Back To The Epilogue

Evading Control Flow Guard via Unaligned Targets

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Outline

- Control Flow Integrity
- Microsoft Control Flow Guard
- BATE: Bypassing CFG
- Impact Evaluation
- Conclusions

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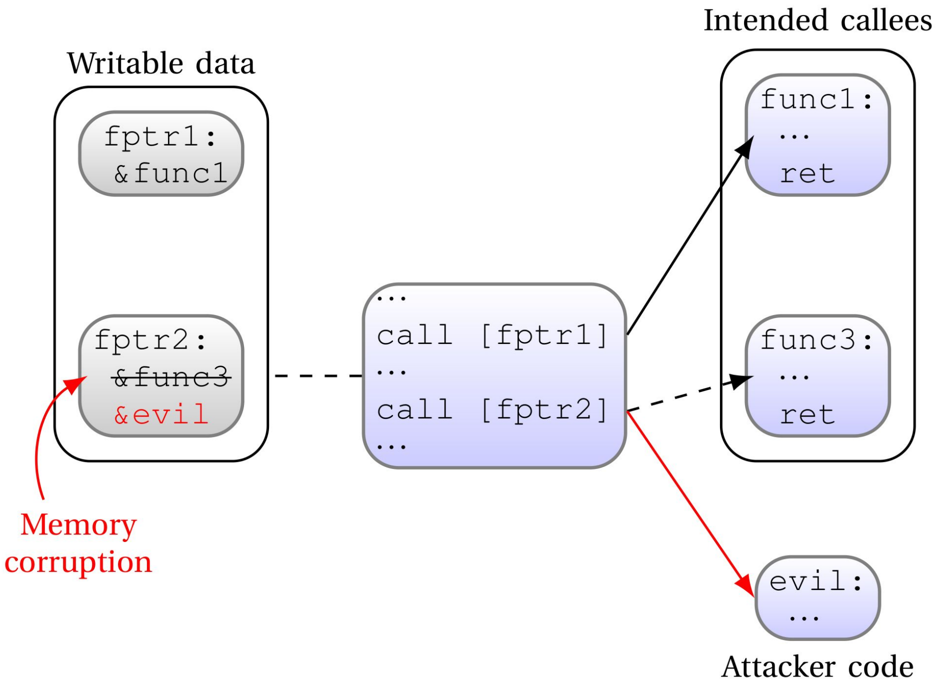
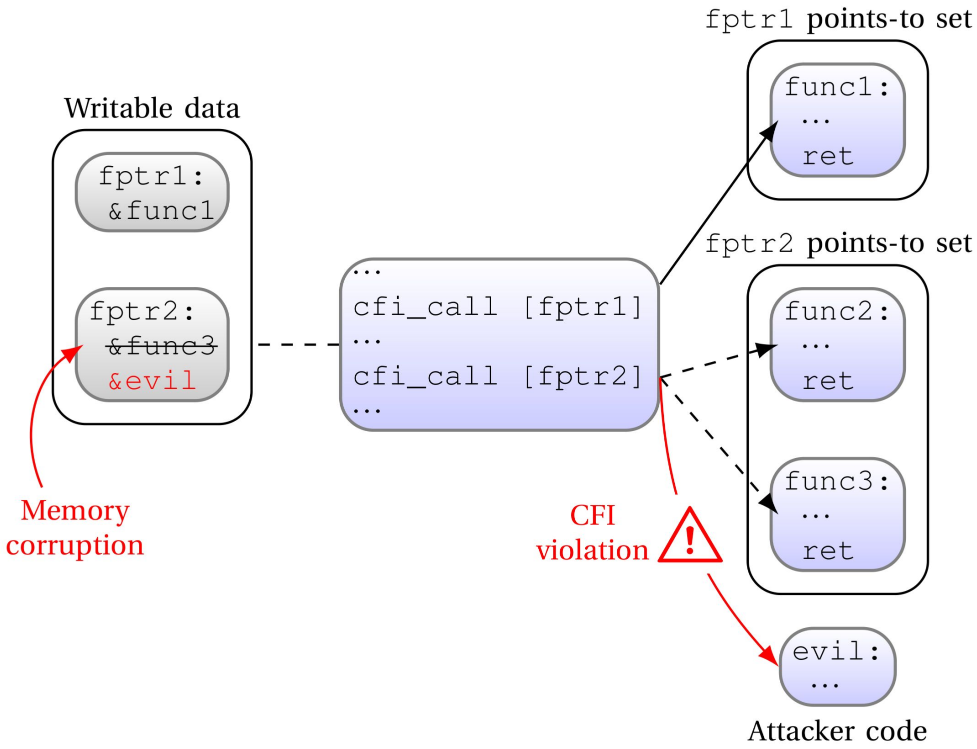
Control Flow Integrity

