Unleashing Use-Before-Initialization Vulnerabilities in the Linux Kernel Using Targeted Stack Spraying

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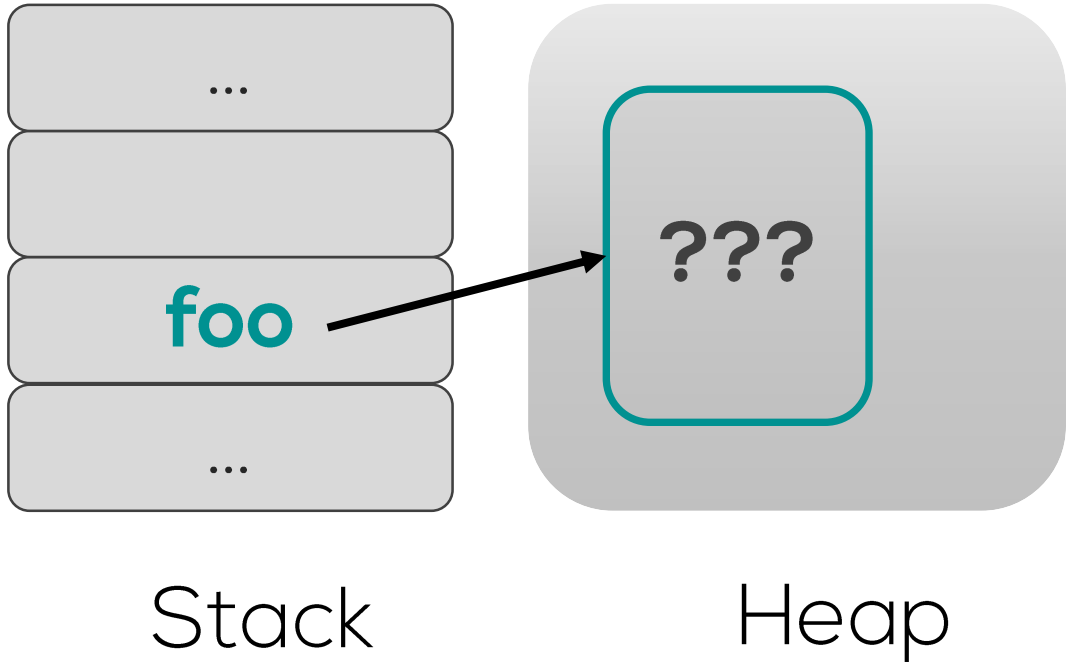
Starting with the famous brother: Use-after-free

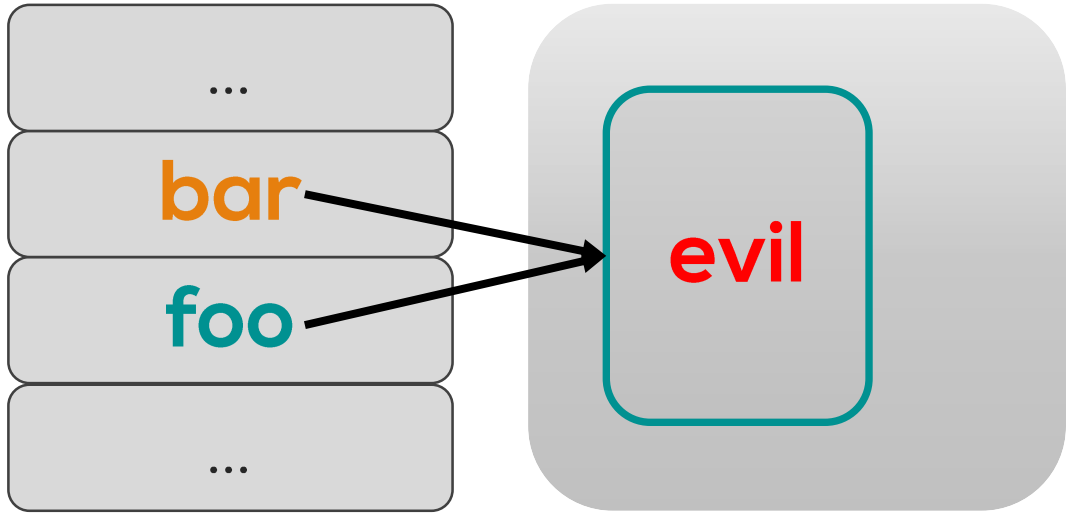
```
char* foo = (char*) malloc (100);
*foo = "abc";
free (foo);


printf(%s, *foo);
```



*foo = **???**

Starting with the famous brother: Use-after-free

```
char* foo = (char*) malloc (100);
*foo = "abc";
free (foo);
char* bar = (char*) malloc (100);
*bar = "evil";
printf(%s, *foo);
```



*foo = **"evil"**

Uninitialized use vulnerabilities on the stack

Vulnerable Function:

```
struct A *foo;
...
foo->complete();
```

Uninitialized use vulnerabilities on the stack

Setup function:

```
int buf[50];
for (i=0; i<50; i++)
{
      buf[i]=evil;
}
```

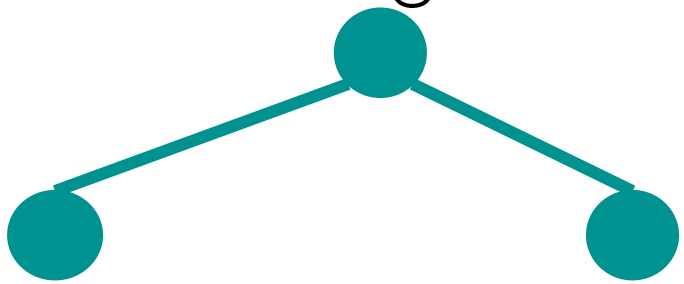
Vulnerable Function:

```
struct A *foo;

...
foo->complete();
```

evil->complete()

