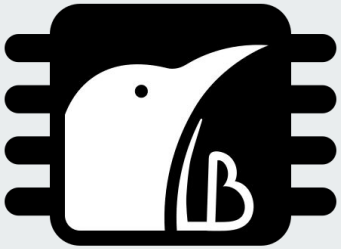


www.linuxboot.org

LinuxBoot progress: boot anything from Linux

Chris Koch (@hugelgupf) Google
Ofir Weisse **UMich**

Platform Security Summit - October 1, 2019

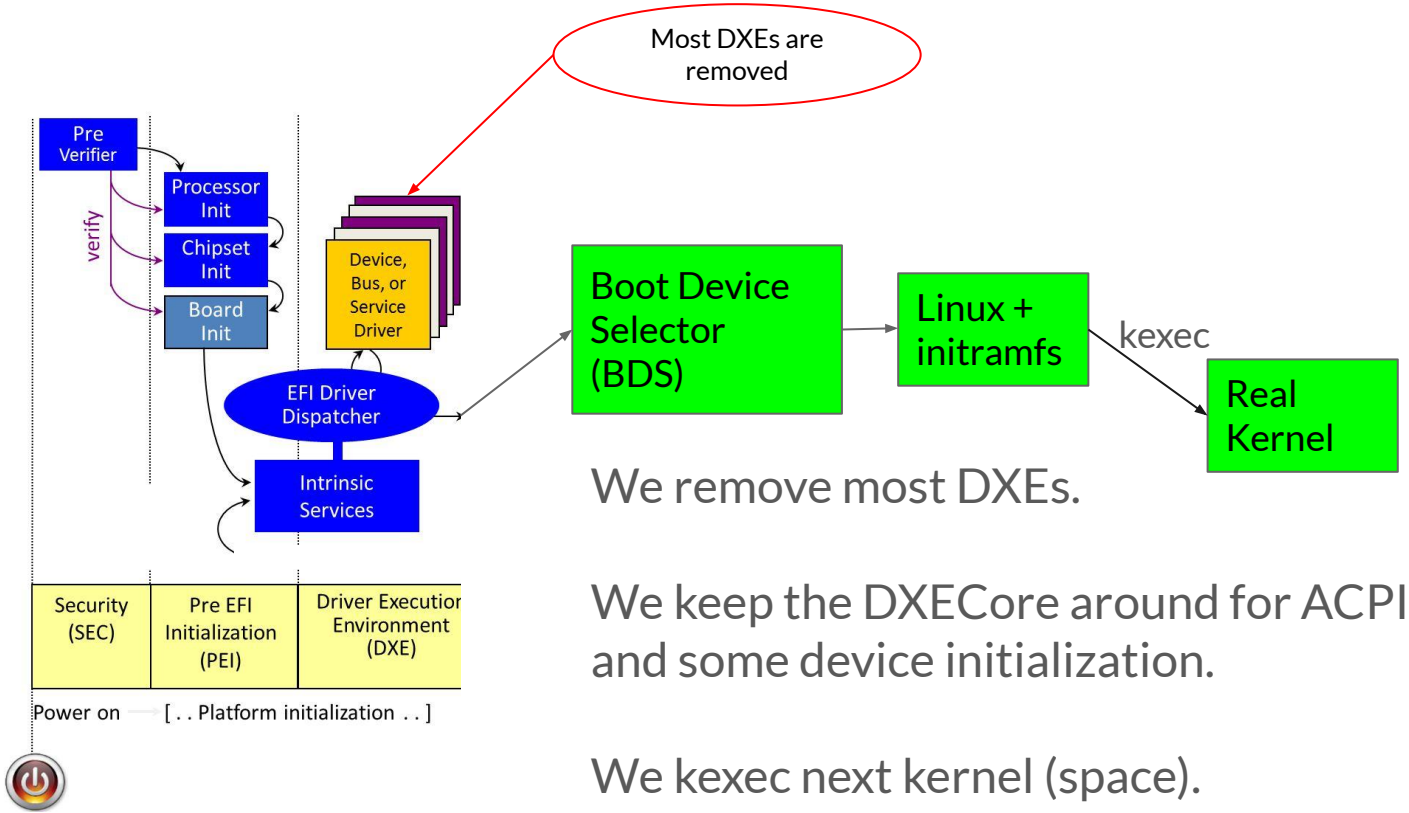
with

Ron Minnich, Ryan O'Leary, Gan Shun Lim, Max Shegai, Trammell Hudson,
Jean-Marie Verdun, David Hendricks, Andrea Barberio, Philipp Deppenwiese **and many others**

Recap: LinuxBoot on UEFI

Linux knows how to initialize devices.

Compile kernel as a PE32 executable: EFI_STUB



We remove most DXEs.

We keep the DXECore around for ACPI and some device initialization.

We kexec next kernel (space).

Why?

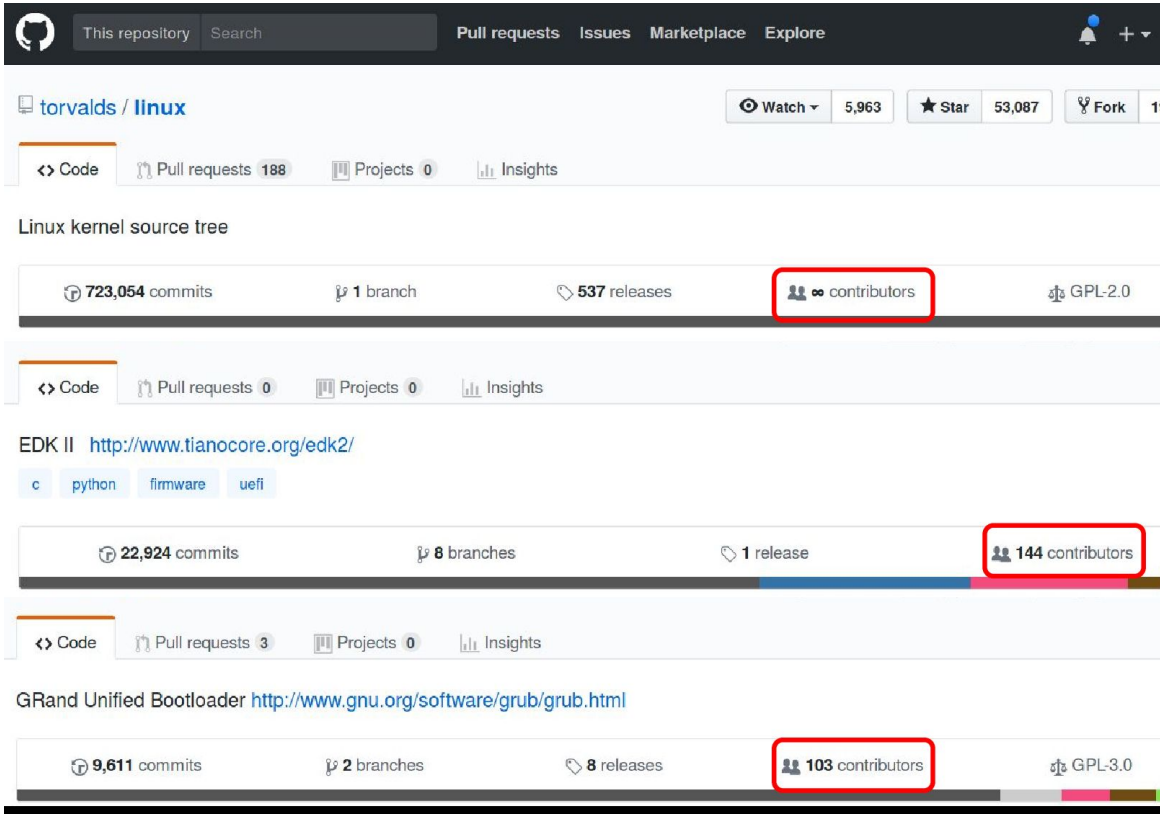
We've replaced UEFI complexity with Linux Kernel complexity