Memory corruption vulnerabilities lead to **Control Flow Hijacking**



Control Flow Integrity

CFIs prevent redirection of **control flow** to arbitrary locations



Control Flow Integrity

- CFIs can protect:
  - **Forward edges** *(calls, jumps)*
  - **Backward edges** *(return addresses)*

- Statically determined **set of valid targets** for a call

Control Flow Integrity

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- Statically determined **set of valid targets** for a call

Undecidable!

- Resort to **approximations** of such sets:
  - **Coarse** grained *(single valid target set)*
  - **Fine** grained *(valid target set per call site)*

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Control Flow Guard - Overview

- **Coarse Grained** CFI mechanism
  - *Deployed in Microsoft Windows since Windows 8.1*
    (500 million machines worldwide)
  - Compile time → *valid target table* for **any** indirect branch

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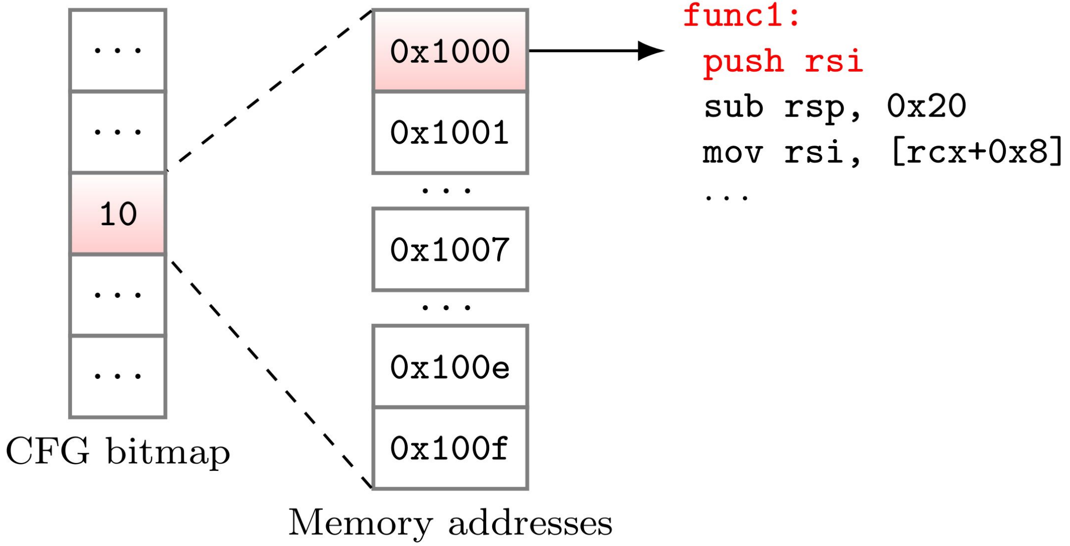
      (500 million machines worldwide)
    - Compile time → *valid target table* for **any** indirect branch
    - Module loading → *CFG bitmap* **for 16-byte aligned ranges**

