Know Where You Come From

Enforcing Program Behavior Through Syscall Sequences and Origins

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Who am I?

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- Memory safety vulnerabilties are common

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- Sandboxing helps in limiting their post-exploitation impact

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  - lot of manual work

Motivation

- Memory safety vulnerabilties are common
- Sandboxing helps in limiting their post-exploitation impact
- Linux seccomp:
  - lot of manual work$\rightarrow$ automated [Can+21]

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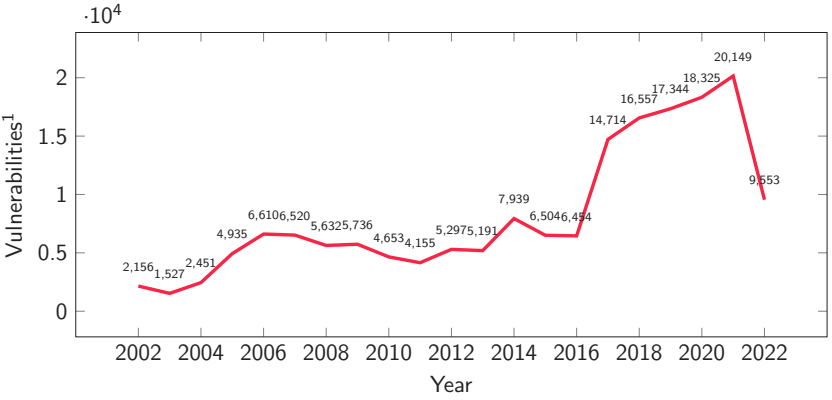
  - lot of manual work$\rightarrow$ automated [Can+21]
  - stateless

- Memory safety vulnerabilties are common
- Sandboxing helps in limiting their post-exploitation impact
- Linux seccomp:
  - lot of manual work$\rightarrow$ automated [Can+21]
  - stateless
- CFI only within one domain

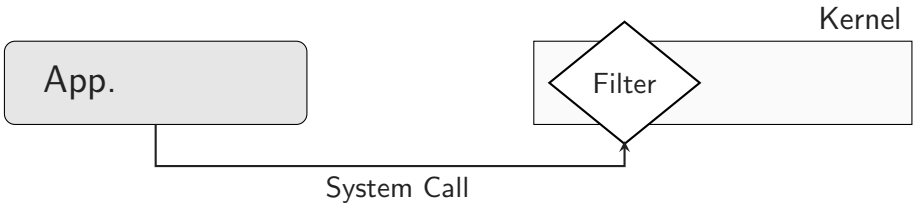
CVEs

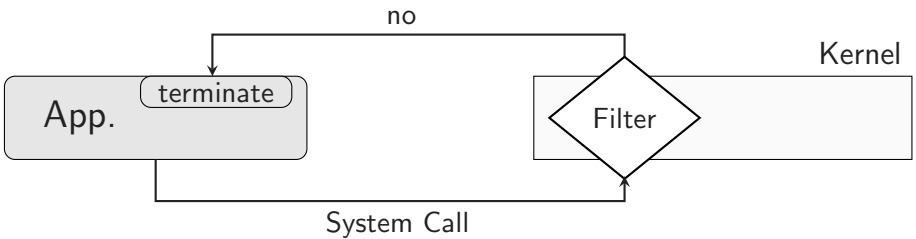


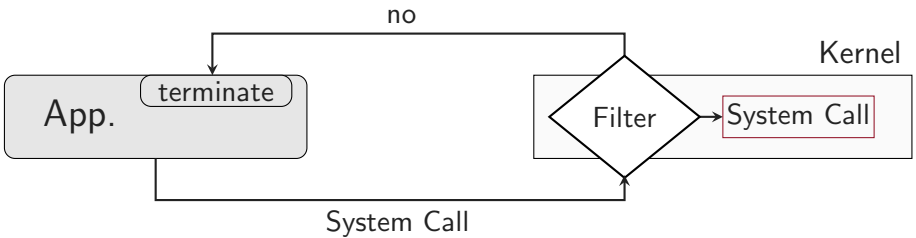
[1]Source: `http://www.cvedetails.com/vulnerabilities-by-types.php`

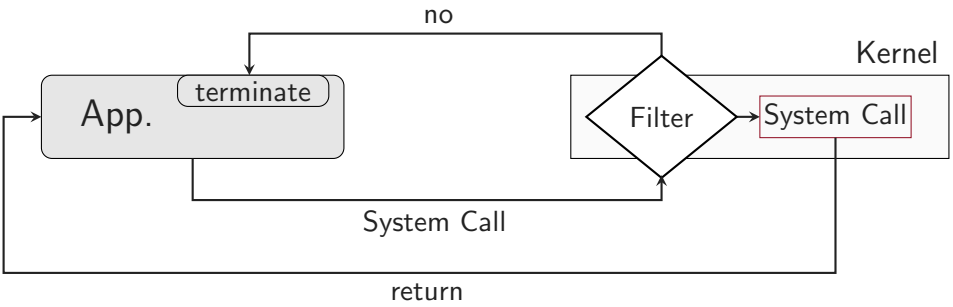

Kernel
App.


Kernel
App.
install
Filter


Kernel
App.
Filter
System Call


no
Kernel
terminate
App.
Filter
System Call


no
Kernel
terminate
App.
Filter
System Call
System Call


no
Kernel
terminate
App.
Filter
System Call
System Call
return

Sample

```c
int main(int argc, char *argv[]) {
    int infd, outfd;
    ssize_t read_bytes;
    char buffer[1024];

    printf("Copying '%s' to '%s'\n", argv[1], argv[2]);
    if((infd = open(argv[1], O_RDONLY)) > 0) {
      if((outfd = open(argv[2], O_WRONLY | O_CREAT, 0644)) > 0) {
        while((read_bytes = read(infd, &buffer, 1024)) > 0)
          write(outfd, &buffer, (ssize_t)read_bytes);
      }
    }
    close(infd);
    close(outfd);
    return 0;
}
```

Sample

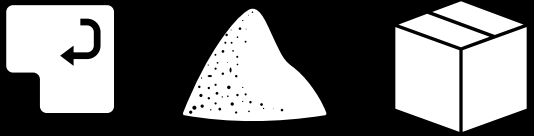
```c
int main(int argc, char *argv[]) {
    int infd, outfd;
    ssize_t read_bytes;
    char buffer[1024];

    printf("Copying '%s' to '%s'\n", argv[1], argv[2]);
    if((infd = open(argv[1], O_RDONLY)) > 0) {
      if((outfd = open(argv[2], O_WRONLY | O_CREAT, 0644)) > 0) {
        while((read_bytes = read(infd, &buffer, 1024)) > 0)
          write(outfd, &buffer, (ssize_t)read_bytes);
      }
    }
    close(infd);
    close(outfd);
    return 0;
}
```