Little review & visibility

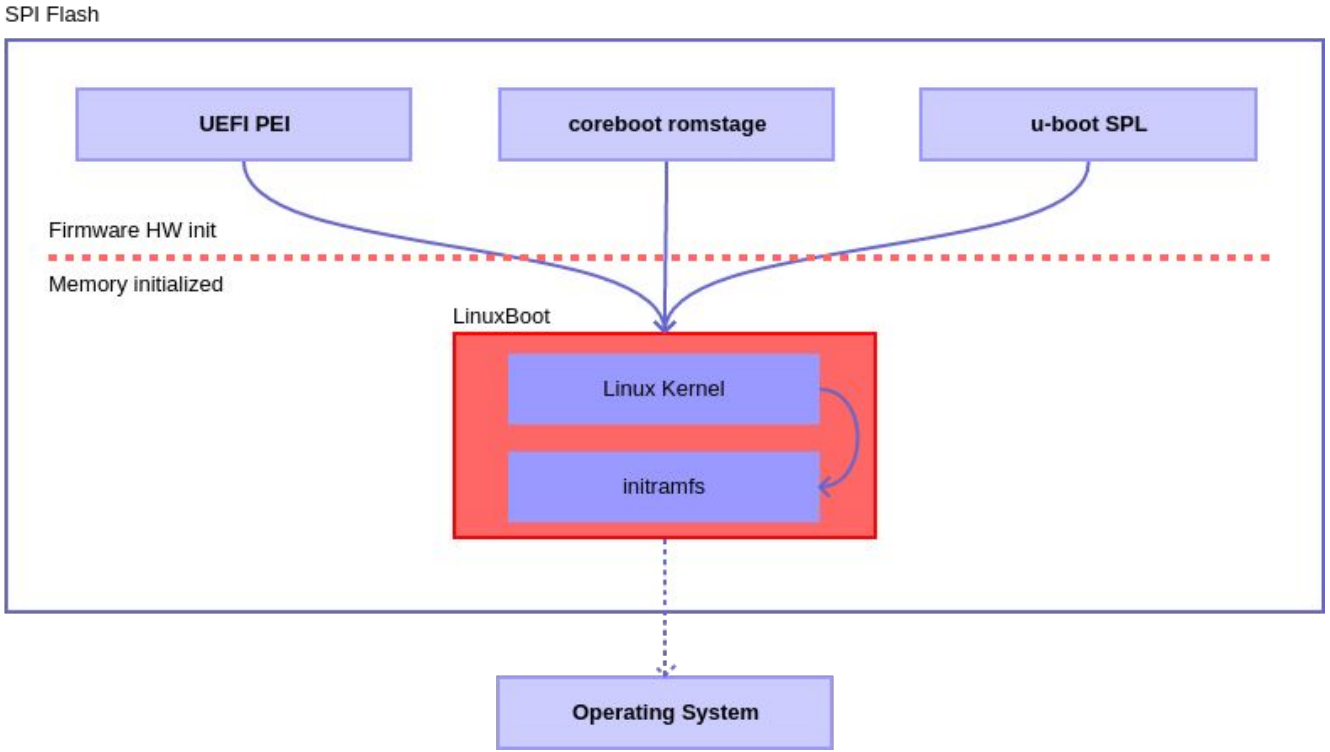
vs

an uncountable number of contributors

(Also, reproducible builds)



Not on UEFI?


SPI Flash
UEFI PEI
coreboot romstage
u-boot SPL
Firmware HW init
Memory initialized
LinuxBoot
Linux Kernel
initramfs
Operating System

u-root: pointlessly rewriting things in Go

- We have the full toolset of Linux applications at our fingertips in firmware now.
  - Let's use them!
  - Let's use a memory-safe language.
  - Let's use a language that makes concurrency easy.
- Enter **u-root**: 3MB - 5MB (compressed) initramfs in **Go**
  - busybox-like tools (cat, dd, ls, cp, cpio, …)
  - kexec-based bootloaders (PXE- and GRUB-compatible boot tools, ...)
  - github.com/u-root/u-root

Progress: Project Health

- New: merging duplicate projects
  - systemboot + u-root: Facebook + Google
  - systemboot had TPM + certificate support
  - u-root the “cleaner” bootloaders
  - deduplicate + improve code health

unit test in pkg/gpio

```go
func TestExport(t *testing.T) {
	testutil.SkipIfNotRoot(t)

	if err := Export(10); err != nil {
		t.Errorf("Could not export pin 10: %v", err)
	}

	// Only 10-20 are valid GPIOs in the mock chip.
	if err := Export(9); err == nil {
		t.Errorf("Export(pin 9) should have failed, got nil")
	}
}
```

CI presubmit:
VM-based
integration tests

(still needs work!)

Launch VM with unit tests in pkg/gpio

```go
func TestIntegration(t *testing.T) {
	vmtest.GolangTest(t, []string{"github.com/u-root/u-root/pkg/gpio"}, &vmtest.Options{
		QEMUOpts: qemu.Options{
			// Make GPIOs nums 10 to 20 available through the
			// mockup driver.
			KernelArgs: "gpio-mockup.gpio_mockup_ranges=10,20",
		},
	})
}
```

```
q, cleanup := vmtest.QEMUTest(t, &vmtest.Options{
        BuildOpts: uroot.Opts{
                Commands: uroot.BusyBoxCmds(
                        "github.com/u-root/u-root/cmds/core/init",
                        "github.com/u-root/u-root/cmds/core/kexec",
                ),
                ExtraFiles: []string{
                        "/tmp/multibootKernel:kernel",
                },
        },
        Uinit: []string{
                `kexec -l kernel -e -d --module="/kernel foo=bar" --module="/bbin/bb"`,
        },
        QEMUOpts: qemu.Options{
                SerialOutput: &serial,
        },
})
defer cleanup()

if err := q.Expect(`"status": "ok"`); err != nil {
        t.Logf(string(serial.Bytes()))
        t.Fatalf(`expected '"status": "ok"', got error: %v`, err)
}
```

