Windows Kernel Fuzzing for Beginners

Ben Nagy

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ohai.

- Not oldsk00l. Just old.
- ~ 5 weeks experience with Windows Kernel
- > 5 years experience with Fuzzing
- Hate all Technology
- Ruby and Drinking Make the Pain Go Away

Disclaimer:
I am aware of the prevailing opinion that fuzzing talks without bugs suck, by definition. I do not have any bugs. Even if I did have bugs, I wouldn't tell you. There are no bugs. There are, however, otters and buff Russian men of dubious sexuality. Also, many red boxes. You have been warned.

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Secret Fuzzing Wisdoms

- Select a Good Target
- Acquire Essential Knowledge
- Apply Fuzzing Canon - DIGS
  - How do we Deliver
  - How do we Instrument
  - How do we Generate
  - How does that Scale

Secret Fuzzing Wisdoms

- Delivery, Instrumentation, Generation
  - Gotta keep em separated!
  - Please stop writing heavily coupled tools, kthx
- A good toolchain allows rapid retargeting
  - Start fuzzing with a stupid generator
  - Cold cores find no bugs!

Target Selection

```
n_bugs = p_bug * n_tests
```

- p_bug / testing speed is inherently target specific
- Can tune the equation
  - Better (possibly slower) Generators
  - More Scale
  - Rapid Tooling (lead time counts!)
  - Better Samples
  - Pre Fuzzing Toolchain

p_bug++

- Feedback Driven Fuzzing
  - Via code coverage, success rate or some other metric
  - Eg SAGE, bunny, EFS, Flayer
  - PRO - Awesome, super elite, finds bugs dumb fuzzers will never hit
  - CON – Slow, difficult to write, poor Windows support
- Fault Injection / deeply instrumented fuzzing
  - Inject bad data close to code being attacked
  - PRO - vastly simplifies delivery
  - CON - need to then check reachability
- Corpus Distillation
  - Low effort, high reward technique
  - Need a way to measure coverage (tricky for kernel stuff)

Target Selection

```
n_bugs = p_bug * n_tests
```

- More broadly, n_bugs isn’t interesting
- Are there USEFUL bugs in there?
- If there are, can we locate them
  - Bug Chaff
  - Post Fuzzing Toolchain

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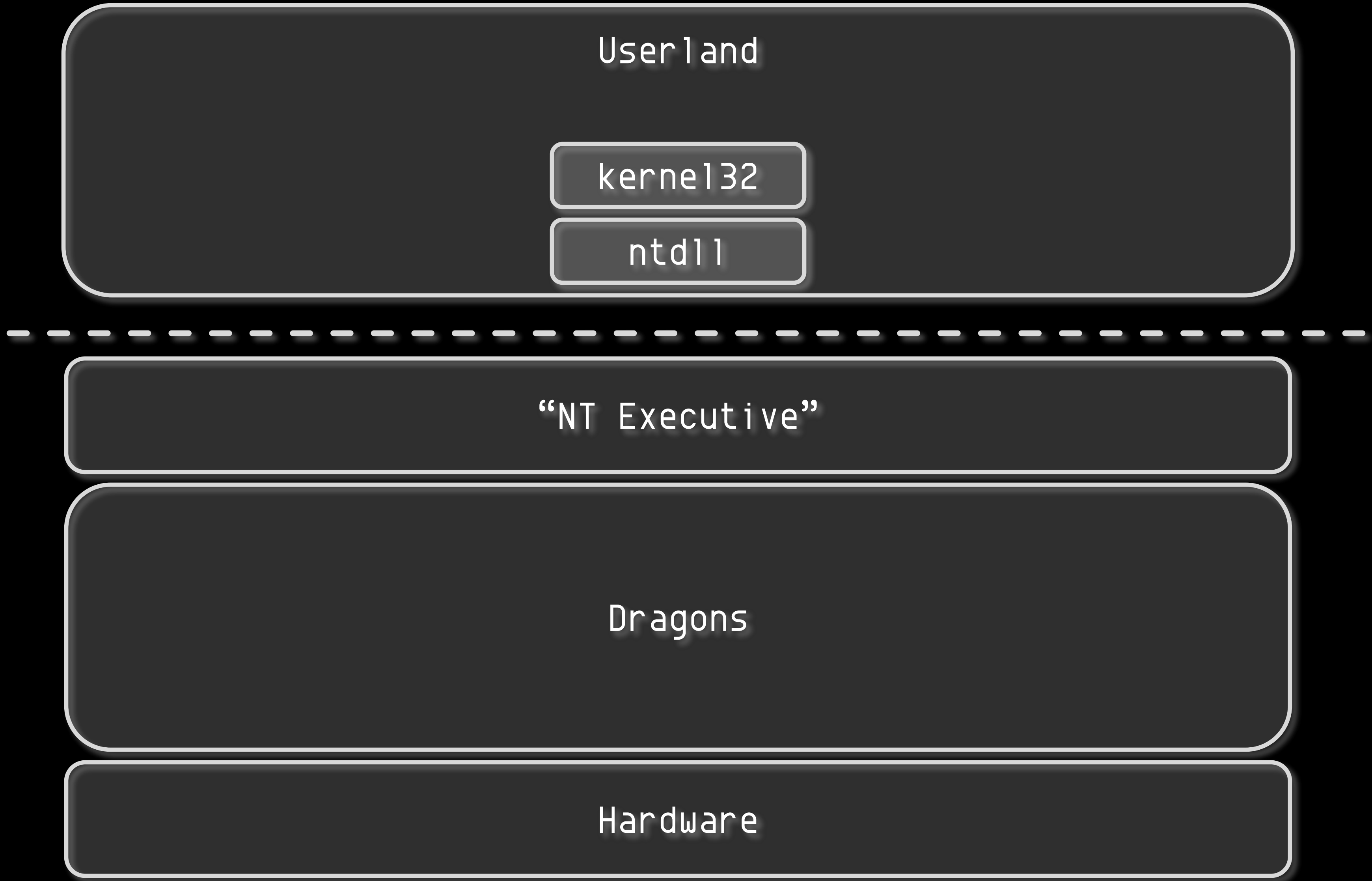
Target Selection