Uninitialized uses pose critical security risks

Overlapping Memory



1

Setup Function:
Control uninitialized variable

2

Vulnerable Function:
Uninitialized Use

Arbitrary read, write, and execution

In reality, uninitialized-use problems are overlooked

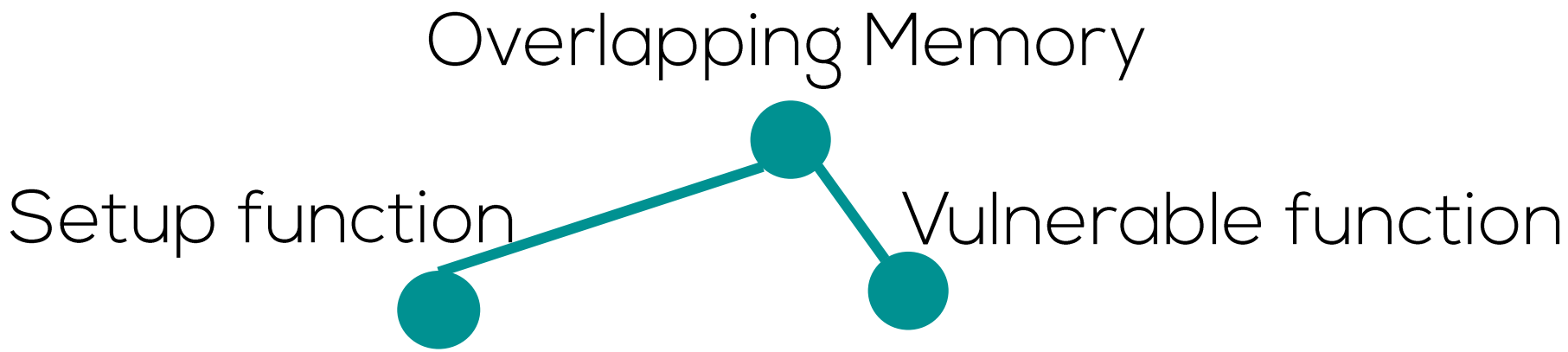
- Uninitialized uses were regarded as undefined behaviors

2015-2016: **16** Linux kernel patches, **1** CVE

- Full memory safety techniques exclude uninitialized uses as a target

- Widespread belief: uninitialized memory is uncontrollable

Manually exploiting unitialized uses in the Linux kernel stack is difficult



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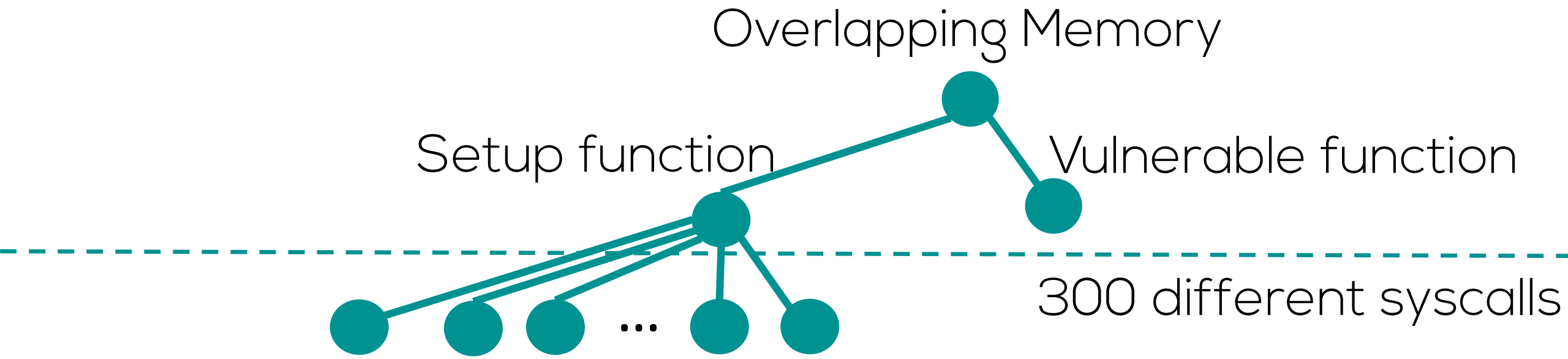

