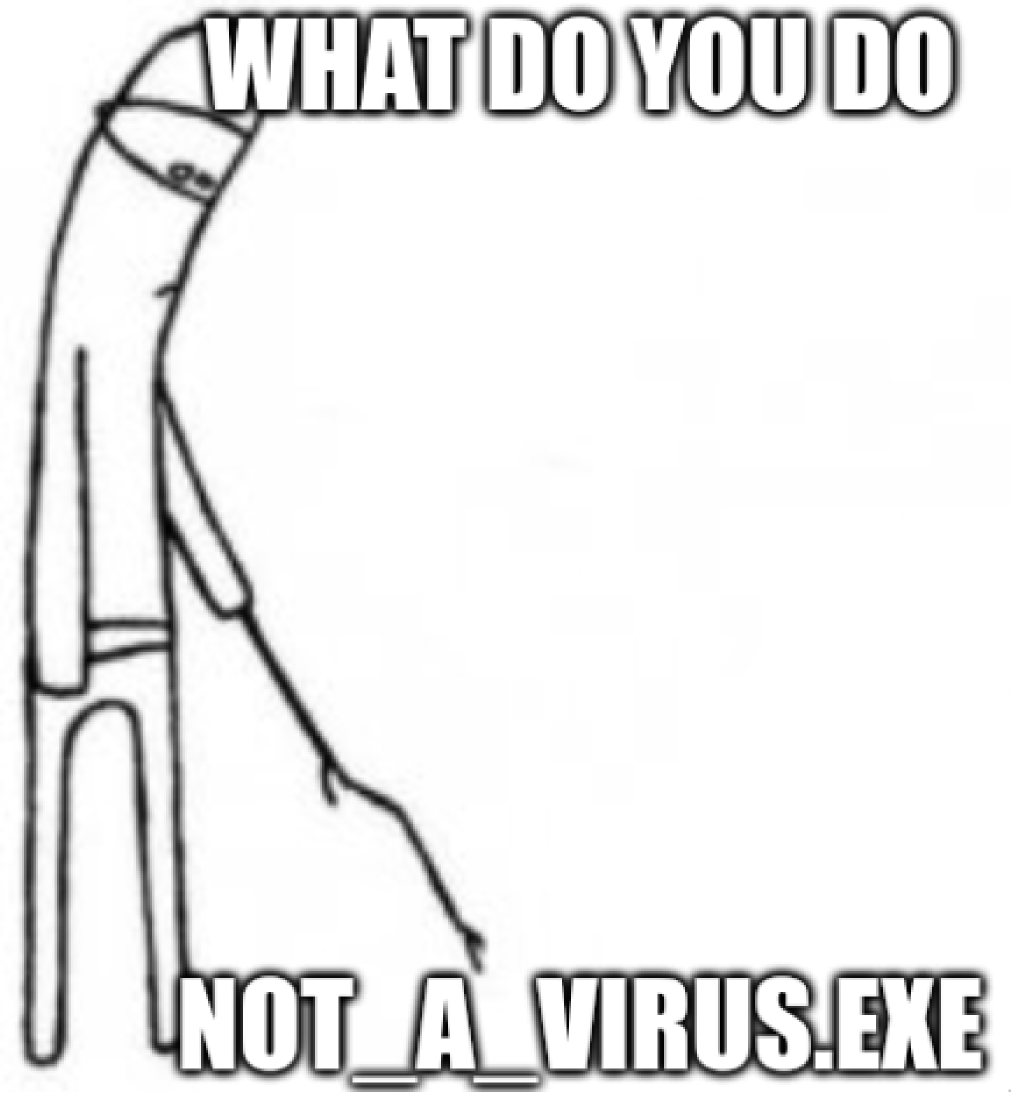
Reverse Engineering 101

As I like to call it:



Assembly Recap

CPUs work with registers and memory

x86-64 has many registers such as `rax, rbx, rcx, rdx, rdi, rsi, rsp, rip, r8–r15`

Special registers:

`rip` : Current instruction pointer

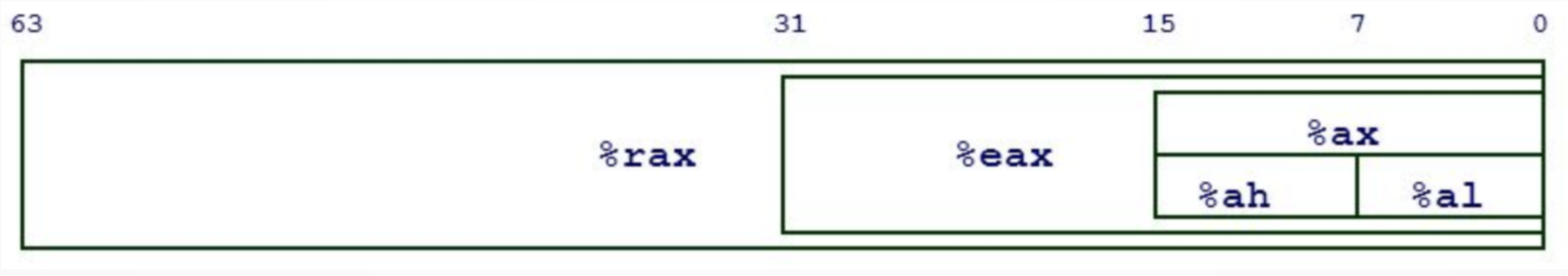
`rsp` : Current stack pointer

`rbp` : Stack frame base pointer

`cr3` : Virtual memory selector for a process

Assembly Recap

We can access certain bits of registers individually:



1

This allows for backwards compatability

32-bit programs can just use `eax`

Assembly Recap

Instruction format:

```
<instruction_mnemonic>  <destination>, <source>
```

```
mov     rax,                 rbx
```

-> Means move rbx to rax

-> The compiler turns assembly into actual opcodes

```
mov     rax,                 rbx
```

=> 0x48, 0x89, 0xd8

Online (dis)assembler: https://defuse.ca/online-x86-assembler.htm#disassembly

Assembly Recap

Data Movement

`mov rax, rbx` Moves rbx into rax

`mov rax, 0x4000` Moves 0x4000 into rax

`mov rax, [rbx]` Moves the 8-byte value at the address of rbx into rax

=> rbx = 0x400000 `mov rax, [0x400000]`

=> `rax = *0x400000;`

Assembly Recap

Arithmetics

`add rax, rbx`	Adds rbx to rax
`sub rax, rbx`	Substracts rbx from rax
`xor rax, rbx`	...
`and rax, rbx`	...
...	

Assembly Recap

Control Flow

`call function` Calls a function

`ret` Returns from a function to the next instruction

Example:

`call target`

=> `mov rax, 3`

=> `ret`

`mov rbx, rax` <=

rbx = 3

Assembly Recap

Control Flow

`jmp address` Always jump to address

`jnz address` Jump if not zero
`je address` Jump if equal
`jle address` Jump if less or equal
=> Based on EFLAGS (special registers)

Assembly Recap

Control Flow

```
cmp rax, rbx
jle error
ret
```

Jump to error IF RAX <= RBX

Otherwise return from the function

C to assembly

```
int x;
x = 10;
```

```
mov rax, 10
```

Not every C line is atomic in asm:

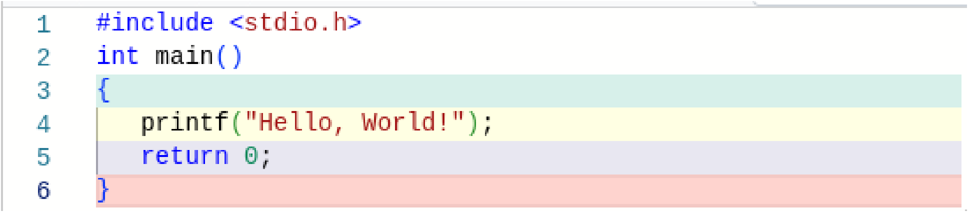
```
x = x + 10;
```

```
mov rbx, rax // temporary value
add rbx, 10  // add 10
mov rax, rbx // move temp back to x
```