Syscalls: 0 1 2 3 16 19 20 60 72 202 231

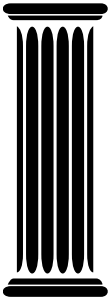
black hat

ENTER SANDBOX

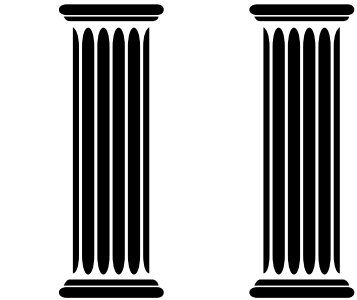


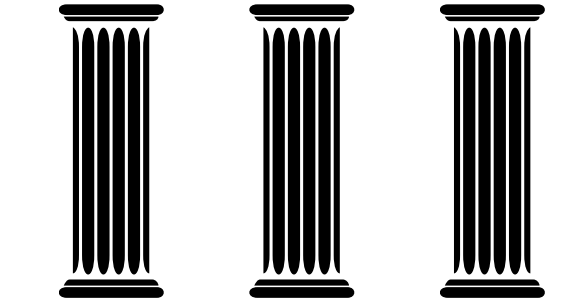
https://github.com/chestnut-sandbox/Chestnut

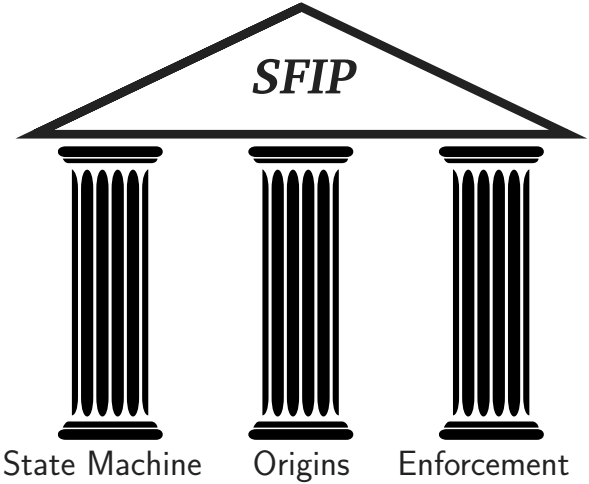
Claudio Canella (@cc0x1f), Mario Werner (we.rner.at), Michael Schwarz (@misc0110)



State Machine


State Machine
Origins


State Machine
Origins
Enforcement


SFIP
State Machine
Origins
Enforcement

Syscalls from C Functions?

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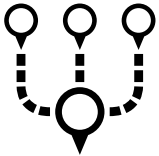
Precise Control-Flow Graph?

Challenges

Syscalls from C Functions?

Precise Control-Flow Graph?



Non-bijective Mappings?

Compiler: Extraction

Compiler: Extraction

Library: Setup

Compiler: Extraction

Library: Setup

Kernel: Enforcement

Source Code

```
L01: void foo(int test) {
L02:   scanf(...);
L03:   if(test)
L04:     printf(...)
L05:   else
L06:     syscall(read, ...);
L07:   int ret = bar(...);
L08:   if(!ret)
L09:     exit(0);
L10:   return ret;
L11: }
```

Syscall and CFG Extraction

Source Code

```
L01: void foo(int test) {
L02:   scanf(...);
L03:   if(test)
L04:     printf(...)
L05:   else
L06:     syscall(read, ...);
L07:   int ret = bar(...);
L08:   if(!ret)
L09:     exit(0);
L10:   return ret;
L11: }
```

extract →

Extracted Function Info

```
{
  "Transitions": {
    "L03": [L04,L06],
    "L04": [L07],
    "L06": [L07]
    "L08": [L09,L10]
  }
  "Call Targets": {
    "L02": ["scanf"],
    "L04": ["printf"],
    "L07": ["bar"],
    "L09": ["exit"],
  }
  "Syscalls": {
    "L06" : [read]
  }
}
```

Syscall Offset Extraction

Translation Unit 1

```
L01: void func() {
     .func:39:
L02:   asm("syscall"::"a"(39));
     ...
     .syscall_cp:3:
L08:   syscall_cp(close,0);
L09: }
```

Syscall Offset Extraction

Translation Unit 1

```
L01:  void func() {
      .func:39:
L02:    asm("syscall"::"a"(39));
      ...
      .syscall_cp:3:
L08:    syscall_cp(close,0);
L09:  }
```

extract →

Extraction TU 1

```
"Offsets": {
  "func": {
    "39": [L02]
  }
}
"Unknown Offsets": {
  "syscall_cp": [3]
}
```

Syscall Offset Extraction

Translation Unit 1

```
L01: void func() {
       .func:39:
L02:   asm("syscall"::"a"(39));
       ...
       .syscall_cp:3:
L08:   syscall_cp(close,0);
L09: }
```

extract →

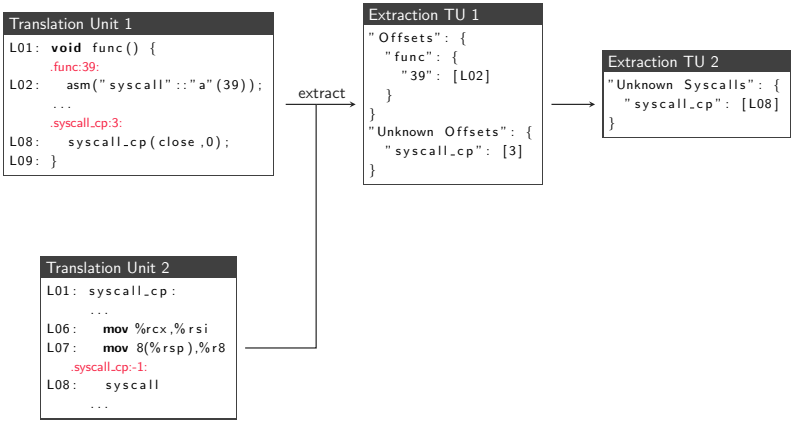
Extraction TU 1

```
"Offsets": {
  "func": {
    "39": [L02]
  }
}
"Unknown Offsets": {
  "syscall_cp": [3]
}
```

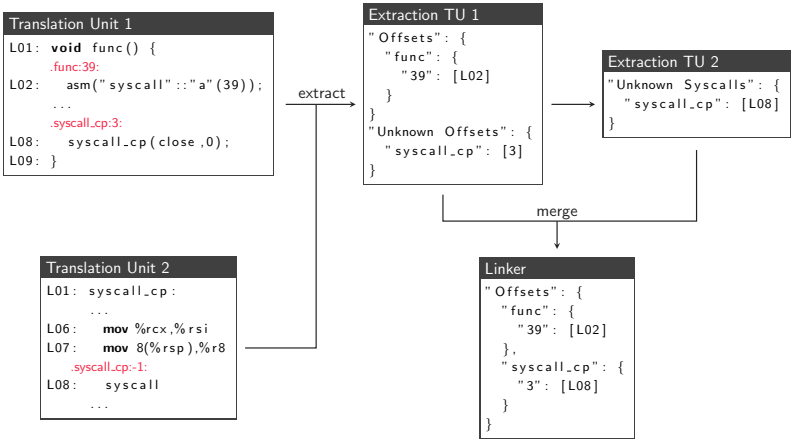
Translation Unit 2

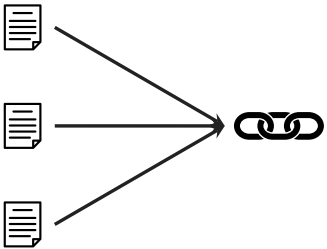
```
L01: syscall_cp:
       ...
L06:   mov %rcx,%rsi
L07:   mov 8(%rsp),%r8
       .syscall_cp:-1:
L08:   syscall
       ...
```

