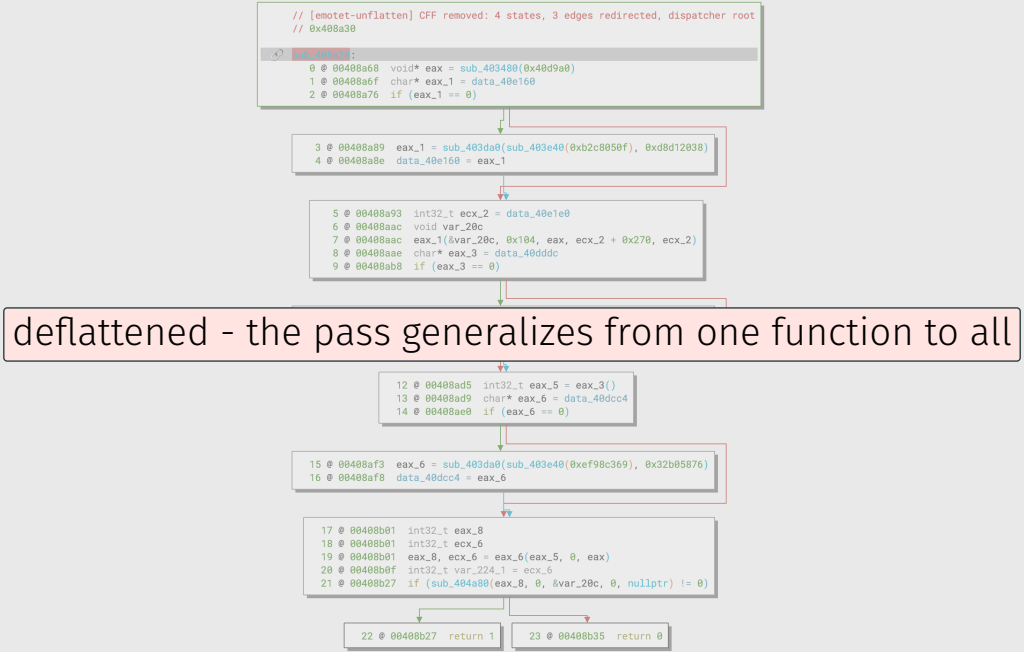



sub_403e40():
0 @ 00408a26 int32_t eax = 0x315df59c
1 @ 00408a35 void var_20c
2 @ 00408a35 int32_t ecx
3 @ 00408a35 while (true)
4 @ 00408a35 if (eax == 0x2e17fb81)
5 @ 00408a68 void* eax_2 = sub_403480(0x40d9a0)
6 @ 00408a6f char* eax_3 = data_40e160
7 @ 00408a76 if (eax_3 == 0)
8 @ 00408a89 eax_3 = sub_403da0(sub_403e40(0xb2c8050f), 0xd8d12038)
9 @ 00408a8e data_40e160 = eax_3
10 @ 00408a93 int32_t ecx_2 = data_40e1e0
11 @ 00408aac eax_3(&var_20c, 0x104, eax_2, ecx_2 + 0x270, ecx_2)
12 @ 00408aae char* eax_5 = data_40dddc
13 @ 00408ab8 if (eax_5 == 0)
14 @ 00408acb eax_5 = sub_403da0(sub_403e40(0xef98c369), 0x1d0c230b)
15 @ 00408ad0 data_40dddc = eax_5
16 @ 00408ad5 int32_t eax_7 = eax_5()
17 @ 00408ad9 char* eax_8 = data_40dcc4
18 @ 00408ae0 if (eax_8 == 0)
19 @ 00408af3 eax_8 = sub_403da0(sub_403e40(0xef98c369), 0x32b05876)
20 @ 00408af8 data_40dcc4 = eax_8
21 @ 00408b01 ecx = eax_8(eax_7, 0, eax_2)
22 @ 00408b03 eax = 0x322b299a
23 @ 00408a3c if (eax == 0x315df59c)
24 @ 00408a5c eax = 0x2e17fb81
25 @ 00408a43 if (eax == 0x322b299a)
26 @ 00408a43 break
27 @ 00408a4e if (eax == 0x365d8bc)
28 @ 00408a5b return 0
29 @ 00408b0f int32_t var_224_2 = ecx
30 @ 00408b27 if (sub_404a80(eax, 0, &var_20c, 0, nullptr) != 0)
31 @ 00408b27 return 1
32 @ 00408b35 return 0