Control Flow Guard - Overview

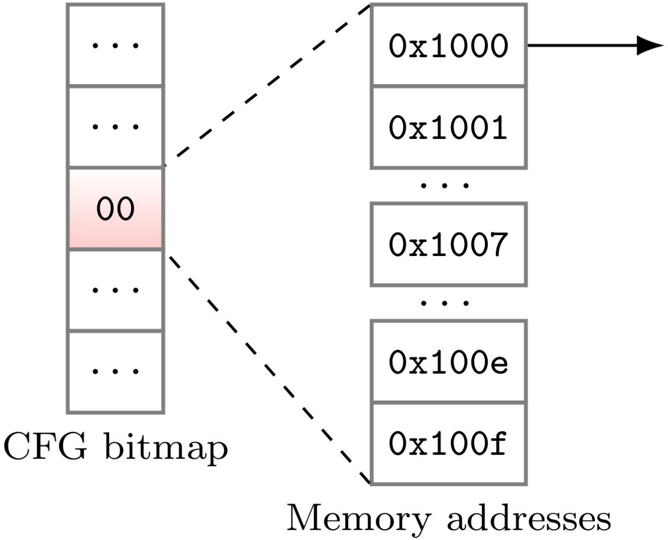
10: Aligned valid target



```
func1:
 push rsi
 sub rsp, 0x20
 mov rsi, [rcx+0x8]
 ...
```

Control Flow Guard - Overview

00: No valid target



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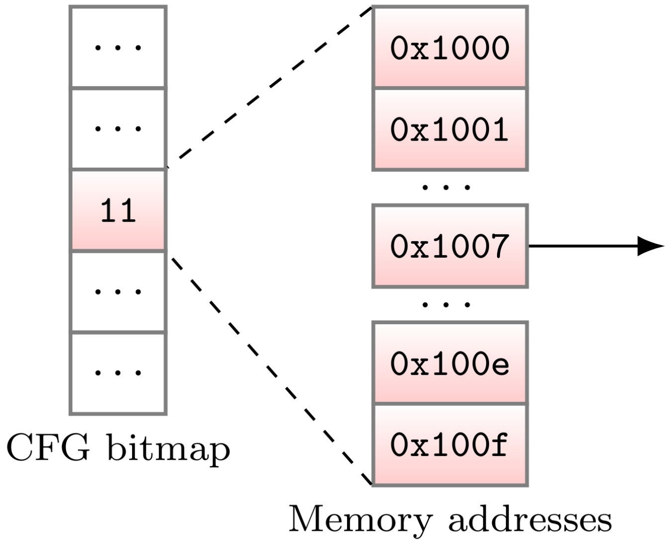
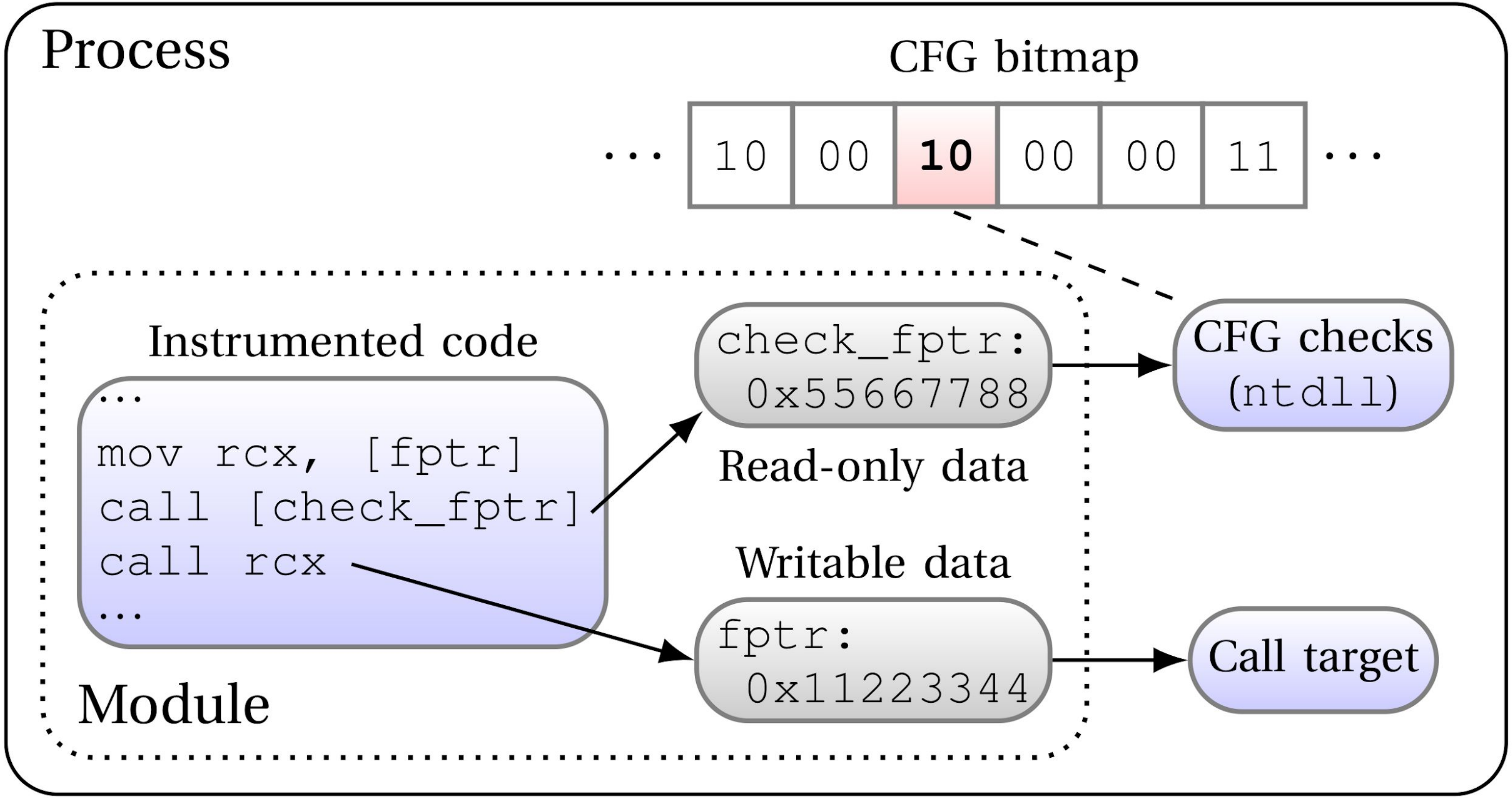
Control Flow Guard - Overview