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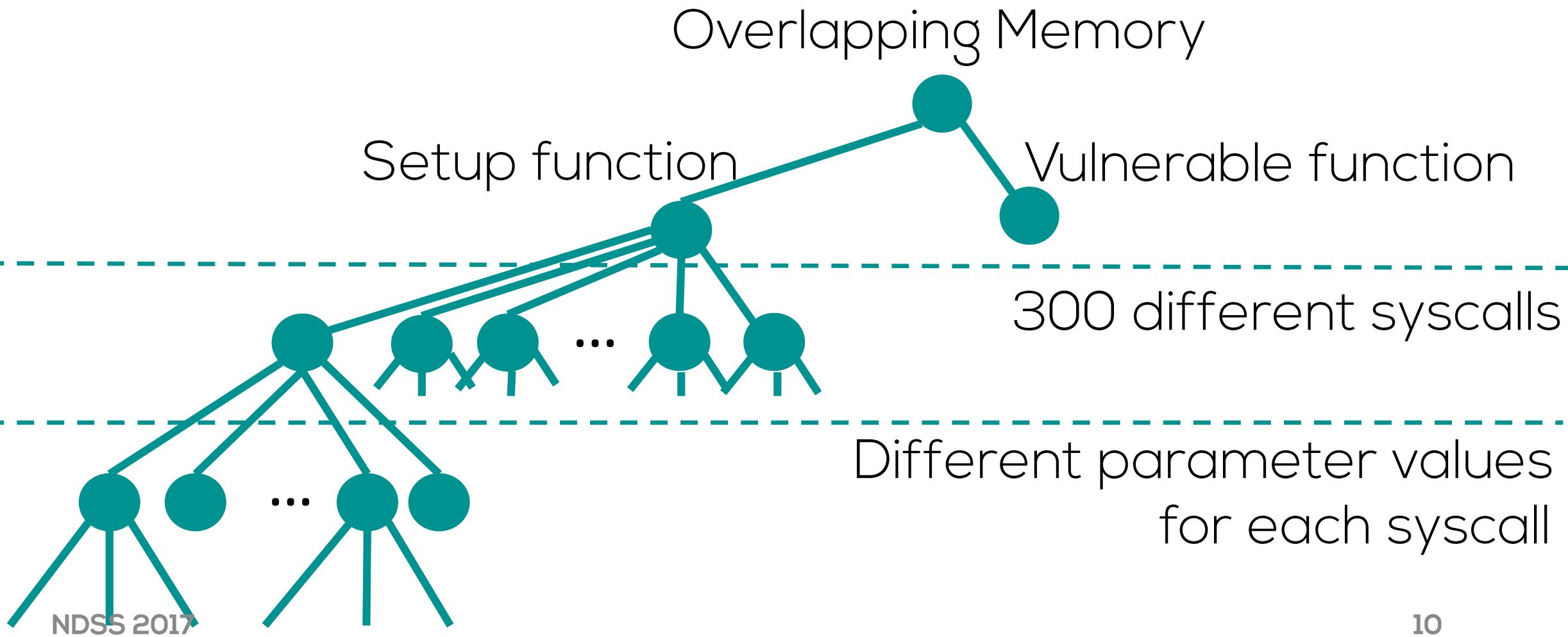
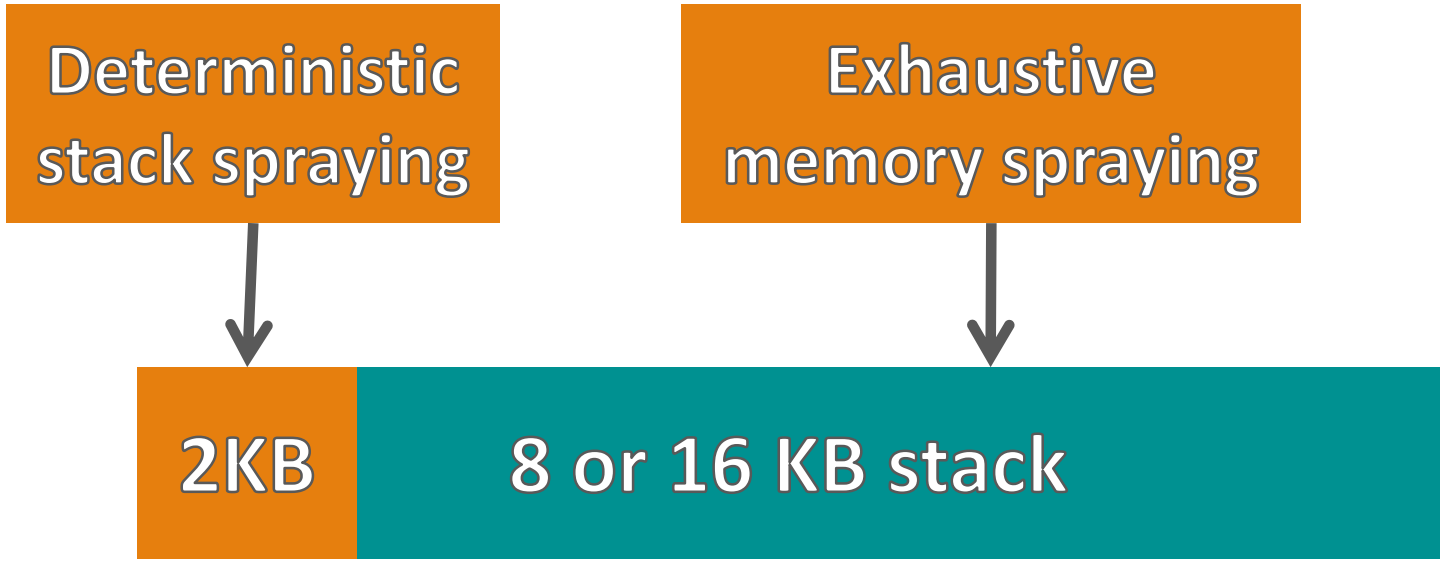