flattened Emotet function

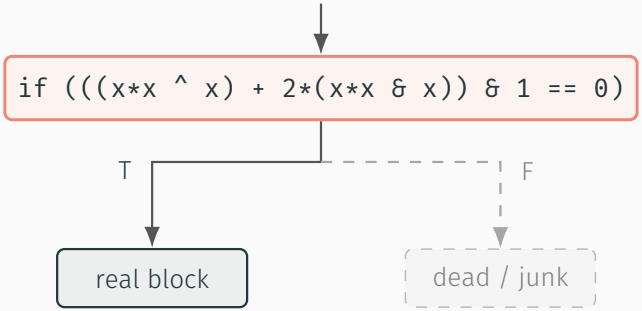

// [emotet-unflatten] CFF removed: 4 states, 3 edges redirected, dispatcher root
// 0x408a30
sub_408a72:
0 @ 00408a68 void* eax = sub_403480(0x40d9a0)
1 @ 00408a6f char* eax_1 = data_40e160
2 @ 00408a76 if (eax_1 == 0)
3 @ 00408a89 eax_1 = sub_403da0(sub_403e40(0xb2c8050f), 0xd8d12038)
4 @ 00408a8e data_40e160 = eax_1
5 @ 00408a93 int32_t ecx_2 = data_40e1e0
6 @ 00408aac void var_20c
7 @ 00408aac eax_1(&var_20c, 0x104, eax, ecx_2 + 0x270, ecx_2)
8 @ 00408aae char* eax_3 = data_40dddc
9 @ 00408ab8 if (eax_3 == 0)
10 @ 00408acb eax_3 = sub_403da0(sub_403e40(0xef98c369), 0x1d0c230b)
11 @ 00408ad0 data_40dddc = eax_3
12 @ 00408ad5 int32_t eax_5 = eax_3()
13 @ 00408ad9 char* eax_6 = data_40dcc4
14 @ 00408ae0 if (eax_6 == 0)
15 @ 00408af3 eax_6 = sub_403da0(sub_403e40(0xef98c369), 0x32b05876)
16 @ 00408af8 data_40dcc4 = eax_6
17 @ 00408b01 int32_t eax_8
18 @ 00408b01 int32_t ecx_6
19 @ 00408b01 eax_8, ecx_6 = eax_6(eax_5, 0, eax)
20 @ 00408b0f int32_t var_224_1 = ecx_6
21 @ 00408b27 if (sub_404a80(eax_8, 0, &var_20c, 0, nullptr) != 0)
22 @ 00408b27 return 1
23 @ 00408b35 return 0

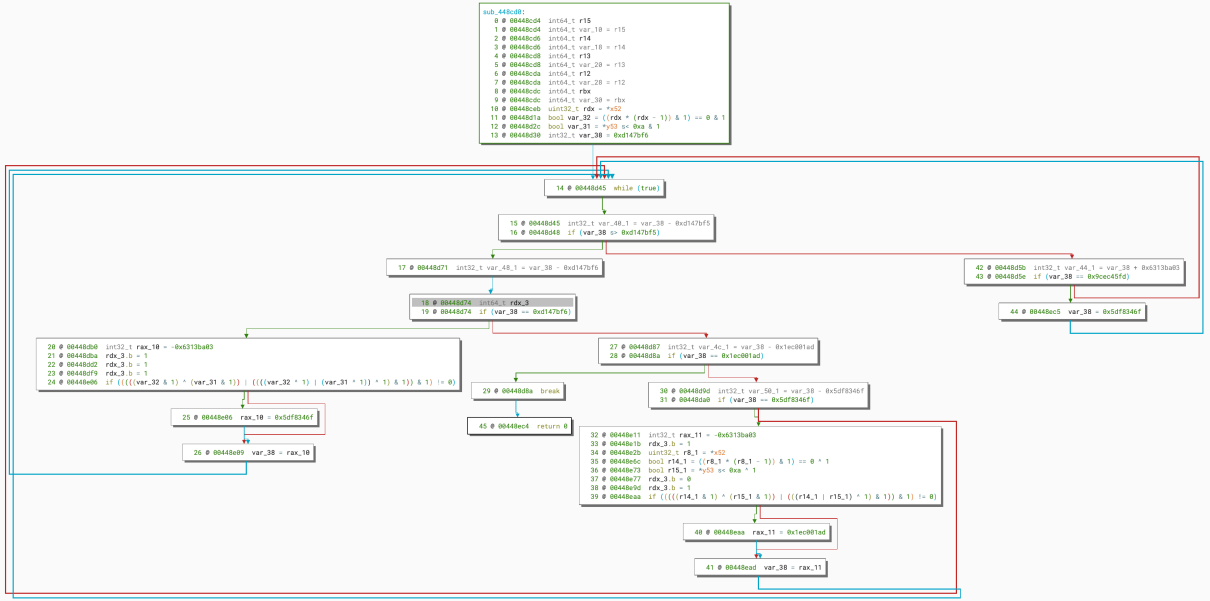


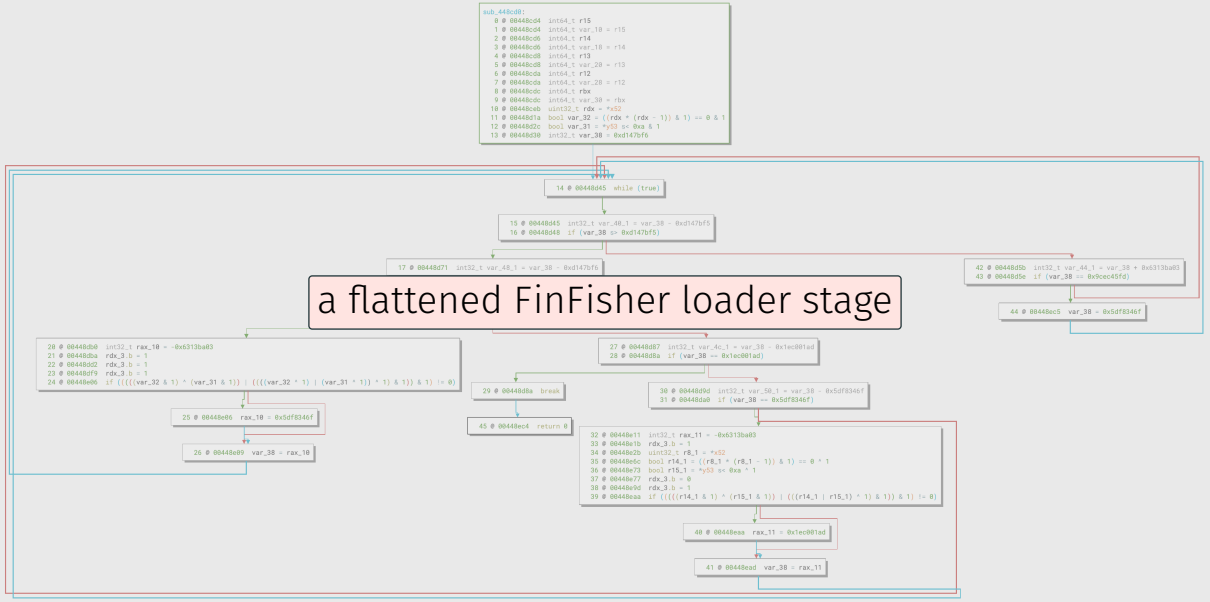
deflattened - the pass generalizes from one function to all

