This work is licensed under a Creative Commons license

Attribution-NonCommercial-NoDerivatives 4.0 International
(CC BY-NC-ND 4.0)

You are free to:

Share copy and redistribute the material in any medium or format.

Under the following terms:

Attribution You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

NonCommercial You may not use the material for commercial purposes.

NoDerivatives If you remix, transform, or build upon the material, you may not distribute the modified material.

$ whoami

Giovanni Lagorio

mail `giovanni.lagorio@unige.it`

web `https://csec.it/people/giovanni_lagorio/`

github/twitter/... `zxgio`

- Assistant Professor at the University of Genoa
- Security enthusiast
  - Main interests: ethical hacking, reverse engineering and exploitation
  - CTF player/organizer, co-founded ZenHack CTF Team in 2017
  - Organizer and trainer for CyberChallenge.IT @ UniGE since 2018

`https://zenhack.it`

Binary Reverse Engineering

with Ghidra

Giovanni Lagorio

giovanni.lagorio@unige.it
https://csec.it/people/giovanni_lagorio
Twitter & GitHub: zxgio

DIBRIS - Dipartimento di Informatica, Bioingegneria, Robotica e Ingegneria dei Sistemi
University of Genova, Italy

www.zenhack.it

Outline

Reversing

How can we know what a program *really* does?
In particular, a binary program, without anything else
No source code, no documentation, no symbols, ...

Reverse engineering (AKA *reversing*) consists in attempting to understand how a device/process/piece-of-software accomplishes a task

- in our case, what a program does, and how

Reversing challenges

- low-level languages
- often, no “symbols”; i.e. meaningful names
- (almost) no type information
- no class/module/namespace boundaries
- code and data can be mixed, and they usually do
- difficulty in adding/changing/removing instructions
- ...

With some effort and the right tools, we’ll break programs apart to learn how they work and what they do.

An old saying goes: *Once you speak machine code, then every program becomes open-source* ☺

Beware

We always reverse engineer programs that have been explicitly written to be reversed (the so-called "crackmes", and some CTF-like challenges), open-source software or malware

- It is not easy to find detailed and practical advice about the legal boundaries of reversing copyrighted software in EU, US, . . . worldwide
- As far as I understand (but I am not a lawyer), in EU you are allowed to reverse engineer a program for private purposes or to understand its interfaces to allow another program to interface with it

Never run unknown files

Unless you're 100% confident they are safe

Exercises/assignments, not clearly marked as malware, are safe (AFAIK ☺)

Static vs Dynamic Analysis

Broadly speaking, we can split our methods/tools into

- Static analysis: we reason about the binary without running it
  - you can analyze the whole binary in one go
  - you don't need a CPU/system that can run such a binary
  - (obviously, almost) no knowledge of runtime states
  - can be difficult to pinpoint *interesting* parts
- Dynamic analysis: we run the binary and analyze it, or log its behavior, as it executes
  - often simpler, can observe runtime states
  - can be harmful; e.g., malware
  - not everything is necessarily apparent
  - for each run you observe *that* particular execution, and might miss *interesting* parts of the code; e.g.

    ```
    if (random()==0xcafebabe) { /* interesting stuff */ }
    ```

First approach: identification/integrity checking

How can we check the "identity" of a file?

Hash functions:

Linux/WSL	`md5sum`, `sha*sum`, ...
Windows	*HashMyFiles*
	`https://www.nirsoft.net/utils/hash_my_files.html`
	...

→`sample{1,2}.elf`

Format and strings

The first approach usually consists in checking

Formats
- file
- diec https://github.com/horsicq/Detect-It-Easy
- polyfile https://github.com/trailofbits/polyfile
- ...
- when in doubt, hex editors (e.g., ImHex https://github.com/WerWolv/ImHex)

Strings
- strings
- floss https://github.com/mandiant/flare-floss
- ...

Executable specific tools

ELF `hte`, `readelf`, `objdump`, `nm`, ...

- XELFViewer
  `https://github.com/horsicq/XELFViewer`

PE `hte`, `dumpbin.exe`, ...

- PE Bear
  `https://github.com/hasherezade/pe-bear`
- PE Studio
  `https://www.winitor.com/download`
- XPEViewer
  `https://github.com/horsicq/XPEViewer`
- ...

