ECE 6504

Embedded and Controls Systems Security: Stack Smashing V

Reading:

T:*kBouncer, ROPGuard, ROPecker,* and *Evaluating the Effectiveness of Current Anti-ROP Defenses*
N:*Security Based on Physical Unclonability and Disorder*

“Learn from the mistakes of others. You can never live long enough to make them all yourself.”

–Groucho Marx

stack protection methods:

1. make the overflow difficult to exploit
2. make overflow noticeable
3. make it impossible

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detect ROP activity

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1. make the overflow difficult to exploit
2. make overflow noticeable
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assuming failure

detect ROP activity

1. fixed load addresses
2. shared libraries incompatible with ASLR
3. base address of a DLL can be either calculated via leaked pointer or brute-forced

an ideal ROP detector:

1. operates w/binaries (no source needed)
2. w/o debug symbols
3. does not insert code into calls
4. low overhead (time, memory)

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	ROP Types	No Source Code	No Binary Rewriting	Run-time Efficiency
DROP [1]	Ret-based	√	X	X
ROPDefender [2]	Ret-based	√	X	X
ROPGuard [3]	Ret-based	√	X	√
Return-less Kernel [4]	Ret-based	X	√	√
CFLocking [5]	All	X	√	√
G-Free [6]	All	X	√	√
ILR [7]	All	√	X	√
Binary Stirring [8]	All	√	X	√
IPR [9]	All	√	X	√
CCFIR [10]	All	√	X	√
KBouncer [11]	All	√	X	√
ROPecker	All	√	√	√

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kBouncer

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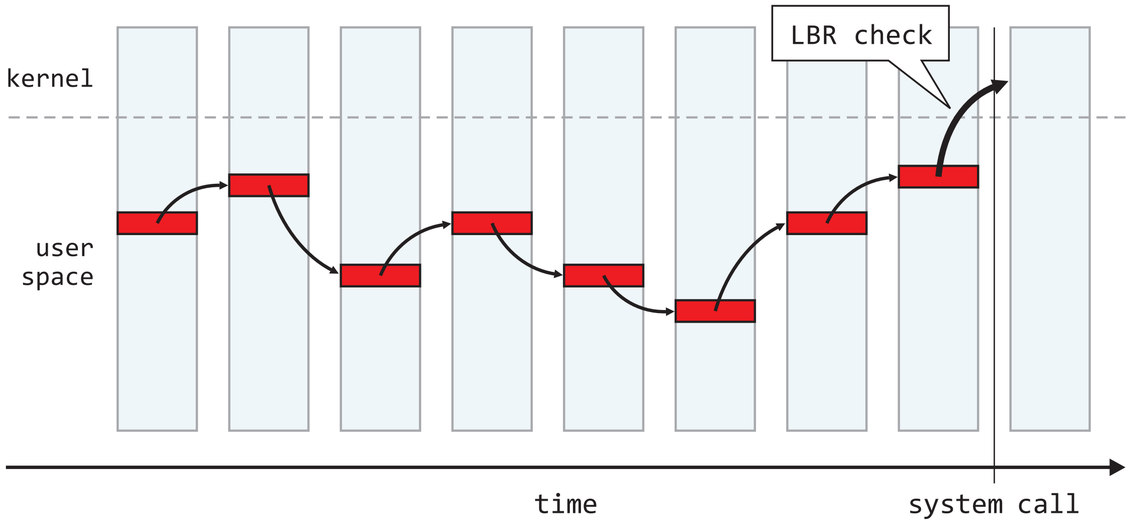

system call anatomy (UNIX)

1. indirect branches (red)
2. wrapper function for call (exposed directly)

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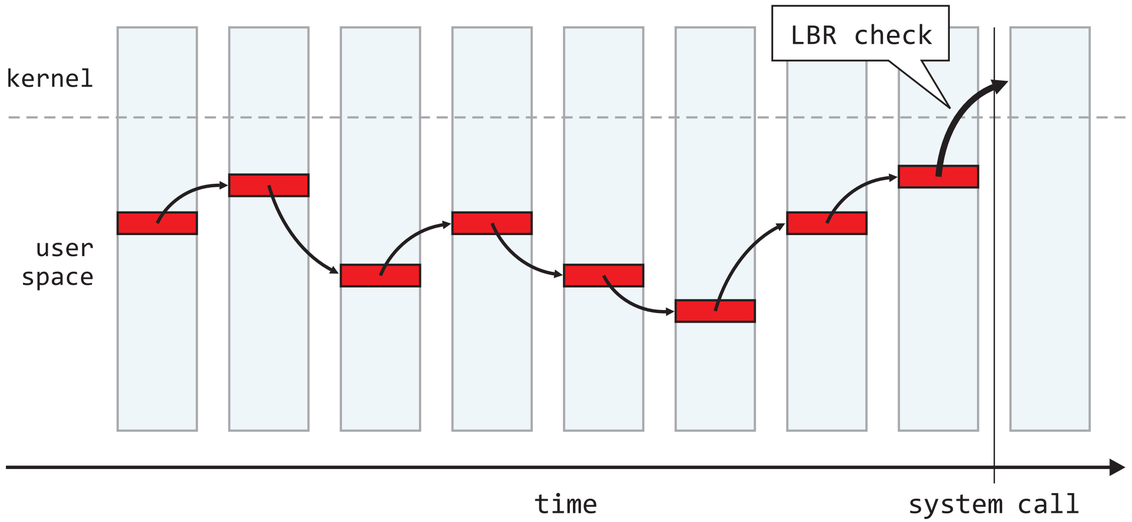

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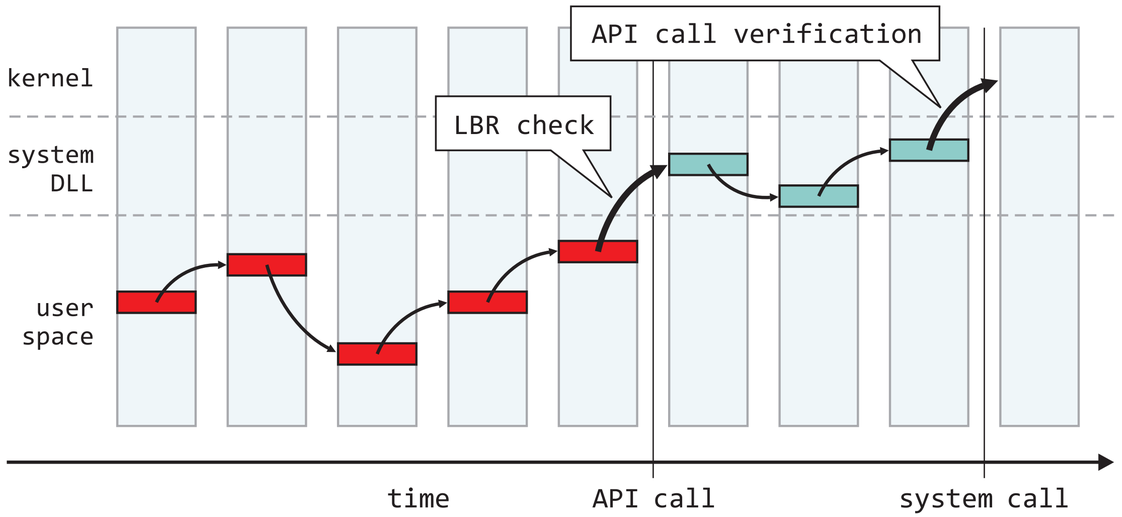
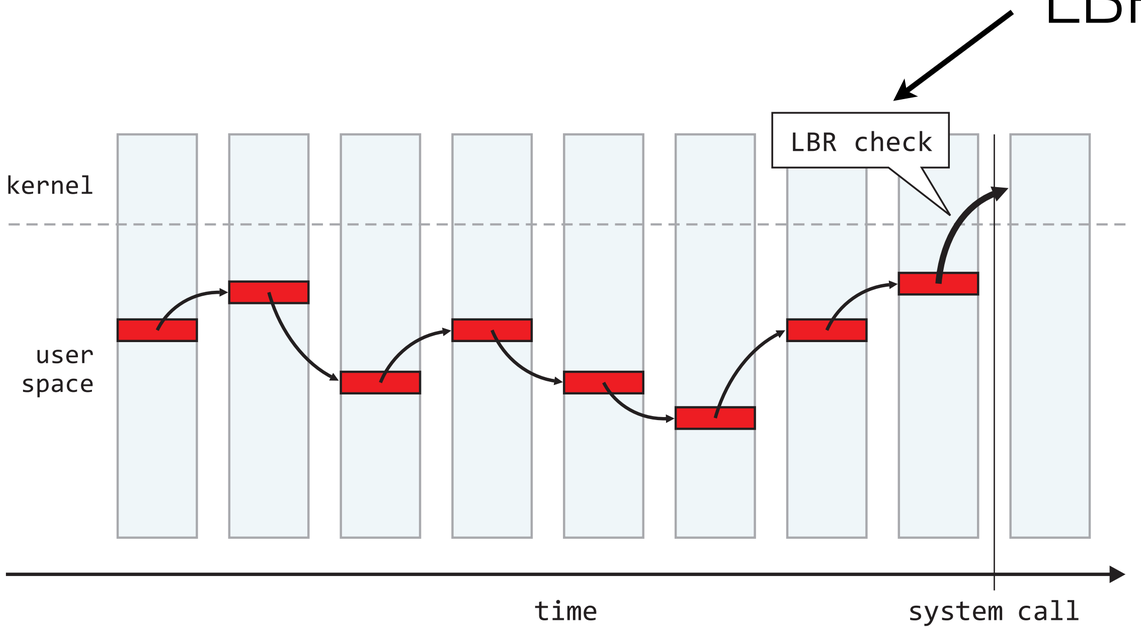
system call anatomy (Windows)

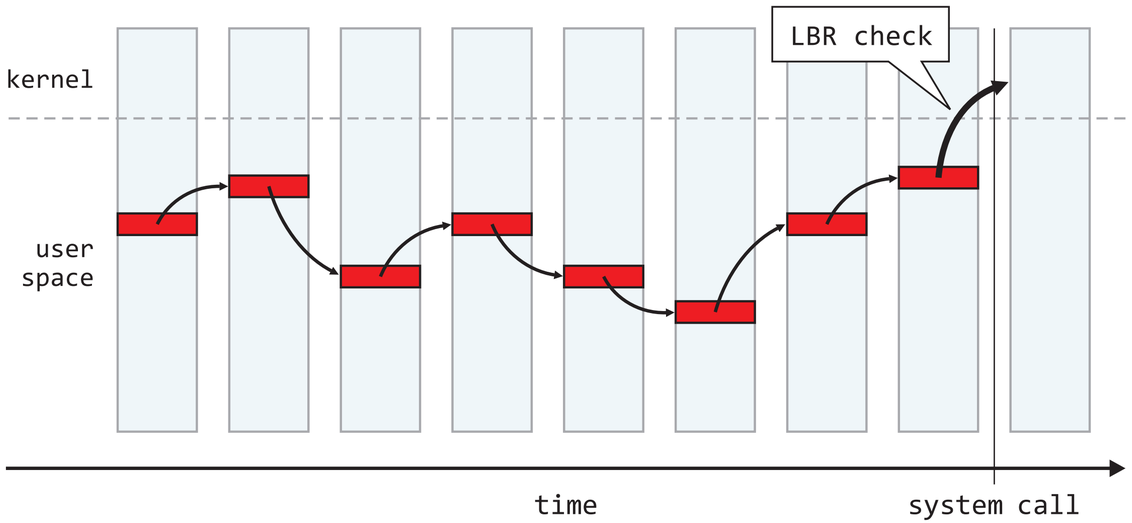
1. indirect branches
2. Windows API
3. Native API (not exposed)





LBR:

1. last branch record
2. hardware debug
3. last 16 branches
   a. address of
   b. target of
4. kernel-mode only