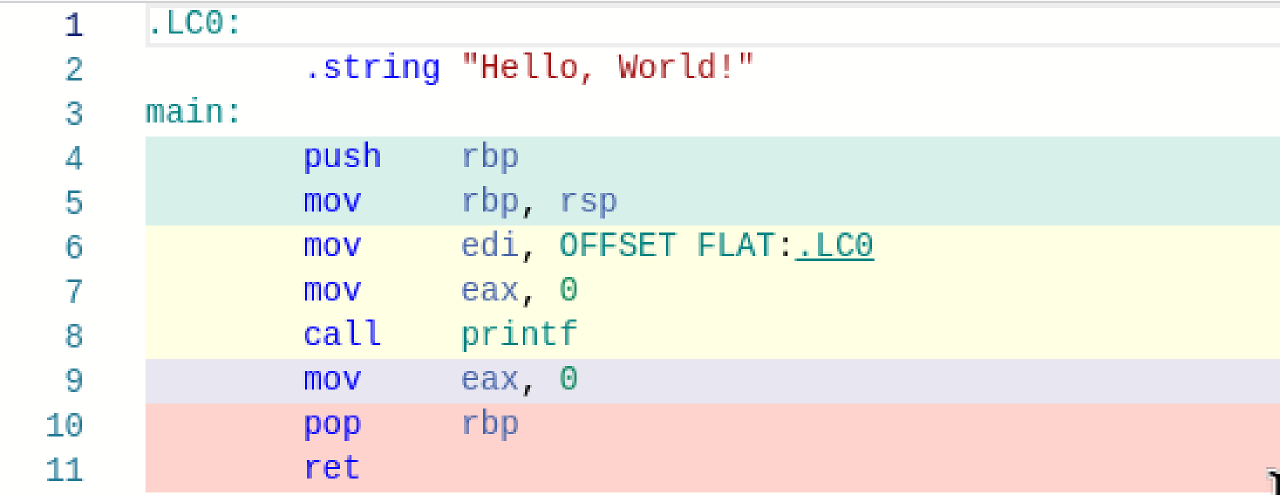
C to assembly

C to asm in the browser:

https://godbolt.org/#

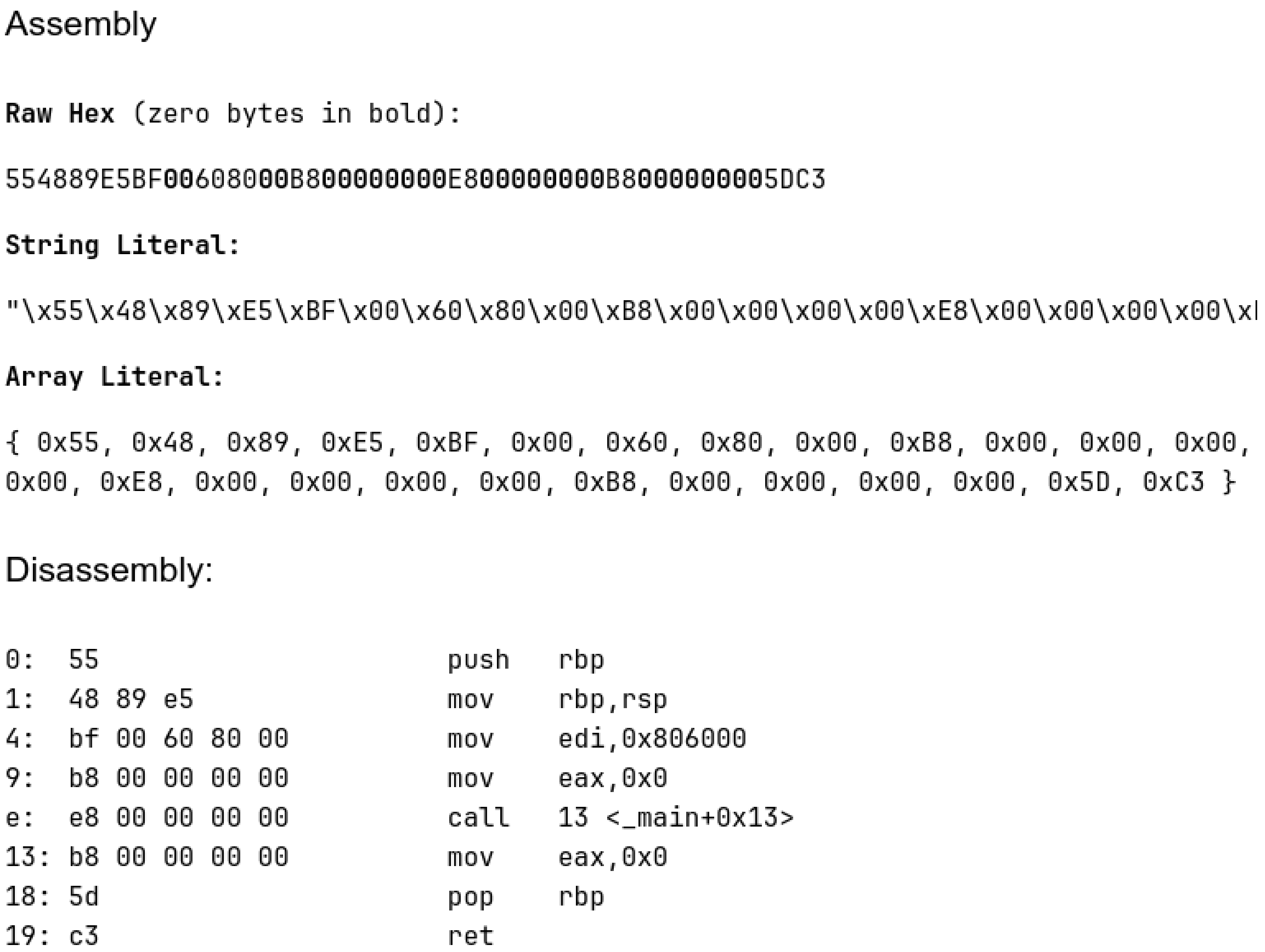


```c
#include <stdio.h>
int main()
{
    printf("Hello, World!");
    return 0;
}
```



```asm
.LC0:
        .string "Hello, World!"
main:
        push    rbp
        mov     rbp, rsp
        mov     edi, OFFSET FLAT:.LC0
        mov     eax, 0
        call    printf
        mov     eax, 0
        pop     rbp
        ret
```

Done by https://defuse.ca/online-x86-assembler.htm#disassembly



Assembly

Raw Hex (zero bytes in bold):

```
554889E5BF00608000B800000000E800000000B8000000005DC3
```

String Literal:

```
"\x55\x48\x89\xE5\xBF\x00\x60\x80\x00\xB8\x00\x00\x00\x00\xE8\x00\x00\x00\x00\x
```

Array Literal:

```
{ 0x55, 0x48, 0x89, 0xE5, 0xBF, 0x00, 0x60, 0x80, 0x00, 0xB8, 0x00, 0x00, 0x00,
0x00, 0xE8, 0x00, 0x00, 0x00, 0x00, 0xB8, 0x00, 0x00, 0x00, 0x00, 0x5D, 0xC3 }
```

Disassembly:

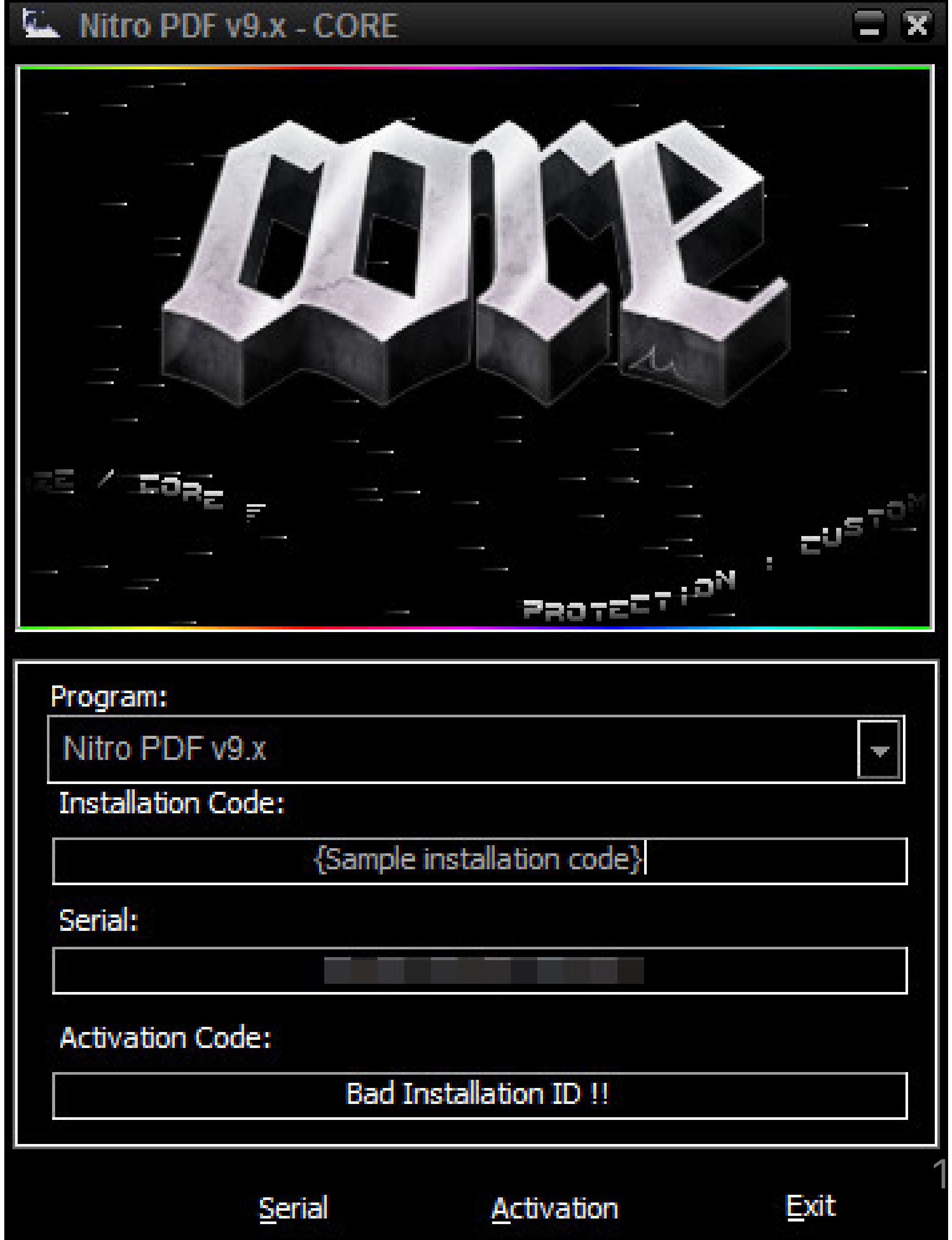
```
0:  55                      push   rbp
1:  48 89 e5                mov    rbp,rsp
4:  bf 00 60 80 00          mov    edi,0x806000
9:  b8 00 00 00 00          mov    eax,0x0
e:  e8 00 00 00 00          call   13 <_main+0x13>
13: b8 00 00 00 00          mov    eax,0x0
18: 5d                      pop    rbp
19: c3                      ret
```

Rev 101

- Analysis of a system, program or (obfuscated) source code
  - Often binary analysis
- Find out what it’s doing
  - Revertible, Exploitable?

Real world usage

- Malware research
- Bug hunting in consumer software & operating systems
- Modding games
  - Cracking
- Debugging



Program: Nitro PDF v9.x

Installation Code: {Sample installation code}

Serial: [redacted]

Activation Code: Bad Installation ID !!