Linux: beware of 32-bit executables in modern distros

In order to run/debug 32-bit executables on 64-bit Ubuntu systems, you need to add 32-bit libraries:

- `sudo dpkg --add-architecture i386`
- `sudo apt update`
- `sudo apt install libc6-dbg:i386`

A (simpler) alternative seems to be installing the package `gcc-multilib`

Other distributions should provide analogous packages.

Demo/exercise: restricted-area v1.0

CTFs and Flags

All challenge descriptions are *tongue in cheek*: don't take them too seriously ☺ (but read them carefully, since they may contain hints)

In these exercises, *flags* are strings in the format `BASC{...}`.

> *A flag is trapped inside a restricted area, protected by a super-secure password. Will you find it?*

→ `restricted_area_v1`

Demo/exercise: restricted-area v2.0

> *We fixed all vulnerabilities of the previous version.*
> *This program doesn't accept any password, so you can't guess them! Ahahah*
> *Can you still manage to get the flag?*

→ `restricted_area_v2`

Can you find the flag... with the tools discussed so far?

To go deeper, we need to look at the code...

How could we analyse/reverse machine code?

1. Disassemble, i.e. decoding bytes into assembler instructions
2. Group instructions into blocks and functions
3. Abstract into graphs
   - control-flow graphs describe the structure of functions
   - call graphs describe the relationships between functions
   - code/data cross references help in understanding dependencies and find interesting (starting) points, to explore further
4. Decompile, i.e. *trying* to recover corresponding C code

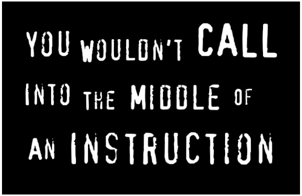
The general goal is inferring higher-level semantics, by giving meaningful names, and adding comments

- e.g. "increment variable `counter`" instead of `ADD [RSP-0x1C],1` or "call function `ask_password`" instead of `CALL 0x61a4be0032`

Disassembling

Disassembling might sound boring and trivial,
however. . . [ACvdV+16, JZL+20]

- How do you distinguish between *code* and *data*?
  - E.g., compilers may embed data inside code sections
- Instructions could be *overlapped* [JLH13, LD03]



https://twitter.com/awesomekling/status/1369178264716120065

- Code can be *encrypted*/*packed*/*obfuscated*/. . .

Types of disassemblers

Static disassemblers can be split into

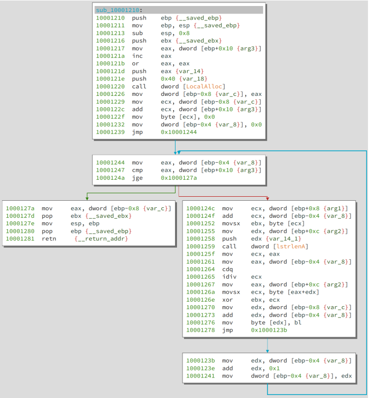
- Linear sweep
  - start at the beginning
    - disassemble the first instruction
    - then the following one,
    - and so on
  - no attempt to understand the control flow
- Recursive traversal
  - focus on of control flow
  - start at the entry point
    - if non-branch, continue to the next instruction
    - if branch, continue to possible targets

→ `asm-examples/tricky_disasm/tricky.asm`

Basic Blocks

Basic blocks are sequences of instructions in which

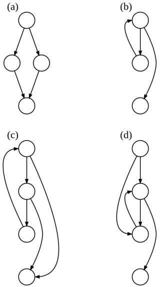
- flow of control enters at the beginning
- leaves at the end, without branching (except at the end)



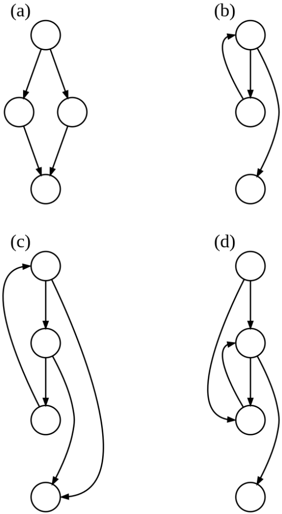
Control flow graph

A Control Flow Graph captures the execution paths that can take place inside a function