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1. many indirect calls
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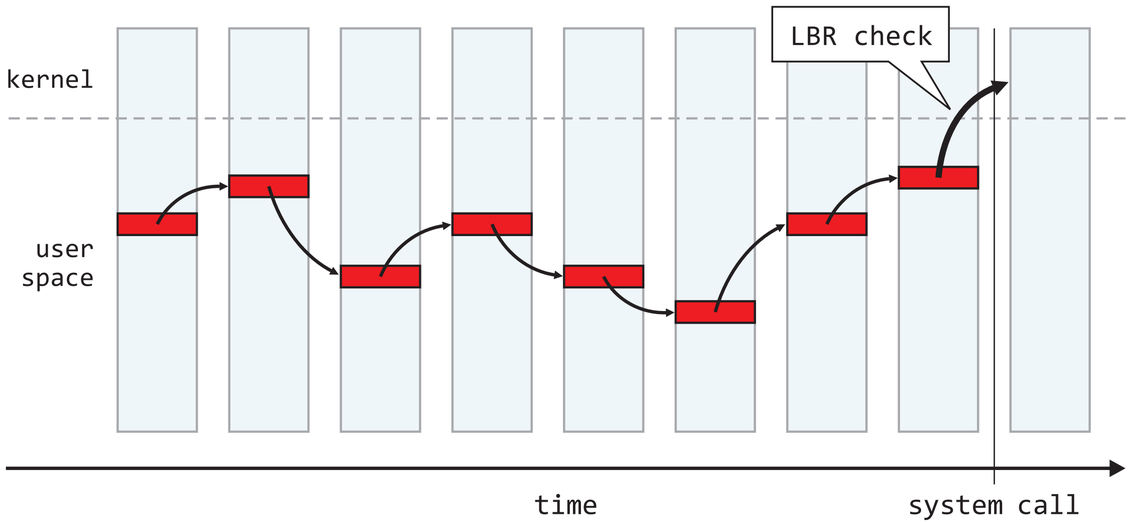

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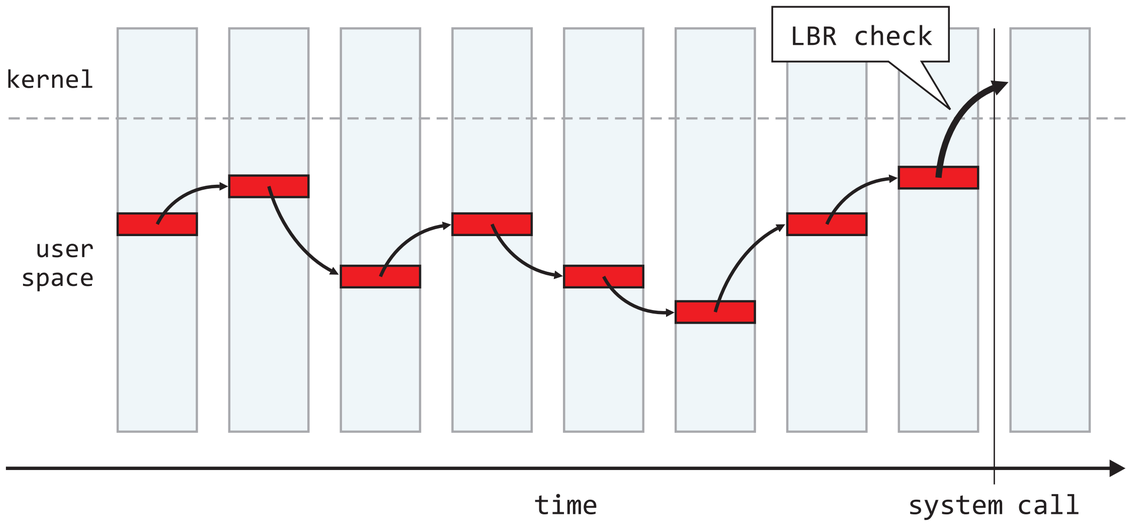

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use LBR to distinguish

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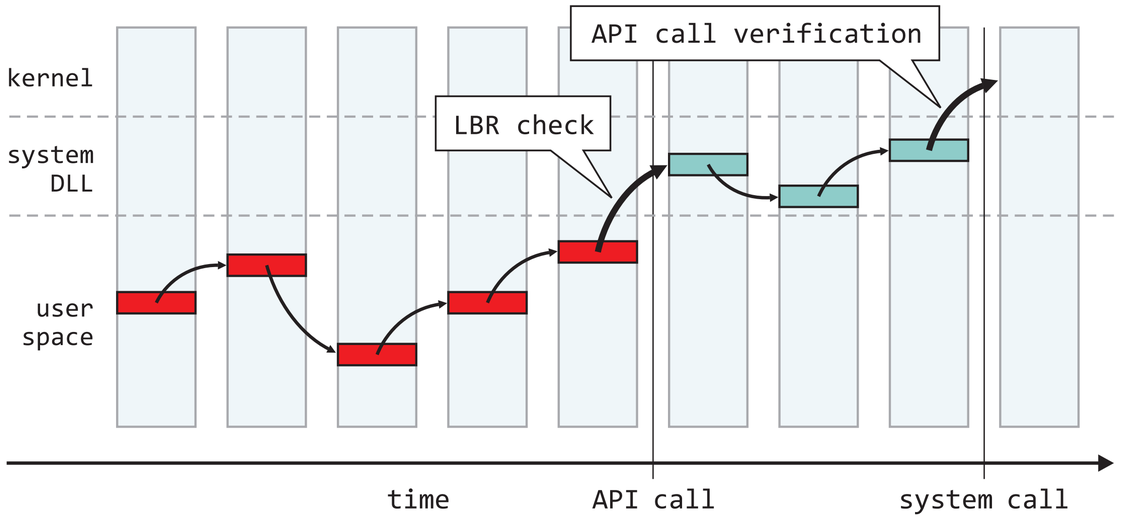
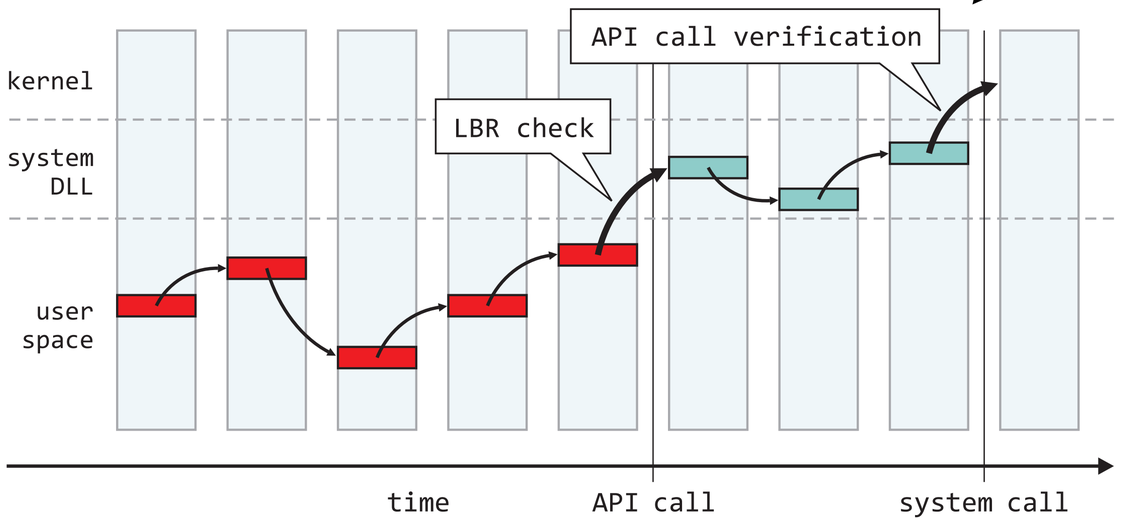


exploit code:

1. does not (usually) invoke system call directly
2. detection code runs at (select) API calls

if it does:

easy to verify that API hasn't made call



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ROP detection:

1. illegal returns
2. gadget chaining

violation of calling convention

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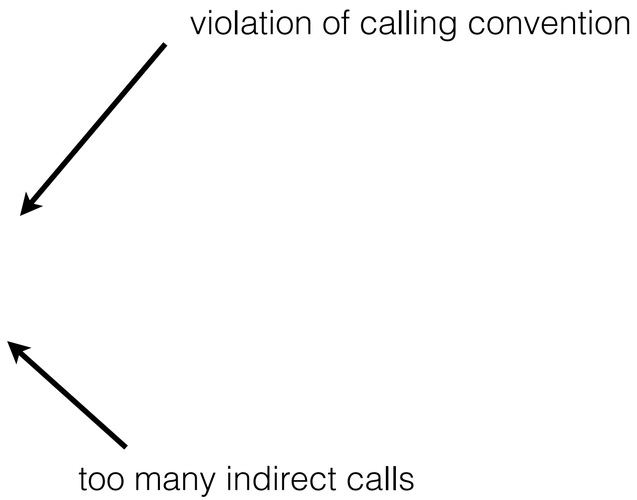
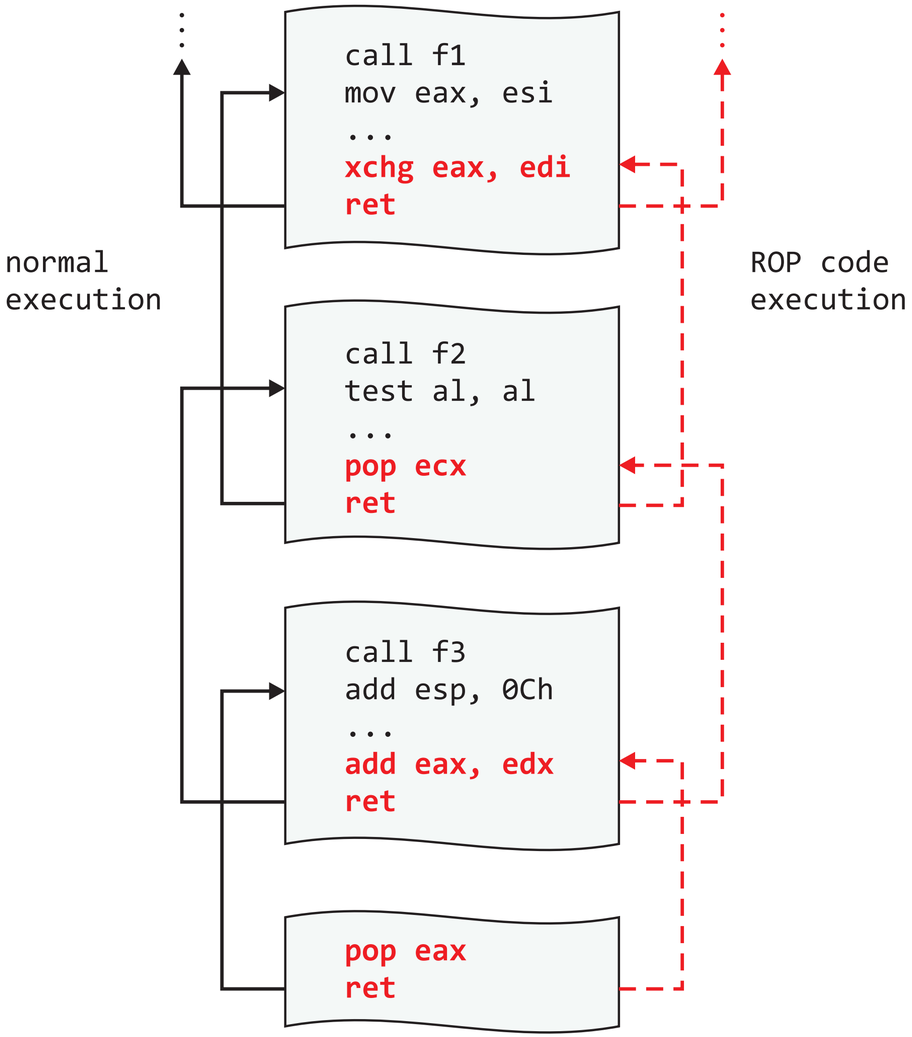


