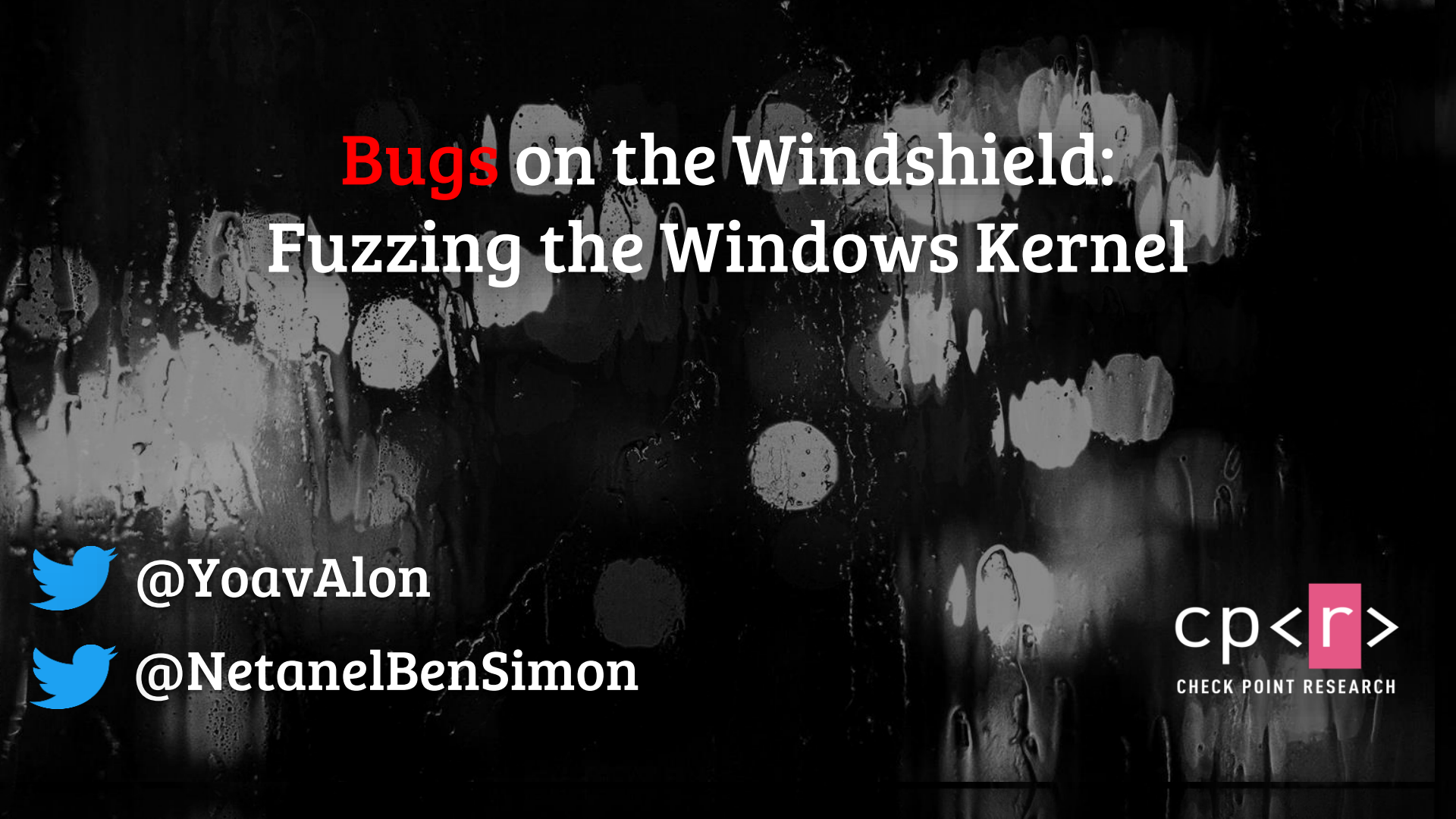

Bugs on the Windshield:
Fuzzing the Windows Kernel
@YoavAlon
@NetanelBenSimon
cp<r>
CHECK POINT RESEARCH

Who Are We?

Yoav Alon (@yoavalon)

CTO @ Orca Security

MSRC MVSR 2019

Netanel Ben Simon (@NetanelBenSimon)

Researcher @ Check Point Research

MSRC MVSR 2019


We
Fuzzing

Motivation

We had a successful fuzzing campaign against binary format parsers

- Adobe Reader & MS Edge

WinAFL has been successfully used to identify bugs in Windows software, such as

- [Adobe] CVE-2018-4985, CVE-2018-5063, CVE-2018-5064, CVE-2018-5065, CVE-2018-5068, CVE-2018-5069, CVE-2018-5070, CVE-2018-12754, CVE-2018-12755, CVE-2018-12764, CVE-2018-12765, CVE-2018-12766, CVE-2018-12767, CVE-2018-12768, CVE-2018-12848, CVE-2018-12849, CVE-2018-12850, CVE-2018-12840, CVE-2018-15956, CVE-2018-15955, CVE-2018-15954,CVE-2018-15953, CVE-2018-15952, CVE-2018-15938, CVE-2018-15937, CVE-2018-15936, CVE-2018-15935, CVE-2018-15934, CVE-2018-15933, CVE-2018-15932 , CVE-2018-15931, CVE-2018-15930 , CVE-2018-15929, CVE-2018-15928, CVE-2018-15927, CVE-2018-12875, CVE-2018-12874 , CVE-2018-12873, CVE-2018-12872,CVE-2018-12871, CVE-2018-12870, CVE-2018-12869, CVE-2018-12867 , CVE-2018-12866, CVE-2018-12865 , CVE-2018-12864 , CVE-2018-12863, CVE-2018-12862, CVE-2018-12861, CVE-2018-12860, CVE-2018-12859, CVE-2018-12857, CVE-2018-12839 - found by Yoav Alon and Netanel Ben-Simon from Check Point Software Technologies

https://research.checkpoint.com/2018/50-adobe-cves-in-50-days/

Motivation

- We wanted a bigger challenge
  - fuzzing Windows Kernel seemed hard enough
- We can build a full chain

Obligatory slides - What is fuzzing?

A method for automatic software testing

- Inputs: target software + CPU time
- Outputs: bugs

Example of a basic fuzzer:

Obligatory slides - What is fuzzing?

A method for automatic software testing

- Inputs: target software + CPU time
- Outputs: bugs

Example of a basic fuzzer:

```
$ ./test_program < /dev/urandom
```

Obligatory slides - What is fuzzing?

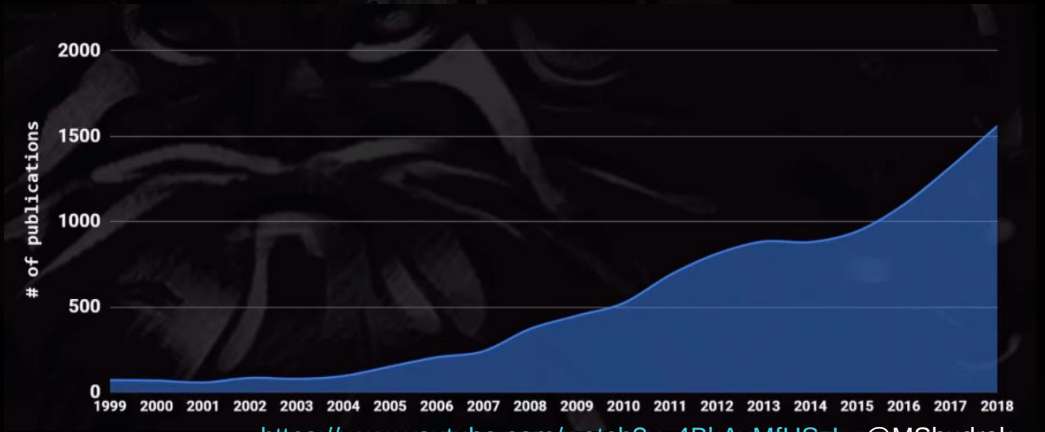
A method for automatic software testing

- Inputs: target software + CPU time
- Outputs: bugs

Example of a basic fuzzer:

```
$ ./test_program < /dev/urandom
```

Active area of research:



https://www.youtube.com/watch?v=4BkAxMfHSzI - @MShudrak

Structure of modern fuzzers

Modern fuzzers consist of

- Test case generator/mutator
- Bug oracle
- Feedback mechanism - usually code coverage

Examples: AFL, libfuzzer, honggfuzz...

Structure of modern fuzzers

Modern fuzzers consist of

- Test case generator/mutator
- Bug oracle
- Feedback mechanism - usually code coverage

Examples: AFL, libfuzzer, honggfuzz...

```
$ ./test_program < /dev/urandom
Segmentation fault (core dumped)
```

Structure of modern fuzzers

Modern fuzzers consist of

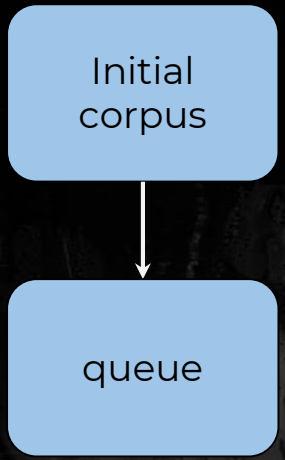
- Test case generator/mutator
- Bug oracle
- Feedback mechanism - usually code coverage

Examples: AFL, libfuzzer, honggfuzz...

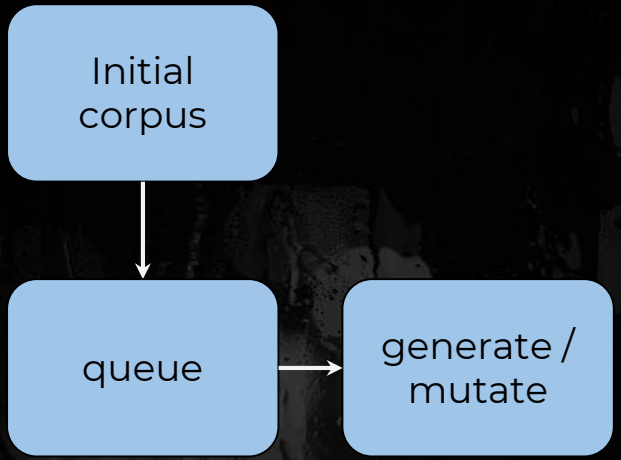
Coverage Guided Fuzzing process

Initial corpus

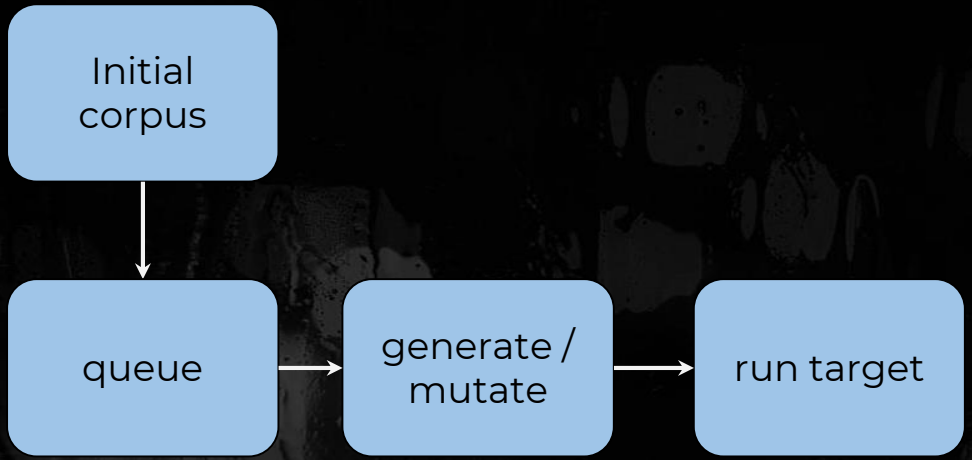
Coverage Guided Fuzzing process



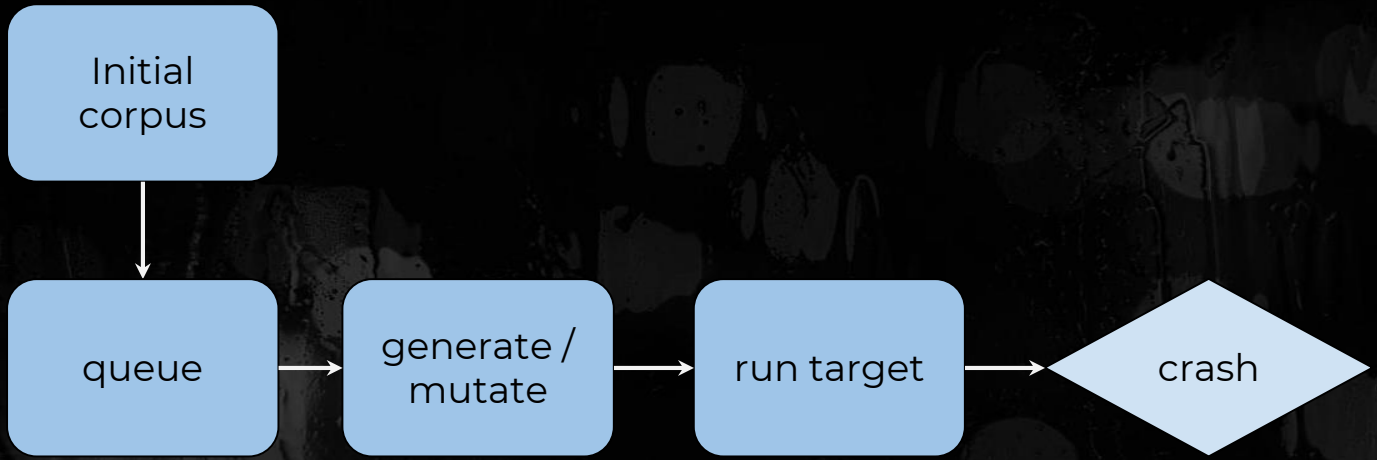
Coverage Guided Fuzzing process



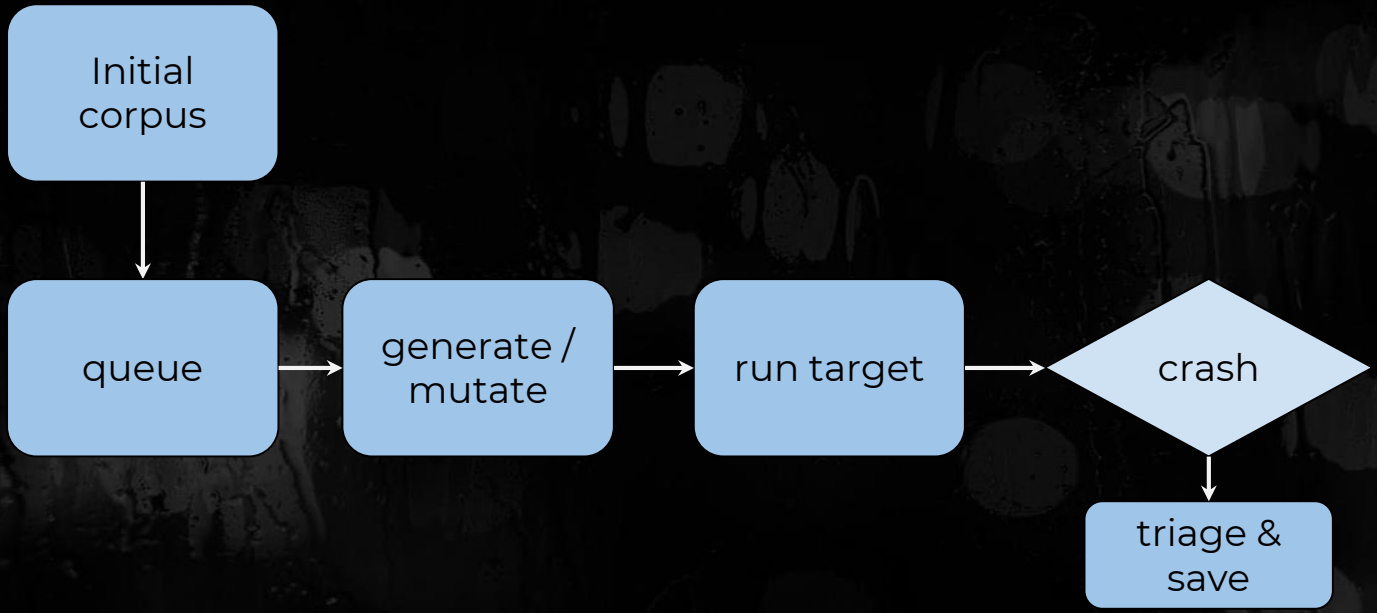
Coverage Guided Fuzzing process



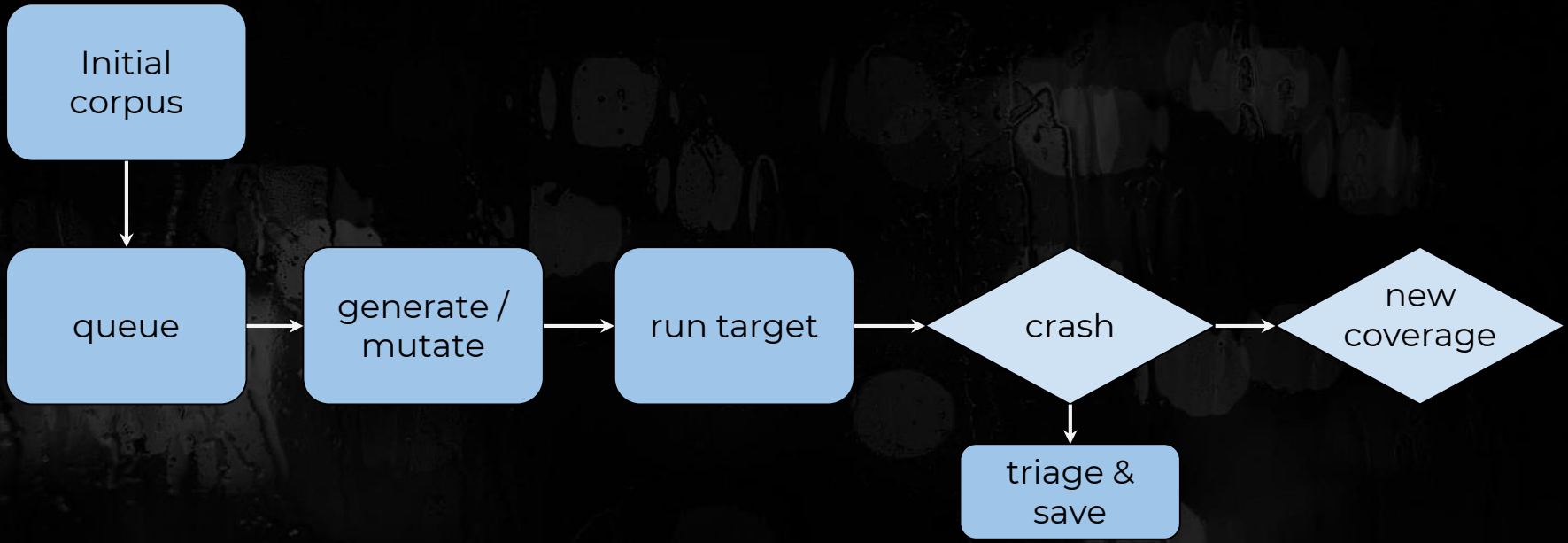
Coverage Guided Fuzzing process



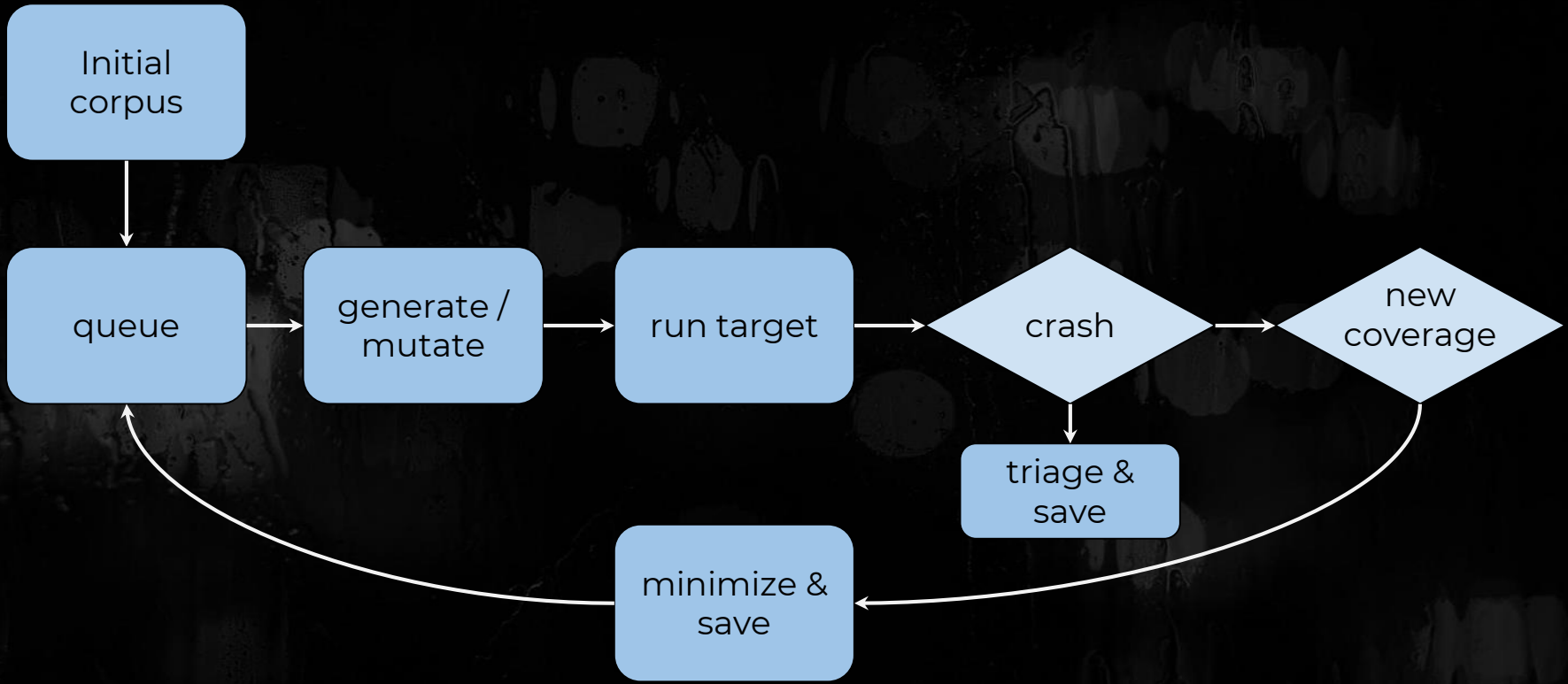
Coverage Guided Fuzzing process



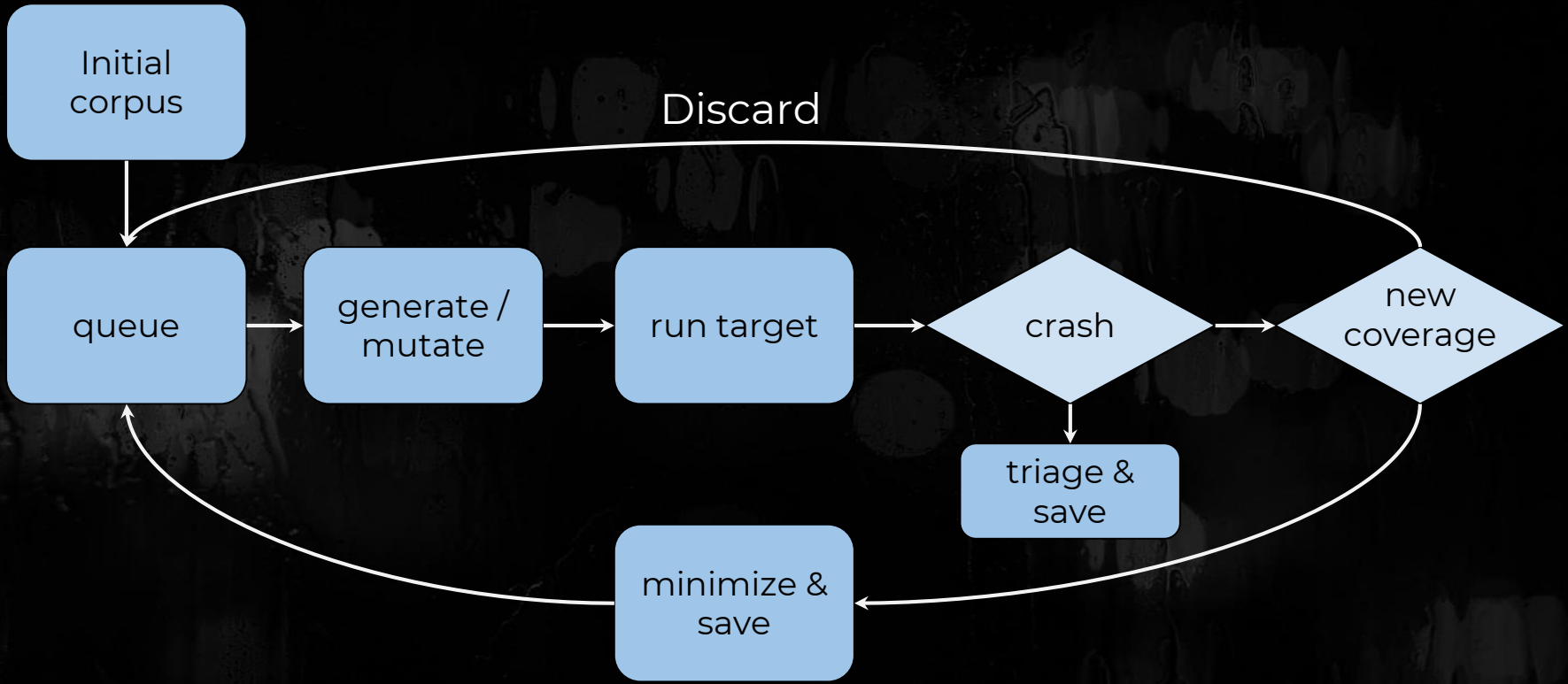
Coverage Guided Fuzzing process



Coverage Guided Fuzzing process



Coverage Guided Fuzzing process




We have experience with AFL

We have experience with AFL

Can we use AFL to attack the Windows kernel?

kAFL
AFL with a “k”

kAFL: Hardware-Assisted Feedback Fuzzing for OS Kernels

Sergej Schumilo
Ruhr-Universität Bochum

Cornelius Aschermann
Ruhr-Universität Bochum

Robert Gawlik
Ruhr-Universität Bochum

Sebastian Schinzel
Münster University of Applied Sciences

Thorsten Holz
Ruhr-Universität Bochum

kAFL

AFL with a “k”

kAFL
AFL with a “k”

Trophies

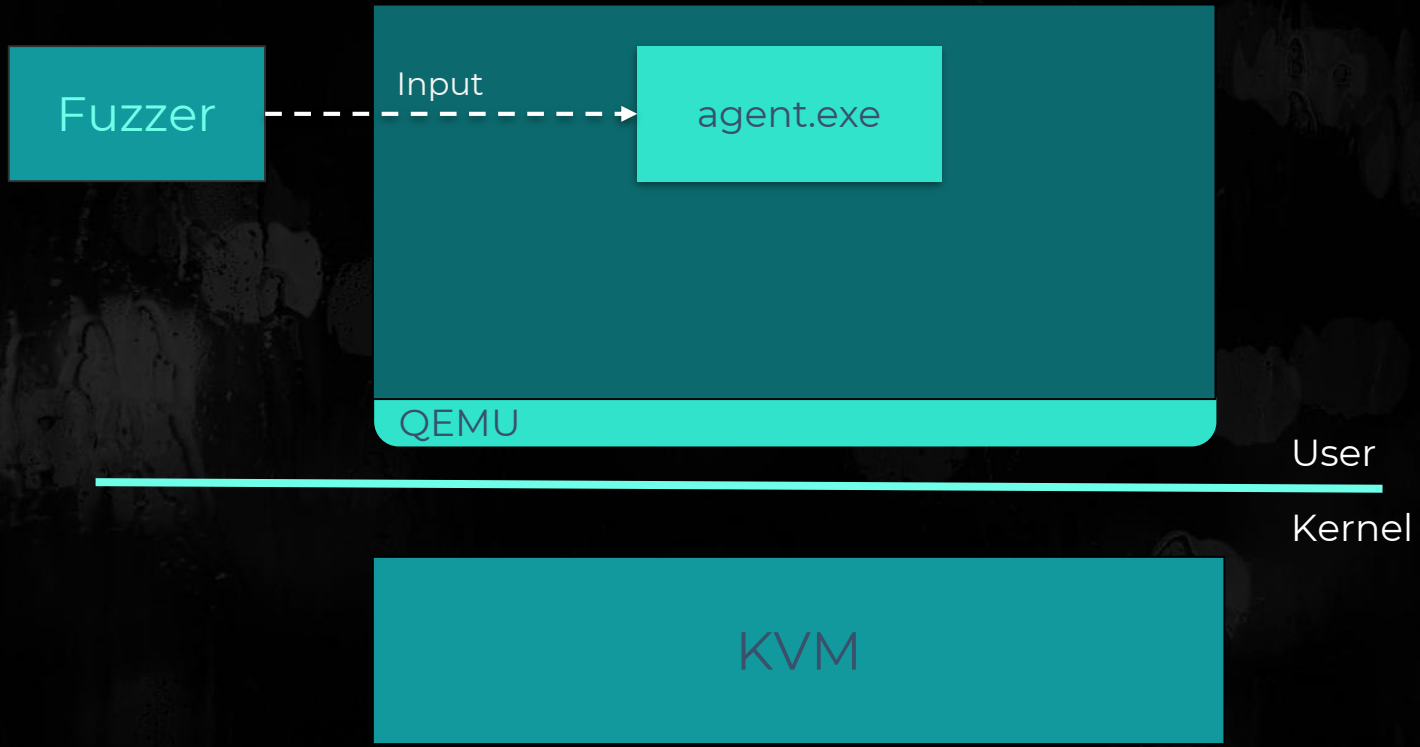
- Linux keyctl null pointer dereference (CVE-2016-8650)
- Linux EXT4 memory corruption
- Linux EXT4 denial of service
- macOS APFS memory corruption (CVE-2017-13800)
- macOS HFS memory corruption (CVE-2017-13830)