11: Unaligned Valid Target



```
func1:
 ...
 add rsp, 0x40
 pop rdi
 pop rbx
 ret
func2:
 push rsi
 sub rsp, 0x20
 mov rsi, [rcx+0x8]
 ...
```

Control Flow Guard - Runtime



```
...
mov rcx, [fptr]
call [check_fptr]
call rcx
...
```

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Bypassing CFG

- Multiple issues
  - **Unaligned targets**
  - No backwards-edge CFI
  - Process-wide bitmap

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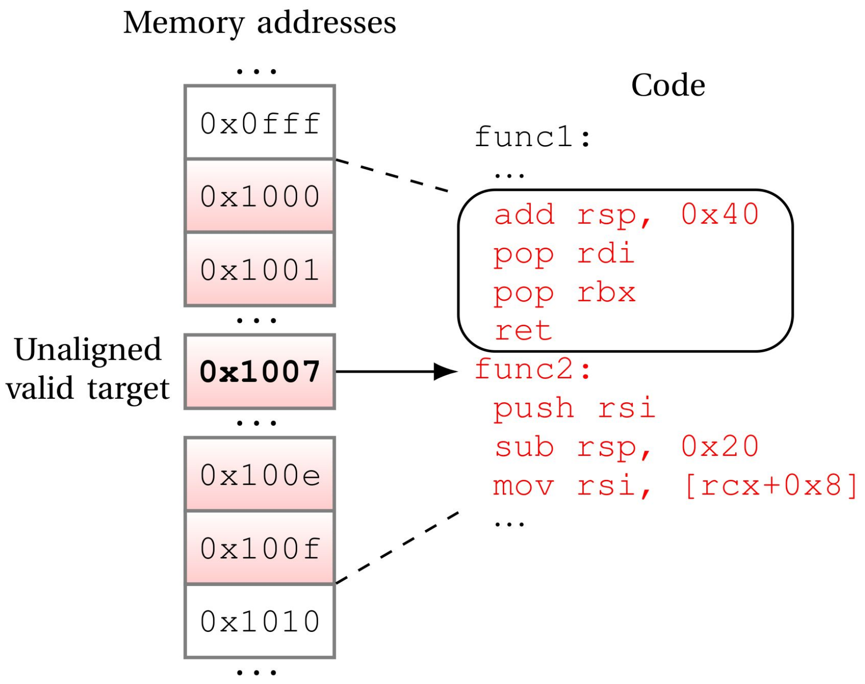
- Functions are made of three parts
  - Prologue *(allocate stack, save registers)*
  - Body
  - **Epilogue** *(deallocate stack, restore registers, return)*