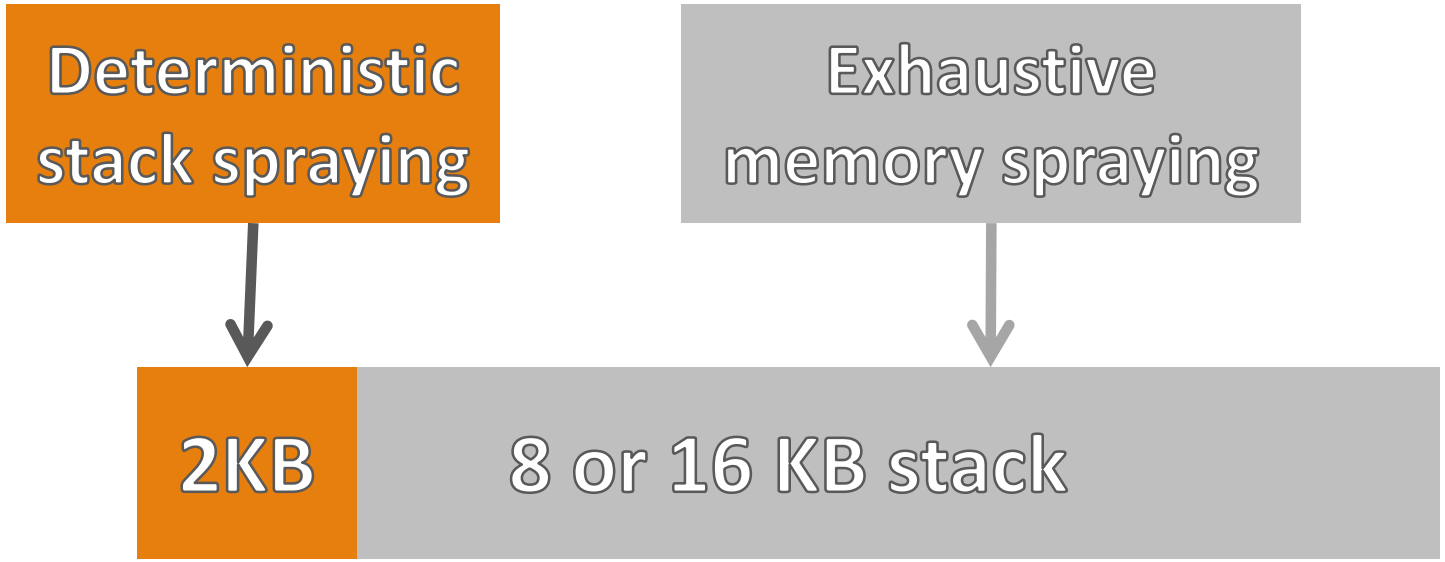
Primary kernel stack usage

- 90% of all system calls only use the first 2KB of the kernel stack
- Most interesting region to target

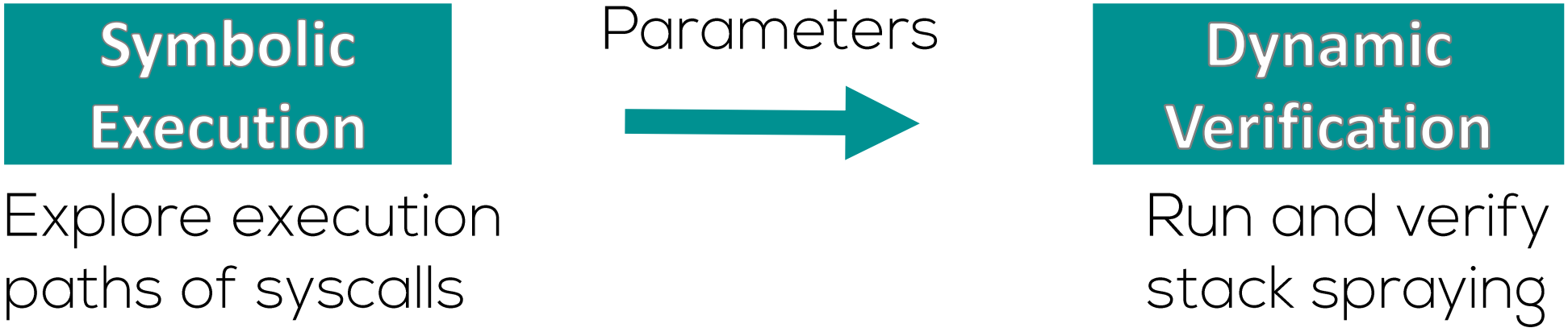
Targeted stack spraying



Targeted stack spraying

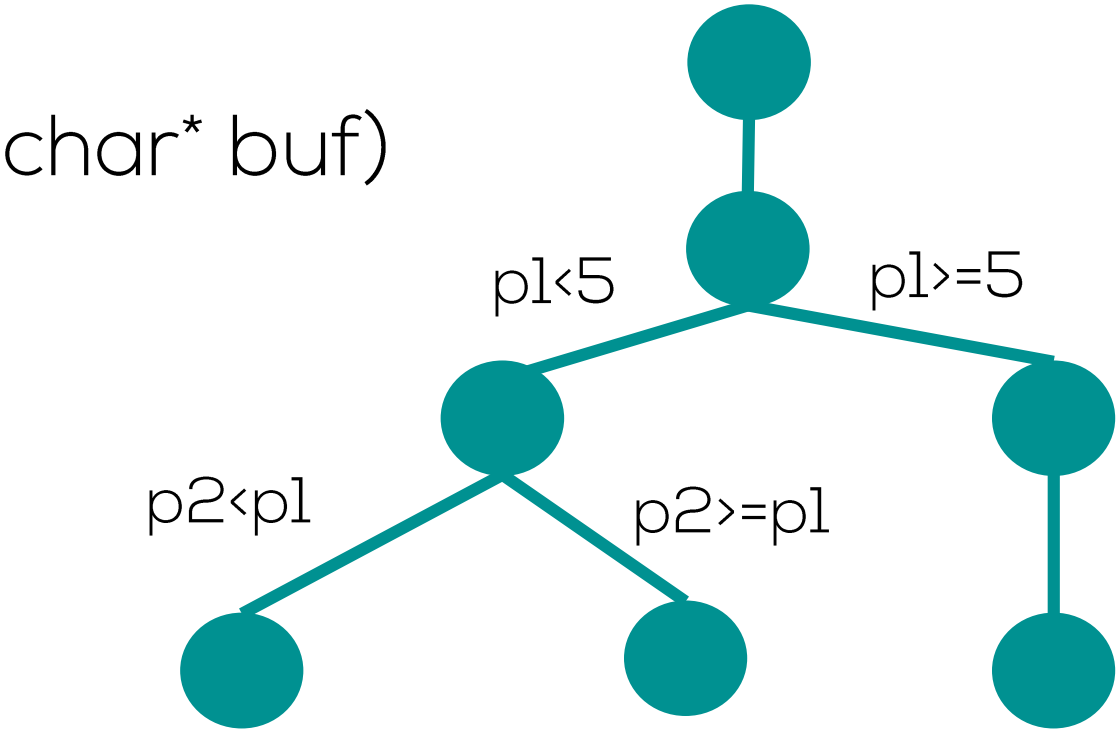


Deterministic stack spraying overview



Path exploration using Symbolic Execution

syscall(int p1, int p2, char* buf)