kAFL Architecture

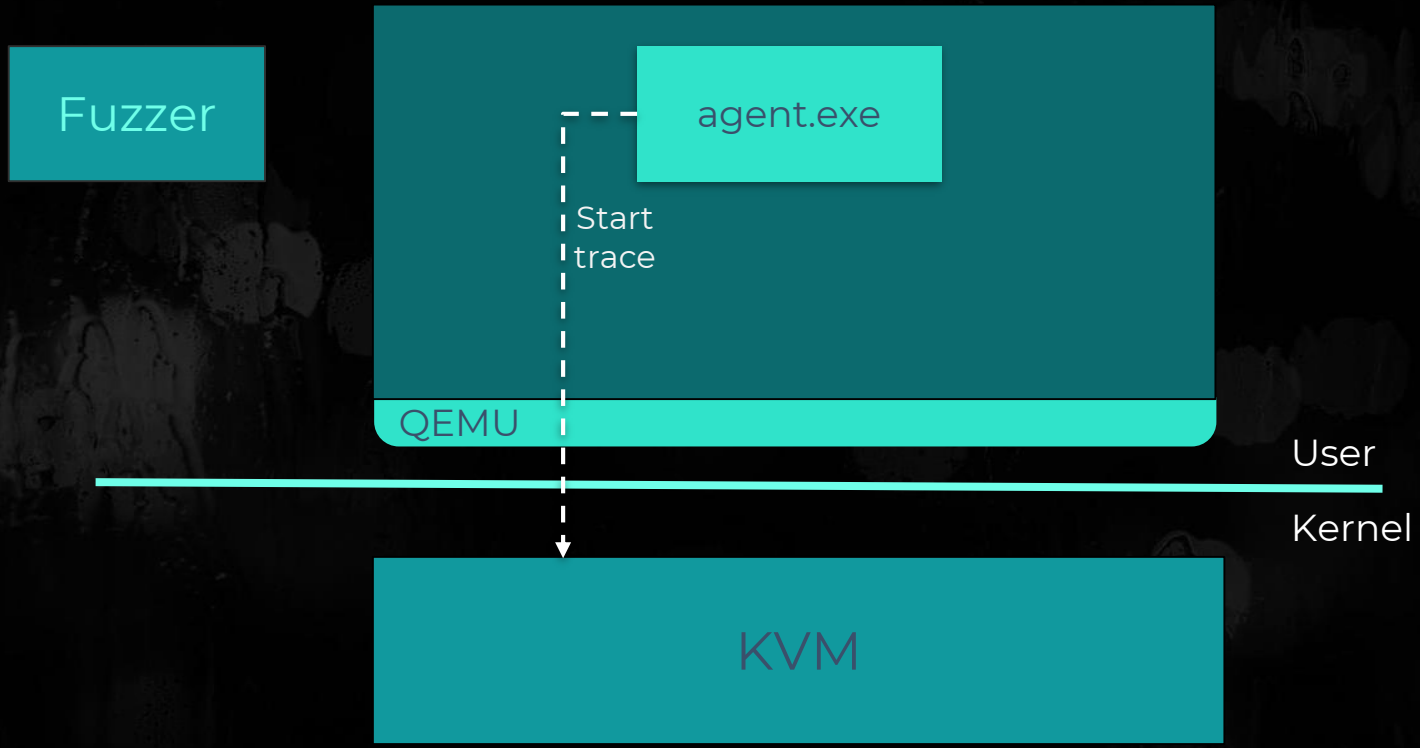
kAFL Architecture

kAFL Architecture

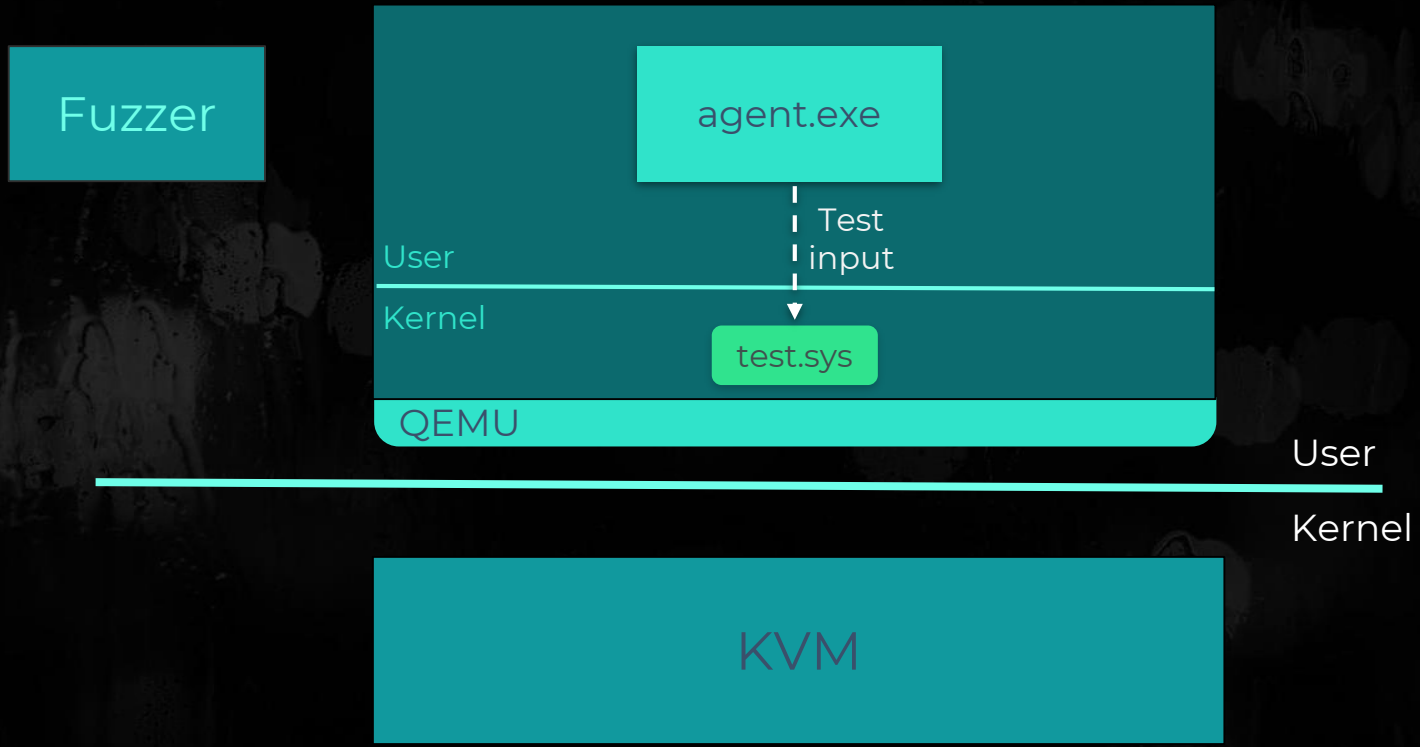
kAFL Architecture



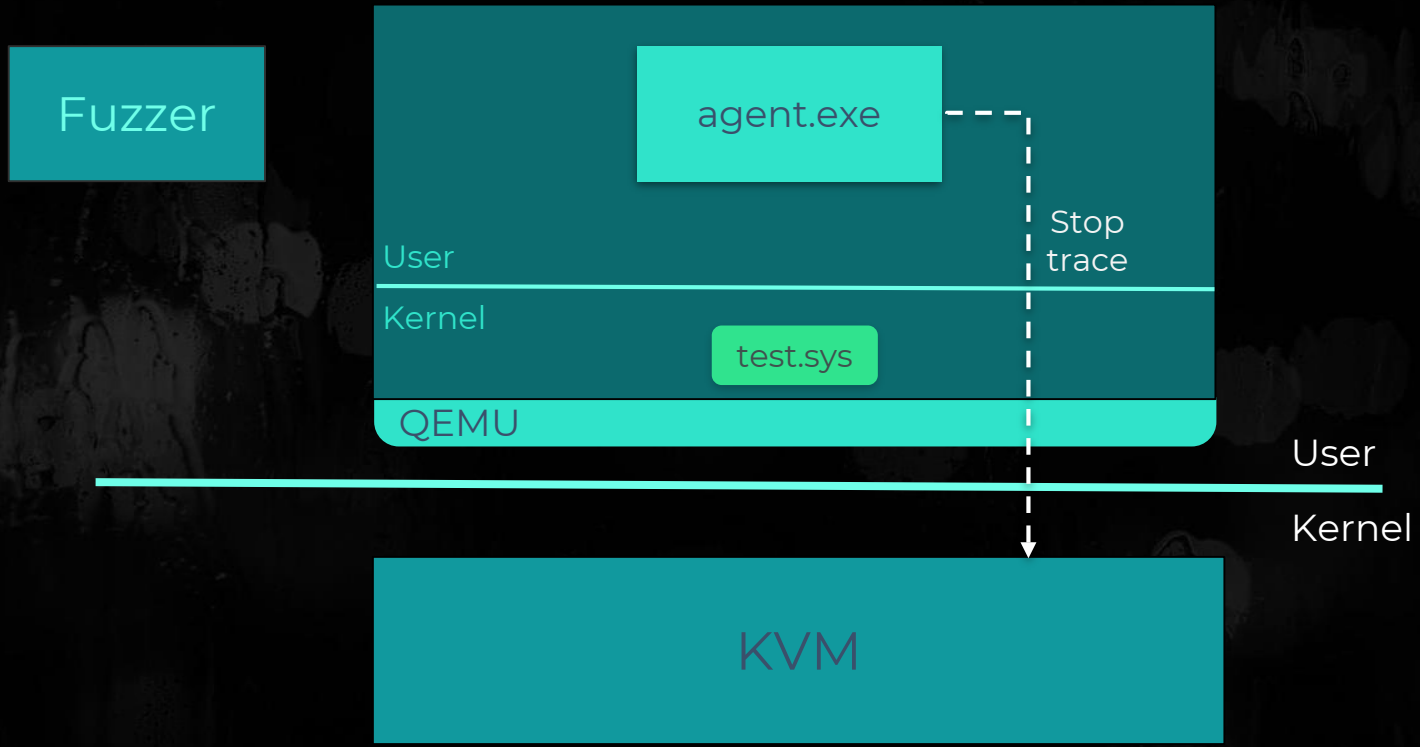
kAFL
Architecture



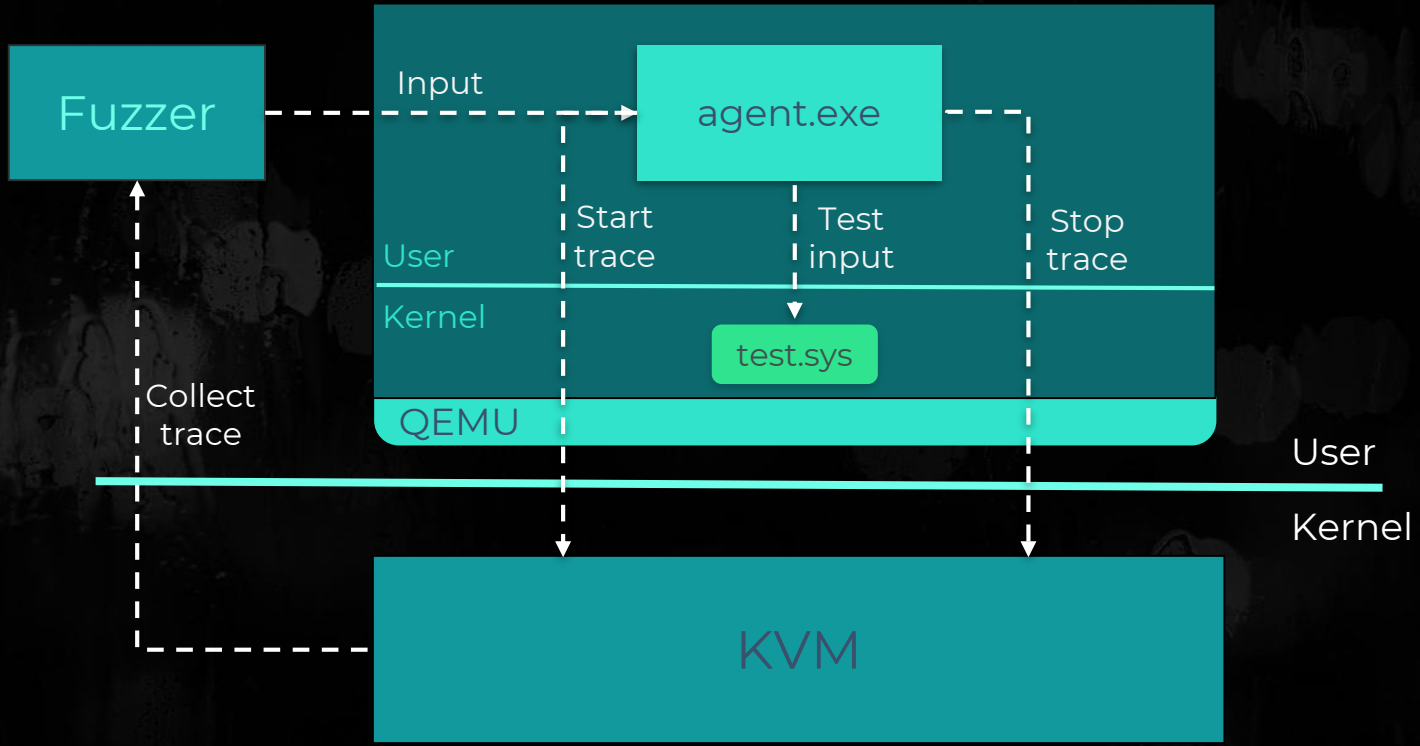
kAFL Architecture



kAFL Architecture



kAFL Architecture



kAFL

Coverage - Intel Processor Trace

Low-overhead hardware execution tracing feature

The trace information is written in a compressed form to physical memory

kAFL uses a fast decoder to generate full traces

kAFL

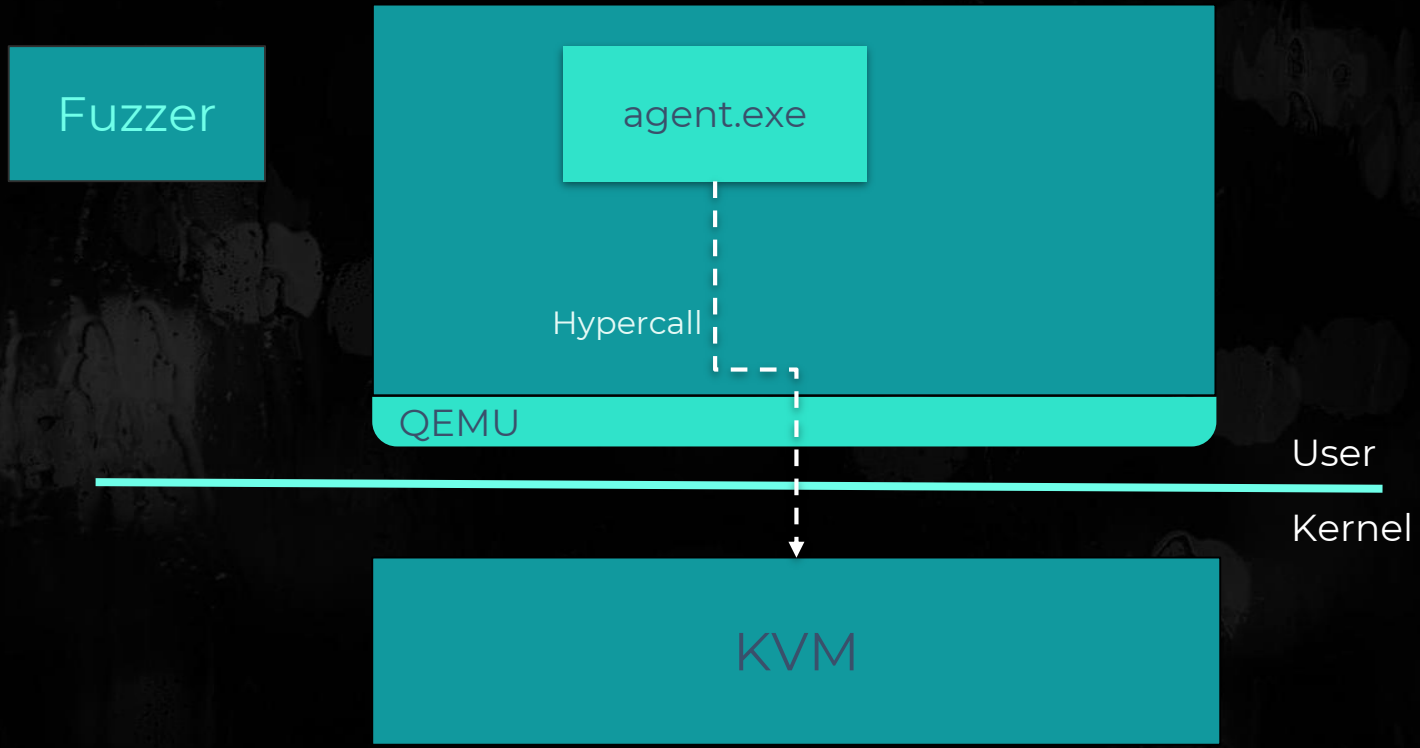
How to detect crashes?

kAFL

How to detect crashes?

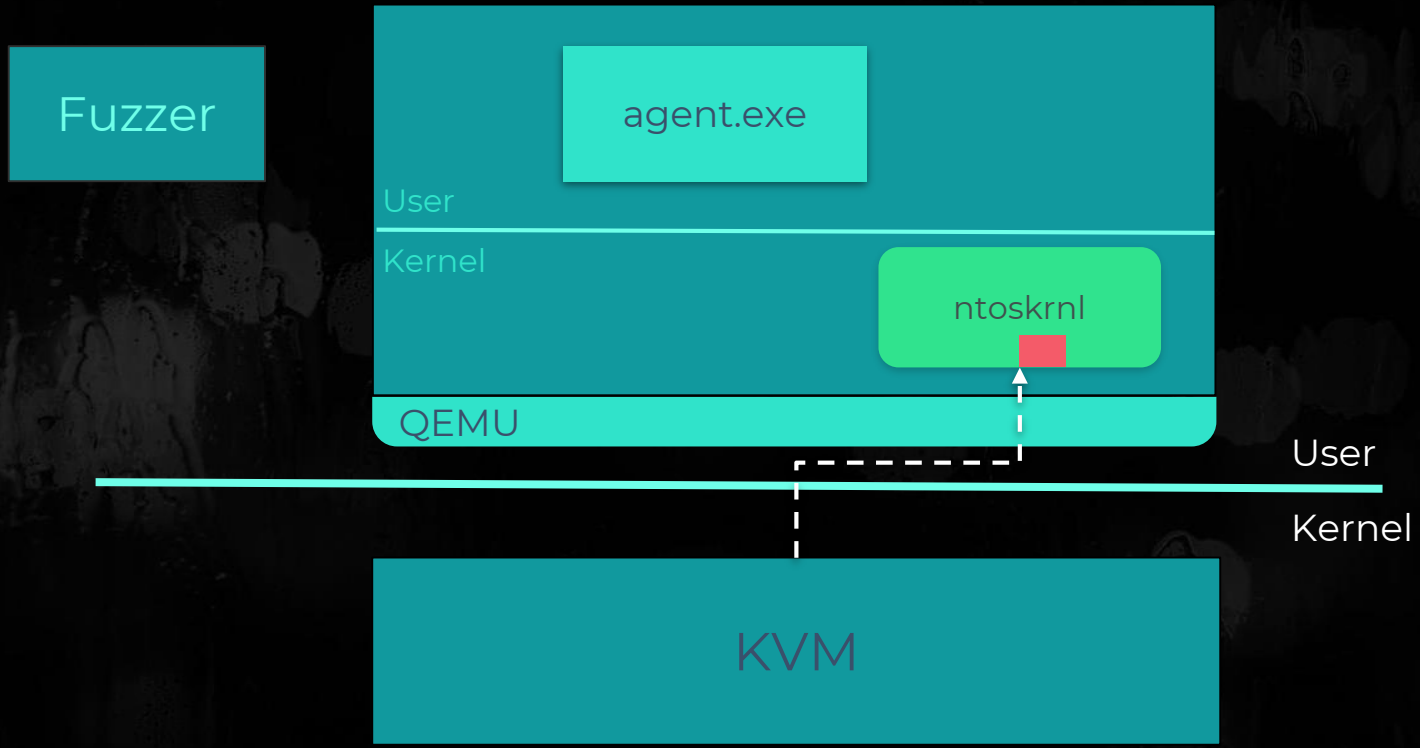
kAFL

How to detect crashes?



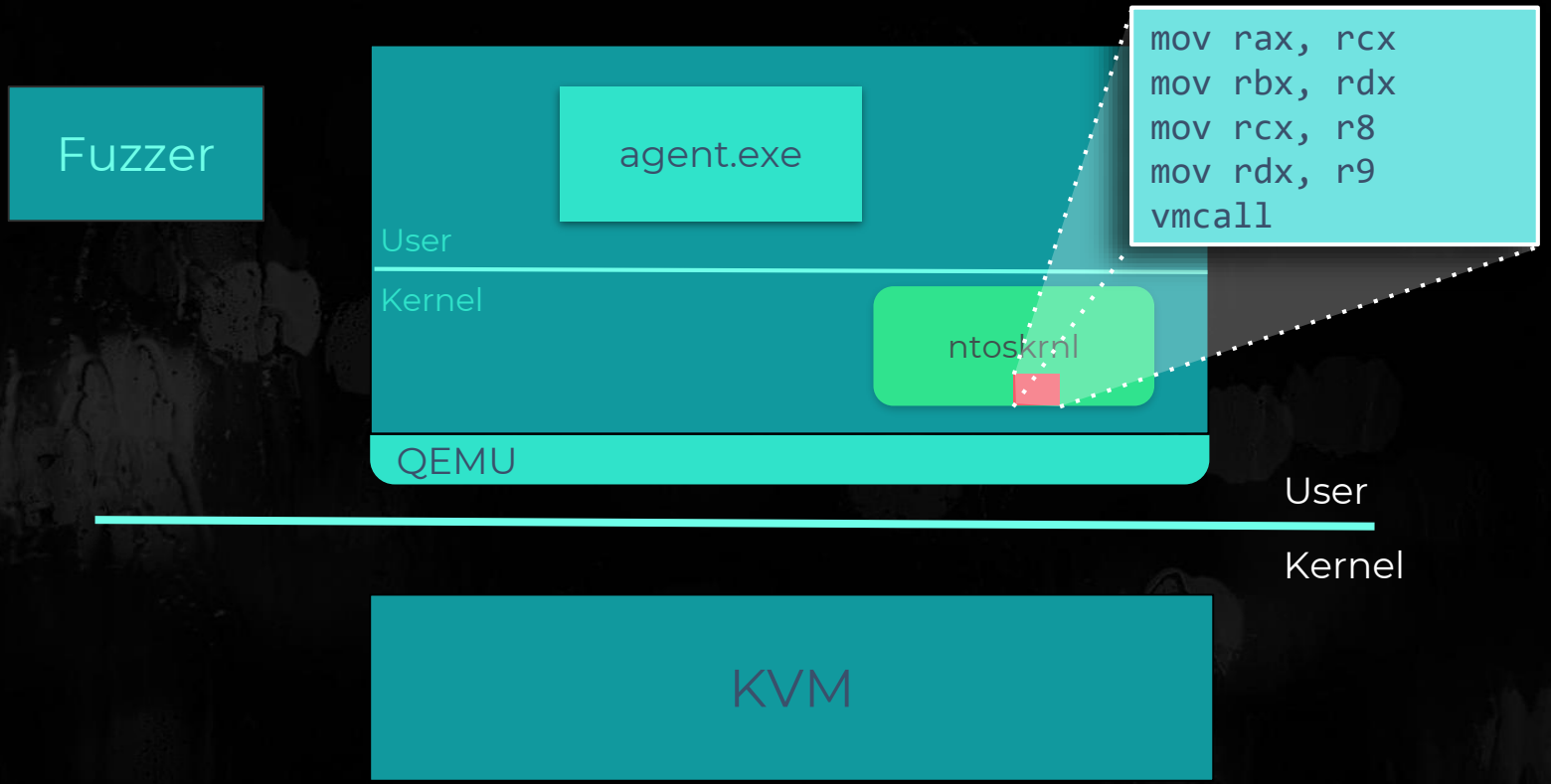
kAFL

How to detect crashes?



kAFL

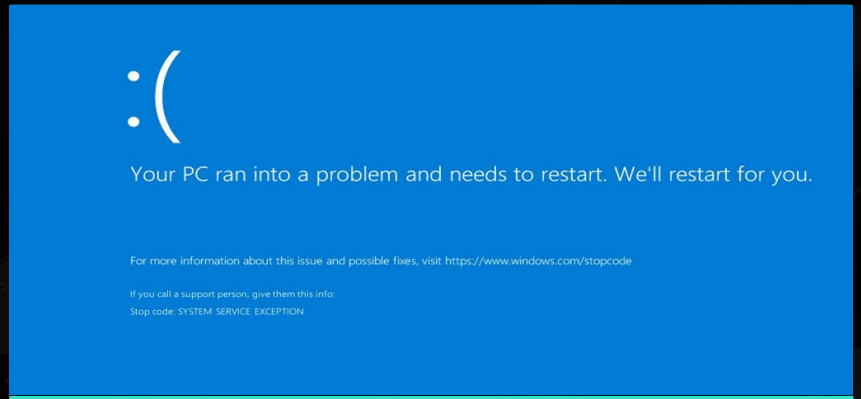
How to detect crashes?



kAFL

How to detect crashes?

Fuzzer



QEMU

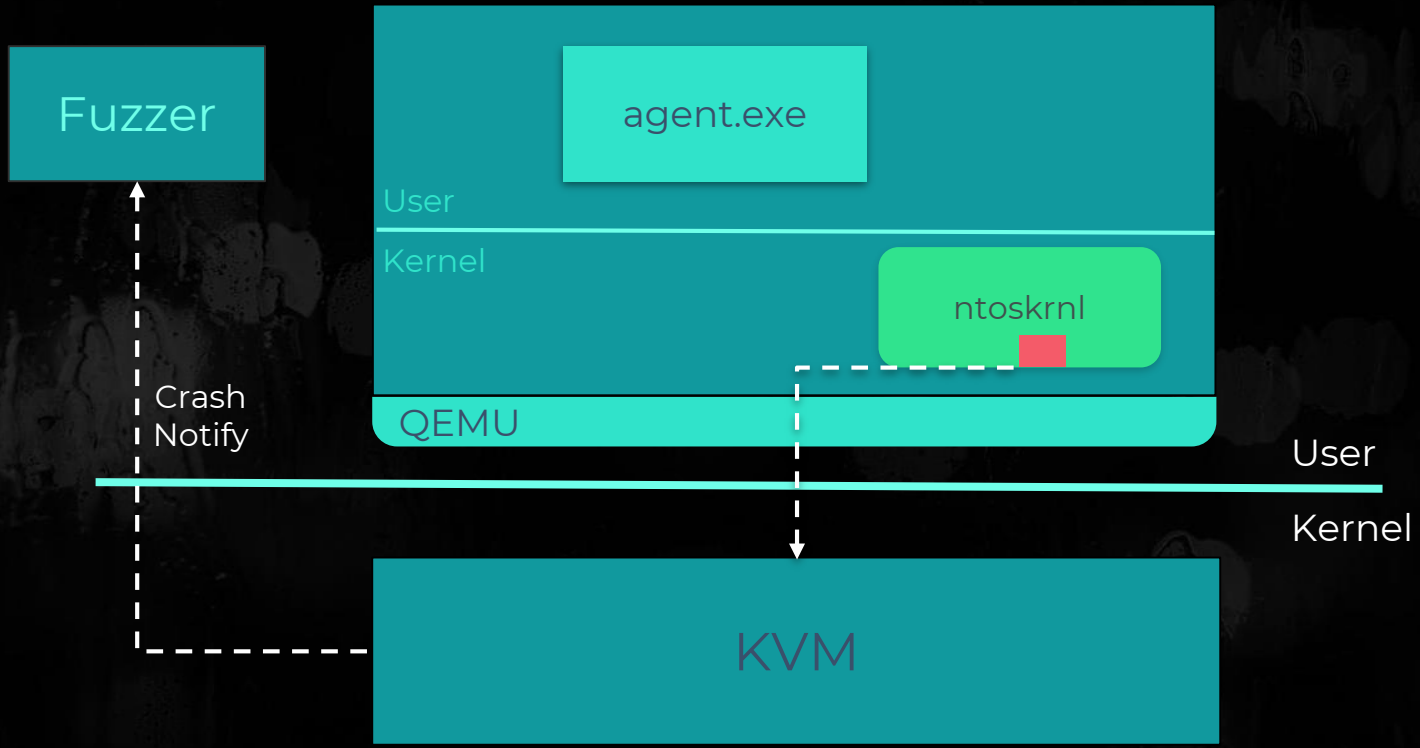
User

Kernel

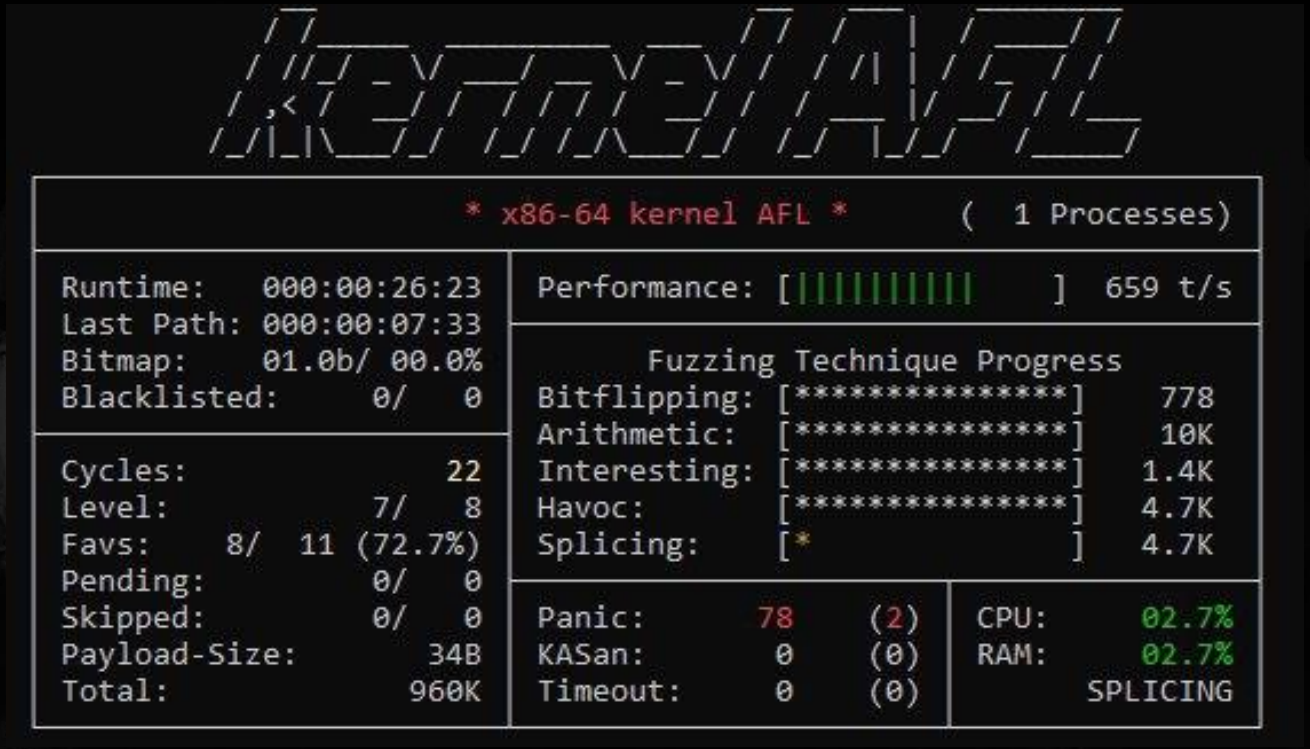
KVM

kAFL

How to detect crashes?



kAFL
Dashboard



What to attack with kAFL?

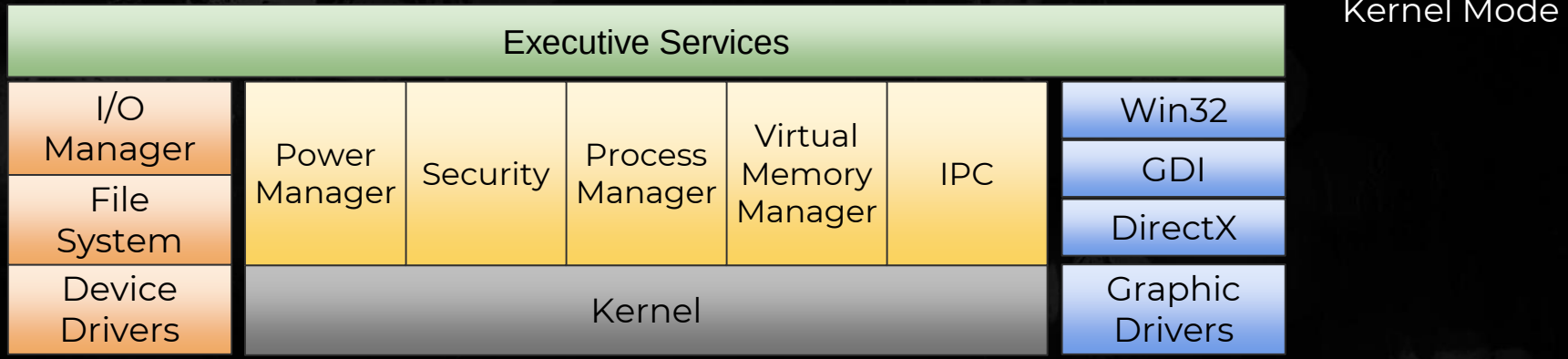
Good targets for AFL/kAFL

- Fast (>100 iter/s)
- Parsers, especially for binary formats

What to attack with kAFL?

Good targets for AFL/kAFL

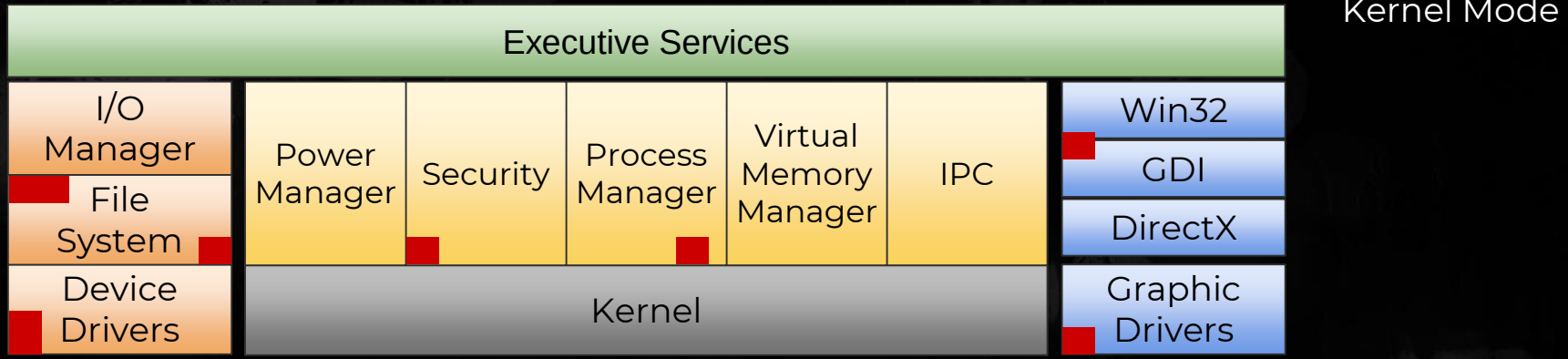
- Fast (>100 iter/s)
- Parsers, especially for binary formats



What to attack with kAFL?

Good targets for AFL/kAFL

- Fast (>100 iter/s)
- Parsers, especially for binary formats



Typical kernel bug: CVE-2018-0744

```
int main(int argc, char **argv) {
    WNDCLASSEX WindowClass = {0};
    HWND WindowA, WindowB, WindowC;
    ATOM Atom;
    WindowClass.cbSize          = sizeof(WNDCLASSEX);
    WindowClass.lpfnWndProc     = DefWindowProc;
    WindowClass.lpszClassName   = "Class";
    Atom = RegisterClassEx(&WindowClass);
    WindowA = CreateWindowEx(0, MAKEINTATOM(Atom), "One", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC);
    WindowB = CreateWindowEx(0, MAKEINTATOM(Atom), "Two", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    GetDC(WindowA);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC | CS_OWNDC);
    WindowC = CreateWindowEx(0, MAKEINTATOM(Atom), "Three", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
}
```

Typical kernel bug: CVE-2018-0744

```
int main(int argc, char **argv) {
    WNDCLASSEX WindowClass = {0};
    HWND WindowA, WindowB, WindowC;
    ATOM Atom;
    WindowClass.cbSize         = sizeof(WNDCLASSEX);
    WindowClass.lpfnWndProc    = DefWindowProc;
    WindowClass.lpszClassName  = "Class";
    Atom = RegisterClassEx(&WindowClass);
    WindowA = CreateWindowEx(0, MAKEINTATOM(Atom), "One", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC);
    WindowB = CreateWindowEx(0, MAKEINTATOM(Atom), "Two", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    GetDC(WindowA);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC | CS_OWNDC);
    WindowC = CreateWindowEx(0, MAKEINTATOM(Atom), "Three", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
}
```

Typical kernel bug: CVE-2018-0744

```
int main(int argc, char **argv) {
    WNDCLASSEX WindowClass = {0};
    HWND WindowA, WindowB, WindowC;
    ATOM Atom;
    WindowClass.cbSize          = sizeof(WNDCLASSEX);
    WindowClass.lpfnWndProc     = DefWindowProc;
    WindowClass.lpszClassName   = "Class";
    Atom = RegisterClassEx(&WindowClass);
    WindowA = CreateWindowEx(0, MAKEINTATOM(Atom), "One", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC);
    WindowB = CreateWindowEx(0, MAKEINTATOM(Atom), "Two", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    GetDC(WindowA);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC | CS_OWNDC);
    WindowC = CreateWindowEx(0, MAKEINTATOM(Atom), "Three", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
}
```

Typical kernel bug: CVE-2018-0744

```
int main(int argc, char **argv) {
    WNDCLASSEX WindowClass = {0};
    HWND WindowA, WindowB, WindowC;
    ATOM Atom;
    WindowClass.cbSize          = sizeof(WNDCLASSEX);
    WindowClass.lpfnWndProc     = DefWindowProc;
    WindowClass.lpszClassName   = "Class";
    Atom = RegisterClassEx(&WindowClass);
    WindowA = CreateWindowEx(0, MAKEINTATOM(Atom), "One", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC);
    WindowB = CreateWindowEx(0, MAKEINTATOM(Atom), "Two", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    GetDC(WindowA);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC | CS_OWNDC);
    WindowC = CreateWindowEx(0, MAKEINTATOM(Atom), "Three", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
}
```

Typical kernel bug: CVE-2018-0744

```
int main(int argc, char **argv) {
    WNDCLASSEX WindowClass = {0};
    HWND WindowA, WindowB, WindowC;
    ATOM Atom;
    WindowClass.cbSize          = sizeof(WNDCLASSEX);
    WindowClass.lpfnWndProc     = DefWindowProc;
    WindowClass.lpszClassName   = "Class";
    Atom = RegisterClassEx(&WindowClass);
    WindowA = CreateWindowEx(0, MAKEINTATOM(Atom), "One", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC);
    WindowB = CreateWindowEx(0, MAKEINTATOM(Atom), "Two", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    GetDC(WindowA);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC | CS_OWNDC);
    WindowC = CreateWindowEx(0, MAKEINTATOM(Atom), "Three", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
}
```

Typical kernel bug: CVE-2018-0744

```
int main(int argc, char **argv) {
    WNDCLASSEX WindowClass = {0};
    HWND WindowA, WindowB, WindowC;
    ATOM Atom;
    WindowClass.cbSize          = sizeof(WNDCLASSEX);
    WindowClass.lpfnWndProc     = DefWindowProc;
    WindowClass.lpszClassName   = "Class";
    Atom = RegisterClassEx(&WindowClass);
    WindowA = CreateWindowEx(0, MAKEINTATOM(Atom), "One", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC);
    WindowB = CreateWindowEx(0, MAKEINTATOM(Atom), "Two", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    GetDC(WindowA);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC | CS_OWNDC);
    WindowC = CreateWindowEx(0, MAKEINTATOM(Atom), "Three", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
}
```

Typical kernel bug: CVE-2018-0744

```
int main(int argc, char **argv) {
    WNDCLASSEX WindowClass = {0};
    HWND WindowA, WindowB, WindowC;
    ATOM Atom;
    WindowClass.cbSize          = sizeof(WNDCLASSEX);
    WindowClass.lpfnWndProc     = DefWindowProc;
    WindowClass.lpszClassName   = "Class";
    Atom = RegisterClassEx(&WindowClass);
    WindowA = CreateWindowEx(0, MAKEINTATOM(Atom), "One", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC);
    WindowB = CreateWindowEx(0, MAKEINTATOM(Atom), "Two", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    GetDC(WindowA);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC | CS_OWNDC);
    WindowC = CreateWindowEx(0, MAKEINTATOM(Atom), "Three", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
}
```

Typical kernel bug: CVE-2018-0744

```
int main(int argc, char **argv) {
    WNDCLASSEX WindowClass = {0};
    HWND WindowA, WindowB, WindowC;
    ATOM Atom;
    WindowClass.cbSize          = sizeof(WNDCLASSEX);
    WindowClass.lpfnWndProc     = DefWindowProc;
    WindowClass.lpszClassName   = "Class";
    Atom = RegisterClassEx(&WindowClass);
    WindowA = CreateWindowEx(0, MAKEINTATOM(Atom), "One", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC);
    WindowB = CreateWindowEx(0, MAKEINTATOM(Atom), "Two", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
    GetDC(WindowA);
    SetClassLong(WindowA, GCL_STYLE, CS_CLASSDC | CS_OWNDC);
    WindowC = CreateWindowEx(0, MAKEINTATOM(Atom), "Three", 0, CW_USEDEFAULT,
                             0, 128, 128, NULL, NULL, NULL, NULL);
}
```

kAFL

syscall fuzzing

VS

kAFL

syscall fuzzing

VS

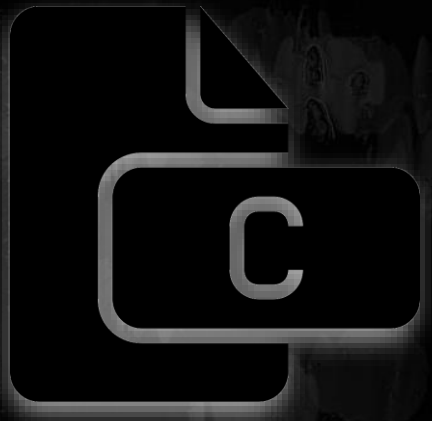
```
00000000  15 b7 2c 56 4f 3c 8f 74  9e d7 8a 10 ca 63 f7 81  |..,VO<.t.....c..|
00000010  c7 11 0b 11 cc 1e 81 15  4f e6 0f 06 b8 de 3a 52  |........O.....:R|
00000020  a2 0a 2e 00 75 9e d5 2e  51 70 9e 5e 13 ae c8 ba  |....u...Qp.^....|
00000030  d3 27 37 dc 14 d0 f3 e8  20 c0 e8 94 69 b2 33 4f  |.'7..... ...i.3O|
00000040  e7 4c dd 0b f3 4c f0 47  d3 09 c9 0b 95 83 37 70  |.L...L.G......7p|
00000050  bf 7a d0 2a 88 d0 2c ab  72 3a 95 56 86 69 88 55  |.z.*..,.r:.V.i.U|
```

kAFL


```
00000000  15 b7 2c 56 4f 3c 8f 74  9e d7 8a 10 ca 63 f7 81  |..,VO<.t.....c..|
00000010  c7 11 0b 11 cc 1e 81 15  4f e6 0f 06 b8 de 3a 52  |........O.....:R|
00000020  a2 0a 2e 00 75 9e d5 2e  51 70 9e 5e 13 ae c8 ba  |....u...Qp.^....|
00000030  d3 27 37 dc 14 d0 f3 e8  20 c0 e8 94 69 b2 33 4f  |.'7..... ...i.3O|
00000040  e7 4c dd 0b f3 4c f0 47  d3 09 c9 0b 95 83 37 70  |.L...L.G......7p|
00000050  bf 7a d0 2a 88 d0 2c ab  72 3a 95 56 86 69 88 55  |.z.*..,.r:.V.i.U|
```

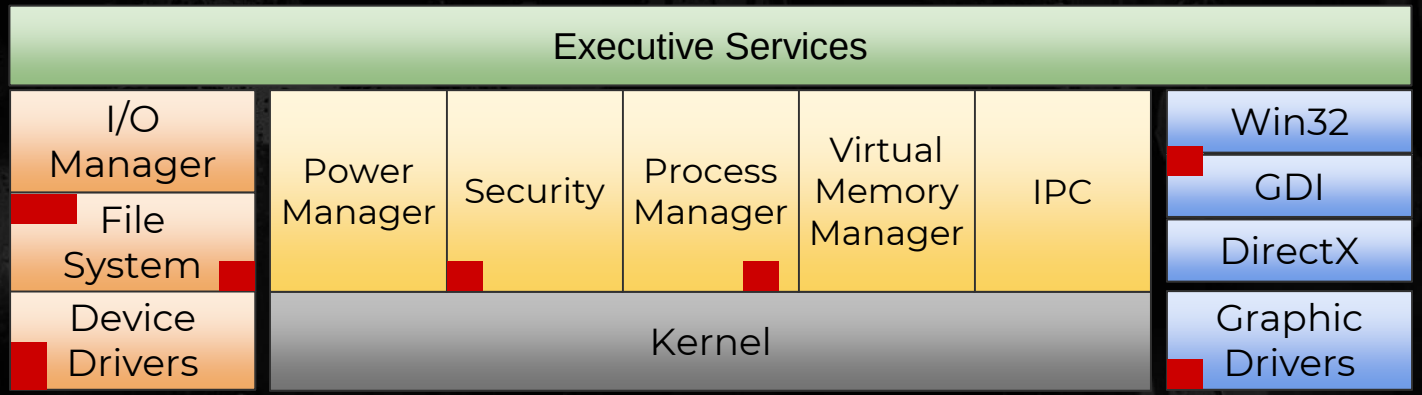
VS

syscall fuzzing



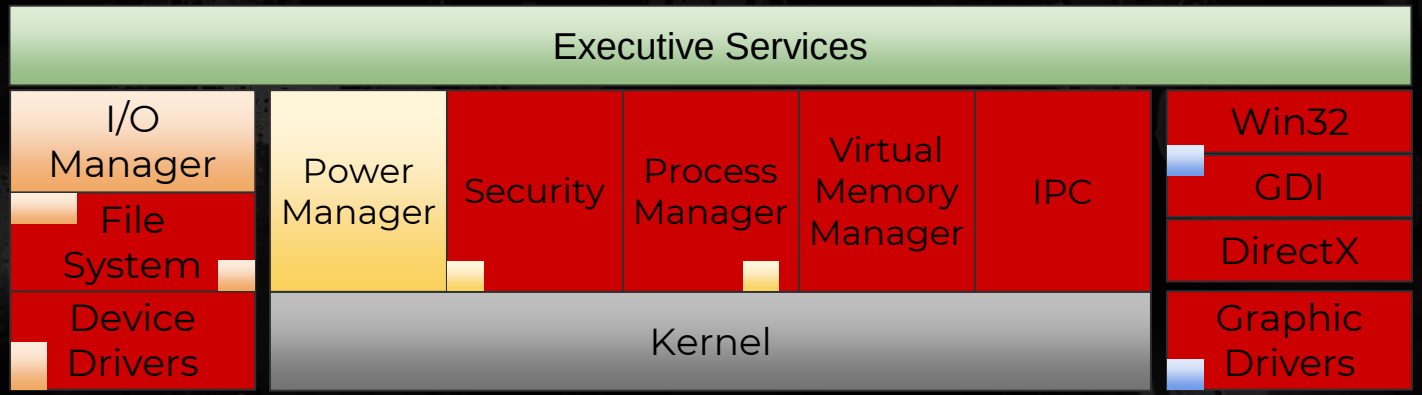

```
void main() {
        fd = open("/proc/self/mem");
        lseek(fd, 0x13337, SEEK_SET);
        read(fd, buffer, _SC_PAGE_SIZE);
        close(obj);
}
```