ROP detection: illegal returns



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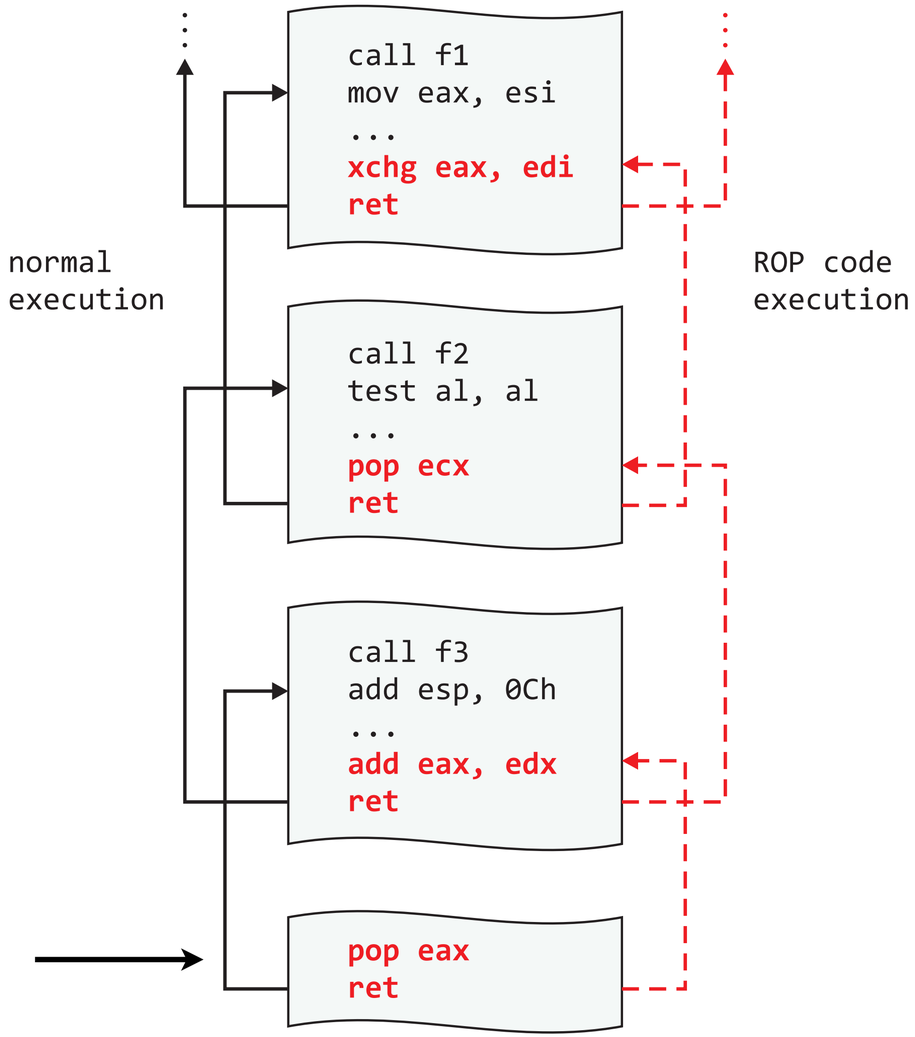

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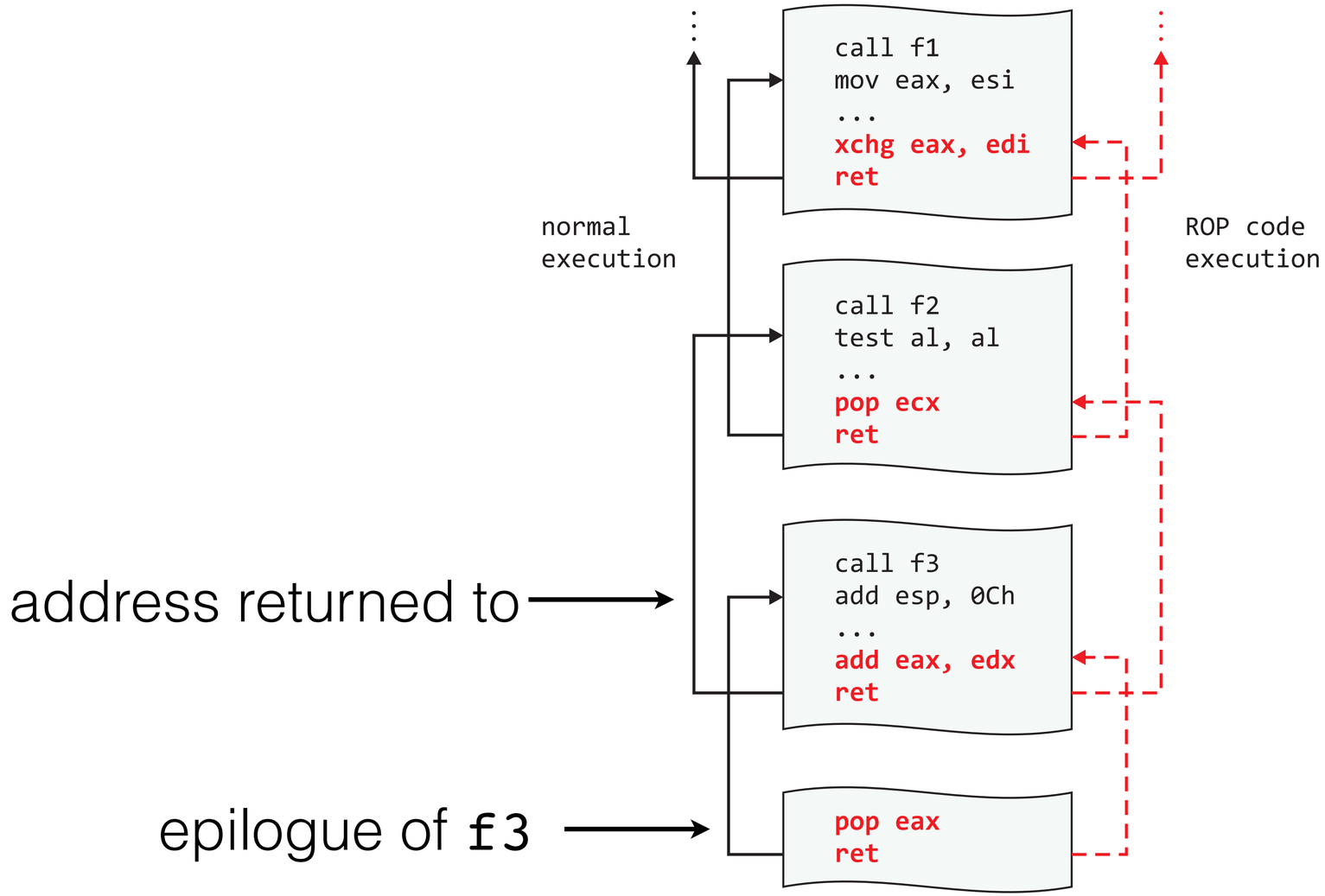

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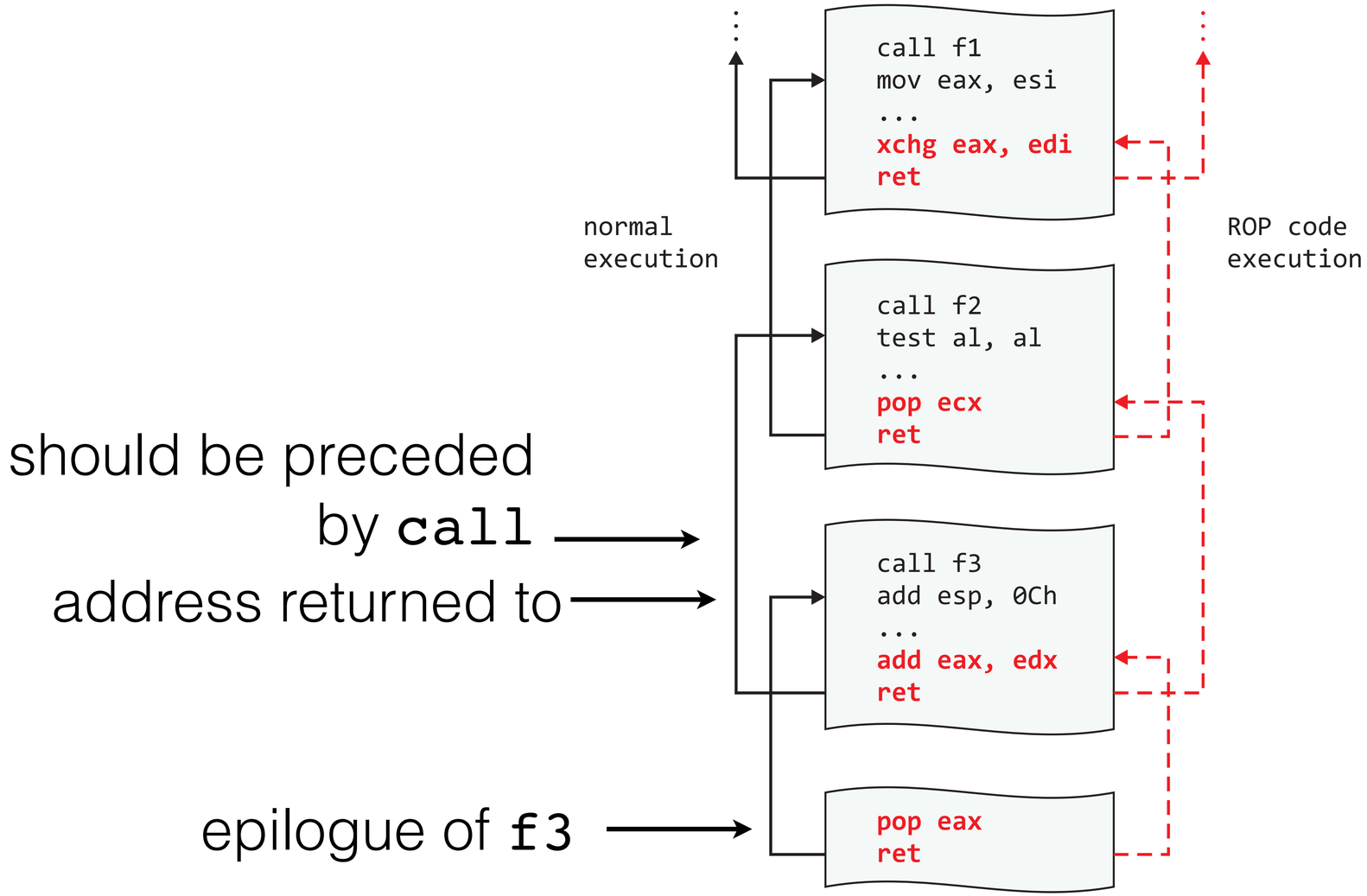