Executables

- ELF
  - Executable and Linking Format (UNIX)
- PE
  - Portable Executable (WINDOWS)
- Tells our OS how to load and execute it
- Contains Imports (Libraries), Exports, Sections, Entrypoint

Tools for executables

- UNIX:
  - file: Tries to determine the filetype
  - strings: Print all ascii strings in the file
  - hexdump: See raw bytes of the file
  - readelf: Parses the elf file and prints info
  - objdump: ELF infos & disassembly
- Windows:
  - CFF Explorer/ Explorer Suite by NTCore

Concepts

- Type of with the binary
  - Static
  - Dynamic
- Emulation/Tracing
- Diffing
- Patching
- Sidechannels
- Symbolic execution

Static analysis

- "Offline" analysis
  - Binary is not executed
- Disassembler
  - Turns opcodes into asm instructions
  - `68 6e 2f 73 68` => `push 0x68732f6e`
- Decompiler
  - Turn asm instructions into somewhat readable code

Static tools

- Native binaries:
    - Ghidra (Free, works well on most arches + languages)
        - Gui sucks => Cutter Plugin
    - IDA: Gold standard for x86, okayish on other arches
    - BinaryNinja: Mix of IDA and Ghidra
        - Especially good for newer languages such as Go and Rust

Static tools cont.

- Python:
  - Pyinstxtractor
    - Extract bundled python files
  - Pycdc
    - Disassemble/Decompile python bytecode

Static tools cont.

- Android APKs
    - Essentially Java
    - Jadx: GUI for apktool essentially
    - apktool: CLI to decompile/compile apks
    - github/patrickfav/uber-apk-signer: Automatically sign apks

Static tools cont.

- .NET
  - DotPeek: Disassembler/Decompiler for .NET
  - ILSpy: Same as above
  - github/Droppers/SingleFileExtractor: Extract .NET from native libraries

Dynamic analysis

- Run/emulate the binary and attach a debugger/tracer
- Breakpoints
  - Addresses in memory where execution shall be paused
    - PAUSE = rip == TARGET
  - Prints infos about current registers/memory
  - Static analysis to find breakpoints
- Single stepping / tracing
  - One instruction at a time, print infos

Dynamic tools

- Native:
  - strace/ltrace: Traces syscalls/library calls
  - GDB
    - pwndbg, gef
  - Emulators
    - QEMU
    - qiling
  - Inbuilt debuggers of decompilers
    - Supports breaking in pseudocode

Dynamic tools cont.

- Android APKs:
    - Android Studio for emulation
    - FRIDA
- .NET
    - JetBrains RIDER
        - Supports binary debugging
        - Disassembles automatically

"Just run it lmao" - analysis

- Running unknown executables
  - **Bad idea**
- Even dockerfiles can be malicious
  - Insomnihack 23 (https://cryptax.github.io/2023/03/25/shame.html)
- Always emulate unknown binaries or use a VM