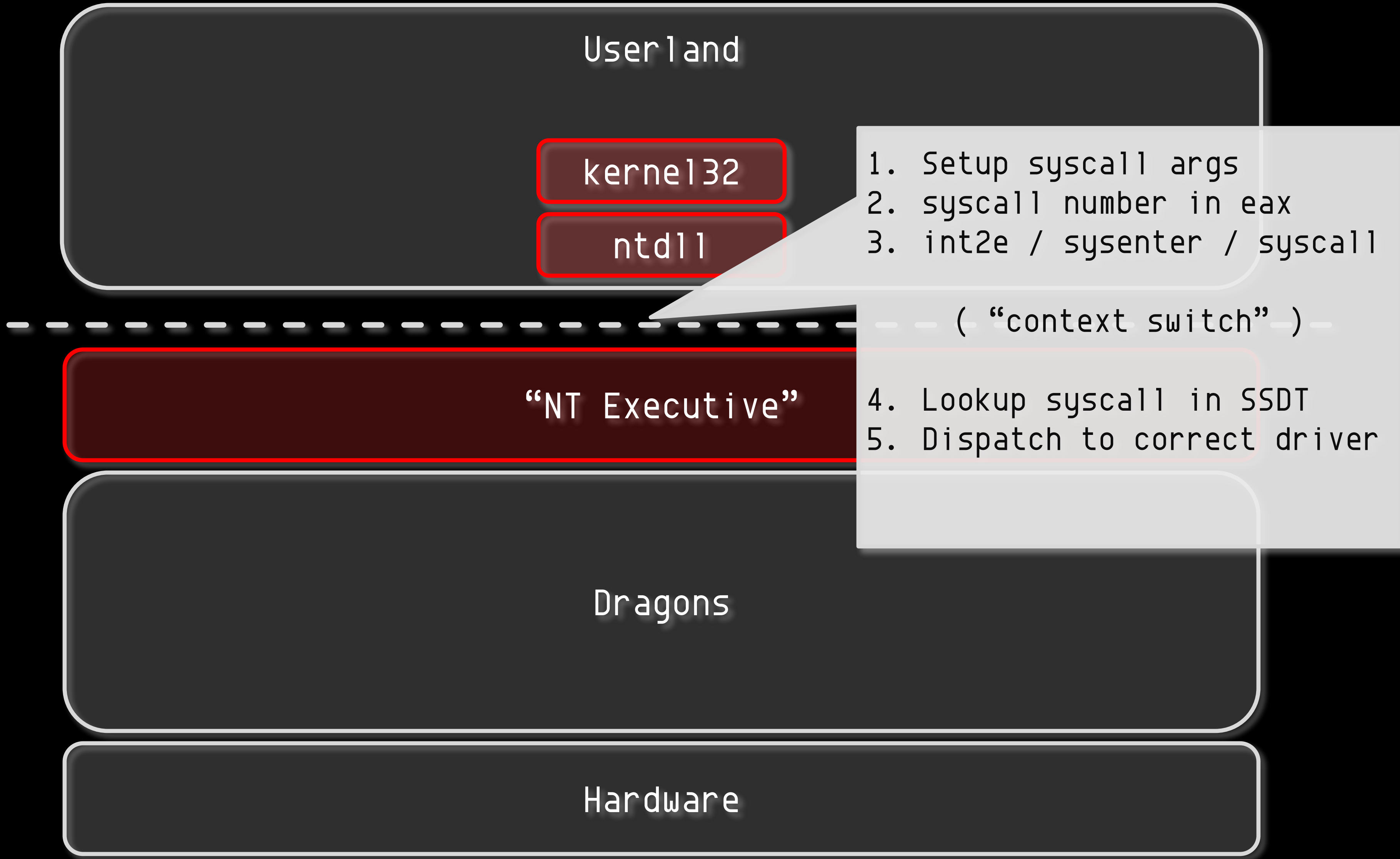
```
n_bugs = p_bug * n_tests
```

- Bug Utility is SUBJECTIVE
- Sell? Use? Fix? Disclose?
- Whatever our utility metric, can we REALISE VALUE
  - Will it provide USEFUL CAPABILITY?
  - Is it RELIABLY exploitable?
  - Will anyone buy it anyway?
  - Is it worth fixing?
  - Will it bring us fame and imply great sexual prowess?

Windows Kernel, Simplified

- Featuring “Barry the Kernel Otter”
- Some stuff is completely missing or wrong
- All of it is greatly simplified
- Real resources abound!
  - MSDN (new layout / navigation is awesome)
  - Anything by j00ru, Alex Ionescu, Tarjei Mandt
  - Anything by Russinovich / Solomon / Probert
  - “CRK” is an academic course, freely downloadable
  - “WRK” is a full windows kernel source tree, plus build tools