Kernel attack surface using kAFL

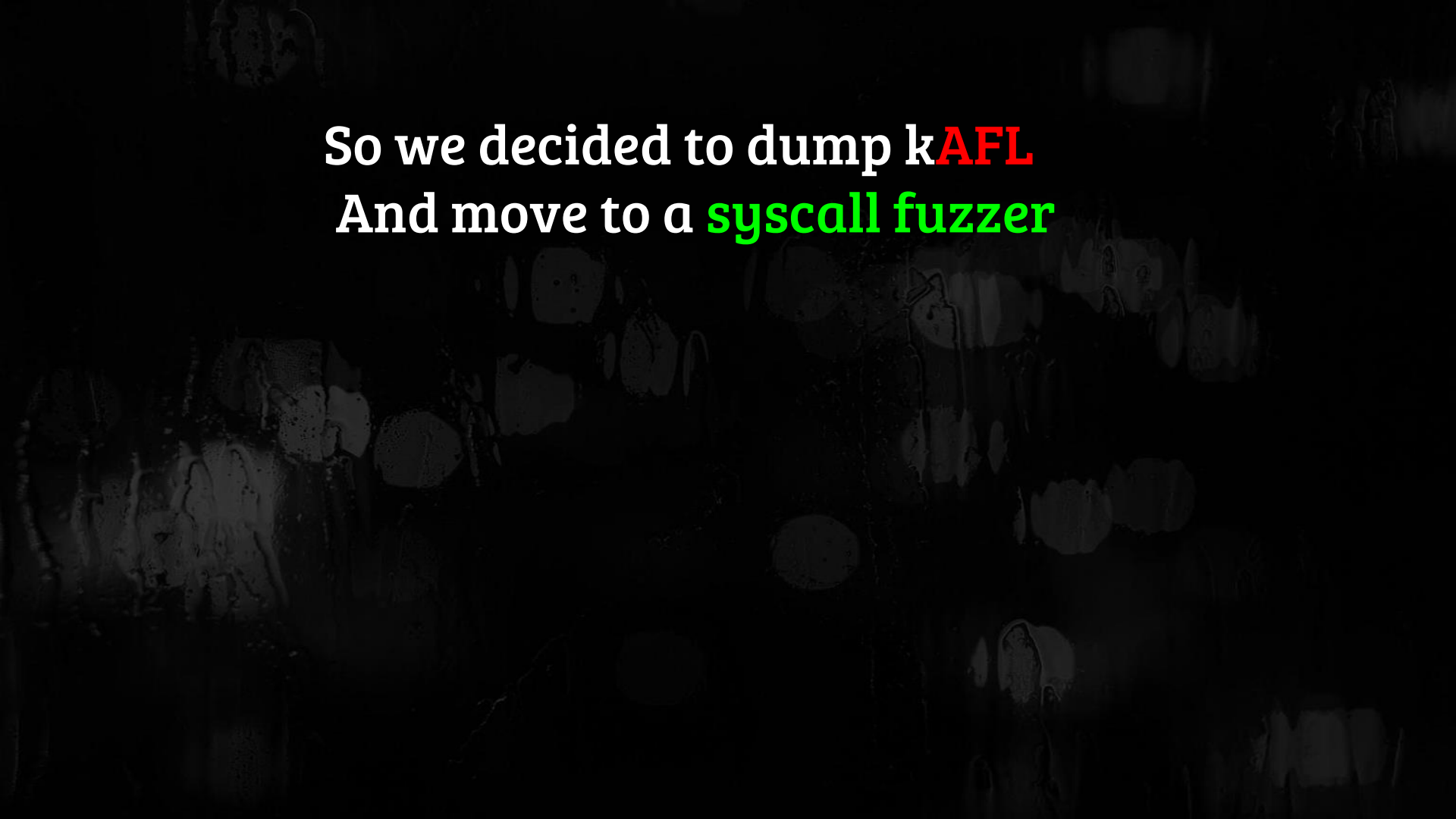


Kernel Mode

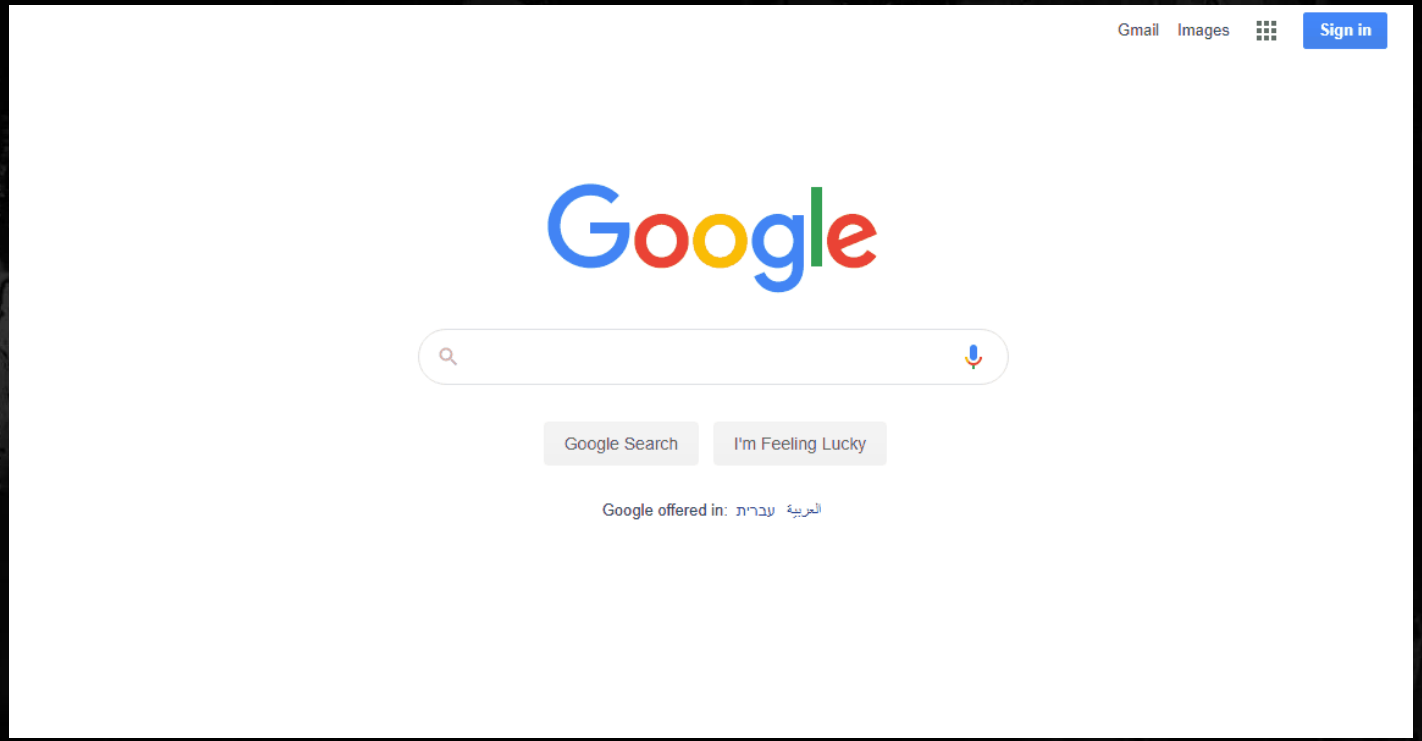
Kernel attack surface using syscall fuzzer



Kernel Mode


So we decided to dump kAFL
And move to a syscall fuzzer

So we decided to dump kAFL
And move to a syscall fuzzer



Syzkaller

Syzkaller

Coverage-guided structure-aware kernel fuzzer

Syzkaller

Coverage-guided structure-aware kernel fuzzer

- “AKA” Smart syscall fuzzer

Syzkaller

Coverage-guided structure-aware kernel fuzzer

- “AKA” Smart syscall fuzzer

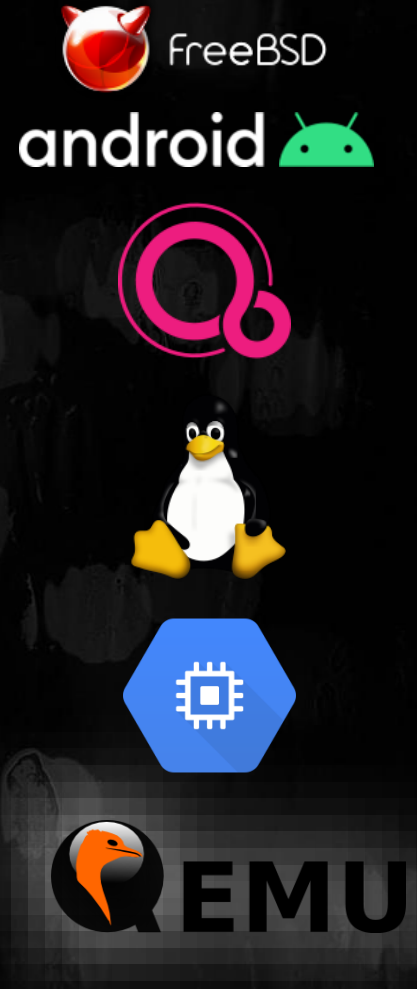
- OS (Linux, BSD, Fuchsia, ...)

Syzkaller

Coverage-guided structure-aware kernel fuzzer

- “AKA” Smart syscall fuzzer

- OS (Linux, BSD, Fuchsia, ...)
- Machines (QEMU, GCE, Mobile phones)

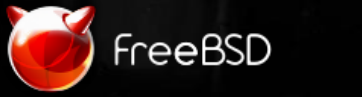


Syzkaller

Coverage-guided structure-aware kernel fuzzer

- “AKA” Smart syscall fuzzer

- OS (Linux, BSD, Fuchsia, ...)
- Machines (QEMU, GCE, Mobile phones)
- Architecture (x86-64, aarch64, ...)



Syzkaller

The hardest working researcher in the Linux Kernel community

Syzkaller

The hardest working researcher in the Linux Kernel community

Found more than 3700 bugs in the linux kernel (!)

Syzkaller

The hardest working researcher in the Linux Kernel community

Found more than 3700 bugs in the linux kernel (!)

CVE-2019-2215

fixed (39):

Title	Repro	Count	Last	Reported	Closed	Patch
BUG: bad unlock balance in ipmr_mfc_seq_stop	C	7493	692d	771d	692d	7d3d60ef ip6mr: fix stale iterator
general protection fault in skb_release_data		1	877d	877d	805d	304b4101 ipv6: fix out of bound writes in __ip6_append_data()
KASAN: slab-out-of-bounds Read in keychord_write	syz	2	899d	897d	892d	913d980e ANDROID: keychord: Fix a slab out-of-bounds read.
KASAN: use-after-free Read in __lock_acquire	C	1161	700d	770d	692d	550c01d0 UPSTREAM: ANDROID: binder: remove waitqueue when thread exits.
KASAN: use-after-free Read in bio_copy_user_iov	syz	73	859d	890d	805d	4099ac93 scsi: sg: protect accesses to 'reserved' page array
KASAN: use-after-free Read in fanout_demux_rollover	C	5	833d	854d	791d	6f7cdd4a packet: hold bind lock when rebinding to fanout hook
KASAN: use-after-free Read in parse_ipsecrequests	C	7	897d	897d	867d	3c17d418 UPSTREAM: af_key: Fix sadb_x_ipsecrequest parsing

Syzkaller

The hardest working researcher in the Linux Kernel community

Found more than 3700 bugs in the linux kernel (!)

CVE-2019-2215

fixed (39):

Title	Repro	Count	Last	Reported	Closed	Patch
BUG: bad unlock balance in ipmr_mfc_seq_stop	C	7493	692d	771d	692d	7d3d60ef ip6mr: fix stale iterator
general protection fault in skb_release_data		1	877d	877d	805d	304b4101 ipv6: fix out of bound writes in __ip6_append_data()
KASAN: slab-out-of-bounds Read in keychord_write	syz	2	899d	897d	892d	913d980e ANDROID: keychord: Fix a slab out-of-bounds read.
KASAN: use-after-free Read in __lock_acquire	C	1161	700d	770d	692d	550c01d0 UPSTREAM: ANDROID: binder: remove waitqueue when thread exits.
KASAN: use-after-free Read in bio_copy_user_iov	syz	73	859d	890d	805d	4099ac93 scsi: sg: protect accesses to 'reserved' page array
KASAN: use-after-free Read in fanout_demux_rollover	C	5	833d	854d	791d	6f7cdd4a packet: hold bind lock when rebinding to fanout hook
KASAN: use-after-free Read in parse_ipsecrequests	C	7	897d	897d	867d	3c17d418 UPSTREAM: af_key: Fix sadb_x_ipsecrequest parsing

Test case generator/mutator

Feedback mechanism

Bug oracle

Test case generator/mutator

Feedback mechanism

Bug oracle

Syzkaller Generated Program

```
r0 = open(&(0x7f0000000000)=”./file0”, 0x3, 0x9)
```

Syzkaller Generated Program

```
r0 = open(&(0x7f0000000000)=”./file0”, 0x3, 0x9)
```

Syzkaller Generated Program

```
r0 = open(&(0x7f0000000000)=”./file0”, 0x3, 0x9)
read(r0, &(0x7f0000000010), 57)
close(r0)
```

Syscall Descriptions

```
exit(error_code int32)


close(fd fd)

resource fd[int32]

open(file filename, flags flags[open_flags], mode flags[open_mode]) fd

open_mode = S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH
```

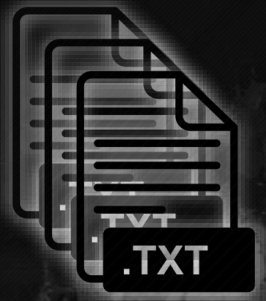
Syscall Descriptions

```
exit(error_code int32)


close(fd fd)

resource fd[int32]

open(file filename, flags flags[open_flags], mode flags[open_mode]) fd

open_mode = S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH
```

Syscall Descriptions

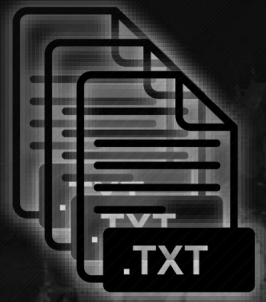
```
exit(error_code int32)


close(fd fd)

resource fd[int32]

open(file filename, flags flags[open_flags], mode flags[open_mode]) fd

open_mode = S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH

read(fd fd, buf buffer[out], count len[buf])
```

Generation



Generation

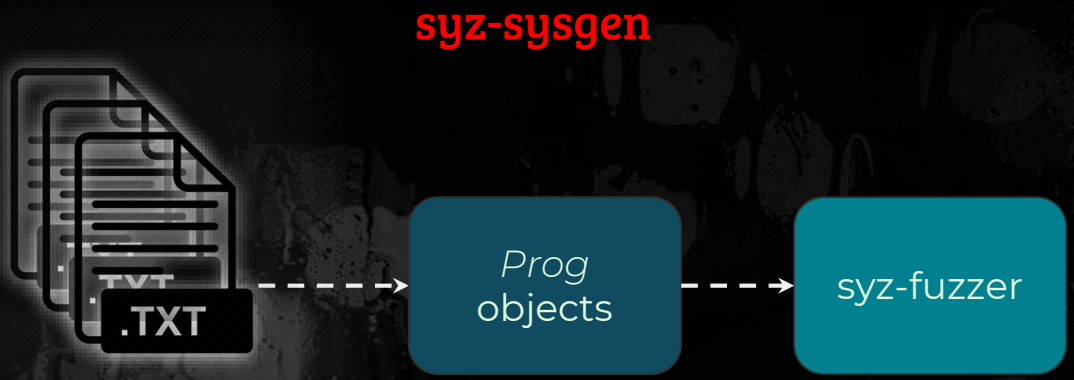
syz-sysgen



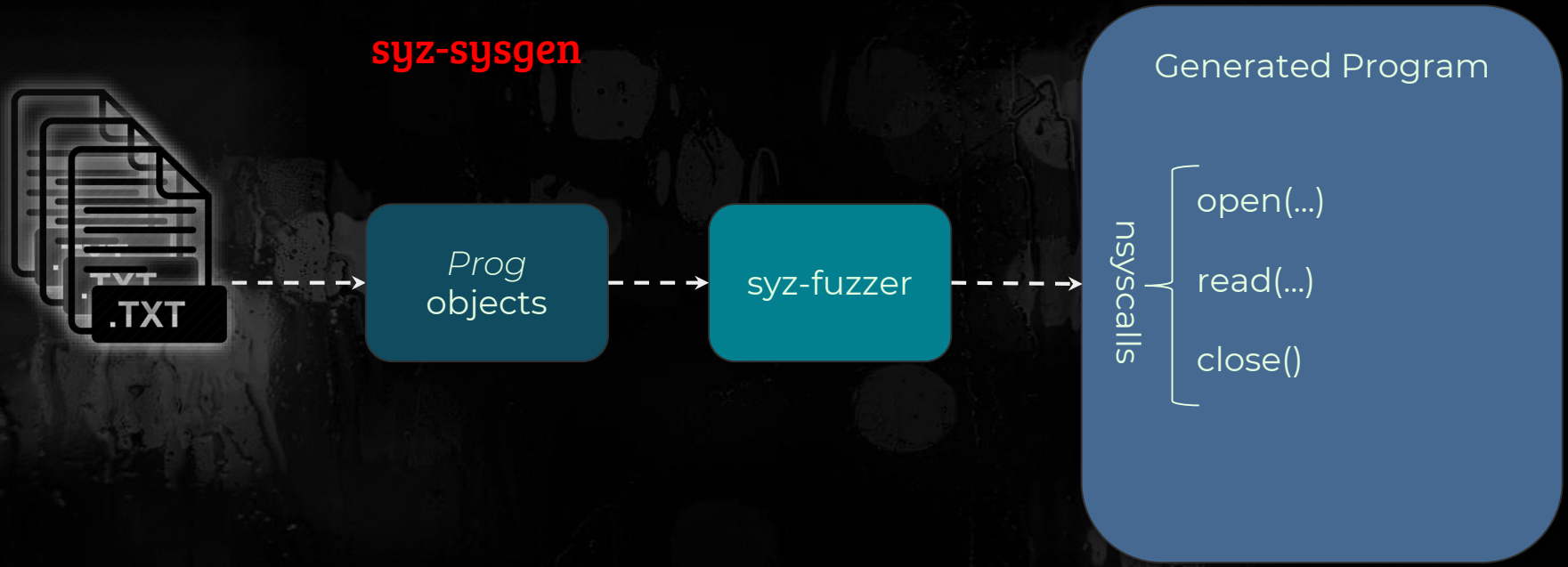
Generation

syz-sysgen

Generation



Generation


syz-sysgen
.TXT
Prog
objects
syz-fuzzer
Generated Program
nsyscalls
open(...)
read(...)
close()

Mutations - insertCall

```
r0 = open(&(0x7f0000000000)=”./file0”, 0x3, 0x9)
write(r0, &(0x7f0000000000)=”41414141”, 4)
close(r0)
```

Mutations - insertCall

```
r0 = open(&(0x7f0000000000)=”./file0”, 0x3, 0x9)
write(r0, &(0x7f0000000000)=”41414141”, 4)
close(r0)
write(r0, &(0x7f0000000000)=”61”, 1)
```

Mutations - mutateArg

```
r0 = open(&(0x7f0000000000)=”./file0”, 0x3, 0x9)
write(r0, &(0x7f0000000010)=”41414141”, 4)
close(r0)
```

Mutations - mutateArg

```
r0 = open(&(0x7f0000000000)=”./RaNdFilEnAmE”, 0x3, 0x9)
write(r0, &(0x7f0000000010)=”41414141”, 4)
close(r0)
```

Mutations - splice

```
r0 = open(&(0x7f0000000000)=”./file0”, 0x3, 0x9)
write(r0, &(0x7f0000000010)=”41414141”, 4)
close(r0)
```

Mutations - splice

```
r0 = open(&(0x7f0000000000)=”./file0”, 0x3, 0x9)
r1 = open(&(0x7f0000000020)=”./file1”, 0x3, 0x9)
write(r0, &(0x7f0000000010)=”41414141”, 4)
close(r0)
```

Mutations - squashAny

```
r0 = open(&(0x7f0000000000)=”./file0”, 0x3, 0x9)
write(r0, &(0x7f0000000010)=”41414141”, 4)
close(r0)
```

Mutations - squashAny

```
r0 = open(&(0x7f0000000000)="./file0", 0x3, 0x9)
write(r0, &(0x7f0000000010)="41413030 4141", 6)
close(r0)
```

Test case generator/mutator

Feedback mechanism

Bug oracle

Test case generator/mutator

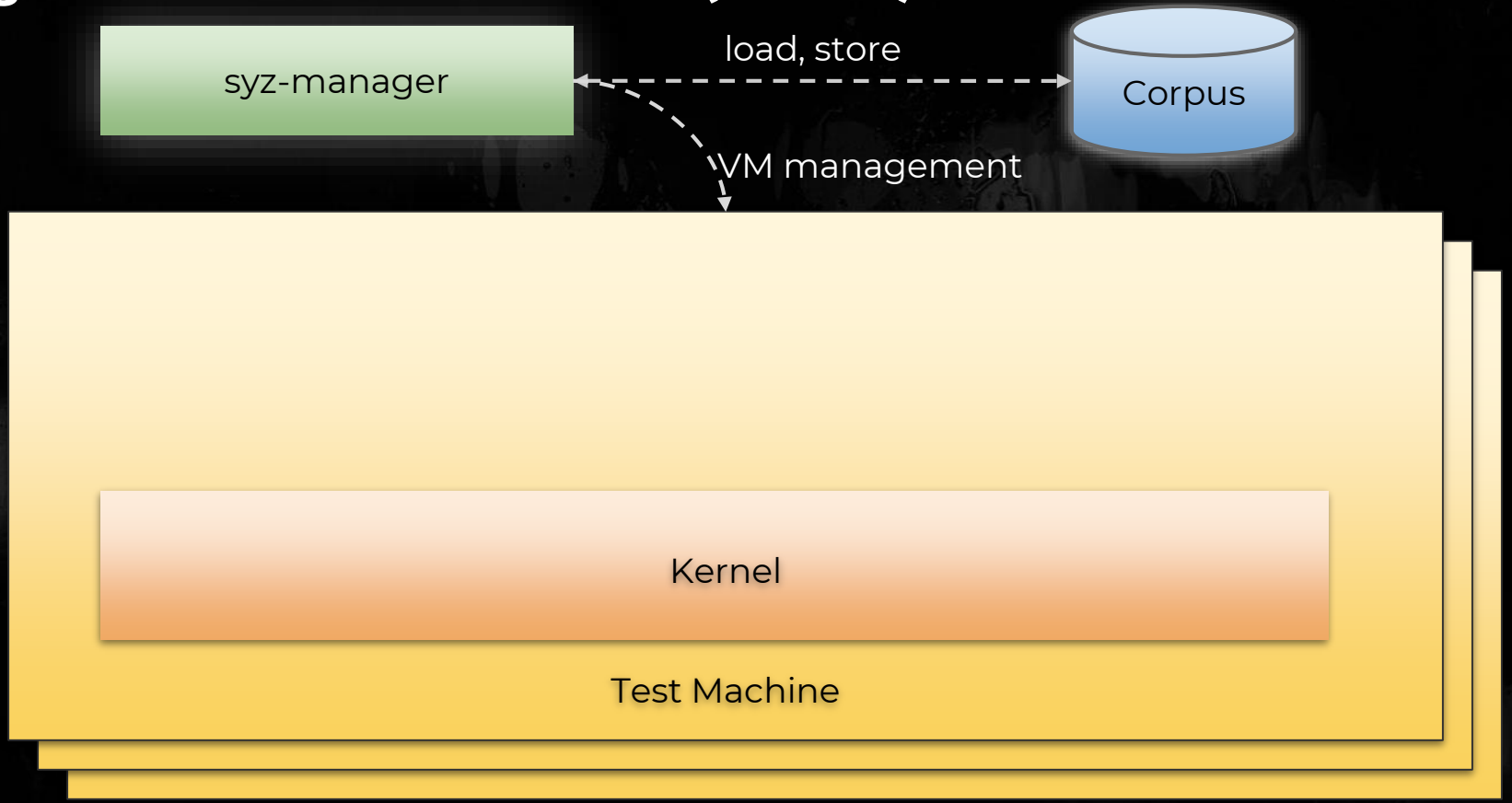
Feedback mechanism

Bug oracle

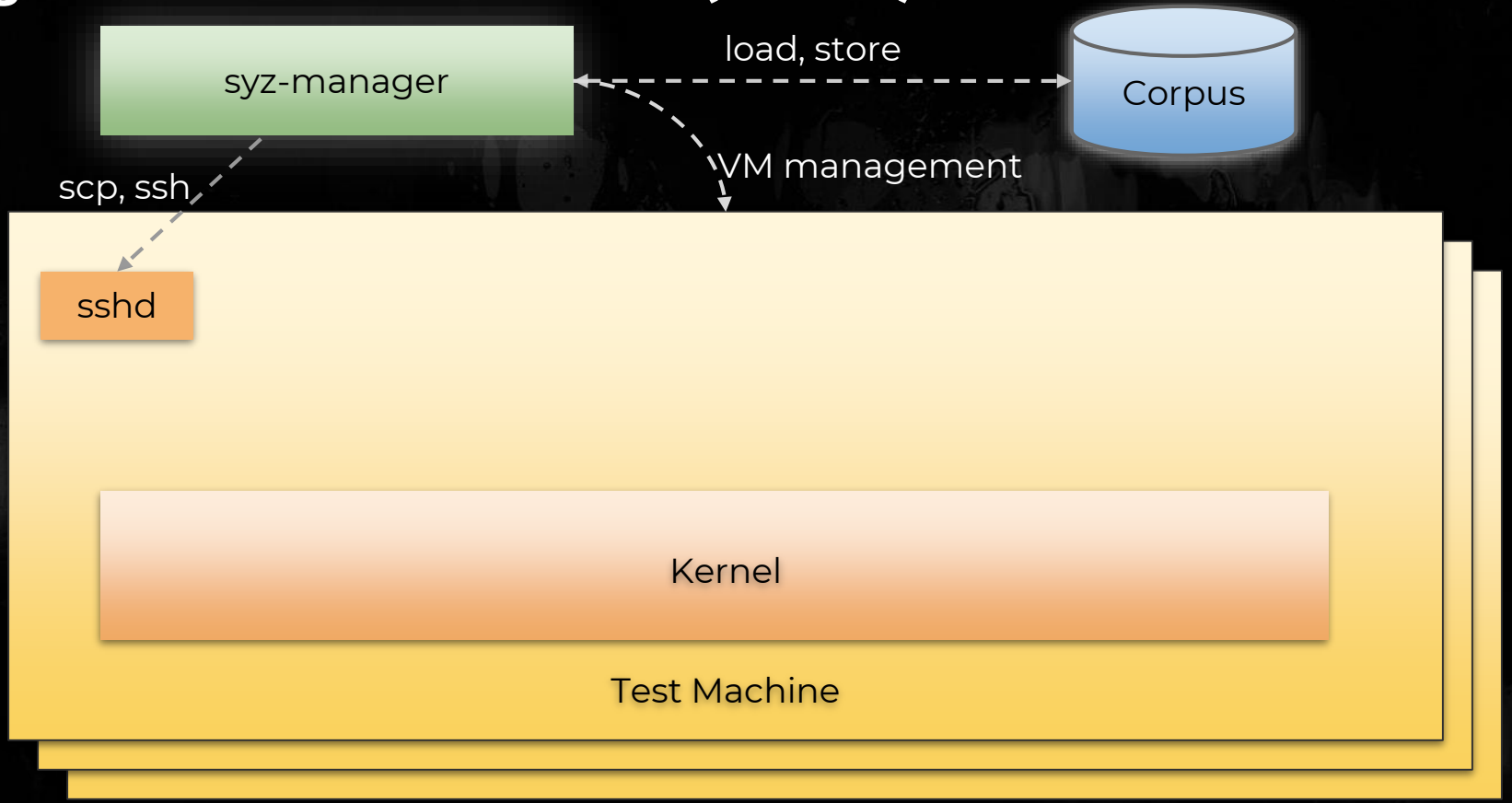
Syzkaller - Architecture (Linux)

Syzkaller - Architecture (Linux)

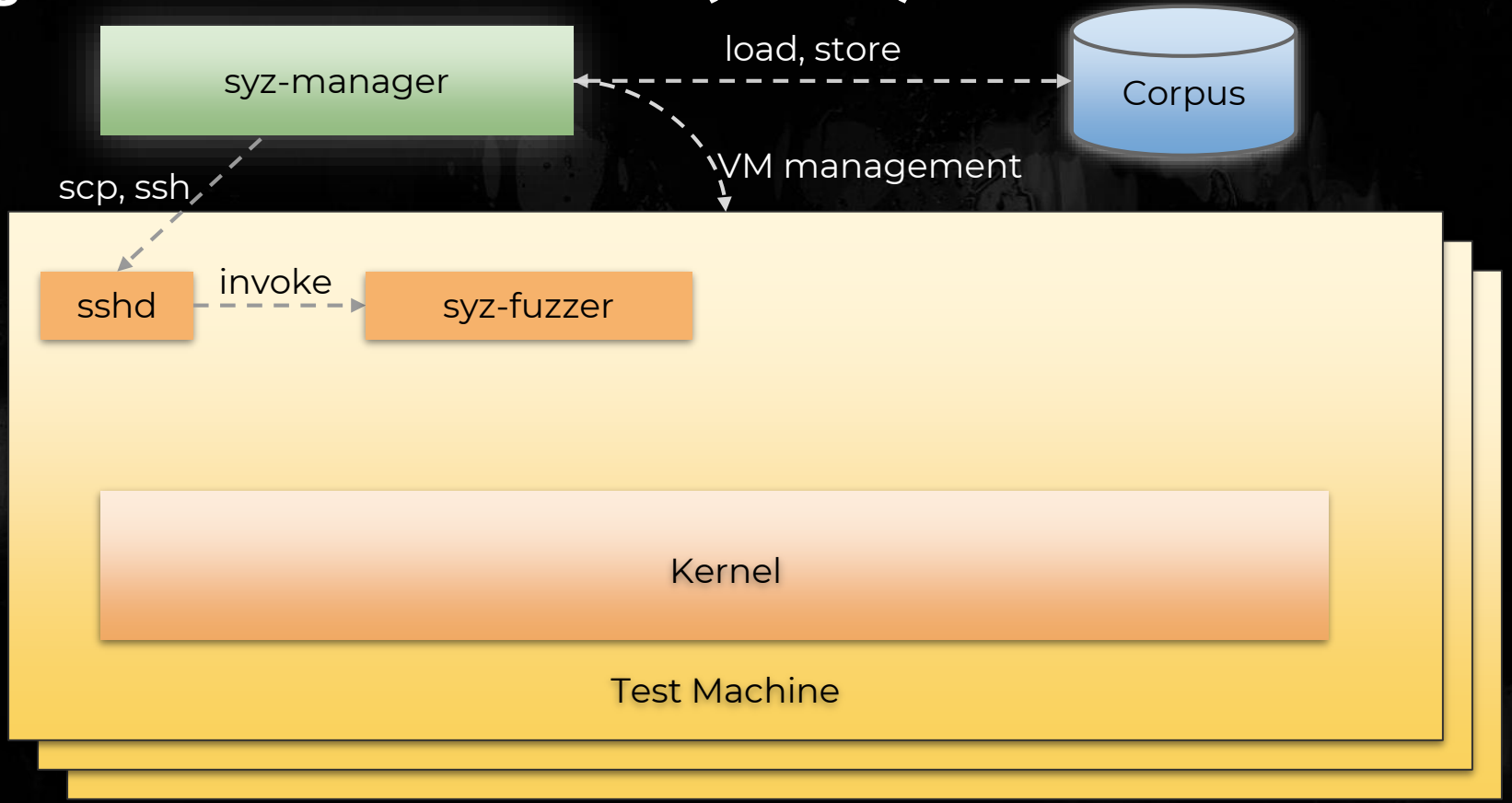
Syzkaller - Architecture (Linux)



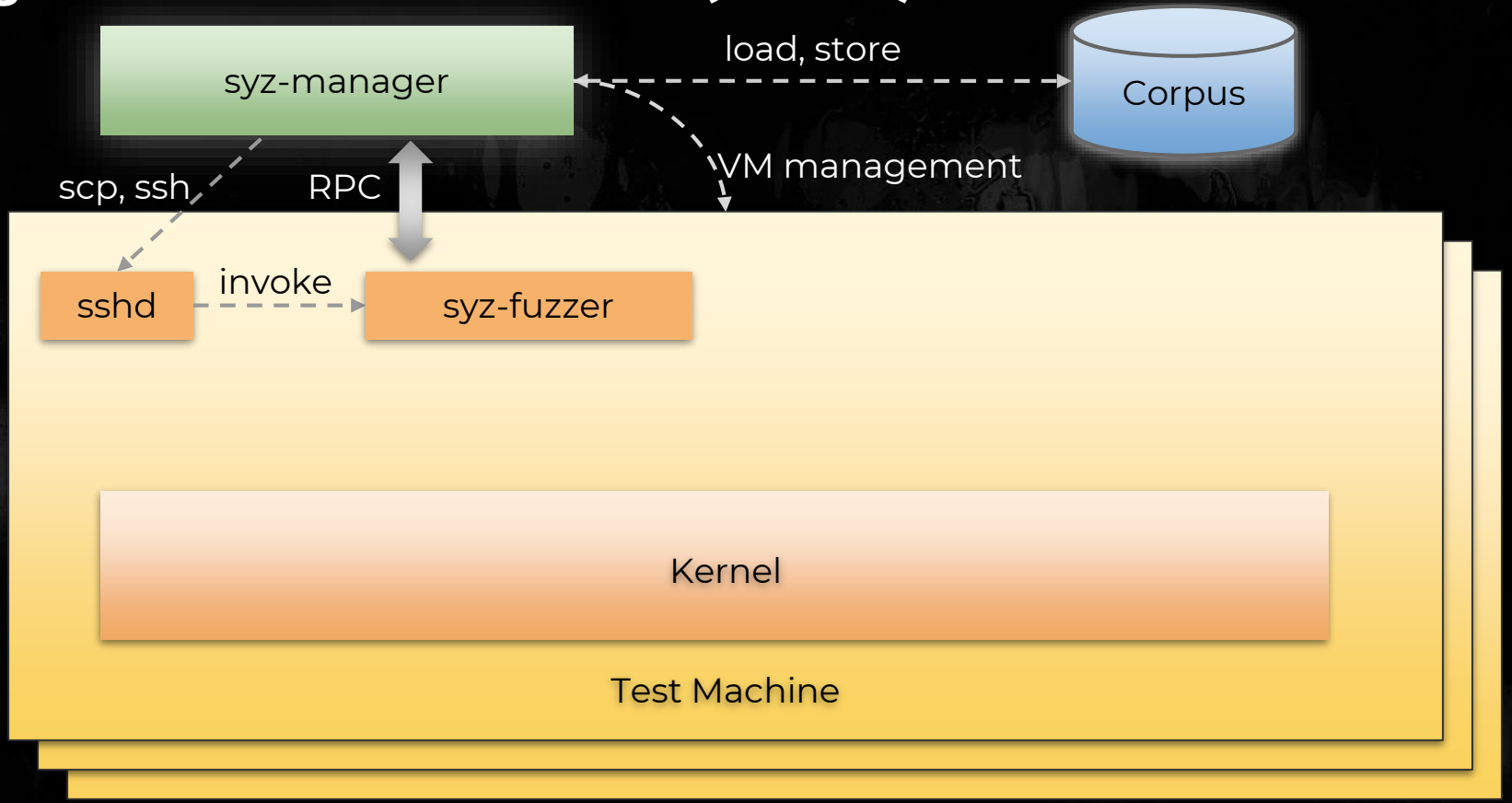
Syzkaller - Architecture (Linux)



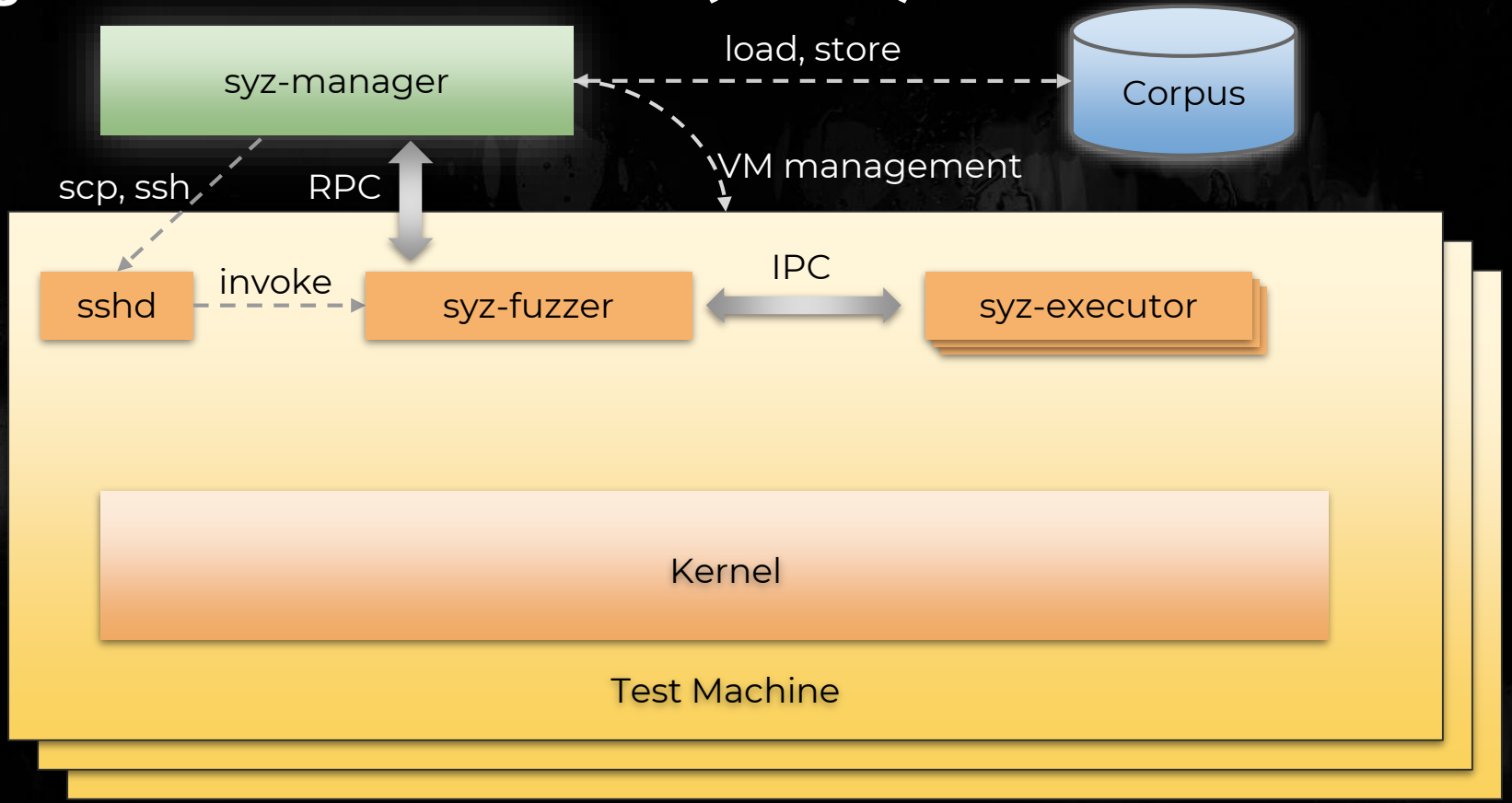
Syzkaller - Architecture (Linux)



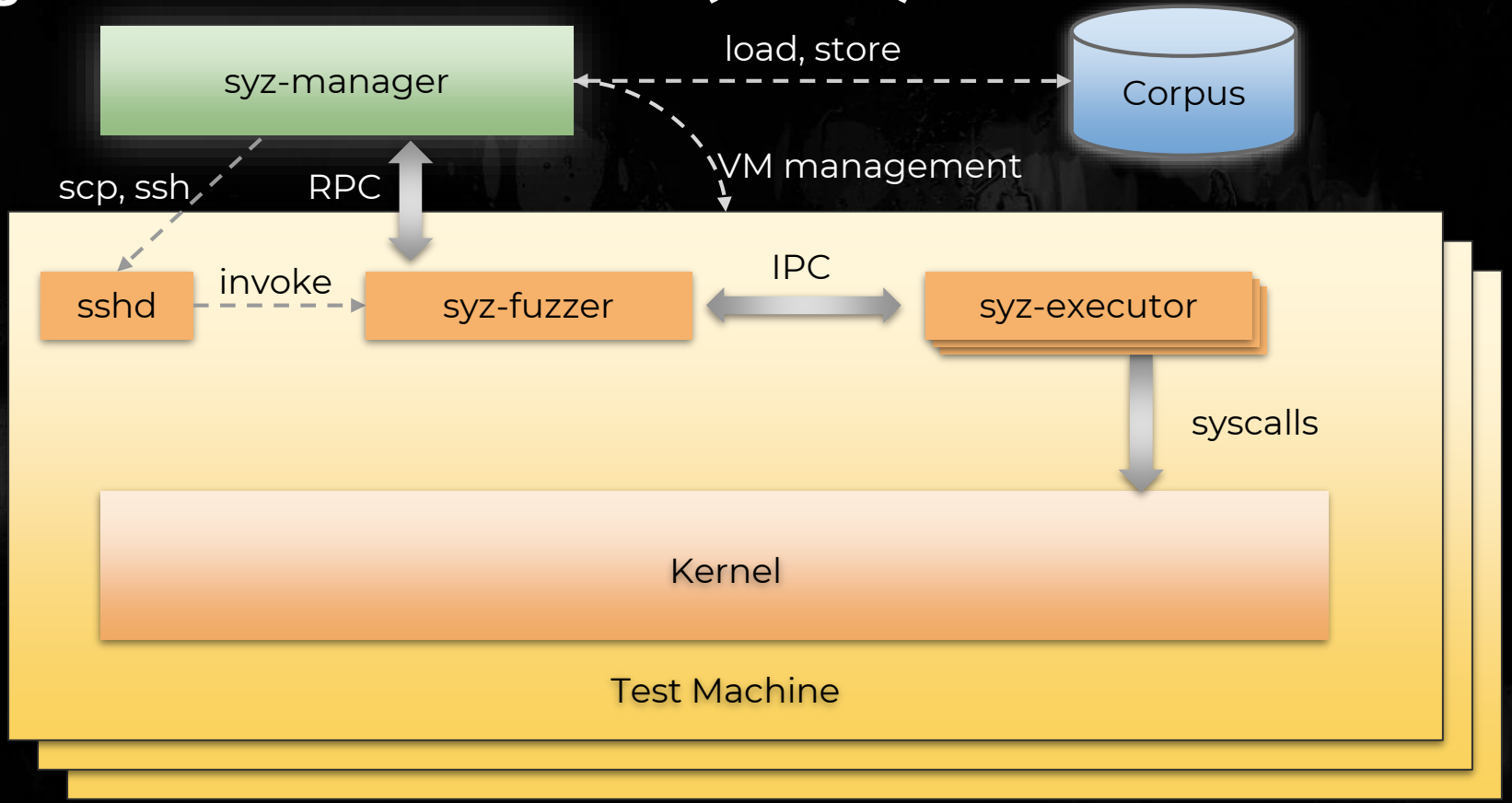
Syzkaller - Architecture (Linux)