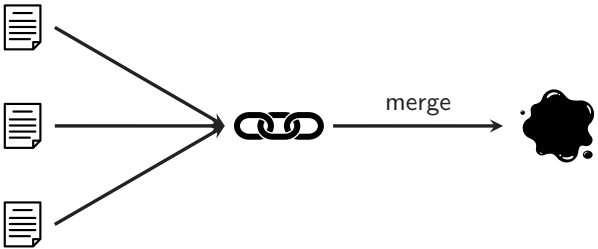
Syscall Offset Extraction



Syscall Offset Extraction






merge

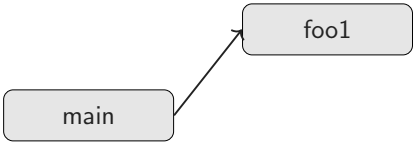
main

Info main

```
Call Targets: {
  "L56": [foo1],
  "L59": [foo2]
}
```

Last Syscalls

State Machine

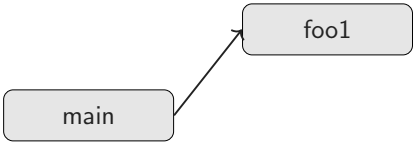


Info foo1

```
Call Targets: {
  "L03": [bar1]
}
Syscalls: {
  "L02": [open]
}
```

Last Syscalls

State Machine



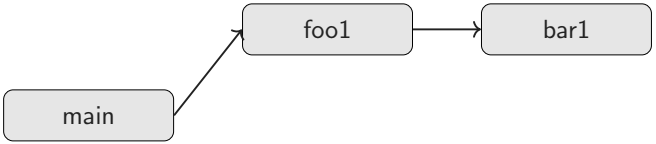
Info foo1

```
Call Targets: {
  "L03": [bar1]
}
Syscalls: {
}
```

Last Syscalls

open

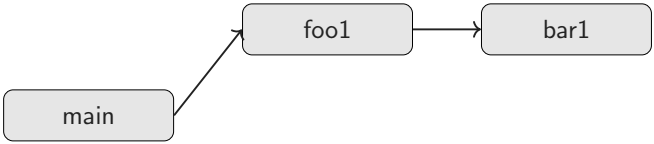
State Machine



Last Syscalls

open

State Machine

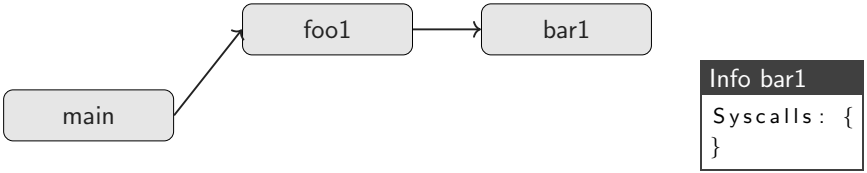


Last Syscalls

open

State Machine

open: [read]

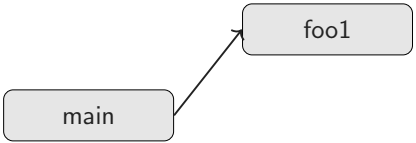


Last Syscalls

read

State Machine

open: [read]



Info foo1

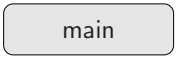
```
Call Targets: {
}
Syscalls: {
}
```

Last Syscalls

read

State Machine

open: [read]



Info main

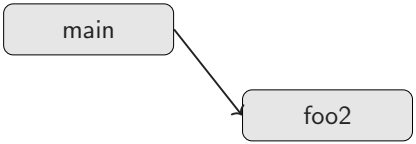
```
Call Targets: {
  "L59": [foo2]
}
```

Last Syscalls

read

State Machine

open: [read]



Info foo2

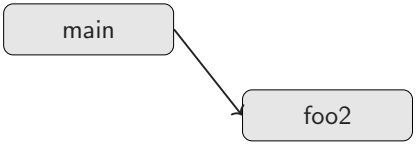
```
Call Targets: {
  "L179": [bar2]
}
Syscalls: {
  "L178": [open]
}
```

Last Syscalls

read

State Machine

open: [read]



Info foo2

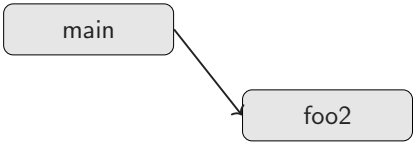
```
Call Targets: {
  "L179": [bar2]
}
Syscalls: {
  "L178": [open]
}
```

Last Syscalls

read

State Machine

open: [read]
read: [open]



Info foo2

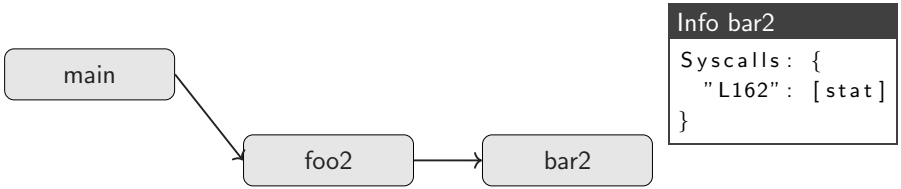
```
Call Targets: {
  "L179": [bar2]
}
Syscalls: {
}
```

Last Syscalls

open

State Machine

open: [read]
read: [open]

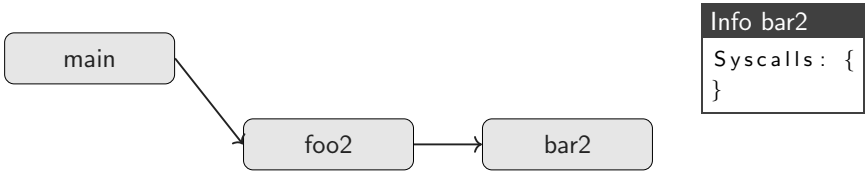


Last Syscalls

open

State Machine

open: [read]
read: [open]

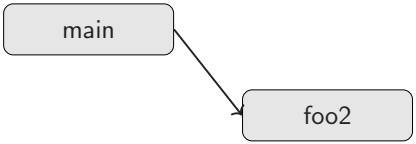


Last Syscalls

stat

State Machine

open: [read,stat]
read: [open]



Info foo2

```
Call Targets: {
}
Syscalls: {
}
```

Last Syscalls

stat

State Machine

open: [read,stat]
read: [open]

Info main

```
Call Targets: {
}
```

Last Syscalls

stat

State Machine

open: [read,stat]
read: [open]