Userland
kernel32
ntdll
“NT Executive”
Dragons
Hardware



1. Setup syscall args
2. syscall number in eax
3. int2e / sysenter / syscall

4. Lookup syscall in SSDT
5. Dispatch to correct driver

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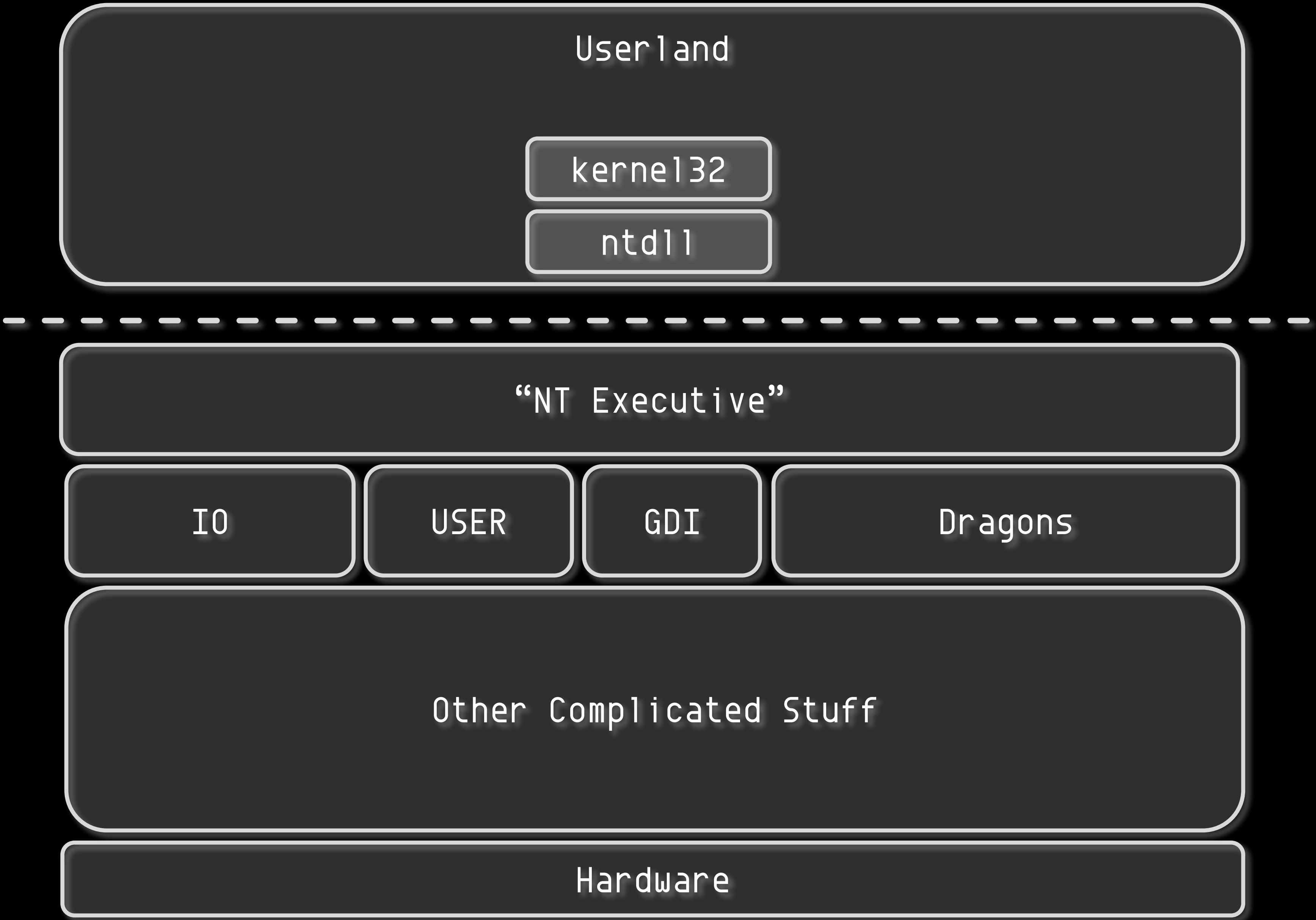
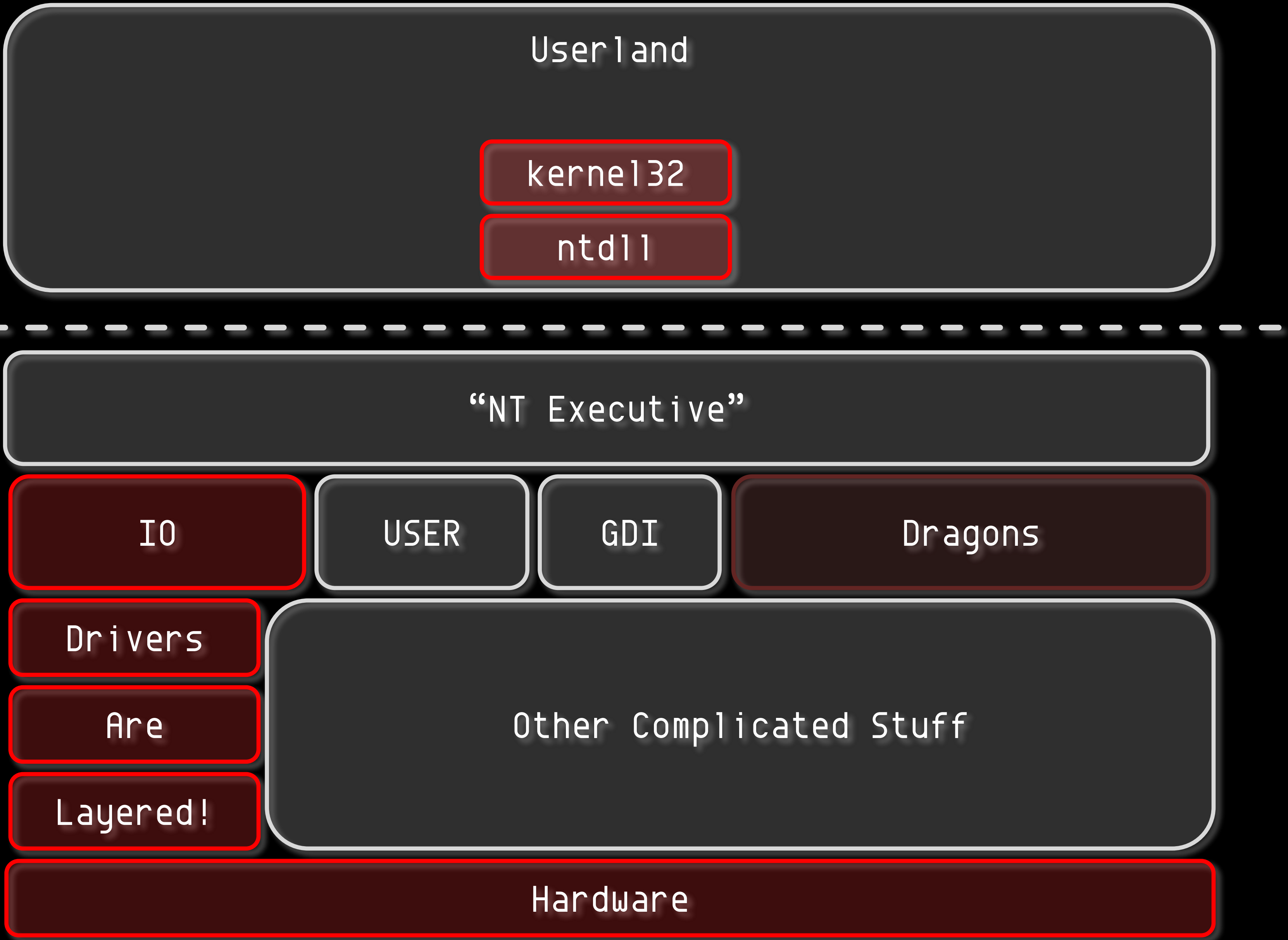
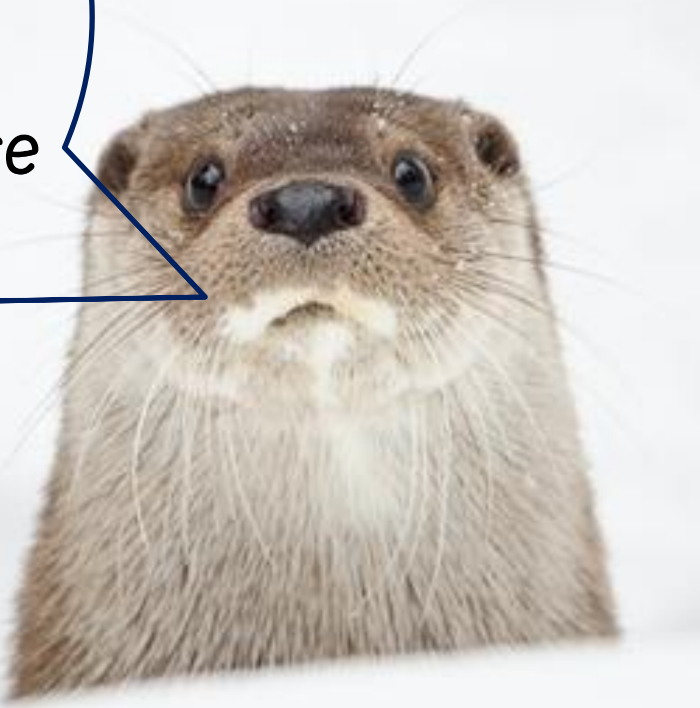
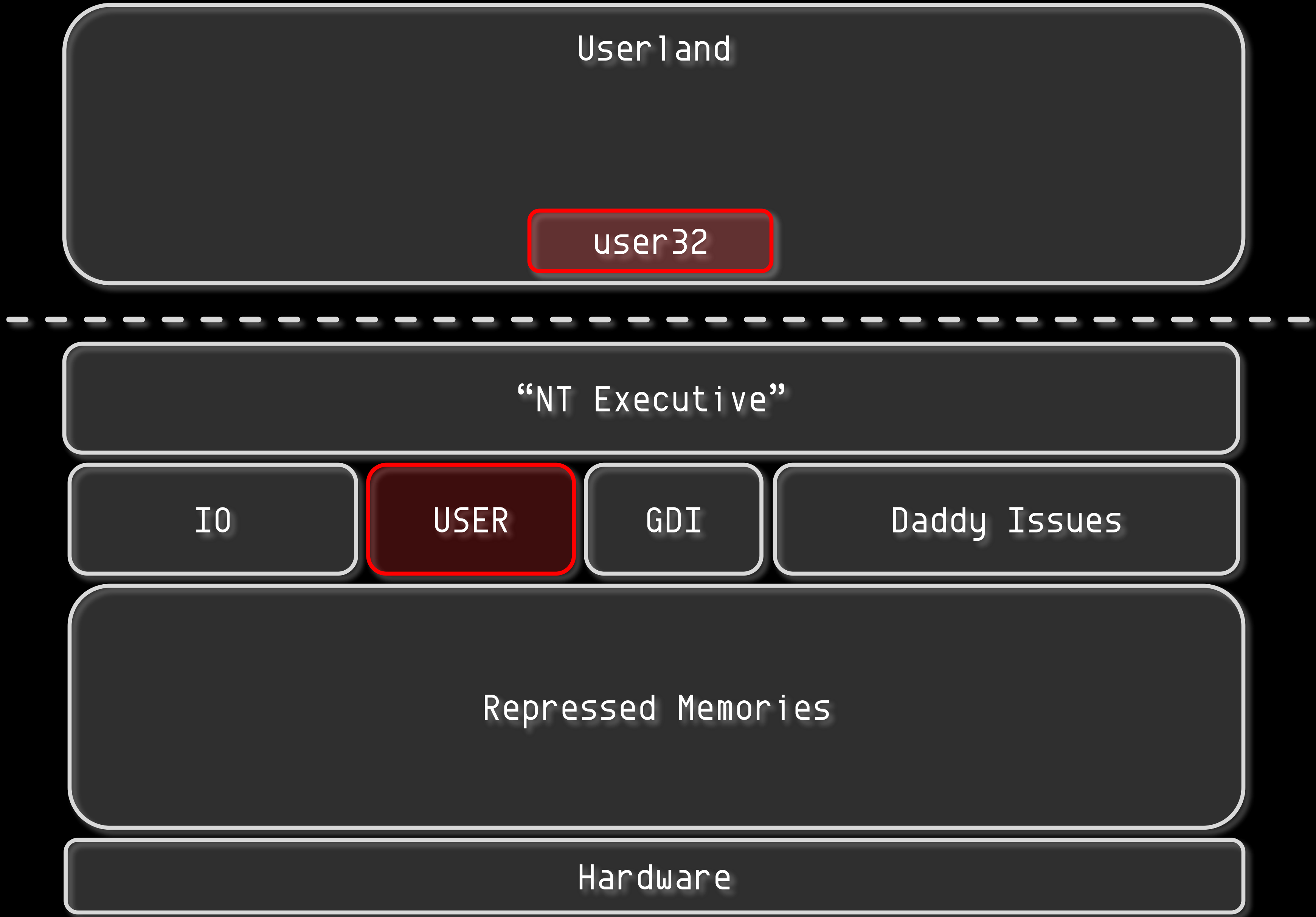

Userland
kernel32
ntdll
“NT Executive”
IO
USER
GDI
Dragons
Other Complicated Stuff
Hardware


Userland
kernel32
ntdll
“NT Executive”
IO
USER
GDI
Dragons
Drivers
Are
Layered!
Other Complicated Stuff
Hardware



- Windows IO is deeply async
- Uses IO Request Packets (IRP)
- “Filter” Drivers can intercept these