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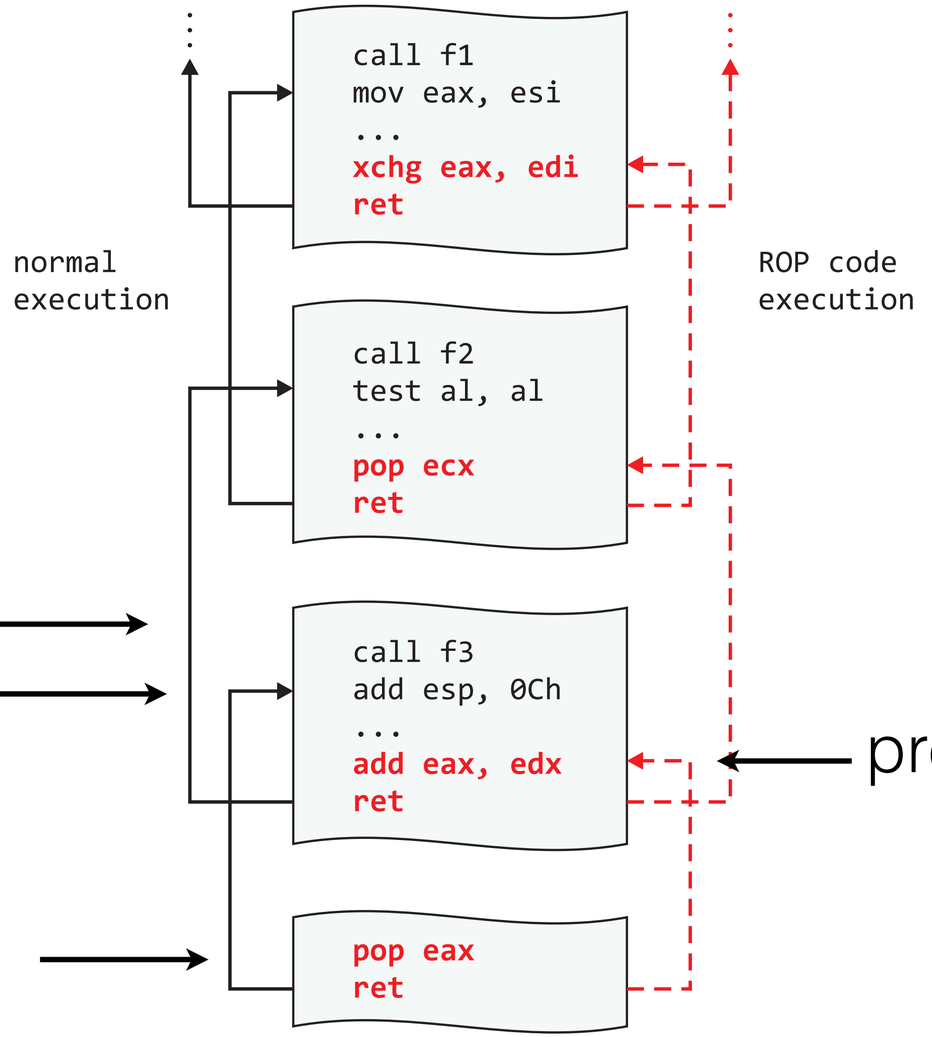

should be preceded by **`call`** → address returned to

epilogue of **`f3`** →

← ROP return to address, not preceded by **`call`**

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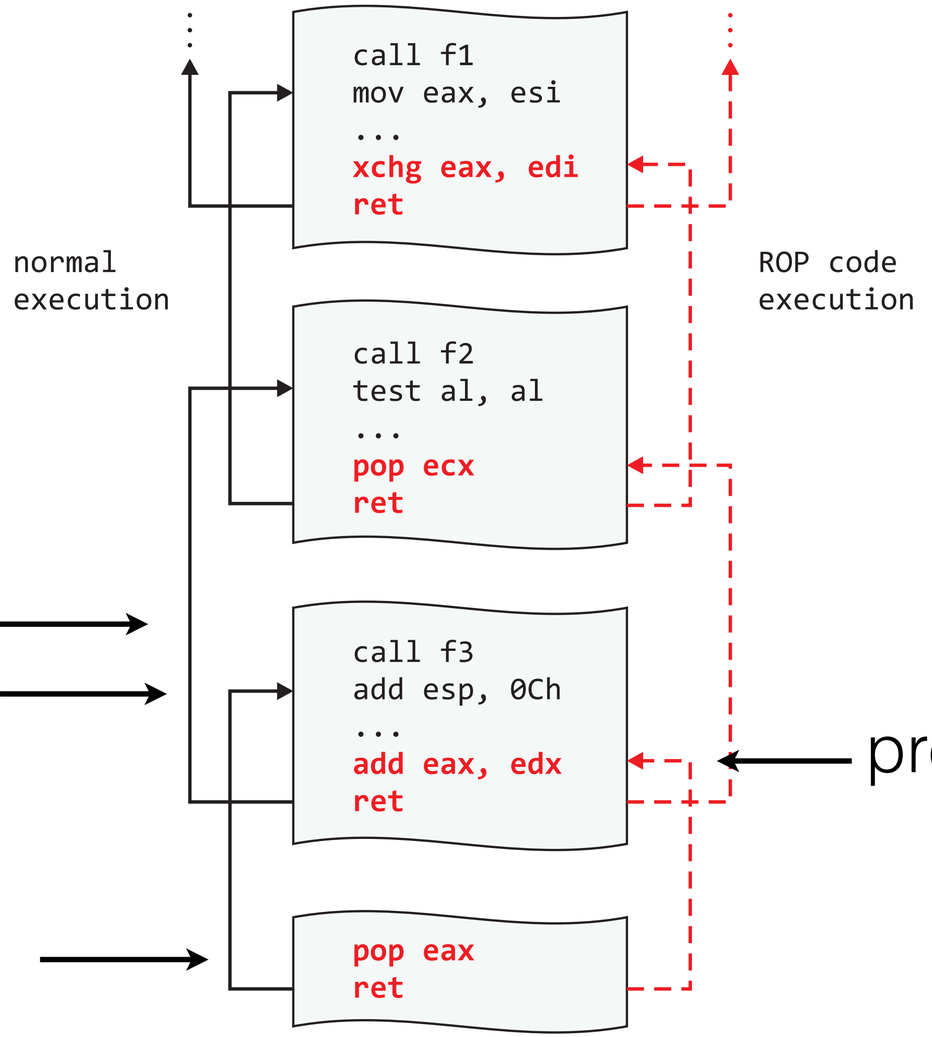

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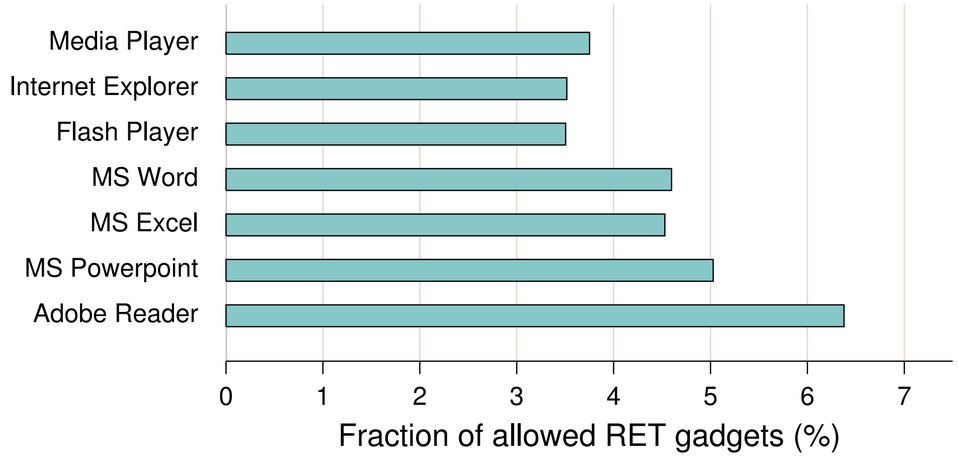
Q: what about gadgets that begin at **`call`**?

prevalence of `call`-preceded gadgets:

1. `call`
2. up-to 20 instructions
3. `ret`



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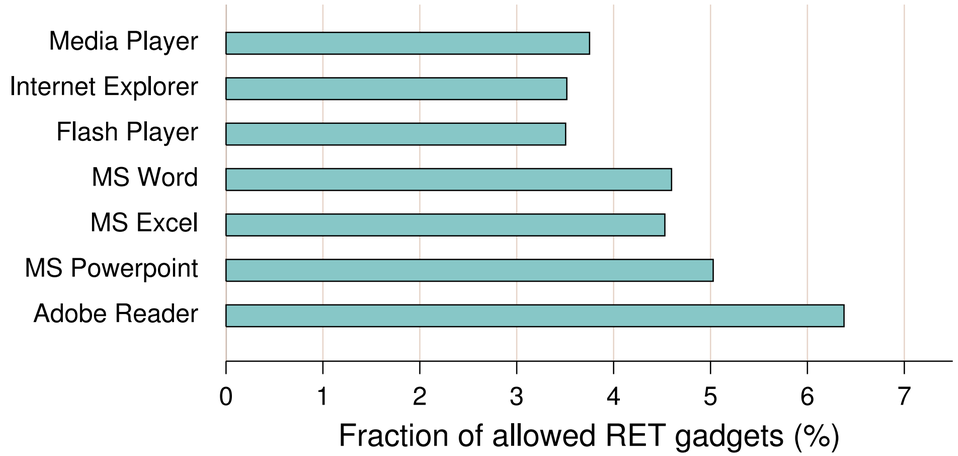

1. thought to be too few
2. non-sense instructions should affect ROP program state

ROP detection: gadget chaining

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sequence of indirect calls, with fewer than 20 instructions between call and return

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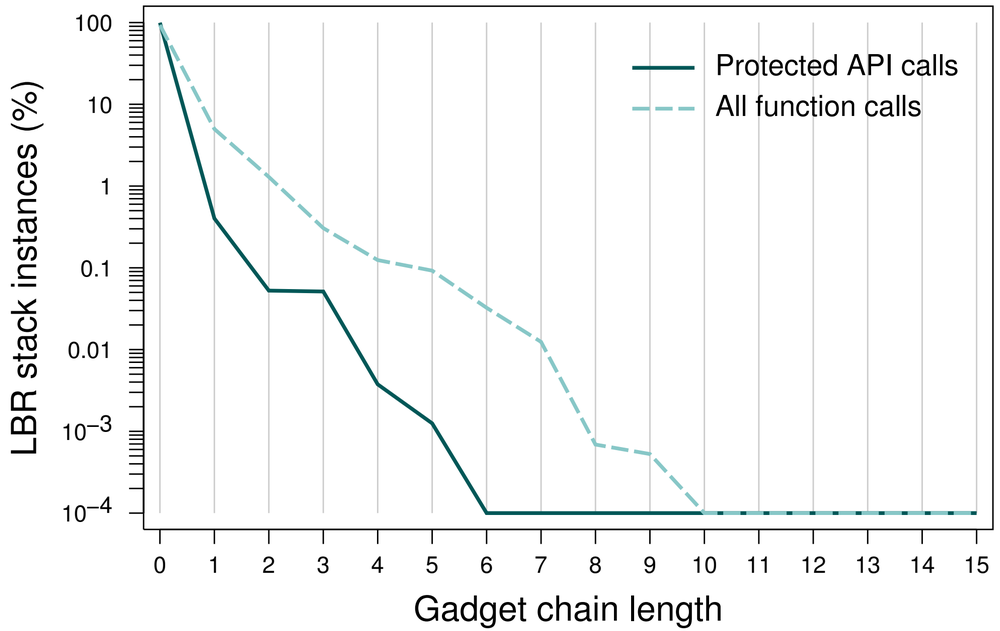