FinFisher

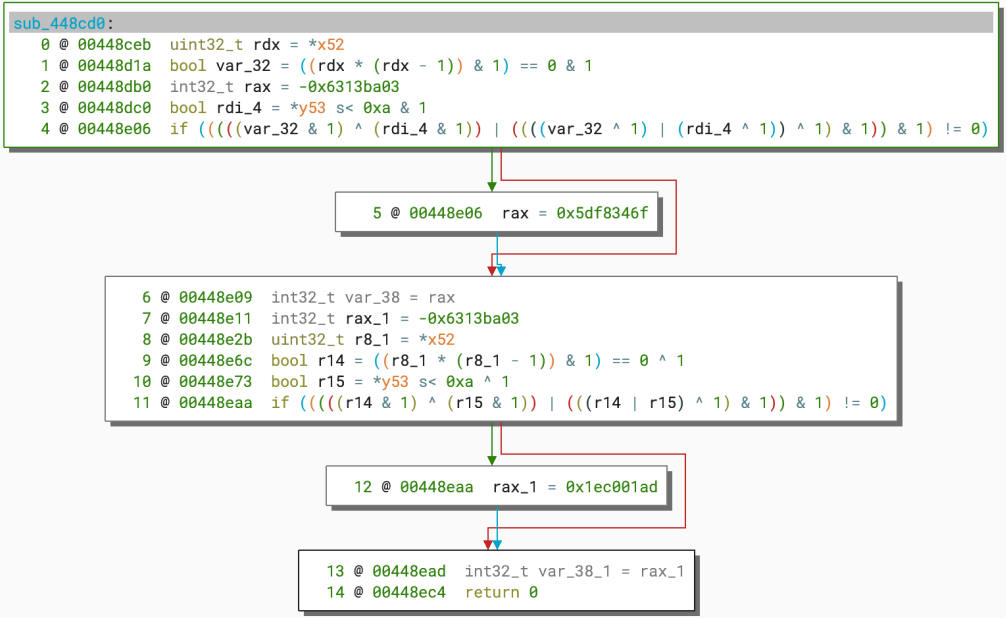
FinFisher: MBA-based Opaque Predicates

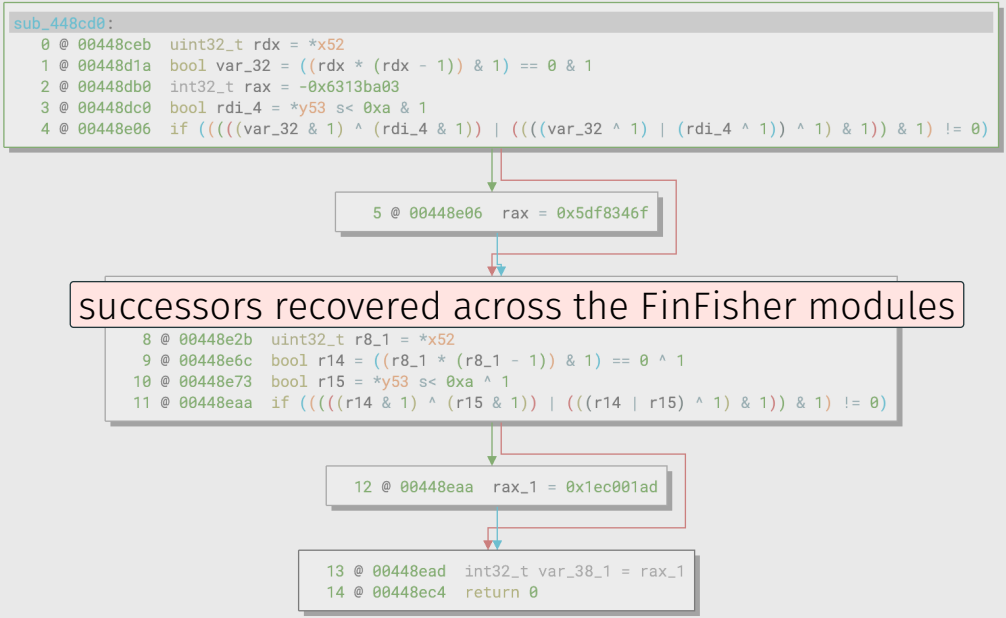



sub_4448cd0:
0 @ 00448cd4 int64_t r15
1 @ 00448cd4 int64_t var_10 = r15
2 @ 00448cd6 int64_t r14
3 @ 00448cd6 int64_t var_18 = r14
4 @ 00448cd8 int64_t r13
5 @ 00448cd8 int64_t var_20 = r13
6 @ 00448cda int64_t r12
7 @ 00448cda int64_t var_28 = r12
8 @ 00448cdc int64_t rbx
9 @ 00448cdc int64_t var_30 = rbx
10 @ 00448ceb uint32_t rdx = *x52
11 @ 00448d1a bool var_32 = ((rdx * (rdx - 1)) & 1) == 0 & 1
12 @ 00448d2c bool var_31 = *y53 s< 0xa & 1
13 @ 00448d30 int32_t var_38 = 0xd147bf6
14 @ 00448d45 while (true)
15 @ 00448d45 int32_t var_48_1 = var_38 - 0xd147bf5
16 @ 00448d48 if (var_38 s> 0xd147bf5)
17 @ 00448d71 int32_t var_48_1 = var_38 - 0xd147bf6
18 @ 00448d74 int64_t rdx_3
19 @ 00448d74 if (var_38 == 0xd147bf6)
20 @ 00448db0 int32_t rax_10 = -0x6313ba03
21 @ 00448dba rdx_3.b = 1
22 @ 00448dd2 rdx_3.b = 1
23 @ 00448df9 rdx_3.b = 1
24 @ 00448e06 if ((((((var_32 & 1) ^ (var_31 & 1)) | (((var_32 ^ 1) | (var_31 ^ 1)) ^ 1) & 1)) & 1) != 0)
25 @ 00448e06 rax_10 = 0x5df8346f
26 @ 00448e09 var_38 = rax_10
27 @ 00448d87 int32_t var_4c_1 = var_38 - 0x1ec001ad
28 @ 00448d8a if (var_38 == 0x1ec001ad)
29 @ 00448d8a break
45 @ 00448ec4 return 0
30 @ 00448d9d int32_t var_50_1 = var_38 - 0x5df8346f
31 @ 00448da0 if (var_38 == 0x5df8346f)
32 @ 00448e11 int32_t rax_11 = -0x6313ba03
33 @ 00448e1b rdx_3.b = 1
34 @ 00448e2b uint32_t r8_1 = *x52
35 @ 00448e6c bool r14_1 = ((r8_1 * (r8_1 - 1)) & 1) == 0 * 1
36 @ 00448e73 bool r15_1 = *y53 s< 0xa ^ 1
37 @ 00448e77 rdx_3.b = 0
38 @ 00448e9d rdx_3.b = 1
39 @ 00448eaa if ((((((r14_1 & 1) ^ (r15_1 & 1)) | (((r14_1 | r15_1) ^ 1) & 1)) & 1) != 0)
40 @ 00448eaa rax_11 = 0x1ec001ad
41 @ 00448ead var_38 = rax_11
42 @ 00448d5b int32_t var_44_1 = var_38 + 0x6313ba03
43 @ 00448d5e if (var_38 == 0x9cec45fd)
44 @ 00448ec5 var_38 = 0x5df8346f