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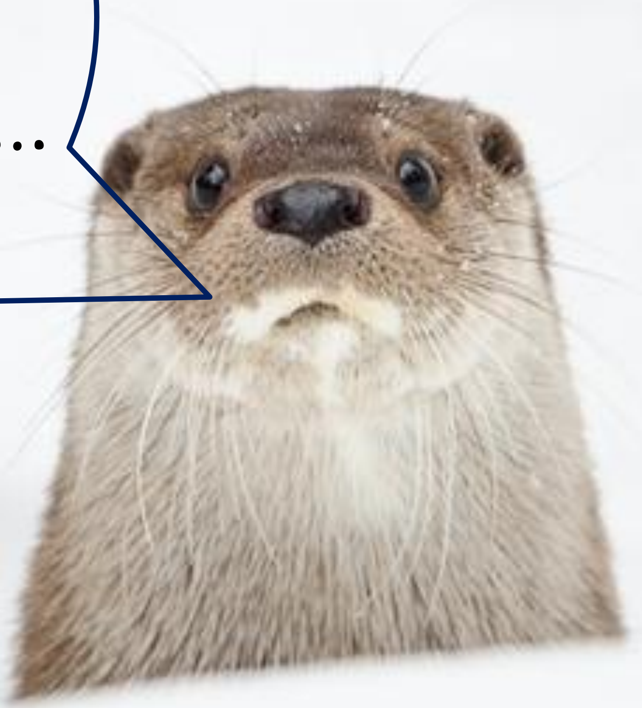
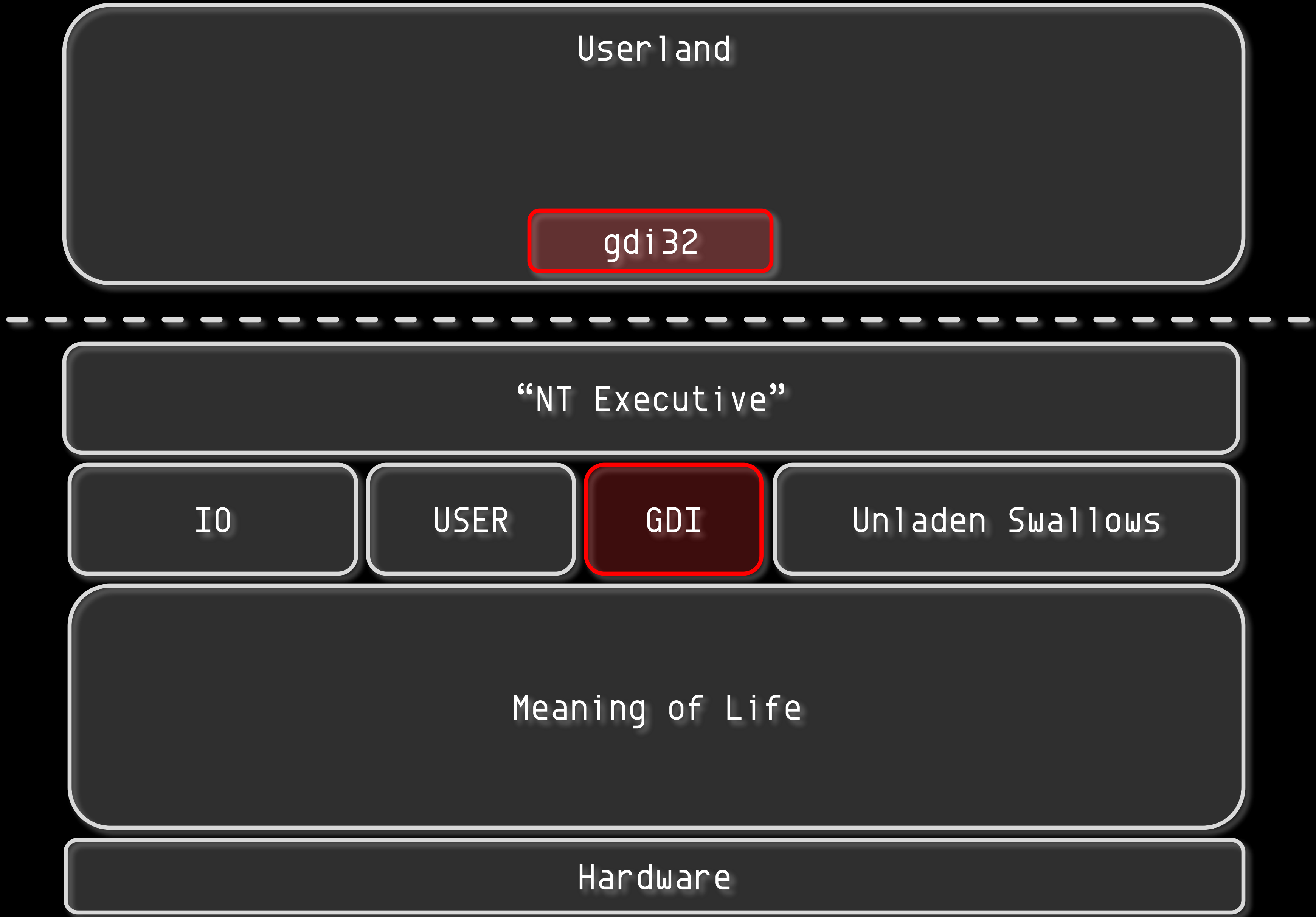
USER runs the GUI