Unaligned Function Epilogues

Unaligned targets allow us to reach **epilogues**

- **Increment** stack pointer



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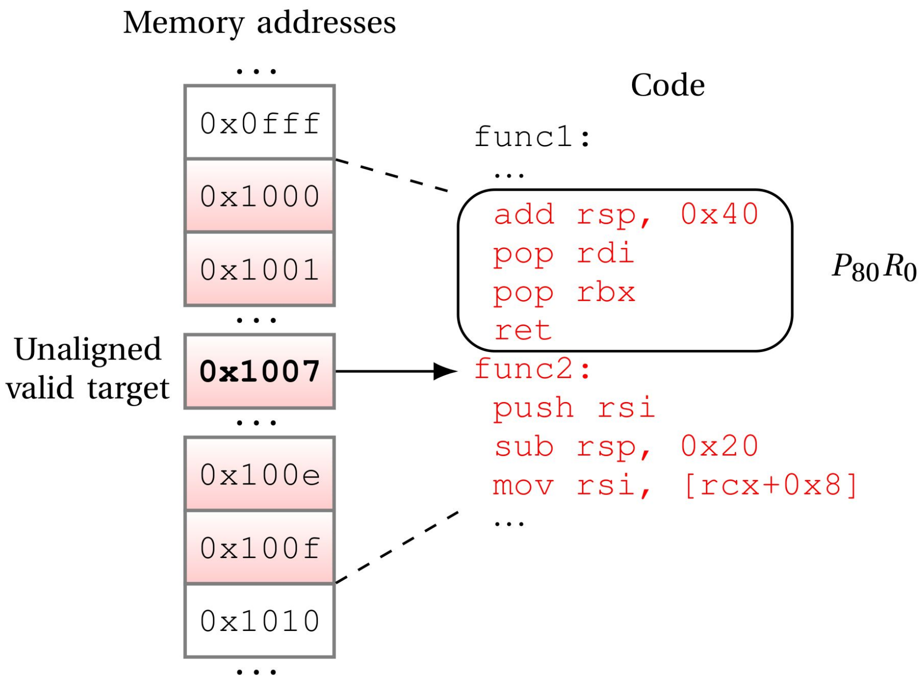
Bypassing CFG