a flattened FinFisher loader stage


sub_448cd0:
0 @ 00448ceb uint32_t rdx = *x52
1 @ 00448d1a bool var_32 = ((rdx * (rdx - 1)) & 1) == 0 & 1
2 @ 00448db0 int32_t rax = -0x6313ba03
3 @ 00448dc0 bool rdi_4 = *y53 s< 0xa & 1
4 @ 00448e06 if ((((((var_32 & 1) ^ (rdi_4 & 1)) | ((((var_32 ^ 1) | (rdi_4 ^ 1)) ^ 1) & 1)) & 1) != 0)
5 @ 00448e06 rax = 0x5df8346f
6 @ 00448e09 int32_t var_38 = rax
7 @ 00448e11 int32_t rax_1 = -0x6313ba03
8 @ 00448e2b uint32_t r8_1 = *x52
9 @ 00448e6c bool r14 = ((r8_1 * (r8_1 - 1)) & 1) == 0 ^ 1
10 @ 00448e73 bool r15 = *y53 s< 0xa ^ 1
11 @ 00448eaa if (((((r14 & 1) ^ (r15 & 1)) | (((r14 | r15) ^ 1) & 1)) & 1) != 0)
12 @ 00448eaa rax_1 = 0x1ec001ad
13 @ 00448ead int32_t var_38_1 = rax_1
14 @ 00448ec4 return 0


sub_448cd0:
0 @ 00448ceb uint32_t rdx = *x52
1 @ 00448d1a bool var_32 = ((rdx * (rdx - 1)) & 1) == 0 & 1
2 @ 00448db0 int32_t rax = -0x6313ba03
3 @ 00448dc0 bool rdi_4 = *y53 s< 0xa & 1
4 @ 00448e06 if (((((var_32 & 1) ^ (rdi_4 & 1)) | ((((var_32 ^ 1) | (rdi_4 ^ 1)) ^ 1) & 1)) & 1) != 0)
5 @ 00448e06 rax = 0x5df8346f
successors recovered across the FinFisher modules
8 @ 00448e2b uint32_t r8_1 = *x52
9 @ 00448e6c bool r14 = ((r8_1 * (r8_1 - 1)) & 1) == 0 ^ 1
10 @ 00448e73 bool r15 = *y53 s< 0xa ^ 1
11 @ 00448eaa if (((((r14 & 1) ^ (r15 & 1)) | (((r14 | r15) ^ 1) & 1)) & 1) != 0)
12 @ 00448eaa rax_1 = 0x1ec001ad
13 @ 00448ead int32_t var_38_1 = rax_1
14 @ 00448ec4 return 0

Summary: Control-Flow Deflattening

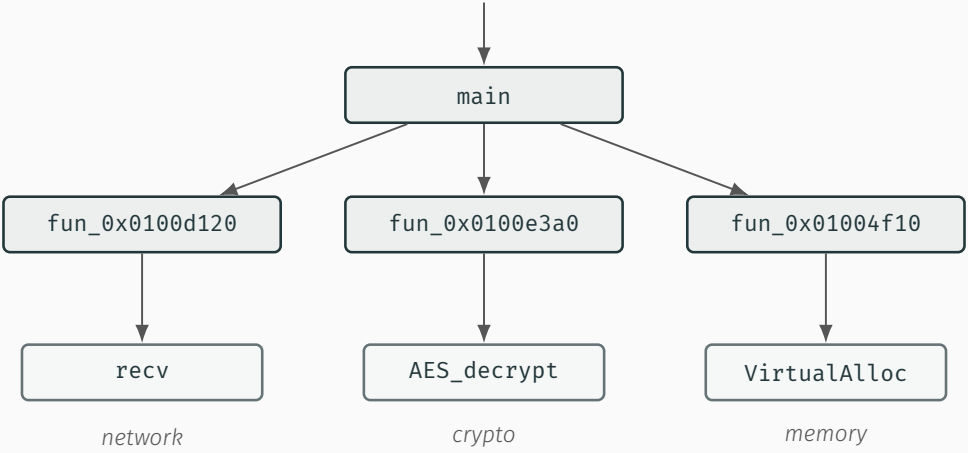
✓ agents can write **decompiler-based deflattening passes**