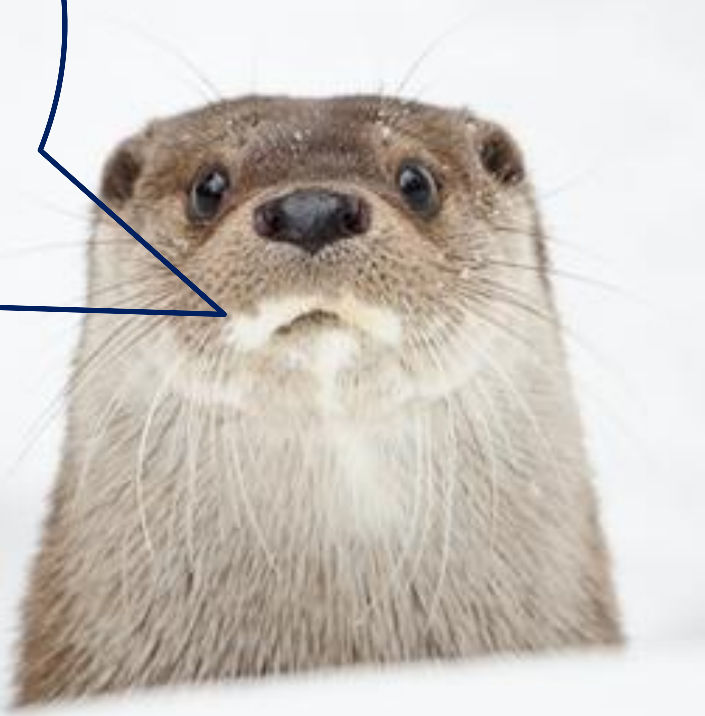
- Windows, Menus, Cursors, Icons…

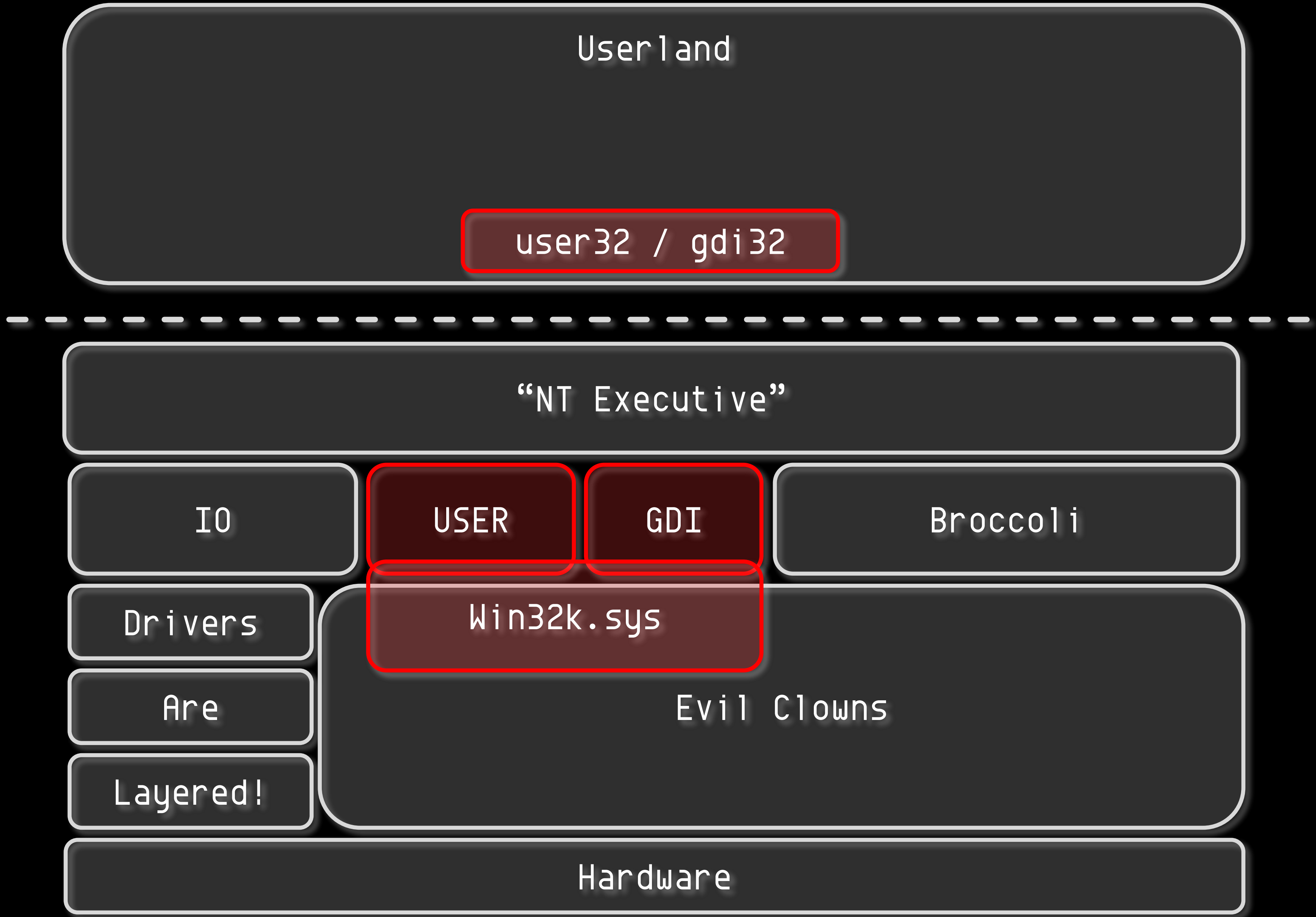



Userland
gdi32
“NT Executive”
IO
USER
GDI
Unladen Swallows
Meaning of Life
Hardware

Graphics Driver Interface

- Basically, it draws stuff
- Moved into kernel space ~NT4
- Bitmaps, Fonts, Metafiles…





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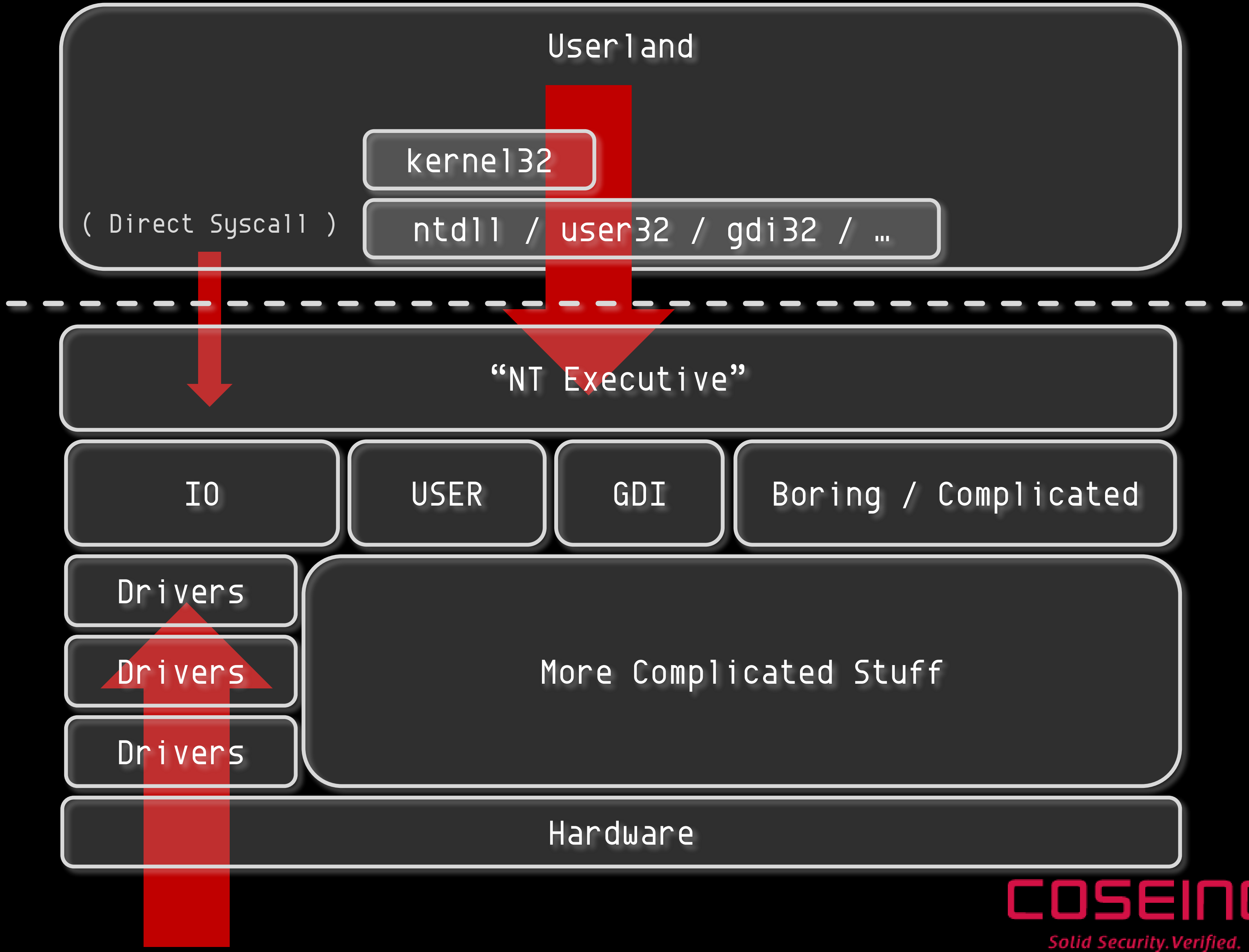
Disco



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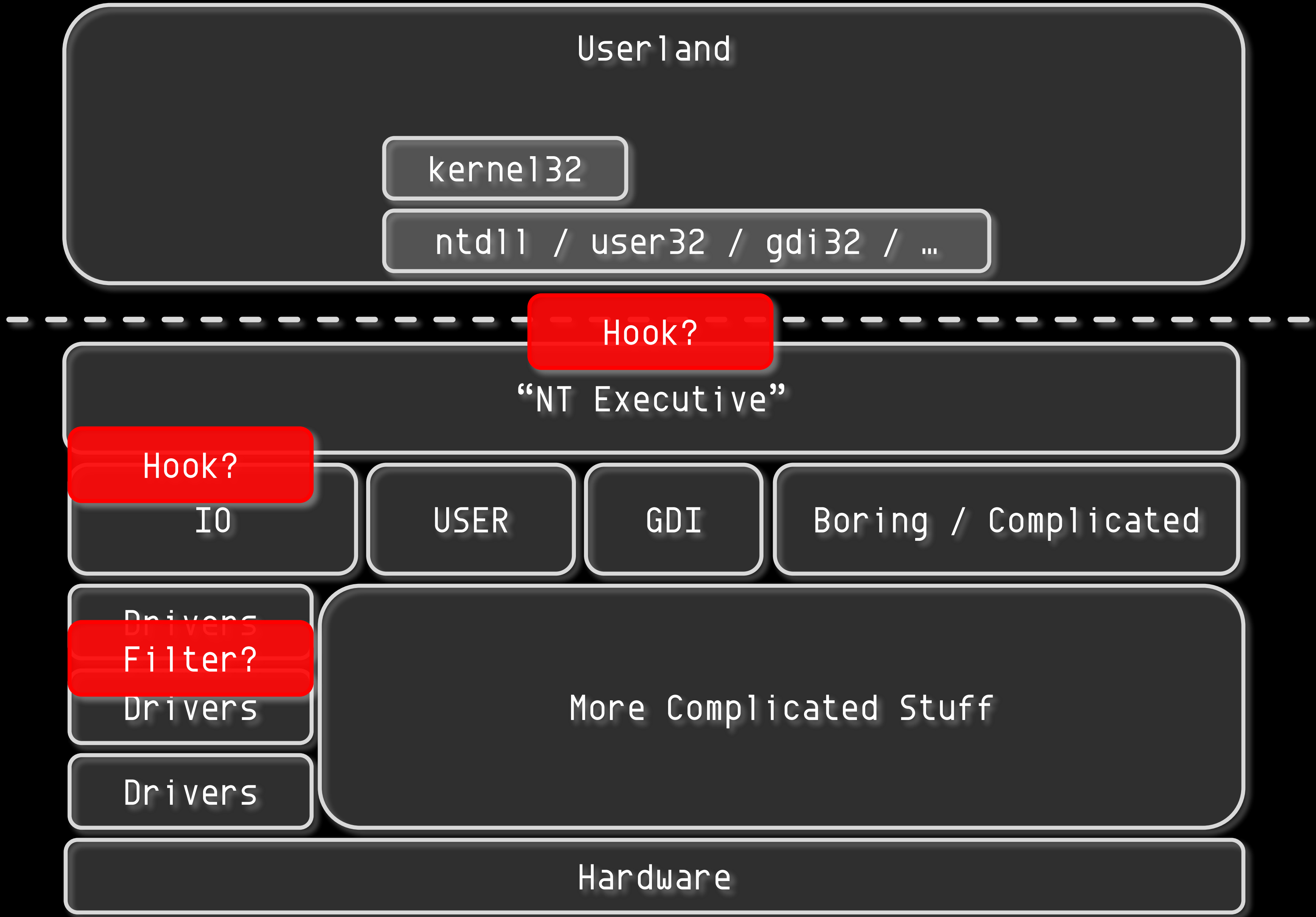