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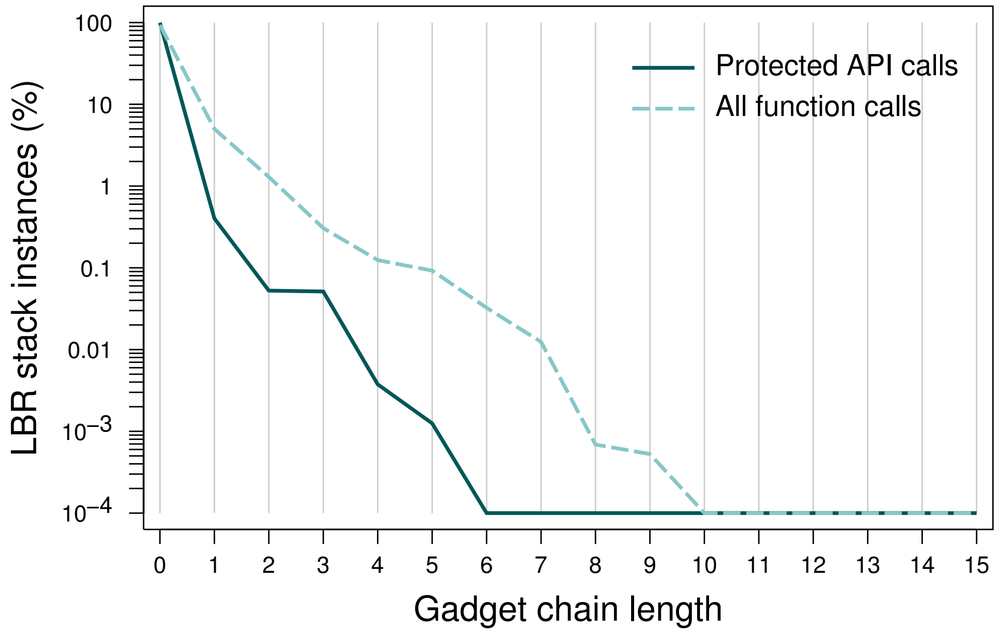

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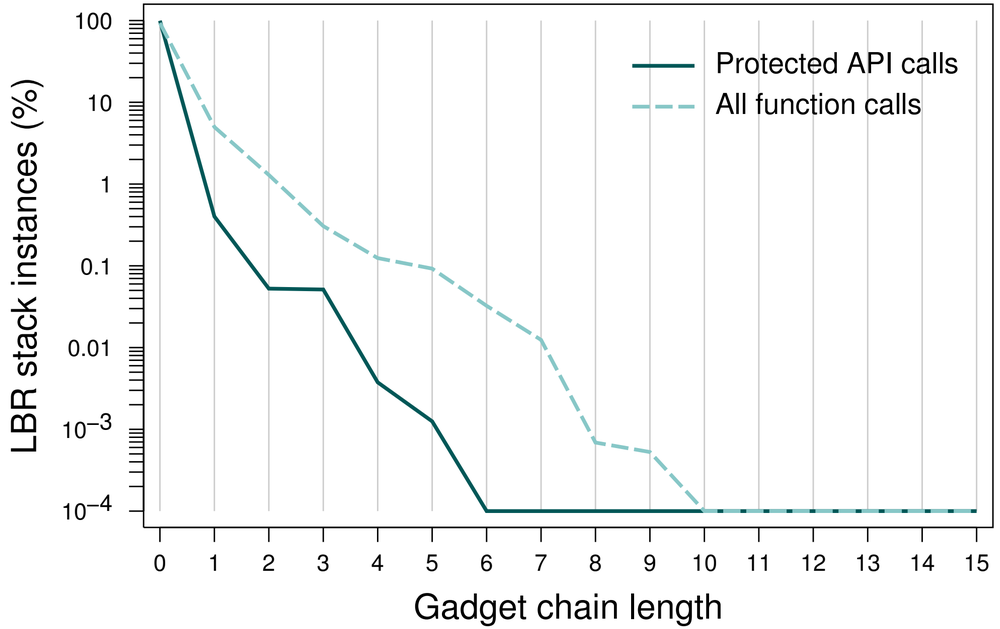

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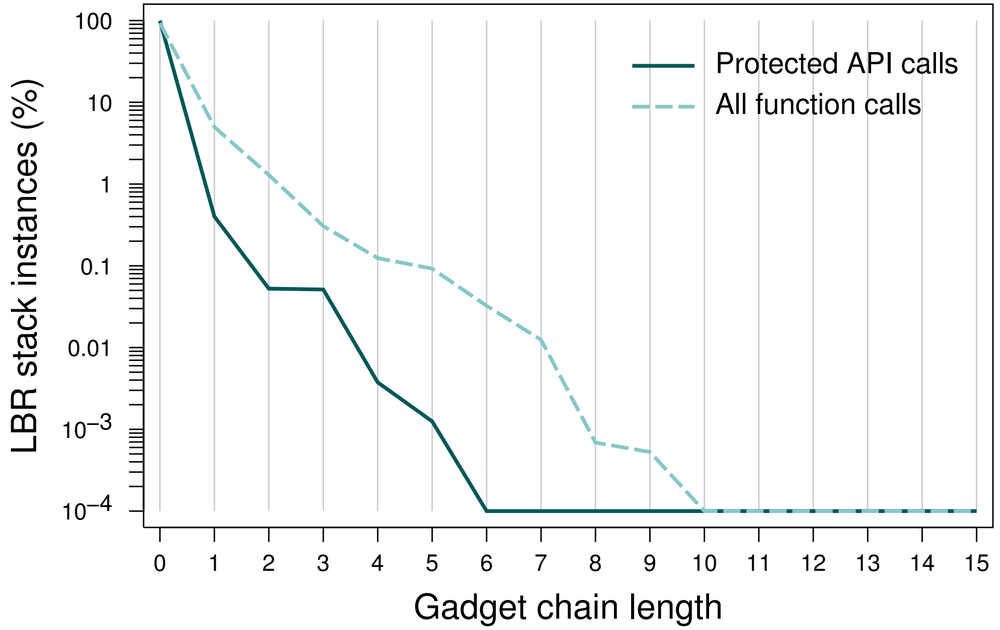

LBR Stack

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01	05F015CA	05F00E17	
02	7C348B06	7C34A028	G01
03	7C34A02A	7C34252C	G02
04	7C34252D	7C36C55A	G03
05	7C36C55B	7C345249	G04
06	7C34524A	7C3411C0	G05
07	7C3411C1	7C34B8D7	G06
08	7C34B8D8	7C366FA6	G07
09	7C366FA7	7C3762FB	G08
10	7C3762FC	7C378C81	G09
11	7C378C84	7C346C0B	G10
12	7C346C0B	7C3415A2	G11
13	7C3415A2	74F64347	
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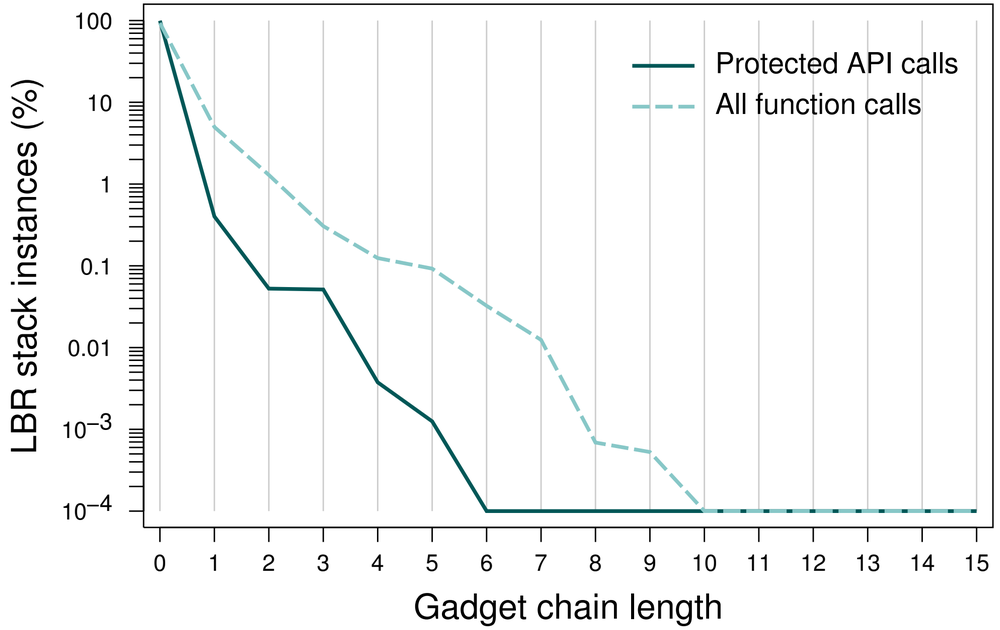

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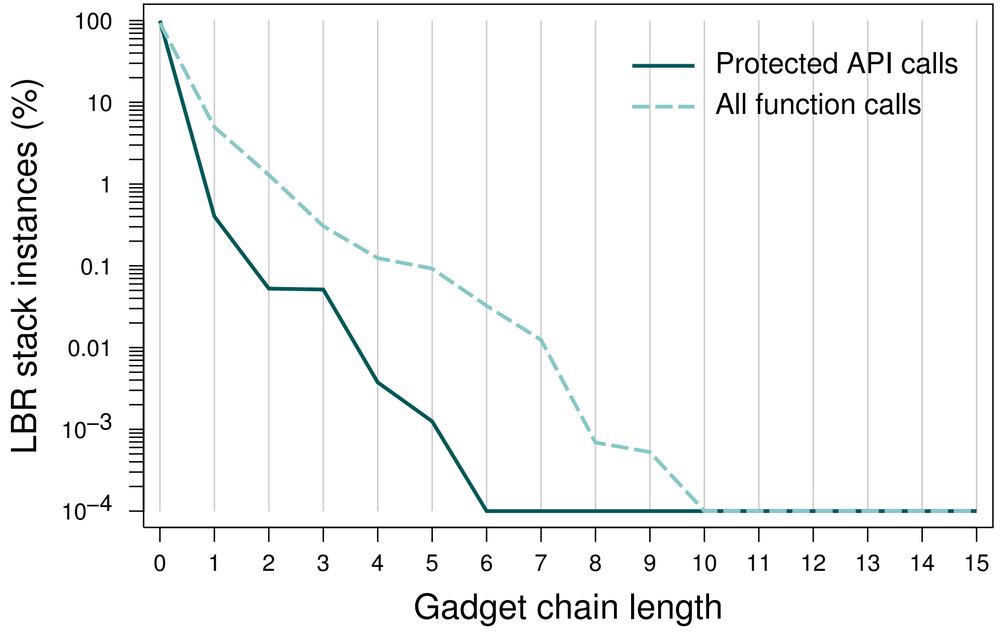

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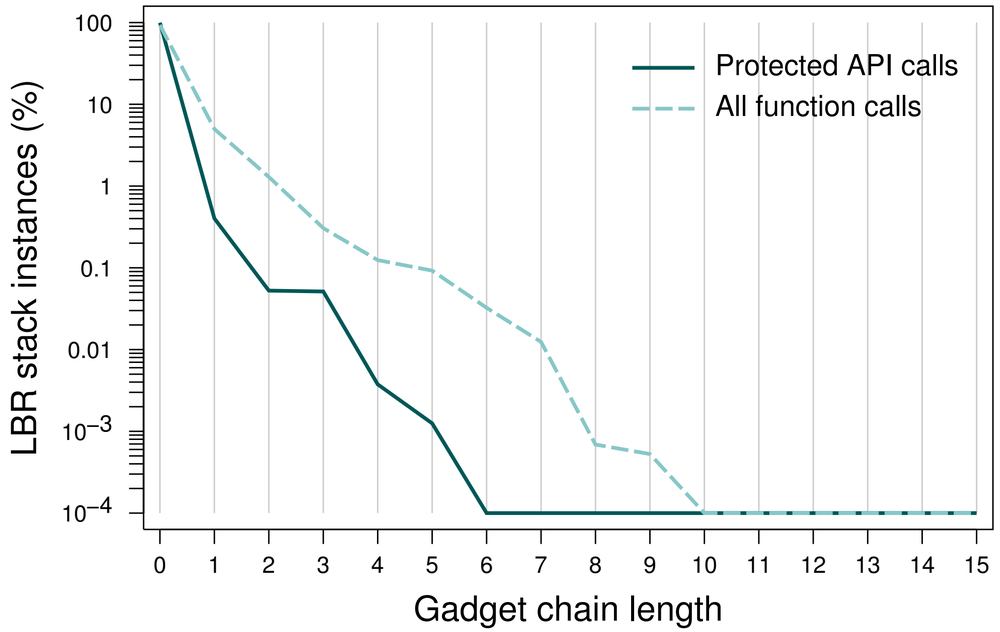