- the nodes are basic blocks
- edges represent potential control flow paths
  - back edges represent loops



CFGs



- (a) an if-then-else
- (b) a while loop
- (c) a loop with two exits, e.g. while with an if. . . break in the middle
- (d) a loop with two entry points, e.g. goto into a while or for loop

`https://en.wikipedia.org/wiki/Control_flow_graph`

CFG Construction challenges

Problematic constructs are:

- indirect jump instructions; mainly used to implement switch statements. [MM16] handles various kinds of jump tables with a backward intraprocedural dataflow analysis; e.g.:

Instruction	Jump target analysis
`mov %ebp,0xf8(%rsp)`	0 ≤%rdx==0xf8(%rsp)==%ebp≤ 5
`cmp $0x5,%ebp` `ja 43a4ab`	0 ≤%ebp≤ 5
`lea 0x525e8f(%rip),%rax` `lea -0x302(%rip),%rcx`	%rax=0x9602a0, %rcx=0x43a116 JTT=0x43a116+[0x9602a0+%rdx×8]
`movslq 0xf8(%rsp),%rdx`	%rdx==0xf8(%rsp)
`add (%rax,%rdx,8),%rcx`	JTT=%rcx+[%rax+%rdx×8]
`jmpq *%rcx`	JTT=%rcx

- non-returning functions; e.g. `exit` or `abort`
  - if not recognized, an nonexistent control flow is assumed from a non-returning call to its next block

CFG Partitioning challenges

Functions can share BBs, their code can be non-contiguous

```
35110db510 <__write>:
35110db510   cmpl $0x0,0x2b8199(%rip)
35110db517   jne 35110db529
35110db519 <__write_nocancel>:
35110db519   mov $0x1,%eax
...
35110db526   jae 35110db559
35110db528   retq
35110db529   sub $0x8,%rsp
...
35110db556   jae 35110db559
35110db558   retq
35110db559   mov 0x2b2a48(%rip),%rcx
...
35110db56c   jmp 35110db558
```

Figure 9: Functions sharing code and non-contiguous functions example from libc. The code in blue is shared by both functions. `__write_nocancel` is also a non-contiguous function, which is separated by the code from `__write`.

From: [MM16]

Tail calls: 2 or 3 functions?

```
BZFILE* BZ_API (BZ2_bzdopen) (int fd, char * mode)
 { return bzopen_or_bzdopen(NULL,fd,mode,1);}
BZFILE* BZ_API (BZ2_bzopen) (char *path, char * mode)
 { return bzopen_or_bzdopen(path,-1,mode,0);}
```

```
// entry point of bzopen_or_bzdopen, but no function symbol
351f40baa0   mov %rbx,-0x30(%rsp)
...
351f40bd70 <BZ2_bzdopen>:
351f40bd70   mov %rsi,%rdx          // set mode
351f40bd73   mov $0x1,%ecx          // set open_mode
351f40bd78   mov %edi,%esi          // set fd
351f40bd7a   xor %edi,%edi          // set path
351f40bd7c   jmpq 351f40baa0
...
351f40bd90 <BZ2_bzopen>:
351f40bd90   mov %rsi,%rdx          // set mode
351f40bd93   xor %ecx,%ecx          // set open_mode
351f40bd95   mov $0xffffffff,%esi   // set fd
351f40bd9a   jmpq 351f40baa0
```

Figure 10: A tail call example from bzip2. BZ2_bzdopen **and** BZ2_bzopen **both perform a tail call to the internal function** bzopen_or_bzdopen, **which does not have a function symbol.**

From: [MM16]

Finding function entry points (without symbols)

Without complete symbols, identifying function entry points becomes significantly more difficult; you can tackle this issue by

- recognizing *function prologue patterns*; *however*, difficult to
  - adapt to variations in compilers and optimization levels
  - detect non-standard/hand-written functions
- parsing `.eh_frame` section
  `http://www.bitlackeys.org/#eh_frame`
- using the CFG; see e.g. [ASB17]

(non-inlined) library functions are somewhat easier to detect:

- in dynamically linked programs, function names cannot be omitted
  - tricky programs may play with `dlsym`/`GetProcAddress` and/or *offsets*
- in statically linked programs we can try *fingerprinting* known functions [JRM11]

Call graphs

Once you have identified functions, then it can be useful representing relationships between functions in a Call Graph

- each node represents a function
- each edge (f, g) indicates that f calls g
  - A cycle indicates recursive calls
- can be computed statically or dynamically
  - E.g. a profiler could produce a dynamic call graph
- a static call graph represents every possible run
  - computing the exact static call graph is an undecidable problem
  - static call graph algorithms are generally overapproximations
    - when function pointers or virtual methods are invoked, a combination of *dataflow* and *data type* analysis can limit the set of potential *targets*
    - if the program loads code modules dynamically at runtime, there is no way to be sure that the control flow graph is complete

Outline

Getting started

- A highly extensible application for software reverse engineering
- Official site: `https://ghidra-sre.org/`
  You find there binaries and installation guide
- Guides/tutorials
  - `docs/GhidraClass`, inside Ghidra installation directory
  - these slides ☺
  - (paid, excellent) The Ghidra Book
    `https://nostarch.com/GhidraBook`
  - (free) "Hands-on Reversing with Ghidra"
    by Jeremy Blackthorne @ Ringzer0 Training 2022
    `https://vimeo.com/728095141`

  script snippets: `https://github.com/HackOvert/GhidraSnippets`
- The main, closed-source, alternatives are:
  - *IDA Pro* `https://hex-rays.com/ida-pro/`
  - *Binary Ninja* `https://binary.ninja/`

Configuration tips

Before running Ghidra you may tweak `support/launch.properties`:

- e.g., when using 4K displays you may need to change `uiScale`:
  `VMARGS_LINUX=-Dsun.java2d.uiScale=2`

The environment

Let's use Ghidra to analyze `restricted_area_v1` ...

- Projects
  - Loaders
  - Tools $\rightarrow$ Code Browser
- [Load-PDB and] Auto-analysis
- Window handling/layout

Shortcuts and suggested options

Shortcut to remember:

- `F1`
- `F4` while the mouse is over any toolbar icon or menu item

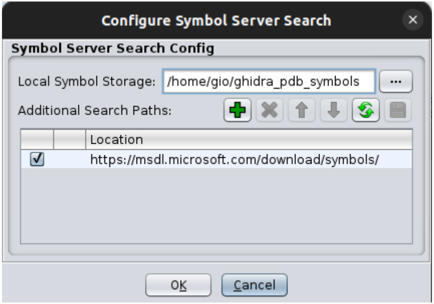
Suggested key bindings (*Edit* → *Tool Options...* →*Key Bindings*):

- ESC/shift-ESC for *Previous/Next location in History*
- X/ctrl-X for *Find References To* and *Show References To Address*

Moreover, you may consider to set "Left" for *Mouse Button Activate* in *Listing Fields*→ *Cursor Text Highlight*

PDB Symbol server

Edit→Symbol Server Config



Then, when you analyze, e.g., a Windows DLL, you can check *Search remote symbol server* in *PDB Universal*

Symbol views

- *Symbol table* displays a tabular view of each symbol
  - *Symbol reference* display the reference information for the selected symbol, and the type of reference

RW	read/write data access
Read	read-only data access
Write	write-only data access
Data	general data access
Branch	conditional jump
Jump	unconditional jump
Call	subroutine/function call
Unknown	all other reference types

- *Symbol tree* hierarchical view

Imported functions

These views are useful to quickly look at imports/exports

Default labels

Default label prefixes

- Common
  - FUN a function
  - DAT a data item (AKA "global variable")
  - LAB code (usually, some jump-target inside a function)
- Others
  - SUB code that has at least one call to it (but it doesn't seem a proper function)
  - EXT an external entry point
  - OFF the associated address is *offcut*, i.e. inside of an instruction or data item
  - UNK none of the above

You can change/assign a label with `L`

Navigation

Views are synchronized

- G to jump to address/label (wildcards)/expression
- toolbar: next/previous
  - location
  - selected/highlighted range
  - code-unit
- double-click on label/address in the code browser
- click on names in *Functions*/...
  (when enabled, otherwise double-click)

"next"/"previous" meaning for I/D/U

When searching for Instructions/Data/Undefined items, Ghidra will skip all contiguous items of the same type. Then, it will search for the item.