Library

- extracts information

Library

- extracts information
- makes offset adjustment

Enforcement

Library

- extracts information
- makes offset adjustment

Kernel

- performs transition check

Enforcement

Library

- extracts information
- makes offset adjustment

Kernel

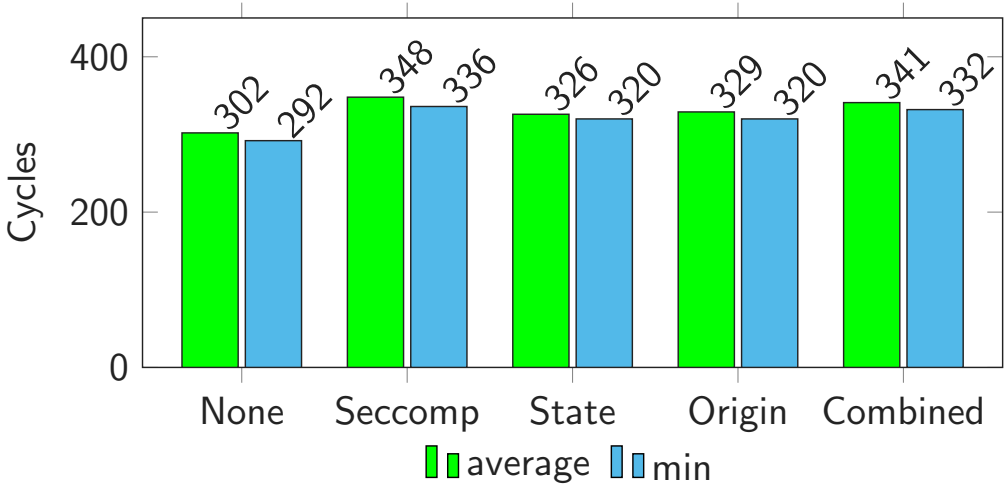
- performs transition check
- performs independent origin check

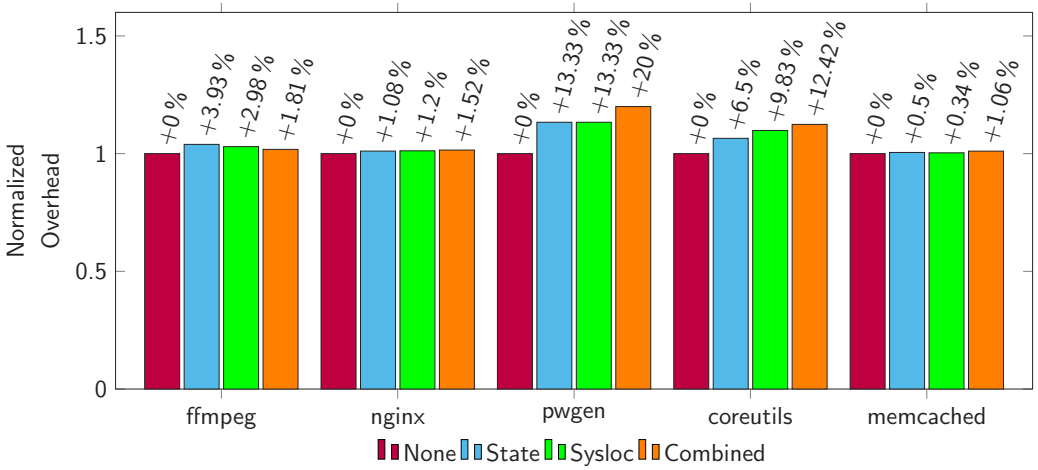
Performance

Performance

Security

Application	Vanilla	SysFlow
ffmpeg	162.12 s	1783.15 s
mupdf	58.01 s	489.85 s
nginx	8.22 s	226.64 s
busybox	16.09 s	81.33 s
coreutils	5.50 s	14.39 s
memcached	2.90 s	4.59 s
pwgen	0.07 s	0.12 s


Cycles
400
200
0
302
292
348
336
326
320
329
320
341
332
None
Seccomp
State
Origin
Combined
average
min


Normalized Overhead
1.5
1
0.5
0
+0 %
+3.93 %
+2.98 %
+1.81 %
+0 %
+1.08 %
+1.2 %
+1.52 %
+0 %
+13.33 %
+13.33 %
+20 %
+0 %
+6.5 %
+9.83 %
+12.42 %
+0 %
+0.5 %
+0.34 %
+1.06 %
ffmpeg
nginx
pwgen
coreutils
memcached
None
State
Sysloc
Combined

Application	Average Transitions	#States
busybox	15.73	24.51
coreutils	15.75	27.11
pwgen	12.42	19
muraster	17.51	41
nginx	65.55	108
ffmpeg	48.48	56
memcached	40.6	87
mutool	32.0	61

Application	Total #Offsets	Avg #Offsets
busybox	102.64	3.75
coreutils	116.71	4.42
pwgen	84	4.42
muraster	193	4.6
nginx	318	3.0
ffmpeg	279	4.98
memcached	317	3.69
mutool	278	4.15

- Use exisiting code to exploit a program

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- Jumps to parts of functions (so called gadgets)

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  - `pop RDI; retq`
  - `syscall; retq`
  - `add RSP, 8; retq`