Commands to build into VM initramfs

File to include in VM initramfs at /kernel

Command to run inside VM

Expect script

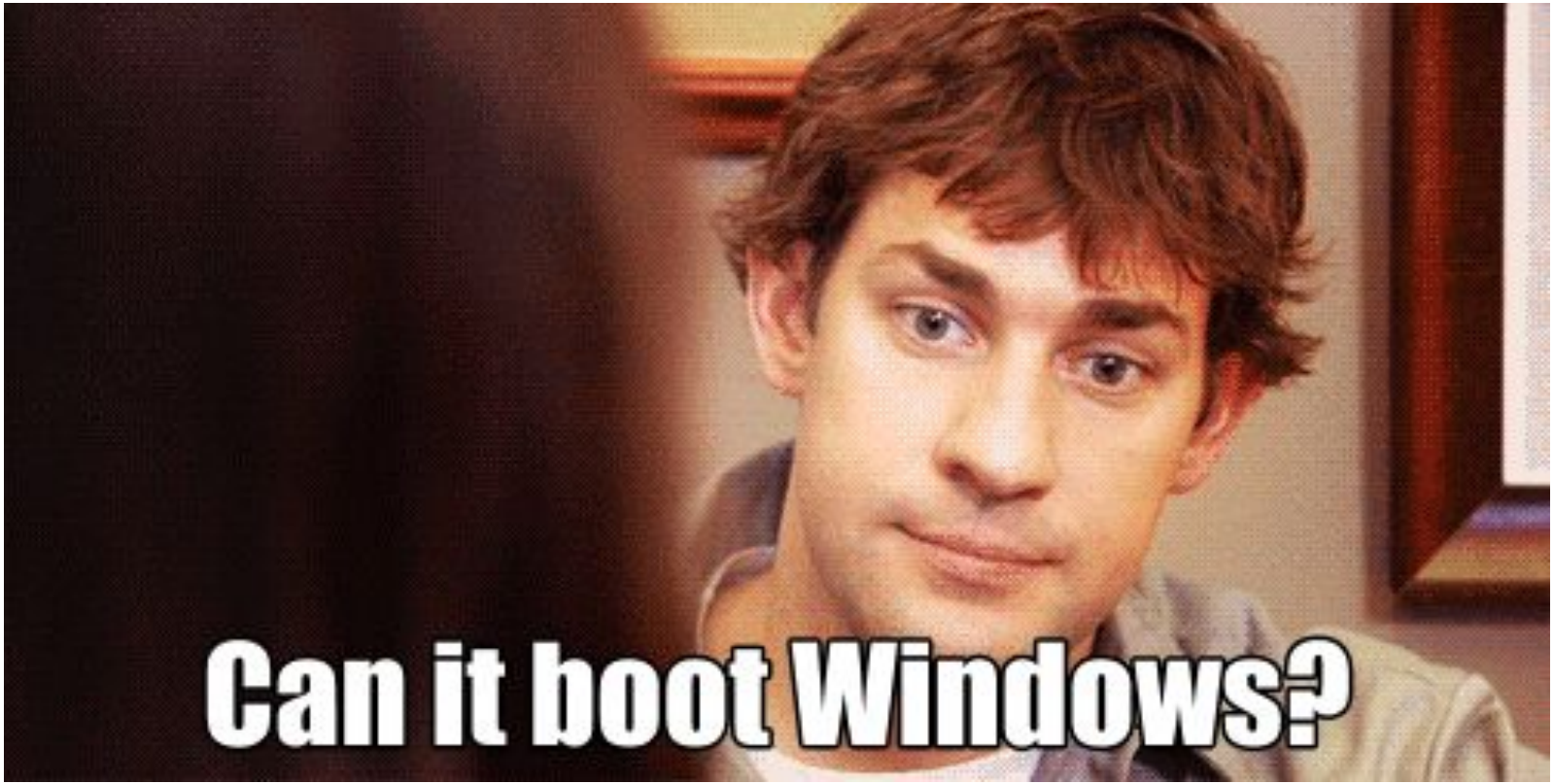
Progress

- New: **kexec multiboot kernels (Xen, ESXi, tboot, ...)**
  - tboot support essential to some of our users
  - Imagine writing a trampoline in Go assembly :)

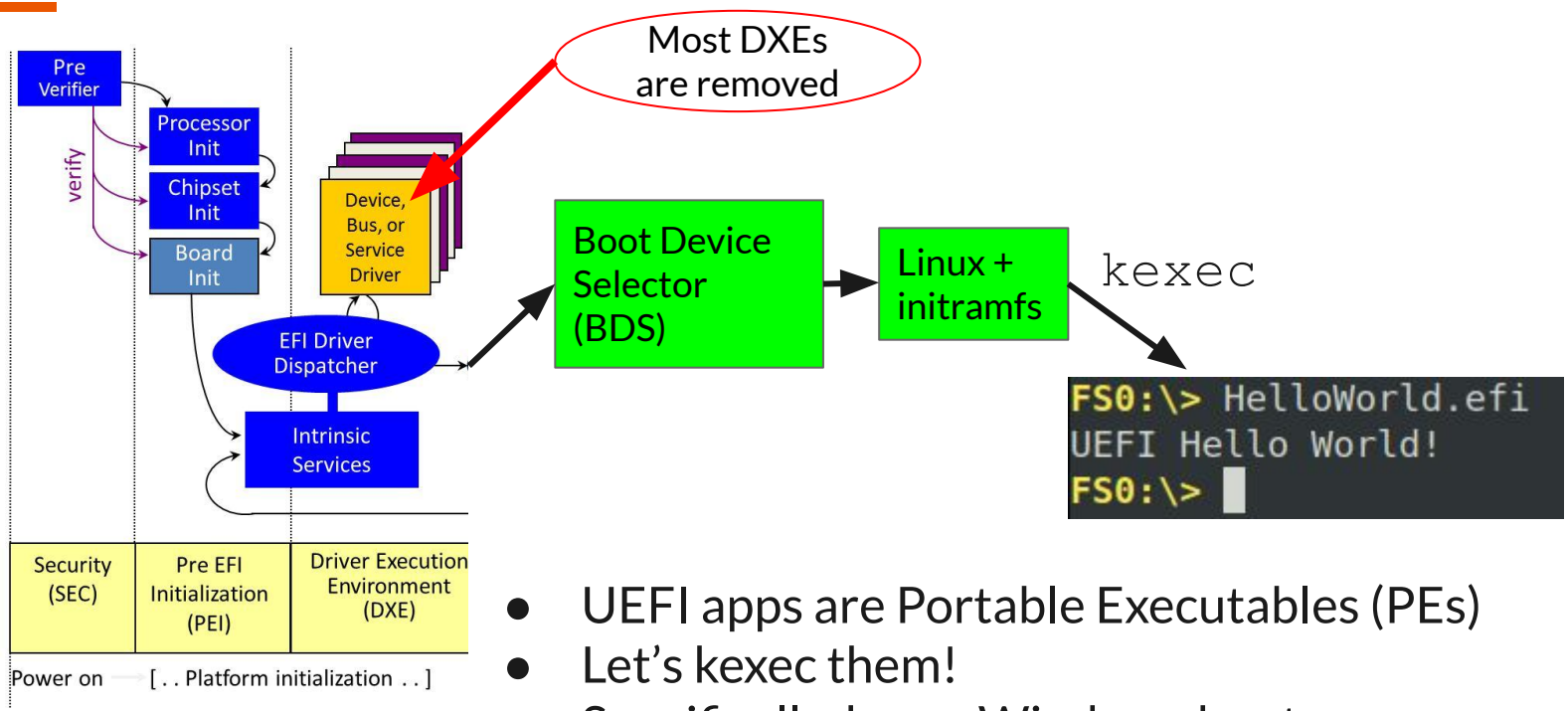
func Load

```
func Load(debug bool, file, cmdline string, modules []string, ibft *ibft.IBFT) error
```

Load parses and loads a multiboot kernel `file` using kexec_load.


Can it boot Windows?

Why not be UEFI compliant



- UEFI apps are Portable Executables (PEs)
- Let's kexec them!
- Specifically, kexec Windows boot-manager

What do you need to boot EFI apps?

