RUHR UNIVERSITÄT BOCHUM RUB

hgi SysSec

Breaking State-of-the-Art Binary Code Obfuscation via Program Synthesis

Black Hat Asia, Singapore

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Syntia: Synthesizing the Semantics of Obfuscated Code

Tim Blazytko, Moritz Contag, Cornelius Aschermann, and Thorsten Holz, *Ruhr-Universität Bochum*

https://www.usenix.org/conference/usenixsecurity17/technical-sessions/presentation/blazytko

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Setting the Scene

- Obfuscated code, semantics?
- Traditional deobfuscation techniques
- **Orthogonal approach**

Motivation

~~Prevent~~ **Complicate** reverse engineering attempts.

- Intellectual Property
- Malicious Payloads
- Digital Rights Management

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> "We achieved our goals. We were uncracked for **13 whole days**."
>
> – Martin Slater, 2K Australia, on *BioShock* (2007).

How to protect software?

Approaches

Abuse shortcomings of file parsers and other tools of the trade.

- `fld tbyte ptr [__bad_values]` crashing OllyDbg 1.10.
- Fake `SizeOfImage` crashing process dumpers.

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Abuse shortcomings of file parsers and other tools of the trade.

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- Fake `SizeOfImage` crashing process dumpers.

Detect artifacts of the debugging process.

- `PEB.BeingDebugged` bit being set.
- `int 2D` and exception handling in debuggers.

Approaches

Abus

Dete

game does not start debugger detected

All Videos Shopping Images News More Settings Tools

About 6.370.000 results (0,51 seconds)

When i run this game i get a debugger error message Debugger ...

https://support.ubi.com/.../When-i-run-this-game-i-get-a-debugger-error-message-De...

When i run this **game** i get the following error message : **Debugger Detected** - Please close it down and restart! Windows NT ... Our **game will not** run while this application is running in memory, to stop this from happening you will need to stop MDM.exe as a startup process. Do the following : Goto the "**Start**" button --> "Run".

Requirements

1. We want the technique to be *semantics-preserving*.

Preserve the observable behavior of the application.

Requirements

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2. We want to avoid external dependencies, focus on code only.

Assume white-box attack scenario.

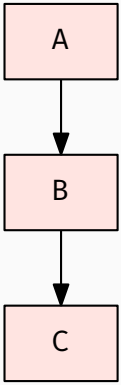
Requirements

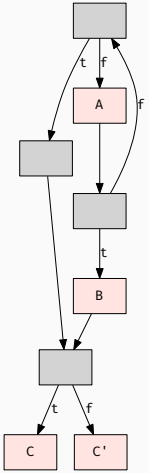
1. We want the technique to be *semantics-preserving*.
2. We want to avoid external dependencies, focus on code only.
3. We want techniques where **effort(deploy)** $\ll$ **effort(attack)**.

Anti-Debugging tricks are effort **1:1**.

Code Obfuscation Techniques

Opaque Predicates


A
B
C


t
f
A
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t
B
t
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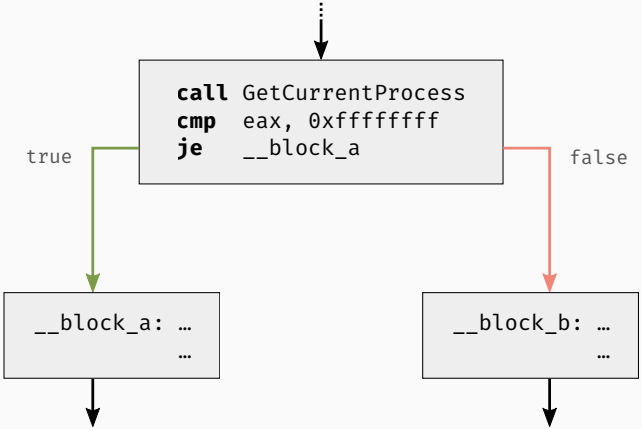
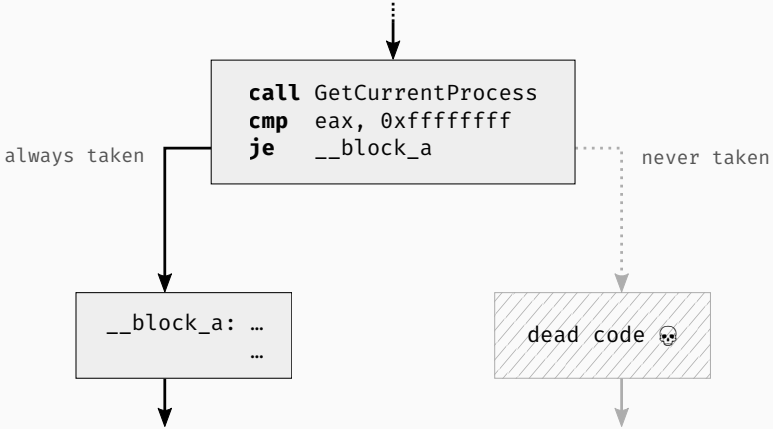
C
C'

Opaque Predicates

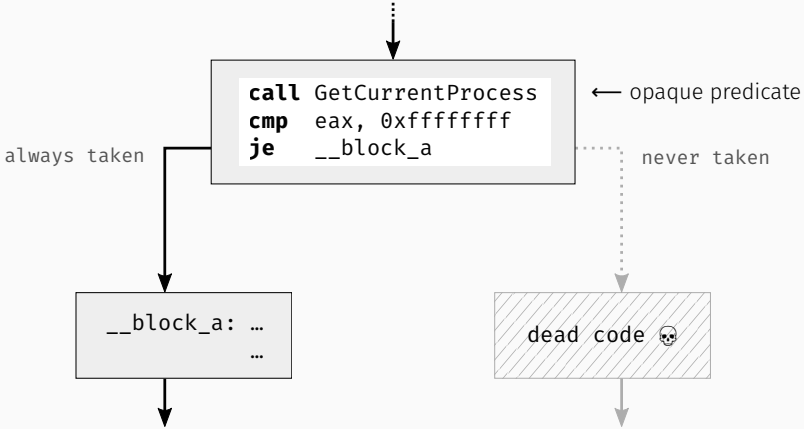


Opaque Predicates



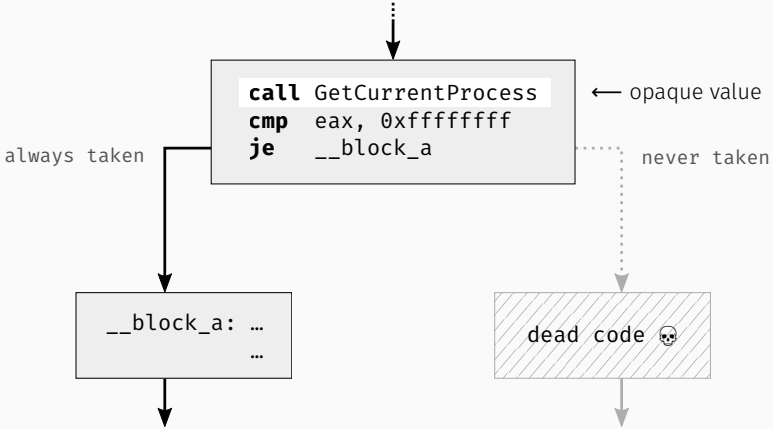
Opaque True Predicate

Opaque Predicates



Opaque True Predicate

Opaque Predicates



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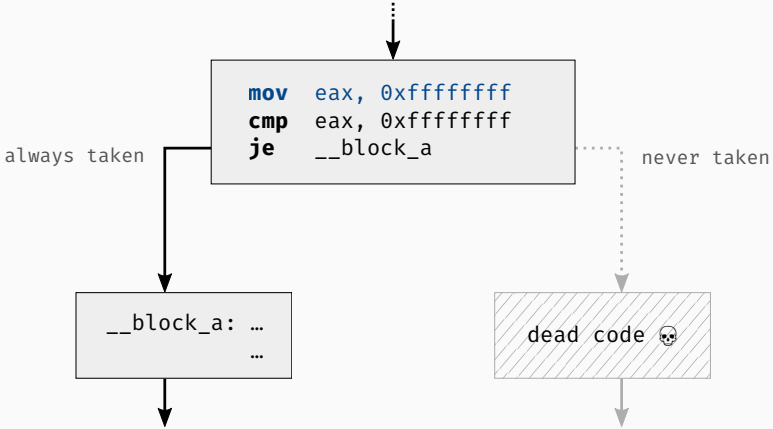
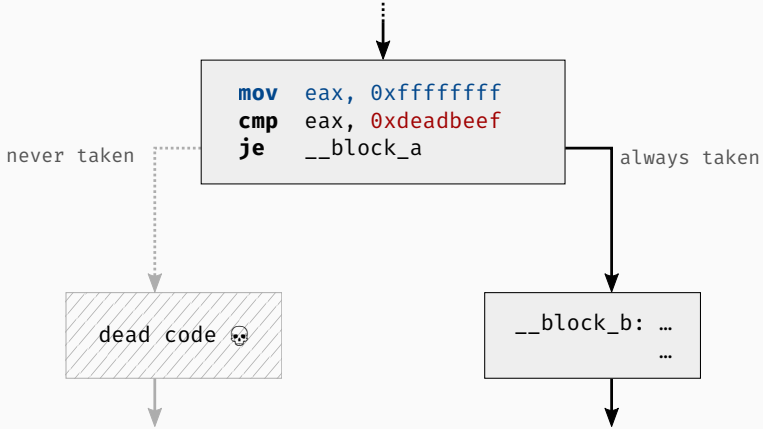
Opaque Predicates



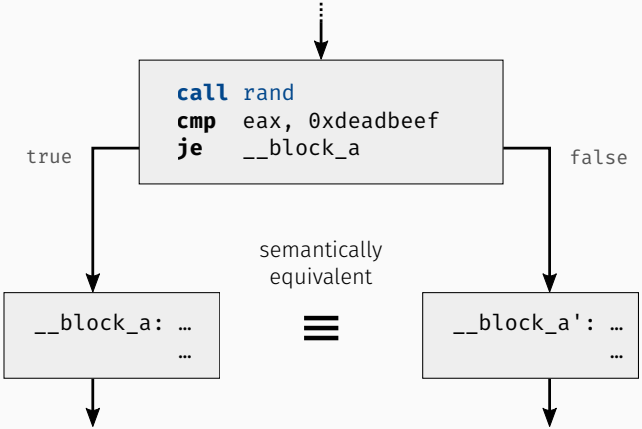
Opaque True Predicate

Opaque Predicates



Opaque False Predicate

Opaque Predicates



Random Opaque Predicate

duplicated block

Opaque Predicates

- ⊕ Increase in complexity (branch count, McCabe)
- ⊕ Can be built on hard problems (e. g., aliasing)
- ⊕ Forces analyst to **encode additional knowledge**
- ⊕ Hard to solve statically

⚠ Examples

- `GetCurrentProcess()` $\Rightarrow -1$
- `fldpi`[1] $\Rightarrow$ `st(0)` $= \pi$
- $x^2 \geq 0 \quad \forall x$
- $x + 1 \neq x \quad \forall x$
- pointer A *must-alias* pointer B
- checksum(*code*) $=$ `0x1c43b5cf`

Opaque Predicates

- ⊕ Increase in complexity (branch count, McCabe)
- ⊕ Can be built on hard problems (e. g., aliasing)
- ⊕ Forces analyst to encode additional knowledge
- ⊕ Hard to solve statically
- ⊖ Solved for free using **concrete execution traces**

⚠ Examples

- `GetCurrentProcess()` $\Rightarrow -1$
- `fldpi`[1] $\Rightarrow$ `st(0)` $= \pi$
- $x^2 \geq 0 \quad \forall x$
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- pointer A *must-alias* pointer B
- checksum(*code*) $=$ `0x1c43b5cf`

Code Obfuscation Techniques

Virtual Machines

Virtual Machines

```
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
```

Virtual Machines

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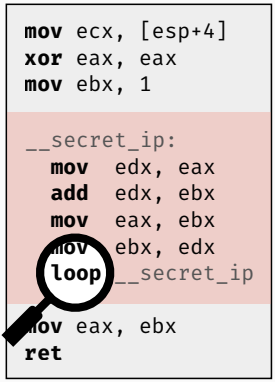
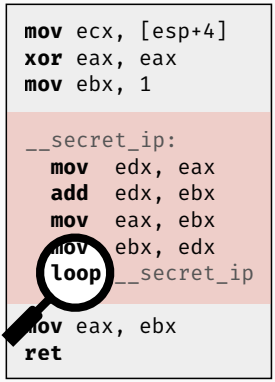
Virtual Machines



Virtual Machines



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 Machines

```
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 Machines

```
mov ecx, [esp+4]
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__secret_ip:
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  db 6f 6f 6b 20 6c 69 6b
  db 65 20 61 6e 79 74 68
     69 6e 67 20 74 6f 20
     65 2e de ad be ef
```

Virtual Machines

Core Components

VM Entry/Exit	Context Switch: native context ⇔ virtual context
VM Dispatcher	Fetch–Decode–Execute loop
Handler Table	Individual VM ISA instruction semantics

- **Entry** Copy native context (registers, flags) to VM context.
- **Exit** Copy VM context back to native context.

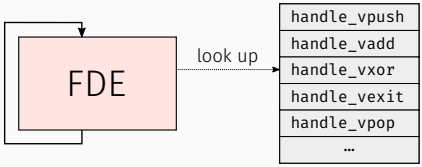
- Mapping from native to virtual registers is often 1:1.

Virtual Machines

Core Components

VM Entry/Exit	Context Switch: native context ⇔ virtual context
VM Dispatcher	Fetch–Decode–Execute loop
Handler Table	Individual VM ISA instruction semantics

1. Fetch and decode instruction
2. Forward virtual instruction pointer
3. Look up handler for opcode in handler table
4. Invoke handler

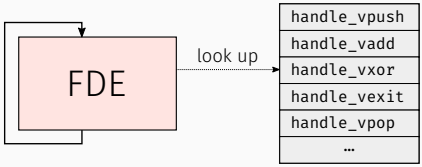


Virtual Machines

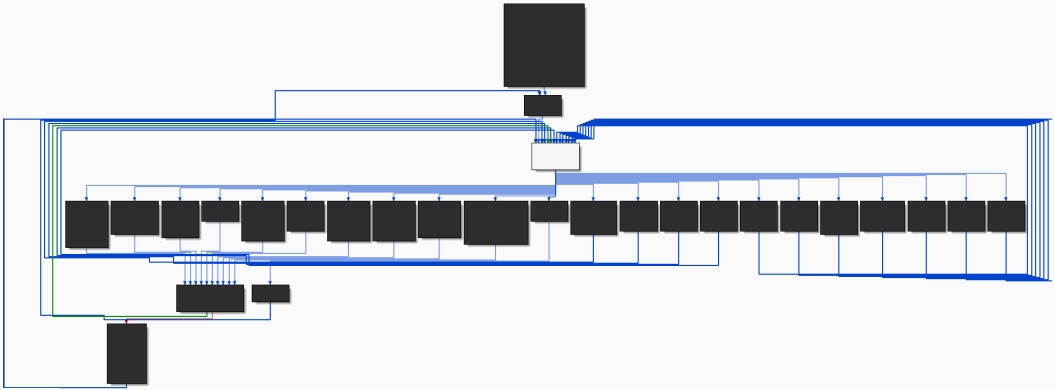
Core Components

VM Entry/Exit	Context Switch: native context ⇔ virtual context
VM Dispatcher	Fetch–Decode–Execute loop
Handler Table	Individual VM ISA instruction semantics

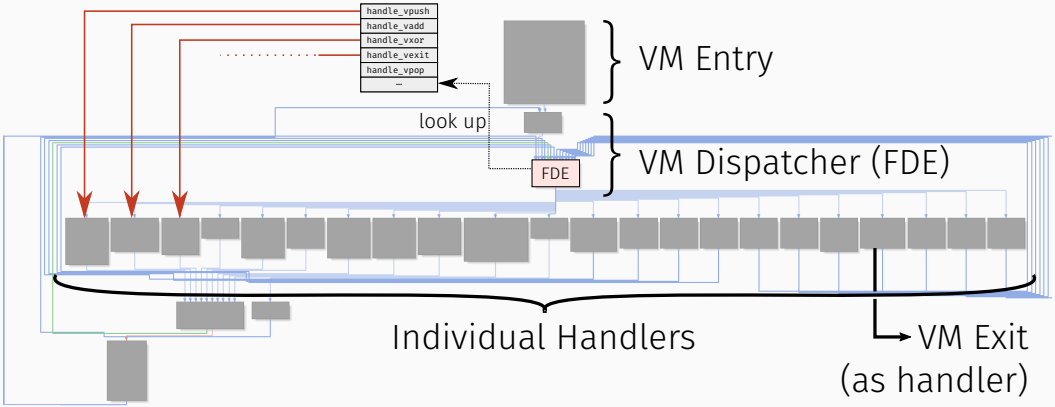
- Table of function pointers indexed by opcode
- One handler per virtual instruction
- Each handler decodes operands and updates VM context



Virtual Machines



Virtual Machines



Virtual Machines

```
__vm_dispatcher:
  mov   bl, [rsi]
  inc   rsi
  movzx rax, bl
  jmp   __handler_table[rax * 8]
```

VM Dispatcher

`rsi` – virtual instruction pointer
`rbp` – VM context

Virtual Machines

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__vm_dispatcher:
  mov   bl, [rsi]
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```

VM Dispatcher

`rsi` – virtual instruction pointer
`rbp` – VM context

```
__handle_vnor:
  mov   rcx, [rbp]
  mov   rbx, [rbp + 4]
  not   rcx
  not   rbx
  and   rcx, rbx
  mov   [rbp + 4], rcx
  pushf
  pop   [rbp]
  jmp   __vm_dispatcher
```

Handler performing `nor`
(with flag side-effects)

Virtual Machine Hardening

Hardening Technique #1 – Obfuscating individual VM components.

- Handlers are *conceptually simple*.

Virtual Machines

Hardening Technique #1 – Obfuscating individual VM components.

- Handlers are *conceptually simple*.
- Apply traditional code obfuscation transformations:
  - Substitution (`mov rax, rbx` ➡ `push rbx; pop rax`)
  - Opaque Predicates
  - Junk Code
  - …