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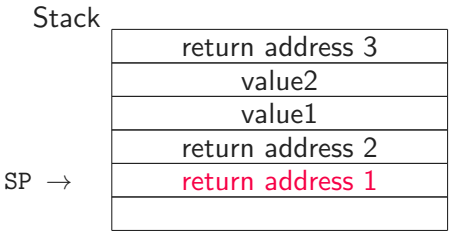
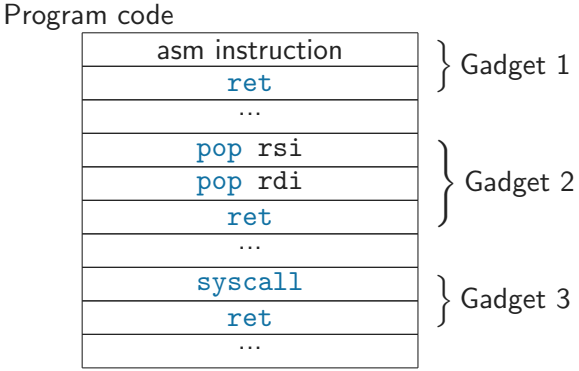
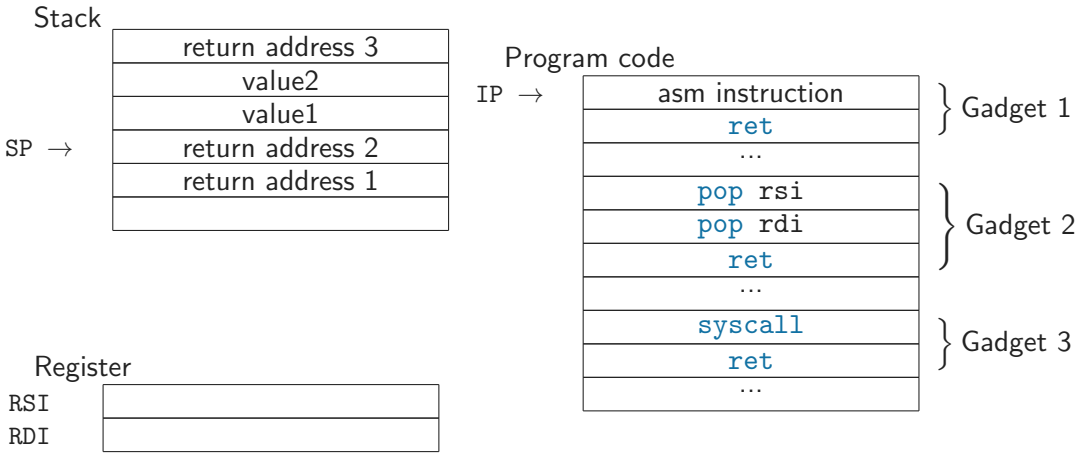
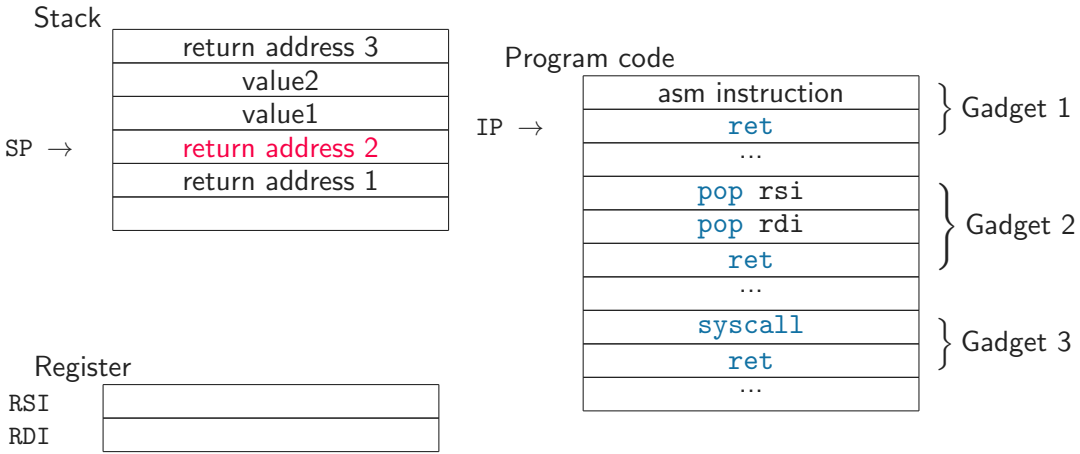
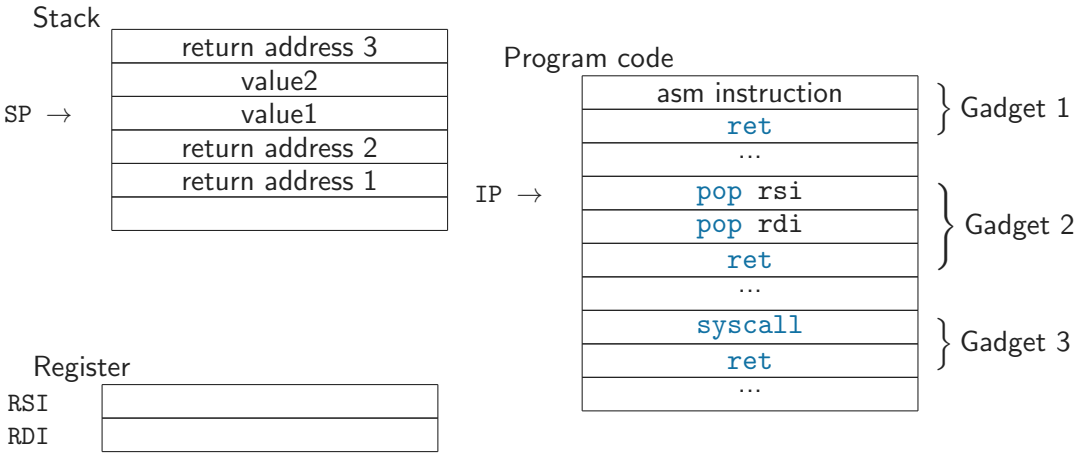
  - `add RSP, 8; retq`
- Gadgets are chained together for an exploit
- Overwrite the stack with gadget addresses and parameters


Stack
return address 3
value2
value1
return address 2
SP →
return address 1
Register
RSI
RDI


Program code
asm instruction
ret
...
pop rsi
pop rdi
ret
...
syscall
ret
...
Gadget 1
Gadget 2
Gadget 3


Stack
return address 3
value2
value1
SP →
return address 2
return address 1
Program code
IP →
asm instruction
ret
...
pop rsi
pop rdi
ret
...
syscall
ret
...
Gadget 1
Gadget 2
Gadget 3
Register
RSI
RDI