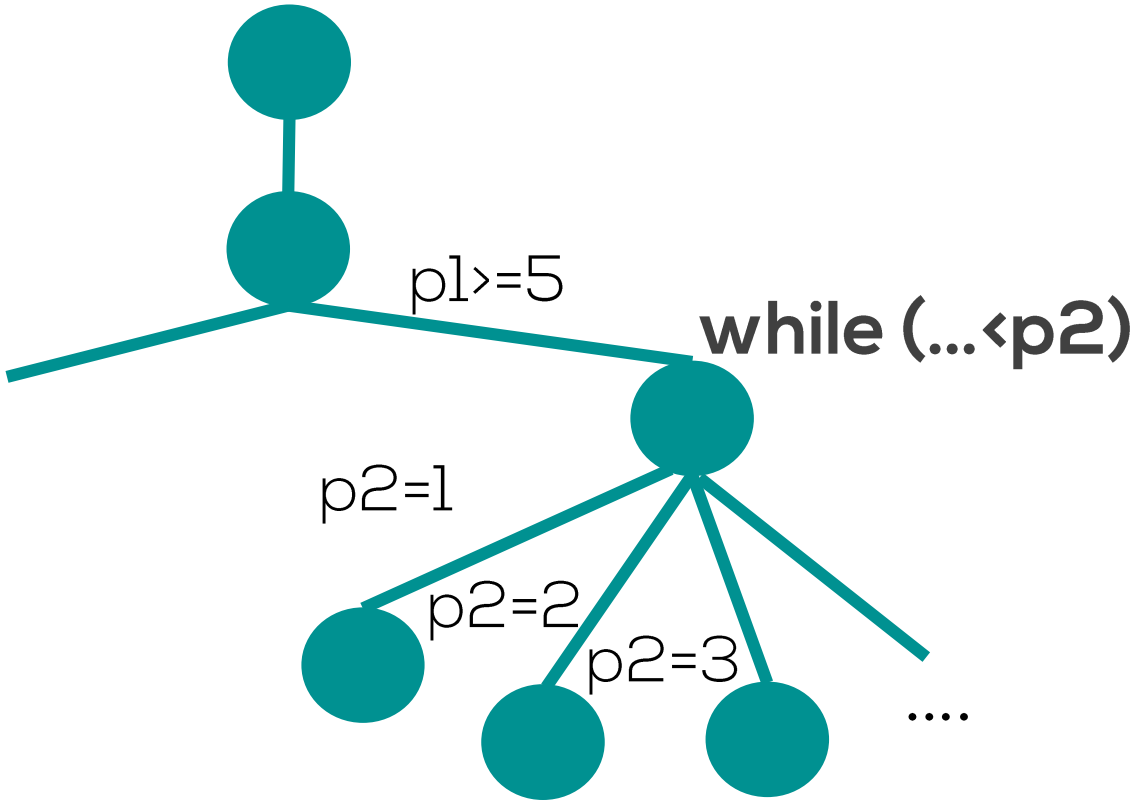


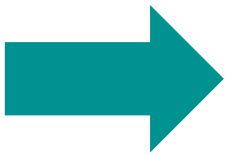
Path 1: p1<5; p2<p1

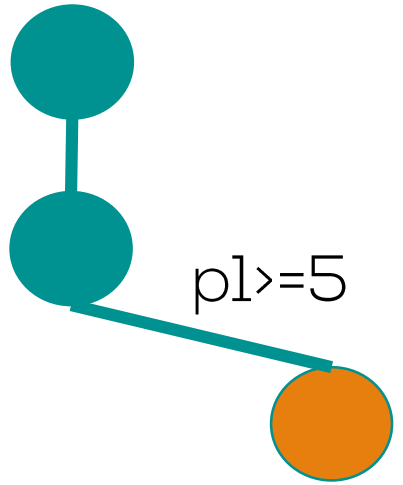
Path 2: p1<5; p2>=p1

Path 3: p1>=5

SE: handling path explosion due to unbounded loops



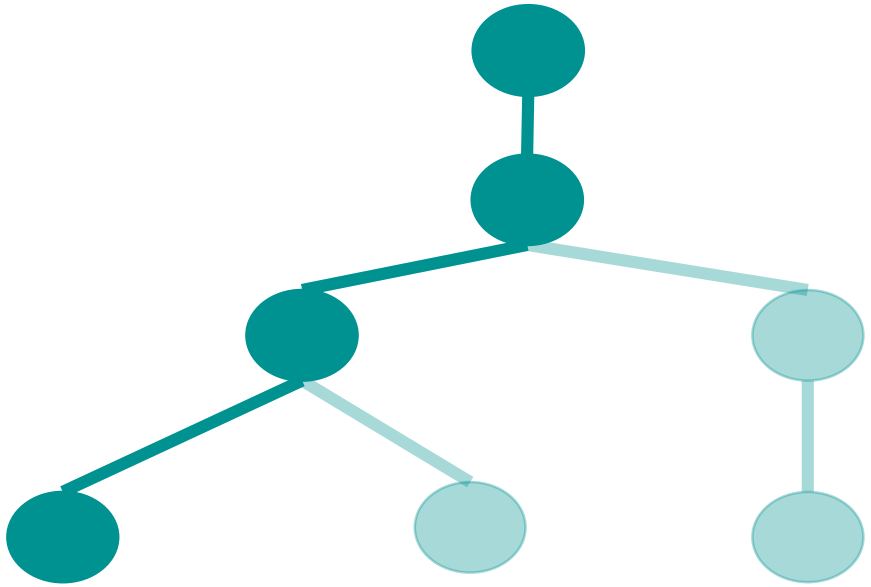




Path 3: p1>=5
LOOP(p2)