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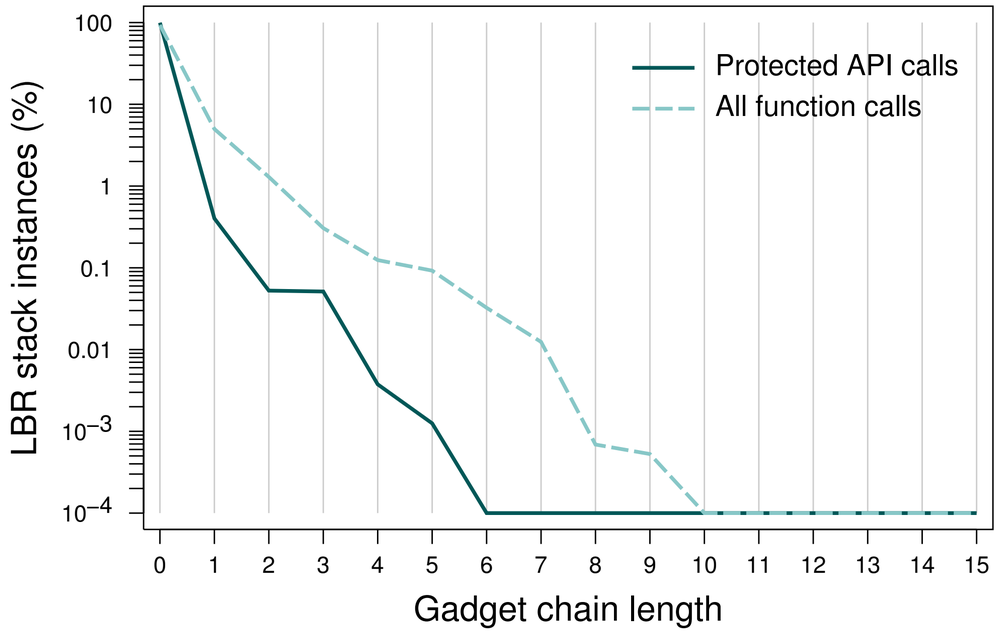

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ROP activity, if > 8

ROPecker

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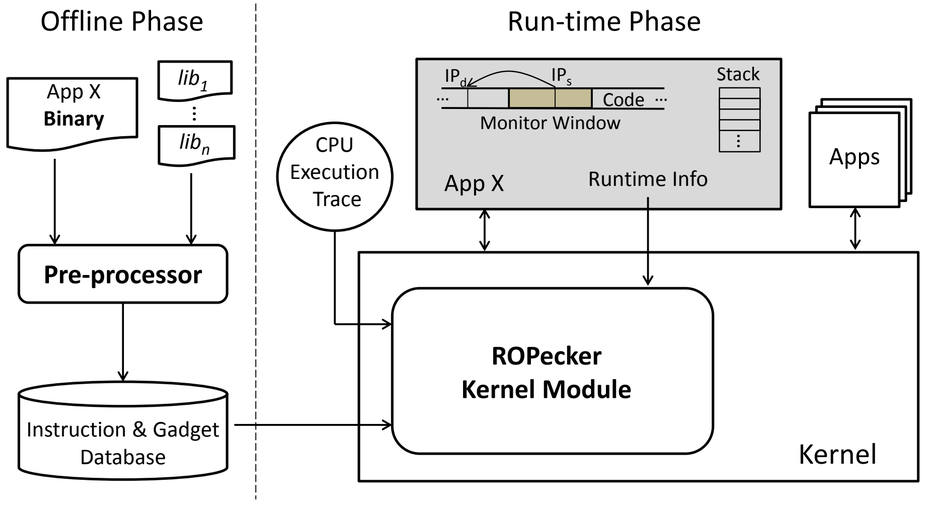

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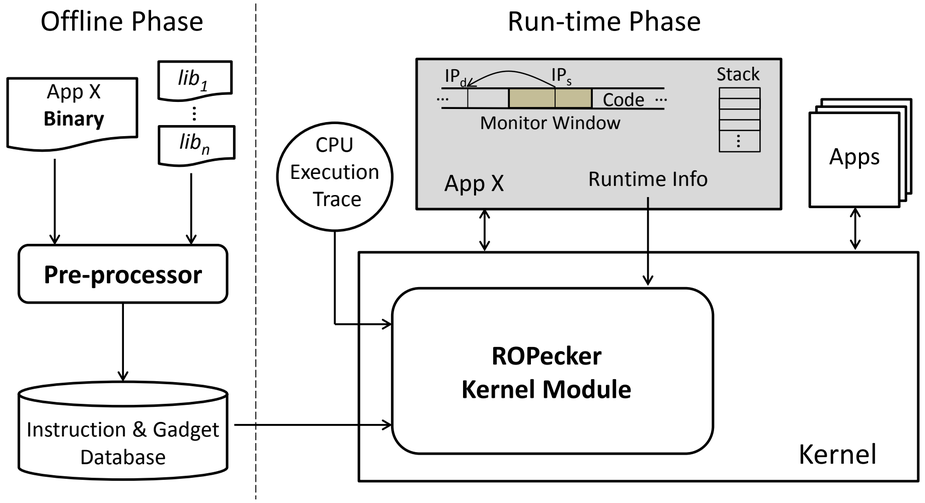
1. uses LBR, as kBouncer; past ROP activity



ROPecker

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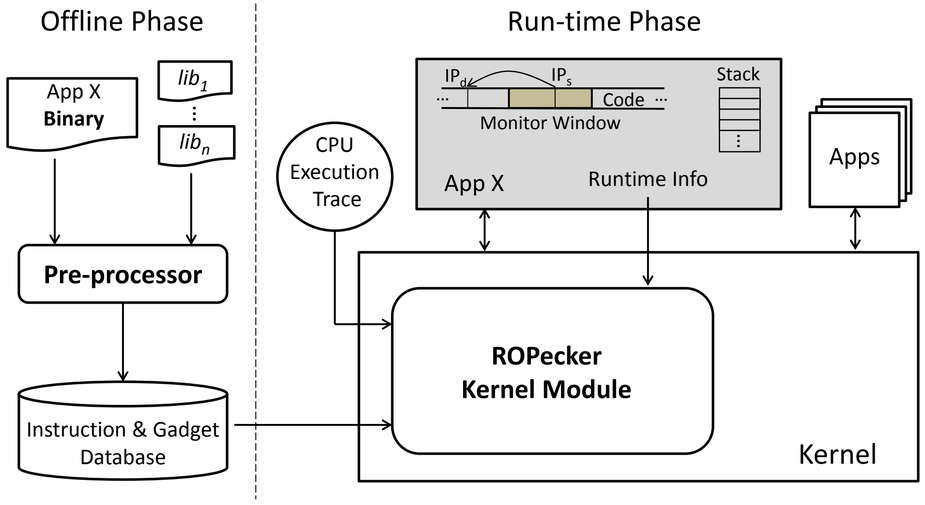

VirginiaTech
Invent the Future

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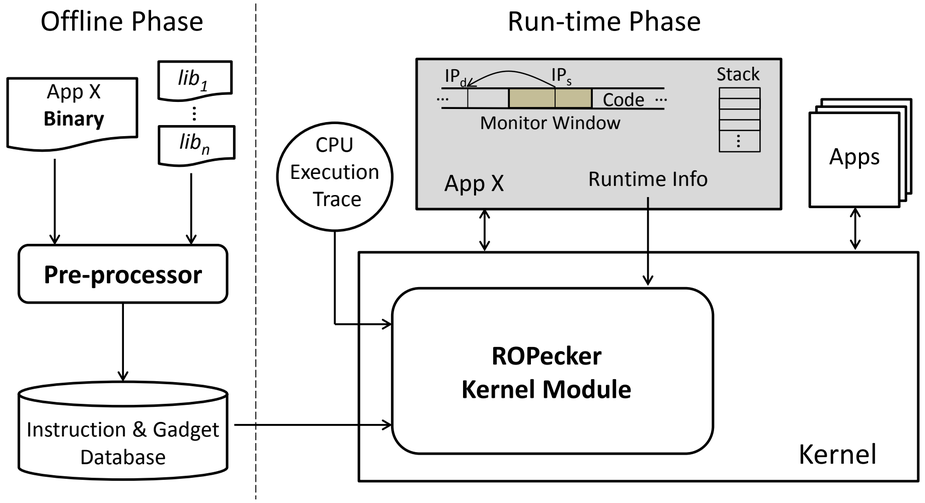

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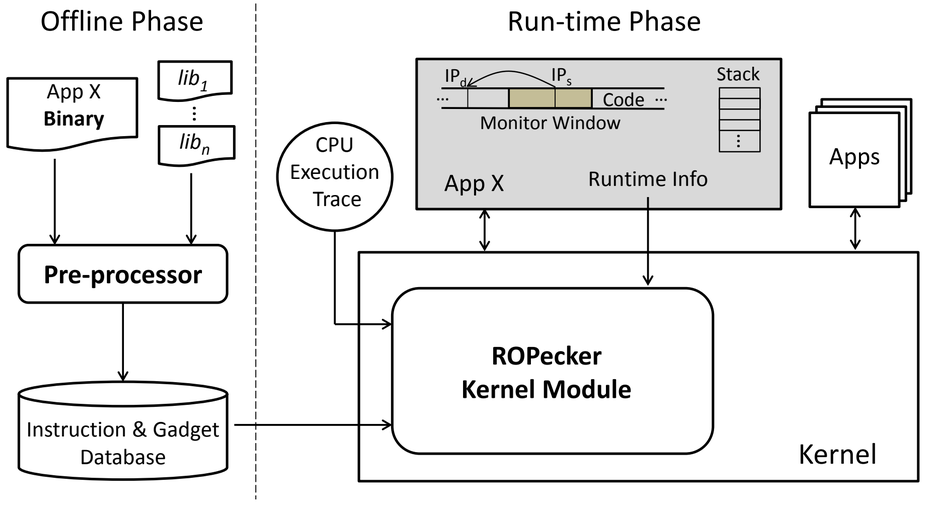
4. identifies potential gadgets



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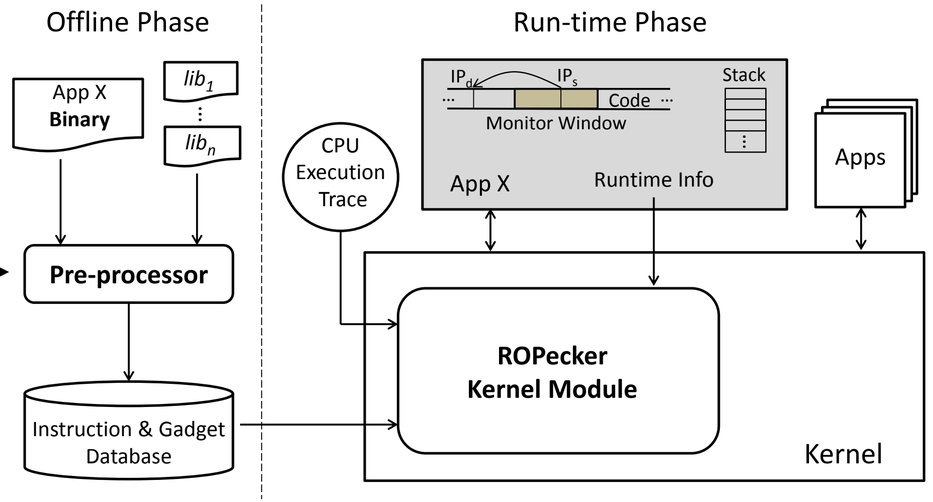
identify potential gadgets (six instructions) via disassembly:

1. application
2. shared library

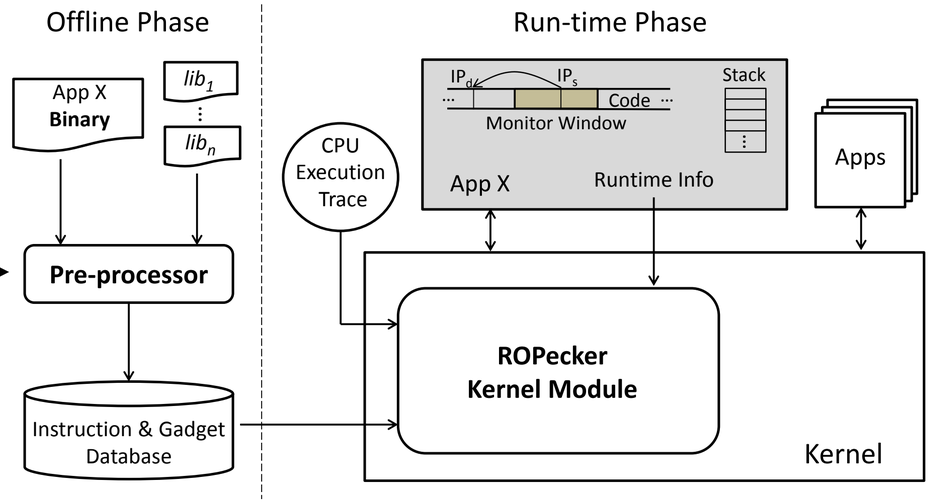


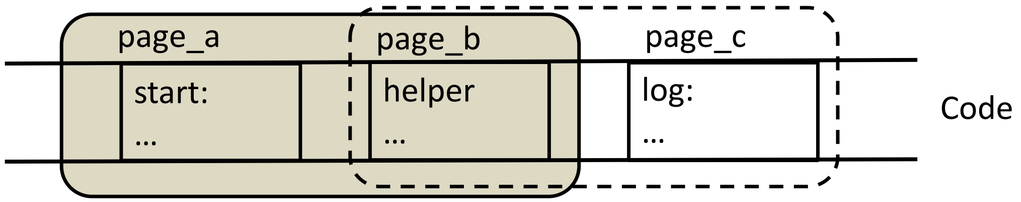
identify potential gadgets (six instructions) via disassembly:

1. application
2. shared library

create db

if addresses of gadget used, we assume ROP activity






```
1:  int helper(int cmd,char* in){
2:  log(cmd, in);
3:  switch(cmd){
4:      case CMD_START:
5:       start(inputs);
6:       break;
        . . .
    }
```

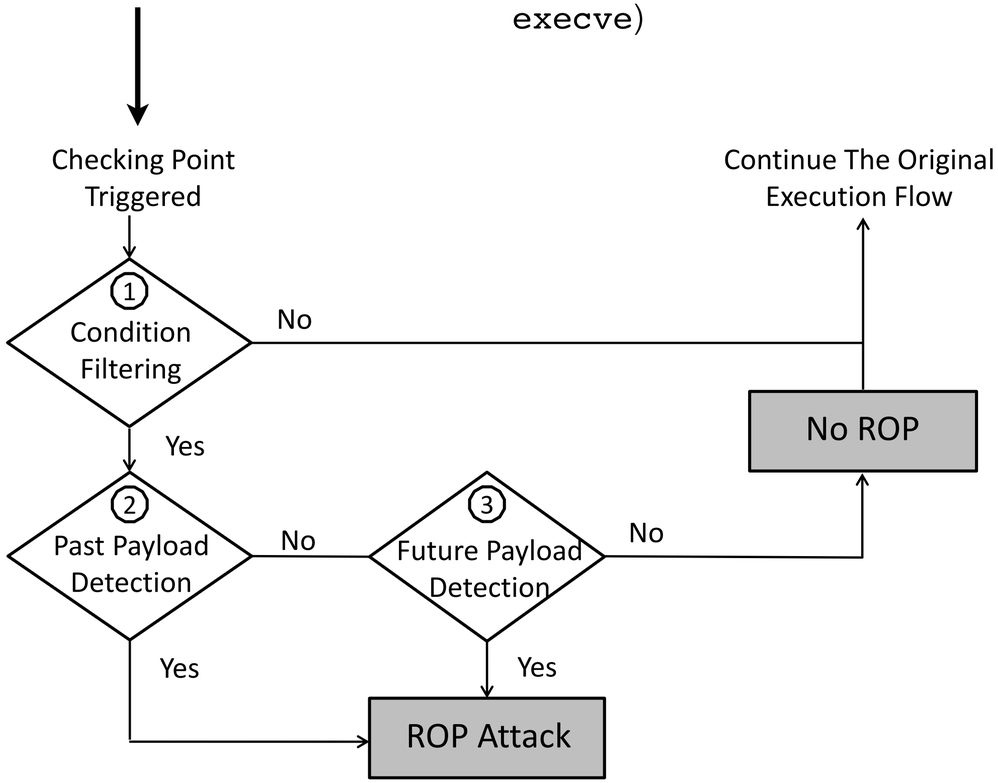
Old Sliding Window

New Sliding Window

sliding window:

1. all pages set NX
2. for each call:
   a. enable X for next N bytes/pages
   b. disable X for previous N bytes/pages
3. 8 KB or 16 KB

1. page fault from execution in NX region
2. call to protect system call (`mprotect, mmap2, execve`)



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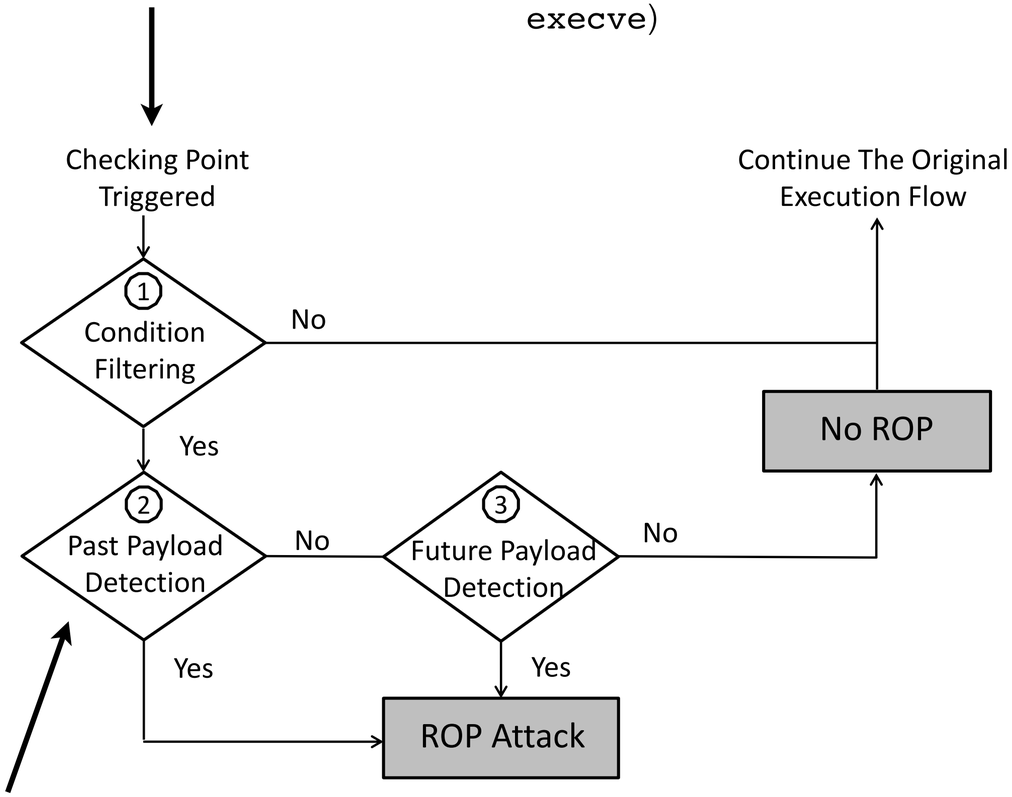

1. for indirect calls after context switch
2. count branches to potential gadgets

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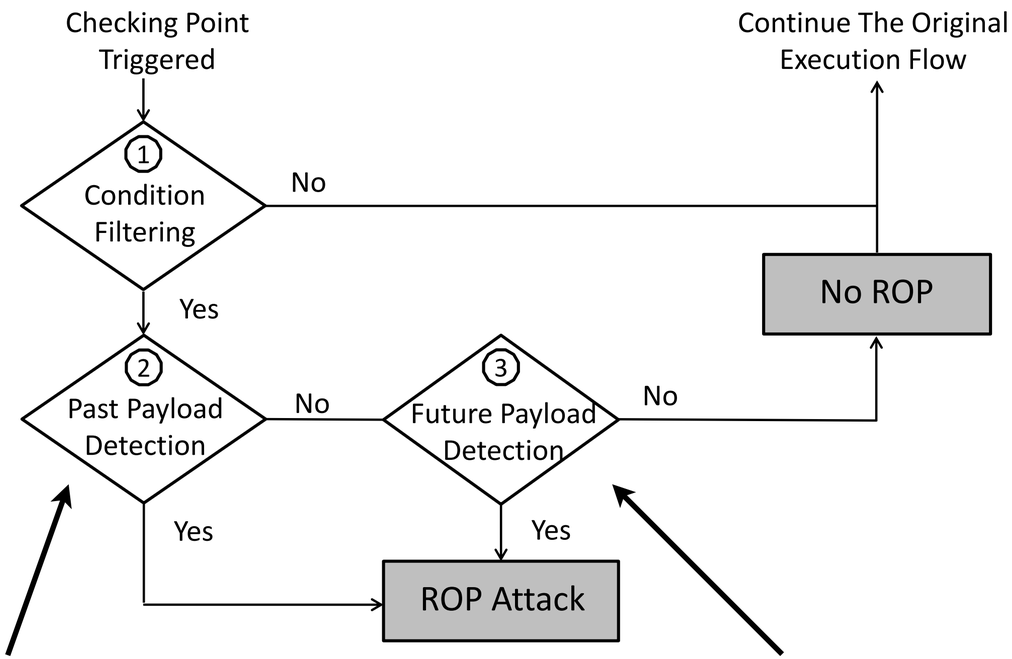
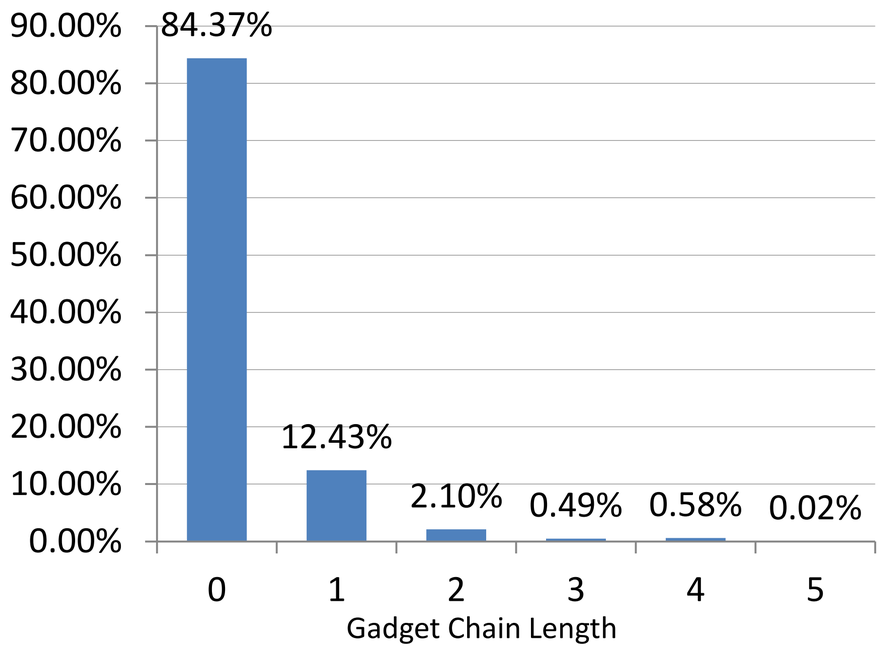