```
mov eax, dword [rbp]
mov ecx, dword [rbp+4]
cmp r11w, r13w
sub rbp, 4
not eax
clc
cmc
cmp rdx, 0x28b105fa
not ecx
cmp r12b, r9b
```

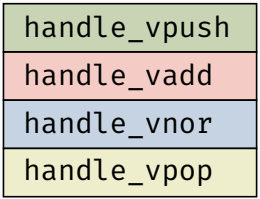
Hardening Technique #2 – Duplicating VM handlers.

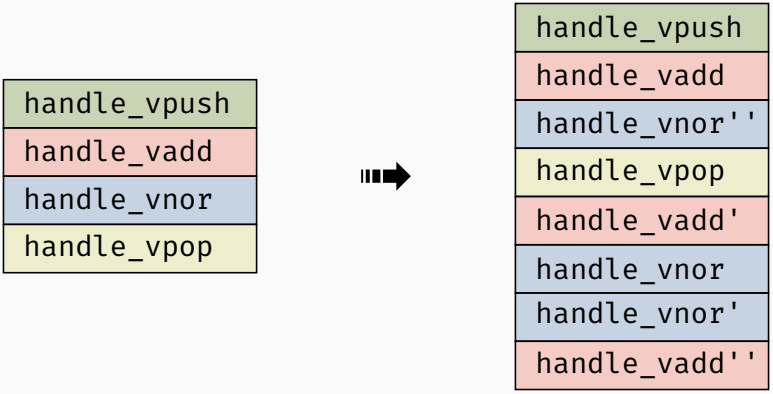
- Handler table is typically indexed using one byte (= 256 entries).

Hardening Technique #2 – Duplicating VM handlers.

- Handler table is typically indexed using one byte (= 256 entries).
- **Idea:** *Duplicate* existing handlers to populate full table.
- Use traditional obfuscation techniques to impede *code similarity* analyses.

Goal: Increase workload of reverse engineer.


handle_vpush
handle_vadd
handle_vnor
handle_vpop

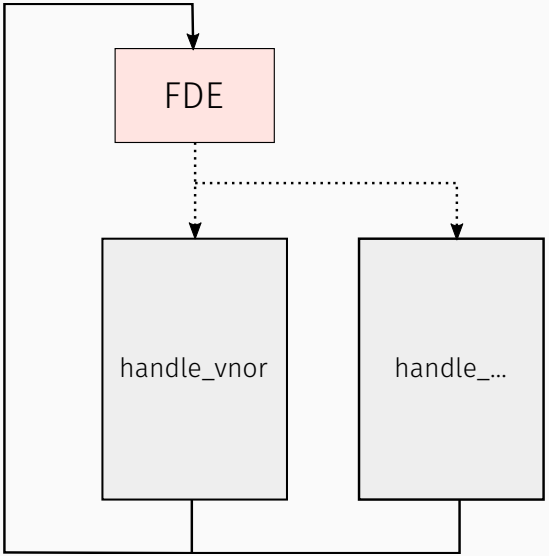

handle_vpush
handle_vadd
handle_vnor
handle_vpop
handle_vpush
handle_vadd
handle_vnor''
handle_vpop
handle_vadd'
handle_vnor
handle_vnor'
handle_vadd''

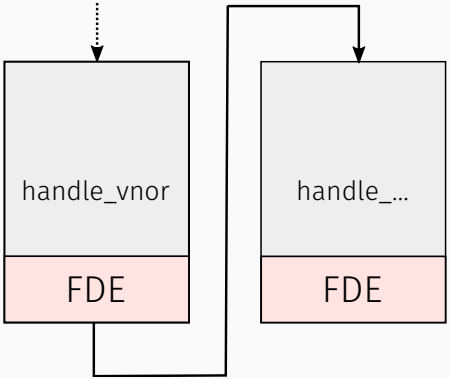
Hardening Technique #3 – No central VM dispatcher.

- A *central* VM dispatcher allows attacker to easily observe VM execution.
- **Idea:** Instead of branching to the central dispatcher, *inline* it into each handler.

Goal: No “single point of failure”.

(Themida, VMProtect Demo)


FDE
handle_vnor
handle_...


handle_vnor
FDE
handle_...
FDE

Programming Techniques
R. Morris Editor

Threaded Code

James R. Bell
Digital Equipment Corporation

The concept of "threaded code" is presented as an alternative to machine language code. Hardware and software realizations of it are given. In software it is realized as interpretive code not needing an interpreter. Extensions and optimizations are mentioned.

Key Words and Phrases: interpreter, machine code, time tradeoff, space tradeoff, compiled code, subroutine calls, threaded code

CR Categories: 4.12, 4.13, 6.33

Fig. 2 Flow of control: interpretive code.

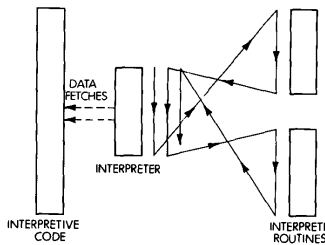
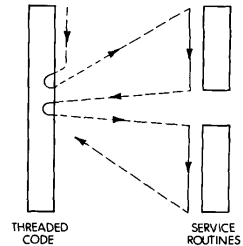


Fig. 3. Flow of control: threaded code.



Hardening Technique #4 – No explicit handler table.

- An *explicit* handler table easily reveals all VM handlers.

Hardening Technique #4 – No explicit handler table.

- An *explicit* handler table easily reveals all VM handlers.
- **Idea:** Instead of querying an explicit handler table, *encode* the next handler address in the VM instruction itself.

Goal: Hide location of handlers that have not been executed yet.

(VMProtect Full, SolidShield)

Hardening Technique #4 – No explicit handler table.

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- Idea

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- Idea

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(VMProtect Full, SolidShield)

SOFTWARE–PRACTICE AND EXPERIENCE, VOL. 11, 963–973 (1981)

Interpretation Techniques*

PAUL KLINT

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SUMMARY

The relative merits of implementing high level programming languages by means of interpretation or compilation are discussed. The properties and the applicability of interpretation techniques known as classical interpretation, direct threaded code and indirect threaded code are described and compared.

KEY WORDS Interpretation versus compilation Interpretation techniques Instruction encoding Code generation Direct threaded code Indirect threaded code.

Hardening Technique #5 – Blinding VM bytecode.

- *Global analyses* on the bytecode possible, easy to patch instructions.

Hardening Technique #5 – Blinding VM bytecode.

- *Global analyses* on the bytecode possible, easy to patch instructions.
- **Idea:**
  - *Flow-sensitive* instruction decoding (“decryption” based on key register).
  - Custom decryption routine per handler, diversification.
  - Patching requires re-encryption of subsequent bytecode.

Goal: Hinder global analyses of bytecode and patching.

$$
\begin{aligned}
\textit{operand} &\leftarrow [\mathbf{vIP} + 0] \\
\\
\\
\\
\textit{context} &\leftarrow \text{semantics}(\textit{context}, \textit{operand}) \\
\textit{next\_handler} &\leftarrow [\mathbf{vIP} + 4] \\
\\
\\
\\
\mathbf{vIP} &\leftarrow \mathbf{vIP} + 8 \\
\textbf{jmp}\ &\textit{next\_handler}
\end{aligned}
$$

$$
\begin{aligned}
&\textit{operand} &&\leftarrow [\mathbf{vIP} + 0] \\
\\
&\textit{operand} &&\leftarrow \text{unmangle}(\textit{operand}, \mathbf{key}) \\
&\mathbf{key} &&\leftarrow \text{unmangle}'(\mathbf{key}, \textit{operand}) \\
\\
&\textit{context} &&\leftarrow \text{semantics}(\textit{context}, \textit{operand}) \\
&\textit{next\_handler} &&\leftarrow [\mathbf{vIP} + 4] \\
\\
&\textit{next\_handler} &&\leftarrow \text{unmangle}''(\textit{next\_handler}, \mathbf{key}) \\
&\mathbf{key} &&\leftarrow \text{unmangle}'''(\mathbf{key}, \textit{next\_handler}) \\
\\
&\mathbf{vIP} \leftarrow \mathbf{vIP} + 8 \\
&\textbf{jmp } \textit{next\_handler}
\end{aligned}
$$

Code Obfuscation Techniques

Mixed Boolean-Arithmetic

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What does this expression compute?

$$(x \oplus y) + 2 \cdot (x \wedge y)$$

Mixed Boolean-Arithmetic

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$$(x \oplus y) + 2 \cdot (x \wedge y)$$
$$= \mathsf{x + y}$$

Mixed Boolean-Arithmetic

What does this expression compute?

$$(((x \oplus y) + ((x \wedge y) \ll 1)) \vee z) + (((x \oplus y) + ((x \wedge y) \ll 1)) \wedge z)$$

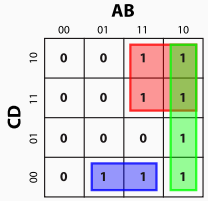
Mixed Boolean-Arithmetic

What does this expression compute?

$$(((x \oplus y) + ((x \wedge y) \ll 1)) \vee z) + (((x \oplus y) + ((x \wedge y) \ll 1)) \wedge z)$$
$$= \mathsf{x + y + z}$$

- Boolean identities?
- Arithmetic identities?
- Karnaugh-Veitch maps?

$$A \cdot 0 = 0$$
$$A + B = \overline{\overline{A} \cdot \overline{B}}$$
$$x^2 - y^2 = (x + y)(x - y)$$



Mixed Boolean-Arithmetic

Boolean-arithmetic algebra BA[n]

$$(\mathrm{B}^n, \wedge, \vee, \oplus, \neg, \leq, \geq, >, <, \leq^s, \geq^s, >^s, <^s, \neq, =, \gg^s, \gg, \ll, +, -, \cdot)$$
is a Boolean-arithmetic algebra BA[n], for $n > 0$, $\mathrm{B} = \{0, 1\}$.

BA[n] includes, amongst others, both:

- Boolean algebra $(\mathrm{B}^n, \wedge, \vee, \neg)$,
- Integer modular ring $\mathbb{Z}/(2^n)$.

No techniques to simplify such expressions easily!

Deobfuscation

Symbolic Execution

```
__handle_vnor:
  mov   rcx, [rbp]
  mov   rbx, [rbp + 4]
  not   rcx
  not   rbx
  and   rcx, rbx
  mov   [rbp + 4], rcx
  pushf
  pop   [rbp]
  jmp   __vm_dispatcher
```

Handler performing `nor`
(with flag side-effects)

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Handler performing `nor`
(with flag side-effects)

rcx ← [rbp]

Symbolic Execution

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```

$$\begin{aligned} \text{rcx} &\leftarrow [\text{rbp}] \\ \text{rbx} &\leftarrow [\text{rbp} + 4] \end{aligned}$$

Handler performing `nor`
(with flag side-effects)

Symbolic Execution

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  pushf
  pop   [rbp]
  jmp   __vm_dispatcher
```

Handler performing `nor`
(with flag side-effects)

$$
\begin{aligned}
\text{rcx} &\leftarrow [\text{rbp}] \\
\text{rbx} &\leftarrow [\text{rbp} + 4] \\
\text{rcx} &\leftarrow \neg\,\text{rcx} = \neg\,[\text{rbp}]
\end{aligned}
$$

Symbolic Execution

```
__handle_vnor:
  mov   rcx, [rbp]
  mov   rbx, [rbp + 4]
  not   rcx
• not   rbx
  and   rcx, rbx
  mov   [rbp + 4], rcx
  pushf
  pop   [rbp]
  jmp   __vm_dispatcher
```

Handler performing `nor`
(with flag side-effects)

$$
\begin{aligned}
\text{rcx} &\leftarrow [\text{rbp}] \\
\text{rbx} &\leftarrow [\text{rbp} + 4] \\
\text{rcx} &\leftarrow \neg\,\text{rcx} = \neg\,[\text{rbp}] \\
\text{rbx} &\leftarrow \neg\,\text{rbx} = \neg\,[\text{rbp} + 4]
\end{aligned}
$$

Symbolic Execution

```
__handle_vnor:
  mov   rcx, [rbp]
  mov   rbx, [rbp + 4]
  not   rcx
  not   rbx
• and   rcx, rbx
  mov   [rbp + 4], rcx
  pushf
  pop   [rbp]
  jmp   __vm_dispatcher
```

Handler performing **nor**
(with flag side-effects)

$$
\begin{aligned}
\text{rcx} &\leftarrow [\text{rbp}] \\
\text{rbx} &\leftarrow [\text{rbp} + 4] \\
\text{rcx} &\leftarrow \neg\,\text{rcx} = \neg\,[\text{rbp}] \\
\text{rbx} &\leftarrow \neg\,\text{rbx} = \neg\,[\text{rbp} + 4] \\
\text{rcx} &\leftarrow \text{rcx} \wedge \text{rbx} \\
&\qquad = (\neg\,[\text{rbp}]) \wedge (\neg\,[\text{rbp} + 4])
\end{aligned}
$$

Symbolic Execution

```
__handle_vnor:
  mov   rcx, [rbp]
  mov   rbx, [rbp + 4]
  not   rcx
  not   rbx
• and   rcx, rbx
  mov   [rbp + 4], rcx
  pushf
  pop   [rbp]
  jmp   __vm_dispatcher
```

Handler performing **nor**
(with flag side-effects)

$$
\begin{aligned}
\text{rcx} &\leftarrow [\text{rbp}] \\
\text{rbx} &\leftarrow [\text{rbp} + 4] \\
\text{rcx} &\leftarrow \neg\,\text{rcx} = \neg\,[\text{rbp}] \\
\text{rbx} &\leftarrow \neg\,\text{rbx} = \neg\,[\text{rbp} + 4] \\
\text{rcx} &\leftarrow \text{rcx} \wedge \text{rbx} \\
&= (\neg\,[\text{rbp}]) \wedge (\neg\,[\text{rbp} + 4]) \\
&= [\text{rbp}] \downarrow [\text{rbp} + 4]
\end{aligned}
$$

Symbolic Execution

```
__handle_vnor:
  mov   rcx, [rbp]
  mov   rbx, [rbp + 4]
  not   rcx
  not   rbx
  and   rcx, rbx
• mov   [rbp + 4], rcx
  pushf
  pop   [rbp]
  jmp   __vm_dispatcher
```

Handler performing **nor**
(with flag side-effects)

$$
\begin{aligned}
\text{rcx} &\leftarrow [\text{rbp}] \\
\text{rbx} &\leftarrow [\text{rbp} + 4] \\
\text{rcx} &\leftarrow \neg\,\text{rcx} = \neg\,[\text{rbp}] \\
\text{rbx} &\leftarrow \neg\,\text{rbx} = \neg\,[\text{rbp} + 4] \\
\text{rcx} &\leftarrow \text{rcx} \wedge \text{rbx} \\
&= (\neg\,[\text{rbp}]) \wedge (\neg\,[\text{rbp} + 4]) \\
&= [\text{rbp}] \downarrow [\text{rbp} + 4] \\
[\text{rbp} + 4] &\leftarrow \text{rcx} = [\text{rbp}] \downarrow [\text{rbp} + 4]
\end{aligned}
$$

Symbolic Execution

```
__handle_vnor:
  mov   rcx, [rbp]
  mov   rbx, [rbp + 4]
  not   rcx
  not   rbx
  and   rcx, rbx
  mov   [rbp + 4], rcx
• pushf
  pop   [rbp]
  jmp   __vm_dispatcher
```

Handler performing `nor`
(with flag side-effects)

$$
\begin{aligned}
\text{rcx} &\leftarrow [\text{rbp}] \\
\text{rbx} &\leftarrow [\text{rbp} + 4] \\
\text{rcx} &\leftarrow \neg\,\text{rcx} = \neg\,[\text{rbp}] \\
\text{rbx} &\leftarrow \neg\,\text{rbx} = \neg\,[\text{rbp} + 4] \\
\text{rcx} &\leftarrow \text{rcx} \wedge \text{rbx} \\
&\qquad = (\neg\,[\text{rbp}]) \wedge (\neg\,[\text{rbp} + 4]) \\
&\qquad = [\text{rbp}] \downarrow [\text{rbp} + 4] \\
[\text{rbp} + 4] &\leftarrow \text{rcx} = [\text{rbp}] \downarrow [\text{rbp} + 4] \\
\\
\text{rsp} &\leftarrow \text{rsp} - 4 \\
[\text{rsp}] &\leftarrow \text{flags}
\end{aligned}
$$

Symbolic Execution

```
__handle_vnor:
  mov   rcx, [rbp]
  mov   rbx, [rbp + 4]
  not   rcx
  not   rbx
  and   rcx, rbx
  mov   [rbp + 4], rcx
  pushf
• pop   [rbp]
  jmp   __vm_dispatcher
```

Handler performing **nor**
(with flag side-effects)

$$
\begin{aligned}
\text{rcx} &\leftarrow [\text{rbp}] \\
\text{rbx} &\leftarrow [\text{rbp} + 4] \\
\text{rcx} &\leftarrow \neg\,\text{rcx} = \neg\,[\text{rbp}] \\
\text{rbx} &\leftarrow \neg\,\text{rbx} = \neg\,[\text{rbp} + 4] \\
\text{rcx} &\leftarrow \text{rcx} \wedge \text{rbx} \\
&\qquad = (\neg\,[\text{rbp}]) \wedge (\neg\,[\text{rbp} + 4]) \\
&\qquad = [\text{rbp}] \downarrow [\text{rbp} + 4] \\
[\text{rbp} + 4] &\leftarrow \text{rcx} = [\text{rbp}] \downarrow [\text{rbp} + 4]
\end{aligned}
$$

$$
\begin{aligned}
\text{rsp} &\leftarrow \text{rsp} - 4 \\
[\text{rsp}] &\leftarrow \text{flags} \\
[\text{rbp}] &\leftarrow [\text{rsp}] = \text{flags} \\
\text{rsp} &\leftarrow \text{rsp} + 4
\end{aligned}
$$

Symbolic Execution

```
__handle_vnor:
  mov   rcx, [rbp]
  mov   rbx, [rbp + 4]
  not   rcx
  not   rbx
  and
  mov
  pushf
  pop   [rbp]
• jmp   __vm_dispatcher
```

$$[\text{rbp}+4] \leftarrow ([\text{rbp}] \downarrow [\text{rbp}+4])$$

$$\begin{aligned}
\text{rcx} &\leftarrow [\text{rbp}] \\
\text{rbx} &\leftarrow [\text{rbp}+4] \\
\text{rcx} &\leftarrow \neg\,\text{rcx} = \neg\,[\text{rbp}] \\
\text{rbx} &\leftarrow \neg\,\text{rbx} = \neg\,[\text{rbp}+4] \\
&\;\;\vdots \\
&= [\text{rbp}] \downarrow [\text{rbp}+4] \\
[\text{rbp}+4] &\leftarrow \text{rcx} = [\text{rbp}] \downarrow [\text{rbp}+4]
\end{aligned}$$

$$\begin{aligned}
\text{rsp} &\leftarrow \text{rsp} - 4 \\
[\text{rsp}] &\leftarrow \text{flags} \\
[\text{rbp}] &\leftarrow [\text{rsp}] = \text{flags} \\
\text{rsp} &\leftarrow \text{rsp} + 4
\end{aligned}$$

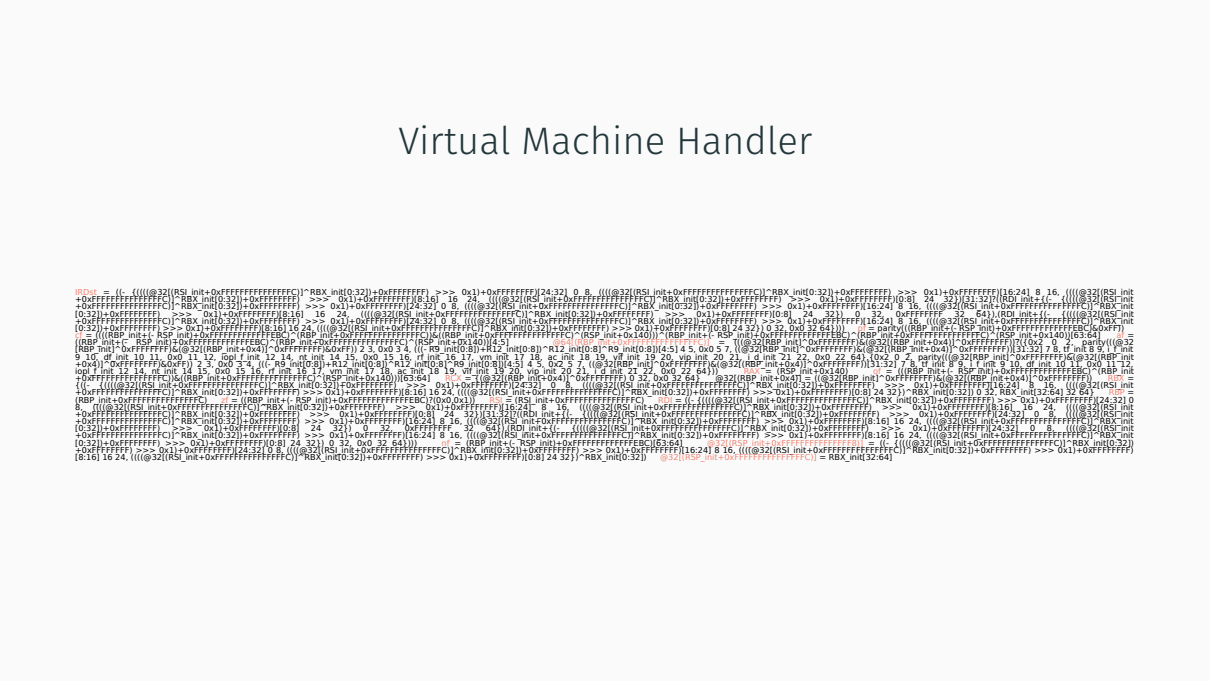
Handler performing **nor**
(with flag side-effects)

Virtual Machine Handler

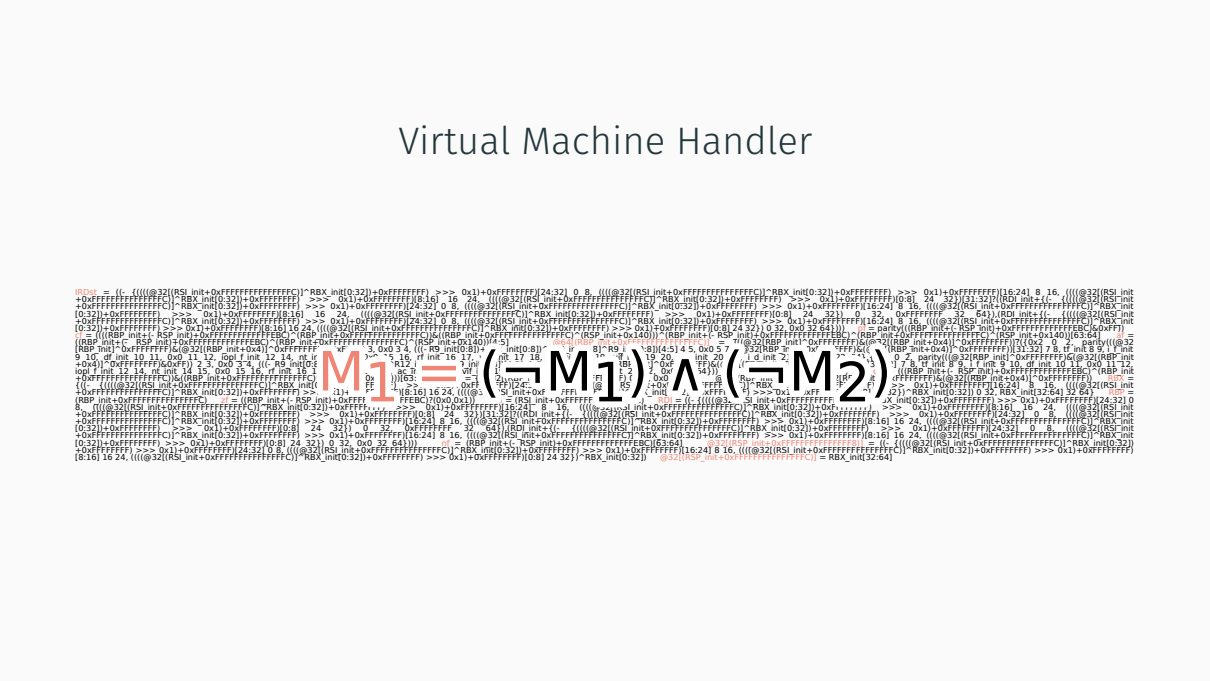
```
mov    eax, dword [rbp]
mov    ecx, dword [rbp + 4]
cmp    r11w, r13w
sub    rbp, 4
not    eax
clc
cmc
cmp    rdx, 0x28b105fa
not    ecx
cmp    r12b, r9b
cmc
and    eax, ecx
jmp    0xc239
mov    word [rbp + 8], eax
pushfq
movzx  eax, r10w
and    ax, di
pop    qword [rbp]
sub    rsi, 4
shld   rax, rdx, 0x1b
xor    ah, 0x4d
mov    eax, dword [rsi]
cmp    ecx, r11d
test   r10, 0x179708d5
xor    eax, ebx
```

```
jmp    0xfffffffffff63380
dec    eax
stc
ror    eax, 1
jmp    0xfffffffffff2a70
dec    eax
clc
bswap  eax
test   bp, 0x5124
neg    eax
test   dil, 0xe9
cmp    bx, r14w
cmc
push   rbx
sub    bx, 0x49f8
xor    dword [rsp], eax
and    bh, 0xaf
pop    rbx
movsxd rax, eax
test   r13b, 0x94
add    rdi, rax
jmp    0xfffffffffffc67c7
lea    rax, [rsp + 0x140]
cmp    rbp, rax
ja     0x6557b
jmp    rdi
```