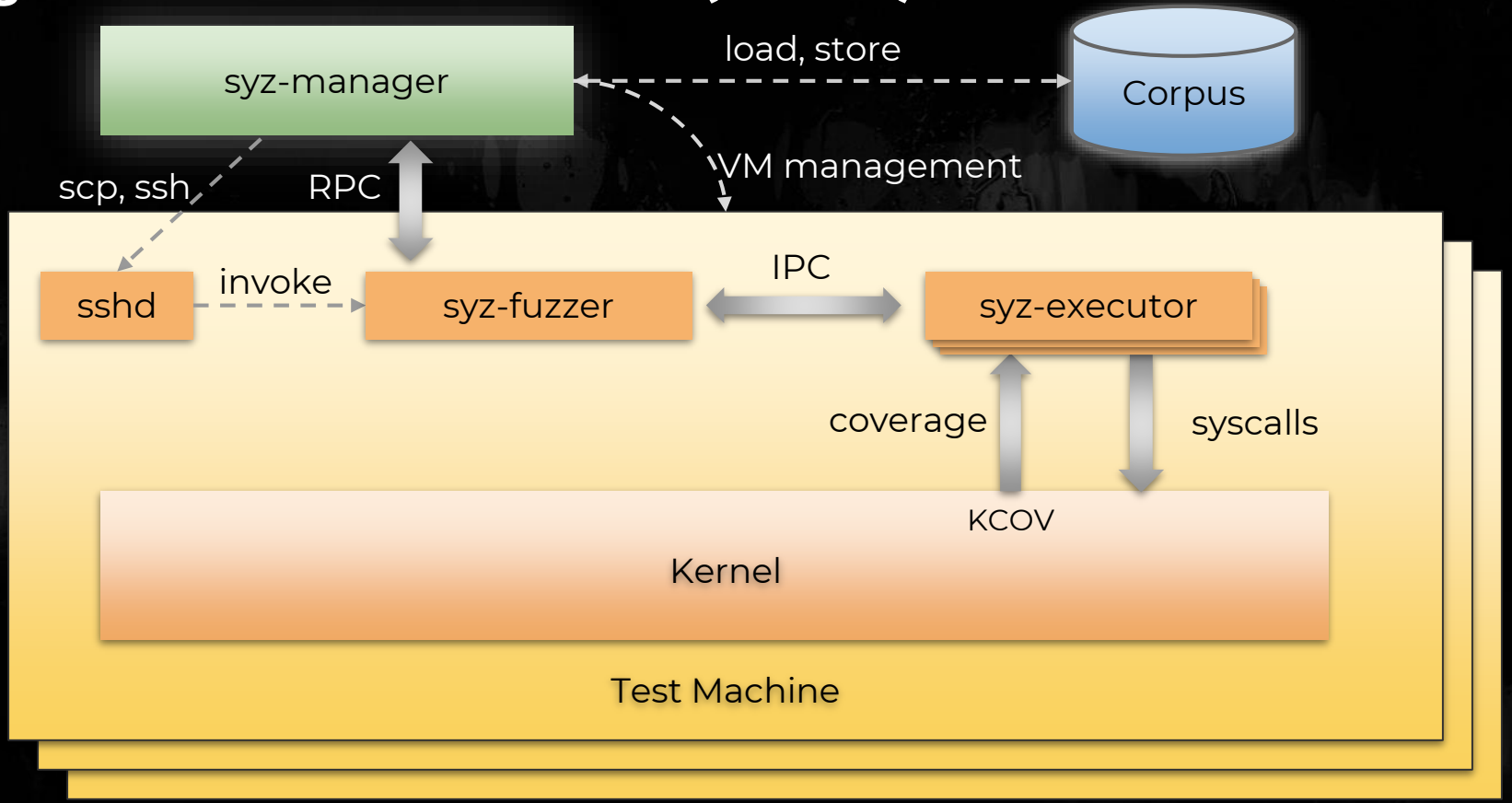
Syzkaller - Architecture (Linux)



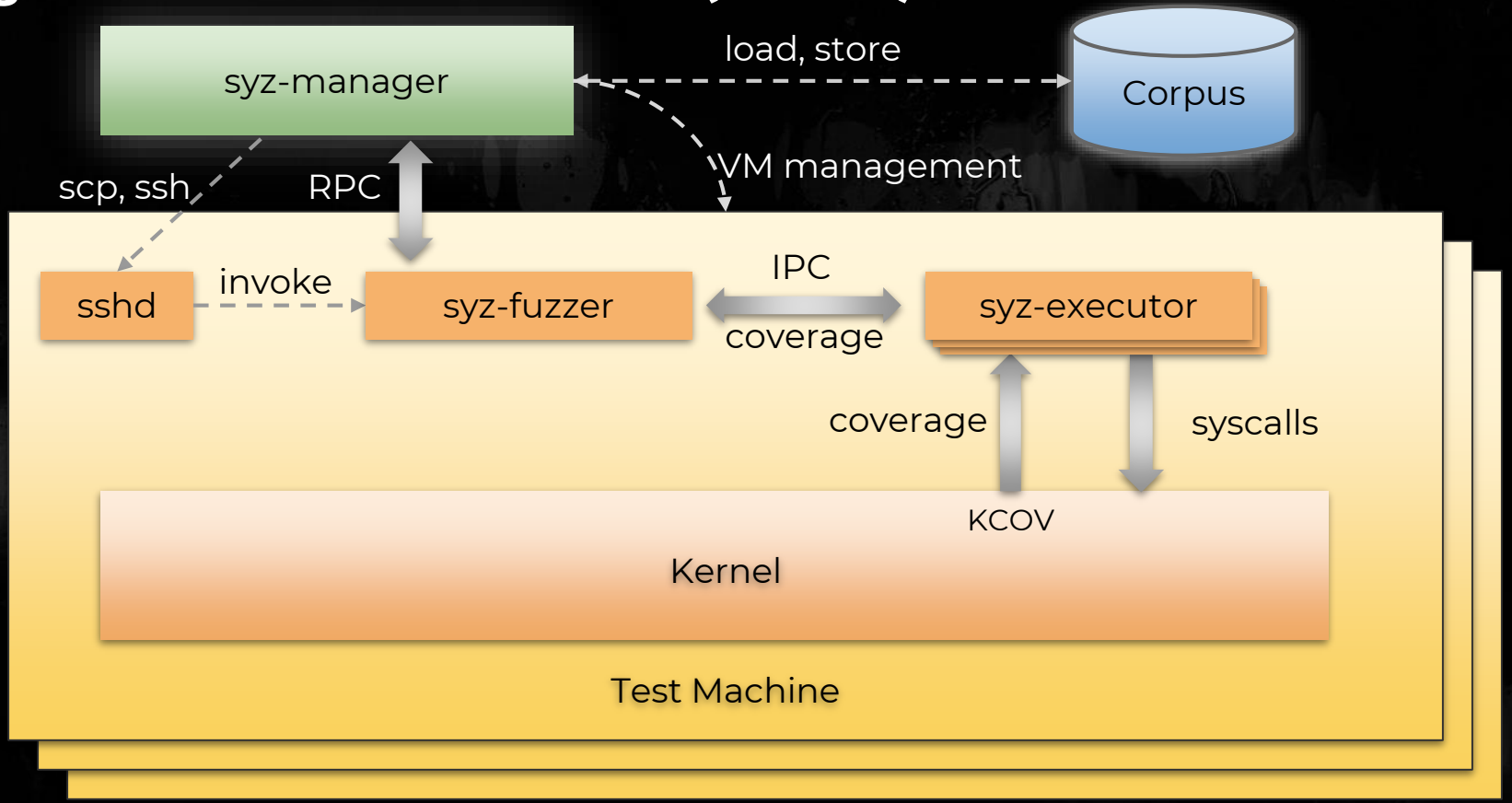
Syzkaller - Architecture (Linux)



Syzkaller - Architecture (Linux)



Syzkaller - Architecture (Linux)



Test case generator/mutator

Feedback mechanism

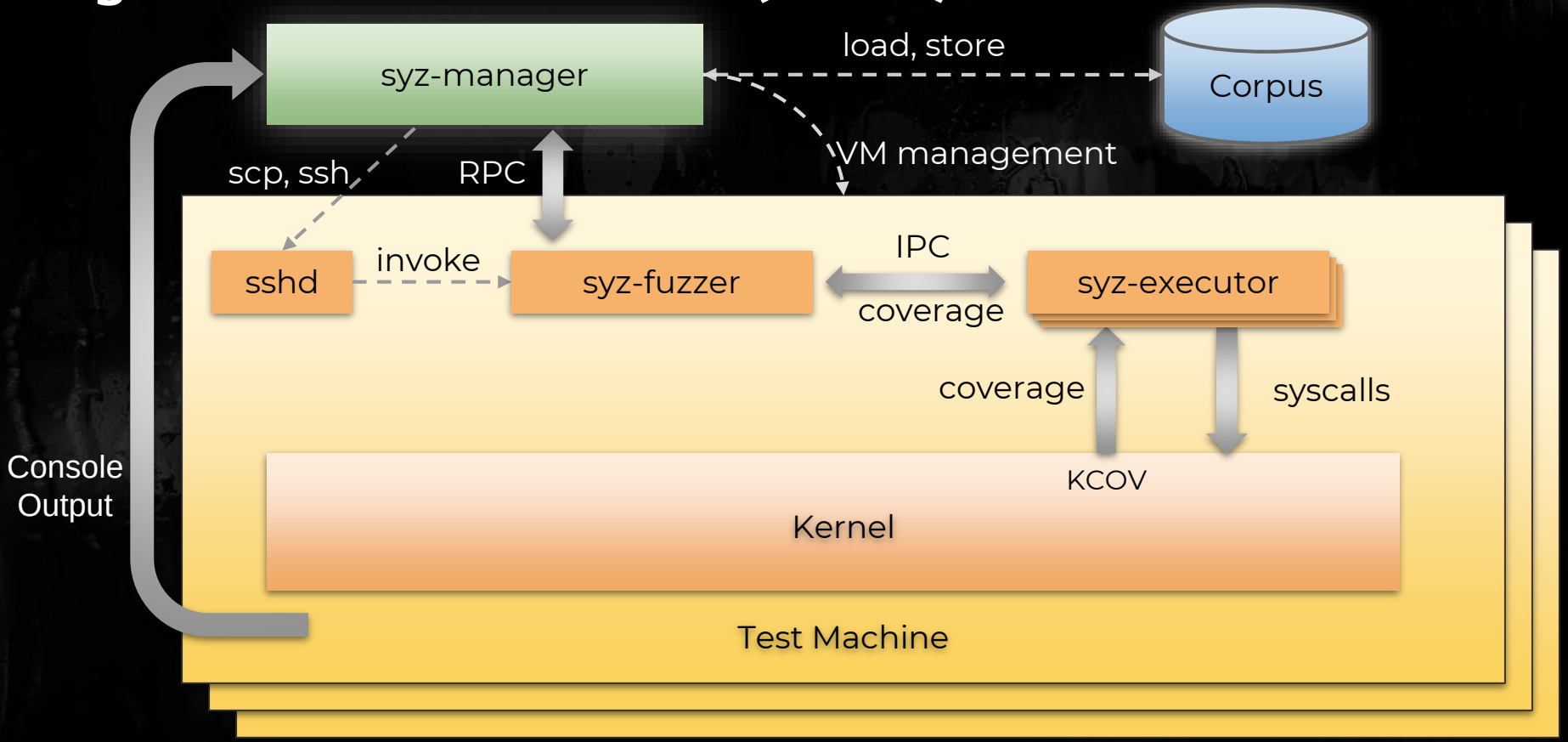
Bug oracle

Test case generator/mutator

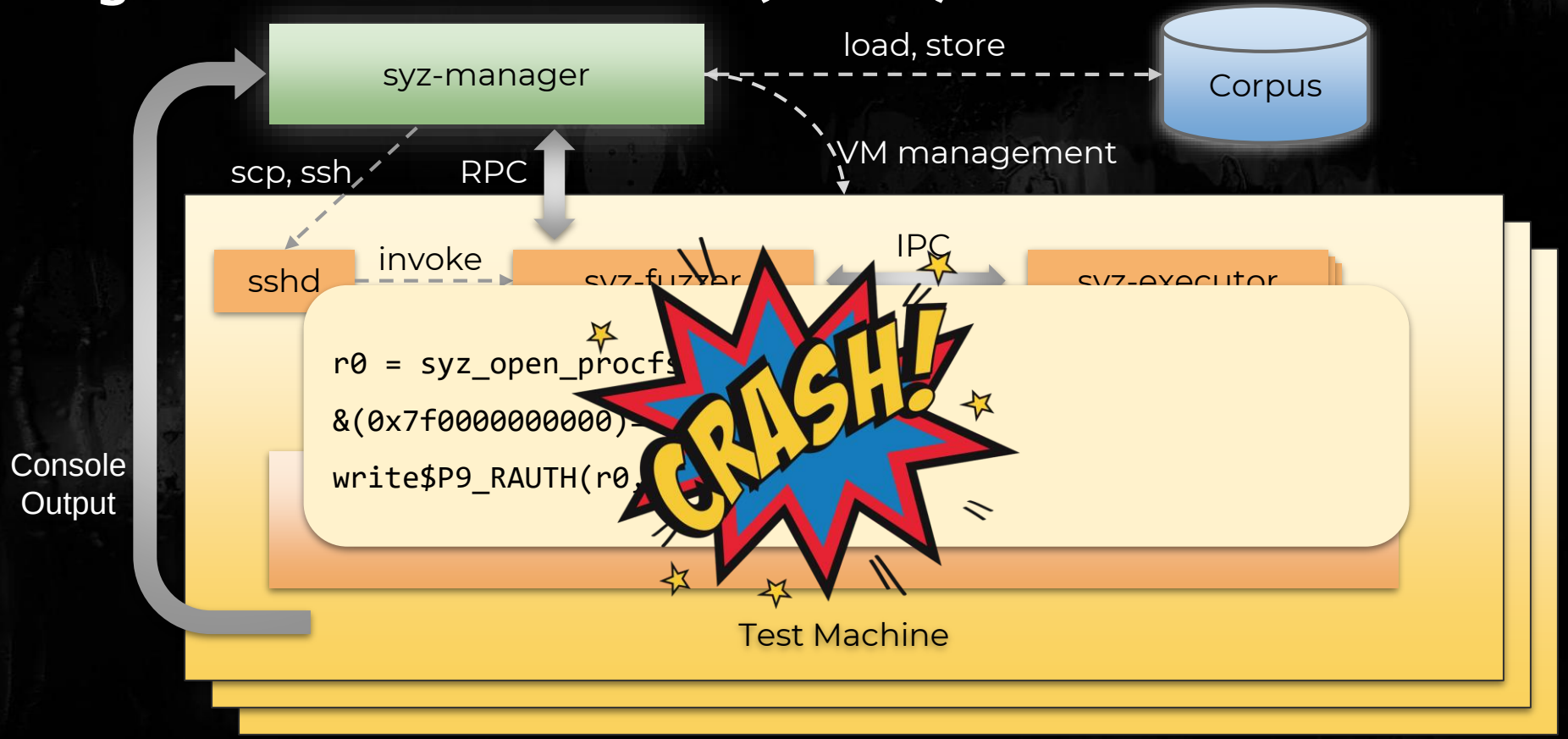
Feedback mechanism

Bug oracle

Syzkaller - Architecture (Linux)



Syzkaller - Architecture (Linux)



Test case generator/mutator

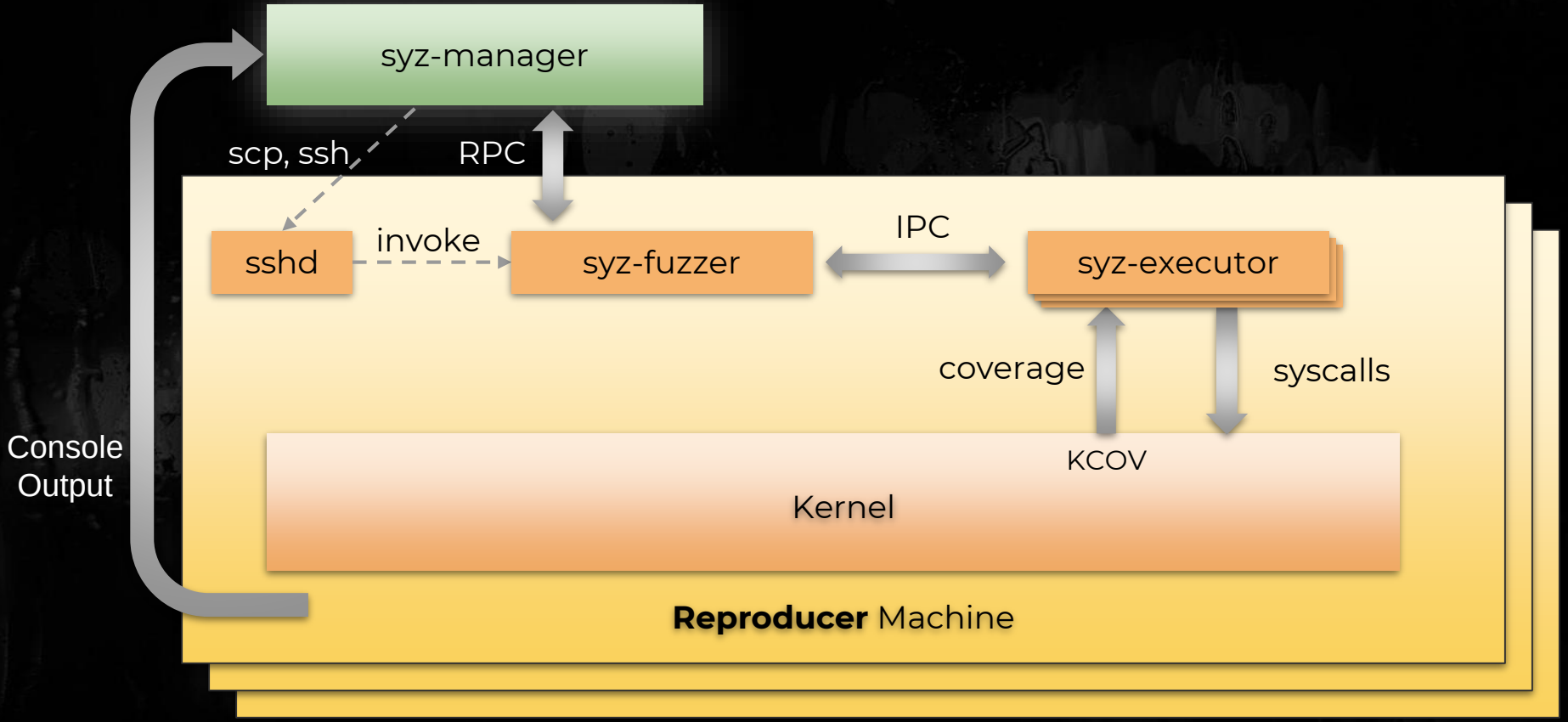
Feedback mechanism

Bug oracle

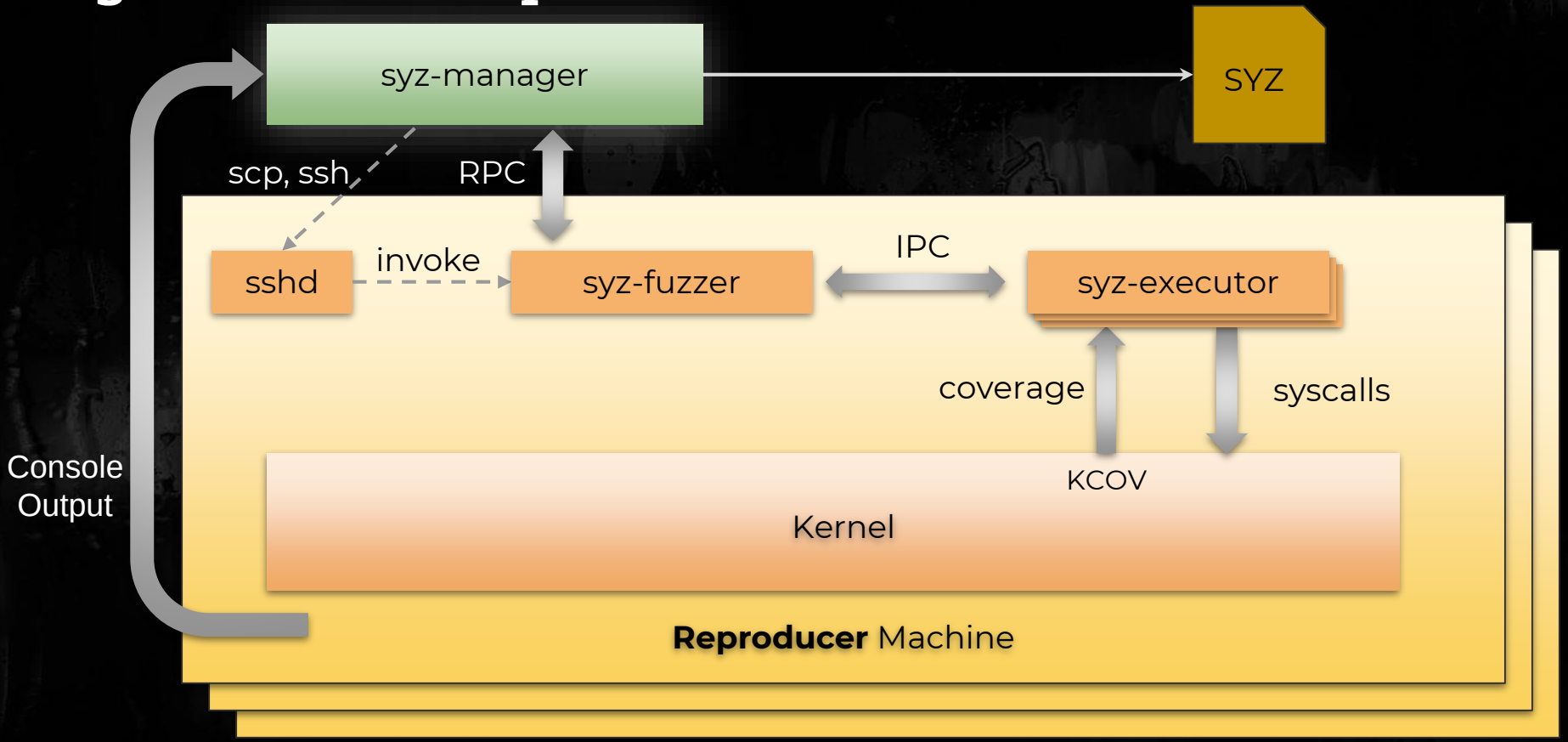
Syzkaller - Unsupervised

syz-manager

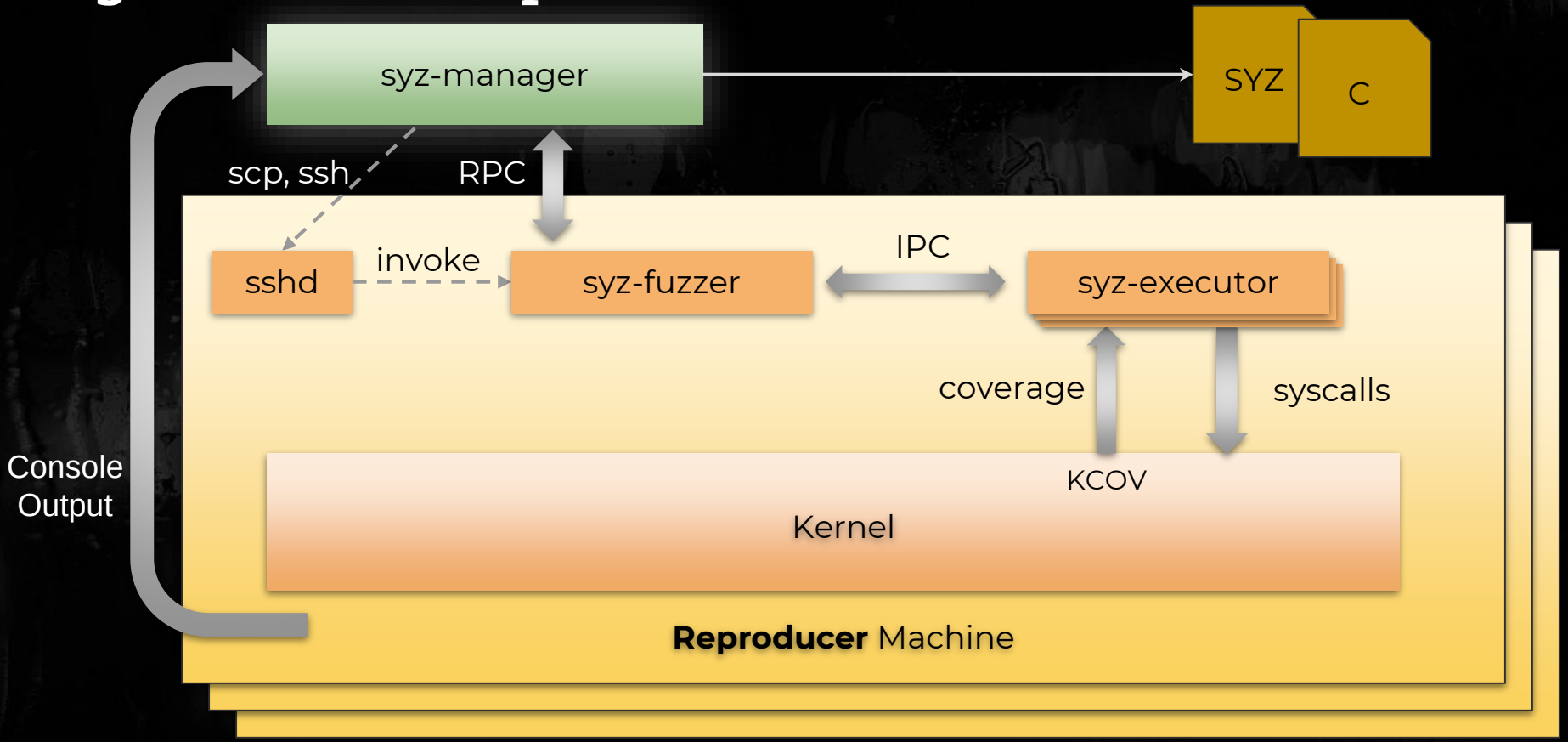
Syzkaller - Unsupervised



Syzkaller - Unsupervised



Syzkaller - Unsupervised



Syzkaller is awesome!


But...


But...
Syzkaller is for Linux

Dmitry Vyukov
(syzkaller's father)

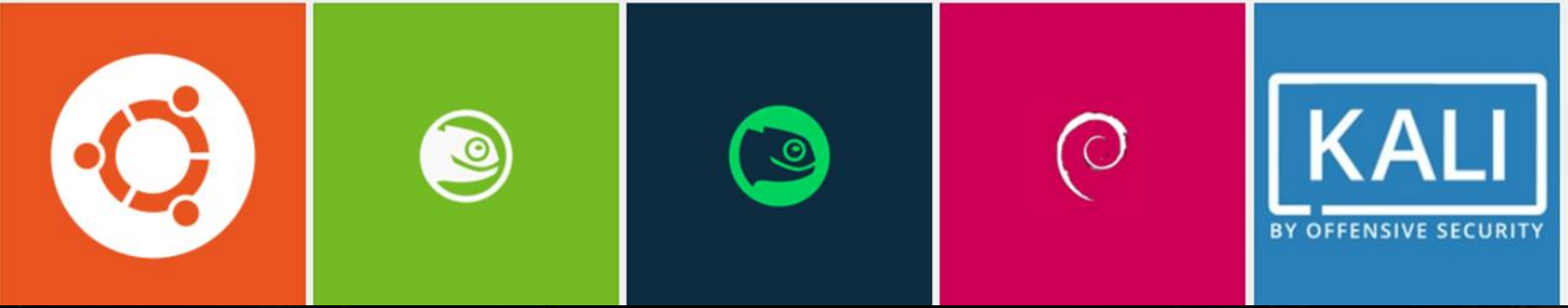
But...
Syzkaller is for Linux

Dmitry Vyukov
(syzkaller's father)

But...
Syzkaller is for Linux
also

Run Linux on Windows

Install and run Linux distributions side-by-side on the Windows Subsystem for Linux (WSL).



WSL - Windows Subsystem for Linux

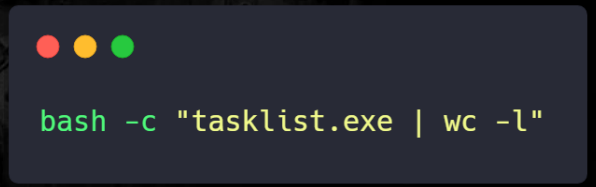
WSL is a compatibility layer for running Linux binaries natively on Windows

Allows to interop linux & windows binaries:

WSL - Windows Subsystem for Linux

WSL is a compatibility layer for running Linux binaries natively on Windows

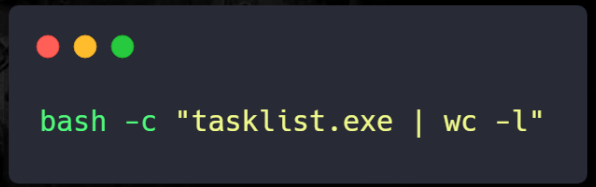
Allows to interop linux & windows binaries:



WSL - Windows Subsystem for Linux

WSL is a compatibility layer for running Linux binaries natively on Windows

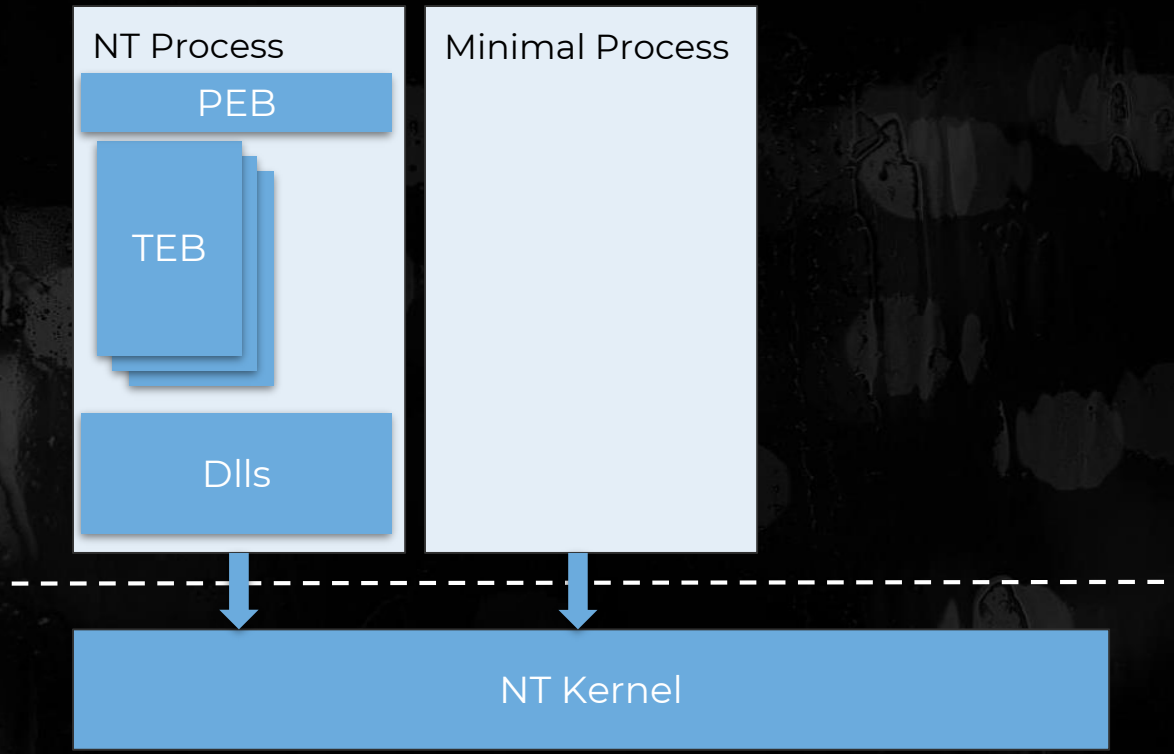
Allows to interop linux & windows binaries:



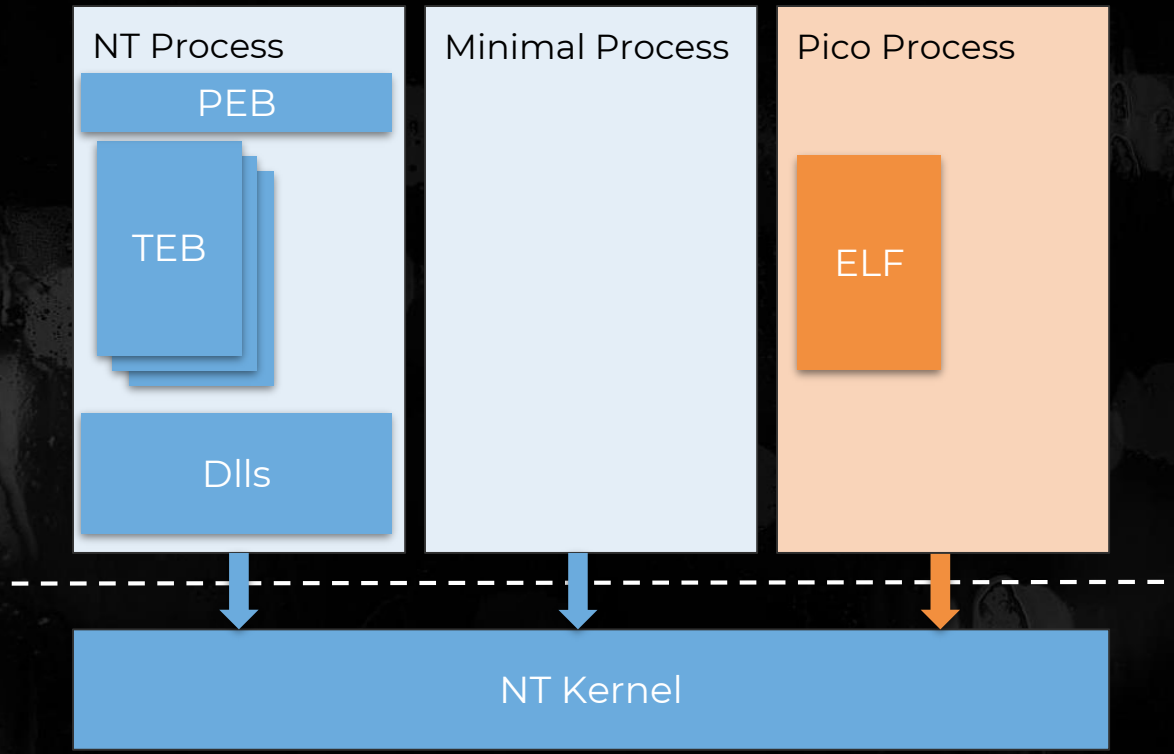
Require less resources than running a Virtual Machine

Aimed for running bash and core Linux commands

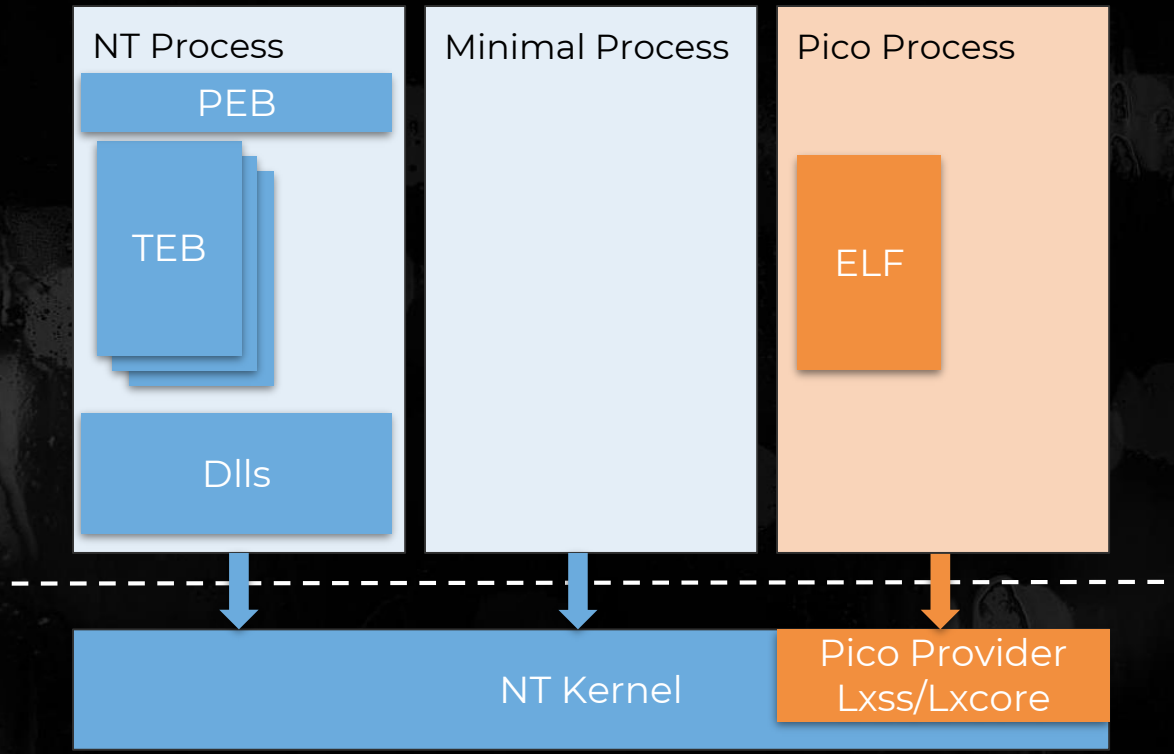
WSL - Bird's eye view



WSL - Bird's eye view



WSL - Bird's eye view



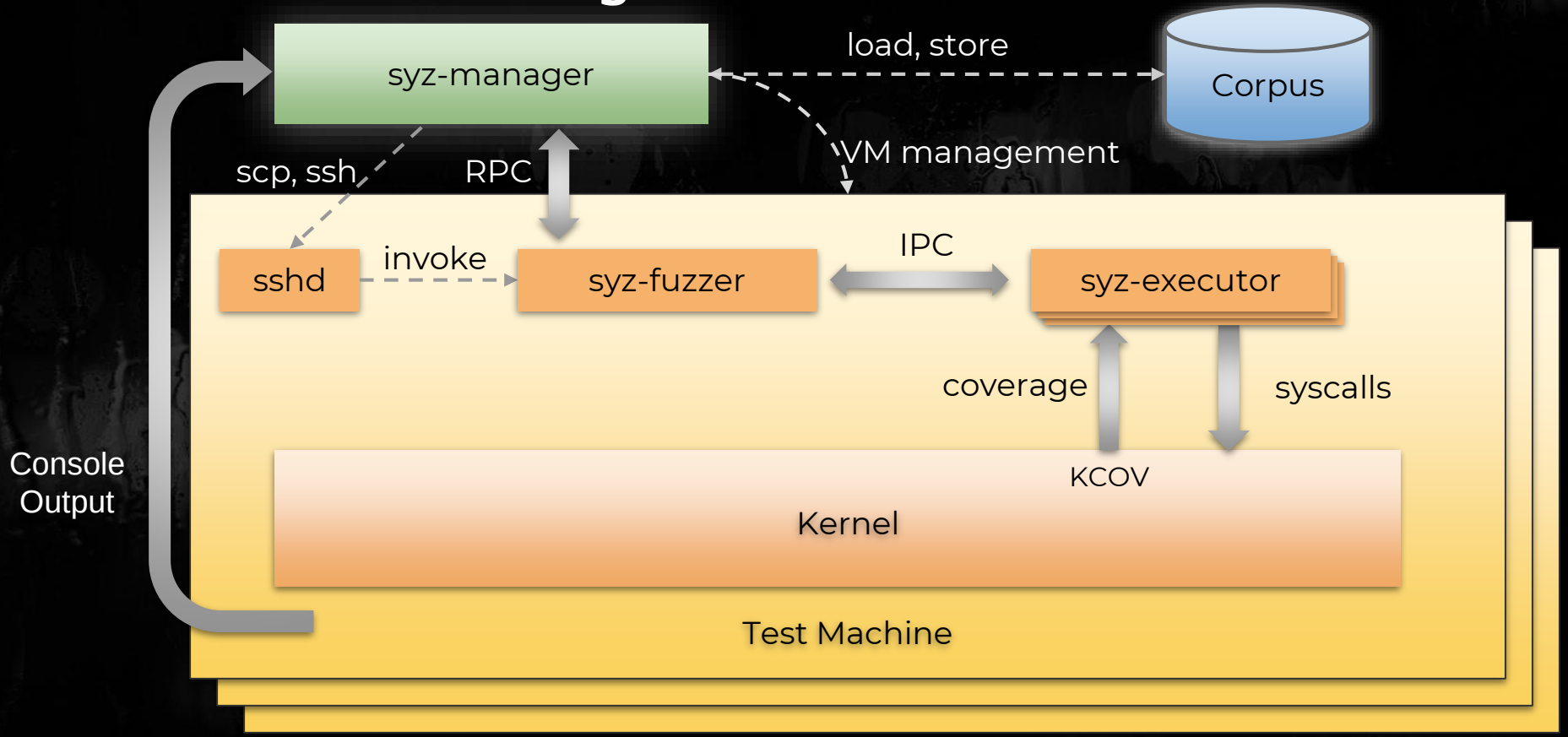
Why WSL?