✗ each pass stays **sample-specific**

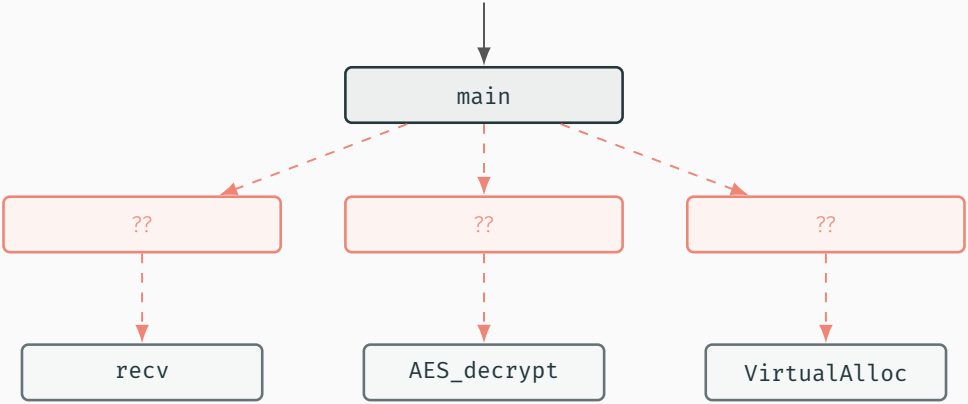
Case Study

Global Call Obfuscation

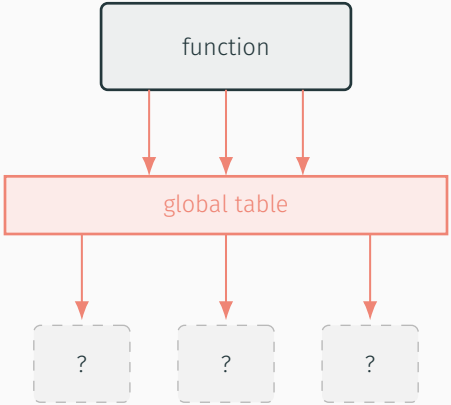
Call Graph Obfuscation



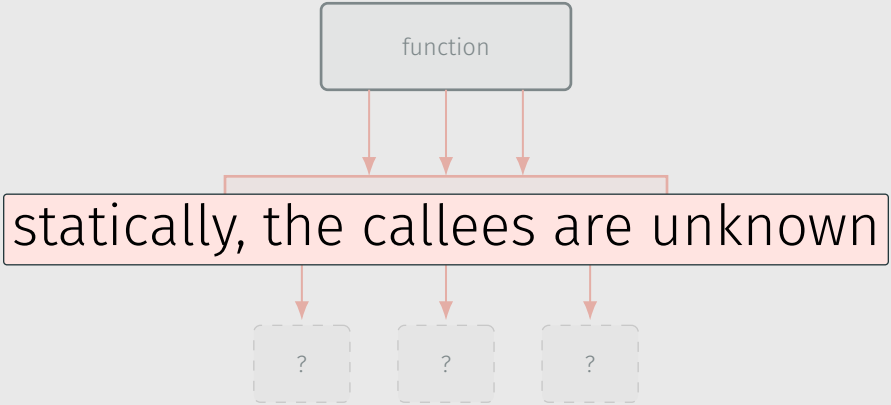
Call Graph Obfuscation



Call Graph Obfuscation



Call Graph Obfuscation

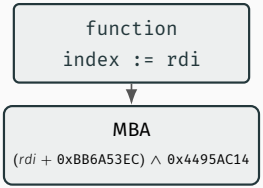


A Modern DRM System

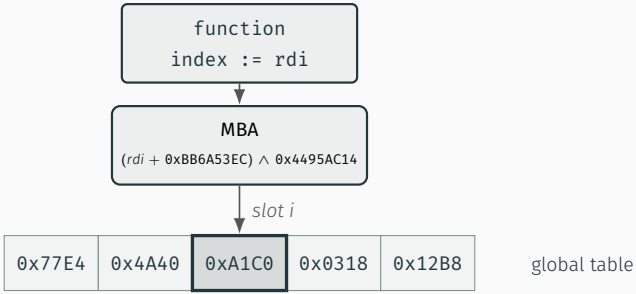
Call Obfuscation Details

```
function
index := rdi
```