Virtual Machine Handler



Virtual Machine Handler



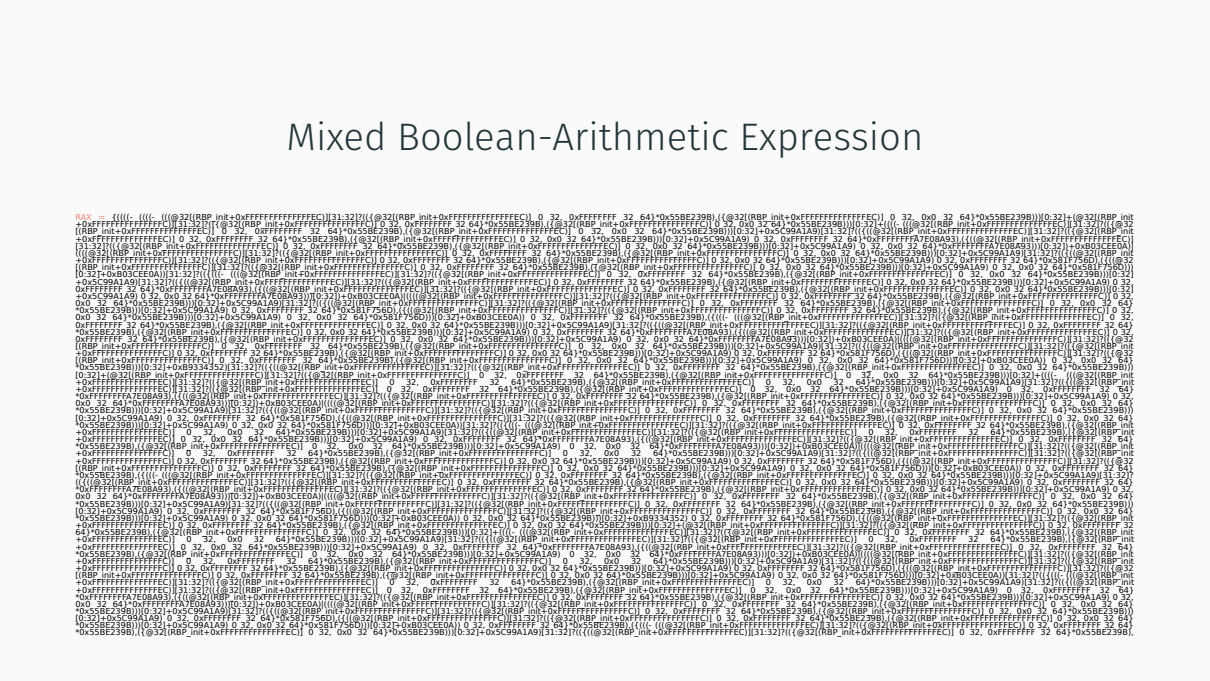
Mixed Boolean-Arithmetic Expression

```
int mixed_boolean(int A, int B, int C) {
    int result;

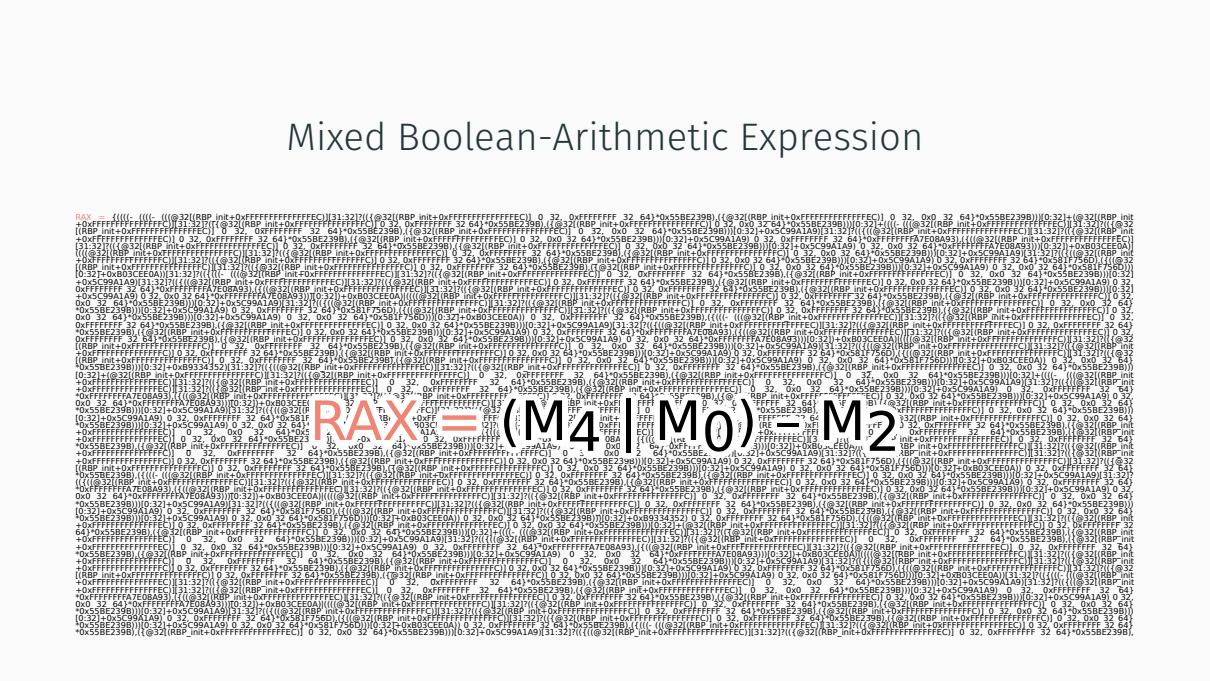
    result = ((((1438524315 + ((((1438524315 + C) + 1438524315 * ((2956783114 - -1478456685 * C) |
    (-1478456685 * (1668620215 - A) - 2956783115))) + A) - 1553572265)) + 1438524315 * ((2956783114 -
    -1478456685 * ((((1438524315 + C) + 1438524315 * ((2956783114 - -1478456685 * C) | (-1478456685 *
    (1668620215 - A) - 2956783115))) + A) - 1553572265)) | (-1478456685 * (1668620215 - B) -
    2956783115))) - ((1438524315 + (1668620215 - ((((1438524315 + C) + 1438524315 * ((2956783114 -
    -1478456685 * C) | (-1478456685 * (1668620215 - A) - 2956783115))) + A) - 1553572265))) +
    1438524315 * ((2956783114 - -1478456685 * (1668620215 - ((((1438524315 + C) + 1438524315 *
    ((2956783114 - -1478456685 * C) | (-1478456685 * (1668620215 - A) - 2956783115))) + A) -
    1553572265))) | (-1478456685 * B - 2956783115)))) + 1553572265;

    return -1478456685 * result - 2956783115;
}
```

Mixed Boolean-Arithmetic Expression



Mixed Boolean-Arithmetic Expression



Symbolic Execution

- ⊕ Captures full semantics of executed code
- ⊕ Computer algebra system, some degree of simplification
- ⊖ Usability decreases with increasing *syntactic* complexity
  - Artificial complexity (substitution, ...)
  - Algebraic complexity (MBA)

Symbolic Execution

- ⊕ Captures full semantics of executed code
- ⊕ Computer algebra system, some degree of simplification
- ⊖ Usability decreases with increasing *syntactic* complexity
  - Artificial complexity (substitution, …)
  - Algebraic complexity (MBA)

What if we could reason about *semantics* only instead of *syntax*?

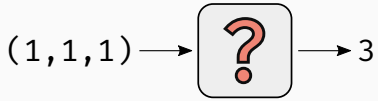
Program Synthesis

We use f as a black-box:

$$f(x, y, z) := (((x \oplus y) + ((x \wedge y) \cdot 2)) \vee z) + (((x \oplus y) + ((x \wedge y) \cdot 2)) \wedge z)$$

We use f as a black-box:

$$f(x, y, z) := (((x \oplus y) + ((x \wedge y) \cdot 2)) \vee z) + (((x \oplus y) + ((x \wedge y) \cdot 2)) \wedge z)$$



We use f as a black-box:

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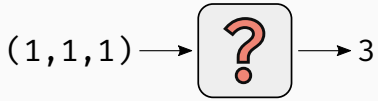
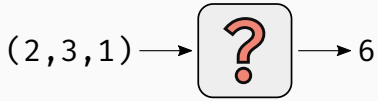


$(1, 1, 1) \rightarrow 3$

We use f as a black-box:

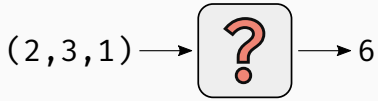
$$f(x, y, z) := (((x \oplus y) + ((x \wedge y) \cdot 2)) \vee z) + (((x \oplus y) + ((x \wedge y) \cdot 2)) \wedge z)$$



$(1, 1, 1) \to 3$

We use f as a black-box:

$$f(x, y, z) := (((x \oplus y) + ((x \wedge y) \cdot 2)) \vee z) + (((x \oplus y) + ((x \wedge y) \cdot 2)) \wedge z)$$

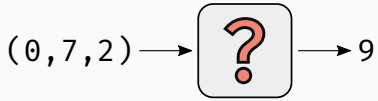


$(1, 1, 1) \to 3$

$(2, 3, 1) \to 6$

We use f as a black-box:

$$f(x, y, z) := (((x \oplus y) + ((x \wedge y) \cdot 2)) \vee z) + (((x \oplus y) + ((x \wedge y) \cdot 2)) \wedge z)$$



$(1, 1, 1) \to 3$

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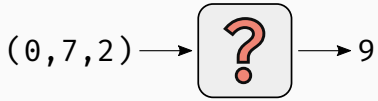
We use f as a black-box:

$$f(x, y, z) := (((x \oplus y) + ((x \wedge y) \cdot 2)) \vee z) + (((x \oplus y) + ((x \wedge y) \cdot 2)) \wedge z)$$



$(1, 1, 1) \to 3$

$(2, 3, 1) \to 6$

$(0, 7, 2) \to 9$

Program Synthesis: A Semantic Approach

We use f as a black-box:

$$f(x, y, z) := (((x \oplus y) + ((x \wedge y) \cdot 2)) \vee z) + (((x \oplus y) + ((x \wedge y) \cdot 2)) \wedge z)$$

$(1, 1, 1) \to 3$

$(2, 3, 1) \to 6$

$(0, 7, 2) \to 9$

We **learn** a function that has the same I/O behavior:

We use f as a black-box:

$$f(x, y, z) := (((x \oplus y) + ((x \wedge y) \cdot 2)) \vee z) + (((x \oplus y) + ((x \wedge y) \cdot 2)) \wedge z)$$

$(1, 1, 1) \to 3$
$(2, 3, 1) \to 6$
$(0, 7, 2) \to 9$

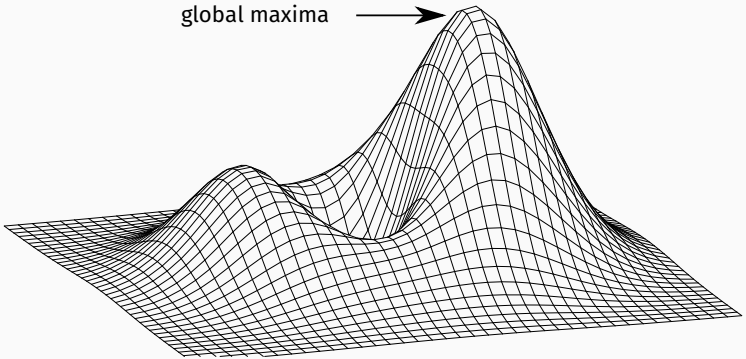
We **learn** a function that has the same I/O behavior:

$$h(x, y, z) := x + y + z$$

How to synthesize programs?

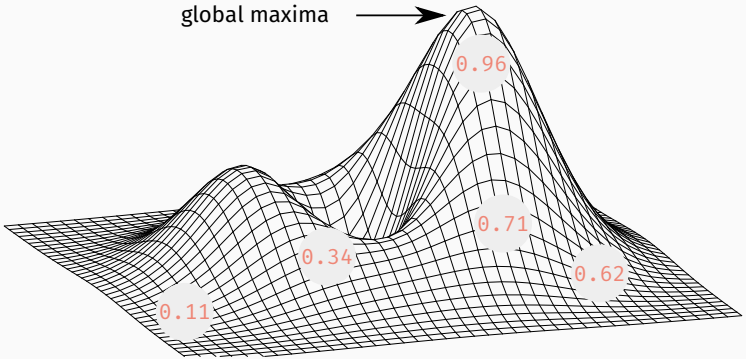
Stochastic Program Synthesis

- probabilistic optimization problem



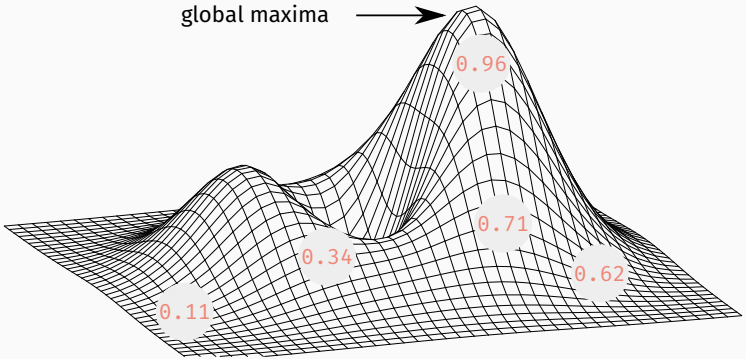
Stochastic Program Synthesis

- probabilistic optimization problem



Stochastic Program Synthesis

- probabilistic optimization problem
- based on Monte Carlo Tree Search (MCTS)



Let's synthesize: $a + b \mod 8$

Program Generation

$$U \to U + U \mid U * U \mid a \mid b$$

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- non-terminal symbol: U

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- input variables: $\{a, b\}$
- candidate programs: $a, \quad b, \quad a * b, \quad a + b, \quad \ldots$

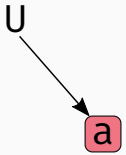
Program Generation

$$U \to U + U \mid U * U \mid a \mid b$$

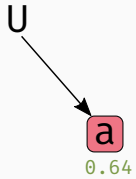
- non-terminal symbol: U
- input variables: $\{a, b\}$
- candidate programs: $a,\ \ b,\ \ a * b,\ \ a + b,\ \ \ldots$
- intermediate programs: $U + U,\ \ U * U,\ \ U + b,\ \ \ldots$

Monte Carlo Tree Search

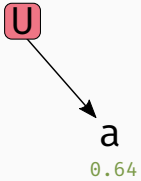
Monte Carlo Tree Search



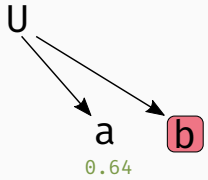
Monte Carlo Tree Search



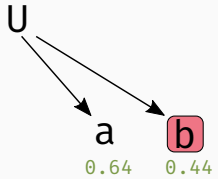
Monte Carlo Tree Search



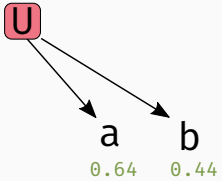
Monte Carlo Tree Search



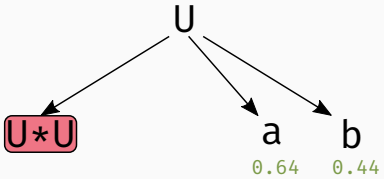
Monte Carlo Tree Search



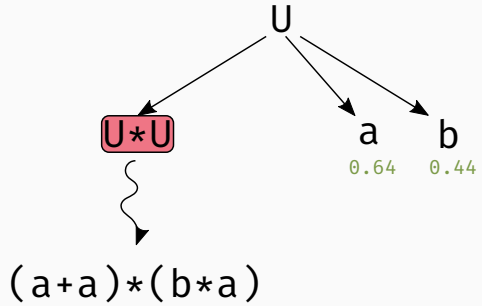
Monte Carlo Tree Search



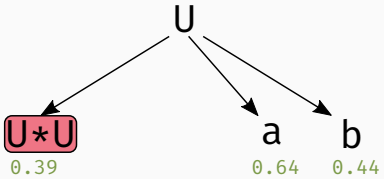
Monte Carlo Tree Search



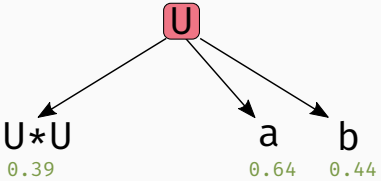
Monte Carlo Tree Search



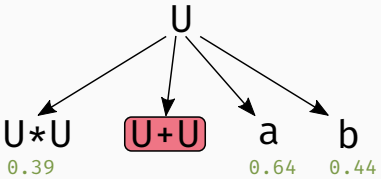
Monte Carlo Tree Search



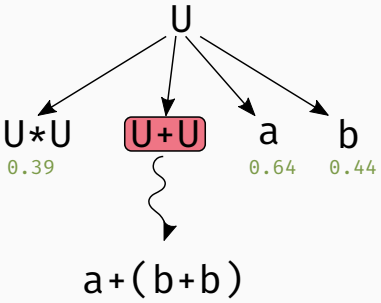
Monte Carlo Tree Search



Monte Carlo Tree Search



Monte Carlo Tree Search



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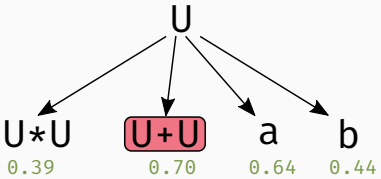

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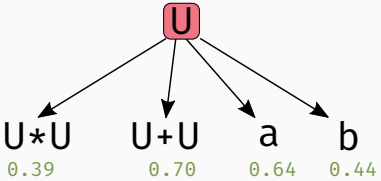

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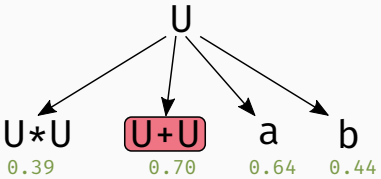

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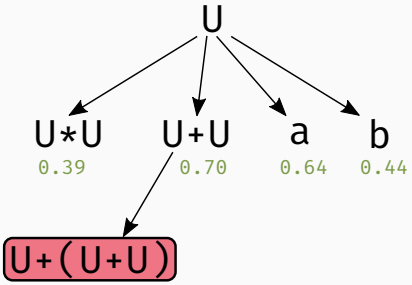

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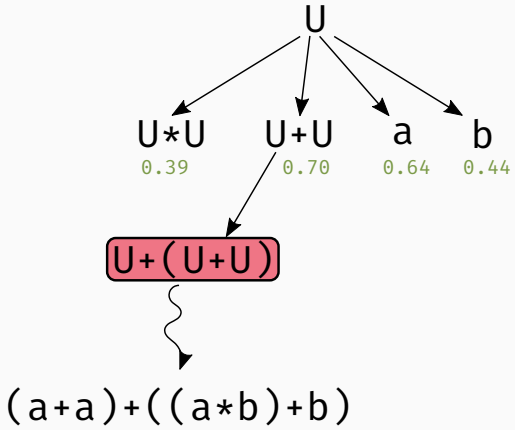

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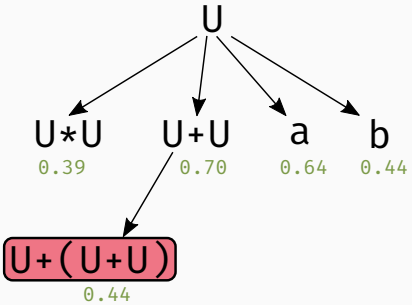