Stack
return address 3
value2
value1
SP →
return address 2
return address 1
Program code
IP →
asm instruction
ret
...
pop rsi
pop rdi
ret
...
syscall
ret
...
Gadget 1
Gadget 2
Gadget 3
Register
RSI
RDI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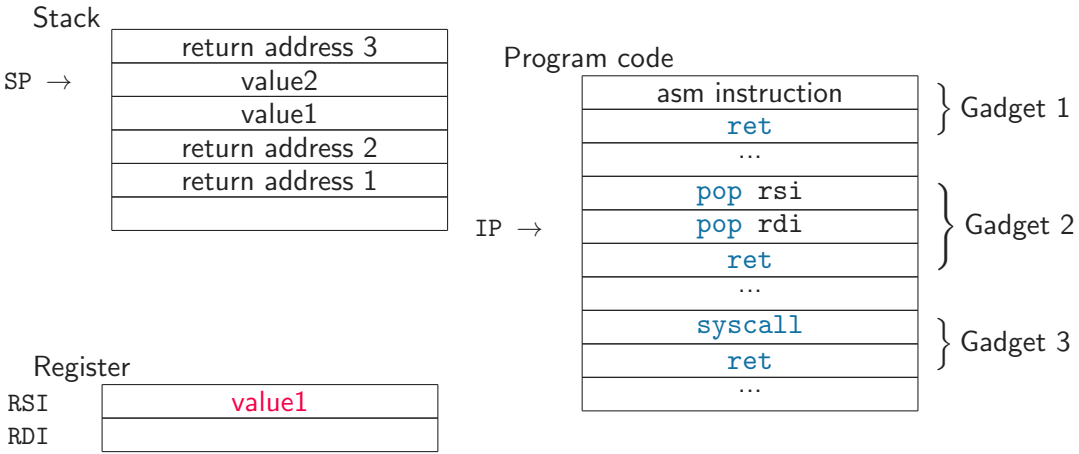
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Register
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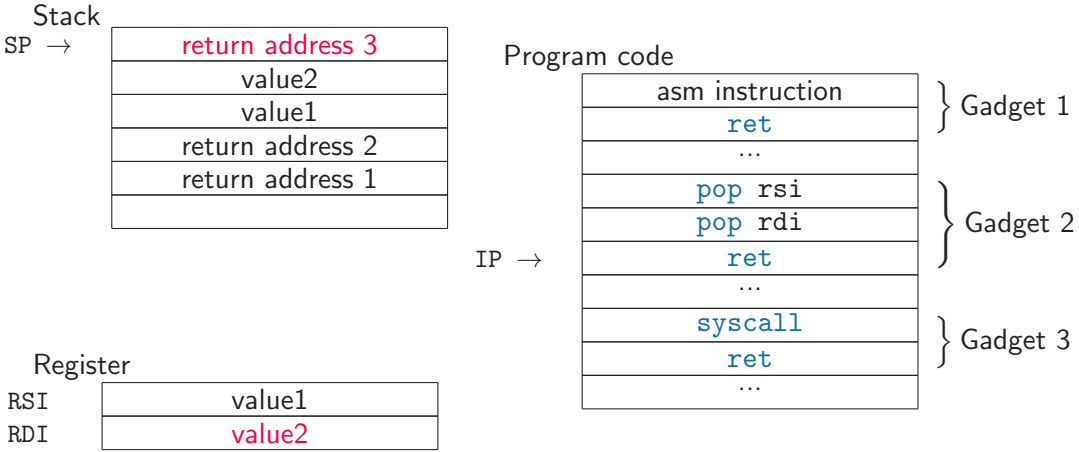
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Gadget 1
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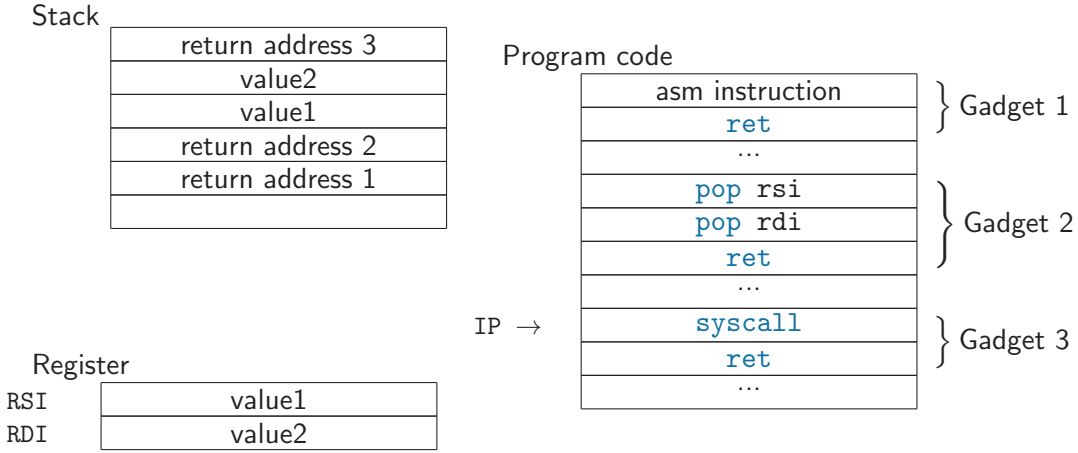
Gadget 3
Register
RSI
RDI
value1
value2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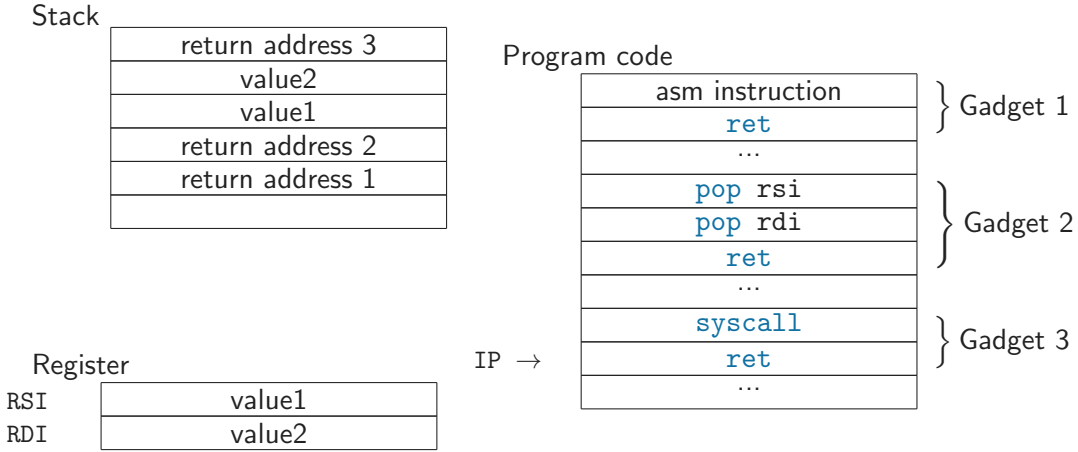
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Gadgets are often unintended

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- This property is due to non-aligned, variable-width opcodes

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$\rightarrow$ easy to find unaligned syscall instructions

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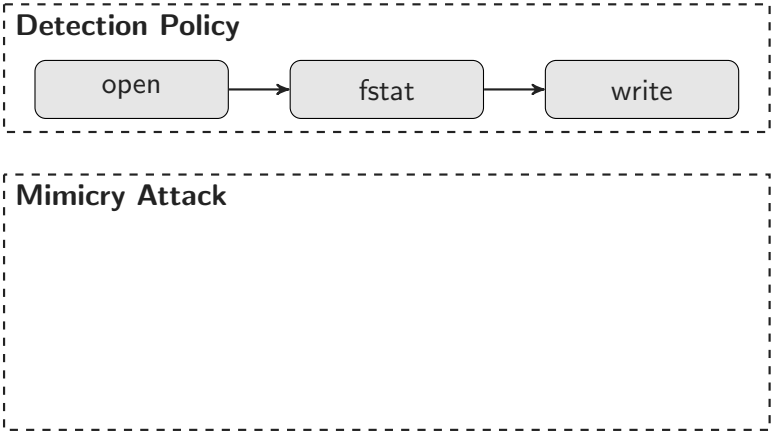
Conclusion