PE32 loader into ring 0

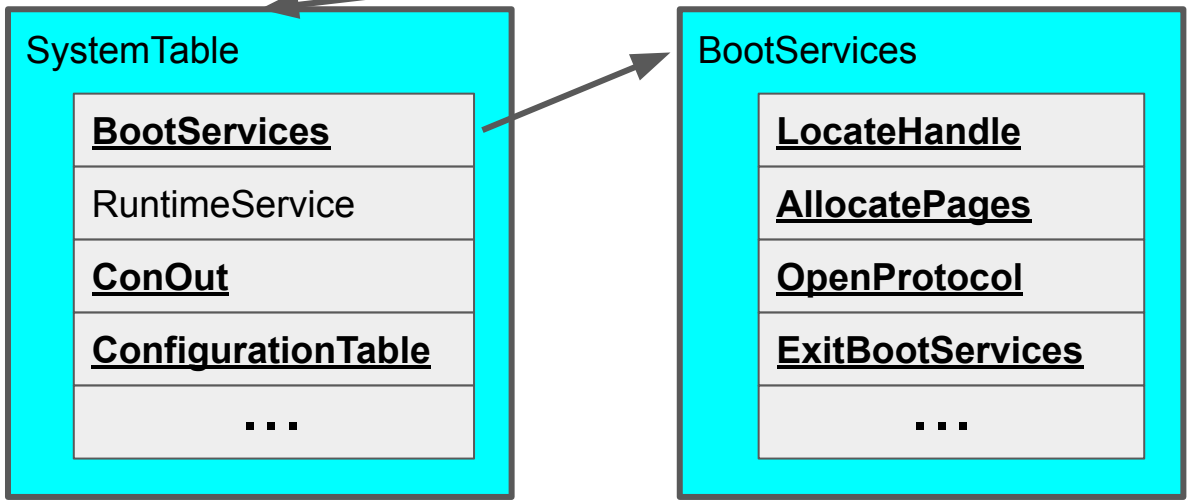
&

pointers to pass to the entrypoint

&

PE32 app expects physical addressing

```
_ModuleEntryPoint ( EFI_HANDLE        ImageHandle,
                    EFI_SYSTEM_TABLE  *SystemTable
```



Let’s collect some info

- Take EDKII, add a bunch of prints
  - What Boot Services are called?
  - What Protocols are invoked?
- Use that to boot Windows in a VM under EDKII/OVMF

Minimum Required EFI Boot Services

Services Used (out of 44)

- StartImage
- LocateHandle
- Open/CloseProtocol
- Allocate/FreePages
- Allocate/FreePool
- GetMemoryMap
- SetWatchdogTimer
- ExitBootServices

Minimum Required EFI Protocols

Services Used (out of 44)

- StartImage
- LocateHandle
- **Open/CloseProtocol**
- Allocate/FreePages
- Allocate/FreePool
- GetMemoryMap
- SetWatchdogTimer
- ExitBootServices

Happy conclusion:
UEFI spec is huge, but only a small subset is actually used

Protocols Used (Out of ~441)

- LoadedImageProtocol
- BlockIoProtocol
- DevicePathProtocol
- SimpleTextInputExProtocol
- StorageSecurityCommandProtocol
- GraphicsOutputProtocol

Launching Windows via kexec

- 3 stage loading process
  - bootmgfw.efi
    - Loads winload.efi
      - which loads ntoskernel.exe
- kexec code for PE32 loader -- **not that hard**
  - validation for this is easy -- launch
    - Linux with PE32-shim
    - An EFI hello world

Debug cycle

Debug cycle

1.Launch

2.Crash

3. Analyze

4. Learn something about

5. Fix

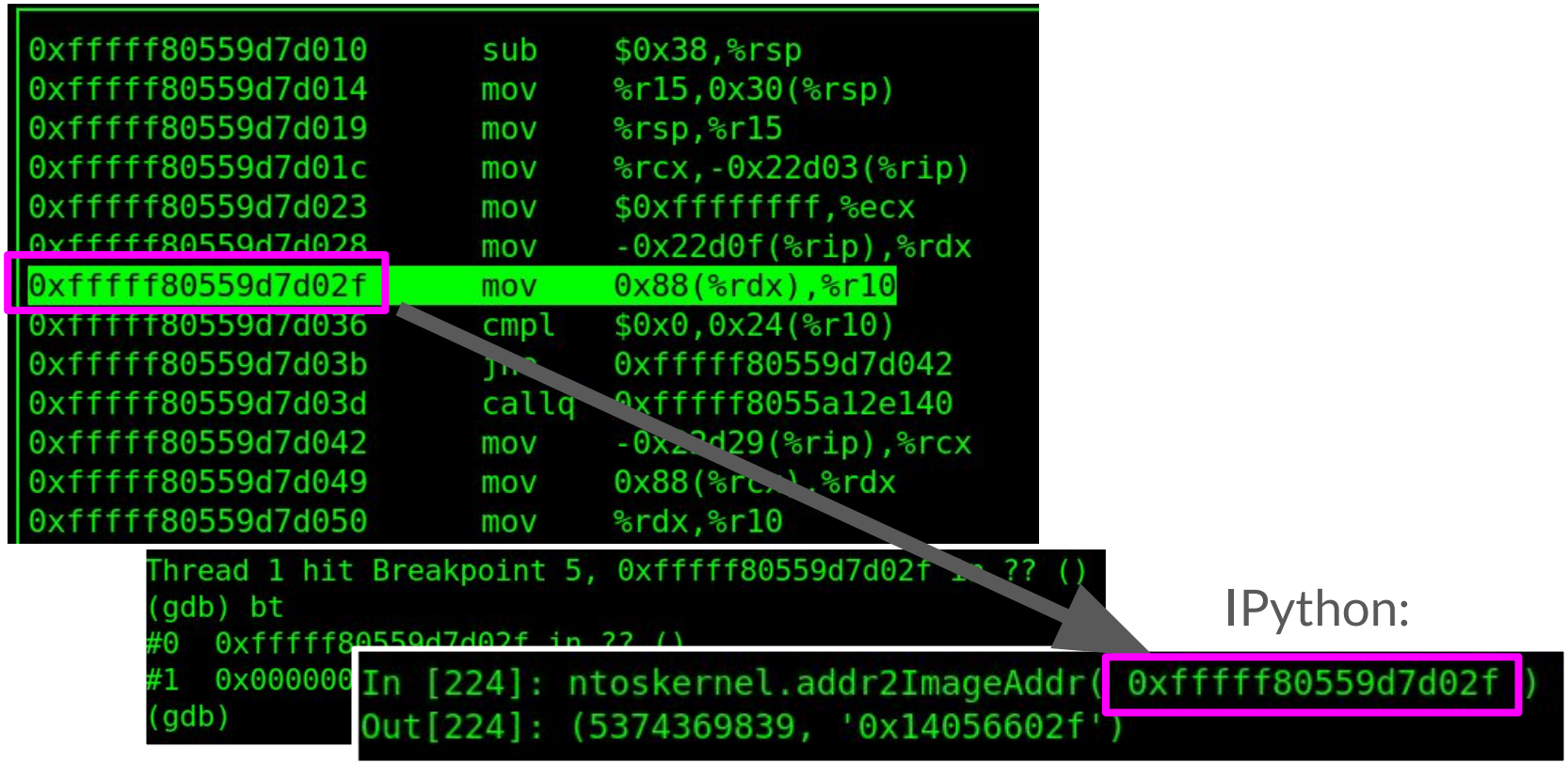
Debugging Example

```
0xfffff80559d7d010      sub    $0x38,%rsp
0xfffff80559d7d014      mov    %r15,0x30(%rsp)
0xfffff80559d7d019      mov    %rsp,%r15
0xfffff80559d7d01c      mov    %rcx,-0x22d03(%rip)
0xfffff80559d7d023      mov    $0xffffffff,%ecx
0xfffff80559d7d028      mov    -0x22d0f(%rip),%rdx
0xfffff80559d7d02f      mov    0x88(%rdx),%r10
0xfffff80559d7d036      cmpl   $0x0,0x24(%r10)
0xfffff80559d7d03b      jne    0xfffff80559d7d042
0xfffff80559d7d03d      callq  0xfffff8055a12e140
0xfffff80559d7d042      mov    -0x22d29(%rip),%rcx
0xfffff80559d7d049      mov    0x88(%rcx),%rdx
0xfffff80559d7d050      mov    %rdx,%r10
```

```
Thread 1 hit Breakpoint 5, 0xfffff80559d7d02f in ?? ()
(gdb) bt
#0  0xfffff80559d7d02f in ?? ()
#1  0x0000000000000000 in ?? ()
(gdb)
```