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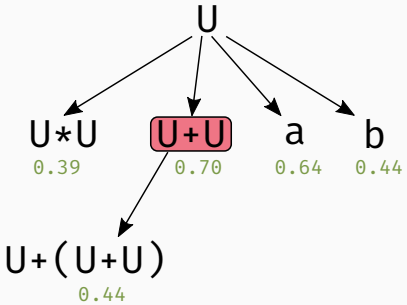

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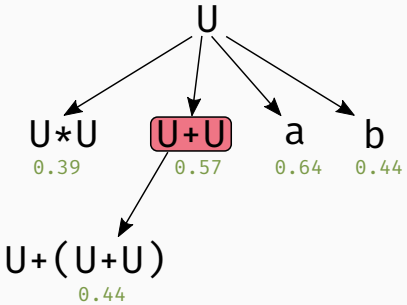

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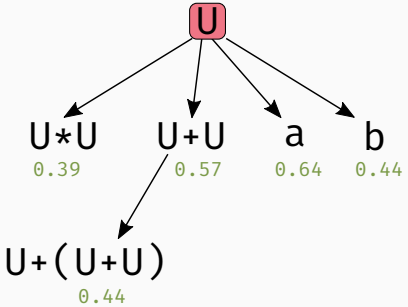

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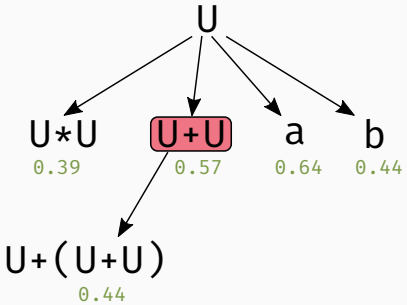

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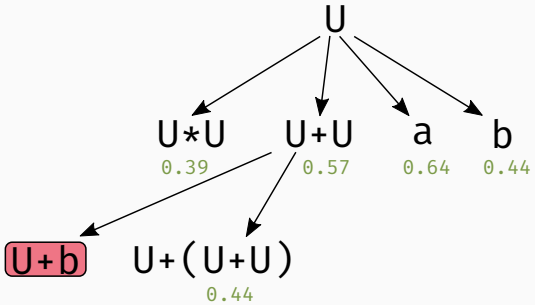

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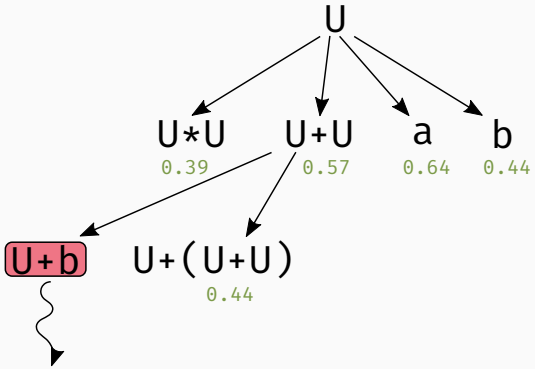

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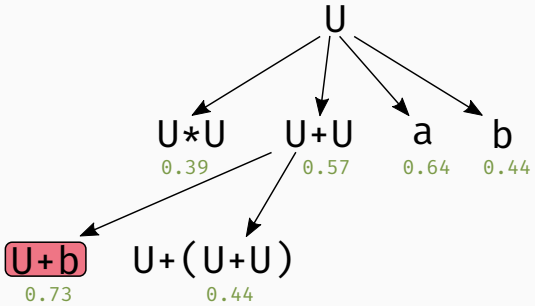

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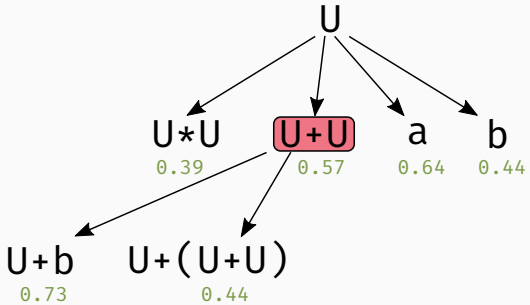

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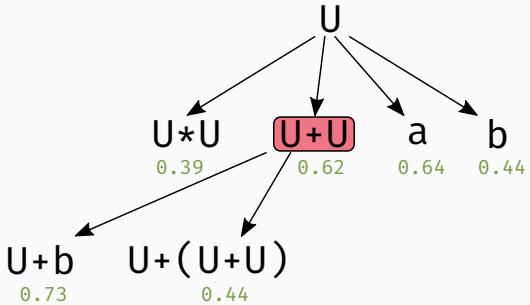

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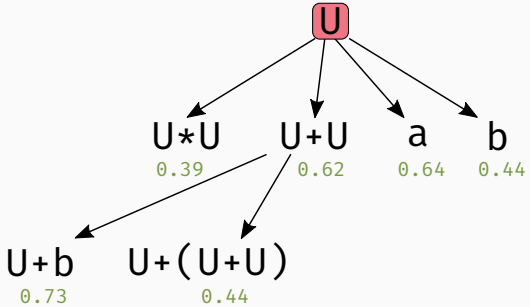

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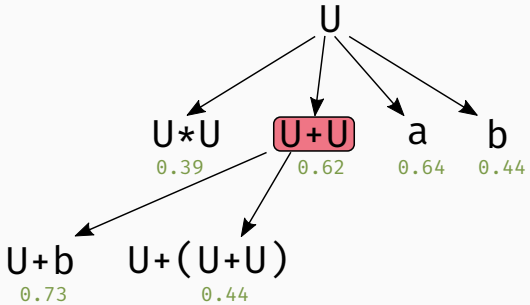

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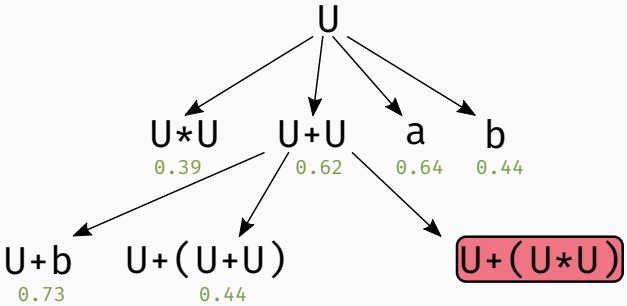

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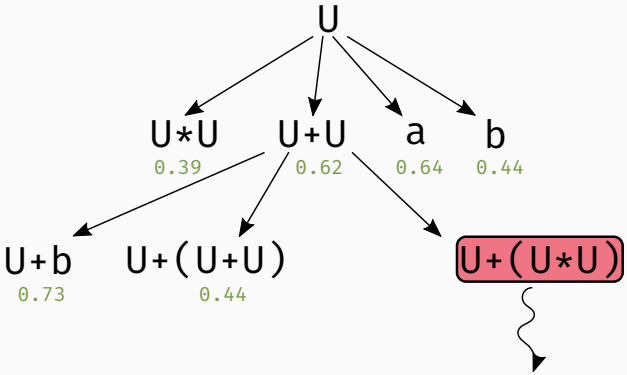

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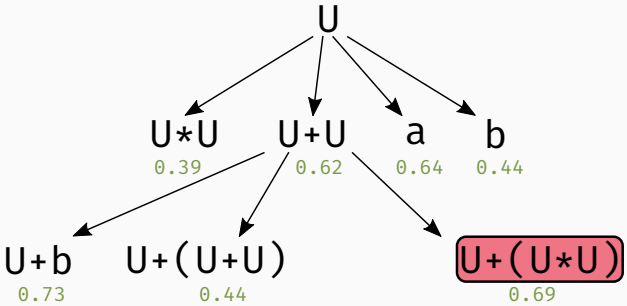

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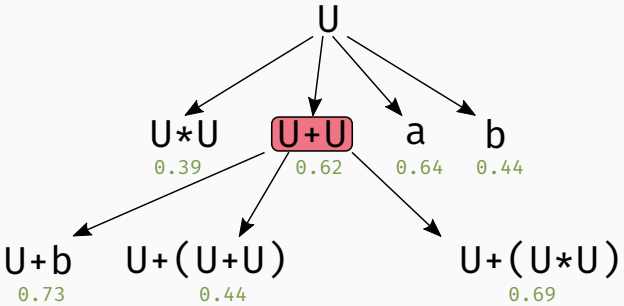

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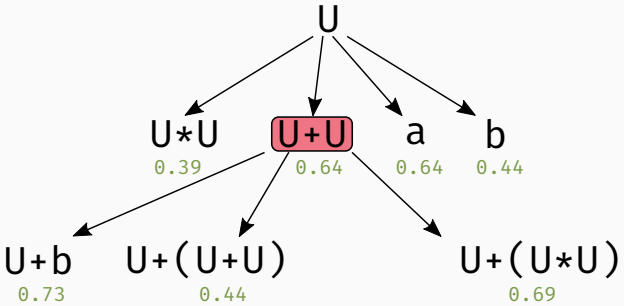

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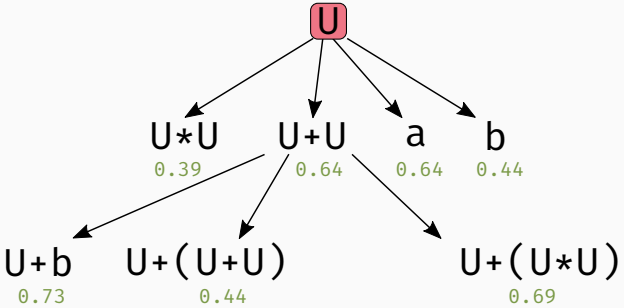

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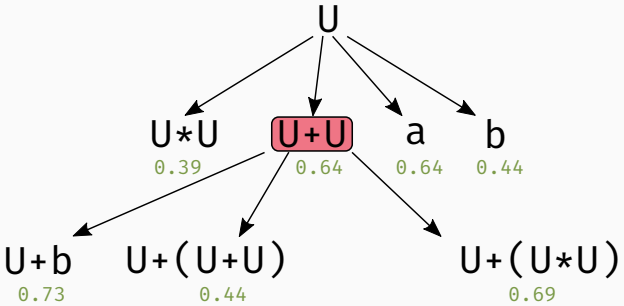

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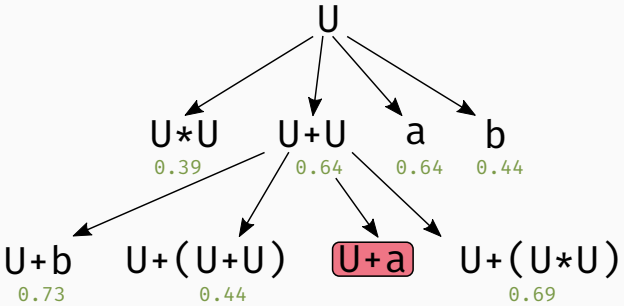

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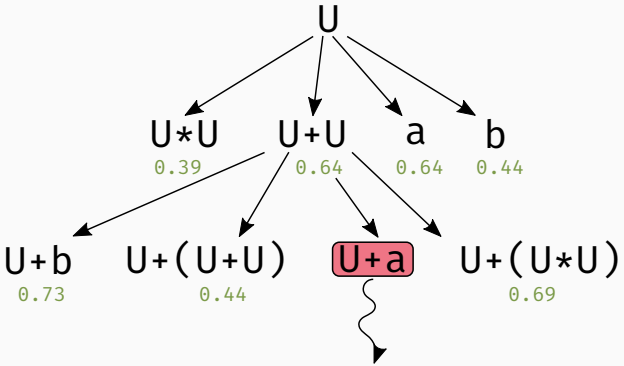

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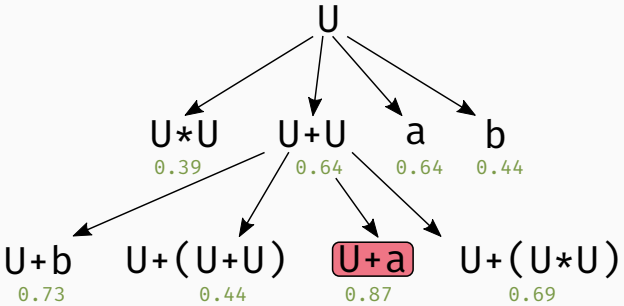

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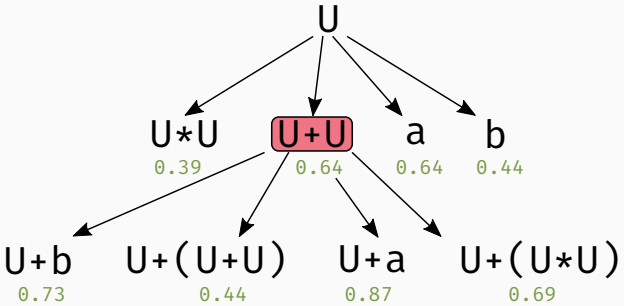

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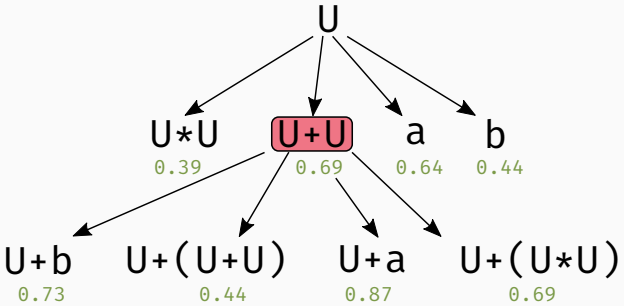

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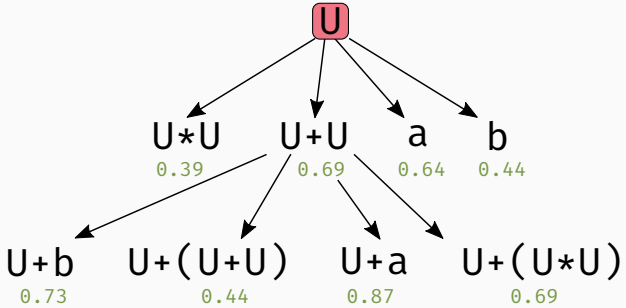

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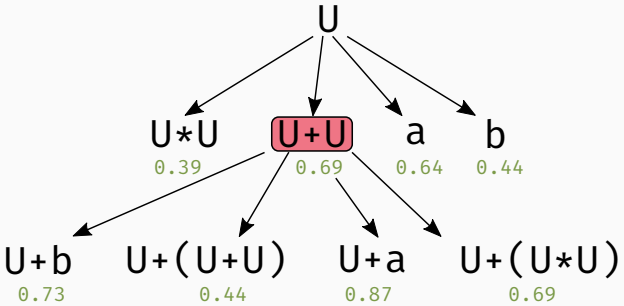

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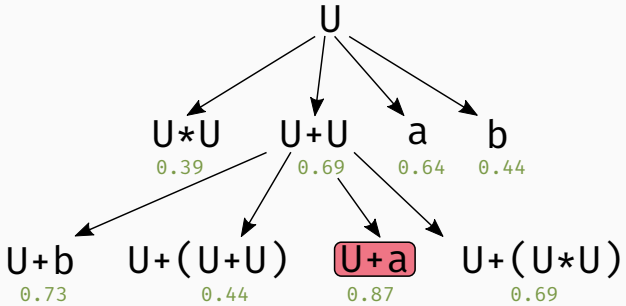

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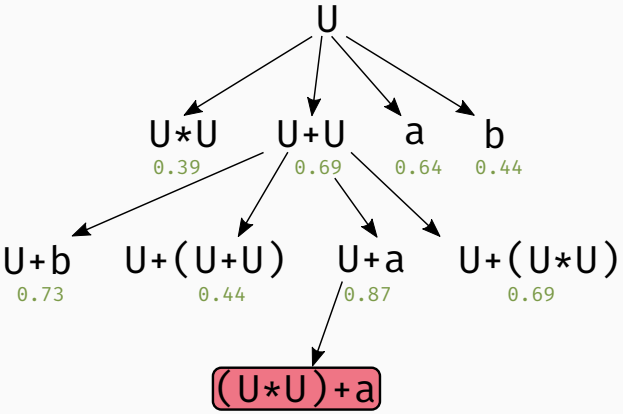

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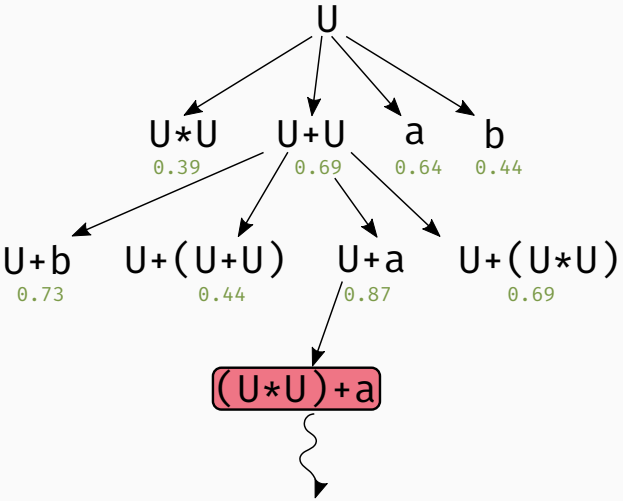

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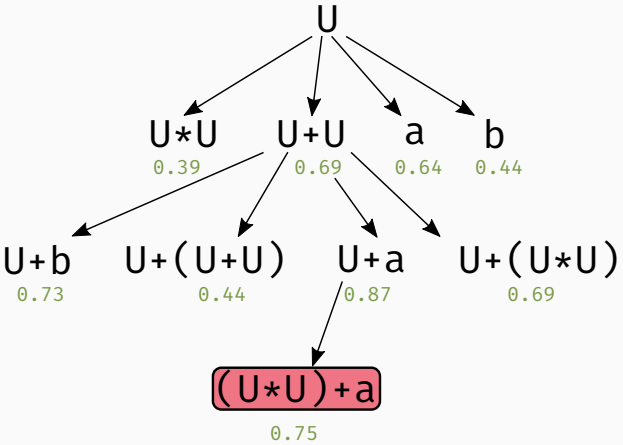

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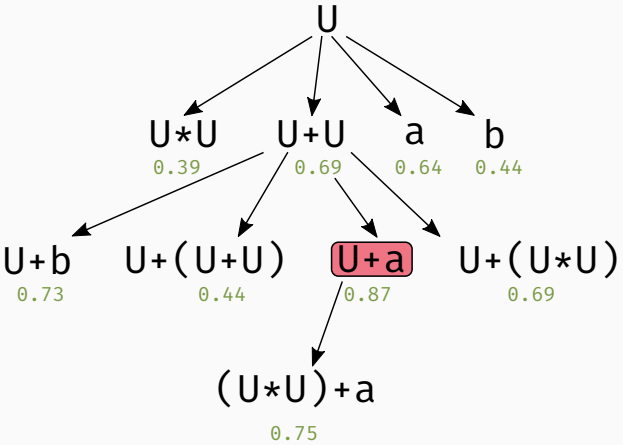

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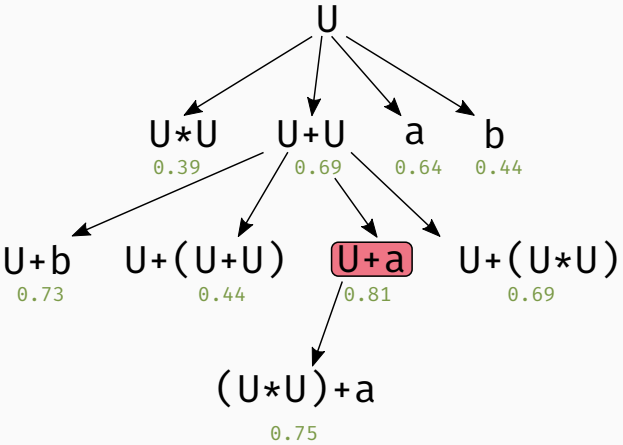

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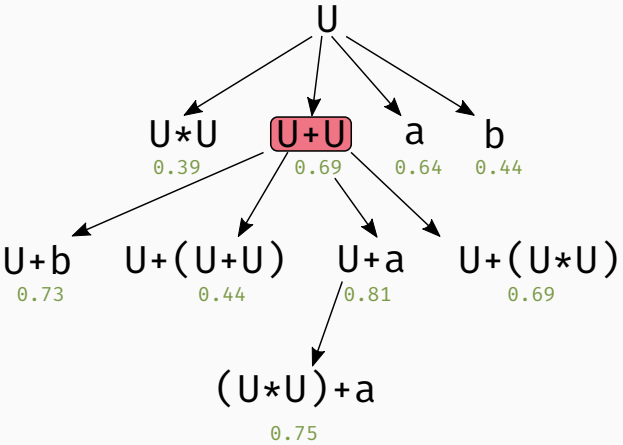

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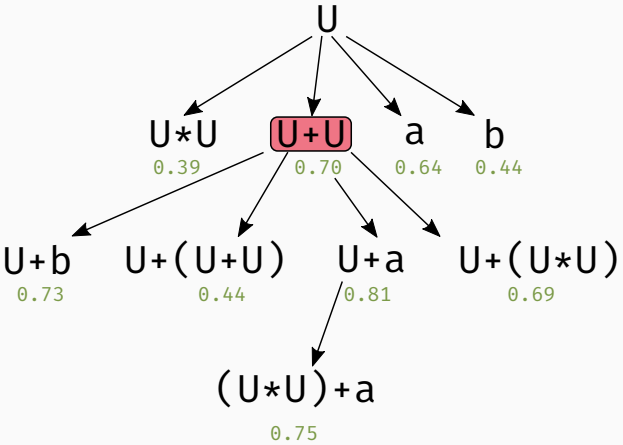