Cross-references

- inside *Listing*

  c call
  j jump
  * pointer
  w write
  r read

- in *Reference to . . .* views

Function calls

To display incoming and outgoing calls:

- *Function Call Graph*
- *Function Call Trees*

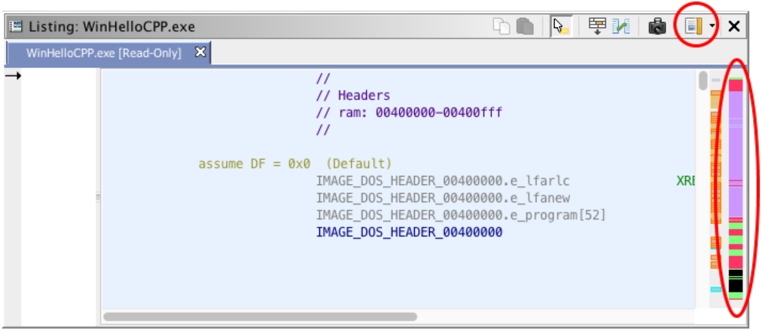
Searching

Search. . .

- **Program Memory** performs searching for byte patterns in program memory
- **Program Text** searches for text strings in various parts of the listing
  - supports wildcards but not full regular-expressions
- **For Strings** finds potential strings within the program memory
- **For . . .** find scalars, instruction patterns, . . .

Bars

- Navigation marker area (right-click to see/select categories)
- Overview bars
  - Entropy
  - Overview



Columns and Column-filters

- Some windows let you choose the columns and their filters (e.g. *Functions* and *Defined Strings*)
- Filters can be saved and reused later

Other views

- *Bytes* (click on its settings for adding "columns")
- *Defined data*
- *Defined strings*

View synchronization

Views are synchronized, you can make snapshots/independent-views with the "camera"

Startup code

When we analyzed `restricted_area_v1`, Ghidra found and jumped to `main`. Let's check `v2` out...

Most executable share the same startup code, which

1. initializes the CRT
   - in Windows the very first thing is initializing the security cookie
2. calls the main function (`main` or `WinMain`)
   - saving the return value *v*
3. cleans up the CRT
4. exits with exit-value *v*

The executable entry-point is called `entry`

`entry`

If Ghidra does not name `entry` automatically, you can find the entry-point by navigating the ELF/PE-header (see *Program trees* → *Headers*)

Linux/Windows: `main`

According to the C standard,

```
int main(void);
int main(int argc, char *argv[]);
```

however, a common extension is

```
int main(int argc, char *argv[], char *envp[]);
```

Decompiler Parameter ID analysis

Turned off by default (because expensive); while generally useful, this analysis can be misleading when looking for `main`/`WinMain` because it can “hide” parameters, at call site, that are unused by the function

Windows: WinMain

https://learn.microsoft.com/en-us/windows/win32/learnwin32/winmain--the-application-entry-point:

```
int __stdcall WinMain(
  [in] HINSTANCE hInstance,
  [in] HINSTANCE hPrevInstance,
  [in] LPSTR     lpCmdLine,
  [in] int       nShowCmd
);
```

- hInstance is actually the module load-address
- hPrevInstance is always 0 (it is from the 16-bit days)
- pCmdLine contains the command-line arguments as a Unicode string
- nCmdShow is a flag that says whether the main application window will be minimized/maximized/...

Linux: the address of `main`

`https://refspecs.linuxbase.org/LSB_3.1.0/LSB-generic/LSB-generic/baselib---libc-start-main-.html`:

In Gdb we can ...

- `start`
- `b __libc_start_main`
- `c`
- find out its first parameter

  32 bits: `p *(void **)($esp+4)`
  64 bits: `p $rdi`

Comments

Comments can be added to any instruction/data-item, with ; (semicolon)

Five categories:

End-of-line (EOL) Displayed to the right of the instruction

Pre Displayed above the instruction and in decompiled code

Post Displayed below the instruction

Plate Displayed as a block header above the instruction, and in decompiled view. Plate comments are automatically surrounded by '*'s

Repeatable Displayed to the right of the instruction if there is no EOL comment.
These are also displayed at the "from" address of a reference (if there is no EOL or repeatable comment defined at that address)

Constants

- convert
- set equate

Note: decompiler and listing views are not “synchronized” as conversions/equates go

Calling conventions

Both `function1` and `function2` takes three integers and print a simple calculation.