- Illegal memory access
- Stack trace is useless

Debugging Example

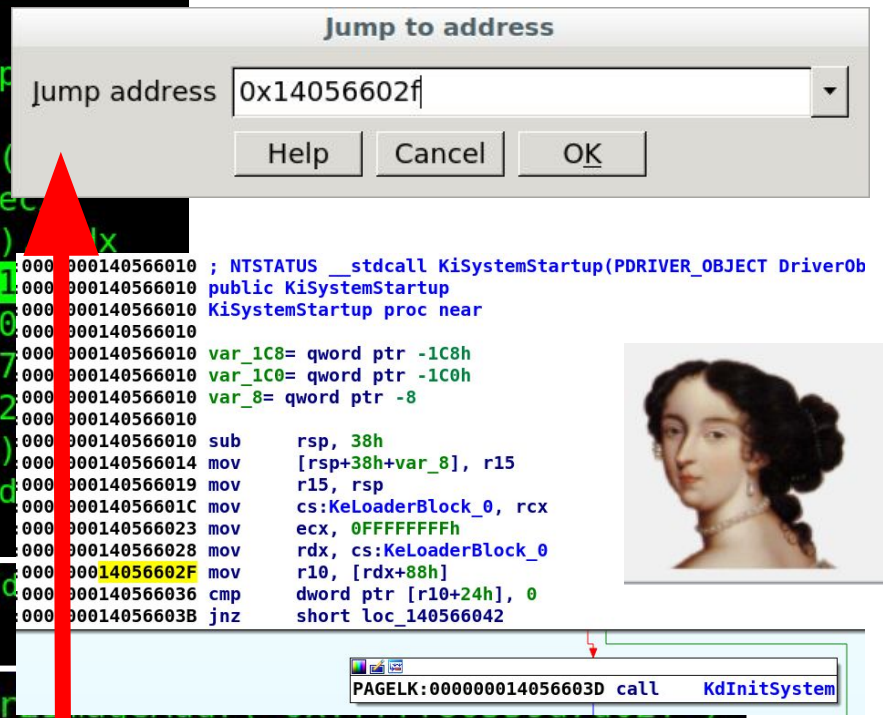


Debugging Example

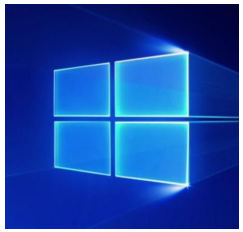
```
0xfffff80559d7d010       sub     $0x38,%rsp
0xfffff80559d7d014       mov     %r15,0x30(%rsp
0xfffff80559d7d019       mov     %rsp,%r15
0xfffff80559d7d01c       mov     %rcx,-0x22d03(
0xfffff80559d7d023       mov     $0xffffffff,%ec
0xfffff80559d7d028       mov     -0x22d0f(%rip)
0xfffff80559d7d02f       mov     0x88(%rdx),%r1
0xfffff80559d7d036       cmpl    $0x0,0x24(%r10
0xfffff80559d7d03b       jne     0xfffff80559d7
0xfffff80559d7d03d       callq   0xfffff8055a12
0xfffff80559d7d042       mov     -0x22d29(%rip)
0xfffff80559d7d049       mov     0x88(%rcx),%rd
0xfffff80559d7d050       mov     %rdx,%r10
```

```
Thread 1 hit Breakpoint 5, 0xfffff80559d7d
(gdb) bt
#0  0xfffff80559d7d02f in ?? ()
#1  0x000000
(gdb)
```

```
In [224]: ntoskernel.addr
Out[224]: (5374369839, '0x14056602f')
```