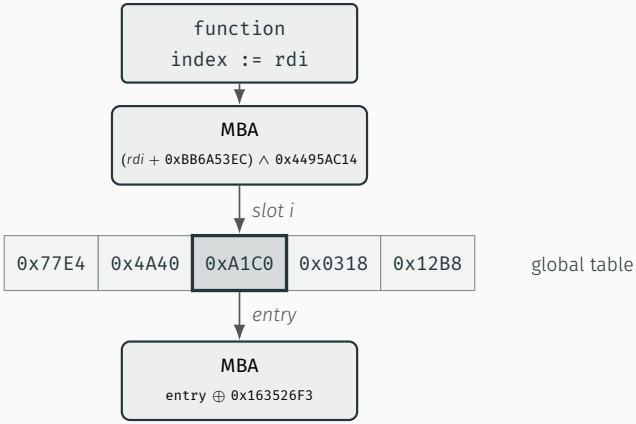
Call Obfuscation Details



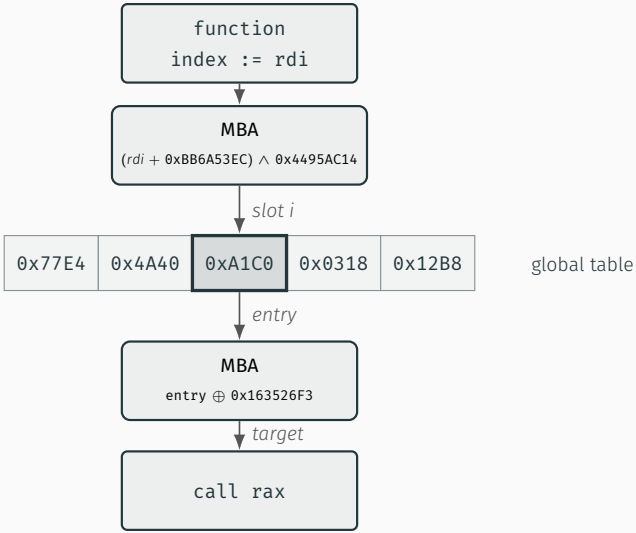
Call Obfuscation Details



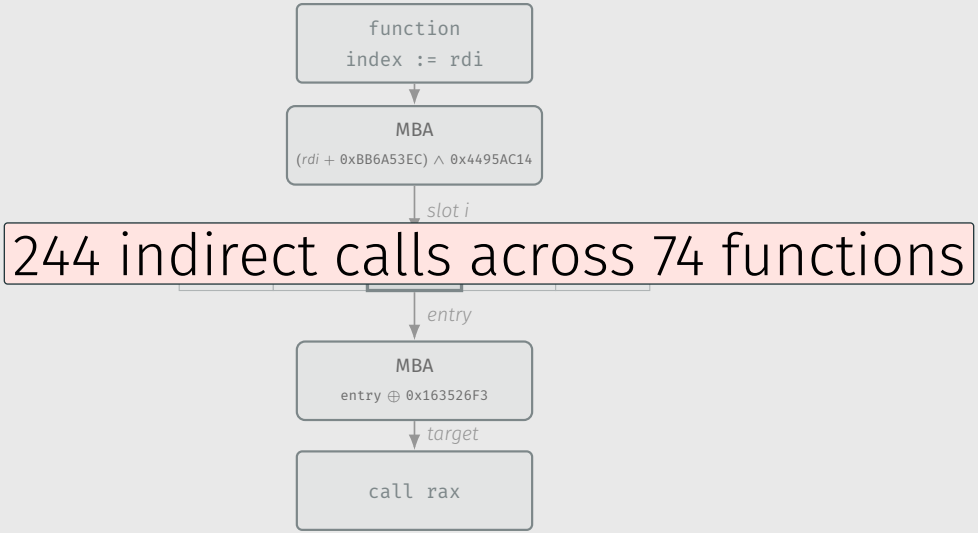
Call Obfuscation Details



Call Obfuscation Details



Call Obfuscation Details



Agentic Recovery: False Starts

Most of the calls in this binary are indirect - recover their targets.

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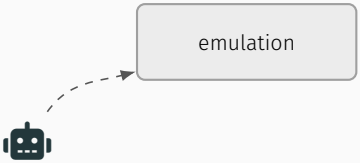

Agentic Recovery: False Starts

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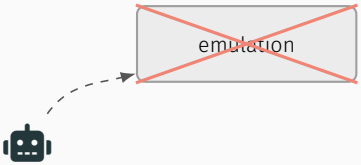

Agentic Recovery: False Starts

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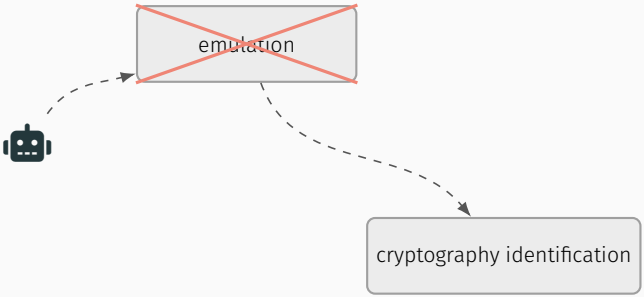

Agentic Recovery: False Starts

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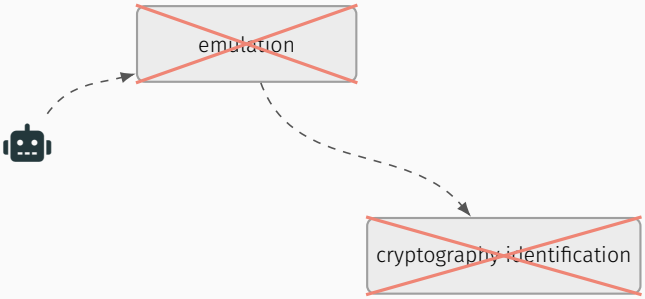
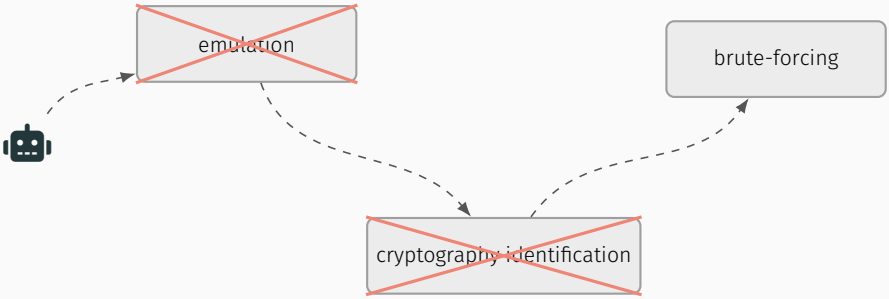


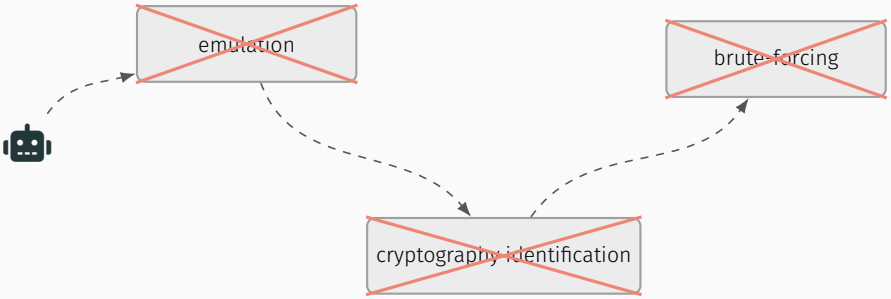
Agentic Recovery: False Starts

Most of the calls in this binary are indirect - recover their targets.