Similar to fuzzing Linux

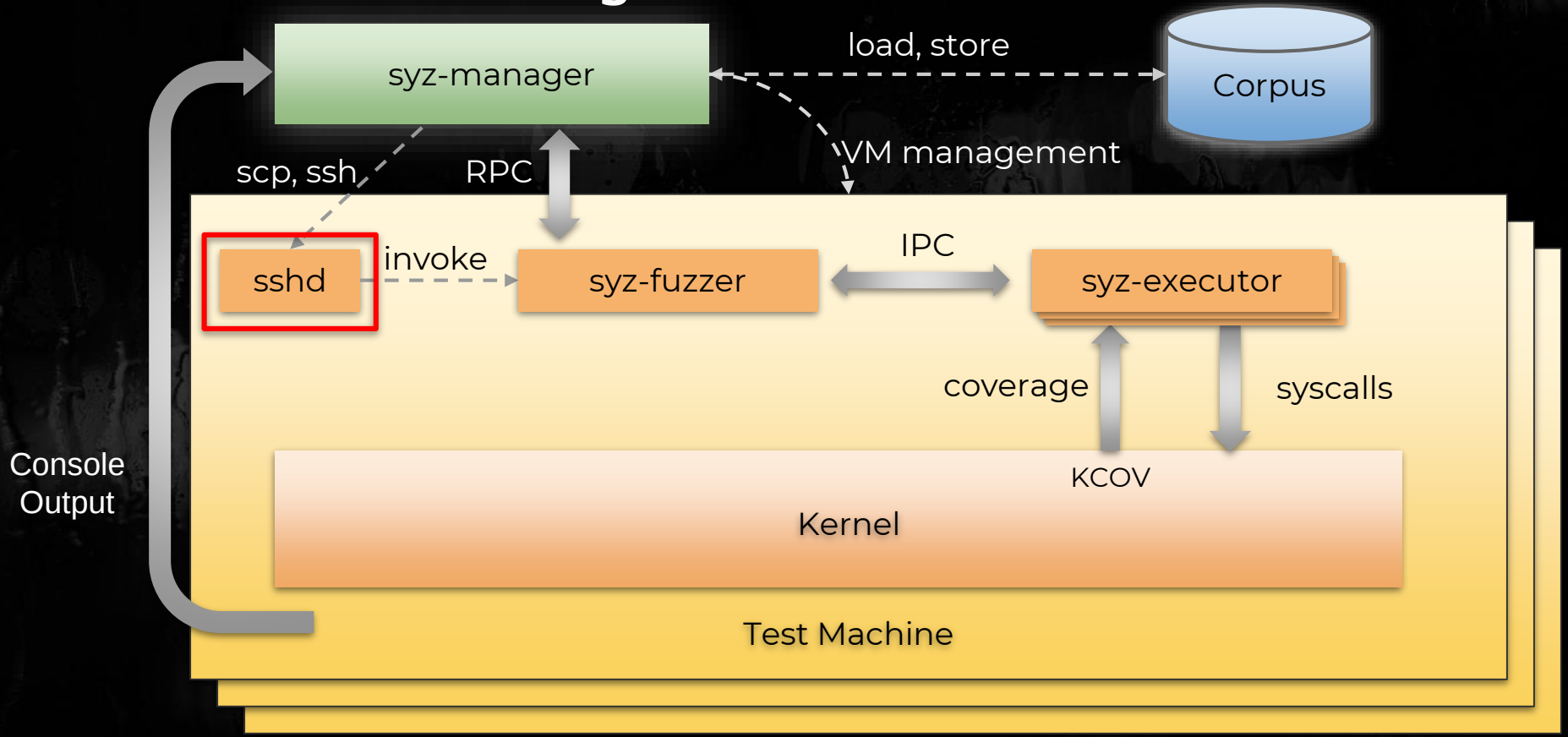
Relatively new (2 drivers, ~1MB in size)

First steps with syzkaller

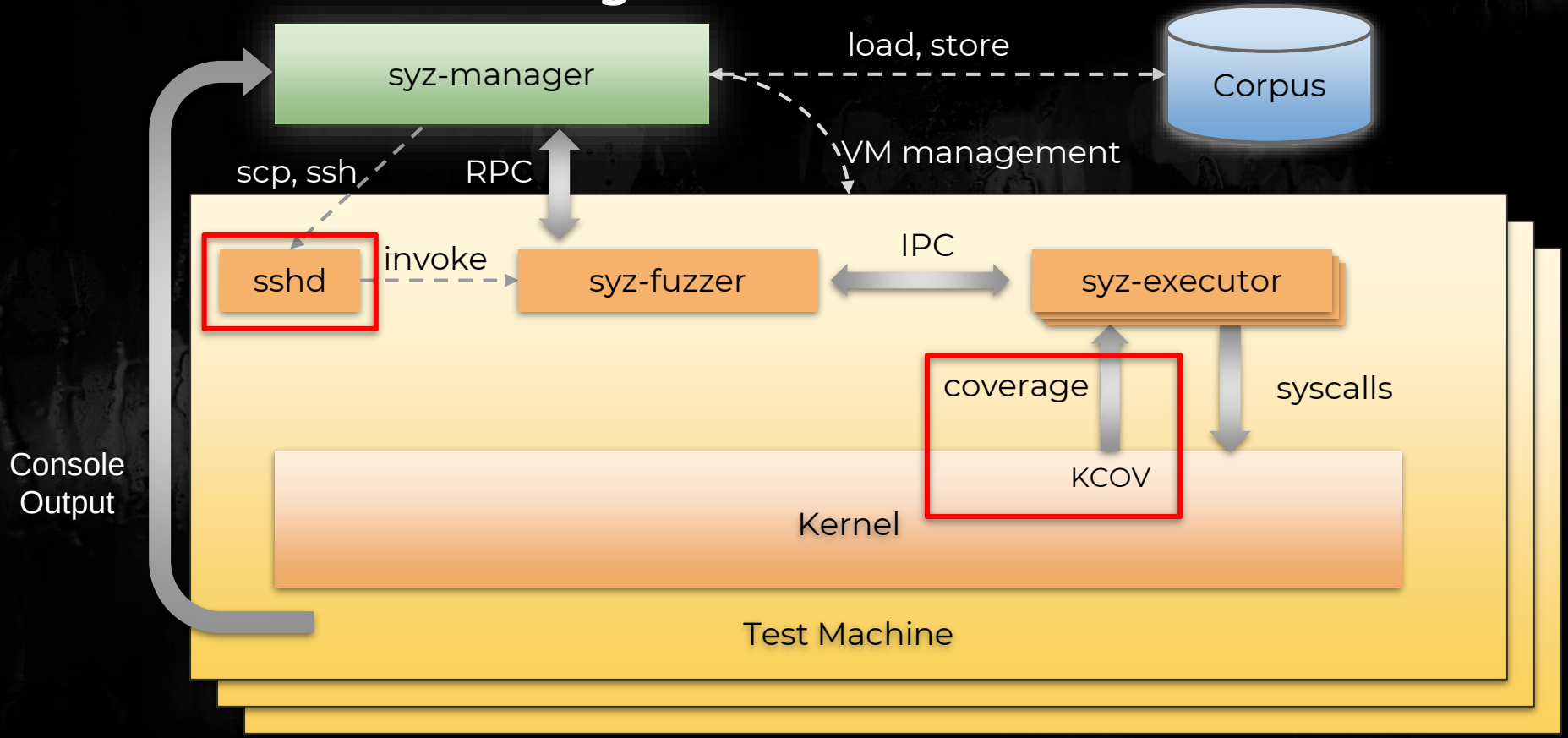
What do we need to get started



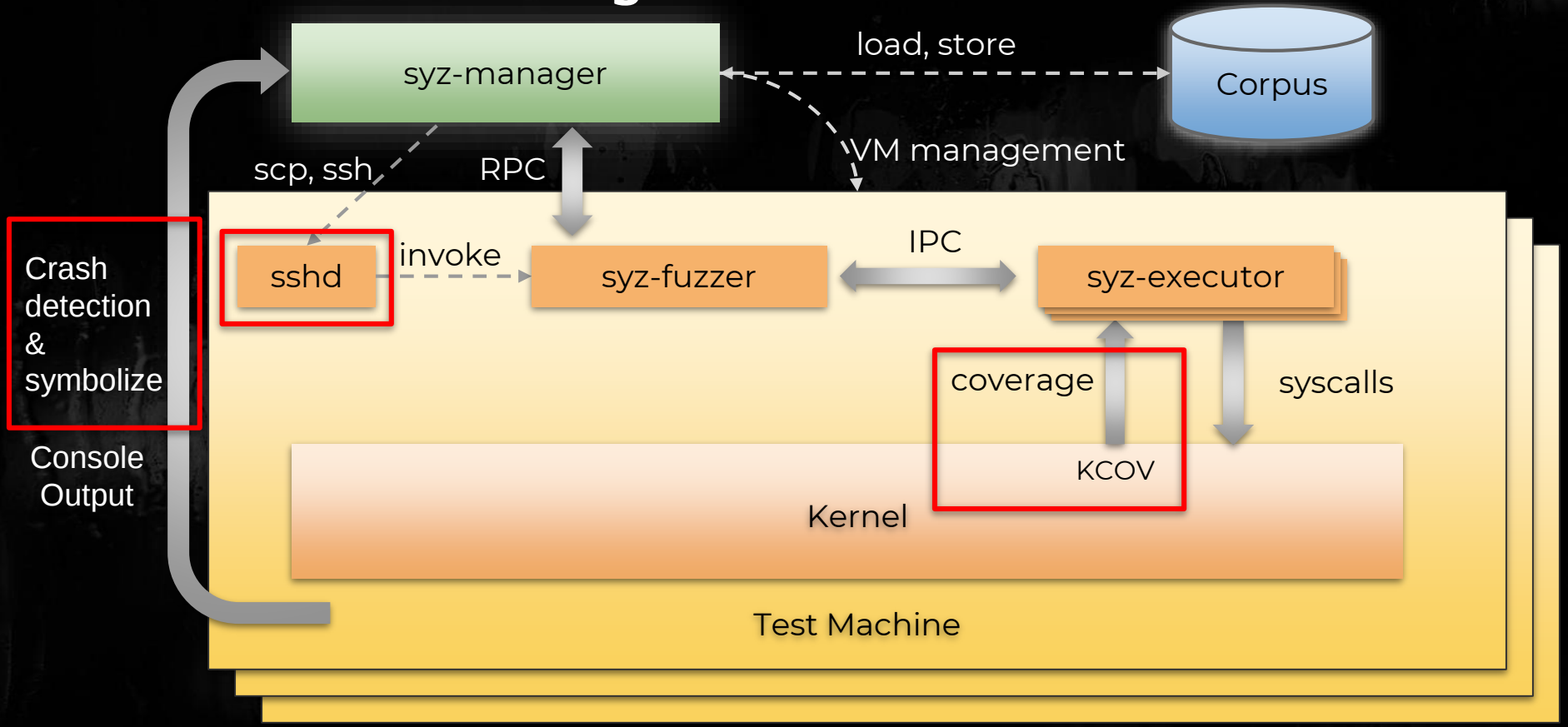
What do we need to get started



What do we need to get started



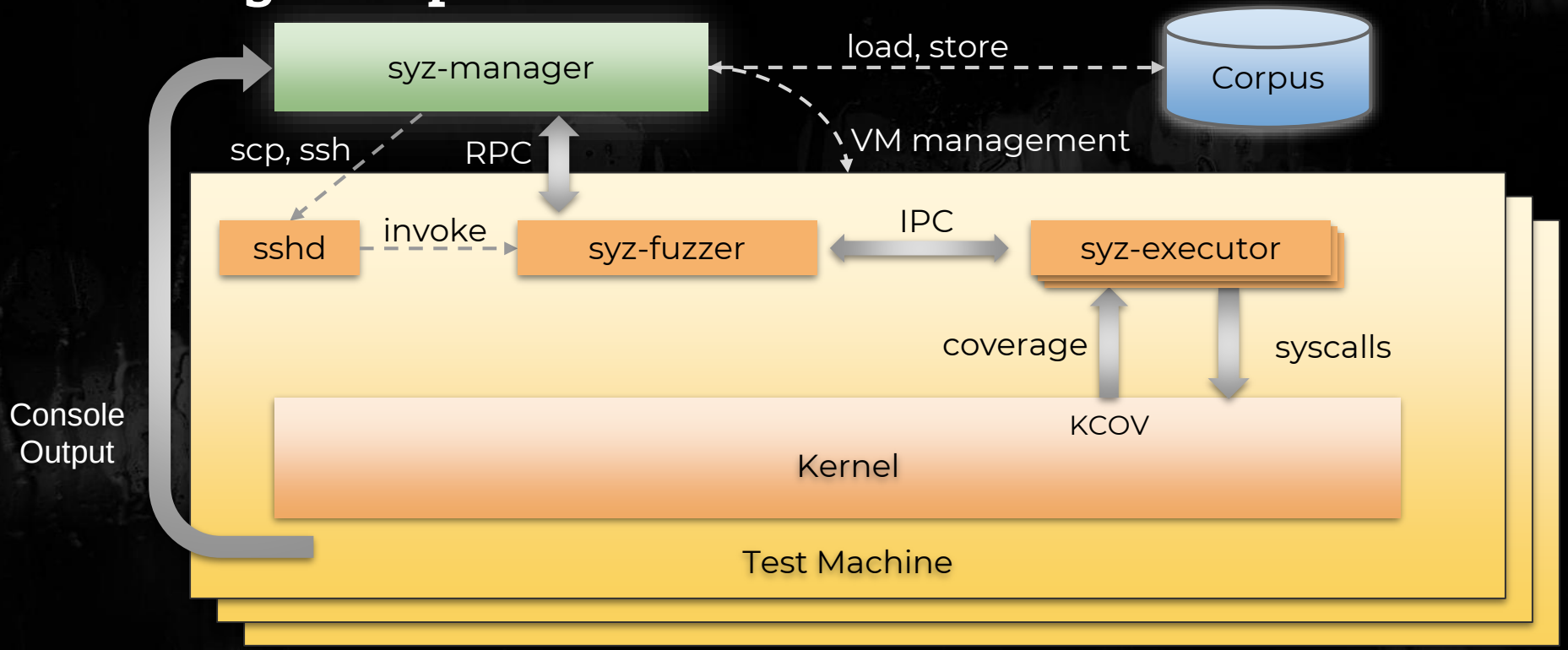
What do we need to get started



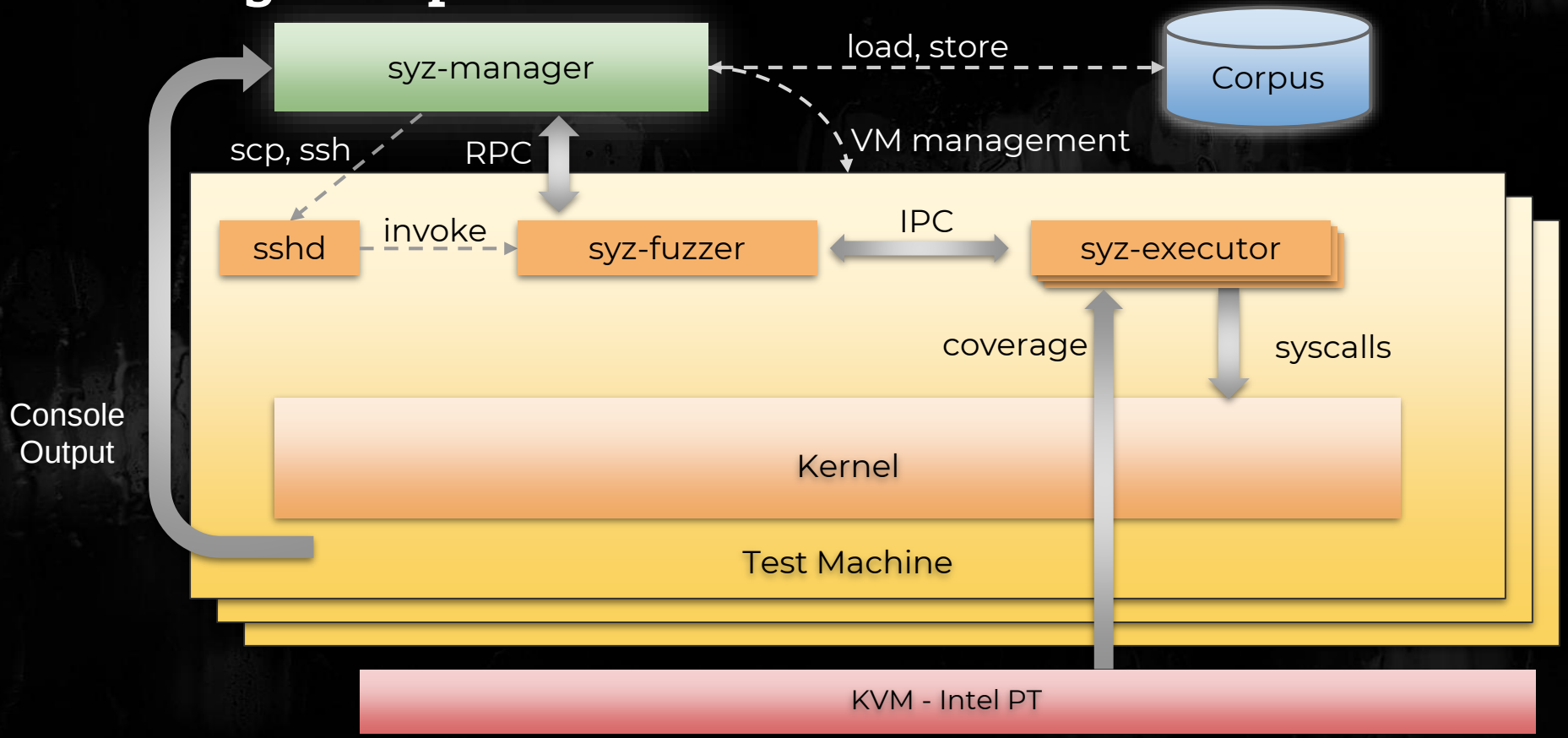
Syzkaller - WSL coverage

- Windows is a closed source compiled binary
  - We can't use -fsanitize=trace-pc (like KCOV)
- Options
  - Emulation - bochs
  - Static Binary Instrumentation
  - Hypervisor - like Apple Pie
  - **Hardware support - Intel PT**

Coverage - Implementation



Coverage - Implementation



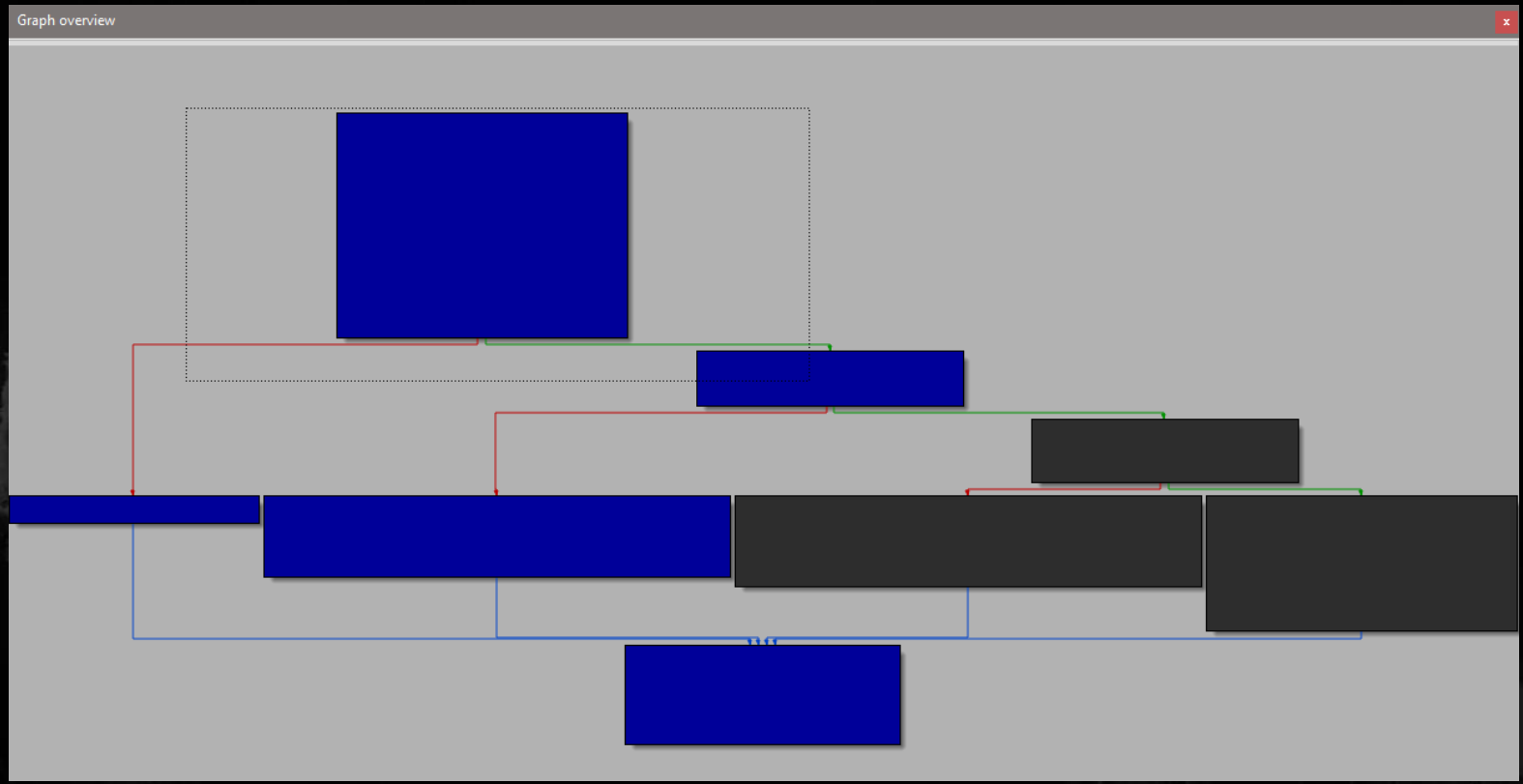
Syzkaller - WSL coverage

59.08	LxpEpollContextAddFileDescriptor	0x1C004DD5C	37 / 79	218 / 369	1353	45	
70.37	LxpMiFreeOverlappingRange	0x1C0086200	43 / 68	209 / 297	1137	46	
46.53	LxpDevTerminalDefaultDeviceControl	0x1C00FD6BC	37 / 89	208 / 447	1889	48	
65.13	LxpMmMremap	0x1C0088AEC	54 / 100	325 / 499	1889	49	
48.03	LxpEpollContextWait	0x1C004E768	53 / 108	256 / 533	2203	55	
0.00	LxpDevTtyInputWorker	0x1C0101070	0 / 80	0 / 359	1481	55	
0.00	LxpProcFsRootCpuInfoGenerateStringCommon	0x1C00AEADC	0 / 65	0 / 520	2245	56	
0.00	LxpProcFsPidMapsGenerateBufferCommon	0x1C00AA51C	0 / 97	0 / 544	2293	56	
30.02	LxpSemPerformOperations	0x1C00F33F0	19 / 114	142 / 473	1828	58	
81.39	VfsRename	0x1C00929F8	67 / 95	376 / 462	1807	59	
89.53	LxUtilNtStatusToLxError	0x1C00FA894	84 / 94	171 / 191	893	60	
0.00	LxpElfInfoParse	0x1C004CABC	0 / 127	0 / 541	2552	67	
0.00	LxpDevLogTraceLoggingWrite	0x1C00B5024	0 / 105	0 / 431	1626	67	
68.94	LxpMmAllocateMapVm	0x1C0086680	84 / 150	424 / 615	2407	82	
0.00	LxpProcFsPidStatusGenerateBuffer	0x1C00ABC50	0 / 110	0 / 664	2707	82	
80.59	LxpDevTerminalProcessInput	0x1C00FE72C	110 / 149	411 / 510	1859	89	
43.98	_output_l	0x1C0009560	67 / 182	252 / 573	2121	100	

Composer

* - 38.42% - Aggregate

Syzkaller - WSL coverage



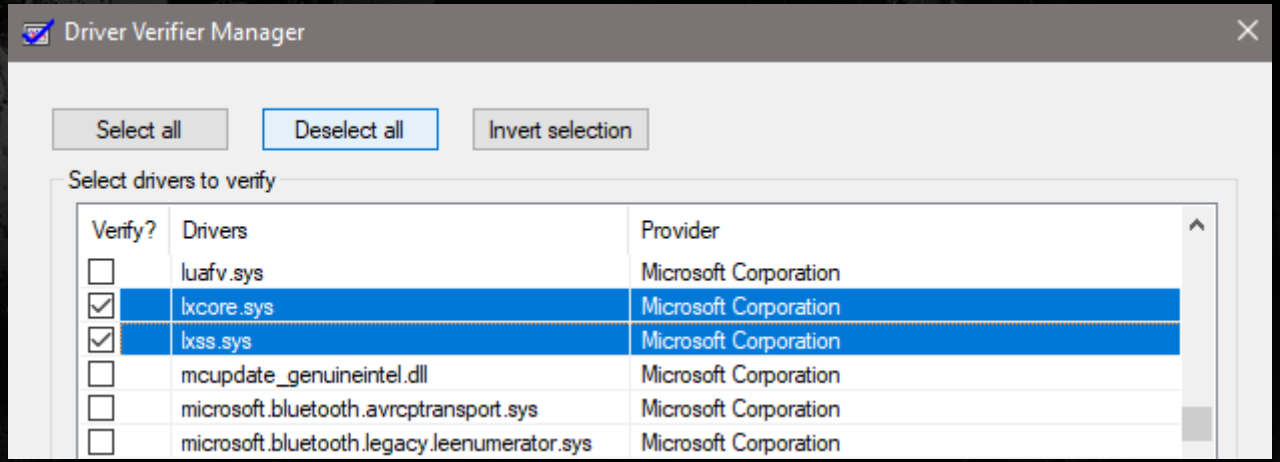
Bug Oracle

We used the same technique as kAFL

Bug Oracle

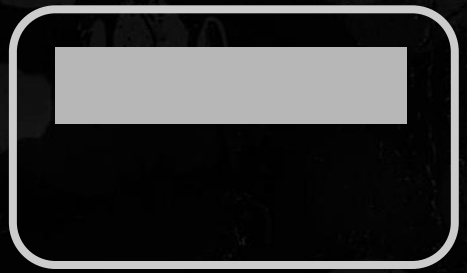
We used the same technique as kAFL

Enabled driver verifier for lxcore & lxss



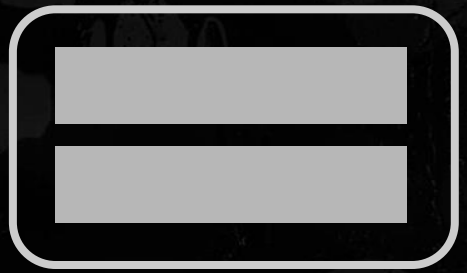
Symbolizing

crashes

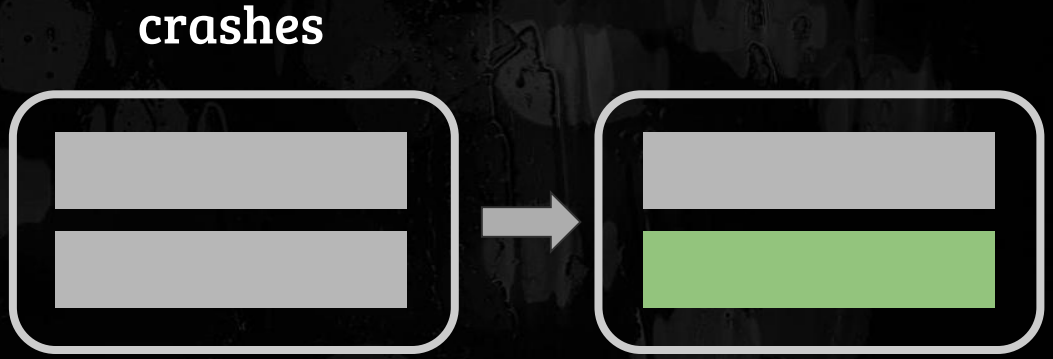


Symbolizing

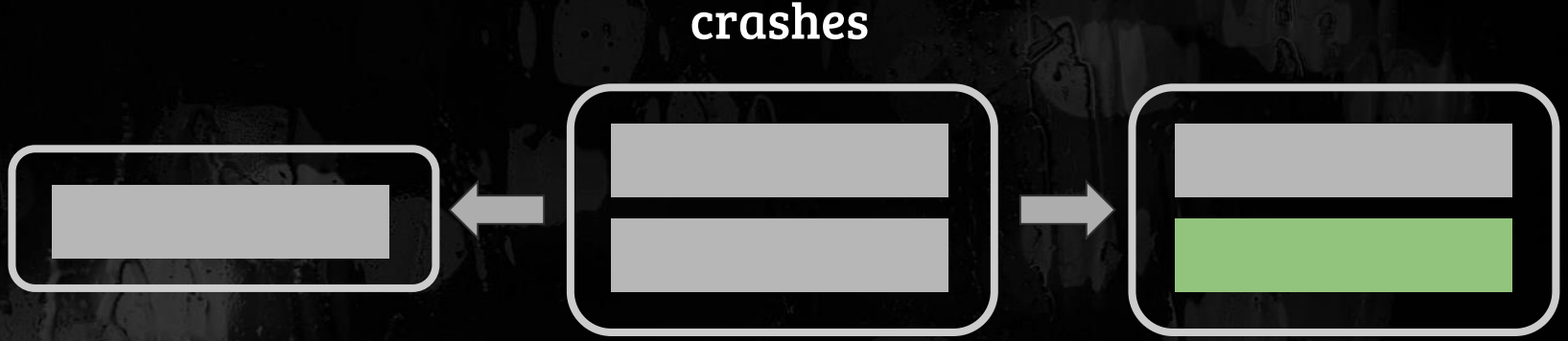
crashes



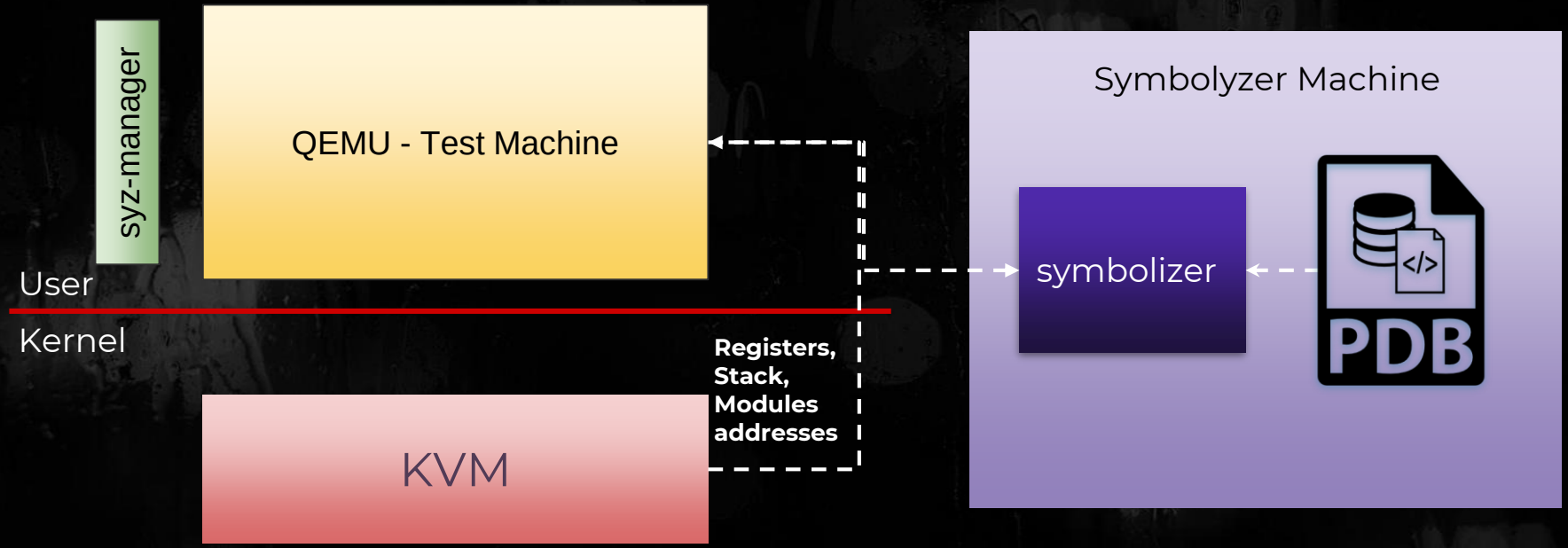
Symbolizing



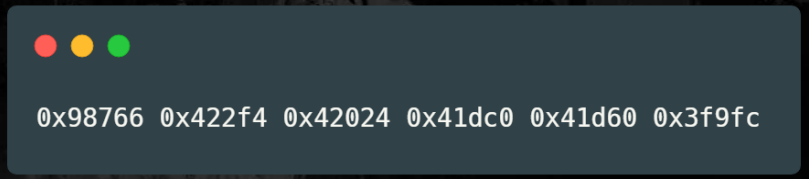
Symbolizing



Syzkaller - WSL Symbolizer



Syzkaller - WSL Symbolizer

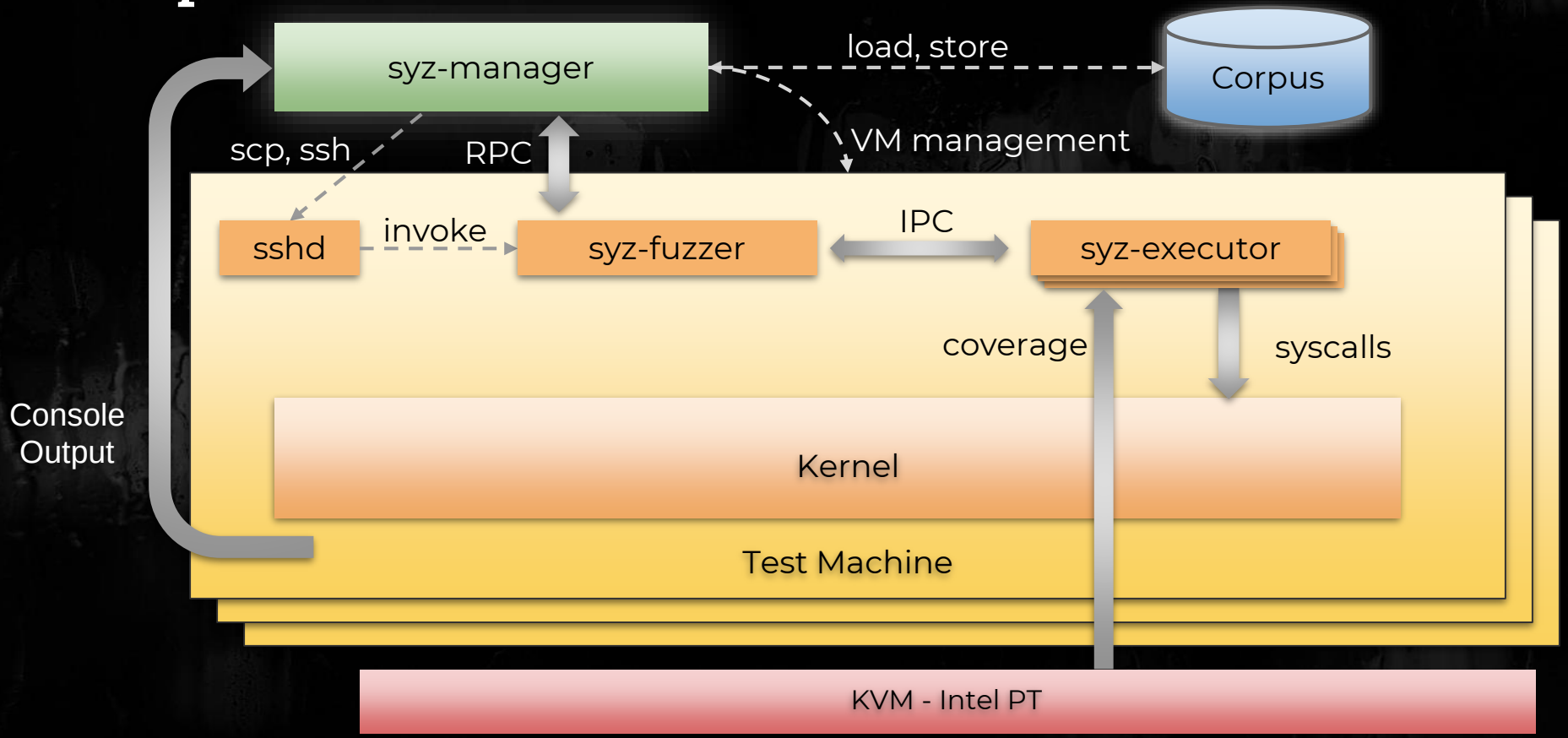


Syzkaller - WSL Symbolizer

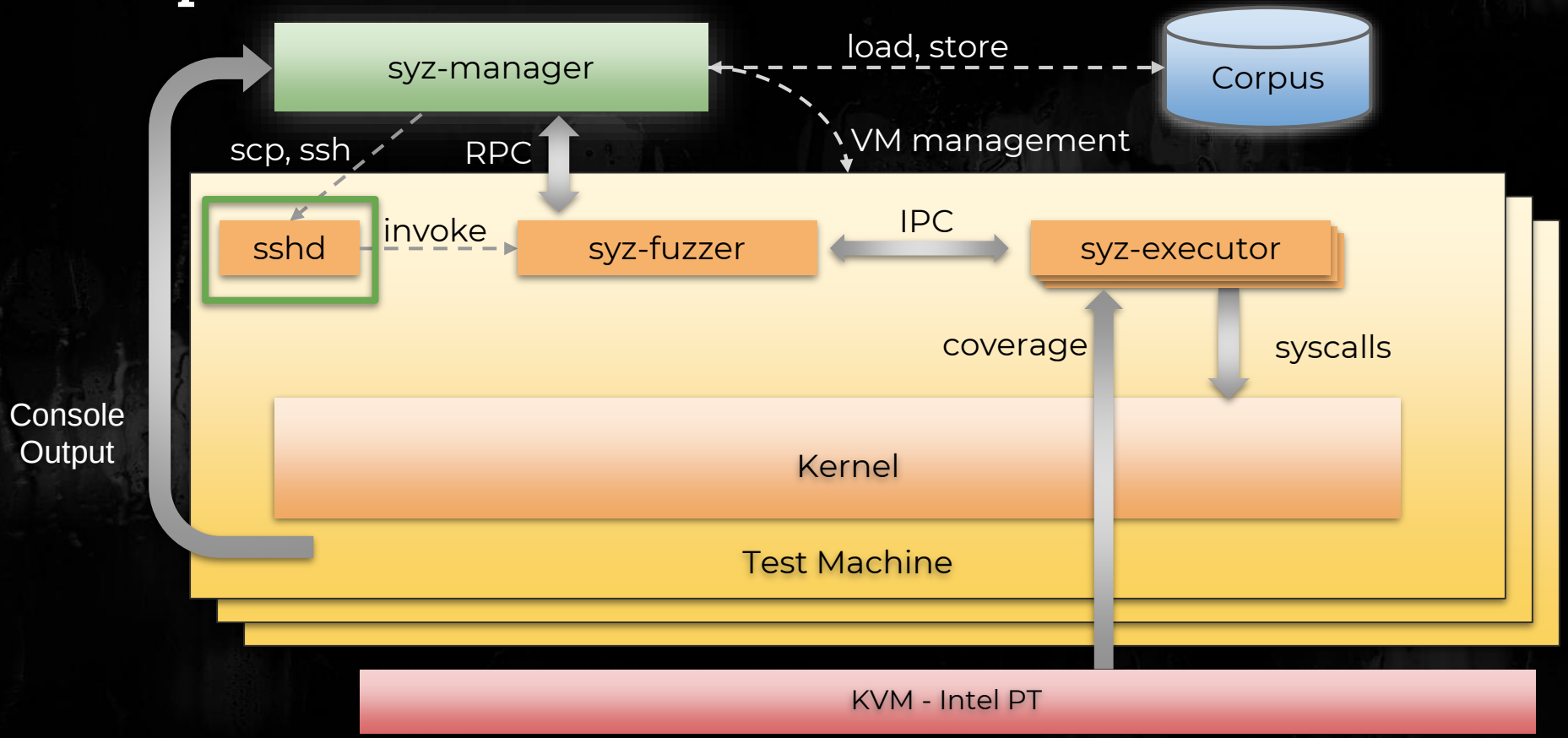
```
0x98766 0x422f4 0x42024 0x41dc0 0x41d60 0x3f9fc
```

```
Callstack:
[0] - ntoskrnl!KiScanBugCheckCallbackList+0000009b
[1] - ntoskrnl!KeBugCheck2+00000d4e
[2] - ntoskrnl!KeBugCheckEx+00000107
[3] - ntoskrnl!KiBugCheckDispatch+00000069
[4] - ntoskrnl!KiSystemServiceHandler+0000007c
[5] - ntoskrnl!RtlpExecuteHandlerForException+0000000f
[6] - ntoskrnl!RtlDispatchException+00000430
[7] - ntoskrnl!KiDispatchException+00000144
[8] - ntoskrnl!KiExceptionDispatch+000000c2
[9] - ntoskrnl!KiPageFault+00000428
[10] - ntoskrnl!RtlpHpVsChunkSplit+000003c5
[11] - ntoskrnl!RtlpHpVsContextAllocateInternal+0000028c
[12] - ntoskrnl!RtlpHpVsContextAllocate+00000046
[13] - ntoskrnl!RtlpAllocateHeapInternal+00000055
[14] - ntoskrnl!RtlAllocateHeap+00000037
[15] - win32kfull!ClassAlloc+00000039
[16] - win32kfull!InternalRegisterClassEx+0000014e
[17] - win32kfull!_RegisterClassEx+00000085
[18] - win32kfull!NtUserRegisterClassExWOW+0000059f
[19] - ntoskrnl!KiSystemServiceCopyEnd+00000025
[20] - 7ff992c825a4
[21] - 7ff993d769c5
[22] - 10
[23] - 20000380
[24] - 45efc00
```