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Bug Classes

- LocalLocal
  - Privilege escalation
  - Sandbox escapes
  - Trending upwards in importance
- RemoteRemote
  - Used to be the shiznit, now plagued by issues
  - Firewalls
  - Were great for indiscriminate attacks, less for targeted
- RemoteLocal
  - Require a user to do something
  - Attack via email, document, URL etc
  - Now the Rolls Royce of bugs

Attack Vector Evaluation

- Coming ‘up’ from the hardware side
  - Will yield RemoteRemotes
  - Just like ‘normal’ network fuzzing
  - SMB, RDP, tcpip.sys, wifi, USB…
  - Reliability issues? Stealth?
  - Hardware differences?

Verdict: You first, guv.

Attack Vector Evaluation

- SSDT Hooks / Filter Drivers / etc
  - Good for attacking 3rd party drivers
  - Fuzzing logic itself really should be in-kernel (inflexible)
  - Public implementations available
  - http://code.google.com/p/ioctlfuzzer

- Finding AV bugs seems too cruel to be sport
- Can’t write drivers in Ruby ☹

Attack Vector Evaluation

- GDI is cool, because RemoteLocals
  - Historically bug prone
- General Syscalls might be fun
  - LocalLocals, but easy to prototype
- USER is tricky, only yields LocalLocals
  - Keyboard Layouts burned by Stuxnet
  - Plus, Tarjei already looked at it

(Moment of Silence in honour of Bug Genocide)

Let's hit GDI!!

GDI - Delivery Vectors

- Here’s what I have so far
  - Fonts - TTF, OTF, FON….
  - Cursors - BMP, CUR (animated)
  - Metafiles - EMF, WMF
  - Images - JPEG, PNG (!!)
- Not even close to complete
  - Metafiles cover a lot, though

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GDI - Fonts

- Great slides from BHEU12

http://media.blackhat.com/bh-eu-12/Lee/bh-eu-12-Lee-GDI_Font_Fuzzing-Slides.pdf

(MANY THANKS to Lee & Chan for also sharing code)

- Fonts are tricky beasts
- You can also embed them (google EOT)
- Simple 9 step process…

GDI - Fonts

1. Load the fuzzed font from a file

```
debug_info "Removing any old copies of #{font_file} "
GDI.RemoveFontResourceEx(font_file, 0, nil) # never know
added=GDI.AddFontResourceEx(font_file, 0, nil)
```

- I'm NOT using FR_PRIVATE
- Works for almost any font type
- Protip - fix checksums
  - (google B1B0AFBA)

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GDI - Window Basics

2. Create a Window Callback

```
def window_proc(hwnd, umsg, wparam, lparam)
  case umsg
    when GDI::WM_DESTROY
      GDI.PostQuitMessage(0)
      return 0
    else
      # This handles all messages we don't explicitly process
      return GDI.DefWindowProc(hwnd, umsg, wparam, lparam)
    end
  0
end
```

GDI - Window Basics

- Lots of people put their logic in here
  - Handle WM_PAINT, WM_RESIZE etc
  - Lots of samples online do it this way, too…
- I never found the need, but YMMV

GDI - Window Basics

3. Register Window Class

```
window_class = GDI::WNDCLASSEX.new
window_class[:lpfnWndProc] = method(:window_proc)
window_class[:hInstance] = hinst
window_class[:hbrBackground] = GDI::COLOR_WINDOW
window_class[:hCursor] = 0

@atom = GDI.RegisterClassEx( window_class )
```

GDI - Window Basics

4. Create a Window Instance

```
@hwnd ||= GDI.CreateWindowEx(
  GDI::WS_EX_LEFT,                               # extended style
  poi(@atom),                                    # class name or atom
  @opts[:title],                                 # window title
  GDI::WS_OVERLAPPEDWINDOW | GDI::WS_VISIBLE, # style
  GDI::CW_USEDEFAULT,                            # X pos
  GDI::CW_USEDEFAULT,                            # Y pos
  @opts[:width],                                 # width
  @opts[:height],                                # height
  0,                                             # parent
  0,                                             # menu
  hinst,                                         # instance
  nil                                            # lparam
)
```

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GDI - Fonts

5. Get Font Face Name (undocumented)

```
success=GDI.GetFontResourceInfo(
  w_fname,
  sz,
  buf,
  2 # asks to receive a LOGFONTW in buf
)
lf=LOGFONTW.new buf # cast the buffer to a LOGFONTW
GDI.WideCharToMultiByte( … lf[:lfFaceName].to_ptr …)
```

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GDI - Fonts

6. “Create” the Font

```
logical_font                    = GDI::LOGFONTW.new
logical_font[:lfHeight]         = font_size
logical_font[:lfFaceName].to_ptr.put_string(0,font_face)
logical_font[:lfItalic]         = 0
logical_font[:lfCharSet]        = GDI::DEFAULT_CHARSET

@current_font=GDI.CreateFontIndirect logical_font
raise_win32_error if @current_font.zero?
```

7. Select it into the DC for our window

```
@old_font=GDI.SelectObject(dc, @current_font)
```

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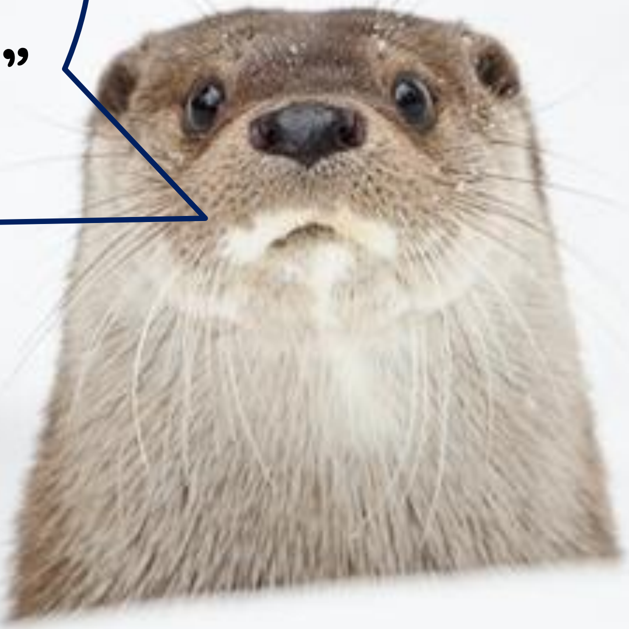
What are Device Contexts?