SFIP imposes significant constraints on control-flow-hijacking attacks


Detection Policy
open
fstat
write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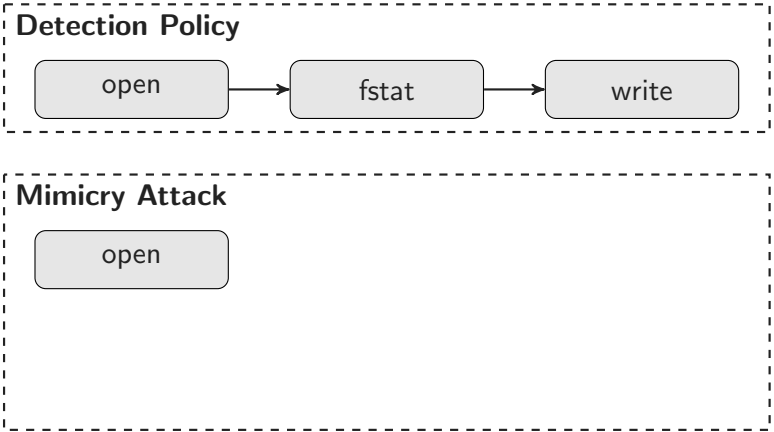
Mimicry Attack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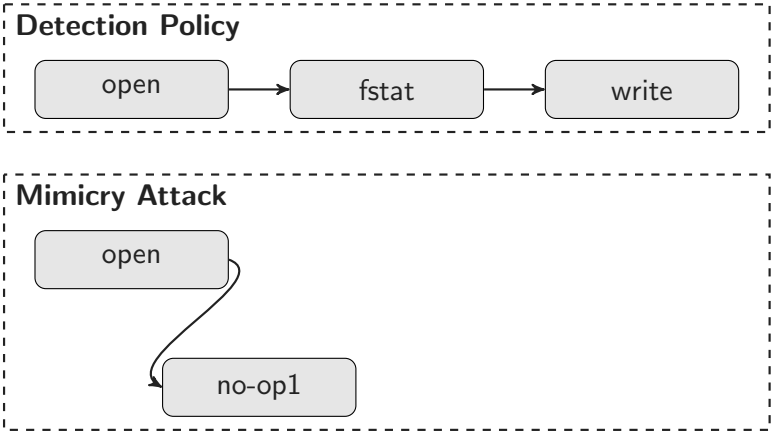
Detection Policy
open
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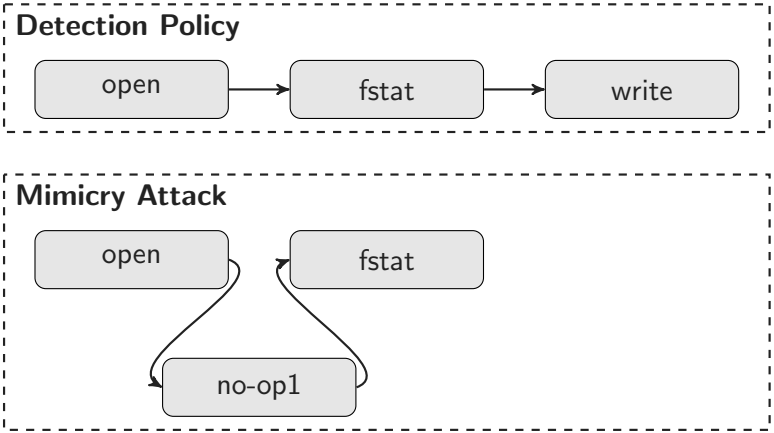
Mimicry Attack
open
no-op1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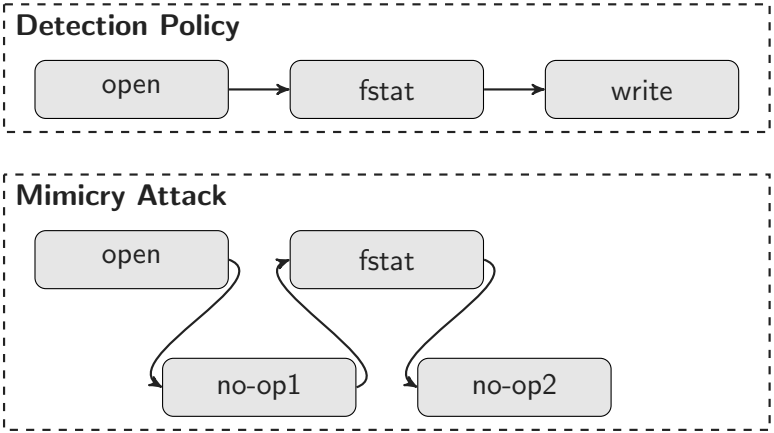
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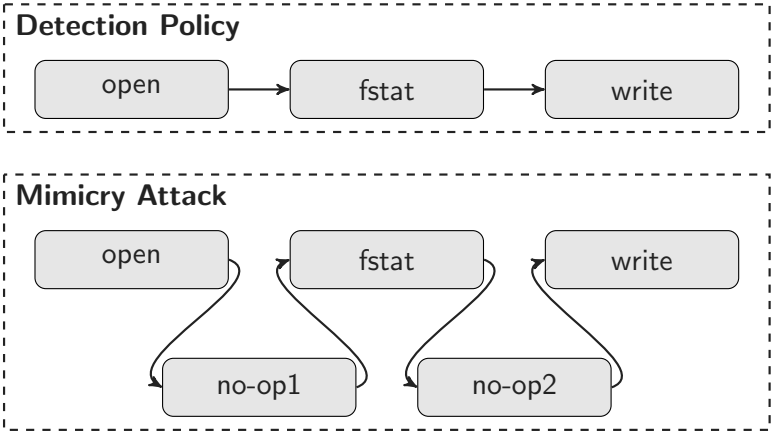
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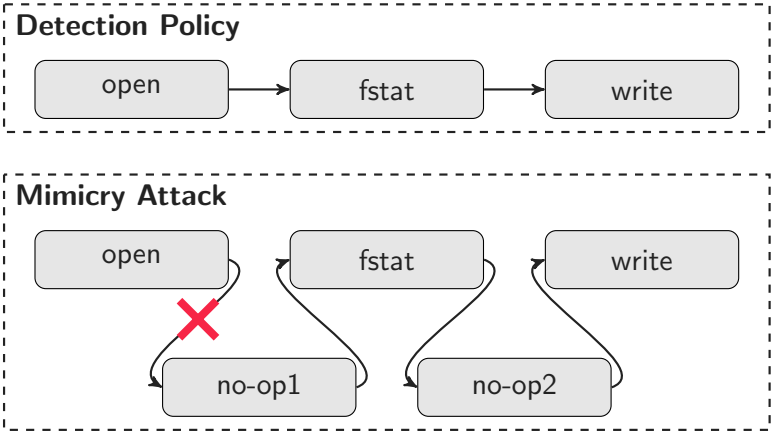
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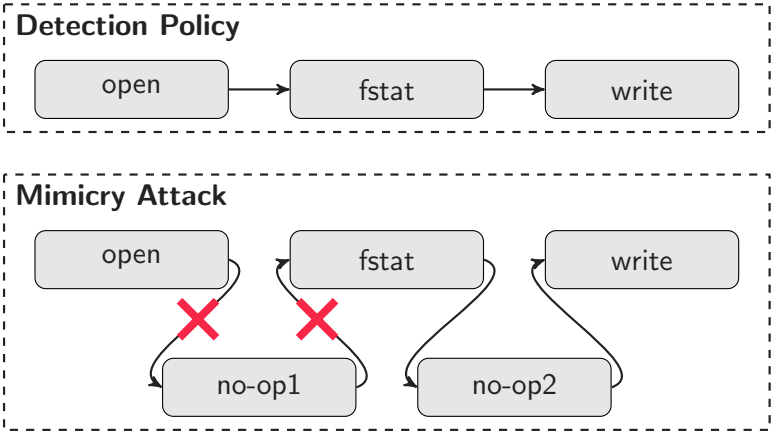
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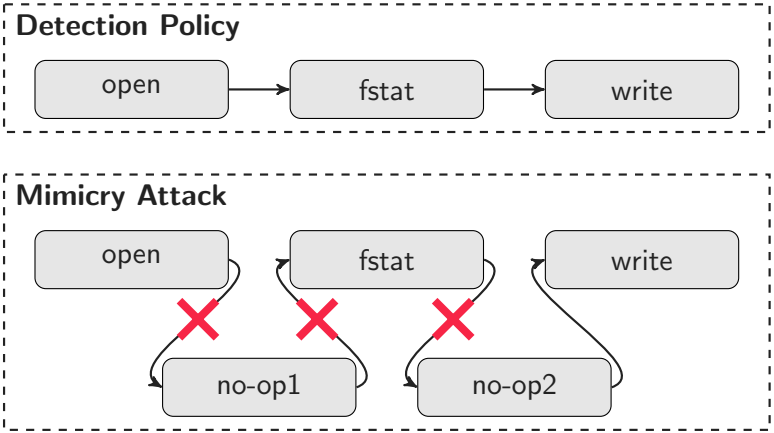
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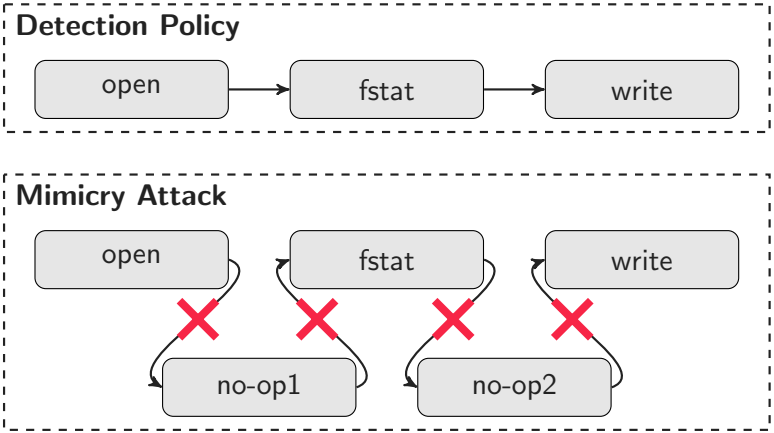
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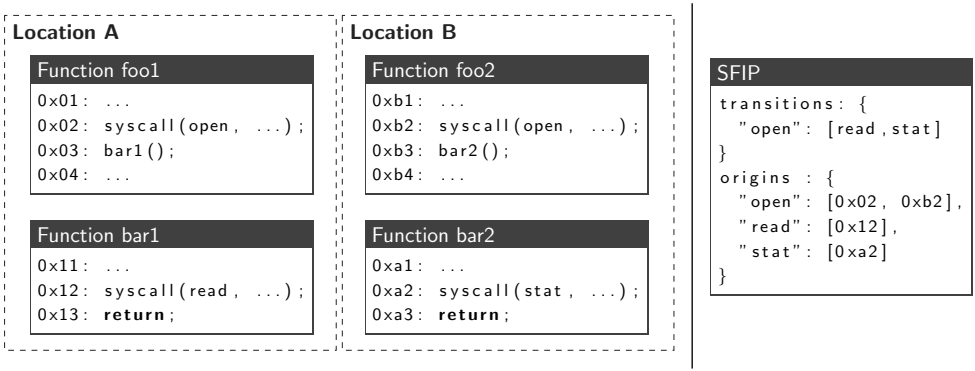
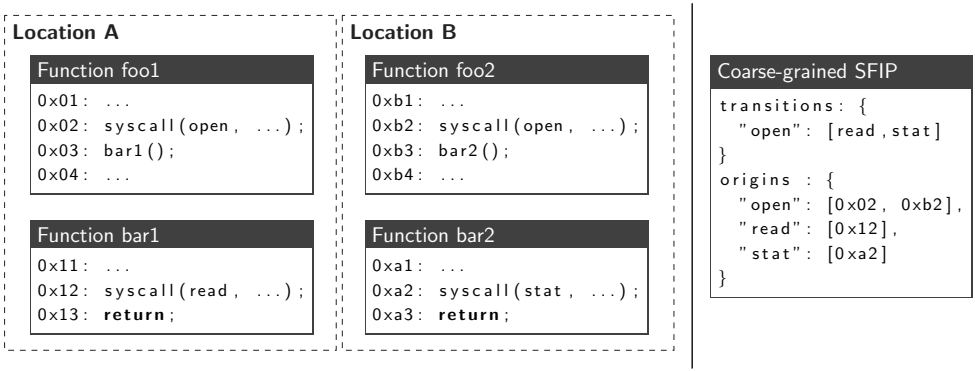
In the near future...