Let's find out what
→ `function1` and
→ `function2` do by ...

1. running them, and guessing
2. using Ghidra decompiler/function graph

Analysis of restricted-area v2.0

. . . and we're back to restricted-area!

- Can you find the address of `main`?
- Identify the function that prints the flag

Why such a function is not called? Can we do something about it?

Two possibilities are:

- altering the control flow by using a debugger
- patching the machine code

Outline

Dynamic Analysis tools

We can observe the execution of a program at many different levels; e.g.,

Linux

- `strace [-f] [-e ...]`
- `ltrace` — some versions don't work with eagerly-bind executables; check with: `readelf --dynamic ...| grep NOW`

  Try: `ltrace -e strcmp ./restricted_area_v1 # same for v2`
- gdb + GEF

Windows

- Process Monitor from the *Sysinternals Suite*
- Tiny Tracer `https://github.com/hasherezade/tiny_tracer`
- x64dbg

. . . and even making our custom analyses by leveraging instrumentation frameworks

Introduction

Debuggers are software (or hardware) that permit to get an insight into what a program/system is doing, by

- pausing the execution at specific places
  - optionally, when some conditions are met
- showing the contents of registers and memory
- resuming the execution
- ...

Symbols and debug information

Programs and libraries can include

- Symbols, mapping names to memory addresses. For instance, they allow you to find in which function the *instruction-pointer* is, ...
- Full debug information, that allow a debugger to match machine code to its corresponding source-level constructs

Released programs typically don't, but they rely on standard libraries...

Symbols in Linux

Libc symbols are distributed separately

- in Ubuntu, `libc6-dbg` and `libc6-dbg:i386`
- in gdb (or `~/.gdbinit`) use:
  `set debug-file-directory /usr/lib/debug`
  then,
- `info address` *`symbol`* shows where data for symbol is stored
- `info symbol` *`addr`* prints the name of symbol stored at *addr*

You can also use `addr2line(1)` to read symbol information

Compiling with `-g`/`-ggdb` adds debug information using DWARF [Eag12] (`http://dwarfstd.org/`)

- to dump DWARF information, `dwarfdump`; e.g. `-l` prints the association between PCs and source lines
  → `c-examples/buggy_factorial`

Symbols in Windows

Symbol information can be downloaded from a symbol server

- official one: `https://msdl.microsoft.com/download/symbols`
- you can set the environment value `_NT_SYMBOL_PATH` to something like: `srv*`*`your-cache-path`*`*`*`server-url`*; e.g.
  `setx _NT_SYMBOL_PATH ^`
  `srv*c:\sym*https://msdl.microsoft.com/download/symbols`
- x64dbg set the server in: Options → Preferences → Misc
- `symchk.exe` from Windows SDK, and other utilities, can download symbols and store them in the cache; e.g.
  `https://github.com/dbgsymbol/getsymbol`

With MS's compiler, `/DEBUG` add debugging information:

1. The linker puts these information into a program database (PDB) file
2. The executable/DLL contains the path of the corresponding PDB
3. A debugger reads the embedded name and uses the PDB

Outline

Experiment

Let's open three times each `restricted_area_v{1,2}` in the debugger.

Obviously, the code is different for v1/2, but you should notice something else. . .

ASLR

In order to prevent an attacker from reliably jumping to, for example, a particular exploited function in memory, ASLR randomly arranges the address space positions of key data areas of a process, including the base of the executable and the positions of the stack, heap and libraries

`https://en.wikipedia.org/wiki/Address_space_layout_randomization`

Memory map

You can synchronize the static and dynamic addresses by setting the Image Base from the Memory Map

- however, there other ways...