- Bits of screen or printer
- Include "graphics attributes"
- (eg brushes, fonts, etc)



GDI - Fonts

8. How big is a ‘line’ of text?

```
# build the string one glyph at a time until the
# text extent is greater than our rect width
sz = GDI::SIZE.new
until sz[:cx] > width || str.empty?
  out << str.slice!( 0,1 )
  GDI.GetTextExtentPoint32( dc, out, out.size, sz )
  guess = out.size
end
```

GDI - Fonts

9. Actually draw some f**king text

```
GDI.send(
  text_out_method,          # ExtTextOutW / A
  dc,                       # device context
  0,                        # X start
  @current_y,               # Y start
  GDI::ETO_GLYPH_INDEX,     # For ‘raw’ mode
  this_line,                # RECT
  out,                      # str to draw
  out.size,                 # size
  nil                       # lpDx
)
@current_y+=sz[:cy]
```

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ETO_GLYPH_INDEX

“ The lpString array refers to an array returned from GetCharacterPlacement and should be parsed directly by GDI as no further language-specific processing is required. ”

– MSDN

(This is why we use ExtTextOut and not DrawText)

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That Sucked!
(Still better than Gtk tho)

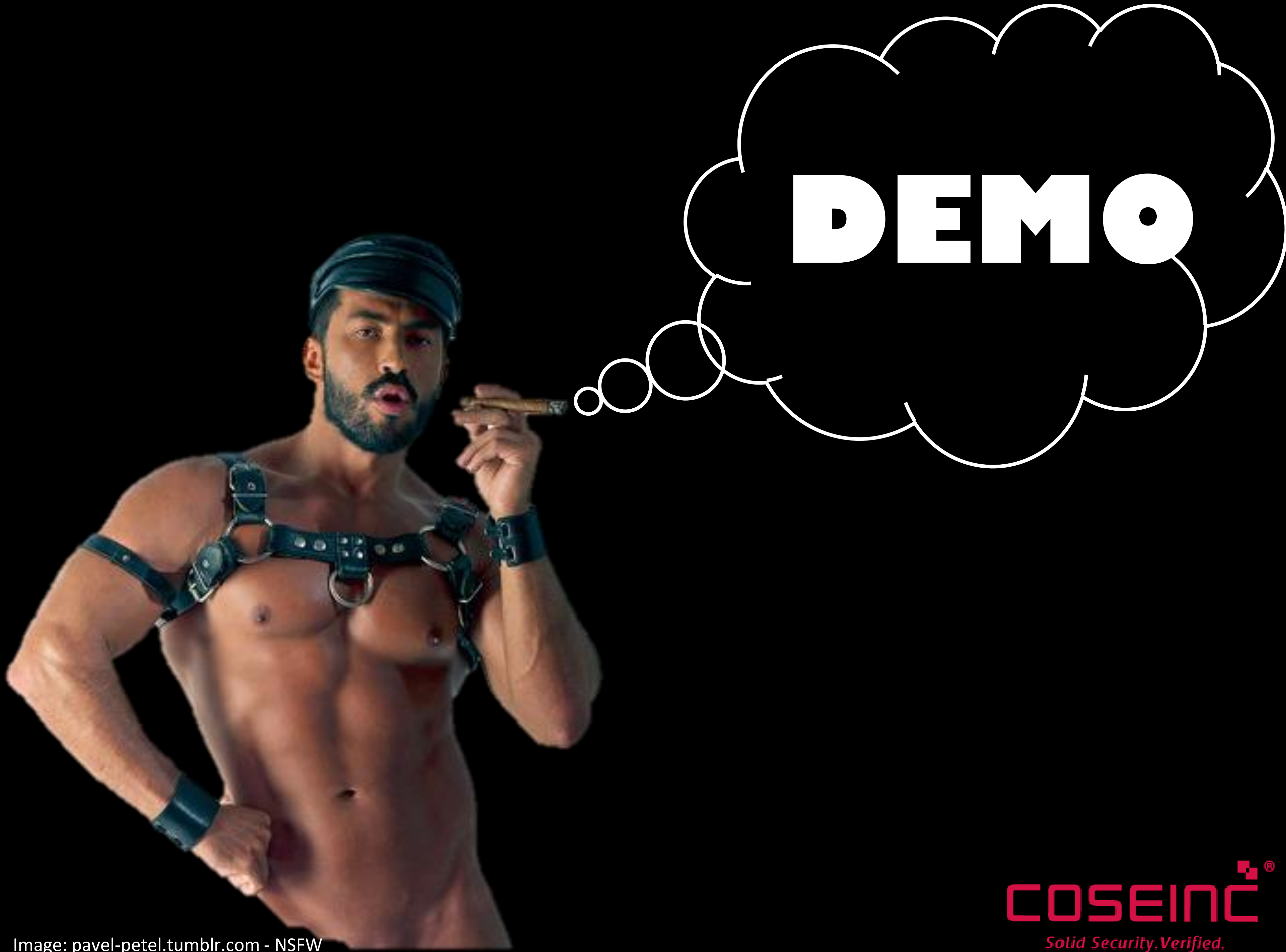

Image: pavel-petel.tumblr.com - NSFW

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GDI - Cursors

```
hCursor=GDI.LoadCursorFromFile cursor_file
raise_win32_error if hCursor.zero?
@old_cursor=GDI.SetCursor hCursor
debug_info "Set cursor #{cursor_file}”
```

- WTF? Why no DC?
  - The cursor is a shared resource!
  - Not supposed to change it unless mouse is over you
  - Pff, whatever.

GDI - Cursors

```
@old_clip  = GDI::RECT.new
@clip      = GDI::RECT.new
GDI.SetForegroundWindow @hwnd    # _try_ to get focus
GDI.GetClipCursor @old_clip
GDI.GetWindowRect @hwnd, @clip
GDI.ClipCursor @clip          # Clipping changes it
GDI.ClipCursor @old_clip      # Put it back
```