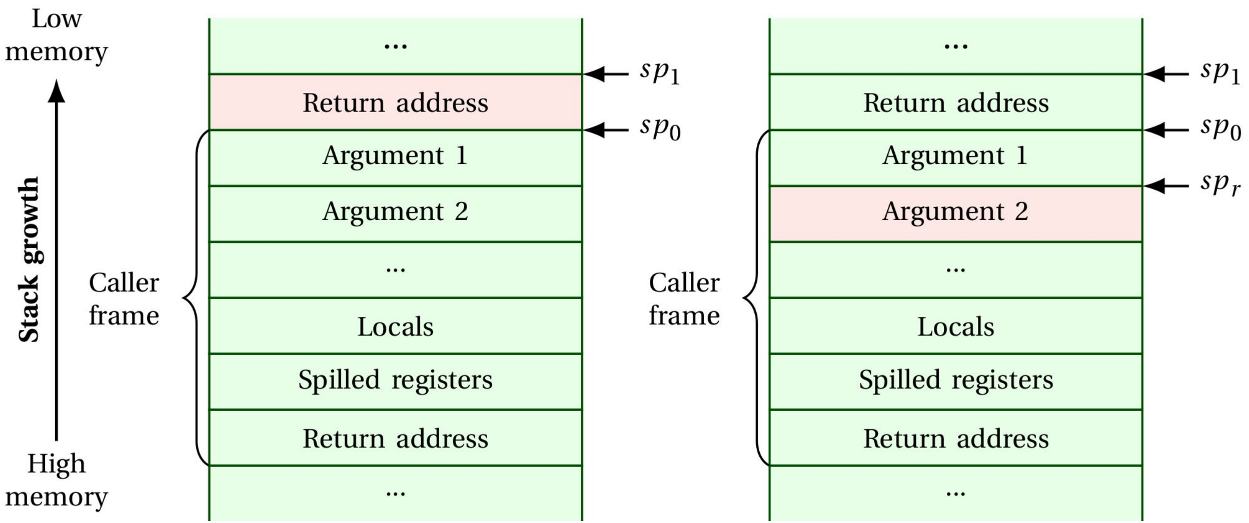
Define **PR gadgets**

- Increment stack pointer by *P* bytes **before** returning
- Increment stack pointer by *R* bytes **after** returning



Bypassing CFG

Hijack execution to a PR gadget to **pivot** the stack



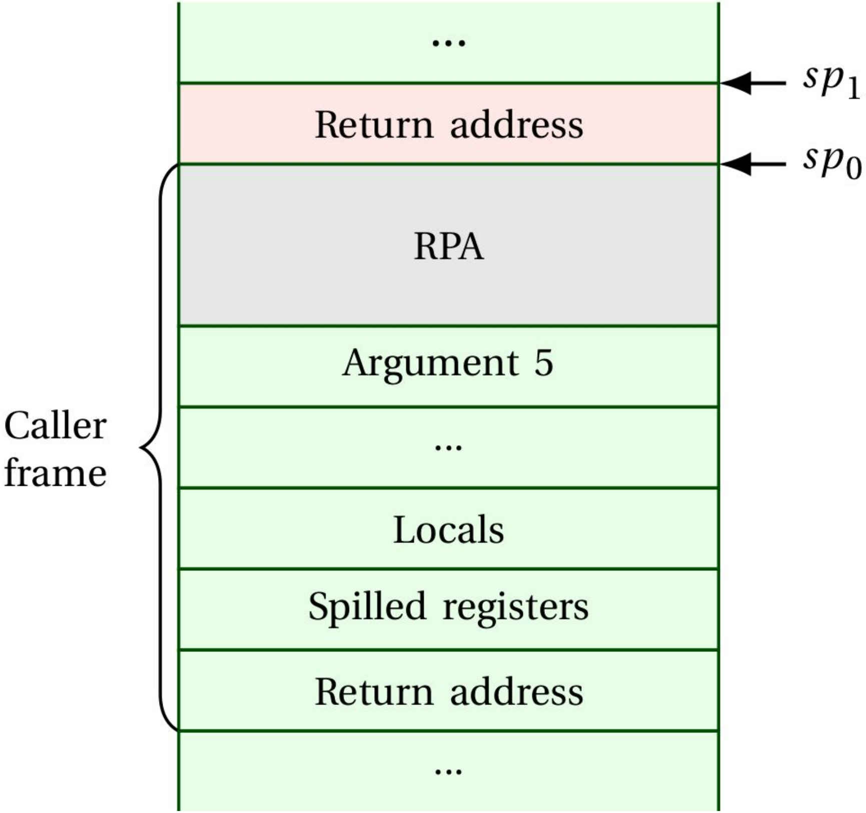
Return address into attacker-controlled data