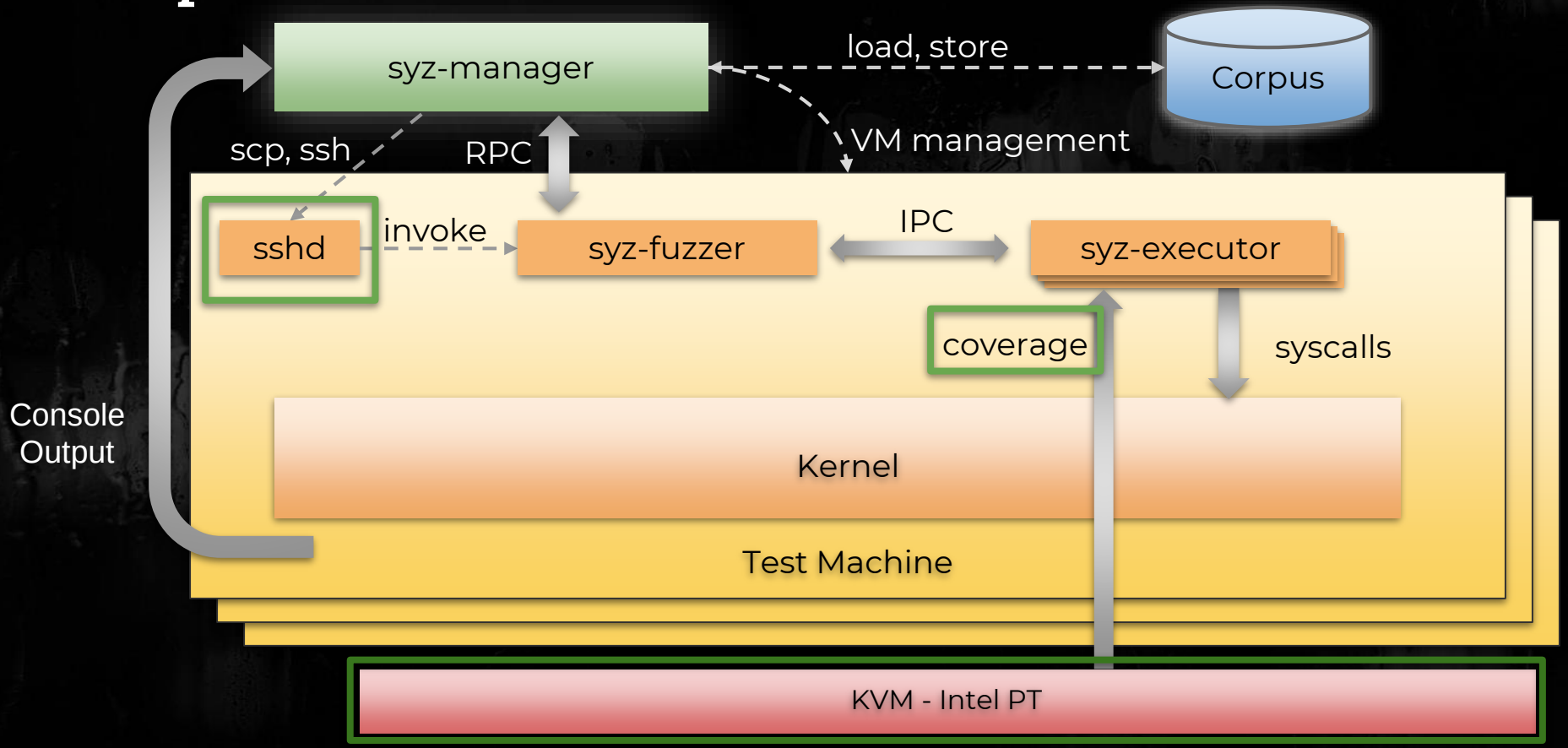
Recap


syz-manager
load, store
Corpus
scp, ssh
RPC
VM management
sshd
invoke
syz-fuzzer
IPC
syz-executor
coverage
syscalls
Console Output
Kernel
Test Machine
KVM - Intel PT

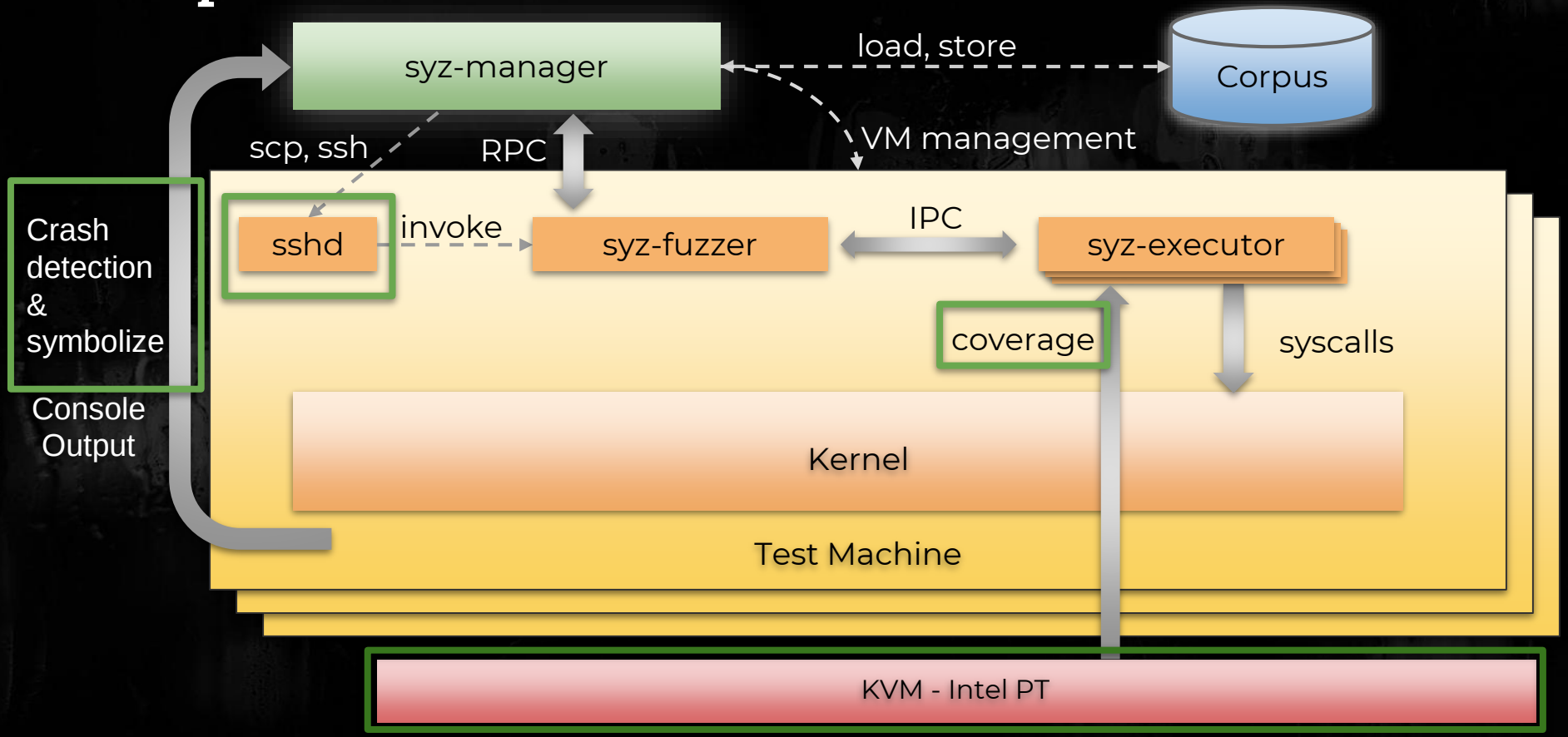
Recap


syz-manager
load, store
Corpus
scp, ssh
RPC
VM management
sshd
invoke
syz-fuzzer
IPC
syz-executor
coverage
syscalls
Console Output
Kernel
Test Machine
KVM - Intel PT

Recap


syz-manager
load, store
Corpus
scp, ssh
RPC
VM management
sshd
invoke
syz-fuzzer
IPC
syz-executor
coverage
syscalls
Console Output
Kernel
Test Machine
KVM - Intel PT

Recap


syz-manager
load, store
Corpus
scp, ssh
RPC
VM management
Crash detection & symbolize
sshd
invoke
syz-fuzzer
IPC
syz-executor
coverage
syscalls
Console Output
Kernel
Test Machine
KVM - Intel PT

And then it rained bugs!