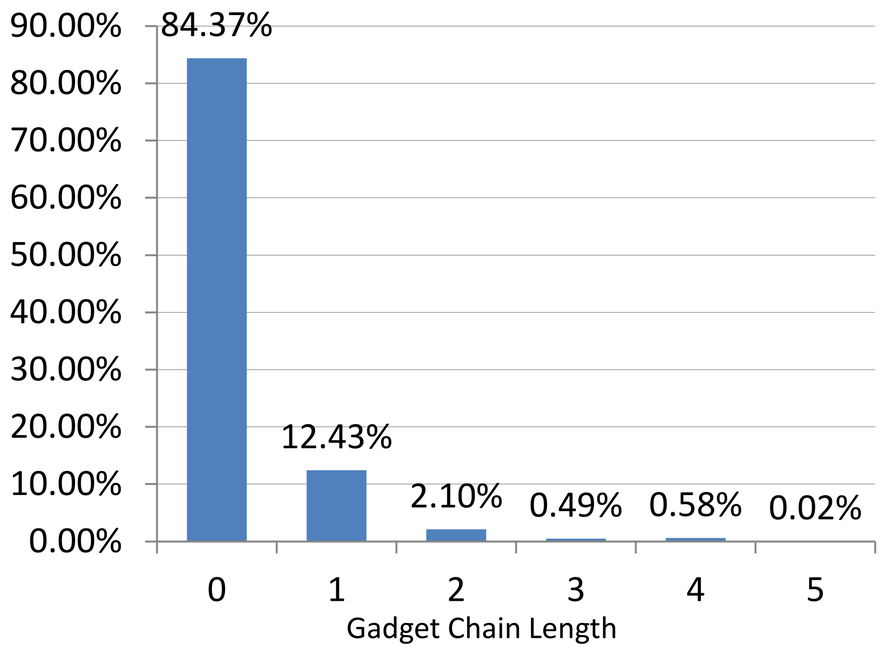
1. for indirect calls after context switch
2. count branches to potential gadgets

1. gadget chain too small?
2. emulate call stack, do we keep returning to suspected gadgets?



length of (potential) gadget chains in non-malicious code

17 popular Linux tools, 12 benchmark tools of SPEC INT2006, and 3 large binaries



if count from (2,3) > 11—16, have ROP activity

length of (potential) gadget chains in non-malicious code

17 popular Linux tools, 12 benchmark tools of SPEC INT2006, and 3 large binaries

ROPGuard

Fratrić, Ivan. "ROPGuard: Runtime prevention of return-oriented programming attacks." (2012).

runtime checks when critical functions are called:

1. ensure stack pointer stays within area
(prevent stack pivot attack)
2. address of function would be on the top of the stack if called using return otherwise not
3. instructions preceded by call; return address executable; call must be related to function
4. valid stack: return address just below frame pointer
5. stack pointer should always be resolvable from machine code
6. function should not be allowed to make code sections executable; don’t load dlls from some places (network)

Evaluating the Effectiveness of Current Anti-ROP Defenses

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kBouncer assumptions:

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kBouncer assumptions:

1. long gadgets unlikely
2. can't string together non-malicious indirects that exhaust LBR

strategy: last 14 indirect branches should be benign

1. identify: LBR-flushing function
    a. legitimate function
    b. many legitimate indirects (call-preceded)

strategy: last 14 indirect branches should be benign

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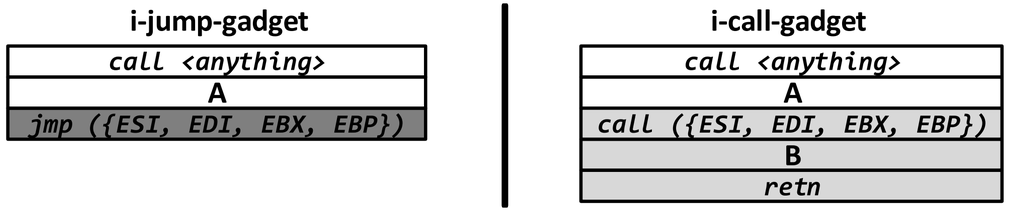
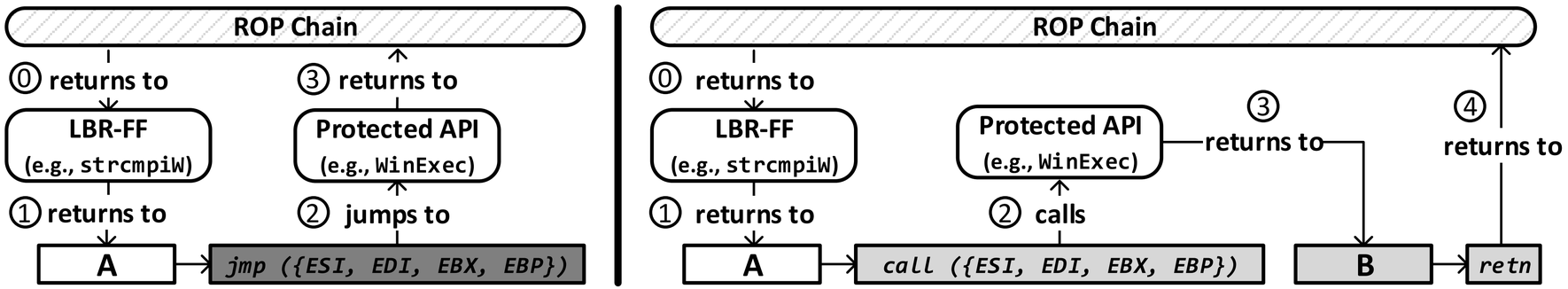
   b. many legitimate indirects (call-preceded)

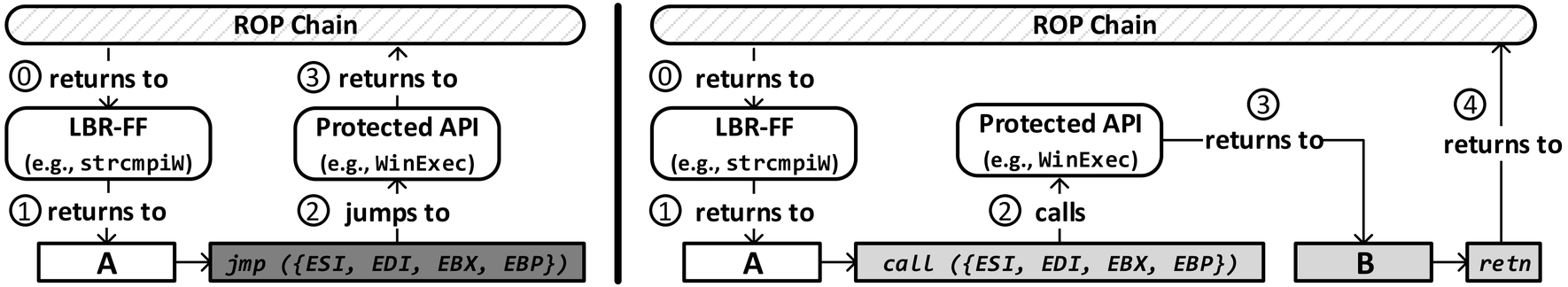
strategy: last 14 indirect branches should be benign

2. identify: call-preceded gadget that doesn't affect ROP state





setup vars/args



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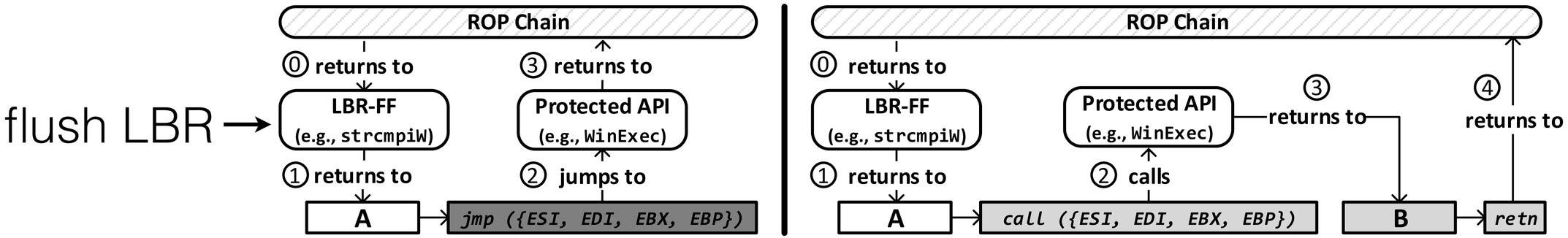

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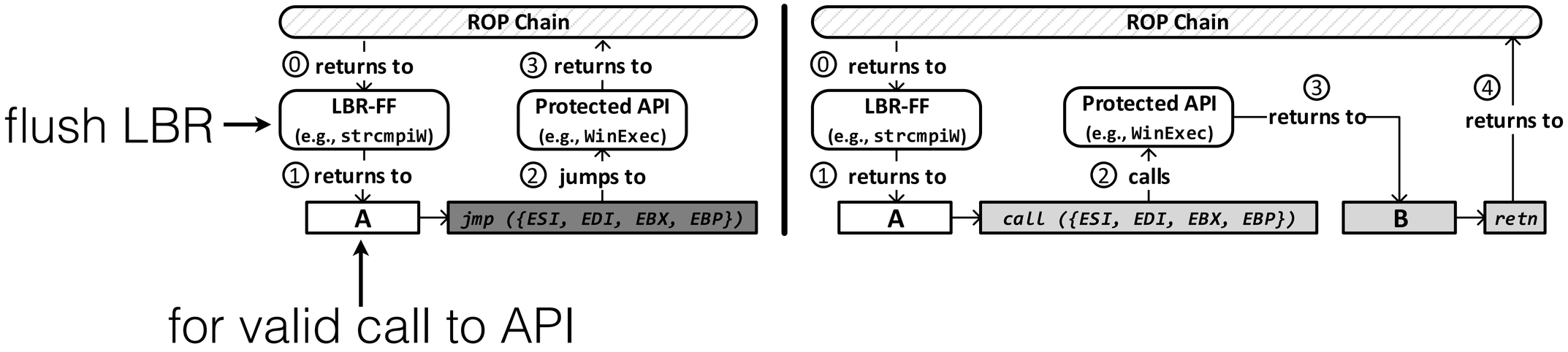

for valid call to API

ROPecker vulnerabilities:

1. long gadgets

ROPecker vulnerabilities:

1. long gadgets
2. gadget that contains direct branch

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3. gadgets within windows

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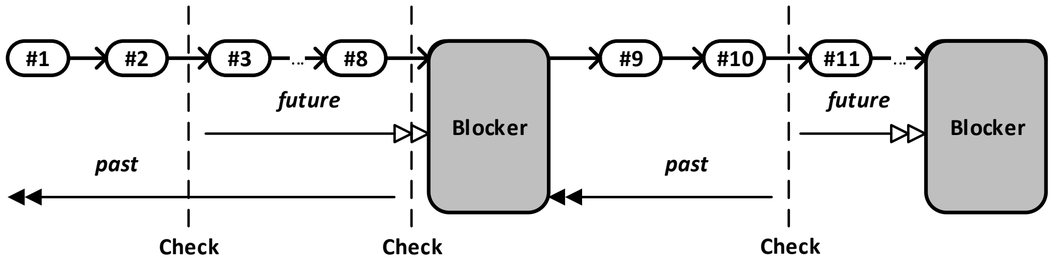

blocker: end of detection

1. smallest window size: one page
2. direct jumps to gadgets
3. long gadgets