Fuzz loop variable (p2) in dynamic verification phase

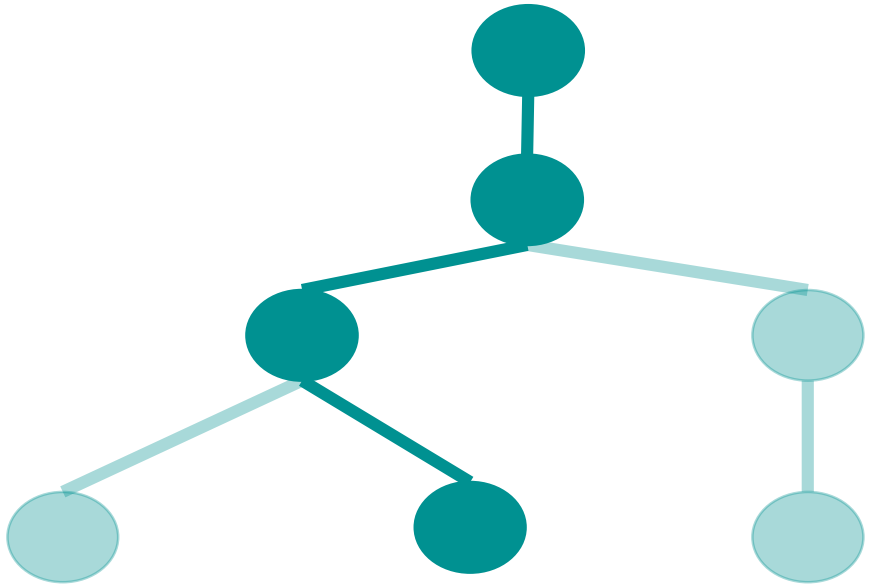
Verify stack spraying by executing paths



Path 1: p1<5; p2<p1

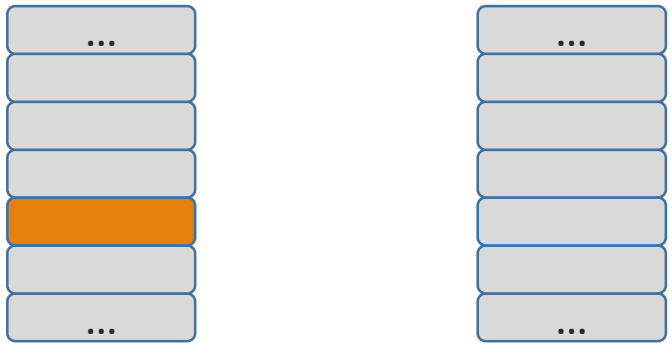
syscall(p1=3, p2=2, buf="UUID")

Verify stack spraying by executing paths

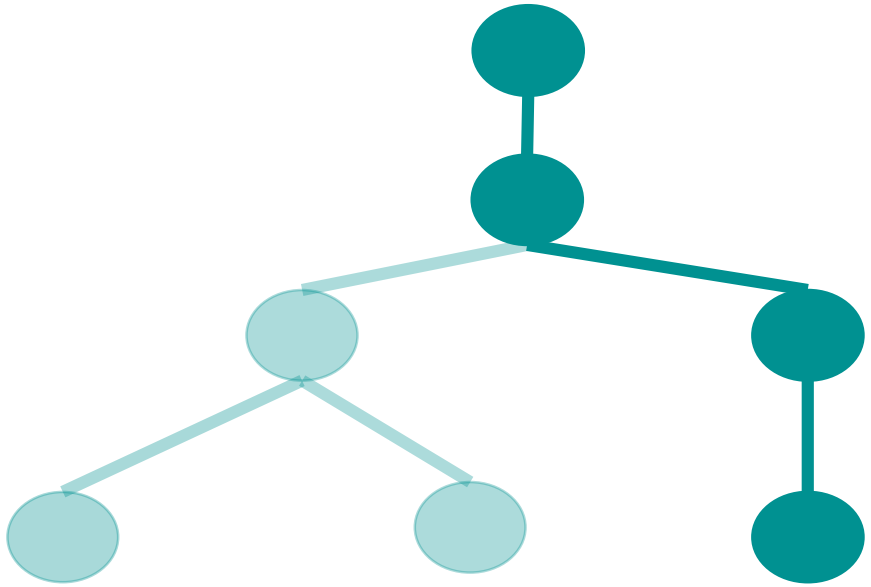


Path 2: p1<5; p2>=p1

syscall(p1=3, p2=3, buf="UUID")