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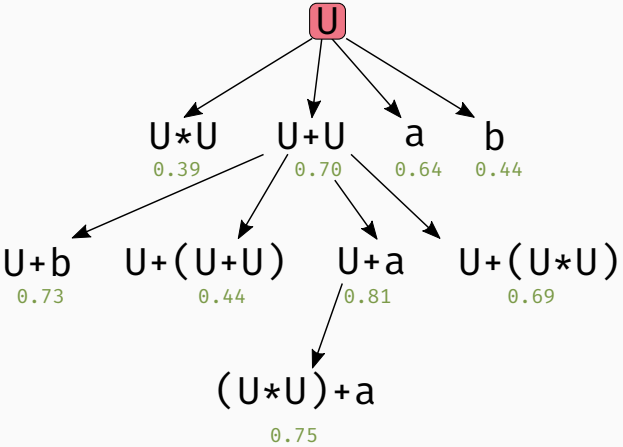

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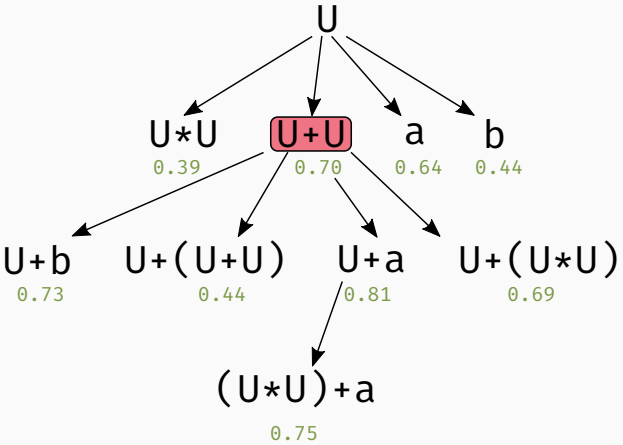

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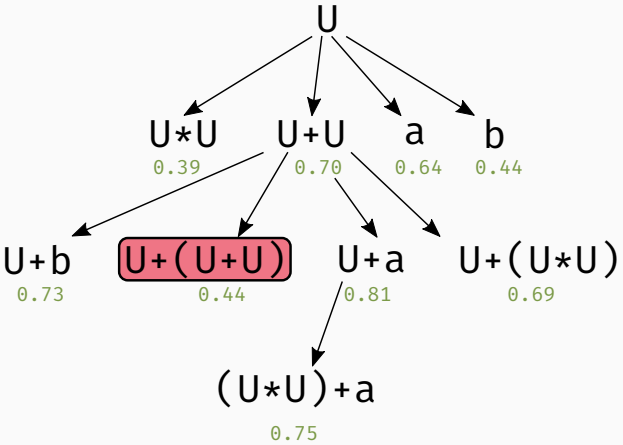

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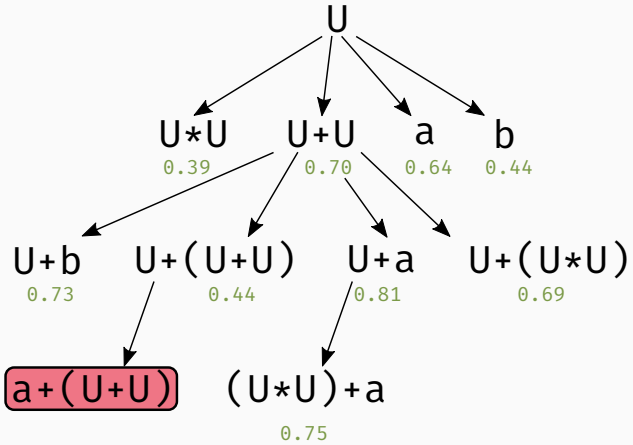

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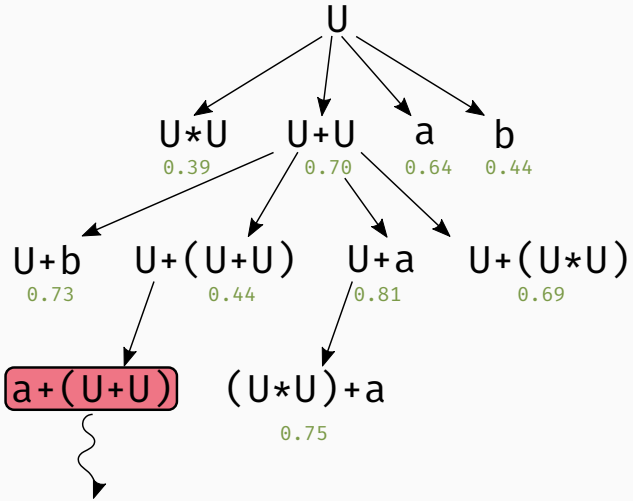

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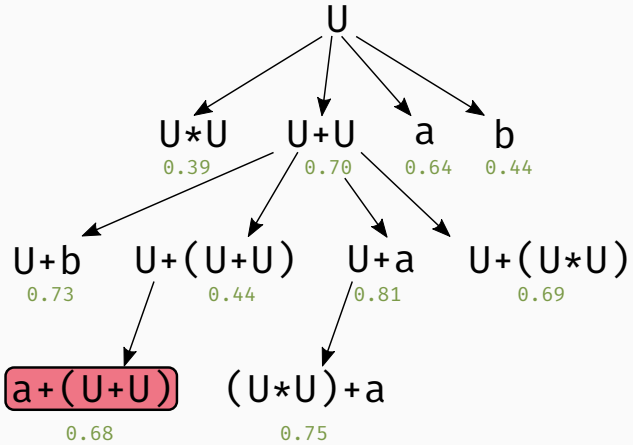

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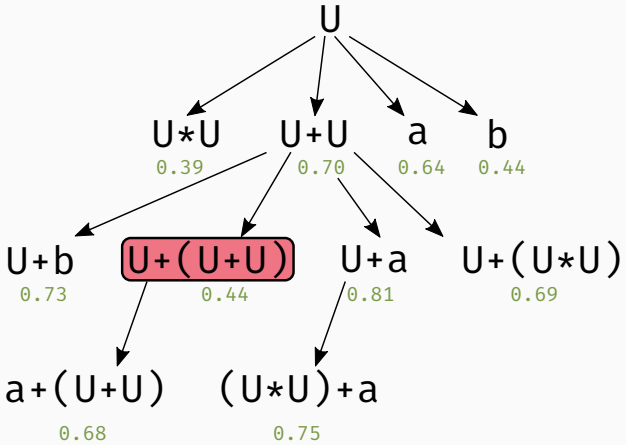

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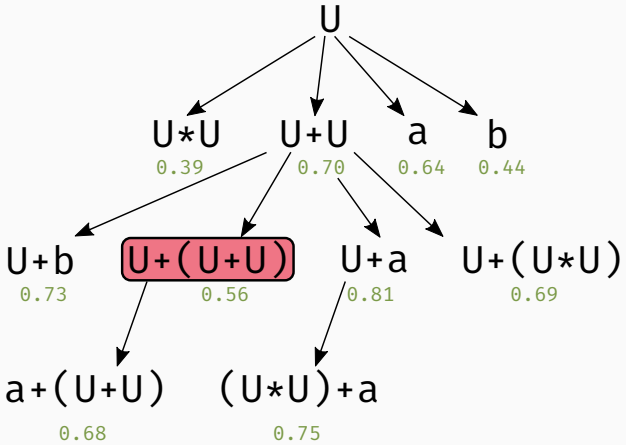

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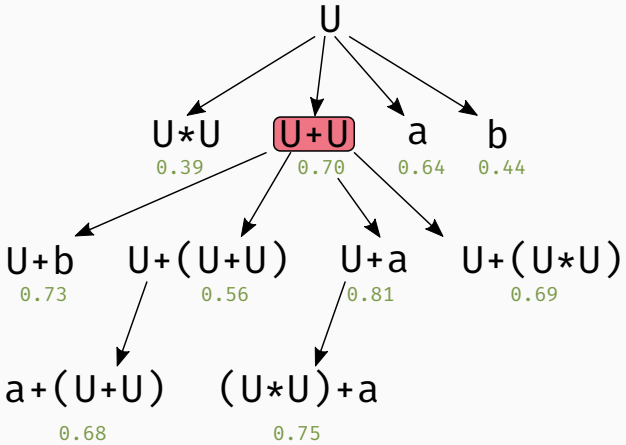

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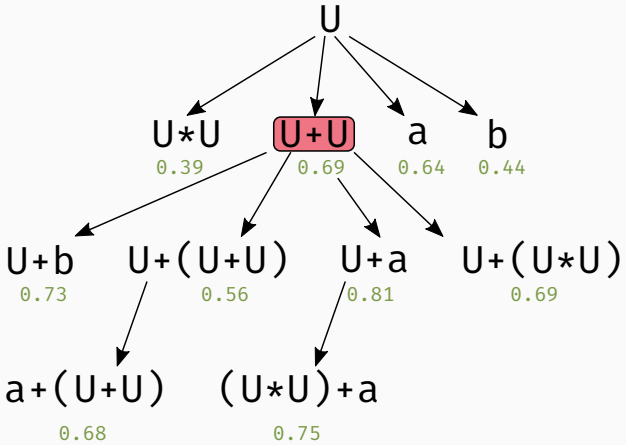

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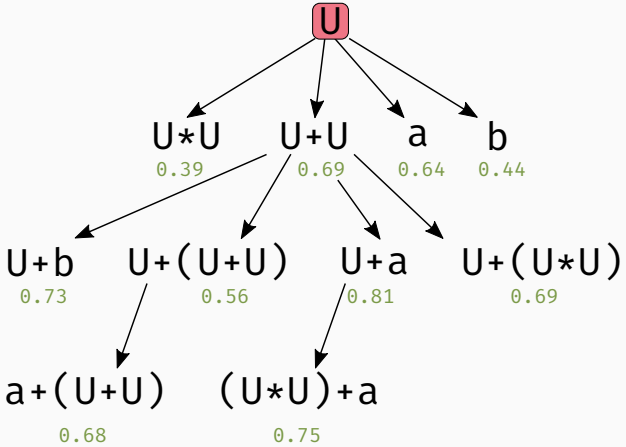

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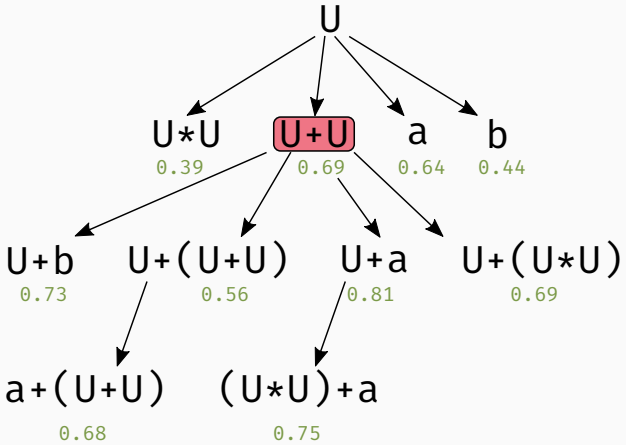

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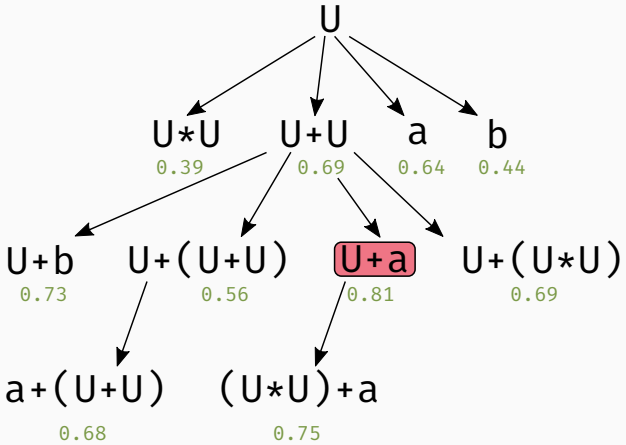

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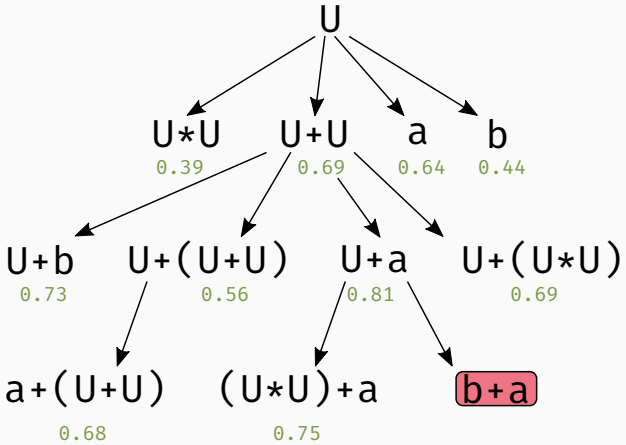

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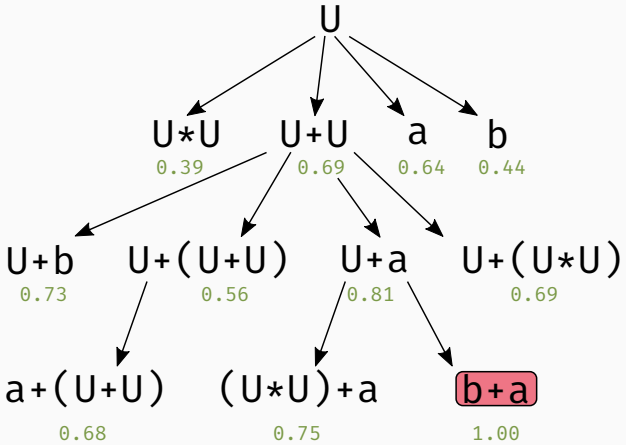

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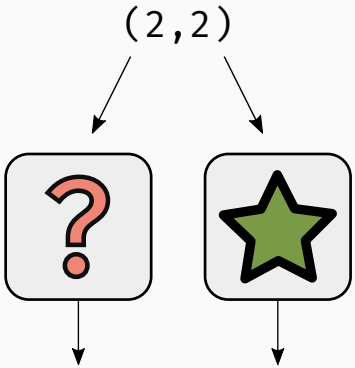

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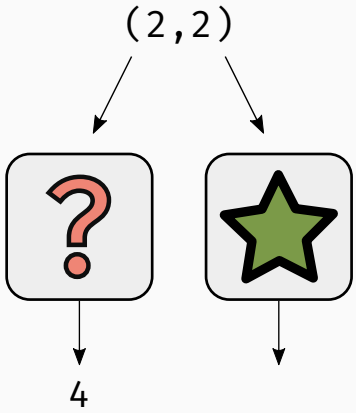

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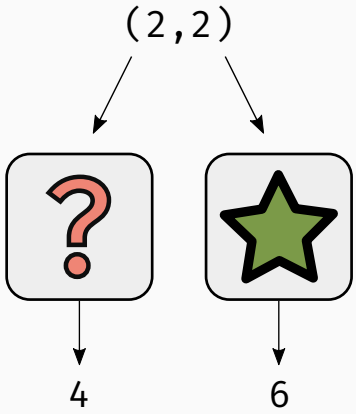
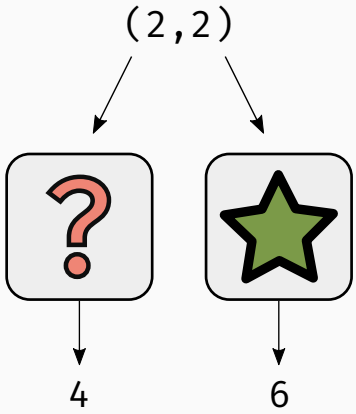
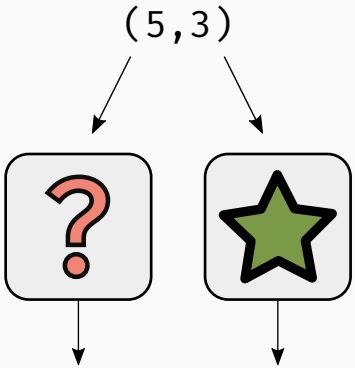


Score Calculation



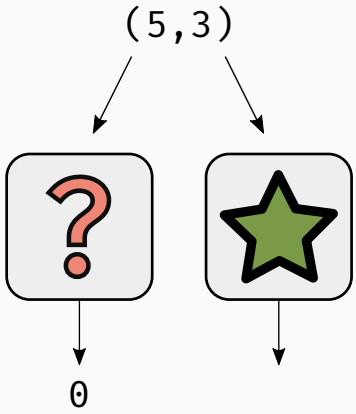
$$\text{similarity}(4, 6) \quad = \quad 0.78$$

Score Calculation



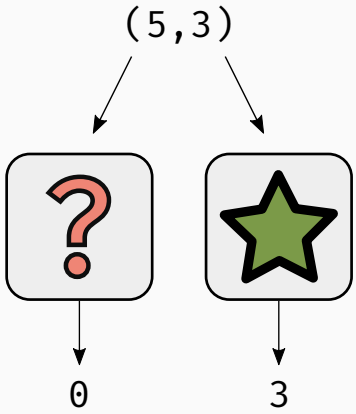
$$\text{similarity}(4, 6) = 0.78$$

Score Calculation



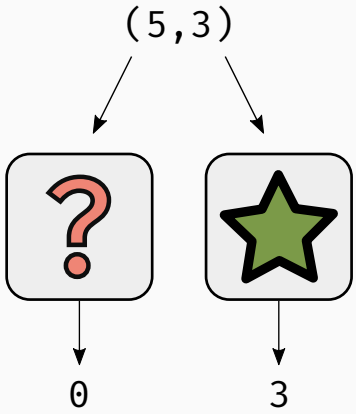
$$\text{similarity}(4, 6) \quad = \quad 0.78$$

Score Calculation



$$\text{similarity}(4, 6) \quad = \quad 0.78$$

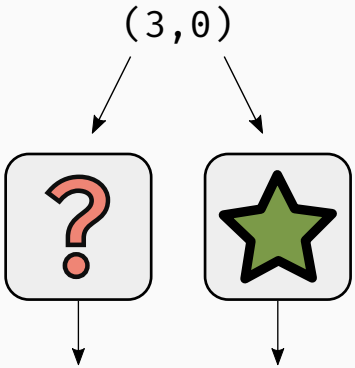
Score Calculation



$$\text{similarity}(4, 6) = 0.78$$

$$\text{similarity}(0, 3) = 0.33$$

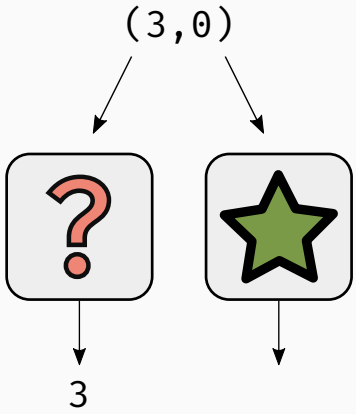
Score Calculation



$$\text{similarity}(4, 6) = 0.78$$

$$\text{similarity}(0, 3) = 0.33$$

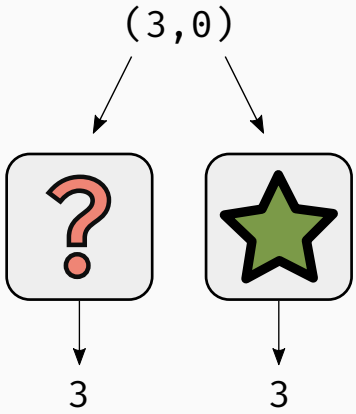
Score Calculation



$$\text{similarity}(4, 6) = 0.78$$

$$\text{similarity}(0, 3) = 0.33$$

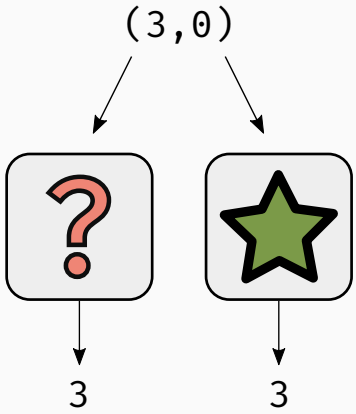
Score Calculation



$$\text{similarity}(4, 6) = 0.78$$

$$\text{similarity}(0, 3) = 0.33$$

Score Calculation

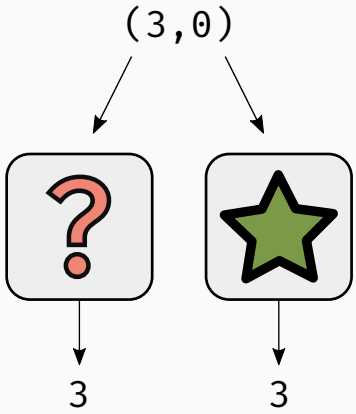


$$\text{similarity}(4, 6) = 0.78$$

$$\text{similarity}(0, 3) = 0.33$$

$$\text{similarity}(3, 3) = 1.0$$

Score Calculation



$$\text{similarity}(4, 6) = 0.78$$

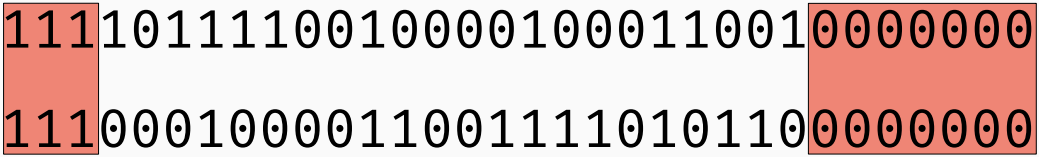
$$\text{similarity}(0, 3) = 0.33$$

$$\text{similarity}(3, 3) = 1.0$$

average score: 0.70

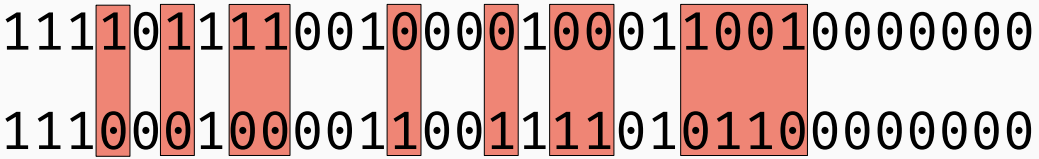
```
11110111100100001000110010000000
11100010000110011110101100000000
```

Let's compare:

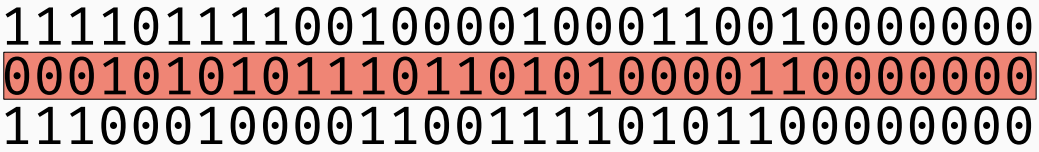


Are they in the same range?