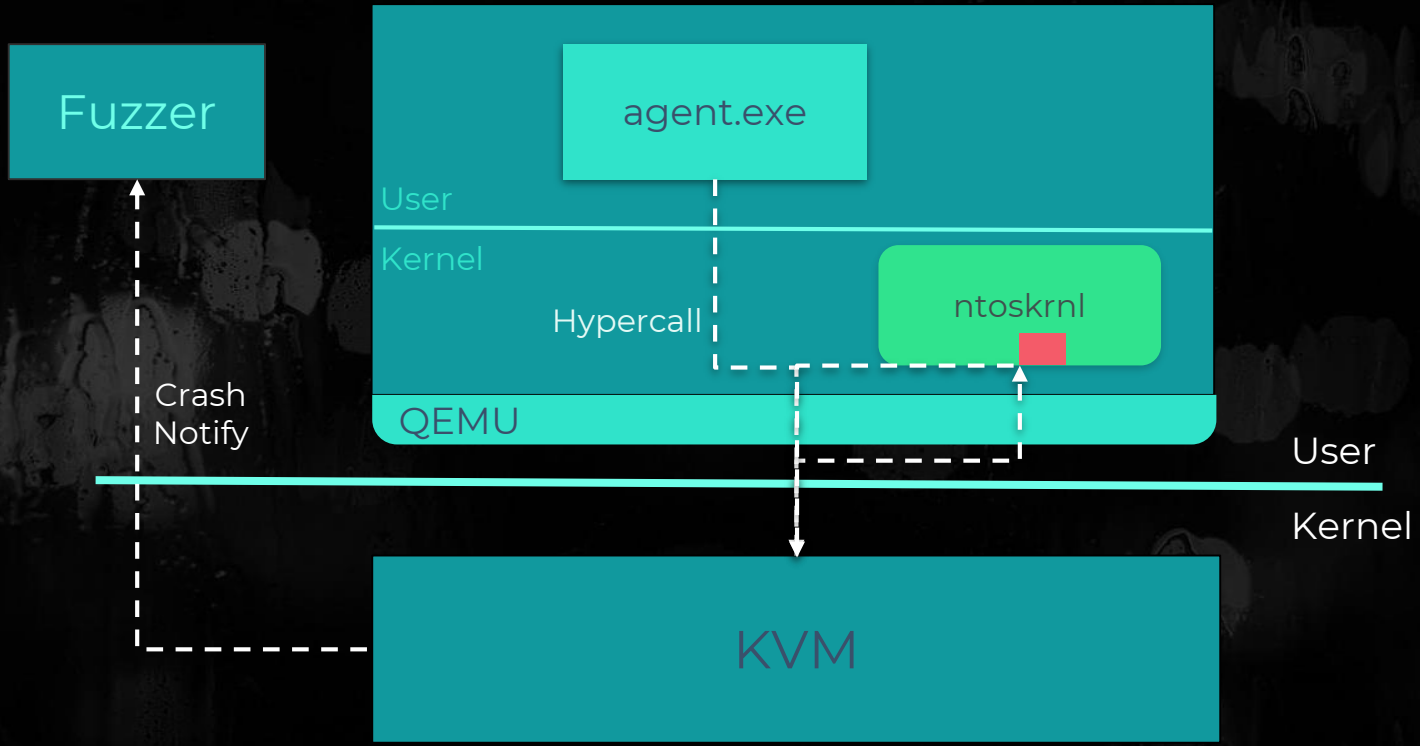

And then it rained bugs!
Not really

Not really

We noticed a crash with CRITICAL_STRUCTURE_CORRUPTION

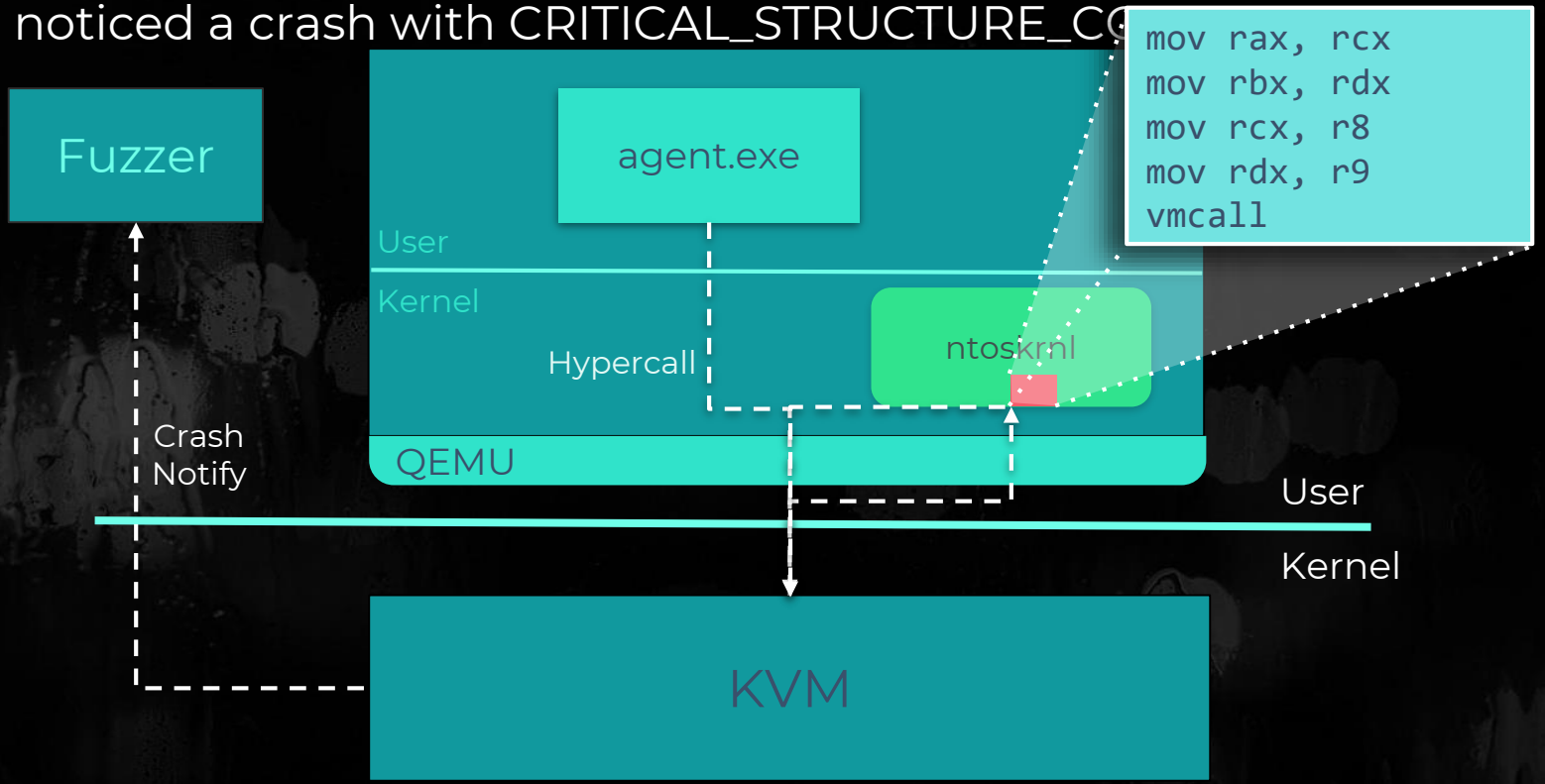
Not really

We noticed a crash with CRITICAL_STRUCTURE_CORRUPTION



Not really

We noticed a crash with CRITICAL_STRUCTURE_C



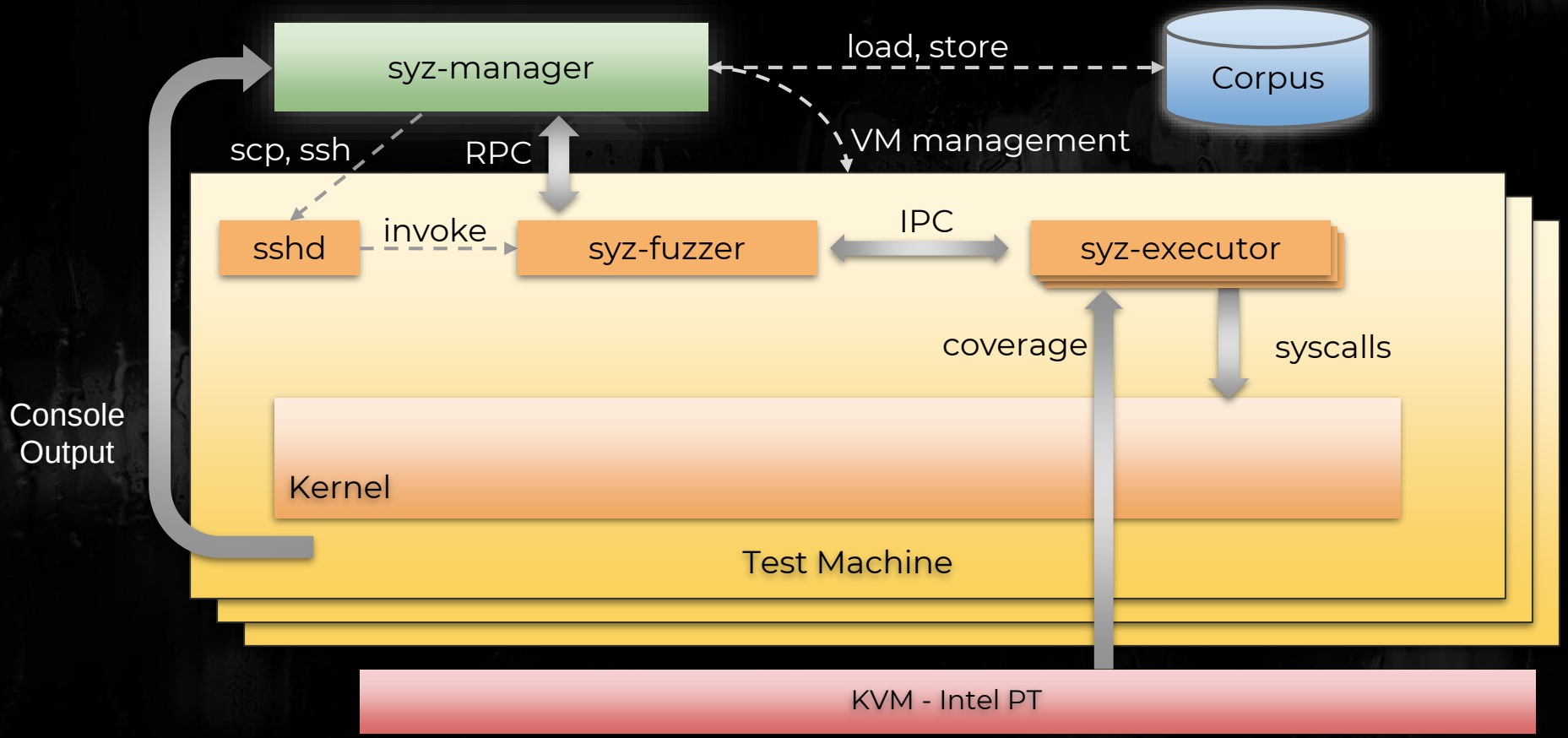
Not really

We noticed a crash with CRITICAL_STRUCTURE_C

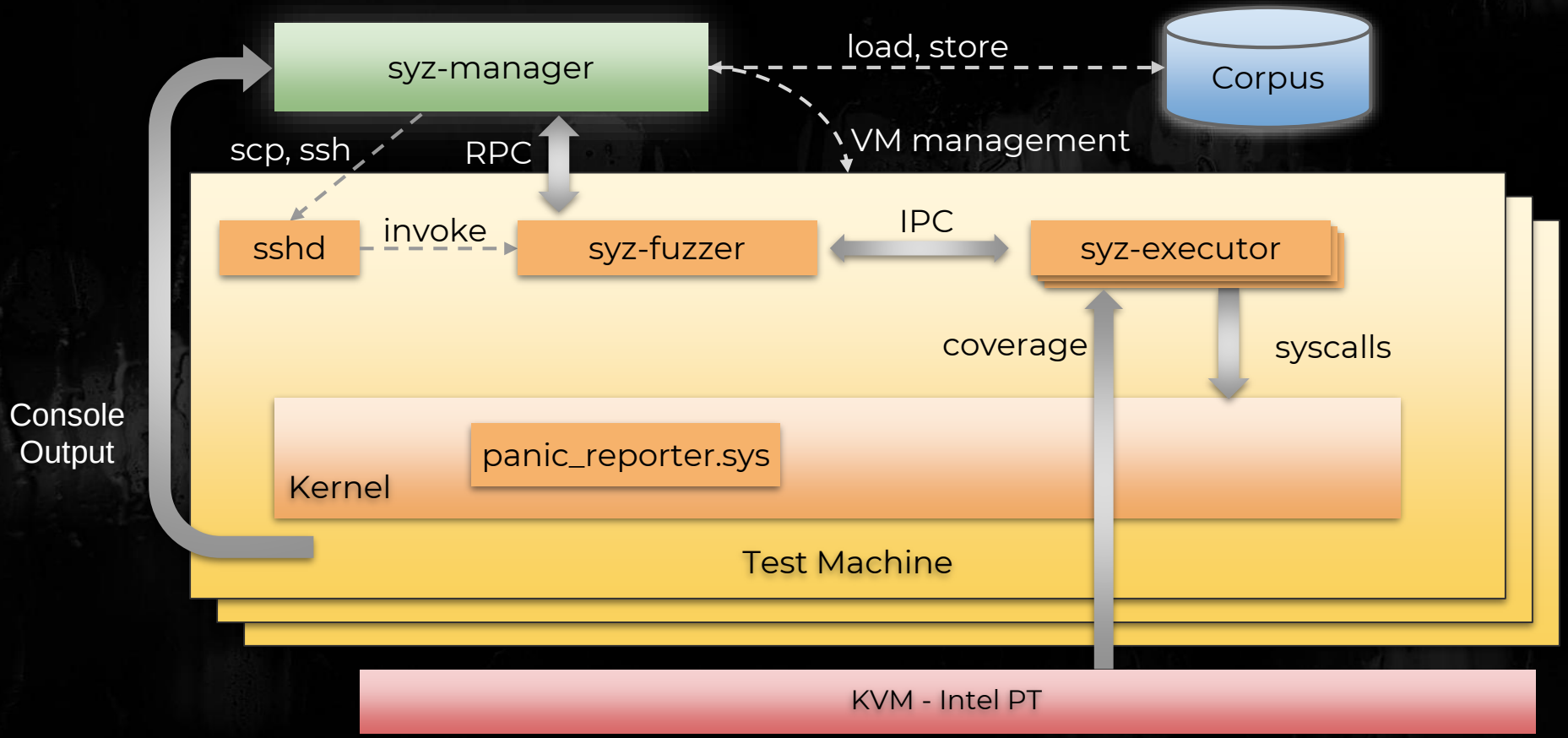
```
mov rax, rcx
```

Fuzz

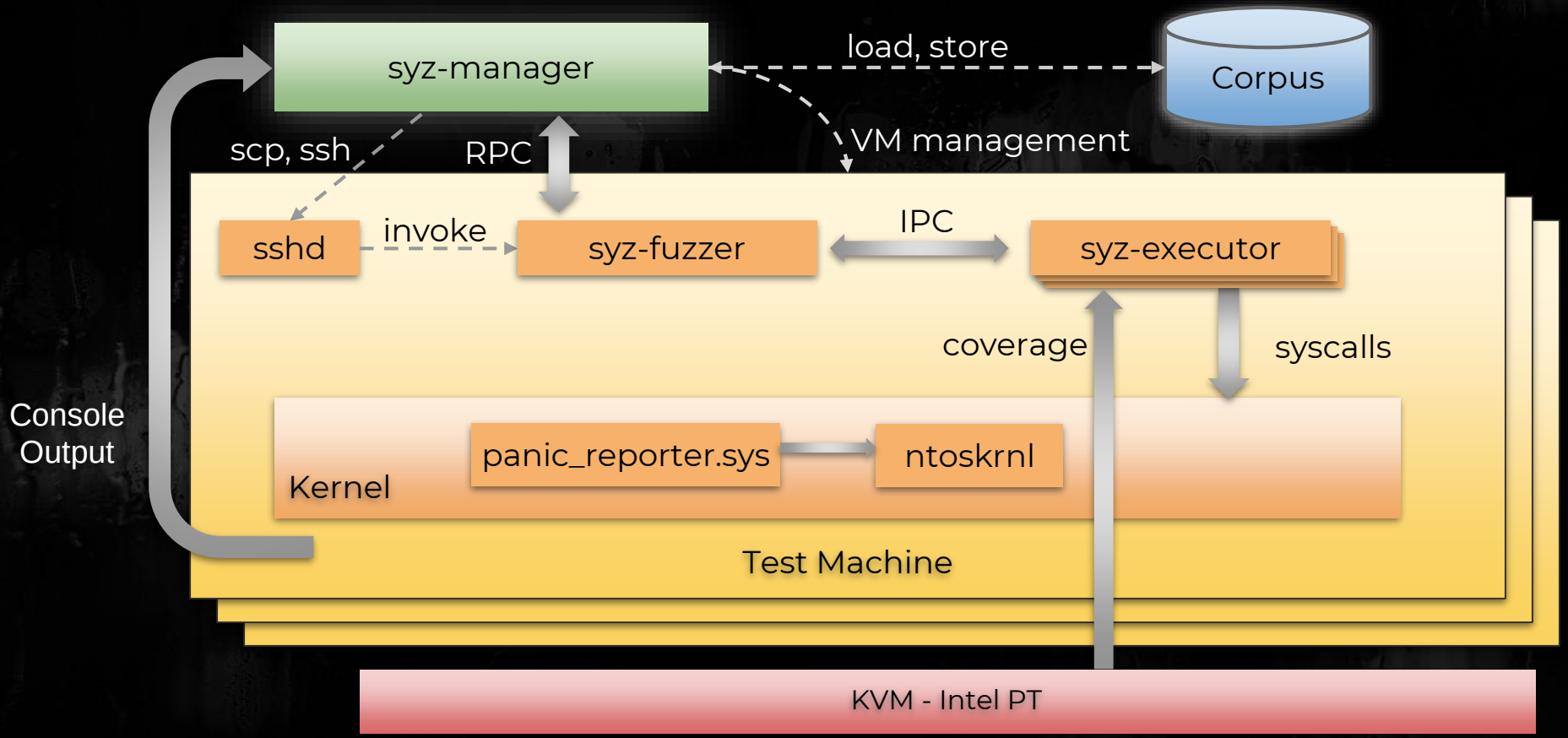
Crash detection



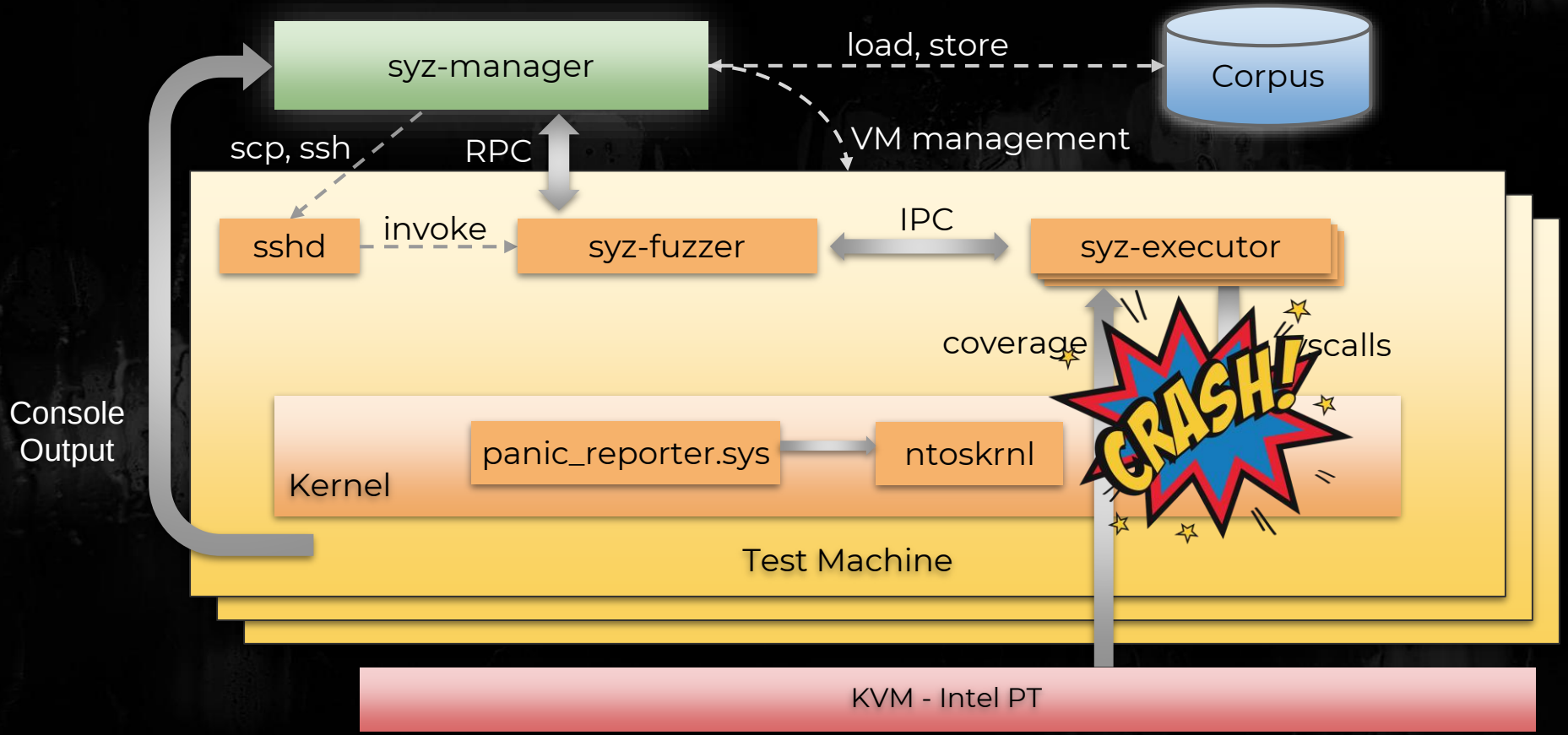
Crash detection



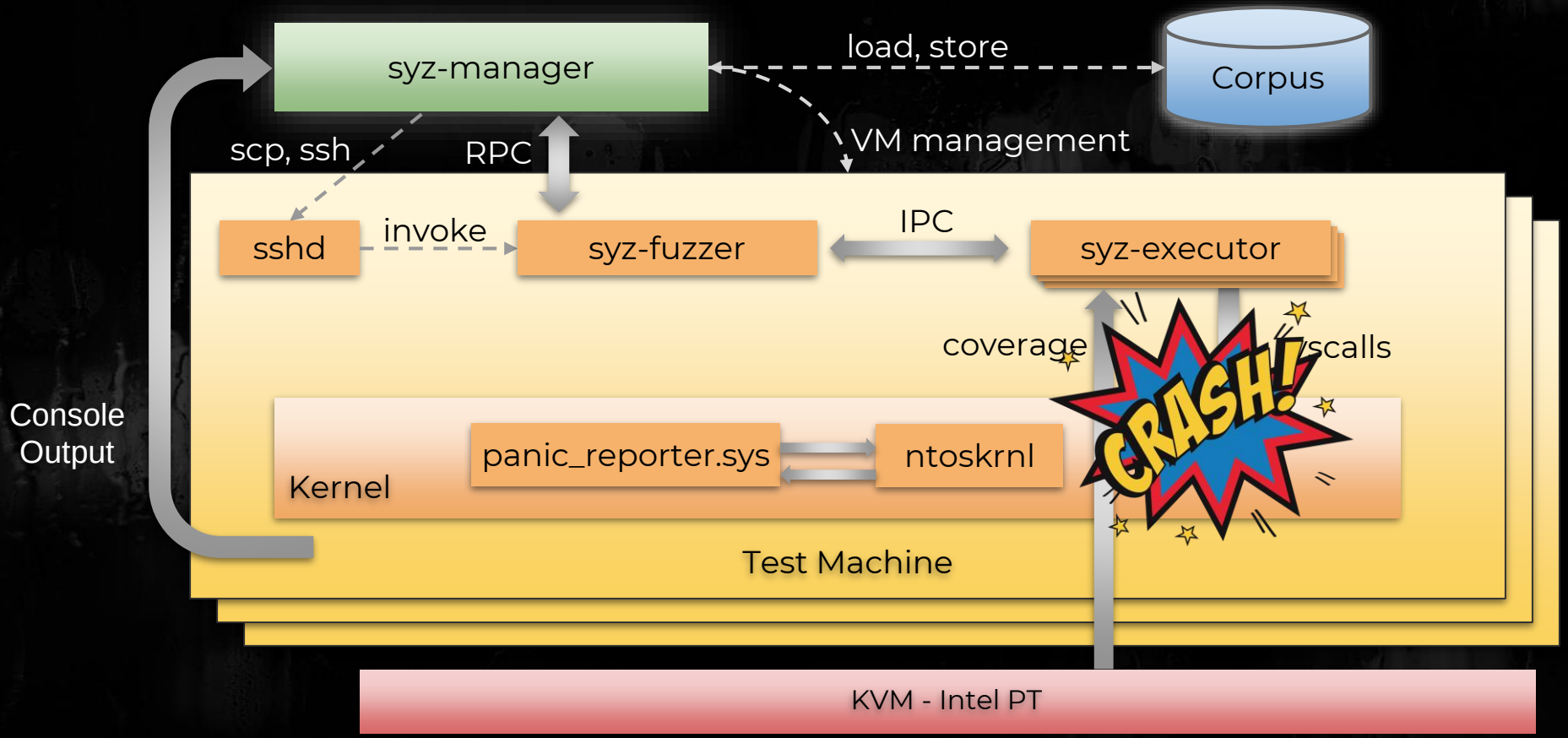
Crash detection



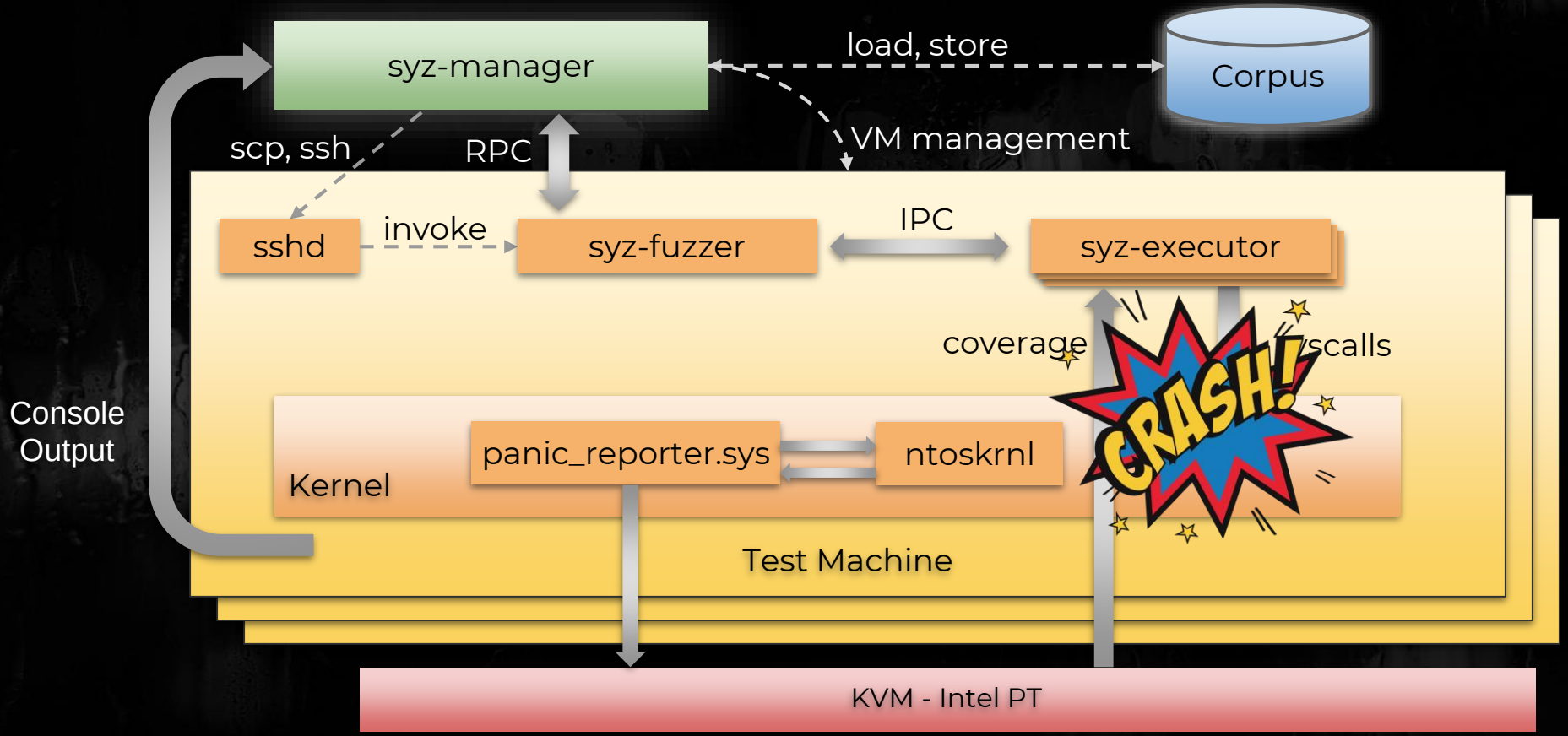
Crash detection



Crash detection



Crash detection



Coverage stability

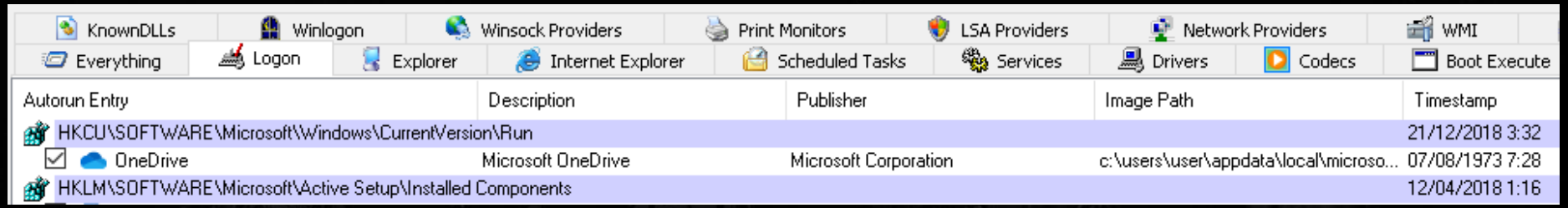
Coverage stability

Coverage stability

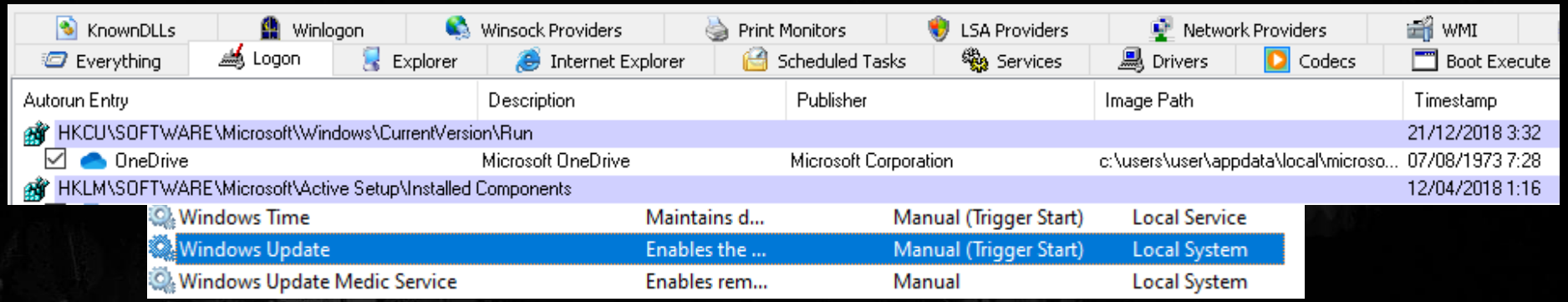
TL; DR

- We added OS thread tracking to KVM
- Allocating a buffer for each thread

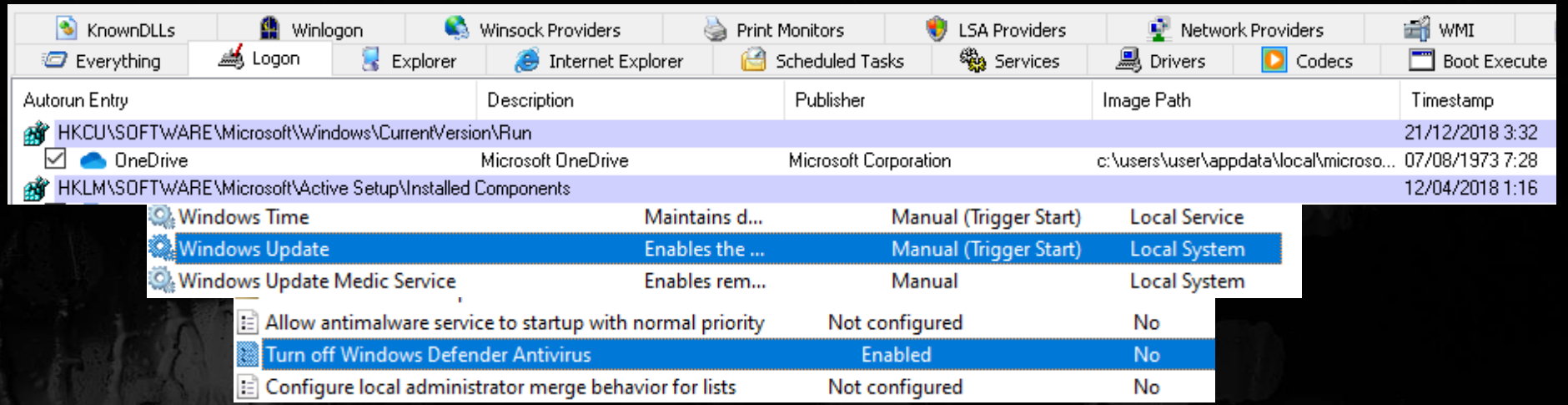
Glitches be crazy



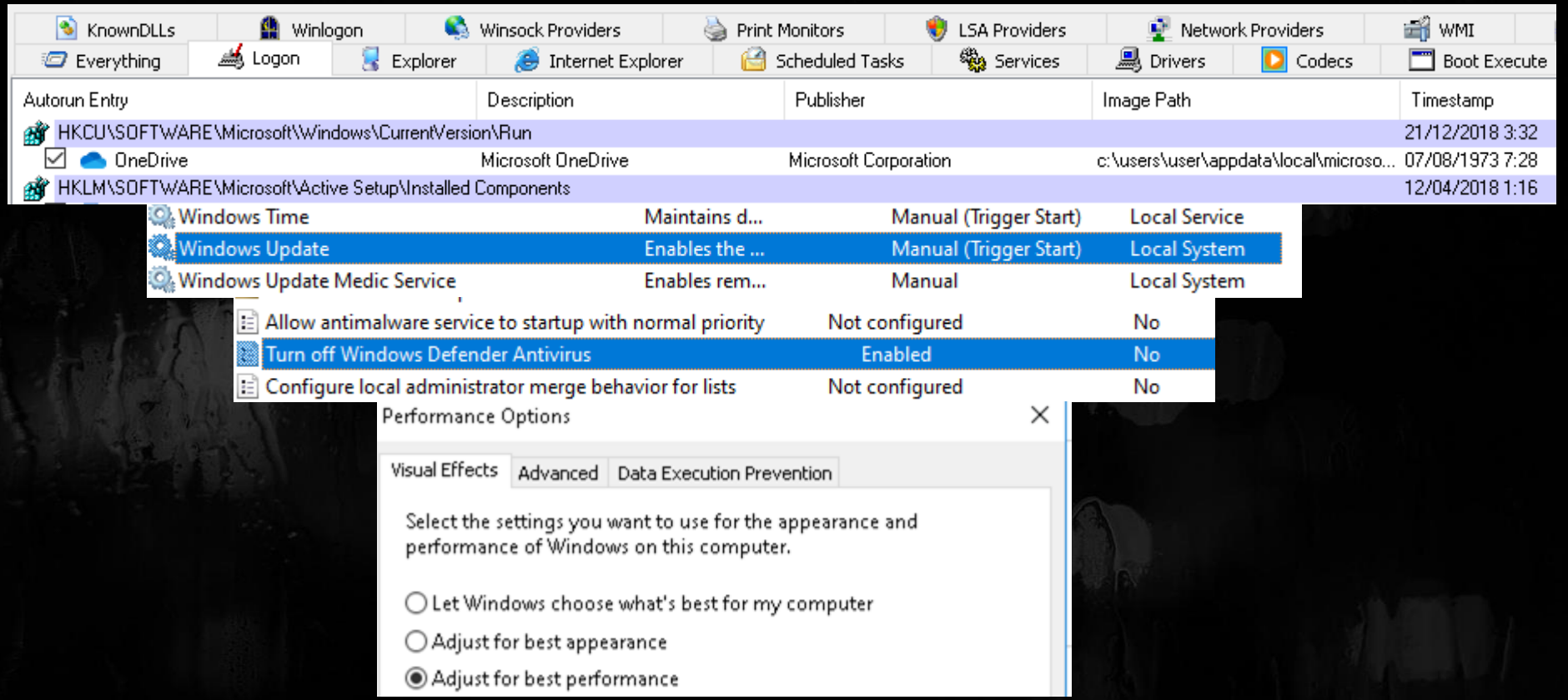
Glitches be crazy



Glitches be crazy



Glitches be crazy



WSL - results

38 vCPUs for 2 weeks

WSL - results

- 38 vCPUs for 2 weeks
- A working prototype

WSL - results

- 38 vCPUs for 2 weeks
- A working prototype
- 4 DoS

WSL - results

- 38 vCPUs for 2 weeks
- A working prototype
- 4 DoS

```c
void main() {
    int fd = open("/proc/self/setgroups", O_RDWR);
    write(fd, 0xdeadbabe, 6)
}
```

```c
void main() {
    unshare(CLONE_NEWNS);
    open("/proc/self/ns/mnt", O_RDONLY);
}
```

< 140

WSL - results

- 38 vCPUs for 2 weeks
- A working prototype
- 4 DoS
- 2 Deadlocks (still not resolved)

```c
void main() {
    int fd = open("/proc/self/setgroups", O_RDWR);
    write(fd, 0xdeadbabe, 6)
}
```

```c
void main() {
    unshare(CLONE_NEWNS);
    open("/proc/self/ns/mnt", O_RDONLY);
}
```

< 140

WSL - results

- 38 vCPUs for 2 weeks
- A working prototype
- 4 DoS
- 2 Deadlocks (still not resolved)
- 0 Vulnerabilities 😕

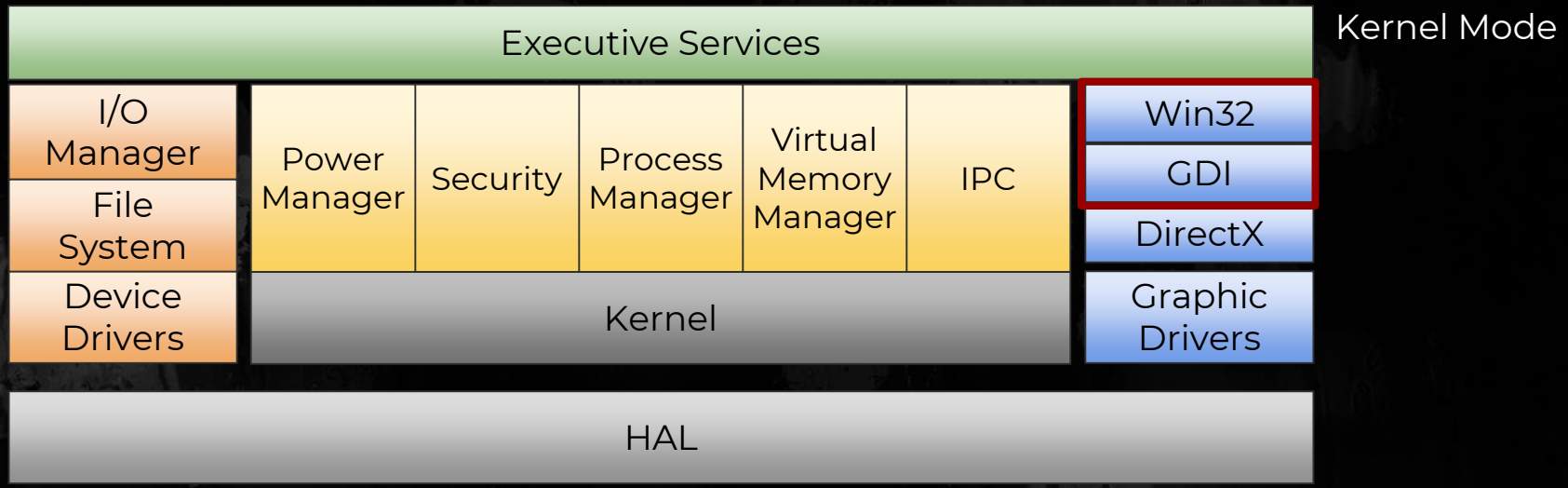
```c
void main() {
    int fd = open("/proc/self/setgroups", O_RDWR);
    write(fd, 0xdeadbabe, 6)
}
```

```c
void main() {
    unshare(CLONE_NEWNS);
    open("/proc/self/ns/mnt", O_RDONLY);
}
```

< 140

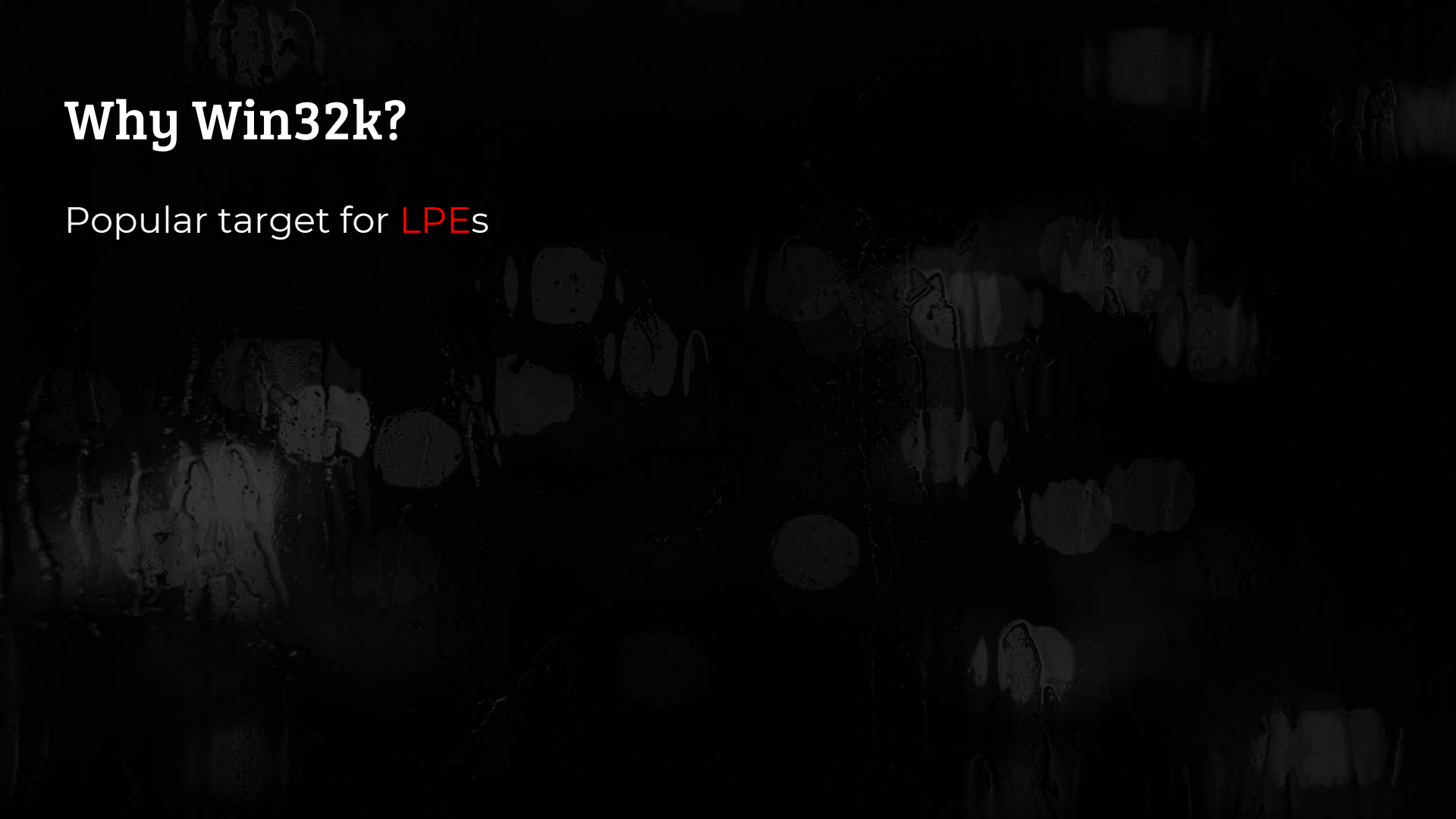
Let’s move to a real target

Windows Kernel



Why Win32k?

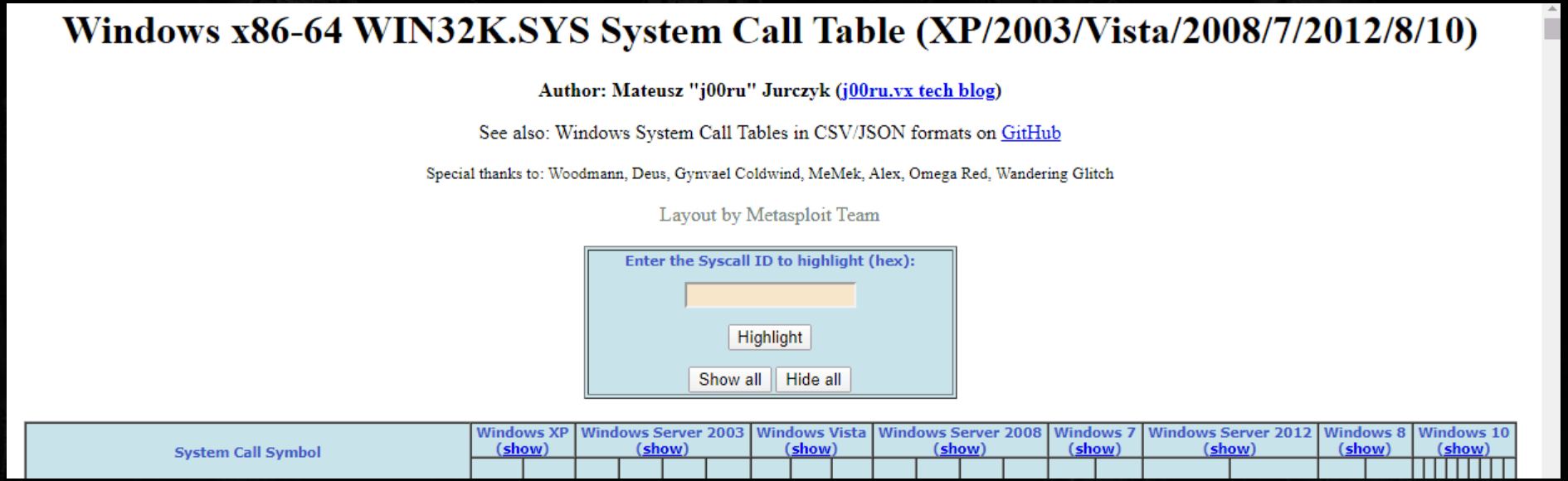
Popular target for LPEs



Why Win32k?

Popular target for LPEs

Huge attack surface >1500 syscalls



Windows x86-64 WIN32K.SYS System Call Table (XP/2003/Vista/2008/7/2012/8/10)

Author: Mateusz "j00ru" Jurczyk (j00ru.vx tech blog)

See also: Windows System Call Tables in CSV/JSON formats on GitHub

Special thanks to: Woodmann, Deus, Gynvael Coldwind, MeMek, Alex, Omega Red, Wandering Glitch

Layout by Metasploit Team

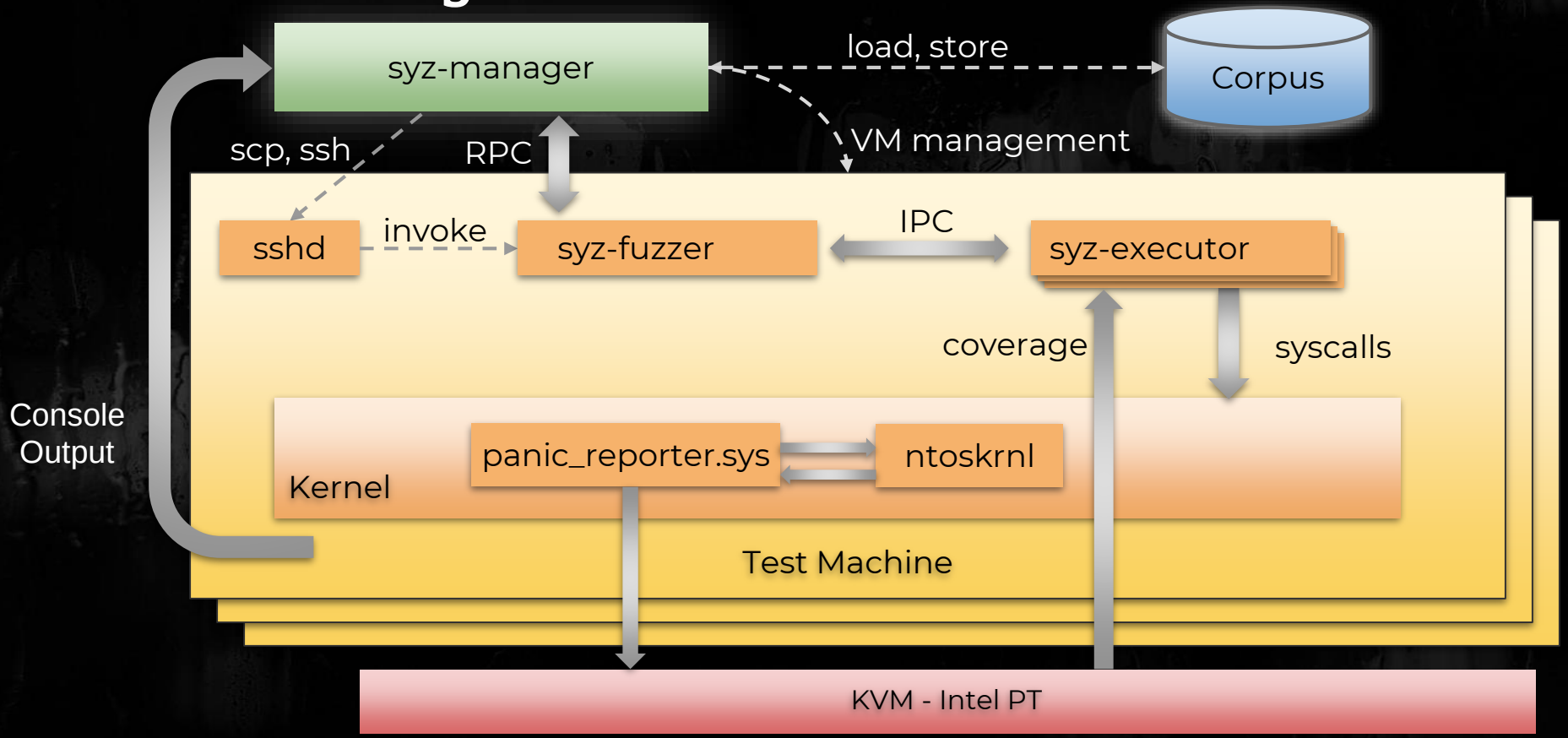
Enter the Syscall ID to highlight (hex):

Highlight

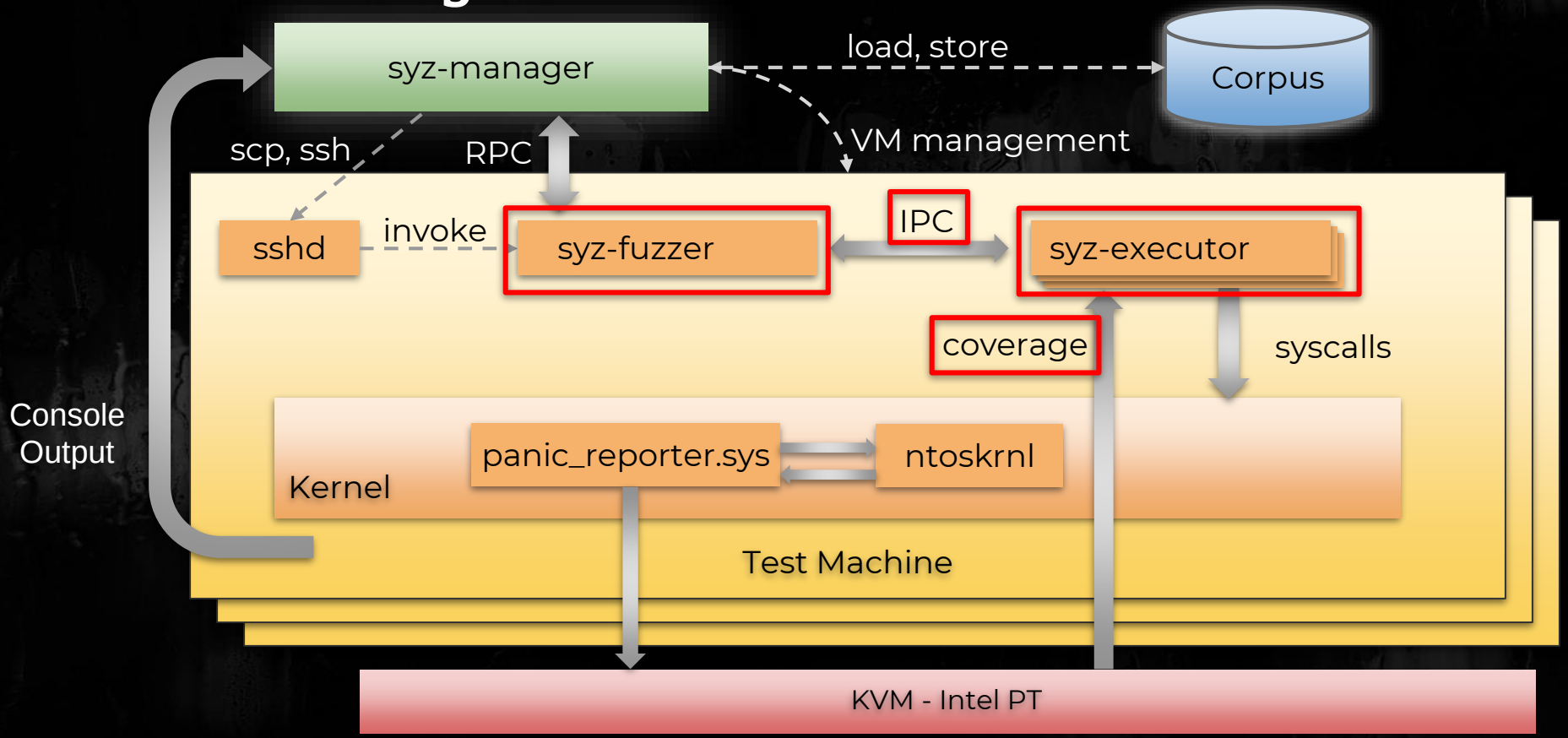
Show all | Hide all

System Call Symbol	Windows XP (show)	Windows Server 2003 (show)	Windows Vista (show)	Windows Server 2008 (show)	Windows 7 (show)	Windows Server 2012 (show)	Windows 8 (show)	Windows 10 (show)

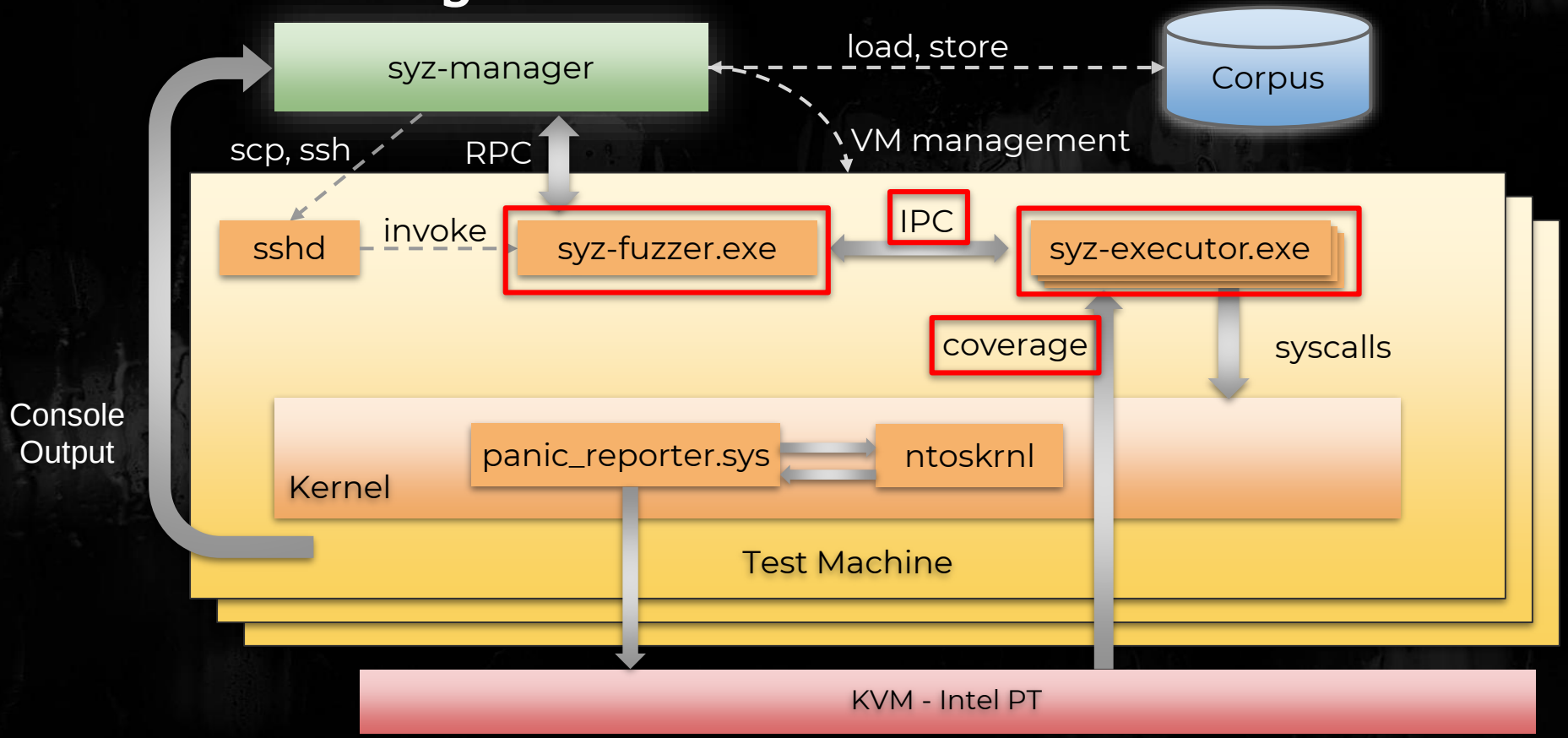
Win32k - changes



Win32k - changes



Win32k - changes



syz-executor changes

- Support for up to 12 parameters for syscalls 🤷
- OS related changes (threads, shared memory, pipes...)
- Expose windows syscalls
- Cross compiled with mingw++

syz-executor changes

- Support for up to 12 parameters for syscalls 🤷
- OS related changes (threads, shared memory, pipes...)
- Expose windows syscalls
- Cross compiled with mingw++

win32u.dll

gdi32.dll

syz-executor changes

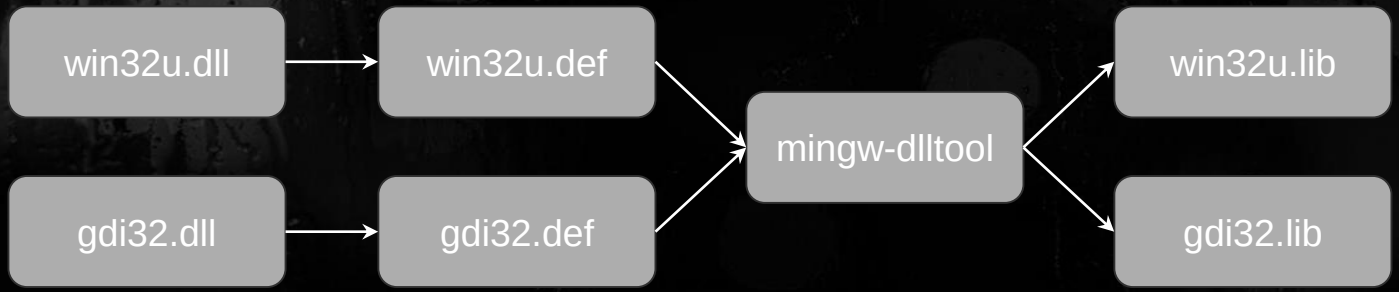
- Support for up to 12 parameters for syscalls 🤷
- OS related changes (threads, shared memory, pipes...)
- Expose windows syscalls
- Cross compiled with mingw++

syz-executor changes

- Support for up to 12 parameters for syscalls 🤷
- OS related changes (threads, shared memory, pipes...)
- Expose windows syscalls
- Cross compiled with mingw++

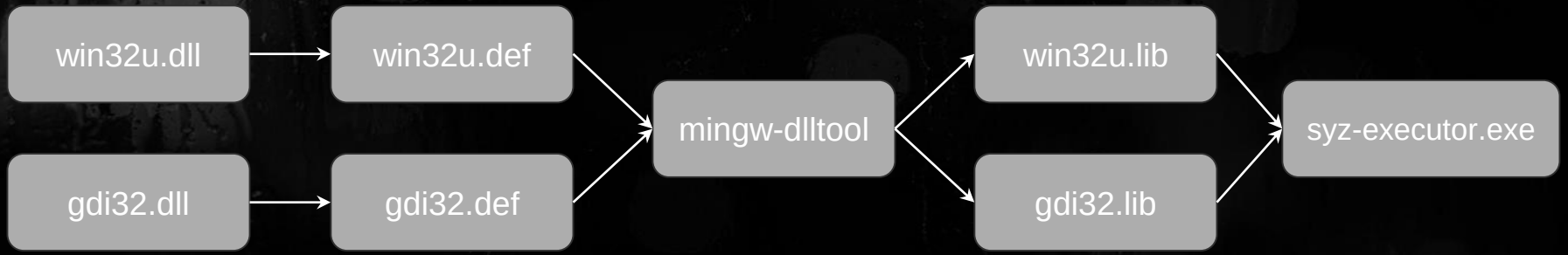
syz-executor changes

- Support for up to 12 parameters for syscalls 🤷
- OS related changes (threads, shared memory, pipes...)
- Expose windows syscalls
- Cross compiled with mingw++



syz-executor changes

- Support for up to 12 parameters for syscalls 🤷
- OS related changes (threads, shared memory, pipes...)
- Expose windows syscalls
- Cross compiled with mingw++



syz-fuzzer

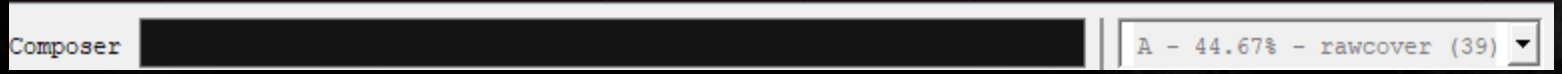
- OS related changes (sharing memory, handles ...)
- Win32k Grammar

Win32k - coverage

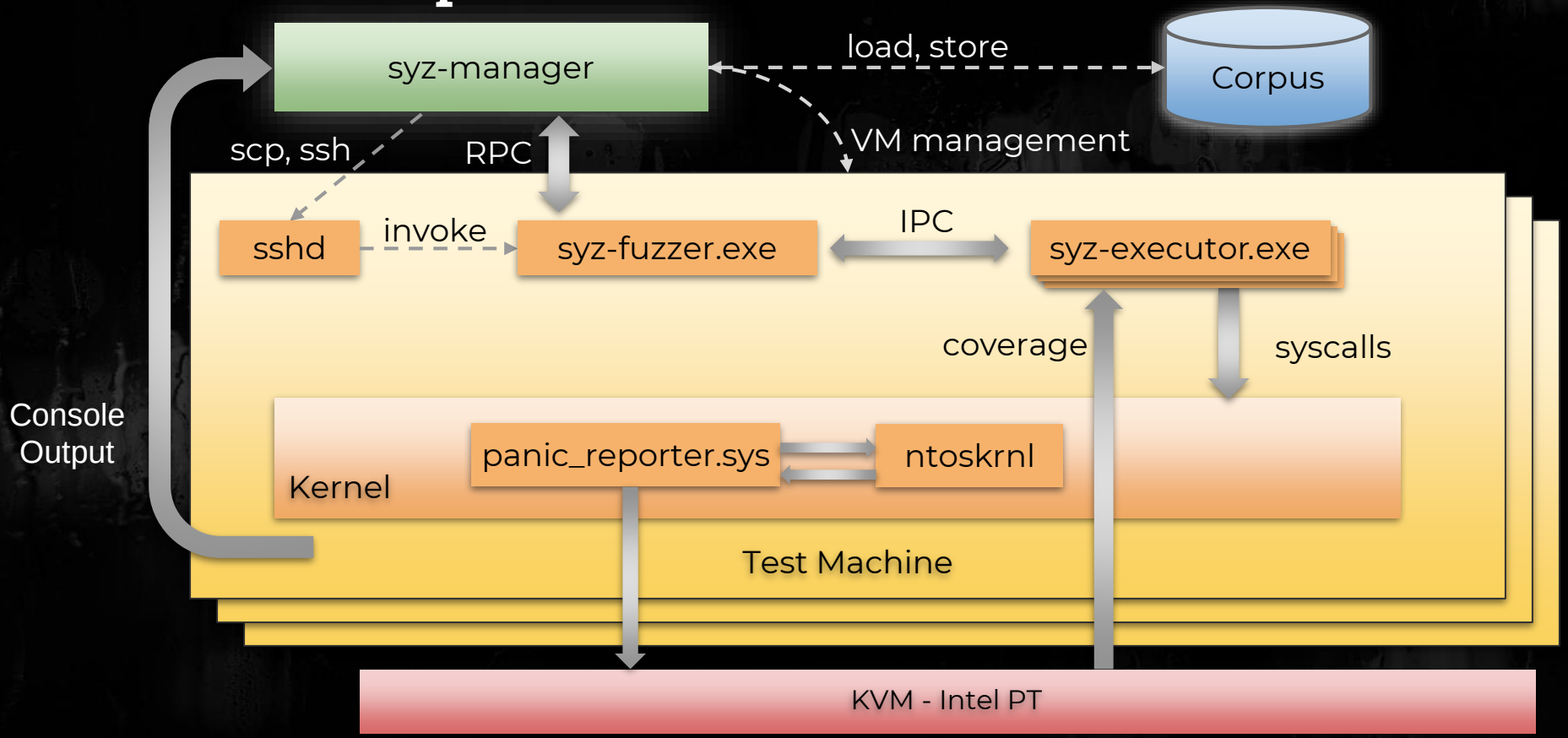
Win32k = win32k.sys + win32kbase.sys + win32kfull.sys

We added coverage support for multiple modules

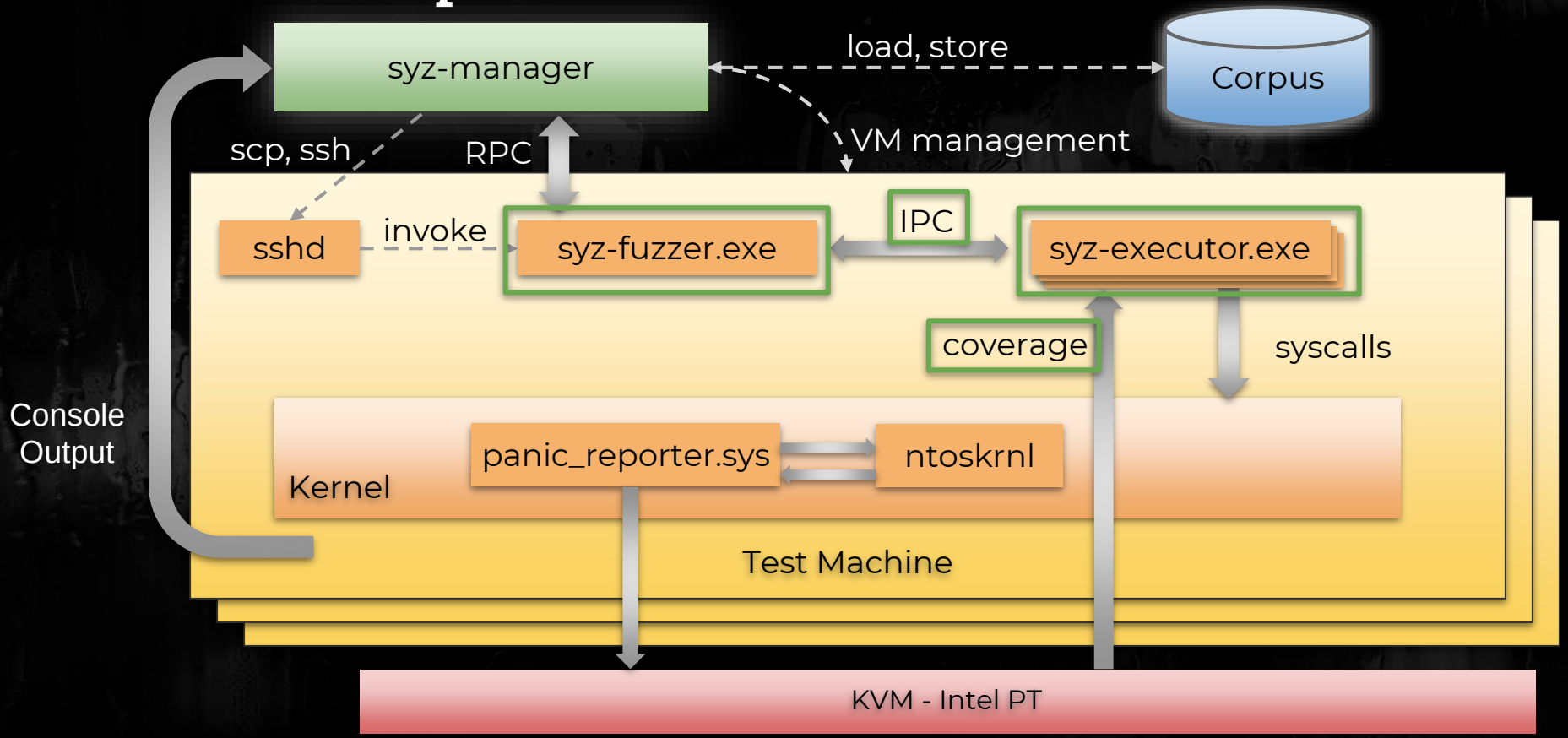
86.88	EngStretchBltOld(_SURFOBJ *,_…	0x1C0272B80	147 / 207	1033 / 1189	6088	129	
44.42	GreSetDIBitsToDeviceInternal	0x1C0085700	93 / 299	605 / 1362	6278	167	
24.13	BltLnkRect(_BLTLNKINFO *,_REC…	0x1C006DF00	43 / 261	324 / 1343	6335	112	
41.30	xxxMenuWindowProc	0x1C02100F0	76 / 329	650 / 1574	6552	209	
43.76	xxxInterSendMsgEx	0x1C0040BA0	122 / 385	673 / 1538	6769	275	
18.67	EngStretchBltNew(_SURFOBJ *,_…	0x1C002D7A8	24 / 229	252 / 1350	7247	142	
57.74	GreExtTextOutWLocked(XDCOBJ &…	0x1C007B690	147 / 369	1097 / 1900	8366	222	
43.02	xxxRealDefWindowProc	0x1C0057BDC	161 / 476	850 / 1976	8389	283	
49.78	NtGdiBitBltInternal	0x1C00818A0	153 / 429	1030 / 2069	9268	252	
42.63	NtGdiAlphaBlend	0x1C007F1A0	131 / 503	951 / 2231	10005	318	
64.16	xxxCreateWindowEx	0x1C0050290	283 / 568	1806 / 2815	13518	322	
43.37	xxxSystemParametersInfoWorker	0x1C00A1DB4	309 / 998	1649 / 3802	16767	619	
33.28	xxxScanSysQueue(tagTHREADINFO…	0x1C00470D0	165 / 771	1091 / 3278	16824	480	



Win32k - Recap



Win32k - Recap



Sanity Check

We used the fuzzer to reproduce CVE-2018-0744
(showed earlier)

Sanity Check

We used the fuzzer to reproduce CVE-2018-0744 (showed earlier)

That didn't work

Sanity Check

We used the fuzzer to reproduce CVE-2018-0744 (showed earlier)

That didn't work

Session 0 ⟶ Session 1

Sanity Check

We used the fuzzer to reproduce CVE-2018-0744
(showed earlier)

That didn't work

Session 0 ⟶ Session 1

Conclusion ⟶ Reproduce old bugs

Stability check

Added ~15 APIs and we let it run for the night


:(BSOD

:(BSOD


:(BSOD

First Bug UAF

```
nt!DbgBreakPointWithStatus
nt!KiBugCheckDebugBreak+0x12
nt!KeBugCheck2+0x957
nt!KeBugCheckEx+0x107
nt!MiSystemFault+0x1ac22a
nt!MmAccessFault+0x327
nt!KiPageFault+0x343
win32kfull!_OpenClipboard+0xd7439
win32kfull!NtUserOpenClipboard+0x14a
nt!KiSystemServiceCopyEnd+0x25
win32u!NtUserOpenClipboard+0x14
USER32!OpenClipboard+0x11
```

First Bug UAF

```
nt!DbgBreakPointWithStatus
nt!KiBugCheckDebugBreak+0x12
nt!KeBugCheck2+0x957
nt!KeBugCheckEx+0x107
nt!MiSystemFault+0x1ac22a
nt!MmAccessFault+0x327
nt!KiPageFault+0x343
win32kfull!_OpenClipboard+0xd7439
win32kfull!NtUserOpenClipboard+0x14a
nt!KiSystemServiceCopyEnd+0x25
win32u!NtUserOpenClipboard+0x14
USER32!OpenClipboard+0x11
```

Reproduces on some machines

What the **fuzz**?