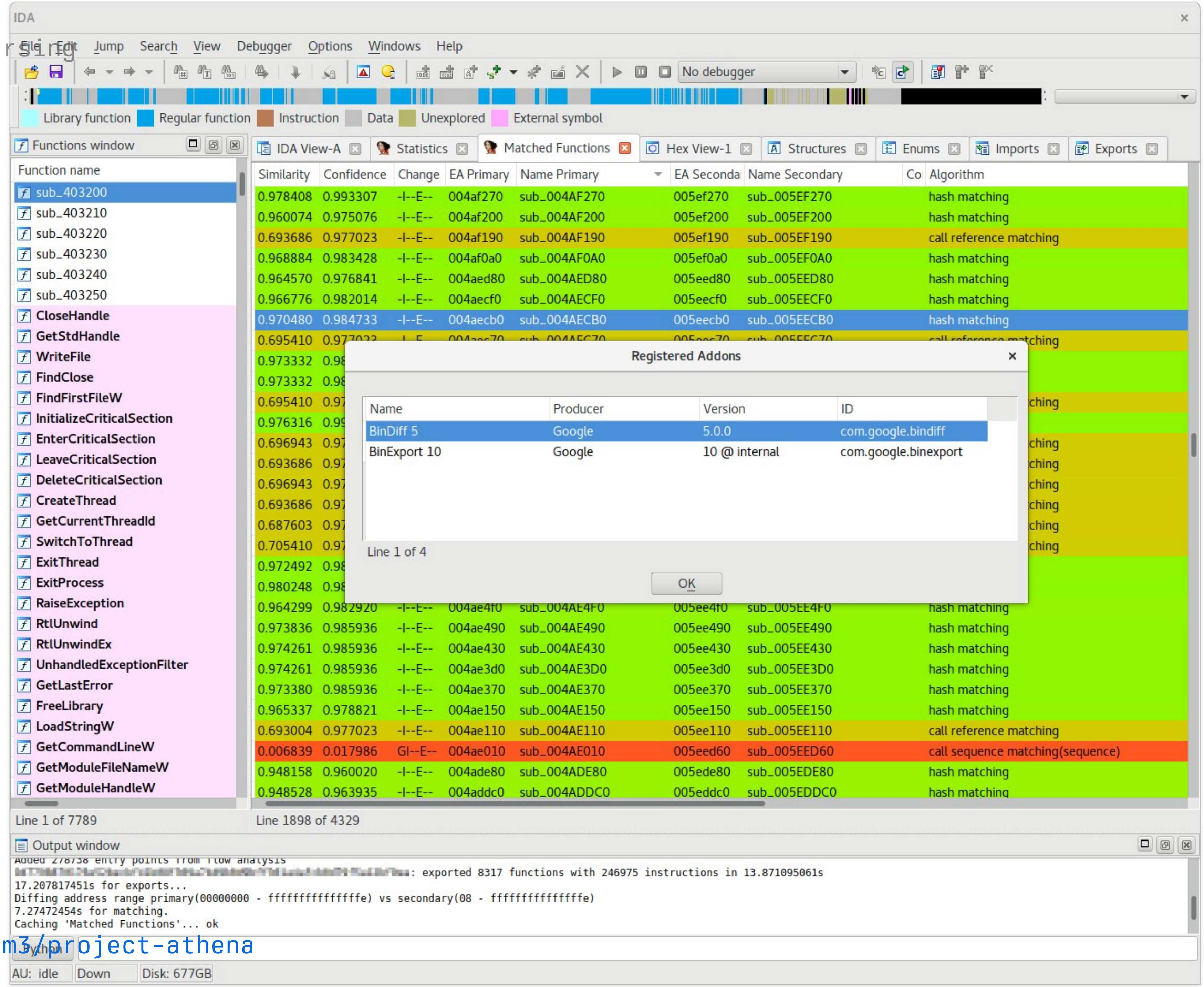
"Just run it lmao" - done right

- Emulation
  - Works cross OS
- Full system emulation
  - Qiling, QEMU System/Usermode
- Instruction emulation
  - **No syscall support**
  - e.g. Unicorn Engine
  - Lots of manual work

Diffing

- Prerequisite: Static analysis
- Needs 2+ program databases (e.g. from IDA)
- BinDiff databases
    - Find matching functions/patterns
    - See newly added functions

2



Function name
sub_403200
sub_403210
sub_403220
sub_403230
sub_403240
sub_403250
CloseHandle
GetStdHandle
WriteFile
FindClose
FindFirstFileW
InitializeCriticalSection
EnterCriticalSection
LeaveCriticalSection
DeleteCriticalSection
CreateThread
GetCurrentThreadId
SwitchToThread
ExitThread
ExitProcess
RaiseException
RtlUnwind
RtlUnwindEx
UnhandledExceptionFilter
GetLastError
FreeLibrary
LoadStringW
GetCommandLineW
GetModuleFileNameW
GetModuleHandleW