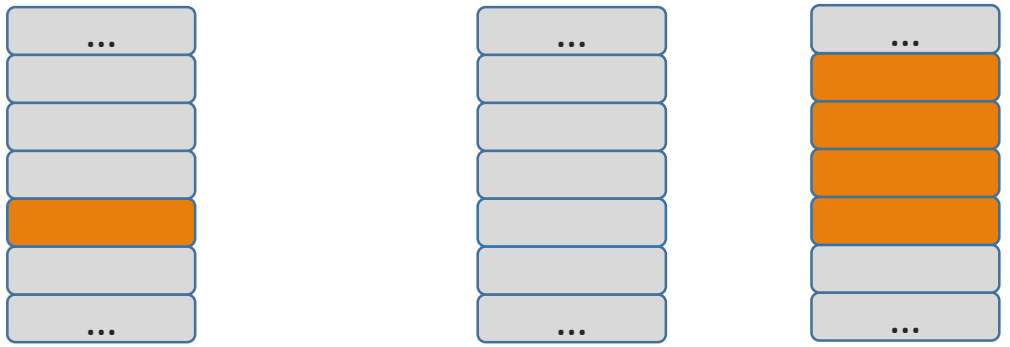


Verify stack spraying by executing paths

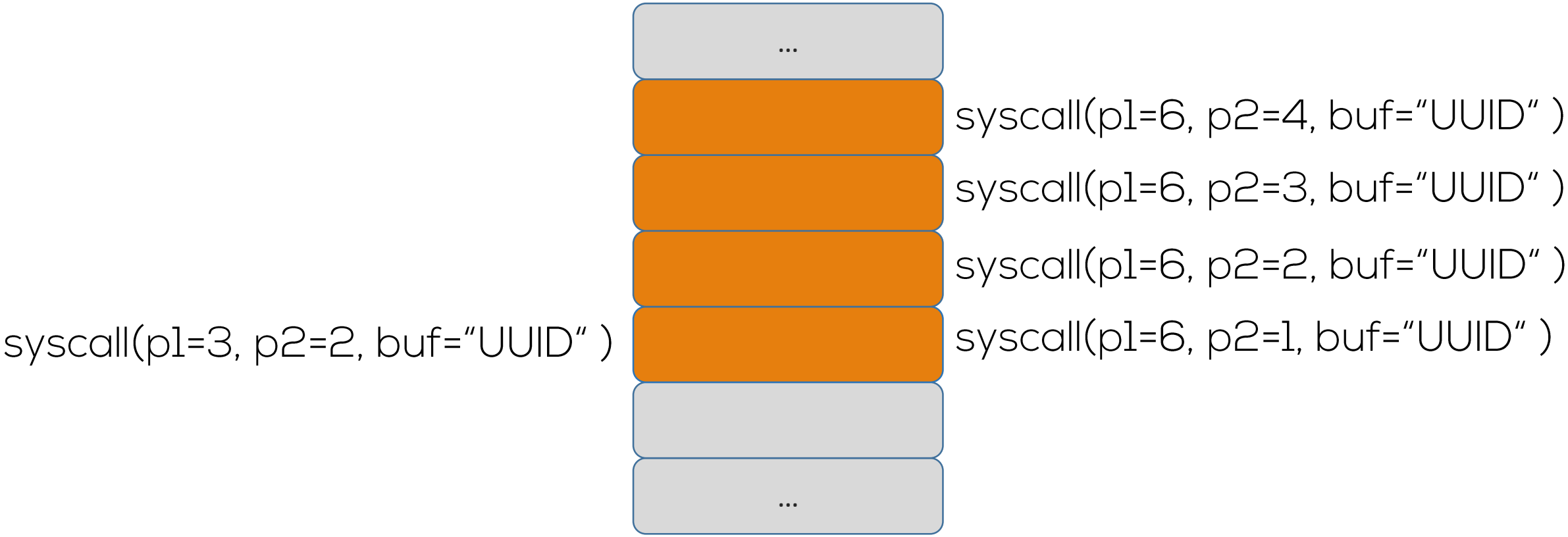


Path 3: p1>=5

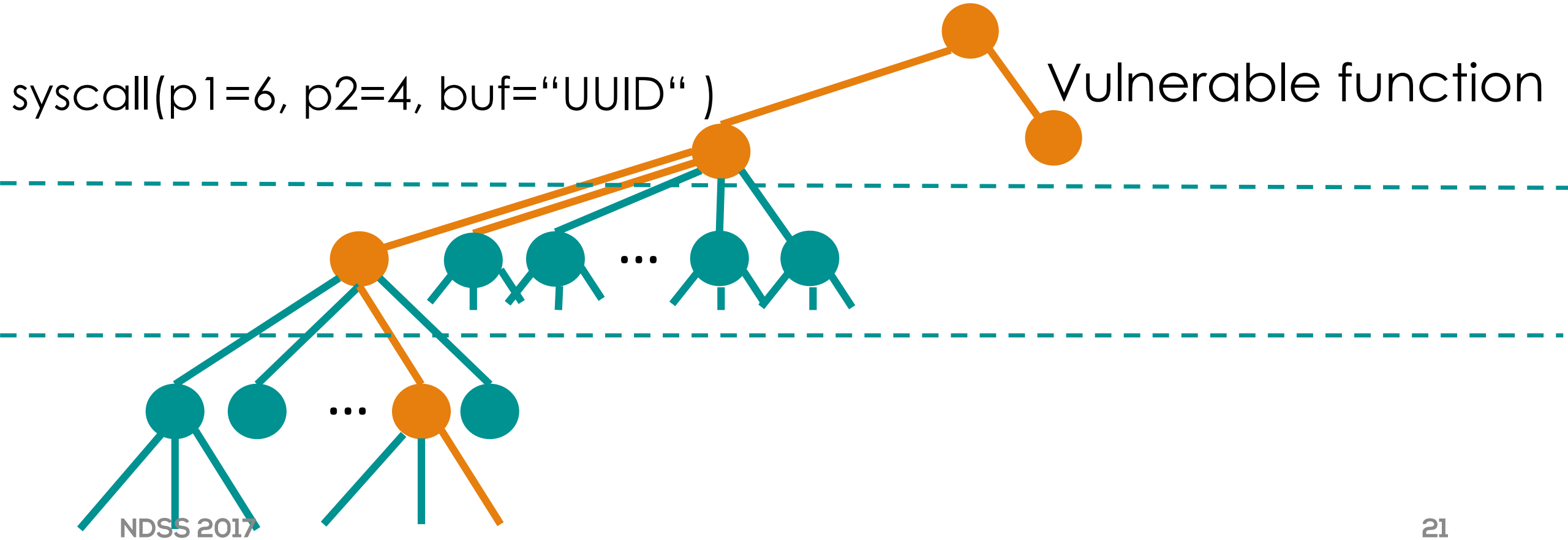
syscall(p1=6, FUZZ(p2), buf="UUID")