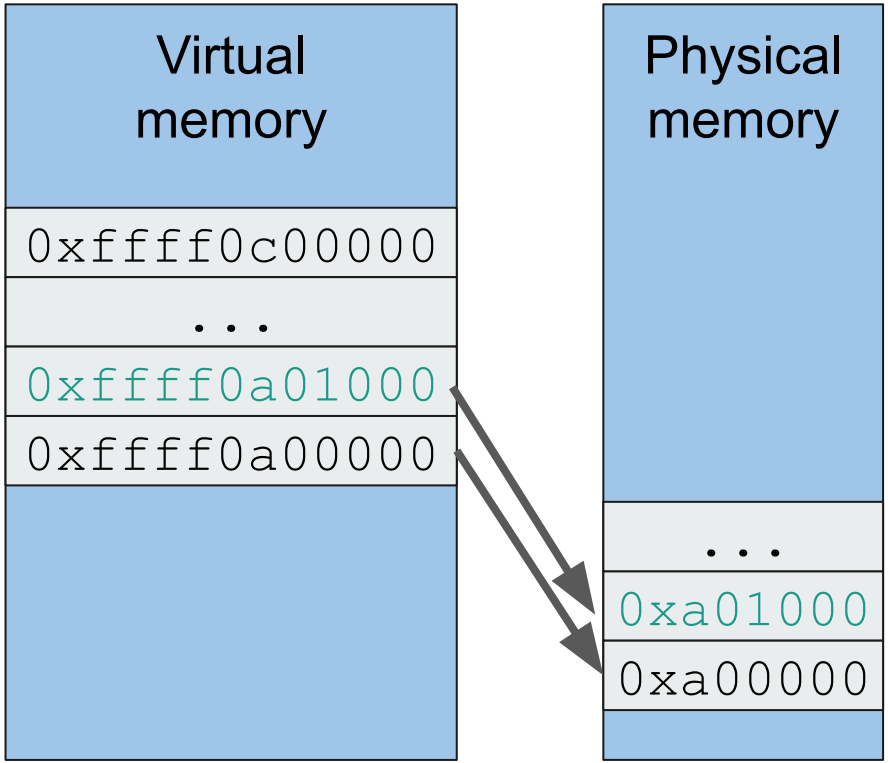
Challenge: Physical Addressing



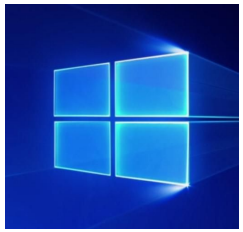
1. AllocatePage

0xffff0a00000

2. kmalloc



Challenge: Physical Addressing

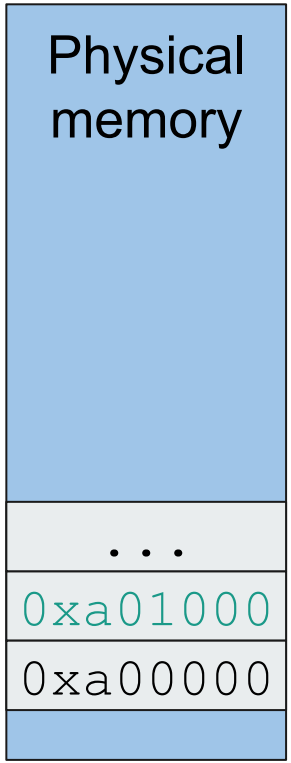


1. AllocatePage

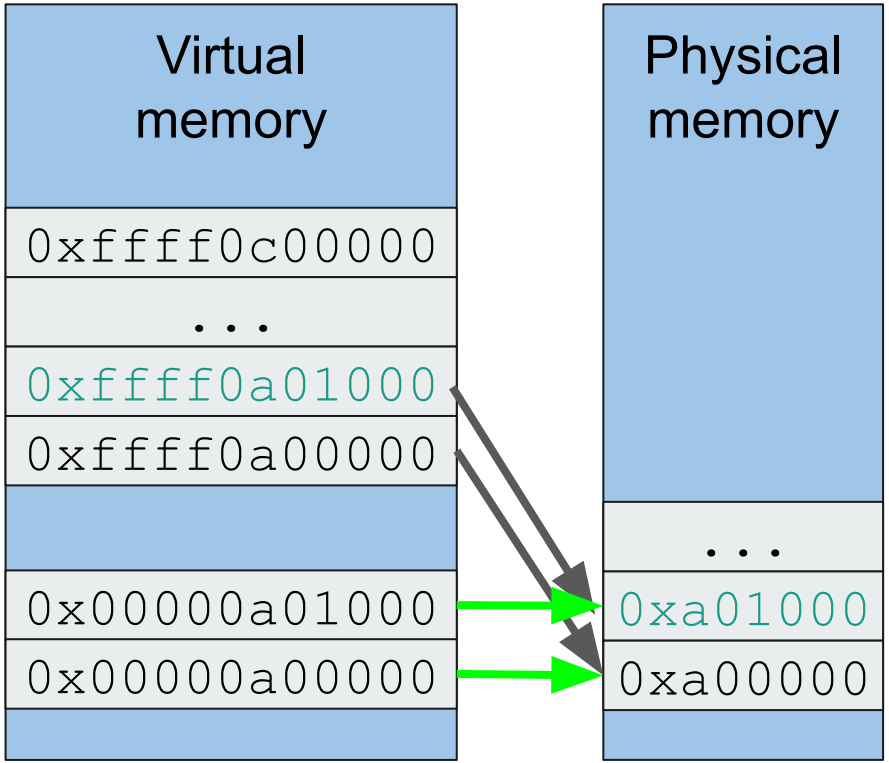
`0xffff0a00000`

2. kmalloc

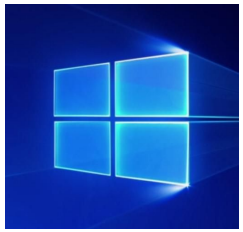
3. Change CR3
4. Access “physical” page **`0xffff0a00000`**



Solution: 1:1 Virtual-to-Physical Mapping



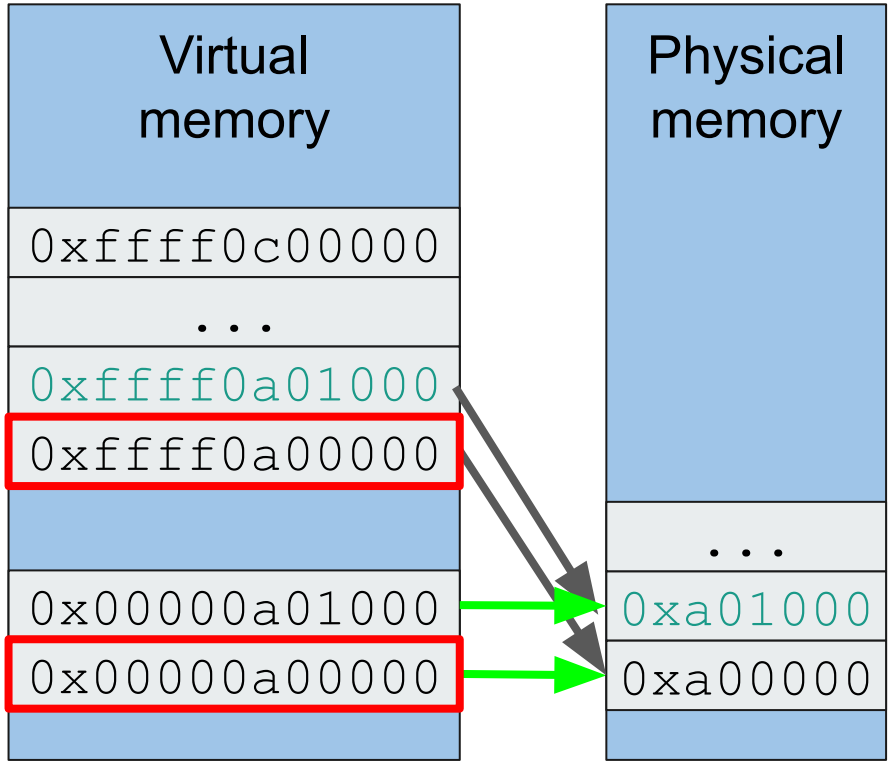
Solution: 1:1 Virtual-to-Physical Mapping



1. AllocatePage

0xa00000

2. kmalloc
3. map 1:1



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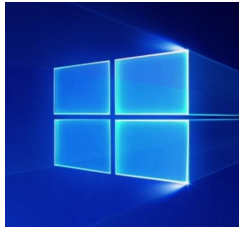
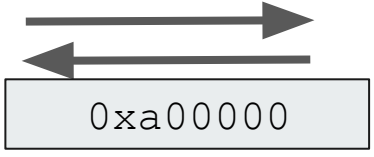
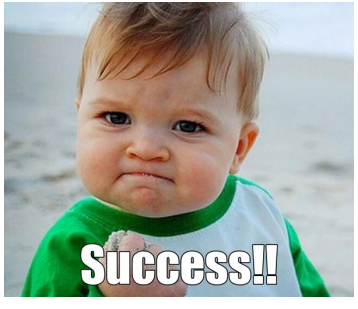
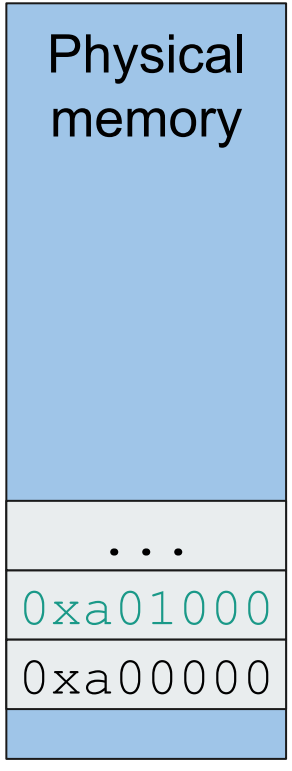


1. AllocatePage



2. kmalloc
3. map 1:1
4. Change CR3
5. Access “physical” page **0xa00000**

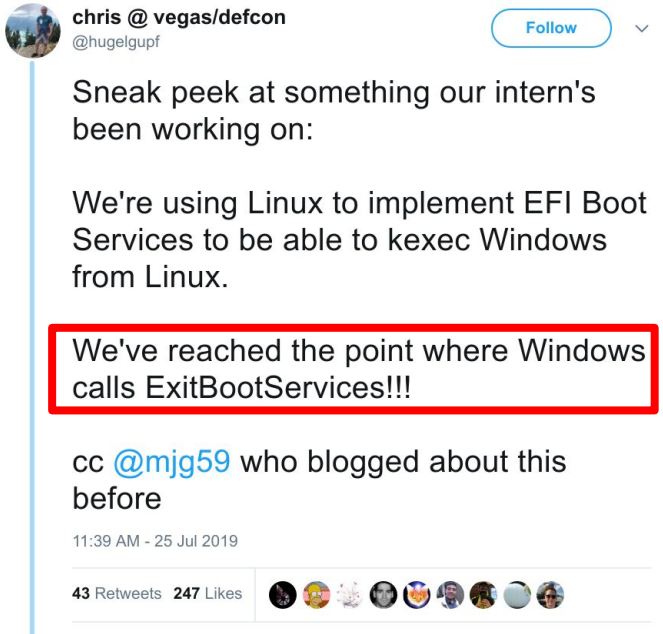




Whoa moment 1

- ExitBootServices is called
- Most cores seems to be in KiIdleLoop
- 1 core in KiSystemCall64

```
(gdb) info threads
  Id   Target Id         Frame
  1    Thread 1 (CPU#0 [halted ]) 0xfffff8035aa94e0f in ?? ()
  2    Thread 2 (CPU#1 [halted ]) 0xfffff8035aa94e0f in ?? ()
  3    Thread 3 (CPU#2 [halted ]) 0xfffff8035aa94e0f in ?? ()
* 4    Thread 4 (CPU#3 [halted ]) 0xfffff8035aa94e0f in ?? ()
  5    Thread 5 (CPU#4 [halted ]) 0xfffff8035aa94e0f in ?? ()
  6    Thread 6 (CPU#5 [running]) 0xfffff8035a665cf8 in ?? ()
```



chris @ vegas/defcon
@hugelgupf
Follow

Sneak peek at something our intern's been working on:

We're using Linux to implement EFI Boot Services to be able to kexec Windows from Linux.