- Really crappy / fragile method!
  - Works, though

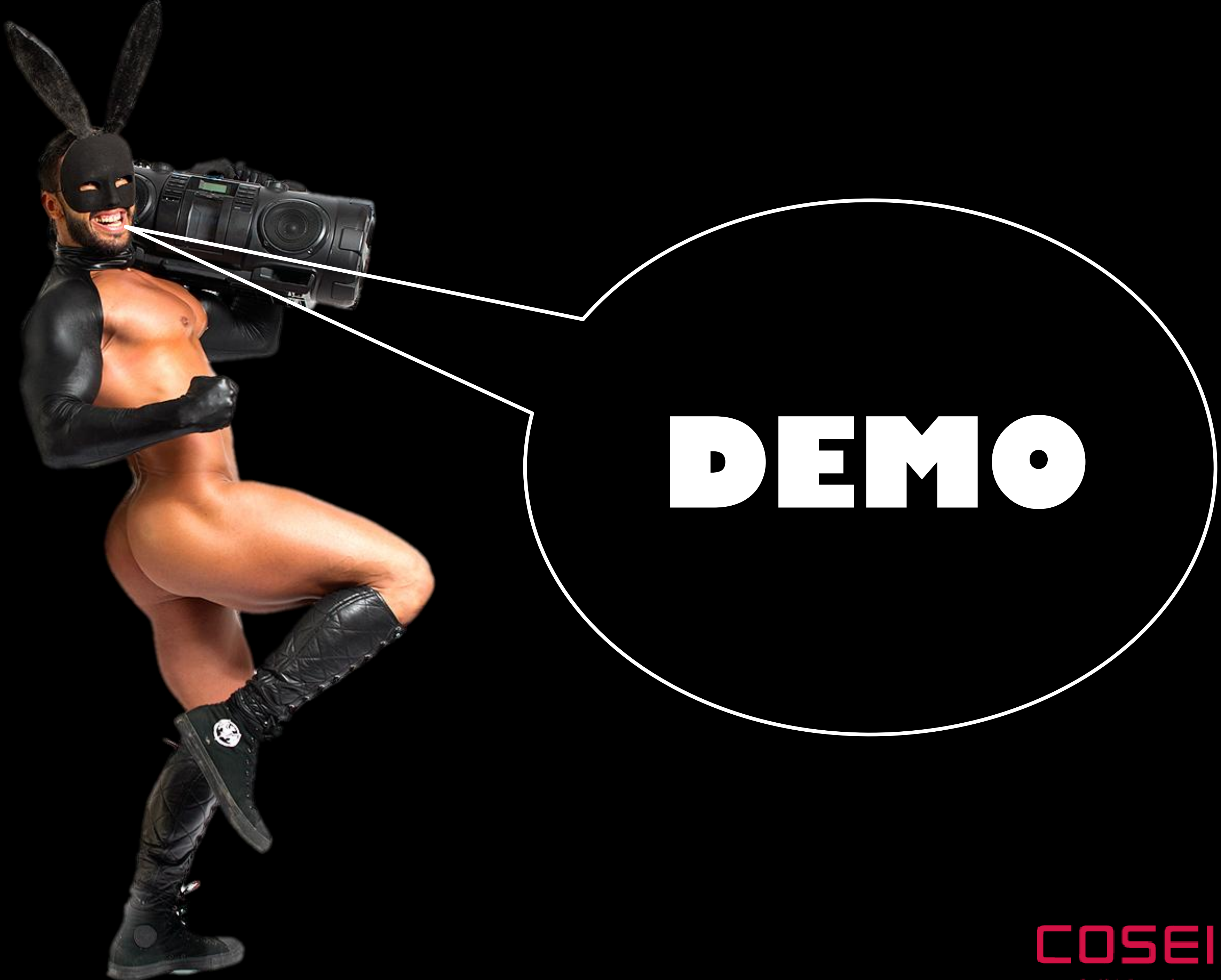

Image: pavel-petel.tumblr.com - NSFW

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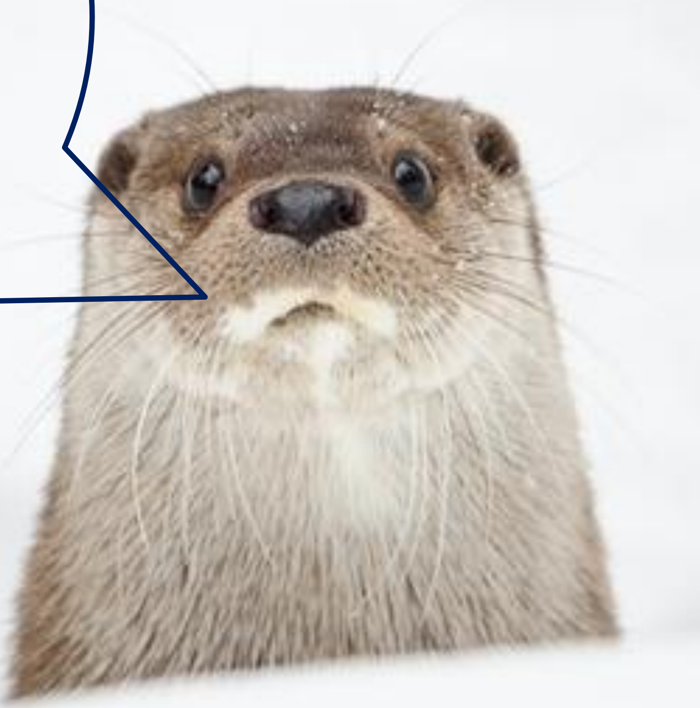

Metafiles!

- Like a ‘script’ of GDI commands
- ‘Scalable’ == ‘Fun’
- SetAbortProc used to be lolz

GDI - Metafiles - WMF

```
if wmf_data[0..3] == "\xD7\xCD\xC6\x9A"
  debug_info “Aldus Placeable Metafile!"
  pdata = pstr( wmf_data[22..-1] )
```

- WMF has no scaling / position data
- APM header is a standard ‘nonstandard’
- Provides the missing info

Cannot the Scaling! What do?

1. Play in MSPAINT.EXE
   – Uses GDI+ internally, converts to BMP
   – Draws the BMP to the DC

2. Use Coordinate Spaces & Transforms API
   – Parse the APM Header
   – Do lots of annoying maths with pels and twips
   – Actually, just saying ‘pels’ and ‘twips’ is annoying

3. Convert to EMF, play that
   – May lose some evil, but very easy to do

GDI - Metafiles - WMF & EMF

```
emf_handle = GDI.SetWinMetaFileBits(
  pdata.size,
  pdata,
  dc,
  nil
) # convert to EMF if required…
raise_win32_error if emf_handle.zero?
GDI.PlayEnhMetaFile dc, emf_handle, rect
GDI.DeleteEnhMetaFile emf_handle
```

DEMO

Image: pavel-petel.tumblr.com - NSFW

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GDI - JPEG / PNG

The **StretchDIBits** function copies the color data for a rectangle of pixels in a DIB, JPEG, or PNG image to the specified destination rectangle. If the destination rectangle is larger than the source rectangle, this function stretches the rows and columns of color data to fit the destination rectangle. If the destination rectangle is smaller than the source rectangle, this function compresses the rows and columns by using the specified raster operation.

- MSDN

GDI - JPEG / PNG

To ensure proper metafile spooling while printing, applications must call the CHECKJPEGFORMAT or CHECKPNGFORMAT escape to verify that the printer recognizes the JPEG or PNG image, respectively, before calling **StretchDIBits**.

- MSDN

Fine. Let’s be a Printer.

1. (Optional) Get default printer

```
buf=pstr( "\x00" * 260 )
buf_sz=FFI::MemoryPointer.new( :ulong )
buf_sz.write_ulong buf.size
if GDI.GetDefaultPrinter buf, buf_sz
  buf.read_string buf=pstr( "\x00" * 260 )
…
```

(Or just specify “Fax” etc)

Fine. Let’s be a Printer.

2. (Optional) Check for JPEG Support

```
escape_code=FFI::MemoryPointer.new :ulong
escape_code.write_ulong GDI::CHECKJPEGFORMAT
# Check if CHECKJPEGFORMAT exists
res=GDI.ExtEscape(
  printer_dc,
  GDI::QUERYESCSUPPORT,
  escape_code.size,
  escape_code,
  0,
  nil
)
if res > 0
  status=FFI::MemoryPointer.new :ulong
  res=GDI.ExtEscape(
    printer_dc,
    GDI::CHECKJPEGFORMAT,
    p_jpeg_data.size,
    p_jpeg_data,
    status.size,
    status
  )
```

Yes, I realise you can’t read this….

Just use one of the built-in printers like XPS or OneNote, they support JPEG.

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3. Fill Out Bitmap Info Struct

```
bmi_header                  = GDI::BITMAPINFOHEADER.new
bmi_header[:biSize]         = GDI::BITMAPINFOHEADER.size
bmi_header[:biWidth]        = img_width
# top down image - negative height value
bmi_header[:biHeight]             = -img_height
bmi_header[:biPlanes]             = 1
bmi_header[:biBitCount]           = 0
bmi_header[:biCompression]        = GDI::BI_JPEG
bmi_header[:biSizeImage]          = img_data.bytesize
```

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4. Do the Thing

```
printer_dc=GDI.CreateDC nil, lpszDevice, nil, nil
retval=GDI.StretchDIBits(
  printer_dc,
  0, # dest X
  0, # dest Y
  stretch_width || rand(1000),  # width
  stretch_height || rand(1000), # height
  0, # src X
  0, # src Y
  img_width,
  img_height,
  pstr( img_data ),
  bmi_header,
  GDI::DIB_RGB_COLORS, GDI::SRCCOPY
)
```

If this returns > 0 then it is "scan lines copied", which should be the same as your JPEG height. Yay.

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NO DEMO

Image: pavel-petel.tumblr.com - NSFW

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One More Thing...

```
# first 4 args are passed in registers.
register_args=args.shift( 4 ).zip %w( rcx rdx r8 r9 )
register_args.map! {|arg,reg| "mov #{reg}, #{arg}" }
# the rest are passed on the stack
stack_args=args.reverse.map {|arg| "push #{arg}"}
stub_x64=[
  "mov r10, rcx",                        # don't know why
  "mov eax, #{syscall}",                 # syscall in eax
  "syscall",                             # make the call
  "add rsp, #{stack_args.size * 8}",     # clean up the stack
  "ret"
]
asm = (register_args + stack_args + stub_x64).join "\n"
opcodes = Metasm::Shellcode.assemble(
  Metasm::X86_64.new, asm
).encode_string
p_opcodes = FFI::MemoryPointer.from_string opcodes
```

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One More Thing…

```
Syscall.VirtualProtect(
  p_opcodes,
  p_opcodes.size,
  PAGE_EXECUTE_READWRITE,
  FFI::MemoryPointer.new( DWORD ) # receives old protection value
)
hThread = Syscall.CreateThread(
  nil,
  0,
  p_opcodes,
  nil,
  CREATE_SUSPENDED,
  nil
)
self.raise_win32_error if hThread.zero?
Syscall.CloseHandle hThread
```

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1 Line Syscall Fuzzer!

```
Syscall.call64
rand(0x2000),
*(Array.new(6).map {rand
2**32}) until @bsod
```

Basic technique stolen from jduck's MS10-073 exploit, updated to work on x86 / x64. Props to the Metasm team.

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Out of time!!

- Did not talk about…
- Case Generation
  - I mainly use ‘Millerfuzz’ & Radamsa from OUSPUG
  - (and secret stuff)
- Scale
  - Scaling by VM pairs has proved fragile
  - I use ‘checkpoints’ with auto-reboot on BSOD
  - You can test with NotMyFault tool
  - Any uncleared dump + checkpoint sent for analysis
  - VMs don’t always reboot cleanly ☹
  - Private WER server may be better?

kthxbai

- As I mentioned, 5 weeks ago I knew ~nothing about the kernel
- Anything I got right is probably thanks to:
  - Lee & Chan for their code from BHEU12
  - Tarjei Mandt, Alex Ionescu, jduck
  - New MSDN Nagivation Interface
  - Luck

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</talk>

?

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