Output Similarity: similarity(O, O')



How many bits are different?



How close are they numerically?

DEMO

How to synthesize obfuscated code?

Obtaining Code

static disassembly

Obtaining Code

static disassembly

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

memory dump

Obtaining Code

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

```
mov     r15, 0x200
xor     r15, 0x800
mov     rbx, rbp
add     rbx, 0xc0
mov     rbx, qword ptr [rbx]
mov     r13, 1
mov     rcx, 0
mov     r15, rbp
add     r15, 0xc0
or      rcx, 0x88
add     rbx, 0xb
mov     r15, qword ptr [r15]
or      r12, 0xffffffff80000000
sub     rcx, 0x78
movzx   r10, word ptr [rbx]
xor     r12, r13
add     r12, 0xffff
add     r15, 0
mov     r8, rbp
sub     rcx, 0x10
or      r12, r12
or      rcx, 0x800
movzx   r11, word ptr [r15]
xor     rcx, 0x800
mov     r12, r15
add     r8, 0
xor     r12, 0xf0
mov     rbx, 0x58
add     r11, rbp
mov     r15, rdx
xor     r10d, dword ptr [r12]
sub     r15, 0x800
or      rdx, 0x400
mov     rsi, 0x200
mov     r14, rbp
sub     rsi, rsi
mov     rdi, rbp
mov     r8, 0x400
sub     rsi, r9
sub     r8, rsi
add     r14, 0
add     rsi, rax
and     r8, 0x88
xor     rsi, r14
mov     rsi, rbp
add     rdi, 0xc0
sub     r8, rdi
add     r8, 0x78
add     rsi, 4
mov     rcx, 0x200
mov     rdi, qword ptr [rdi]
add     dword ptr [rsi], 0x254
xor     rcx, 0xf0
add     rcx, r10
add     rdi, 6
mov     r8, 0x400
mov     ax, word ptr [rdi]
mov     r8, 1
```

static disassembly

memory dump

instruction trace

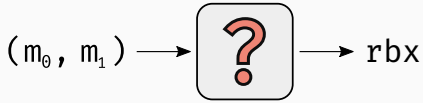
Learning Code Semantics

```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```

Handler performing `nor`
(with flag side-effects)

Learning Code Semantics

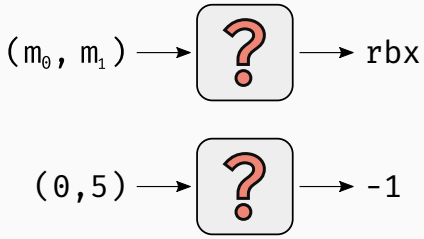
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```



Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

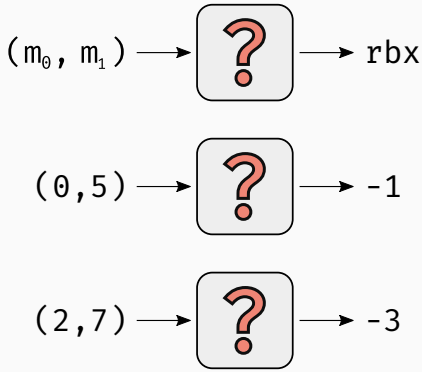
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```



Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```

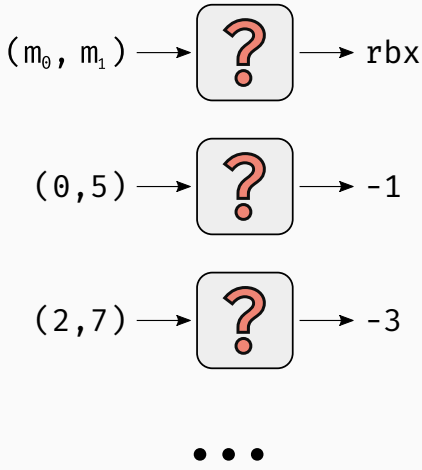


Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

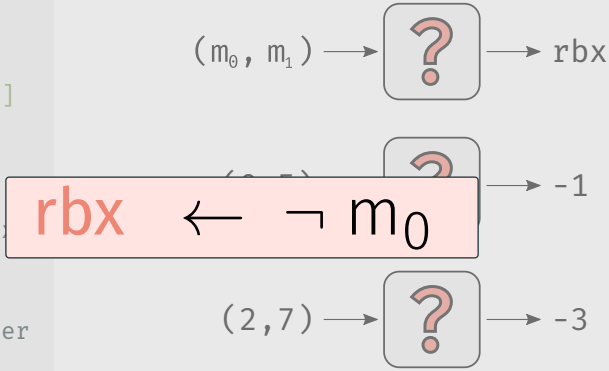
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```

Handler performing **nor**
(with flag side-effects)



Learning Code Semantics

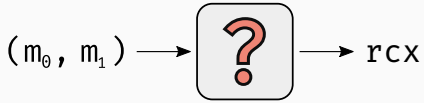
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```



Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

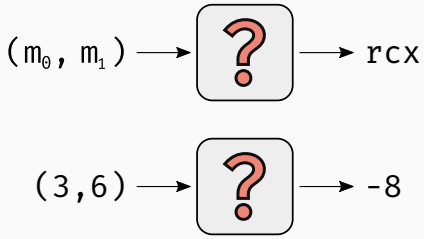
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```



Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

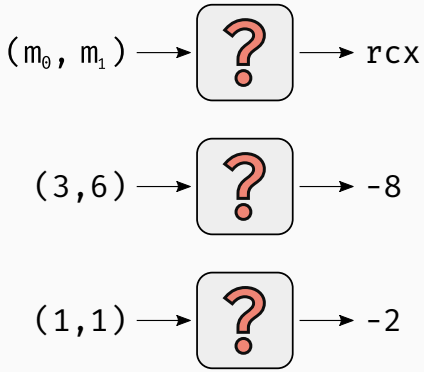
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```



Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
• and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```

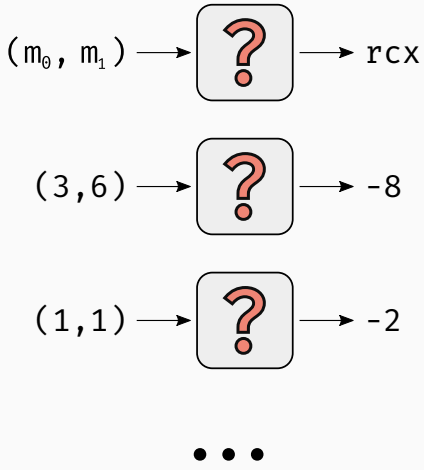


Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

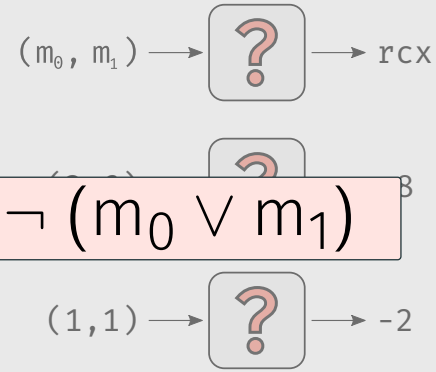
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
• and   rcx, rbx
mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```

Handler performing **nor**
(with flag side-effects)



Learning Code Semantics

```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rb
mov   [rbp +
pushf
pop   [rbp]
jmp   __vm_dispatcher
```

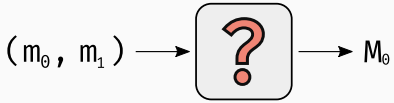


$$rcx \leftarrow \neg (m_0 \vee m_1)$$

Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

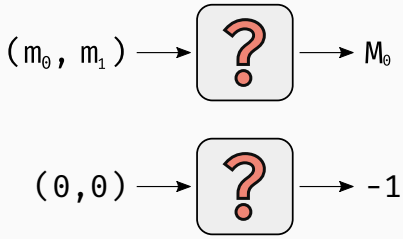
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
• mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```



Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

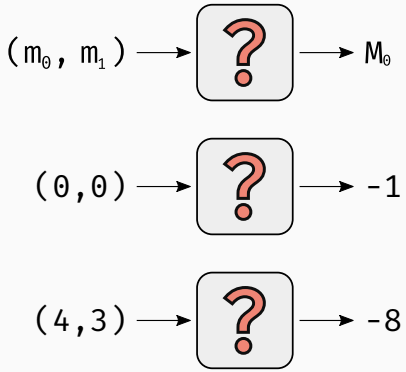
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
• mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```



Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
• mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```

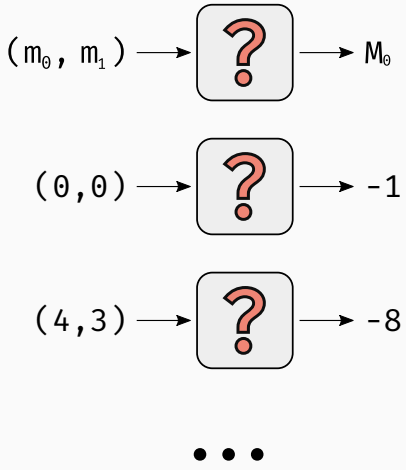


Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

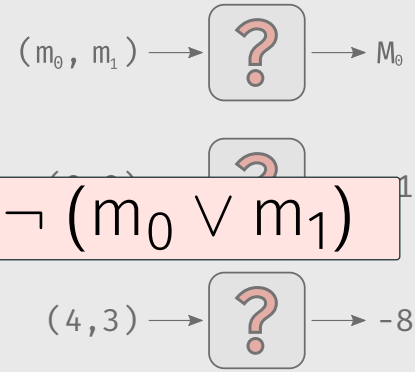
```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rbx
• mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```

Handler performing **nor**
(with flag side-effects)



Learning Code Semantics

```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
not   rbx
and   rcx, rb
mov   [rbp +
pushf
pop   [rbp]
jmp   __vm_dispatcher
```



$$M_0 \leftarrow \neg (m_0 \vee m_1)$$

Handler performing **nor**
(with flag side-effects)

Learning Code Semantics

```
__handle_vnor:
mov   rcx, [rbp]
mov   rbx, [rbp + 4]
not   rcx
• not   rbx
• and   rcx, rbx
• mov   [rbp + 4], rcx
pushf
pop   [rbp]
jmp   __vm_dispatcher
```

Handler performing **nor**
(with flag side-effects)

$$rbx \leftarrow \neg\, m_0$$

$$rcx \leftarrow \neg\, (m_0 \vee m_1)$$

$$M_0 \leftarrow \neg\, (m_0 \vee m_1)$$

I/O Sampling

WinDbg

Valgrind

x64dbg

Pin

bochs
think inside the bochs.

DynamoRIO

Unicorn

Miasm

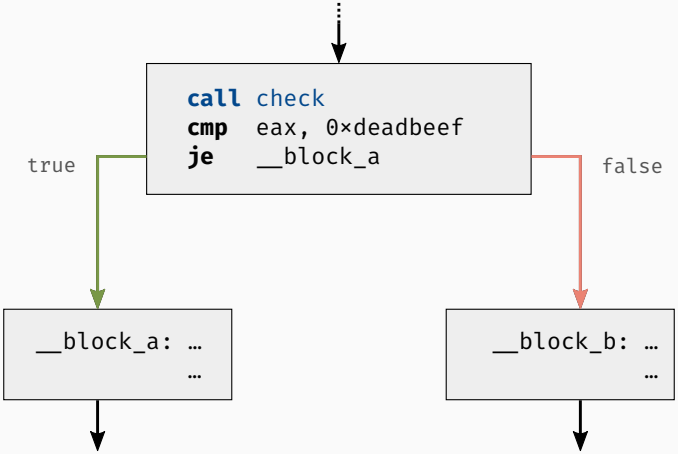
angr

TRITON
Dynamic Binary Analysis

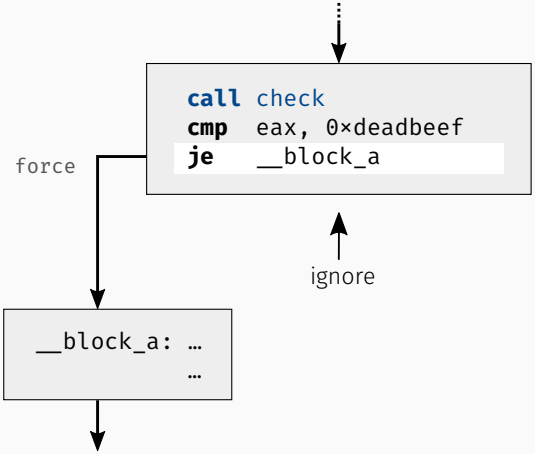
<your tool here>

Metasm

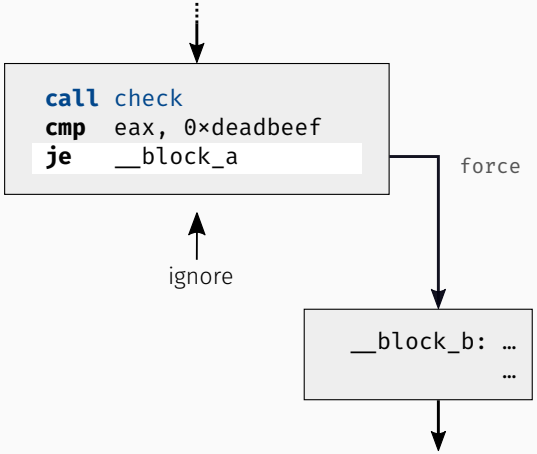
Instruction Trace: Forced Execution



Instruction Trace: Forced Execution



Instruction Trace: Forced Execution



Syntia

- program synthesis framework for code deobfuscation
- written in Python
- random I/O sampling for assembly code
- MCTS-based program synthesis

`https://github.com/RUB-SysSec/syntia`

DEMO

Breaking Virtual Machine Obfuscation

Reminder: Virtual Machine Hardening

Hardening Technique #1 – Obfuscating individual VM components.

Hardening Technique #2 – Duplicating VM handlers.

Hardening Technique #3 – No central VM dispatcher.

Hardening Technique #4 – No explicit handler table.

Hardening Technique #5 – Blinding VM bytecode.

#1: Obfuscating Individual VM Components

```
mov   r15, 0x200
xor   r15, 0x800
mov   rbx, rbp
add   rbx, 0xc0
mov   rbx, qword ptr [rbx]
mov   r13, 1
mov   rcx, 0
mov   r15, rbp
add   r15, 0xc0
or    rcx, 0x88
add   rbx, 0xb
mov   r15, qword ptr [r15]
or    r12, 0xffffffff80000000
sub   rcx, 0x78
movzx r10, word ptr [rbx]
xor   r12, r13
add   r12, 0xffff
add   r15, 0
mov   r8, rbp
sub   rcx, 0x10
or    r12, r12
or    rcx, 0x800
movzx r11, word ptr [r15]
xor   rcx, 0x800
mov   r12, r15
add   r8, 0
xor   r12, 0xf0
mov   rbx, 0x58
add   r11, rbp
xor   rbx, 0x800
and   r12, 0x20
add   rbx, 0x800
mov   r11, qword ptr [r11]
add   rbx, 1
and   r12, r9
mov   rdx, 1
xor   r10d, dword ptr [r8]
sub   r9, r11
pushfq
xor   rbx, 0xf0
xor   rbx, 0x800
and   rdx, r8
mov   r12, rbp
xor   rdx, 0x20
sub   rbx, 4
add   r11, 0x2549b044
or    rbx, 0x78
and   rdx, r10
mov   rax, 0
add   r12, 0x42
mov   r15, rdx
xor   r10d, dword ptr [r12]
sub   r15, 0x800
or    rdx, 0x400
mov   rsi, 0x200
mov   r14, rbp
sub   rsi, rsi
mov   rdi, rbp
mov   r8, 0x400
sub   rsi, r9
sub   r8, rsi
mov   r14, 0
add   rsi, rax
and   r8, 0x88
xor   rsi, r14
mov   rsi, rbp
add   rdi, 0xc0
sub   r8, rdi
add   r8, 0x78
add   rsi, 4
mov   rcx, 0x200
mov   rdi, qword ptr [rdi]
add   dword ptr [rsi], 0x2549b044
xor   rcx, 0xf0
add   rcx, r10
add   rdi, 6
sub   r13, 0x400
mov   ax, word ptr [rdi]
mov   r8, 1
mov   rsi, rbp
and   rcx, 8
sub   rcx, 1
mov   rcx, rdi
add   rsi, 0x29
or    rcx, 8
mov   r8, rsi
add   rcx, 4
mov   r13b, byte ptr [rsi]
cmp   r13b, 0xd2
jbe   0x204
and   rcx, r13
or    rcx, r13
or    rcx, 4
mov   rbx, rbp
or    rcx, 4
sub   rcx, 0x400
add   rax, rbp
or    rcx, 0x80
add   rcx, 0x80
add   rbx, 0x5a
add   r8, 1
or    r8, 0x78
add   word ptr [rbx], r10w
mov   r15, rax
sub   r15, rax
pop   r9
mov   rcx, rbp
add   rcx, 0xc0
mov   rcx, qword ptr [rcx]
add   rcx, 8
movzx r10, word ptr [rcx]
mov   r9, rbp
add   r9, 0
xor   r10d, dword ptr [r9]
and   rdi, 0xffffffff80000000
sub   r13, 0xf0
mov   rsi, 0
add   r13, 0x20
mov   rbx, rbp
or    r13, 0x88
and   rcx, 8
or    r8, 0x58
add   rbx, 0xc0
mov   rbx, qword ptr [rbx]
sub   rcx, 0x20
add   rdi, 0x80
sub   r13, 0x10
add   rbx, 8
mov   si, word ptr [rbx]
or    r9, 0xffff
sub   r9, 1
mov   r9, rbp
mov   r12, 0x58
add   r9, 0
sub   r13, 0x80
mov   r15, r13
or    rcx, r12
xor   esi, dword ptr [r9]
mov   r10, rbp
add   r10, 0xcc
sub   r15, 0x20
xor   esi, dword ptr [r10]
xor   r13, 0x90
add   rdi, 0x10
mov   r14, rsi
mov   rdx, rbp
add   rdx, 0
dword ptr [rdx], esi
xor   r12, 1
mov   r13, r15
or    r14, r14
mov   rax, rbp
and   rcx, r13
add   rax, 4
sub   r8, 0x80000000
add   r13, 0xffff
and   rcx, 0x20
mov   r10, rbp
add   r13, r15
add   r14, r8
add   r10, 0x89
xor   word ptr [r10], si
xor   rdx, r11
mov   rsi, rbp
sub   rdx, rbx
and   rax, 0x40
or    rbx, 0xf0
add   r11, 0x5a
mov   r8, rcx
movzx rsi, word ptr [rsi]
mov   rax, 0x200
mov   r14, rbp
and   rax, rdx
and   rcx, 0x20
add   r14, 0x89
or    rax, 0x40
xor   si, 0x7a28
add   rdx, 0x78
add   rbx, 0x20
movzx r14, word ptr [r14]
mov   rcx, 0x58
add   rsi, rbp
xor   rax, rdx
add   r8, 0x80
add   r14, rbp
add   r8, r15
mov   r14, 0x29
and   rdx, 0x10
mov   r14, qword ptr [r14]
add   qword ptr [rsi], r14
pushfq
xor   r11, r14
mov   rbx, rbp
mov   r13, 0x12
mov   r8, 0
and   r14, 0x88
and   r13, 0x40
add   r13, 1
mov   rdx, rbp
mov   r14, 0x200
add   rdx, 0xc0
add   r11, r14
or    r15, 0x88
mov   rdx, qword ptr [rdx]
mov   r8b, byte ptr [rdx]
cmp   r8b, 0
je    0x49e
mov   rdx, rbp
or    r11, 0x40
and   r15, 1
xor   r11, 0x10
add   rdx, 0xc0
or    r14, 4
mov   r15, 0x12
mov   rdx, qword ptr [rdx]
sub   r11, r8
add   rdx, 4
or    r11, 0x80
mov   r8w, word ptr [rdx]
mov   r14, r8
add   r8, rbp
or    r13, 4
pop   r10
mov   qword ptr [r8], r10
jmp   0x4ae
xor   rsi, 0x88
xor   rbx, 0xffffffff80000000
add   rsi, 0x78
mov   r10b, 0x68
mov   r9, 0x12
or    rbx, r10
and   r15, 0x78
mov   r14, rbp
or    r9, 8
add   r14, 0x29
xor   rbx, rdi
and   r15, 0x3f
mov   byte ptr [r14], r10b
mov   rax, 0x58
mov   r8, rbp
sub   rsi, 0x78
add   r8, 0x127
mov   rdi, rbx
xor   rbx, 0x3f
mov   r8, qword ptr [r8]
xor   rsi, 1
mov   rax, rbp
add   r15, 0x3f
or    r15, 0xffffffff80000000
add   rax, 0xc0
or    rdi, r14
and   rsi, 1
mov   rax, qword ptr [rax]
and   rdi, 0x7fffffff
add   rax, 2
sub   rsi, 4
or    rbx, rsi
movzx rax, word ptr [rax]
mov   r9, rbp
mov   r13, 0x200
mov   r10, 0x58
add   r9, 0
or    r10, 0x20
add   eax, 0x3f505c07
add   r15, 0x88
mov   r12, rbp
or    rdi, 0x90
add   r12, 0
or    rbx, 0x80
add   rcx, 0xf0
mov   r13, 0x400
add   dword ptr [r12], eax
and   rsi, r8
or    r10, 8
and   rbx, 0x20
mov   rax, 0xffff
mov   r11, 0
add   r13, r8
or    rbx, 1
shl   rax, 3
add   r8, rax
or    rbx, r15
sub   r15, 0x10
or    r11, r13
mov   rbx, qword ptr [r8]
mov   rdx, rbp
add   qword ptr [rdx], 0xd
jmp   rbx
```