First Bug UAF

```
nt!DbgBreakPointWithStatus
nt!KiBugCheckDebugBreak+0x12
nt!KeBugCheck2+0x957
nt!KeBugCheckEx+0x107
nt!MiSystemFault+0x1ac22a
nt!MmAccessFault+0x327
nt!KiPageFault+0x343
win32kfull!_OpenClipboard+0xd7439
win32kfull!NtUserOpenClipboard+0x14a
nt!KiSystemServiceCopyEnd+0x25
win32u!NtUserOpenClipboard+0x14
USER32!OpenClipboard+0x11
```

Reproduces on some machines

What the **fuzz**?

```
void crash() {
    OpenClipboard(0);
    HWINSTA wnd1 = OpenClipboard(0, 0, WINSTA_READSCREEN | WINSTA_ENUMDESKTOPS, 0);
    HWINSTA wnd2 = GetDesktopWindow();
    OpenClipboard(wnd2);
    SetProcessWindowStation(wnd1);
}
```

First Bug UAF

```
}
UserSetLastError(5i64);
// ;
// ; Check if ETW 487d6e37-1b9d-46d3-a8fd-54ce8bdf8a53 has specific flag
// ;
if ( (unsigned int)Win32kTraceLoggingLevel > 5
  && TlgKeywordOn((__int64)&Win32kTraceLoggingLevel, 0x400000000000i64) )
{
  thread_info = *(_QWORD *)(winsta_tag + 48);
  // ;
  // ; // pti = tagTHREADINFO
  // ; // ppi = PPROCESSINFO
  // ;
  // ; pti->ppi->W32Pid
  // ;
  v14 = *(_DWORD *)(*(_QWORD *)(thread_info + 416) + 56i64);
  v17 = &v14;
  v18 = 4i64;
  TlgCreateWsz(&v19, (unsigned __int16 *)(*(_QWORD *)(thread_info + 416) + 960i64));
  // ;
  // ; call EtwWriteTransfer
  // ;
  TlgWrite((__int64)&Win32kTraceLoggingLevel, (unsigned __int8 *)&unk_1C02D87BC, 0i64, 0i64, v13, (__int64)&v16);
}
```

000BAD80 _OpenClipboard:61 (1C00BB980)

First Bug UAF

```
}
UserSetLastError(5i64);
// ;
// ; Check if ETW 487d6e37-1b9d-46d3-a8fd-54ce8bdf8a53 has specific flag
// ;
if ( (unsigned int)Win32kTraceLoggingLevel > 5
  && TlgKeywordOn((__int64)&Win32kTraceLoggingLevel, 0x400000000000i64) )
{
  thread_info = *(_QWORD *)(winsta_tag + 48);
  // ;
  // ; // pti = tagTHREADINFO
  // ; // ppi = PPROCESSINFO
  // ;
  // ; pti->ppi->W32Pid
  // ;
  v14 = *(_DWORD *)(*(_QWORD *)(thread_info + 416) + 56i64);
  v17 = &v14;
  v18 = 4i64;
  TlgCreateWsz(&v19, (unsigned __int16 *)(*(_QWORD *)(thread_info + 416) + 960i64));
  // ;
  // ; call EtwWriteTransfer
  // ;
  TlgWrite((__int64)&Win32kTraceLoggingLevel, (unsigned __int8 *)&unk_1C02D87BC, 0i64, 0i64, v13, (__int64)&v16);
}
```

000BAD80 _OpenClipboard:61 (1C00BB980)

First Bug UAF

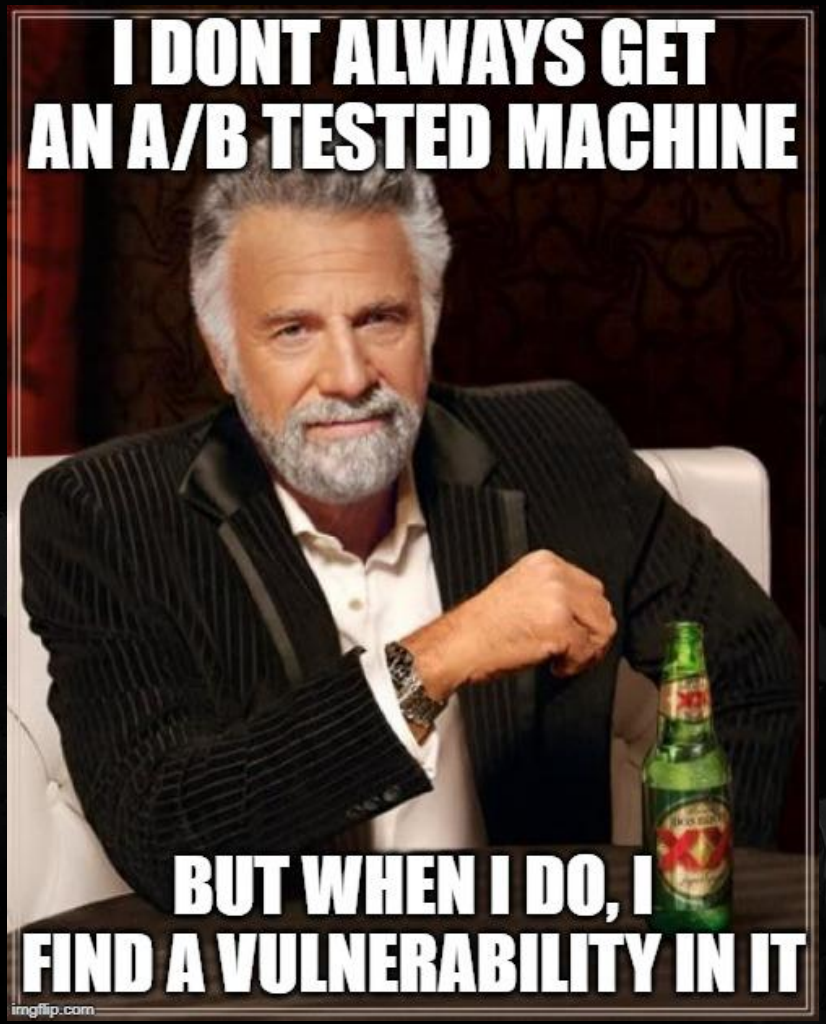
```
}
UserSetLastError(5i64);
// ;
// ; Check if ETW 487d6e37-1b9d-46d3-a8fd-54ce8bdf8a53 has specific flag
// ;
if ( (unsigned int)Win32kTraceLoggingLevel > 5
  && TlgKeywordOn((__int64)&Win32kTraceLoggingLevel, 0x400000000000i64) )
{
  thread_info = *(_QWORD *)(winsta_tag + 48);
  // ;
  // ; // pti = tagTHREADINFO
  // ; // ppi = PPROCESSINFO
  // ;
  // ; pti->ppi->W32Pid
  // ;
  v14 = *(_DWORD *)(*(_QWORD *)(thread_info + 416) + 56i64);
  v17 = &v14;
  v18 = 4i64;
  TlgCreateWsz(&v19, (unsigned __int16 *)(*(_QWORD *)(thread_info + 416) + 960i64));
  // ;
  // ; call EtwWriteTransfer
  // ;
  TlgWrite((__int64)&Win32kTraceLoggingLevel, (unsigned __int8 *)&unk_1C02D87BC, 0i64, 0i64, v13, (__int64)&v16);
}
```

000BAD80 _OpenClipboard:61 (1C00BB980)

First Bug UAF

```
}
UserSetLastError(5i64);
// ;
// ; Check if ETW 487d6e37-1b9d-46d3-a8fd-54ce8bdf8a53 has specific flag
// ;
if ( (unsigned int)Win32kTraceLoggingLevel > 5
  && TlgKeywordOn((__int64)&Win32kTraceLoggingLevel, 0x400000000000i64) )
{
  thread_info = *(_QWORD *)(winsta_tag + 48);
  // ;
  // ; // pti = tagTHREADINFO
  // ; // ppi = PPROCESSINFO
  // ;
  // ; pti->ppi->W32Pid
  // ;
  v14 = *(_DWORD *)(*(_QWORD *)(thread_info + 416) + 56i64);
  v17 = &v14;
  v18 = 4i64;
  TlgCreateWsz(&v19, (unsigned __int16 *)(*(_QWORD *)(thread_info + 416) + 960i64));
  // ;
  // ; call EtwWriteTransfer
  // ;
  TlgWrite((__int64)&Win32kTraceLoggingLevel, (unsigned __int8 *)&unk_1C02D87BC, 0i64, 0i64, v13, (__int64)&v16);
}
```

000BAD80 _OpenClipboard:61 (1C00BB980)


I DONT ALWAYS GET
AN A/B TESTED MACHINE
BUT WHEN I DO, I
FIND A VULNERABILITY IN IT
imgflip.com

Back to checking stability

We re-installed windows, let it run again for the night

We got another bug

2nd Bug

```
nt!RtlpHpVsChunkSplit+0x3c5
nt!RtlpHpVsContextAllocateInternal+0x28c
nt!RtlpHpVsContextAllocate+0x46
nt!RtlpAllocateHeapInternal+0x55
nt!RtlAllocateHeap+0x37
win32kfull!ClassAlloc+0x39
win32kfull!InternalRegisterClassEx+0x14e
win32kfull!_RegisterClassEx+0x85
win32kfull!NtUserRegisterClassExWOW+0x59f
nt!KiSystemServiceCopyEnd+0x25
win32u!NtUserRegisterClassExWOW+0x14
USER32!RegisterClassExWOWA+0x205
USER32!RegisterClassExA+0x30
poc!main+0x67 [r:\poc\poc\main.cpp @ 15]
```

DoS in RegisterClassExA

```
int main(int  argc, char **argv) {
    WNDCLASSEX WindowClass = { 0 };

    WindowClass.cbSize = sizeof(WNDCLASSEX);
    WindowClass.cbClsExtra = 0x2771;
    WindowClass.lpfnWndProc = DefWindowProc;
    WindowClass.lpszClassName = "Class";

    RegisterClassExA(&WindowClass);
    return 0;
}
```

Motivation++

15 syscalls → 2 Bugs

~1500 syscalls → ~200 Bugs

Win32k - grammar

Create syscall grammar from scratch

Automation?

Win32k - grammar

Create syscall grammar from scratch

Automation?

```
HWND
WINAPI
CreateWindowExA(
    _In_ DWORD dwExStyle,
    _In_opt_ LPCSTR lpClassName,
    _In_opt_ LPCSTR lpWindowName,
    _In_ DWORD dwStyle,
    _In_ int X,
    _In_ int Y,
    _In_ int nWidth,
    _In_ int nHeight,
    _In_opt_ HWND hWndParent,
    _In_opt_ HMENU hMenu,
    _In_opt_ HINSTANCE hInstance,
    _In_opt_ LPVOID lpParam);
```

Win32k - grammar

Create syscall grammar from scratch

Automation?

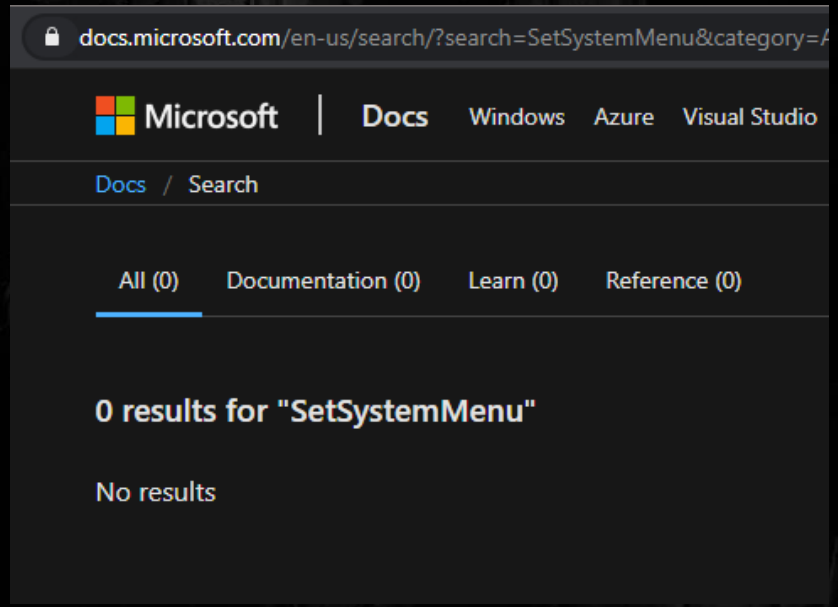
```
HWND
WINAPI
CreateWindowExA(
    _In_ DWORD dwExStyle,
    _In_opt_ LPCSTR lpClassName,
    _In_opt_ LPCSTR lpWindowName,
    _In_ DWORD dwStyle,
    _In_ int X,
    _In_ int Y,
    _In_ int nWidth,
    _In_ int nHeight,
    _In_opt_ HWND hWndParent,
    _In_opt_ HMENU hMenu,
    _In_opt_ HINSTANCE hInstance,
    _In_opt_ LPVOID lpParam);
```

Win32k - grammar

Create syscall grammar from scratch

Automation?

```
HWND
WINAPI
CreateWindowExA(
    _In_ DWORD dwExStyle,
    _In_opt_ LPCSTR lpClassName,
    _In_opt_ LPCSTR lpWindowName,
    _In_ DWORD dwStyle,
    _In_ int X,
    _In_ int Y,
    _In_ int nWidth,
    _In_ int nHeight,
    _In_opt_ HWND hWndParent,
    _In_opt_ HMENU hMenu,
    _In_opt_ HINSTANCE hInstance,
    _In_opt_ LPVOID lpParam);
```



Win32k - grammar

- Technically windows is open source
  - Windows NT Leaked sources - https://github.com/ZoloZiak/WinNT4
  - Windows 2000 Leaked sources - https://github.com/pustladi/Windows-2000
  - ReactOS (Leaked w2k3 sources?) - https://github.com/reactos/reactos
  - Windows Research Kit - https://github.com/Zer0Mem0ry/ntoskrnl
- For each syscall
  - We looked at the sources + MSDN
  - Verified definition with IDA / WinDbg
- Most APIs are pretty simple
- But others are a nightmare

```
SetBkColor(hDc HDC, color int32)
EndPage(hDc HDC)
EndPath(hDc HDC)
CloseFigure(hDc HDC)
BeginPath(hDc HDC)
SetMetaRgn(hDc HDC)
StrokePath(hDc HDC)
GetWindowTextA(hWnd HWND, lpString buffer[out], nMaxCount len[lpString])
SaveDC(hDc HDC)
StrokeAndFillPath(hDc HDC)
StartPage(hDc HDC)
CancelDC(hDc HDC)
GetSystemPaletteUse(hDc HDC)
ChildWindowFromPointEx(hWnd HWND, pt ptr[in, POINT], flags int32[0:4]) HWND
WidenPath(hDc HDC)
SwapBuffers(hDc HDC)
AbortDoc(hDc HDC)
FlattenPath(hDc HDC)
UpdateColors(hDc HDC)
CreateHalftonePalette(hDc HDC) HPALETTE
SelectPalette(hDc HDC, hPal HPALETTE, bForceBkgd int32[0:1]) HPALETTE
FillPath(hDc HDC)
EndDoc(hDc HDC)
PathToRegion(hDc HDC) HRGN
AbortPath(hDc HDC)
SetLayout(hDc HDC, l int32[0x0:0x10])
SelectClipPath(hDc HDC, mode int32[0x0:0x10])
PtVisible(hDc HDC, x int32, y int32)
LineTo(hDc HDC, x int32, y int32)
GetNearestColor(hDc HDC, cr int32)
RestoreDC(hDc HDC)
WindowFromPoint(point ptr[in, POINT]) HWND
DrawCaption(hWnd HWND, hDc HDC, point ptr[in, POINT], uflags flags[dc_flags]) HWND
DrawAnimatedRects(hWnd HWND, idAni int32[0:3], lprcFrom ptr[in, RECT], lprcTo ptr[in, R
RegisterHotKey(hWdn HWND[opt], id int32[0:0xff], fsModifiers flags[mod_flags], vk int32
UnregisterHotKey(hWnd HWND[opt], id int32[0x0:0xff])
ShowWindow(hWnd HWND, nCmdShow int32[0x0:0x10])
ShowWindowAsync(hWnd HWND, nCmdShow int32[0x0:0x10])
UpdateLayeredWindow(hWnd HWND, hdcDst HDC[opt], pptDst ptr[in, POINT, opt], ppSize ptr[
FlashWindow(hWnd HWND, bInvert int32[0:1])
FlashWindowEx(pFwi ptr[in, FLASHWINFO])
```

```
GUITHREADINFO {
    cbSize      const[72, int32]
    flags       int32[0:16]
    hwndActive  HWND
    hwndFocus   HWND
    hwndCapture HWND
    hwndMenuOwner   HWND
    hwndMoveSize    HWND
    hwndCaret   HWND
    rcRect      RECT
}

MNDDRAG {
    a   int32
    hMenu   HMENU
    b   int32
    hWnd    HWND
}

TRIVERTEX {
    x   int32
    y   int32
    Red int16
    Green   int16
    Blue    int16
    Alpha   int16
}
```


3 new vulnerabilities in GDI


3 new vulnerabilities in GDI
But we want more!

Going deeper

Fuzzers are not magic

- We need to teach them tricks & help them reach difficult attack surfaces

Our process

- We learn as much we can about the attack surfaces (bug classes, prior work, ..)
- We try to reproduce old bugs
- Take time to look at coverage results

We try to inject insights back into the fuzzing process

Win32k “trick” example

Gdi Shared Handle Table, pointed from the PEB

Win32k “trick” example

Gdi Shared Handle Table, pointed from the PEB

Includes global handles (created by win32k)

Let’s use them - “GetGdiHandle(type, index)”

```
typedef struct {
  PVOID64 pKernelAddress;
  USHORT wProcessId;
  USHORT wCount;
  USHORT wUpper;
  USHORT wType;
  PVOID64 pUserAddress;
} GDICELL;
```

Win32k “trick” example

Gdi Shared Handle Table, pointed from the PEB

Includes global handles (created by win32k)

Let’s use them - “GetGdiHandle(type, index)”

```
typedef struct {
  PVOID64 pKernelAddress;
  USHORT wProcessId;
  USHORT wCount;
  USHORT wUpper;
  USHORT wType;
  PVOID64 pUserAddress;
} GDICELL;
```

Using this trick CVE-2019-1159 UAF triggered by one syscall

```
void crash() {
    GetDCEx(0, hGlobalHrgn, DCX_EXCLUDERGN);
}
```

Results - Win32k

60 vCPUs & 1.5 months of fuzzing part time

Results - Win32k

60 vCPUs & 1.5 months of fuzzing part time

8 vulns, 6 CVEs (1 duplicate, 1 pending)

Results - Win32k

60 vCPUs & 1.5 months of fuzzing part time

8 vulns, 6 CVEs (1 duplicate, 1 pending)

- CVE-2019-1014, CVE-2019-1096, CVE-2019-1159, CVE-2019-1164, CVE-2019-1256, CVE-2019-1286

Results - Win32k

- 60 vCPUs & 1.5 months of fuzzing part time
- 8 vulns, 6 CVEs (1 duplicate, 1 pending)
  - CVE-2019-1014, CVE-2019-1096, CVE-2019-1159, CVE-2019-1164, CVE-2019-1256, CVE-2019-1286
- 3 DOS, 1 crash in WinLogon and few deadlocks

LPE → RCE?

WMF - Windows Metafile Format

Designed back in 1990s

Supports both **vector graphics** and **bitmaps**

The image is basically a lists of records describing GDI calls

Microsoft Extended WMF:

- EMF
- EMF+
- EMFSPOOL

https://j00ru.vexillium.org/slides/2016/pacsec.pdf

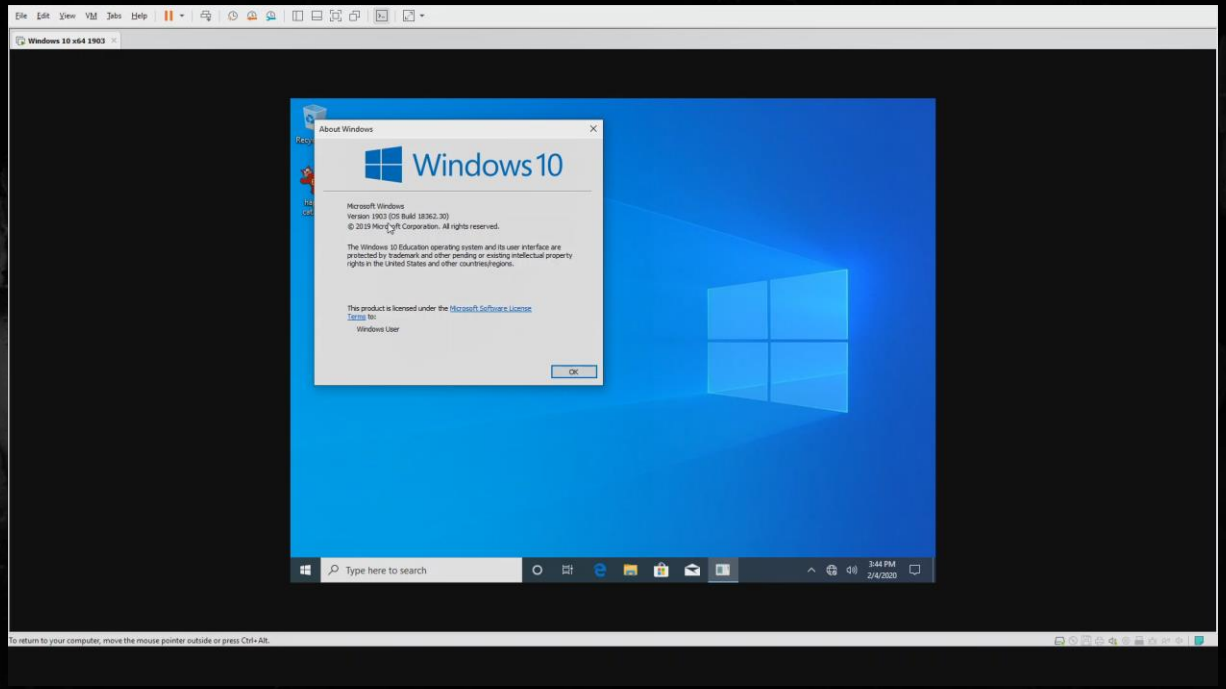
EMF - Enhanced Metafile Format

EMF - Enhanced Metafile Format

EMF - Enhanced Metafile Format

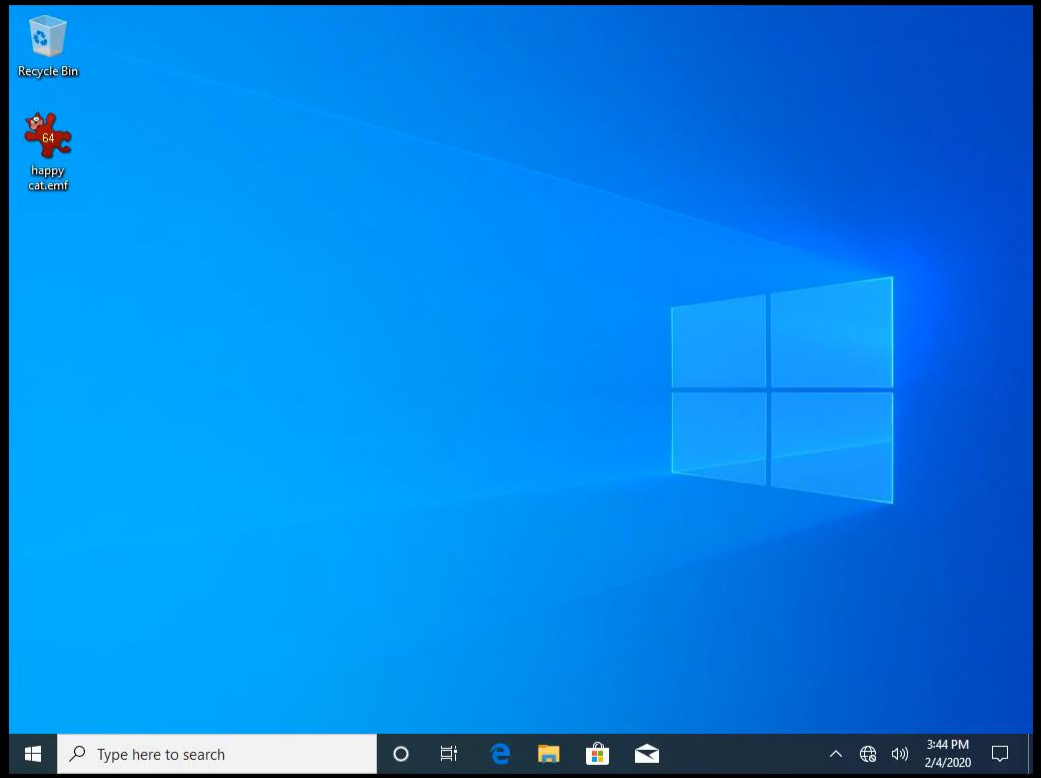

We happen to have a
vulnerability in StretchBlt

GDI -> EMF -> RCE: DEMO



File Edit View VM Tabs Help

Windows 10 x64 1903



To direct input to this VM, move the mouse pointer inside or press Ctrl+G.

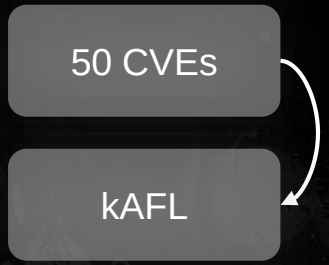
Future work

- Win32k
  - DirectX drivers
  - Win32 callbacks (callbacks in general)
- Bochspwn Reloaded + Generated corpus (450k)
- Open source
- The rest of the kernel

Summary

50 CVEs

Summary



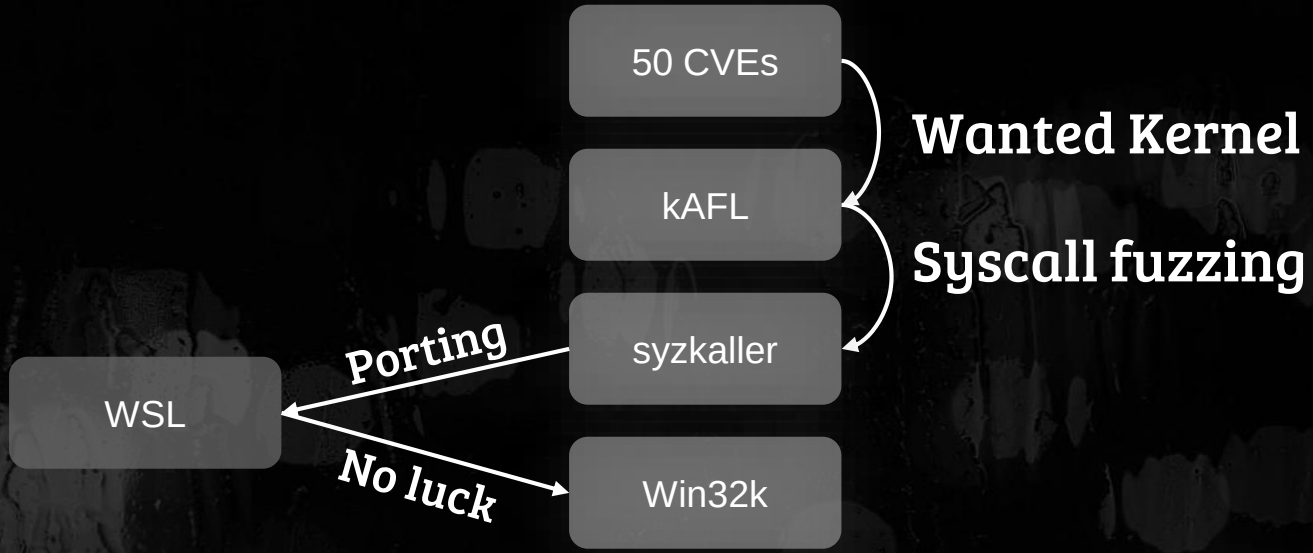
Wanted Kernel

Summary

Summary


50 CVEs
kAFL
syzkaller
WSL
Porting
Wanted Kernel
Syscall fuzzing

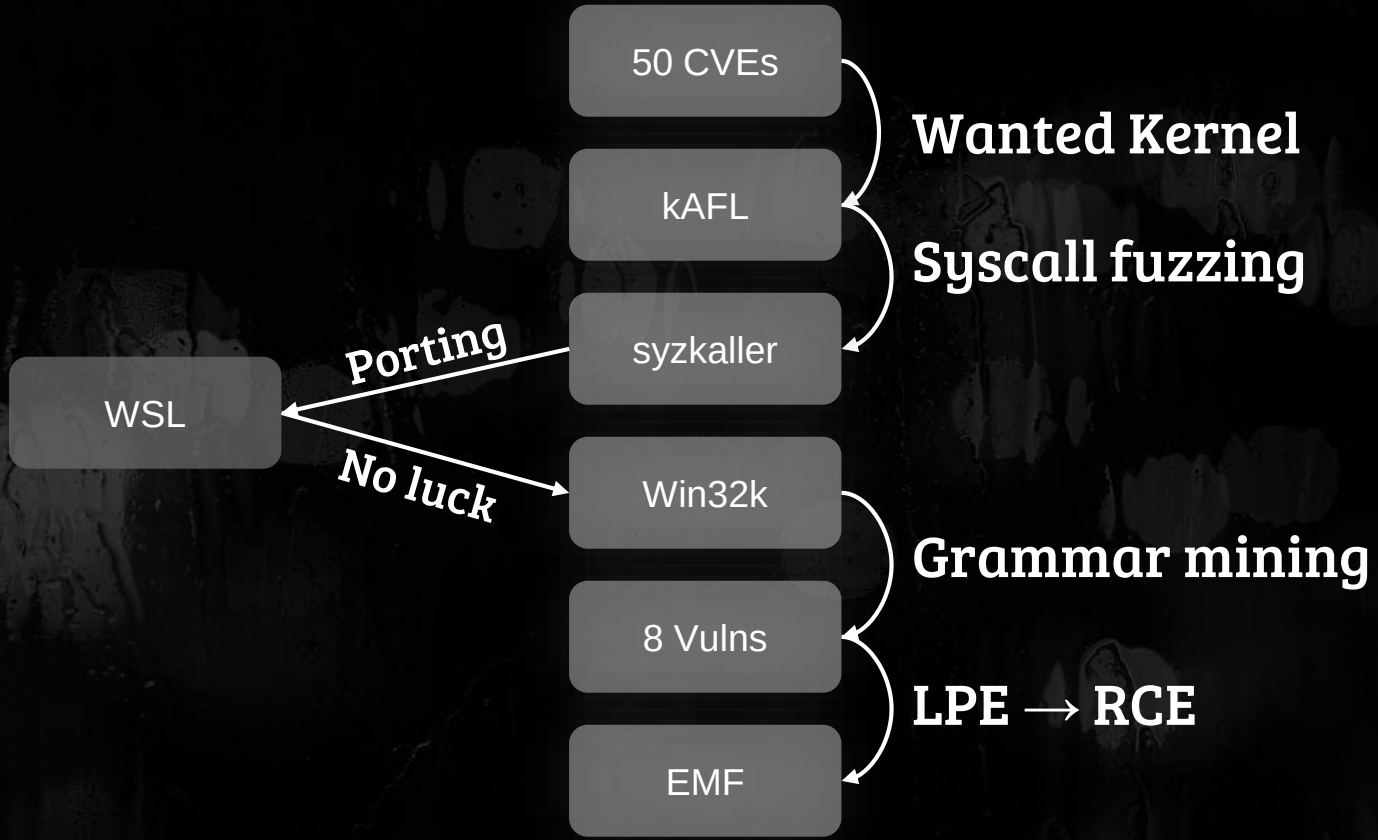
Summary


50 CVEs
kAFL
syzkaller
WSL
Win32k
Wanted Kernel
Syscall fuzzing
Porting
No luck

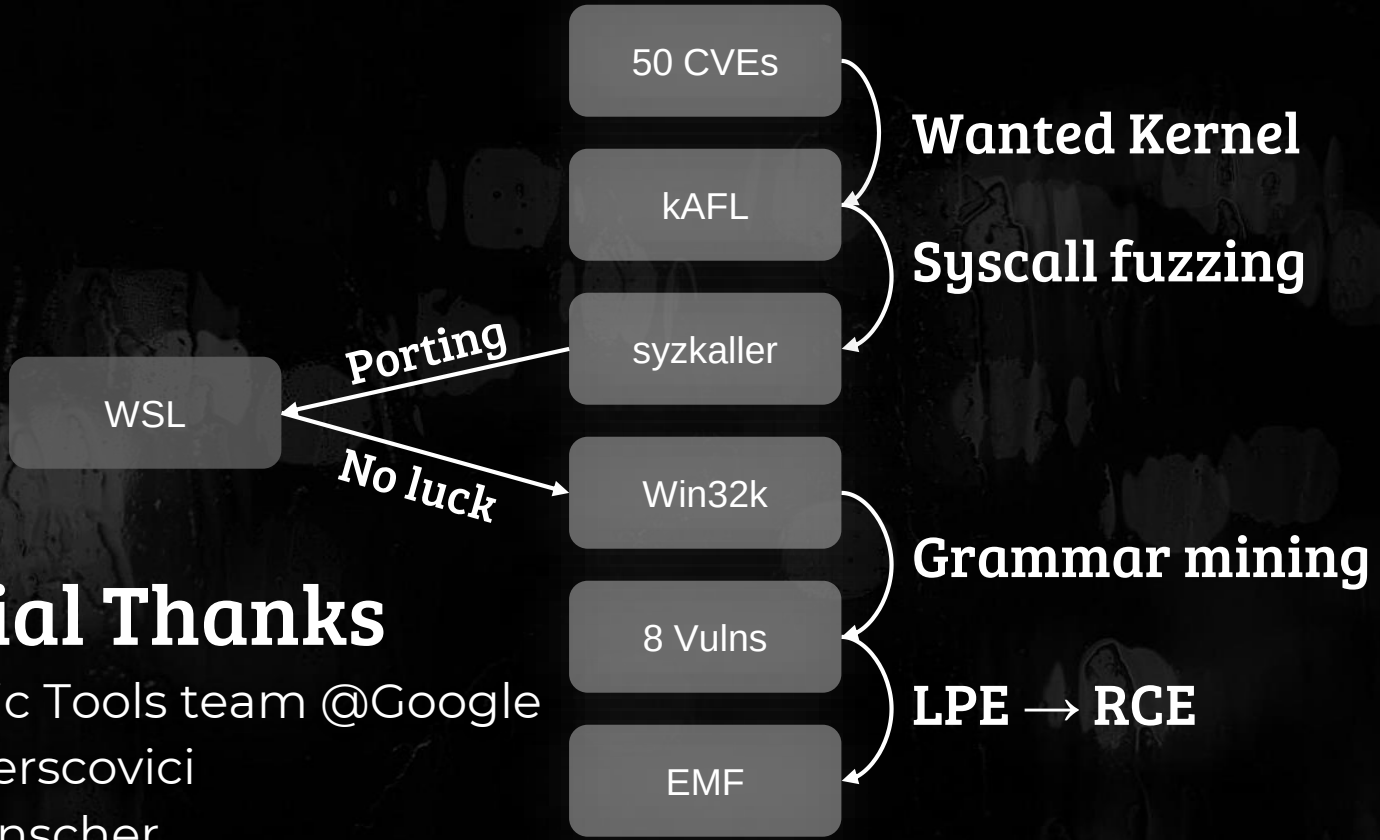
Summary


50 CVEs
Wanted Kernel
kAFL
Syscall fuzzing
syzkaller
Porting
WSL
No luck
Win32k
Grammar mining
8 Vulns

Summary


50 CVEs
kAFL
syzkaller
WSL
Porting
No luck
Win32k
8 Vulns
EMF
Wanted Kernel
Syscall fuzzing
Grammar mining
LPE → RCE

Summary



Special Thanks

Dynamic Tools team @Google
Omri Herscovici
Ran Menscher

cp<r>
CHECK POINT RESEARCH

Questions?

 @YoavAlon

 @NetanelBenSimon