Line 1 of 7789

Similarity	Confidence	Change	EA Primary	Name Primary	EA Seconda	Name Secondary	Co	Algorithm
0.978408	0.993307	-I--E--	004af270	sub_004AF270	005ef270	sub_005EF270		hash matching
0.960074	0.975076	-I--E--	004af200	sub_004AF200	005ef200	sub_005EF200		hash matching
0.693686	0.977023	-I--E--	004af190	sub_004AF190	005ef190	sub_005EF190		call reference matching
0.968884	0.983428	-I--E--	004af0a0	sub_004AF0A0	005ef0a0	sub_005EF0A0		hash matching
0.964570	0.976841	-I--E--	004aed80	sub_004AED80	005eed80	sub_005EED80		hash matching
0.966776	0.982014	-I--E--	004aecf0	sub_004AECF0	005eecf0	sub_005EECF0		hash matching
0.970480	0.984733	-I--E--	004aecb0	sub_004AECB0	005eecb0	sub_005EECB0		hash matching
0.695410	0.977023	-I--E--	004aec70	sub_004AEC70	005eec70	sub_005EEC70		call reference matching
0.973332	0.98							
0.973332	0.98							
0.695410	0.97							ching
0.976316	0.99							
0.696943	0.97							ching
0.693686	0.97							ching
0.696943	0.97							ching
0.693686	0.97							ching
0.687603	0.97							ching
0.705410	0.97							ching
0.972492	0.98							
0.980248	0.98							
0.964299	0.982920	-I--E--	004ae4f0	sub_004AE4F0	005ee4f0	sub_005EE4F0		hash matching
0.973836	0.985936	-I--E--	004ae490	sub_004AE490	005ee490	sub_005EE490		hash matching
0.974261	0.985936	-I--E--	004ae430	sub_004AE430	005ee430	sub_005EE430		hash matching
0.974261	0.985936	-I--E--	004ae3d0	sub_004AE3D0	005ee3d0	sub_005EE3D0		hash matching
0.973380	0.985936	-I--E--	004ae370	sub_004AE370	005ee370	sub_005EE370		hash matching
0.965337	0.978821	-I--E--	004ae150	sub_004AE150	005ee150	sub_005EE150		hash matching
0.693004	0.977023	-I--E--	004ae110	sub_004AE110	005ee110	sub_005EE110		call reference matching
0.006839	0.017986	GI--E--	004ae010	sub_004AE010	005eed60	sub_005EED60		call sequence matching(sequence)
0.948158	0.960020	-I--E--	004ade80	sub_004ADE80	005ede80	sub_005EDE80		hash matching
0.948528	0.963935	-I--E--	004addc0	sub_004ADDC0	005eddc0	sub_005EDDC0		hash matching

Line 1898 of 4329

Registered Addons

Name	Producer	Version	ID
BinDiff 5	Google	5.0.0	com.google.bindiff
BinExport 10	Google	10 @ internal	com.google.binexport

Line 1 of 4

OK

```
Added 278738 entry points from flow analysis
[redacted]: exported 8317 functions with 246975 instructions in 13.871095061s
17.207817451s for exports...
Diffing address range primary(00000000 - fffffffffffffffe) vs secondary(08 - fffffffffffffffe)
7.27472454s for matching.
Caching 'Matched Functions'... ok
```

Patching

- Modify instructions to get different behaviour
  - e.g. `jnz address` => `jz address`
- Remove instructions by using NOPs
  - `mov eax, ebx` => `nop nop`
- Used to bypass checks or security
- What happens if we leak some infos by doing this?

Sidechannels

- Leak infos
- Bruteforce inputs much faster e.g 26*6 instead of 26**6
- Timing attacks

  or
- CPU metric attacks
  - perf-tools on Linux

Symbolic execution

- Execute a program
- Find all paths and values that satisfy each branching condition
- Output inputs that satisfy certain branches

Given this function, how many paths are there?

```
int get_sign(int x) {
  if (x == 0)
    return 0;

  if (x < 0)
    return -1;
  else
    return 1;
}
```

Three branching conditions, which inputs satisfy each path?

```
int get_sign(int x) {
  if (x == 0)
    ...
  if (x < 0)
  ...
  if (x > 0)
  ...
}
```

Symbolic execution tools

- angr
  - Black box (works on binary level)
- klee
  - White box (requires source code)
- manticore (unmaintained)
  - Like angr black box, requires more fine tuning

How2Start

1. Run strings and gather infos about the binary
2. What's the goal?
    - Want a key/input?
    - Optimization problem?
3. Optional: Can we cheese it?
    - Sidechannels? Do we have an oracle?
    - Symbolic execution
    - Patching or info leaks?

How2Start cont.

4. *Actually* reverse the binary and figure out the *actual* solution
5. ???
6. Validate solution

Live demo - cracking

References

https://ike.mahaloz.re/

https://godbolt.org/

https://dogbolt.org/

https://defuse.ca/online-x86-assembler.htm#disassembly

https://ctf101.org/