#1: Obfuscating Individual VM Components

```
mov     r15, 0x200
xor     r15, 0x800
mov     rbx, rbp
add     rbx, 0xc0
mov     rbx, qword ptr [rbx]
mov     r13, 1
mov     rcx, 0
mov     r15, rbp
add     r15, 0xc0
or      rcx, 0x88
add     rbx, 0xb
mov     r15, qword ptr [r15]
or      r12, 0xffffffff80000000
sub     rcx, 0x78
movzx   r10, word ptr [rbx]
xor     r12, r13
add     r12, 0xffff
add     r15, 0
mov     r8, rbp
sub     rcx, 0x10
or      r12, r12
or      rcx, 0x800
movzx   r11, word ptr [r15]
xor     rcx, 0x800
mov     r12, r15
add     r8, 0
xor     r12, 0xf0
mov     rbx, 0x58
add     r11, rbp
xor     rbx, 0x800
and     r12, 0x20
add     rbx, 0x800
mov     r11, qword ptr [r11]
add     rbx, 1
and     r12, r9
mov     rdx, 1
xor     r10d, dword ptr [r8]
sub     r9, r11
pushfq
xor     rbx, 0xf0
xor     rbx, 0x800
and     rdx, r8
mov     r12, rbp
xor     rdx, 0x20
sub     rbx, 4
add     r11, 0x2549b044
or      rbx, 0x78
and     rdx, r10
mov     rax, 0
add     r12, 0x42
```

```
mov     r15, rdx
xor     r10d, dword ptr [r12]
sub     r15, 0x800
or      rdx, 0x400
mov     rsi, 0x200
mov     r14, rbp
sub     rsi, rsi
mov     rdi, rbp
mov     r8, 0x400
sub     rsi, r9
sub     r8, rsi
add     r14, 0
add     rsi, rax
and     r8, 0x88
xor     rsi, r14
mov     rsi, rbp
add     rdi, 0xc0
sub     r8, rdi
add     r8, 0x78
add     rsi, 4
mov     rcx, 0x200
mov     rdi, qword
add     dw                b04
xor     r
add     r
add     r
mov     r8,
mov     ax, word ptr [rdi]
mov     r8, 1
mov     rsi, rbp
and     rcx, 8
sub     rcx, 1
mov     rcx, rdi
add     rsi, 0x29
or      rcx, 8
mov     r8, rsi
add     rcx, 4
mov     r13b, byte ptr [rsi]
cmp     r13b, 0xd2
jbe     0x204
and     r8, r13
or      rcx, r13
or      rcx, 4
mov     rbx, rbp
or      rcx, 4
sub     rcx, 0x400
add     rax, rbp
or      rcx, 0x80
add     rcx, 0x80
add     rbx, 0x5a
```

```
add     r8, 1
or      r8, 0x78
add     word ptr [rbx], r10w
mov     r15, rax
sub     r15, rax
pop     r9
mov     rcx, rbp
add     rcx, 0xc0
mov     rcx, qword ptr [rcx]
add     rcx, 8
movzx   r10, word ptr [rcx]
mov     r9, rbp
add     r9, 0
xor     r10d, dword ptr [r9]
and     rdi, 0xffffffff80000000
sub     r13, 0xf0
mov     rsi, 0
sub     r13, 0x20
mov     rbx, rbp
or      r13, 0x88
and     rcx, 8
mov     r8, 0x58

                  p



add     rbx, 8
mov     si, word ptr [rbx]
or      r9, 0xffff
sub     r9, 1
mov     r9, rbp
mov     r12, 0x58
add     r9, 0
sub     r13, 0x80
mov     r15, r13
or      rcx, r12
xor     esi, dword ptr [r9]
mov     r10, rbp
add     r10, 0xcc
sub     r15, 0x20
xor     esi, dword ptr [r10]
xor     r13, 0x90
add     rdi, 0x10
mov     r14, rsi
mov     rdx, rbp
add     rdx, 0
add     dword ptr [rdx], esi
xor     r12, 1
mov     r13, r15
```

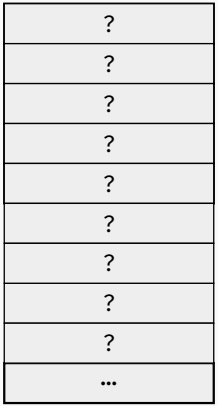
```
or      r14, r14
mov     rax, rbp
and     rcx, r13
add     rax, 4
sub     r8, -0x80000000
add     r13, 0xffff
and     rcx, 0x20
mov     r10, rbp
add     r13, r15
add     r14, r8
add     r10, 0x89
xor     word ptr [r10], si
xor     rdx, r11
mov     rsi, rbp
sub     rdx, rbx
and     rax, 0x40
or      rbx, 0xf0
add     rsi, 0x5a
mov     r8, rcx
movzx   rsi, word ptr [rsi]
mov     rax, 0x200
m             rbp
a             rdx
a             0x20
a             0x80
o
x       s
add     rdx,
add     rdx, 0x20
movzx   r14, word ptr [r14]
mov     rcx, 0x58
add     rsi, rbp
xor     rax, rdx
add     r8, 0x80
mov     r15, rsi
add     r14, rbp
add     r8, r15
mov     rbx, 0
and     rdx, 0x10
mov     r14, qword ptr [r14]
add     qword ptr [rsi], r14
pushfq
xor     r11, r14
add     r15, r14
mov     r13, 0x12
mov     r8, 0
and     r14, 0x88
and     r13, 0x40
add     r13, 1
mov     rdx, rbp
```

```
mov     r14, 0x200
add     rdx, 0xc0
add     r11, r14
or      r15, 0x88
mov     rdx, qword ptr [rdx]
add     rdx, 0xa
add     r11, 0x78
mov     r8b, byte ptr [rdx]
cmp     r8b, 0
je      0x49e
mov     rdx, rbp
or      r11, 0x40
and     r15, 1
xor     r11, 0x10
add     rdx, 0xc0
or      r14, 4
mov     r15, 0x12
mov     rdx, qword ptr [rdx]
sub     r11, r8
add     rdx, 4
or      r11, 0x80
mo      r    word ptr [rdx]
mo             8
ad            p
xo
po
mo      qw         ], r10
jmp     0x4a
xor     rsi, 0x88
xor     rbx, 0xffffffff80000000
add     rsi, 0x78
mov     r10b, 0x68
mov     r9, 0x12
or      rbx, r10
and     r15, 0x78
mov     r14, rbp
or      r9, 8
add     r14, 0x29
xor     rbx, rdi
and     r15, 0x3f
or      byte ptr [r14], r10b
mov     rax, 0x58
mov     r8, rbp
sub     rsi, 0x78
add     r8, 0x127
mov     rdi, rbx
xor     rbx, 0x3f
mov     r8, qword ptr [r8]
xor     rsi, 1
mov     rax, rbp
```

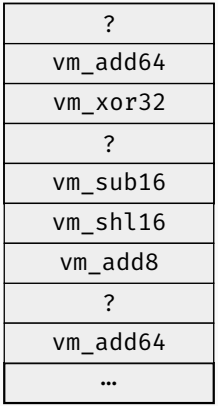
```
add     r15, 0x3f
or      r15, 0xffffffff80000000
and     rsi, r9
add     rax, 0xc0
add     rdi, r14
or      rsi, 1
mov     rax, qword ptr [rax]
and     rdi, 0x7fffffff
add     rax, 2
sub     rsi, 4
or      rbx, rsi
movzx   rax, word ptr [rax]
mov     r9, rbp
mov     r13, 0x200
mov     r10, 0x58
add     r9, 0
or      r10, 0x20
add     eax, dword ptr [r9]
xor     r10, 0x40
add     eax, 0x3f505c07
add     r15, 0x88
mov     r12, rbp
or      rdi, 0x90
add     r12, 0
or      rbx, 0x80
add     rdi, 0xf0
mov     r13, 0x400
add     dword ptr [r12], eax
and     rsi, r8
or      r10, 8
and     rbx, 0x20
and     rax, 0xffff
mov     r11, 0
add     r13, r8
or      rbx, 1
shl     rax, 3
add     r8, rax
or      rbx, r15
sub     r15, 0x10
or      r11, r13
mov     rbx, qword ptr [r8]
mov     rdx, rbp
sub     r13, 0x80
add     rdx, 0xc0
add     qword ptr [rdx], 0xd
jmp     rbx
```

u64 res = $M_{13} + M_{14}$

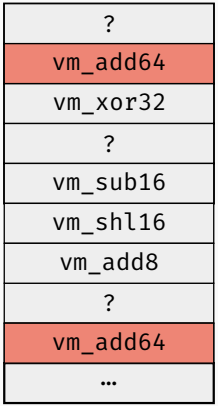
#2: Duplicating VM Handlers



#2: Duplicating VM Handlers



#2: Duplicating VM Handlers



#5: Blinding VM Bytecode

```
mov   r15, 0x200
xor   r15, 0x800
mov   rbx, rbp
add   rbx, 0xc0
mov   rbx, qword ptr [rbx]
mov   r13, 1
mov   rcx, 0
mov   r15, rbp
add   r15, 0xc0
or    rcx, 0x88
add   rbx, 0xb
mov   r15, qword ptr [r15]
or    r12, 0xffffffff80000000
sub   rcx, 0x78
movzx r10, word ptr [rbx]
xor   r12, r13
add   r12, 0xffff
add   r15, 0
mov   r8, rbp
sub   rcx, 0x10
or    r12, r12
or    rcx, 0x800
movzx r11, word ptr [r15]
xor   rcx, 0x800
mov   r12, r15
add   r8, 0
xor   r12, 0xf0
mov   rbx, 0x58
add   r11, rbp
xor   rbx, 0x800
and   r12, 0x20
add   rbx, 0x800
mov   r11, qword ptr [r11]
add   rbx, 1
and   r12, r9
mov   rdx, 1
xor   r10d, dword ptr [r8]
sub   r9, r11
pushfq
xor   rbx, 0xf0
xor   rbx, 0x800
and   rdx, r8
mov   r12, rbp
xor   rdx, 0x20
sub   rbx, 4
add   r11, 0x2549b044
or    rbx, 0x78
and   rdx, r10
mov   rax, 0
add   r12, 0x42
mov   r15, rdx
mov   r10d, dword ptr [r12]
sub   r15, 0x800
or    rdx, 0x400
mov   r15, 0x200
mov   r14, rbp
sub   rsi, rsi
add   rdi, rbp
mov   r8, 0x400
sub   rsi, r9
add   r9, rsi
add   r14, 0
cmp   rsi, rax
xor   rsi, r14
and   r8, 0x88
add   rdi, 0xc0
sub   r8, rdi
add   r8, 0x78
cmp   r13, 4
mov   rcx, 0x200
mov   rdi, qword ptr [rdi]
add   dword ptr [rsi], 0x2549b044
xor   rcx, 0xf0
add   rcx, r10
add   rdi, 0
mov   r8, 0x400
mov   ax, word ptr [rdi]
mov   r8, 1
mov   rsi, rbp
and   rcx, 8
sub   rcx, 1
mov   rcx, rdi
add   rsi, 0x29
or    rcx, 8
mov   r8, rsi
cmp   r14, 4
mov   r13b, byte ptr [rsi]
cmp   r13b, 0xd2
jbe   0x204
and   r8, r13
or    rcx, r13
or    rcx, 4
mov   rbx, rbp
or    rcx, 4
add   rax, rbp
or    rcx, 0x80
add   rcx, 0x80
add   rbx, 0x5a
add   r8, 1
or    r8, 0x78
add   word ptr [rbx], r10w
mov   r15, rax
sub   r15, rax
pop   r9
mov   rcx, rbp
add   rcx, 0xc0
mov   rcx, qword ptr [rcx]
add   rcx, 8
movzx r10, word ptr [rcx]
mov   r9, rbp
add   r9, 0
xor   r10d, dword ptr [r9]
and   rdi, 0xffffffff80000000
sub   r13, 0xf0
mov   rsi, 0
sub   r13, 0x20
mov   rbx, rbp
or    r13, 0x88
and   rcx, 8
mov   r8, 0x58
add   qword ptr [rbx], 0xc0
mov   rbx, qword ptr [rbx]
sub   rcx, 0x20
sub   r13, 0x10
add   rbx, 8
mov   si, word ptr [rbx]
or    r9, 0xffff
sub   r9, 1
mov   r9, rbp
mov   r12, 0x58
add   r9, 0
sub   r13, 0x80
mov   r15, r13
or    rcx, r12
xor   esi, dword ptr [r9]
mov   r10, rbp
add   r10, 0xcc
sub   r15, 0x20
xor   esi, dword ptr [r10]
xor   r13, 0x90
add   rdi, 0x10
mov   r14, rsi
mov   rdx, rbp
add   rdx, 0
add   dword ptr [rdx], esi
xor   r12, 1
mov   r13, r15
or    r14, r14
mov   rax, rbp
and   rcx, r13
add   rax, 4
sub   r8, -0x80000000
add   r13, 0xffff
and   rcx, 0x20
mov   r10, rbp
add   r13, r15
add   r14, r8
add   r10, 0x89
xor   word ptr [r10], si
xor   rdx, r11
mov   rsi, rbp
sub   rdx, rbx
and   rax, 0x40
or    rbx, 0xf0
add   rsi, 0x5a
mov   r8, rcx
movzx rsi, word ptr [rsi]
mov   rax, 0x200
mov   r14, rbp
and   rax, rdx
and   rcx, 0x20
add   r14, 0x89
or    rax, 0x40
xor   si, 0x7a28
add   r8, 0x78
add   rdx, 0x20
movzx r14, word ptr [r14]
mov   r15, 0x58
add   rsi, rbp
xor   rax, rdx
add   r8, 0x80
mov   r15, rsi
add   r14, rbp
add   r8, r15
mov   rbx, 0
and   rdx, 0x10
mov   r14, qword ptr [r14]
add   qword ptr [rsi], r14
pushfq
xor   r11, r14
add   r15, r14
mov   r13, 0x12
mov   r8, 0
and   r14, 0x88
and   r13, 0x40
add   r13, 1
mov   rdx, rbp
mov   r14, 0x200
add   rdx, 0xc0
add   r11, r14
or    r15, 0x88
mov   rdx, qword ptr [rdx]
add   rdx, 0xa
add   r11, 0x78
mov   r8b, byte ptr [rdx]
cmp   r8b, 0
je    0x49e
mov   rdx, rbp
or    r11, 0x40
and   r15, 1
xor   r11, 0x10
add   rdx, 0xc0
or    r14, 4
mov   r15, 0x12
mov   rdx, qword ptr [rdx]
sub   r11, r8
add   rdx, 4
or    r11, 0x80
mov   r8w, word ptr [rdx]
mov   r14, r8
add   r8, rbp
xor   r13, 4
pop   r10
mov   qword ptr [r8], r10
jmp   0x4ae
xor   rsi, 0x88
xor   rbx, 0xffffffff80000000
add   rsi, 0x78
mov   r10b, 0x68
mov   r9, 0x12
or    rbx, r10
and   r15, 0x78
mov   r14, rbp
or    r9, 8
add   r14, 0x29
xor   rbx, rdi
add   r15, 0x3f
or    byte ptr [r14], r10b
mov   rax, 0x58
mov   r8, rbp
sub   rsi, 0x78
add   r8, 0x127
mov   rdi, rbx
xor   rbx, 0x3f
mov   r8, qword ptr [r8]
xor   rsi, 1
mov   rax, rbp
add   r15, 0x3f
or    r15, 0xffffffff80000000
and   rsi, r9
add   rax, 0xc0
add   rdi, r14
or    rsi, 1
mov   rax, qword ptr [rax]
and   rdi, 0x7fffffff
add   rax, 2
sub   rsi, 4
or    rbx, rsi
movzx rax, word ptr [rax]
mov   r9, rbp
mov   r13, 0x200
mov   r10, 0x58
add   r9, 0
or    r10, 0x20
add   eax, dword ptr [r9]
xor   r10, 0x40
add   eax, 0x3f505c07
add   r15, 0x88
mov   r12, rbp
or    rdi, 0x90
add   r12, 0
or    rbx, 0x80
add   rdi, 0xf0
mov   r13, 0x400
add   dword ptr [r12], eax
and   rsi, r8
or    r10, 8
and   rbx, 0x20
and   rax, 0xffff
mov   r11, 0
add   r13, r8
or    rbx, 1
shl   rax, 3
add   r8, rax
or    rbx, r15
sub   r15, 0x10
or    r11, r13
mov   rbx, qword ptr [r8]
mov   rdx, rbp
sub   r13, 0x80
add   rdx, 0xc0
add   qword ptr [rdx], 0xd
jmp   rbx
```