We've reached the point where Windows calls ExitBootServices!!!

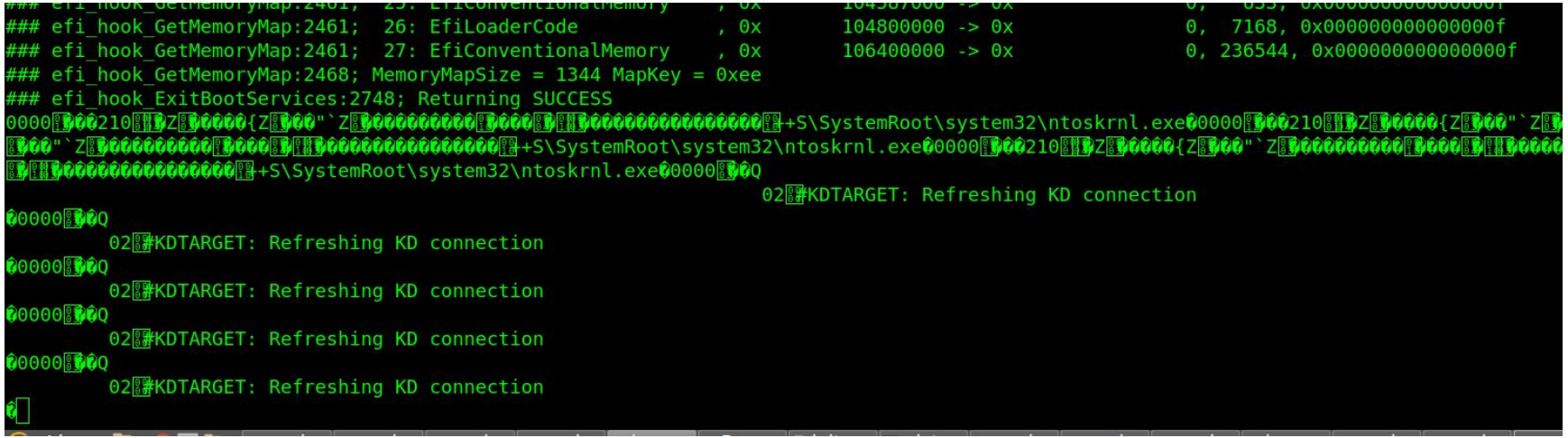
cc @mjg59 who blogged about this before

11:39 AM - 25 Jul 2019

43 Retweets 247 Likes

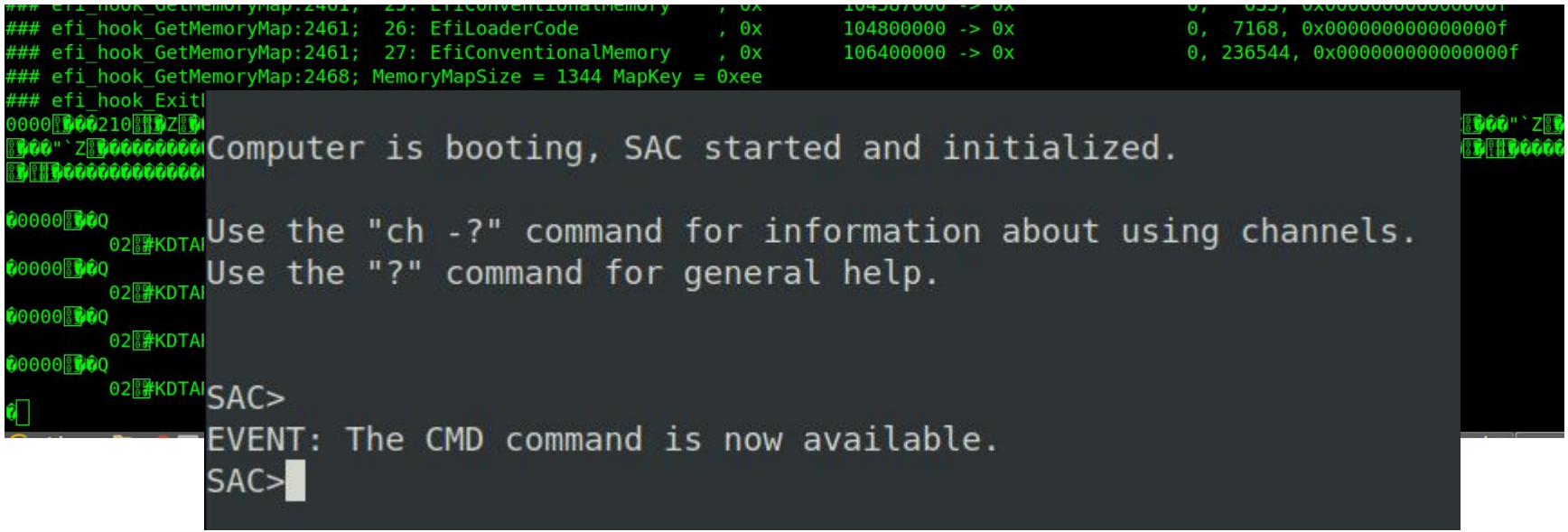
Whoa moment 2

- Enabling kernel debug+EMS



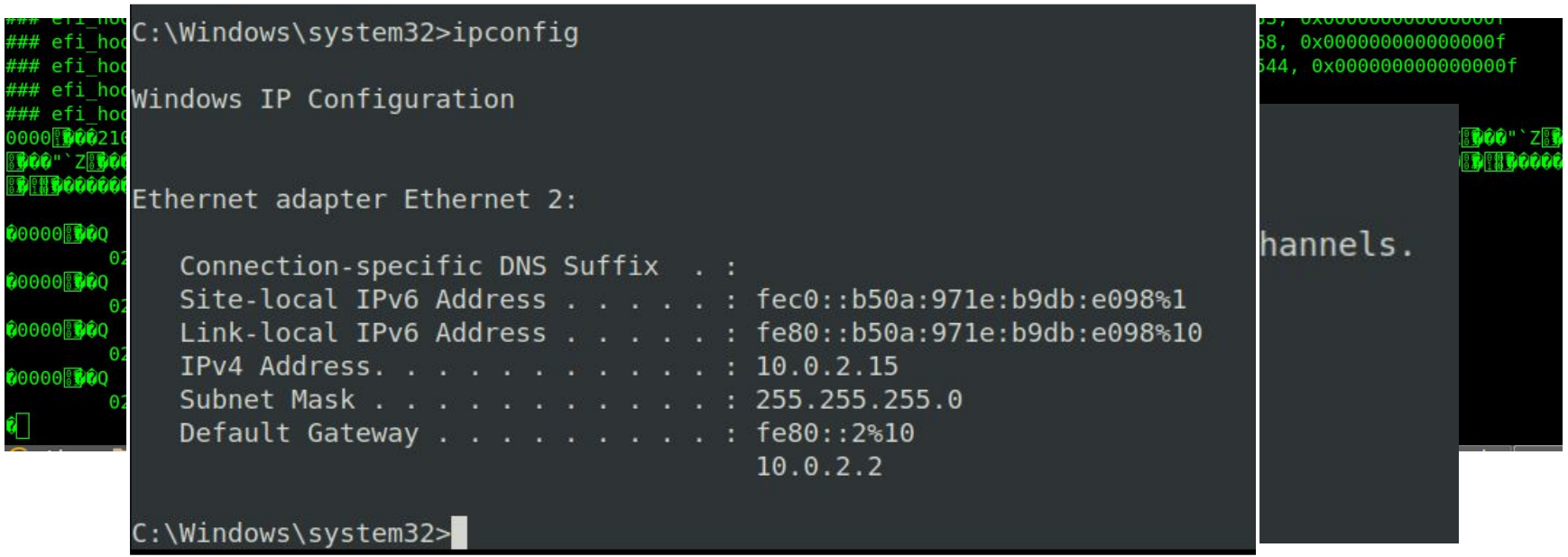
Whoa moment 2

- Enabling kernel debug+EMS



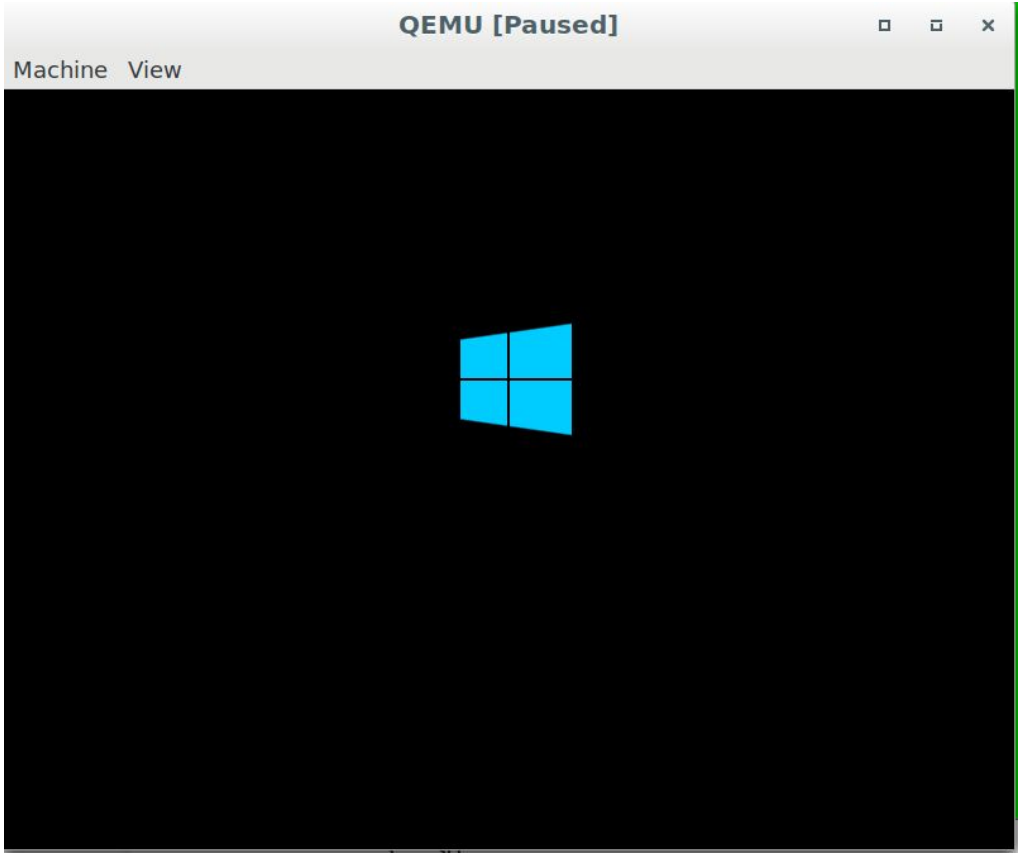
Whoa moment 2

- Enabling kernel debug+EMS



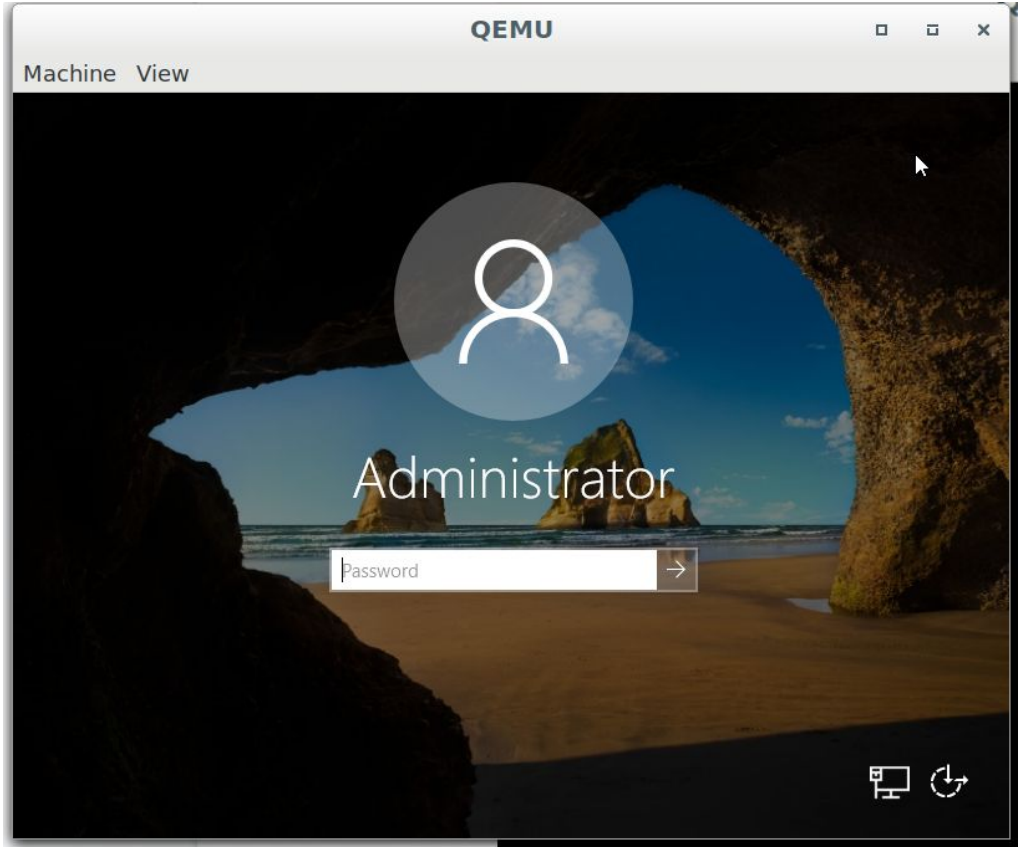
Whoa moment 3

- Enabling graphics
- Using Linux /dev/fb0
- Give the framebuffer to Windows
- And... we crash!



Whoa moment 3

- Enabling graphics
- Using Linux /dev/fb0
- Step 1: Using it ourselves
- Step 2: Giving the framebuffer to Windows
- And... we crash!
- Fix..



Whoa moment 3

- Enabling graphics
- Using Linux /dev/fb0
- Step 1: Using it ourselves
- Step 2: Giving the framebuffer to Windows
- And... we crash!
- Fix..
- Login!

Sign up for the Open Source Firmware Slack
http://slack.u-root.com

Code
https://github.com/oweisse/u-root/tree/kexec_test/booting_windows
https://github.com/oweisse/linux

Thanks to
Ofir Weisse for being a productive PhD intern :)

Me
chrisko@google.com
https://twitter.com/hugelgupf