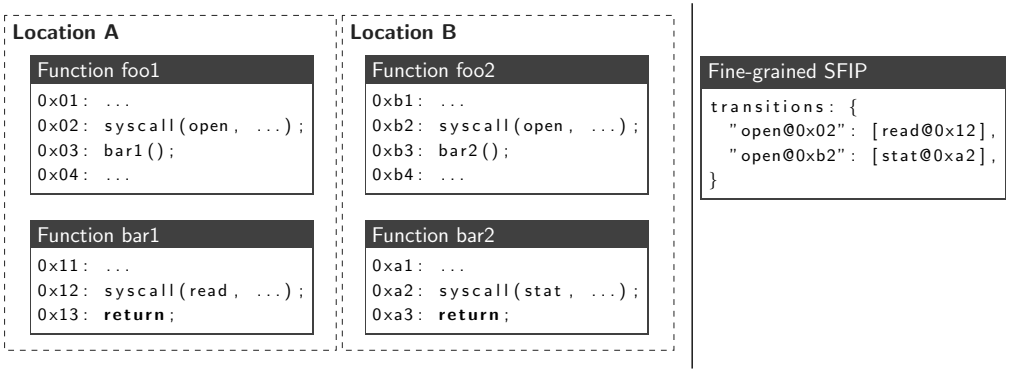
Coarse- to Fine-Grained SFIP

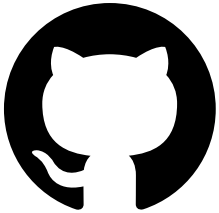


Coarse- to Fine-Grained SFIP



Coarse- to Fine-Grained SFIP





You can find our proof-of-concept implementation of SysFlow on:

- `https://github.com/SFIP/SFIP`

More details in the paper

- More implementation details
- More extensive security discussion
- ...

[Can+22]

Claudio Canella, Sebastian Dorn, Daniel Gruss, Michael Schwarz.
SFIP: Coarse-Grained Syscall-Flow-Integrity Protection in Modern Systems.

SFIP provides

- integrity to user-kernel transitions

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- security via syscall transition and origin checks

and

- is fully automatized
- has minimal runtime overhead

Know Where You Come From

Enforcing Program Behavior Through Syscall Sequences and Origins

Claudio Canella

May 19, 2022

Graz University of Technology

References

[Can+21] C. Canella, M. Werner, D. Gruss, and M. Schwarz. Automating Seccomp Filter Generation for Linux Applications. In: CCSW. 2021.

[Can+22] C. Canella, S. Dorn, D. Gruss, and M. Schwarz. SFIP: Coarse-Grained Syscall-Flow-Integrity Protection in Modern Systems. In: arXiv:2202.13716 (2022).