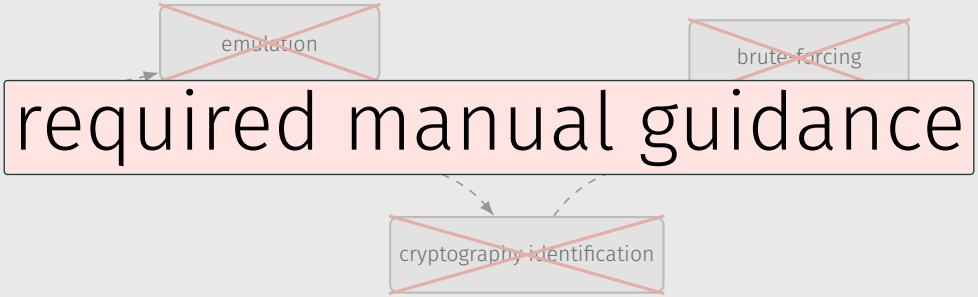
Agentic Recovery: False Starts

Most of the calls in this binary are indirect - recover their targets.



Agentic Recovery: False Starts

Most of the calls in this binary are indirect - recover their targets.



Call-Graph Recovery Process

recover the global table

identification, boundaries

Call-Graph Recovery Process

recover the global table

identification, boundaries

→

propagate the entries

const-prop the slots

Call-Graph Recovery Process

recover the global table

identification, boundaries

→

propagate the entries

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→

simplify MBA

verify with z3

Call-Graph Recovery Process

recover the global table

identification, boundaries

→

propagate the entries

const-prop the slots

→

simplify MBA

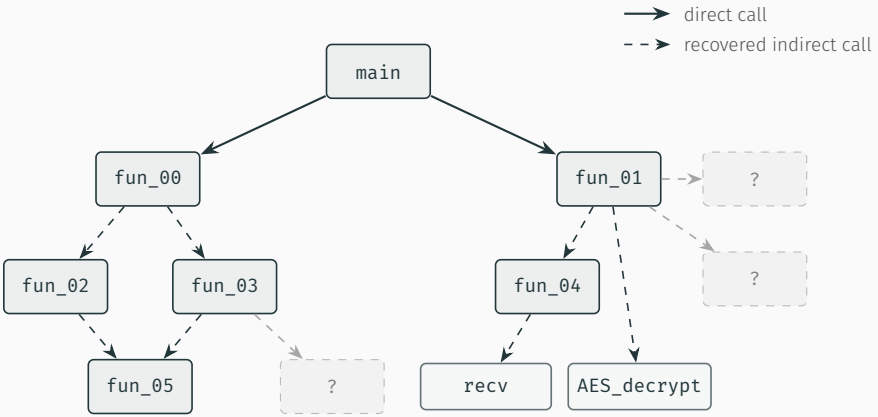
verify with z3

→

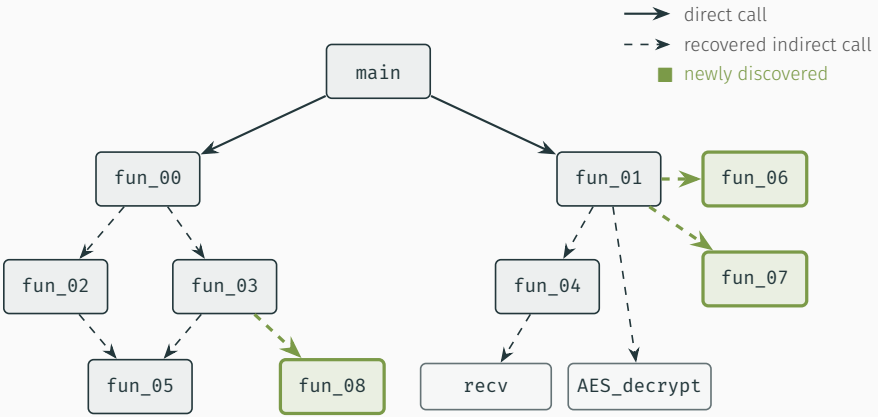
recover the edges

patch calls

The Recovered Call Graph



The Recovered Call Graph



Consequences of Deobfuscation

function boundaries

& more functions discovered

parameter detection

across the whole graph

```
_main:
   0 @ 1001dbb3b  int64_t rax = *___stack_chk_guard
   1 @ 1001dbc22  int32_t var_60 = (((zx.d(&var_60) & 0x99a5cce8) + (zx.d(&var_60) | 0x665a3310) - &var_60)
   1 @ 1001dbc22      ^ 0x1bcd0820) * 0x4b05c2c3 + 2
   2 @ 1001dbc34  char rax_11 = (((data_100338778.d).b - (data_100338958.d).b) ^ 0x43) * 0x45
   3 @ 1001dbc68  (-0x4ada058b + (&jump_table_100330c20)[zx.q((zx.d(rax_11)
   3 @ 1001dbc68      ^ zx.d(*((zx.q(*(zx.q(rax_11) + &data_1002b8ea0)) ^ 0xeb) + &data_1002d6be0))) + 0x1d8)])(&var_60,
   3 @ 1001dbc68      0, &data_1002b8ea0)
   4 @ 1001dbc97  int32_t rcx_8 = 0
   5 @ 1001dbc9e  int32_t var_5c
   6 @ 1001dbc9e  rcx_8.b = var_5c == 0x3145c2fe
   7 @ 1001dbcb9  switch (rcx_8)
```

```
_main:
   0 @ 1001dbb3b  int64_t rax = *___stack_chk_guard
   1 @ 1001dbc22  int32_t var_60 = (((zx.d(&var_60) & 0x99a5cce8) + (zx.d(&var_60) | 0x665a3310) - &var_60)
   1 @ 1001dbc22      ^ 0x1bcd0820) * 0x4b05c2c3 + 2
   2 @ 1001dbc34  char rax_11 = (((data_100338778.d).b - (data_100338958.d).b) ^ 0x43) * 0x45
   3 @ 1001dbc68  (-0x4ada058b +
   3 @ 1001dbc68      ^ zx.d(*((z                                _1002d6be0))) + 0x1d8)])(&var_60,
   3 @ 1001dbc68      0, &data_1002b8ea0)
   4 @ 1001dbc97  int32_t rcx_8 = 0
   5 @ 1001dbc9e  int32_t var_5c
   6 @ 1001dbc9e  rcx_8.b = var_5c == 0x3145c2fe
   7 @ 1001dbcb9  switch (rcx_8)
```