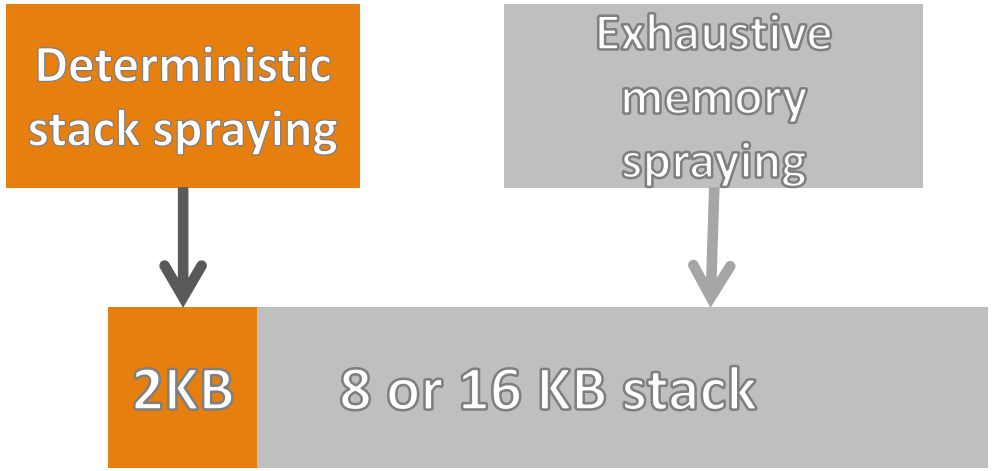
Mapping syscalls and parameters to memory locations



Automatically exploiting uninitialized uses in the Linux kernel is possible!



Achieved Linux kernel stack coverage



Deterministic Stack Spraying: **39%** of 2KB

Deterministc Stack Spraying + Exhaustive Memory Spraying: **91%** of full stack

Real world case study: Linux Kernel Privilege escalation CVE-2010-2963

- CVE-2010-2963: Uninitialized pointer used for write
- Found by Kees Cook

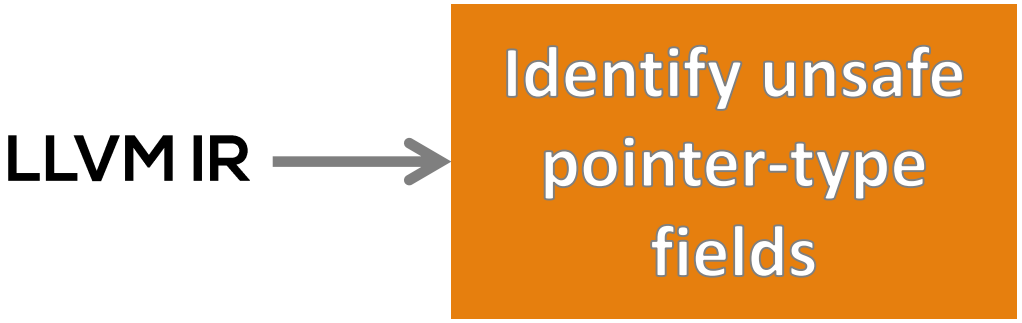
- Setup: get_video_tuner32 → Vuln: get_microcode32

- We automatically found **27** syscalls that can control the uninitialized pointer

Efficient mitigation by zero-initialization

```
struct A *foo;
…
foo->complete();
```

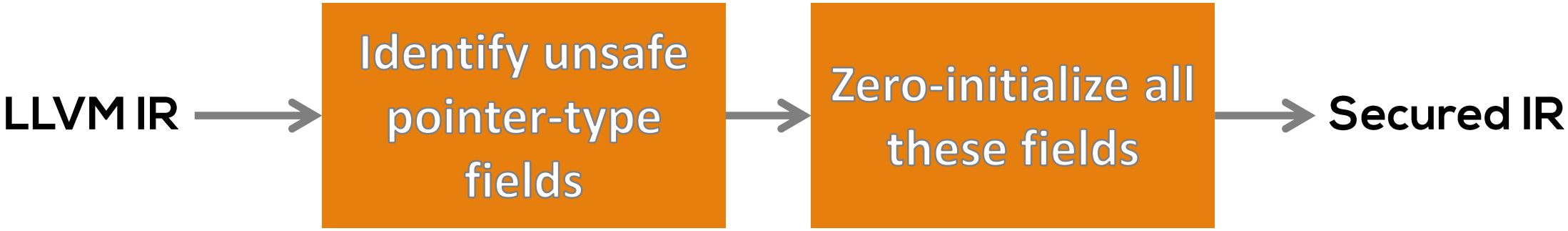
```
struct A *foo;
…
bar(foo);
```



Efficient mitigation by zero-initialization

```
struct A *foo = 0;
…
foo->complete();
```

```
struct A *foo = 0;
…
bar(foo);
```



Mitigation performance overhead

- Syscall performance overhead with LMBench
  - Average: **1.95%**

- User program performance overhead with SPEC benchmarks
  - Average: **0.47%**

Conclusions

- Uninitialized stack variables can be reliably controlled
- Uninitialized use is a critical attack vector
- Memory-safety techniques should include uninitialized use as a prevention target