Useful settings

- You can disable ASLR by

  Linux using the command `setarch`; for instance:
  `setarch $(uname --machine) --addr-no-randomize bash`

  Windows resetting the flag `IMAGE_DLLCHARACTERISTICS_DYNAMIC_BASE` (0x40) in the field `DllCharacteristics` of the `PE_IMAGE_OPTIONAL_HEADER` (e.g., by using PE Bear)

- Windows 10+ implement parallel loading by creating a thread pool of worker threads when the process initializes. You can set registry key
  `HKLM\Software\Microsoft\Windows NT\CurrentVersion\Image File Execution Options\`*`your-program.exe`*`\MaxLoaderThreads`
  to 1, to avoid having multiple threads around

Restricted area, again!

Let's solve `restricted_area_v2` with the help of a debugger

Demo/exercise

> *Volatility is a tendency to change quickly, as it happens with the flag of this challenge.*
> *No, this is not a forensics challenge.*
> *Can you be fast enough to catch the flag?*

→ `volatility`

Ret-sync

- ret-sync stands for *Reverse-Engineering Tools SYNChronization*
- plugins to synchronize a debugging session with a disassembler

`https://github.com/bootleg/ret-sync`

Remote debugging

Ret-sync can be configured via its ".ini" `.sync` file

```
[INTERFACE]
host=...
port=...
```

To enable remote-debugging:

1. find the IP address of the computer running Ghidra
   - typically, Ghidra is run on the host and the debugger inside a VM
   - in VMware, the host-only network (VMnet1) allows you to access an isolated virtual network, completely contained within the host system
2. then, create the configuration file and copy it to both:
   - the user's home directory of the debugger machine; e.g. `c:\users\user\.sync`
   - the user's home directory or the Ghidra project folder (`.../`*`project`*`.rep/.sync`) of the Ghidra machine

Ret-sync bugs

Sometimes ret-sync doesn't work properly with gdb ☹

The following workaround, in the `.sync` file (inside the Ghidra project folder; i.e., `.../`*`project`*`.rep/.sync`), seems to solve the problems:

- set `use_raw_addr=true` under section `[GENERAL]`

Ret-sync shortcuts in Ghidra

Most important are:

F2	Set breakpoint at cursor address
Ctrl-F2	Set hardware breakpoint at cursor address
Alt-F3	Set one-shot breakpoint at cursor address
Ctrl-F3	Set one-shot hardware breakpoint at cursor address
Alt-F2	Translate (rebase in debugger) current cursor address
F5	Go
F10	Step over
F11	Step into

Pwntools

Pwntools is a

- CTF framework and
- exploit development library

written in Python

https://github.com/Gallopsled/pwntools

Demo/exercise

Demo/exercise:
$\rightarrow$ `bomb` (local and “remote”)

Tubes: `pwnlib.tubes`

- `process`
- `sock`
  - `remote`
  - `listen`
- `ssh`
- ...

various methods to interact:

- `send*[after]`
- `recv*`
  - `clean`
    returns all buffered data from a tube by calling `recv` with a low timeout until it fails
- `interactive`
  prints a prompt, and simultaneously reads & writes

https://docs.pwntools.com/en/stable/tubes.html#module-pwnlib.tubes

Context

Many settings controlled via `context`, such as

- `os`: target OS, see `pwnlib.context.ContextType.oses`
- `arch`: architecture; see `pwnlib.context.ContextType.architectures`
- `bits` / `endian`: bit-width/endianness
- `log_level`: logging level; default `logging.INFO`

`context.binary`

The easiest way to *automagically* set all context values is assigning the property `binary`; e.g.:

```
context.binary = './my-binary'
```

(you can also assign an ELF object, which we'll encounter in a few slides)

Packing and unpacking of strings

```
>>> p8(0), p16(0), p32(0), p64(0)
(b'\x00', b'\x00\x00', b'\x00\x00\x00\x00',
 b'\x00\x00\x00\x00\x00\x00\x00\x00')
>>> p32(0xdeadbeef)
b'\xef\xbe\xad\xde'
>>> p32(0xdeadbeef, endian='big')
b'\xde\xad\xbe\xef'
>>> hex(u32(b'\xbe\xba\xfe\xca'))
'0xcafebabe'
```