#5: Blinding VM Bytecode

```
mov     r15, 0x200
xor     r15, 0x800
mov     rbx, rbp
add     rbx, 0xc0
mov     rbx, qword ptr [rbx]
mov     r13, 1
mov     rcx, 0
mov     r15, rbp
add     r15, 0xc0
or      rcx, 0x88
add     r8, 0xb
mov     r15, qword ptr [r15]
or      r12, 0xffffffff80000000
sub     rcx, 0x78
movzx   r10, word ptr [rbx]
xor     r12, r13
add     r12, 0xffff
add     r15, 0
mov     r8, rbp
sub     rcx, 0x10
or      r12, r12
or      rcx, 0x800
movzx   r11, word ptr [r15]
xor     rcx, 0x800
mov     r12, r15
add     r8, 0
xor     r12, 0xf0
mov     rbx, 0x58
add     r11, rbp
xor     rbx, 0x800
and     r12, 0x20
add     rbx, 0x800
mov     r11, qword ptr [r11]
add     rbx, 1
and     r12, r9
mov     rdx, 1
xor     r10d, dword ptr [r8]
sub     r9, r11
pushfq
xor     rbx, 0xf0
xor     rbx, 0x800
and     rdx, r8
mov     r12, rbp
xor     rdx, 0x20
sub     rbx, 4
add     r11, 0x2549b044
or      rbx, 0x78
and     rdx, r10
mov     rax, 0
add     r12, 0x42

mov     r15, rdx
mov     r10d, dword ptr [r12]
sub     r15, 0x800
or      rdx, 0x400
sub     r15, 0x200
mov     r14, rbp
sub     rsi, rsi
add     r11, rbp
mov     r8, 0x400
sub     rsi, r9
add     r8, rsi
add     r14, 0
add     rsi, rax
and     r8, 0x88
xor     rsi, r14
mov     rsi, rbp
add     rdi, 0xc0
sub     r8, rdi
add     r8, 0x78
mov     rsi, 4
mov     rcx, 0x200
mov     rdi, qword ptr [rdi]
add     qword ptr [rsi], 0x2549
xor     rcx, 0xf0
add     rcx, r10
add     r8, 0x400
mov     ax, word ptr [rdi]
mov     r8, 1
mov     rsi, rbp
and     rcx, 8
sub     rcx, 1
mov     rcx, rdi
add     rsi, 0x29
or      rcx, 8
mov     r8, rsi
add     rcx, 4
mov     r13b, byte ptr [rsi]
cmp     r13b, 0xd2
jbe     0x204
and     r8, r13
or      rcx, r13
or      rcx, 4
mov     rbx, rbp
or      rcx, 4
add     rax, rbp
or      rcx, 0x80
add     rcx, 0x80
add     rbx, 0x5a

add     r8, 1
or      r8, 0x78
add     word ptr [rbx], r10w
mov     r15, rax
sub     r15, rax
pop     r9
mov     rcx, rbp
mov     r13, 0x80
mov     r15, rsi
mov     r13, r13
or      rcx, r12
xor     esi, dword ptr [r9]
mov     r10, rbp
add     r10, 0xcc
sub     r15, 0x20
xor     esi, dword ptr [r10]
xor     r13, 0x90
add     rdi, 0x10
mov     r14, rsi
mov     rdx, rbp
add     rdx, 0
add     dword ptr [rdx], esi
xor     r12, 1
mov     r13, r15

or      r14, r14
mov     rax, rbp
and     rcx, r13
add     rax, 4
sub     r8, -0x80000000
add     r13, 0xffff
and     rcx, 0x20

], si

[rsi]

[r14]

add     r9, 0
sub     r13, 0x80
mov     r15, r13
add     r8, r15
xor     rbx, 0
and     rdx, 0x10
add     r14, qword ptr [r14]
add     qword ptr [rsi], r14
pushfq
xor     r11, r14
add     r15, r14
mov     r13, 0x12
mov     r8, 0
and     r14, 0x88
and     r13, 0x40
add     r13, 1
mov     rdx, rbp

mov     r14, 0x200
add     rdx, 0xc0
add     r11, r14
or      r15, 0x88
mov     rdx, qword ptr [rdx]
add     r11, 0x78
mov     r8b, byte ptr [rdx]
cmp     r8b, 0
je      0x40e
mov     rdx, rbp
or      r11, 0x40
and     r15, 1
xor     r11, 0x10
add     rdx, 0xc0
or      r14, 4
mov     r15, 0x12
mov     rdx, qword ptr [rdx]
sub     r11, r8
add     rdx, 4
or      r11, 0x80
mov     r8w, word ptr [rdx]
or      r14, r8
add     r8, rbp
xor     r13, 4
pop     r10
mov     qword ptr [r8], r10
jmp     0x4de
mov     rsi, 0x88
xor     rbx, 0xffffffff80000000
add     rsi, 0x78
mov     r10b, 0x68
mov     r9, 0x12
or      rbx, r10
and     r15, 0x78
mov     r14, rbp
or      r9, 8
add     r14, 0x29
xor     rbx, rdi
and     r15, 0x3f
or      byte ptr [r14], r10b
mov     rax, 0x58
mov     r8, rbp
sub     rsi, 0x78
add     r8, 0x127
mov     rdi, rbx
xor     rbx, 0x3f
mov     r8, qword ptr [r8]
xor     rsi, 1
mov     rax, rbp

add     r15, 0x3f
or      r15, 0xffffffff80000000
and     rsi, r9
add     rax, 0xc0
add     rdi, r14
or      rsi, 1
mov     rax, qword ptr [rax]
and     rdi, 0xffffffff
add     rax, 2
sub     rsi, 4
or      rbx, rsi
movzx   rax, word ptr [rax]
mov     r9, rbp
mov     r13, 0x200
mov     r10, 0x58
add     r9, 0
or      r10, 0x20
add     eax, dword ptr [r9]
xor     r10, 0x40
add     eax, 0x3f505c07
add     r15, 0x88
mov     r12, rbp
or      rdi, 0x90
add     r12, 0
or      rbx, 0x80
add     rdi, 0xf0
mov     r13, 0x400
add     dword ptr [r12], eax
and     rsi, r8
or      r10, 8
and     rbx, 0x20
and     rax, 0xffff
mov     r11, 0
add     r13, r8
or      rbx, 1
shl     rax, 3
add     r8, rax
or      rbx, r15
sub     r15, 0x10
or      r11, r13
mov     rbx, qword ptr [r8]
mov     rdx, rbp
sub     r13, 0x80
add     rdx, 0xc0
add     qword ptr [rdx], 0xd
jmp     rbx
```


```
mov     r9, rbp
…
add     r9, 0
…
add     eax, dword ptr [r9]
…
add     eax, 0x3f505c07
…
mov     r12, rbp
…
add     r12, 0
add     dword ptr [r12], eax
```

#5: Blinding VM Bytecode

```
mov     r9, rbp
…
add     r9, 0
…
add     eax, dword ptr [r9]
…
add     eax, 0x3f505c07
…
add     dword ptr [r12], eax
```

No influence on underlying code's semantics

#3: No Central VM Dispatcher

```
mov   r15, 0x200
xor   r15, 0x800
mov   rbx, rbp
add   rbx, 0xc0
mov   rbx, qword ptr [rbx]
mov   r13, 1
mov   rcx, 0
mov   r15, rbp
add   r15, 0xc0
or    rcx, 0x88
add   rbx, 0xb
mov   r15, qword ptr [r15]
or    r12, 0xffffffff80000000
sub   rcx, 0x78
movzx r10, word ptr [rbx]
xor   r12, r13
add   r12, 0xffff
add   r15, 0
mov   r8, rbp
sub   rcx, 0x10
or    r12, r12
or    rcx, 0x800
movzx r11, word ptr [r15]
xor   rcx, 0x800
mov   r12, r15
add   r8, 0
xor   r12, 0xf0
mov   rbx, 0x58
add   r11, rbp
xor   rbx, 0x800
and   r12, 0x20
add   rbx, 0x800
mov   r11, qword ptr [r11]
add   rbx, 1
and   r12, r9
mov   rdx, 1
xor   r10d, dword ptr [r8]
sub   r9, r11
pushfq
xor   rbx, 0xf0
xor   rbx, 0x800
and   rdx, r8
mov   r12, rbp
xor   rdx, 0x20
sub   rbx, 4
add   r11, 0x2549b044
or    rbx, 0x78
and   rdx, r10
mov   rax, 0
add   r12, 0x42

mov   r15, rdx
mov   r10d, dword ptr [r12]
sub   r15, 0x800
or    rdx, 0x400
mov   r11, 0x200
mov   r14, rbp
sub   rsi, rsi
add   rbx, rsi
add   r14, 0
sub   rsi, r9
movzx r10, word ptr [rcx]
mov   r9, rbp
add   r9, 0
xor   r10d, dword ptr [r9]
and   rdi, 0xffffffff80000000
sub   r13, 0xf0
mov   rsi, 0
sub   r13, 0x20
mov   rbx, rbp
or    r13, 0x88
and   rcx, 8
mov   r8, 0x58
add   qword ptr [rsi], 0x2549b044
xor   rcx, 0xf0
add   rcx, r10
add   r8, 0
mov   r8, 0x400
mov   ax, word ptr [rdi]
mov   r8, 1
mov   rsi, rbp
and   rcx, 8
sub   rcx, 1
mov   rcx, rdi
add   rcx, 0x29
or    rcx, 8
mov   r8, rsi
add   rcx, 4
mov   r13b, byte ptr [rsi]
cmp   r13b, 0xd2
jbe   0x204
and   r8, r13
or    rcx, r13
or    rcx, 4
mov   rbx, rbp
or    rcx, 4
add   rax, rbp
or    rcx, 0x80
add   rcx, 0x80
add   rbx, 0x5a

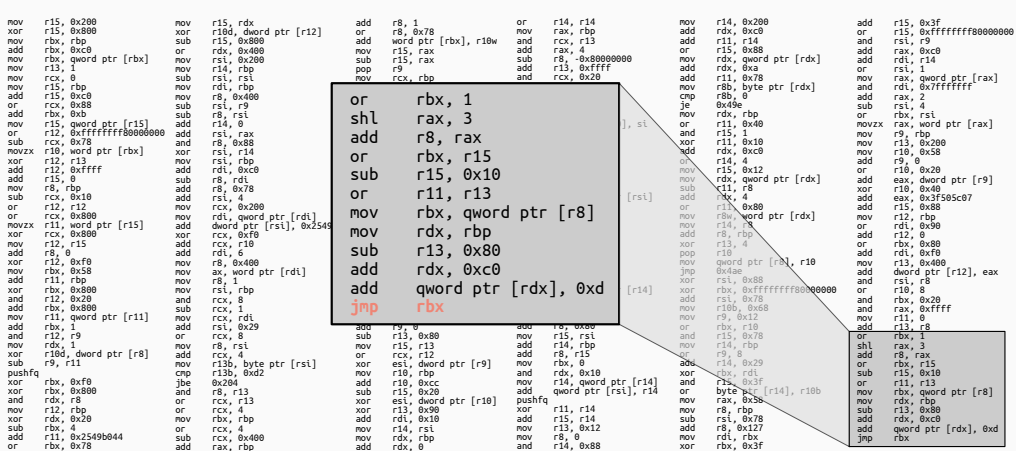
add   r8, 1
or    r8, 0x78
add   word ptr [rbx], r10w
mov   r15, rax
sub   r15, rax
pop   r9
mov   rcx, rbp
add   rcx, 0xc0
mov   rcx, qword ptr [rcx]
add   rcx, 8
movzx r10, word ptr [rcx]
mov   r9, rbp
add   r9, 0
xor   r10d, dword ptr [r9]
and   rdi, 0xffffffff80000000
sub   rdx, rbx
and   rax, 0x40
or    rbx, 0xf0
add   rsi, 0x5a
mov   r8, rcx
movzx rsi, word ptr [rsi]
mov   rax, 0x200
mov   r14, rbp
and   rax, rdx
and   rcx, 0x20
add   r14, 0x89
or    rax, 0x40
xor   si, 0x7a28
add   rdx, 0x78
add   rdx, 0x20
movzx r14, word ptr [r14]
mov   rcx, 0x58
add   rsi, rbp
xor   rax, rdx
add   r8, 0x80
mov   r15, rsi
add   r14, rbp
add   r8, r15
mov   rbx, 0
and   rdx, 0x10
mov   r14, qword ptr [r14]
add   qword ptr [rsi], r14
pushfq
xor   r11, r14
add   r15, r14
mov   r13, 0x12
mov   r8, 0
and   r14, 0x88
and   r13, 0x40
add   r13, 1
mov   rdx, rbp

or    r14, r14
mov   rax, rbp
and   rcx, r13
add   rax, 4
sub   r8, -0x80000000
add   r13, 0xffff
and   rcx, 0x20
mov   r10, rbp
add   r13, r15
cmp   r8b, 0
je    0x49e
mov   rdx, rbp
or    r11, 0x40
and   r15, 1
xor   r11, 0x10
add   rdx, 0xc0
or    r14, 4
mov   r15, 0x12
mov   rdx, qword ptr [rdx]
sub   r11, r8
add   rdx, 4
or    r11, 0x80
mov   r8w, word ptr [rdx]
mov   r14, r8
add   r8, rbp
xor   r13, 4
pop   r10
mov   qword ptr [r8], r10
add   r8, 0x58
jmp   0x4ae
xor   rsi, 0x88
xor   rbx, 0xffffffff80000000
add   rsi, 0x78
mov   r10b, 0x68
mov   r9, 0x12
or    rbx, r10
and   r15, 0x78
mov   r14, rbp
or    r9, 8
add   r14, 0x29
xor   rbx, rdi
add   r15, 0x3f
or    byte ptr [r14], r10b
mov   rax, 0x58
mov   r8, rbp
sub   rsi, 0x78
add   r8, 0x127
mov   rdi, rbx
xor   rbx, 0x3f
mov   r8, qword ptr [r8]
xor   rsi, 1
mov   rax, rbp

mov   r14, 0x200
add   rdx, 0xc0
add   r11, r14
or    r15, 0x88
mov   rdx, qword ptr [rdx]
add   r11, 0x78
mov   r8b, byte ptr [rdx]
cmp   r8b, 0
je    0x49e
mov   rdx, rbp
or    r11, 0x40
and   r15, 1
xor   r11, 0x10
add   rdx, 0xc0
or    r14, 4
mov   r15, 0x12
mov   rdx, qword ptr [rdx]
sub   r11, r8
add   rdx, 4
or    r11, 0x80
mov   r8w, word ptr [rdx]
mov   r14, r8
add   r8, rbp
xor   r13, 4
pop   r10
mov   qword ptr [r8], r10
add   r8, 0x58
jmp   0x4ae
xor   rsi, 0x88
xor   rbx, 0xffffffff80000000
add   rsi, 0x78
mov   r10b, 0x68
mov   r9, 0x12
or    rbx, r10
and   r15, 0x78
mov   r14, rbp
or    r9, 8
add   r14, 0x29
xor   rbx, rdi
add   r15, 0x3f
or    byte ptr [r14], r10b
mov   rax, 0x58
mov   r8, rbp
sub   rsi, 0x78
add   r8, 0x127
mov   rdi, rbx
xor   rbx, 0x3f
mov   r8, qword ptr [r8]
xor   rsi, 1
mov   rax, rbp

add   r15, 0x3f
and   rdi, 0xffffffff80000000
and   rsi, r9
add   rax, 0xc0
add   rdi, r14
or    rsi, 1
mov   rax, qword ptr [rax]
and   rdi, 0xffffffff
add   rax, 2
sub   rsi, 4
or    rbx, rsi
movzx rax, word ptr [rax]
mov   r9, rbp
mov   r13, 0x200
mov   r10, 0x58
add   r9, 0
or    r10, 0x20
add   eax, dword ptr [r9]
xor   r10, 0x40
add   eax, 0x3f505c07
add   r15, 0x88
mov   r12, rbp
or    rdi, 0x90
add   r12, 0
or    rbx, 0x80
add   rdi, 0xf0
mov   r13, 0x400
add   dword ptr [r12], eax
and   rsi, r8
or    r10, 8
and   rbx, 0x20
and   rax, 0xffff
mov   r11, 0
add   r13, r8
or    rbx, 1
shl   rax, 3
add   r8, rax
or    rbx, r15
sub   r15, 0x10
or    r11, r13
mov   rbx, qword ptr [r8]
mov   rdx, rbp
sub   r13, 0x80
add   rdx, 0xc0
add   qword ptr [rdx], 0xd
jmp   rbx
```

#3: No Central VM Dispatcher

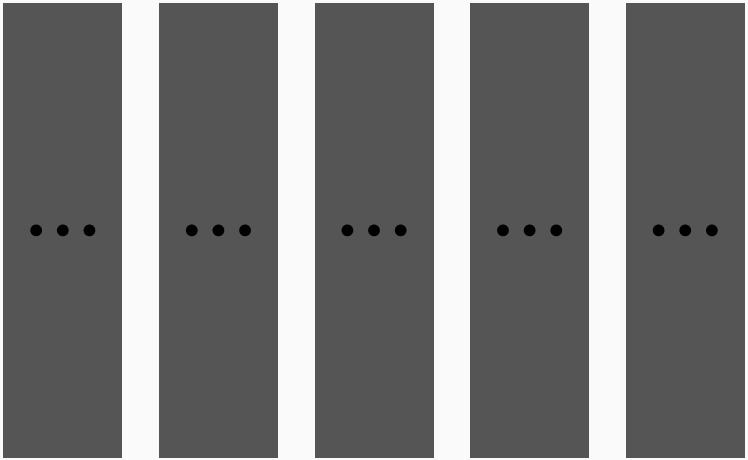


#3: No Central VM Dispatcher

```
or    rbx, 1
shl   rax, 3
add   r8, rax
or    rbx, r15
sub   r15, 0x10
or    r11, r13
mov   rbx, qword ptr [r8]
mov   rdx, rbp
jmp   rbx
```

Split at indirect control-flow transfers

#4: No Explicit Handler Table



#4: No Explicit Handler Table

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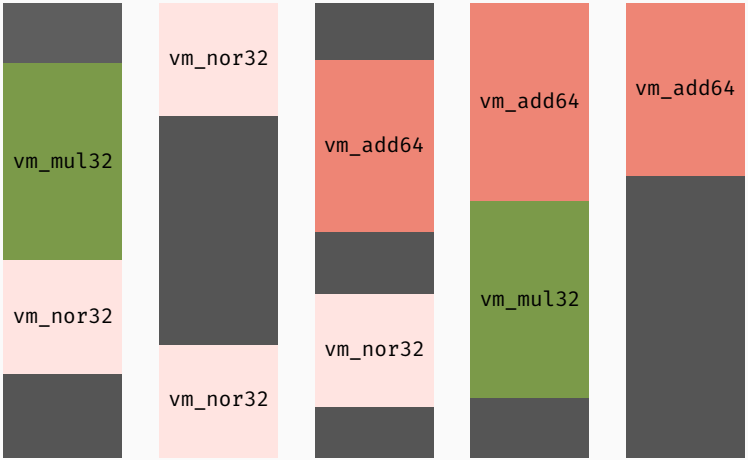

Conclusion

Take Aways

1. syntactic complexity insignificant

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2. semantic complexity low within specified boundaries

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3. learn underlying code's semantics despite obfuscation

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2. semantic complexity low within specified boundaries
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Program Synthesis as an orthogonal approach to traditional techniques

Limitations

Implementation Shortcomings

choosing *meaningful* code window boundaries

$$(x \oplus y) + 2 \cdot (x \wedge y) \quad \text{vs.} \quad (x \oplus y) + 2$$

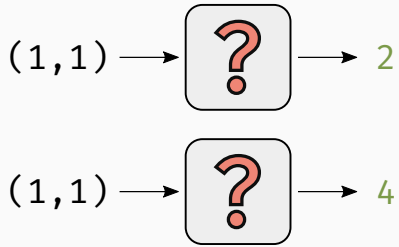
constants

$$x + 15324326921$$

control-flow operations

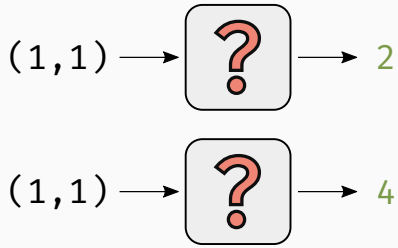
$$x \ ? \ y \ : \ z$$

Limitations



non-determinism

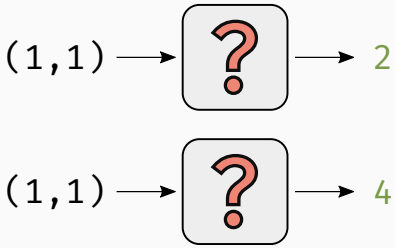
Limitations



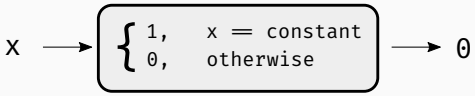
non-determinism

semantic complexity

Limitations



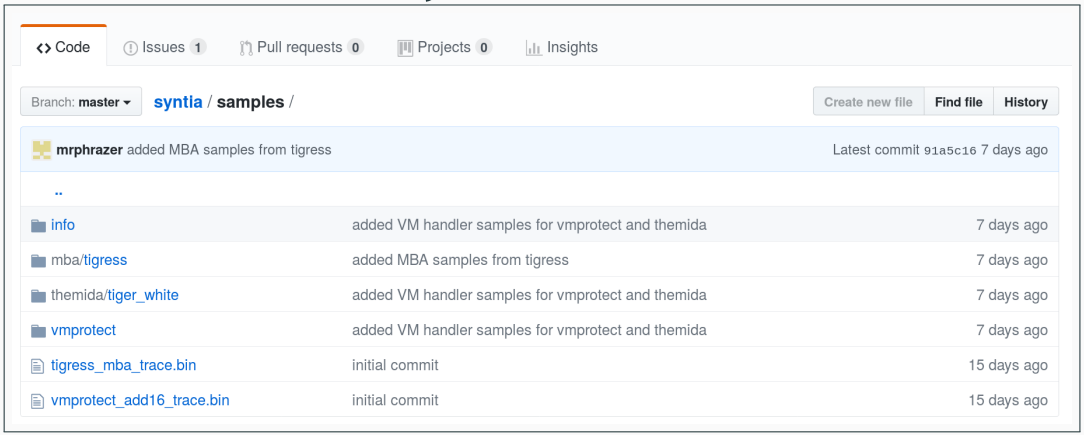
non-determinism



point functions

semantic complexity

Do try it at home!



Code | Issues 1 | Pull requests 0 | Projects 0 | Insights

Branch: master ▾ **syntia** / **samples** /

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mrphrazer added MBA samples from tigress — Latest commit `91a5c16` 7 days ago

..		
info	added VM handler samples for vmprotect and themida	7 days ago
mba/tigress	added MBA samples from tigress	7 days ago
themida/tiger_white	added VM handler samples for vmprotect and themida	7 days ago
vmprotect	added VM handler samples for vmprotect and themida	7 days ago
tigress_mba_trace.bin	initial commit	15 days ago
vmprotect_add16_trace.bin	initial commit	15 days ago

Summary

- obfuscation techniques (opaque predicates, VM, MBA)
- symbolic execution for syntactic deobfuscation
- program synthesis for semantic deobfuscation

`https://github.com/RUB-SysSec/syntia`