call hidden behind indirection

```
_main:
   0 @ 1001dbb3b  int64_t rax = *___stack_chk_guard
   1 @ 1001dbbac  int64_t var_b8
   2 @ 1001dbbac  char rax_3 = (&var_b8 * 0x8a + 0xf) ^ 0x43
   3 @ 1001dbc65  sub_100058530(0x1f, 0, &data_1002b8ea0,
   3 @ 1001dbc65      zx.q(*(zx.q((((data_100338778.d).b - (data_100338958.d).b) ^ 0x43) * 0x45) + &data_1002b8ea0))
   3 @ 1001dbc65          ^ 0xeb,
   3 @ 1001dbc65      -0x385c84ff + (&data_100330c20)[zx.q((zx.d(rax_3)
   3 @ 1001dbc65      ^ zx.d(*((zx.q(*(zx.q(rax_3) + &data_1002b8ea0)) ^ 0x80) + &data_1002d6be0))) + 0x33d)])
   4 @ 1001dbc97  int32_t rcx_6 = 0
   5 @ 1001dbc9e  int32_t var_5c
   6 @ 1001dbc9e  rcx_6.b = var_5c == 0x3145c2fe
   7 @ 1001dbcb9  switch (rcx_6)
```


_main:
0 @ 1001dbb3b int64_t rax = *___stack_chk_guard
1 @ 1001dbbac int64_t var_b8
2 @ 1001dbbac char rax_3 = (&var_b8 * 0x8a + 0xf) ^ 0x43
3 @ 1001dbc65 sub_100058530(0x1f, 0, &data_1002b8ea0,
3 @ 1001dbc65 zx.q(*(zx.q((((
3 @ 1001dbc65 ^ 0xeb,
3 @ 1001dbc65 -0x385c84ff + (
3 @ 1001dbc65 ^ zx.d(*((zx.q(*(zx.q(rax_3) + &data_1002b8ea0)) ^ 0x80) + &data_1002d6be0))) + 0x33d)])
4 @ 1001dbc97 int32_t rcx_6 = 0
5 @ 1001dbc9e int32_t var_5c
6 @ 1001dbc9e rcx_6.b = var_5c == 0x3145c2fe
7 @ 1001dbcb9 switch (rcx_6)
patched call instruction

Summary: Global Call Obfuscation

✓ call graph hidden behind **indirect calls** through one global table

✗ agents get easily confused, we had to step in

✓ successfully broken with constant propagation and **MBA simplification**

Recap

What Worked

- ✓ **commercial VM** — full devirtualization, weeks → hours
- ✓ **anti-cheat** — ∼1,000 VM-entries devirtualized in parallel
- ✓ **game DRM (older)** — VM architecture recovered, path devirtualized
- ✓ **deflattening** — agents write decompiler-based passes
- ✓ **call obfuscation** — recovered via constant propagation + MBA

What Did Not Work

✗ **commercial VM** — lost without targeted guidance

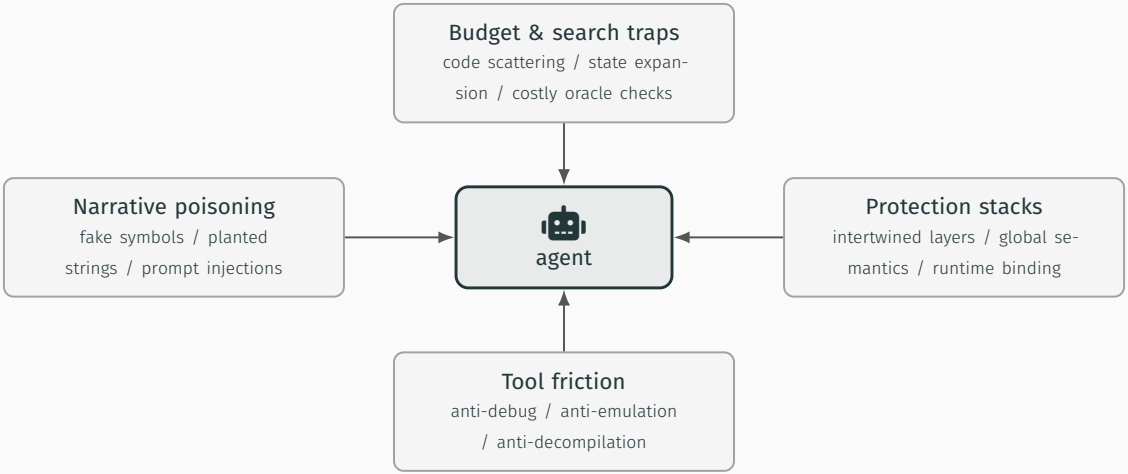
✗ **call obfuscation** — agents get confused, we had to step in

✗ **deflattening** — each pass stays sample-specific

✗ **game DRM (newer)** — stalls under emulation, meaning is runtime-bound

Anti-Agentic Obfuscation

Anti-Agentic Patterns



Wrap-Up

Takeaways

1. Many formerly tedious workflows become cheap to iterate.
2. They still require analyst guidance.
3. The agent becomes an orchestrator of tooling.
4. Defenses must account for agent-assisted attackers.

Agents change the economics of deobfuscation.

Summary

- agents are a force multiplier for deobfuscation
- obfuscation must scale towards agent-assisted attackers

Tim Blazytko

@mr_phrazer

https://synthesis.to

Nicolò Altamura

@nicolodev

https://nicolo.dev