No **backwards-edge** CFI

Bypassing CFG

Problem: on **64-bit**, stack control is harder

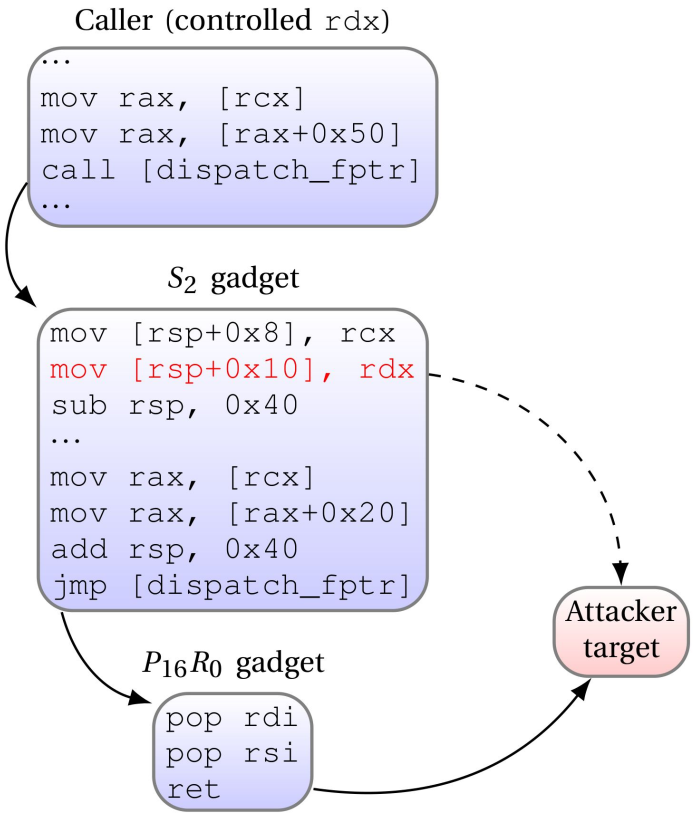
- First 4 **arguments** passed in registers
- *Register Parameter Area* at stack top



Bypassing CFG

Solution: **spill** argument registers to stack

- **S gadgets**
- Chain S gadget - PR gadget



```
...
mov rax, [rcx]
mov rax, [rax+0x50]
call [dispatch_fptr]
...
```

```
mov [rsp+0x8], rcx
mov [rsp+0x10], rdx
sub rsp, 0x40
...
mov rax, [rcx]
mov rax, [rax+0x20]
add rsp, 0x40
jmp [dispatch_fptr]
```

```
pop rdi
pop rsi
ret
```

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Impact Evaluation

- Systematically evaluated Windows' **system libraries**
    - Loaded by a **large number** of processes

	PR	S
32-bit	57	-
64-bit	22	985

Impact Evaluation

- Systematically evaluated Windows' **system libraries**
  - Loaded by a **large number** of processes

- Found PR and S gadgets in **high-risk** libraries
  - **C runtime** (32-bit)
  - Media codecs
  - Script engines

	PR	S
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Conclusions

- **Coarse grained** 16-byte approximation by CFG
    - Well-performing practical design
    - **Very strong assumptions** (→ *alignment)* do not hold

- BATE: High impact attack
    - **Widespread** gadgets
    - General, allows us to **bypass CFG entirely**
    - Feasible in practice

- **Disclosed** to Microsoft
    - Will be mitigated in RS4 (March/April)
    - We have permission to present this work

Thanks!

And align your code :-)

Backup Slides

Related Work

- Gadget Stitching *(Davi et al., 2014)*
  - Chains of CFI-allowed gadgets

- Counterfeit Object-Oriented Programming *(Schuster et al., 2015)*
  - Chains of CFI-allowed virtual methods

Both draw from **restricted gadget sets**

- Writing chains is harder
- BATE enables unrestricted code reuse

More gadgets?!

- Systematically evaluated Microsoft **Office 2016 Suite**
    - Exposed to attacks (e.g., macros on received documents)
    - 64-bit version

- **123 PR gadgets**

- Of which 101 are interesting: $P_{40}R_{0}$

Countermeasures

Aligning targets

- Simple
- May be difficult in corner cases (e.g., handwritten assembly)
- May impact certain optimizations

Making CFG more precise

- Virtual addressing space limitations
- CFG redesign?

Proof-of-Concept

PoC exploit for 64-bit **Edge** on Windows 10

- Based on CVE-2017-720{0,1}
- **Remote code execution** from JavaScript
- MPEG-2 media codec by embedding a video