`https://docs.pwntools.com/en/stable/util/packing.html`

Endianness

context-aware; can be overridden in the parameters

Magic Command-Line Arguments

Settings, when run in `from pwn import *` mode, can be specified by

- adding UPPERCASE arguments to the command-line; those arguments are extracted, and removed from `sys.argv`
- using environment variables, prefixed by `PWNLIB_`

For instance, to enable more verbose debugging:

```
$ PWNLIB_DEBUG=1 python exploit.py
$ python exploit.py DEBUG
```

Then, for instance, to switch between a local/remote target:

```
if args.REMOTE: # equivalent to: args['REMOTE']
        io = remote('exploitme.com', 4141)
else:
        io = process('./pwnable')
```

See http://docs.pwntools.com/en/stable/args.html

Assemble and Disassemble

```
>>> asm('nop')
'\x90'
>>> asm('mov eax, 0xdeadbeef').hex()
'b8efbeadde'
>>> asm('mov eax, 0').hex()
'b800000000'
>>> print(disasm(unhex('6a0258cd80')))
   0:   6a 02                   push   0x2
   2:   58                      pop    eax
   3:   cd 80                   int    0x80
```

ELF parsing and patching

class `ELF` members:

- `sym[bols]` is a *dotdict* of name to address for symbols
  - `prog.symbols['printf']` can be simplified to:
    `prog.symbols.printf`
    `prog.sym.printf`
- `got` is a dotdict of name to address for GOT entries
- `plt` is a dotdict of name to address for PLT entries
  - for an imported function *f*, *elf*`.plt.`*f* `==` *elf*`.symbols.`*f*
- `search(string, writable = False)` → a generator
  search the virtual address space for the specified string
- `(dis)asm` to (dis)assembly using virtual addresses
- `read/write/save`
- ...

To create an ELF from assembly/bytes: `ELF.from_assembly`, and `ELF.from_bytes`

`http://docs.pwntools.com/en/stable/elf/elf.html`

Interfacing with GDB

Example:

```
p = gdb.debug(args=..., gdbscript=...)
```

gdb is run in a new terminal, executing the `gdbscript`

- if tmux detected, defaults to new pane; if you want to change that:
  `context.terminal = ['tmux', 'new-window']`
  `context.terminal = ['tmux', 'split-window', '-h']`
- if Gnome terminal doesn't work automatically, you can try:
  `context.terminal = ['gnome-terminal', '--window', '--', 'bash', '-c']`

See `http://docs.pwntools.com/en/stable/gdb.html` and `https://docs.pwntools.com/en/stable/context.html`

And much more...

- finding ROP gadgets
- preparing format string payloads
- generating Python scripts (`pwn template ...`)
- ...

RTFM `http://docs.pwntools.com/en/stable/index.html`

Jupyter notebooks/PyCharm

to use pwntools inside some environments, you need to set the variable `PWNLIB_NOTERM`; e.g.

```
PWNLIB_NOTERM=1 jupyter notebook
```

Debuggers

https://twitter.com/garabatokid/status/1192753360497197056

Introduction

Instrumentation means inserting new code into a program or a process, to

- observe and/or
- change

its behavior.

- Easy with source programs
  - manually
  - automatically; for instance, in gcc you can use:
    - `-fsanitize=address` to instrument memory access instructions to detect out-of-bounds and use-after-free bugs
    - `-pg`/`-finstrument-functions` to generate profiling code
    - ...
- Interesting on (stripped) binaries ☺

Scenarios

Let's consider three scenarios:

1. Replacing existing code/AKA "patching"
    - This can also be seen as "removing", since we can overwrite with NOPs
2. Inserting/removing code in the middle of existing one
3. Adding new code "somewhere"

Replacing existing code

It's *relatively* easy to replace existing instructions, as long as

1. the new code fits into the space of the old one
2. jump targets are preserved

Examples of safe transformations are:

- "NOPping" annoying checks (anti-analysis? ☺)
- transforming conditional jumps to unconditional ones
- changing constant operands
- ...

e9patch [DGR20] relaxes the former constraint by "punning" bytes following an instruction. I.e., those bytes are used both as the last bytes of the inserted jump *and* the bytes for following instructions

`mov %rax,(%rbx)`

Original:	48	89	03	48	83	c0	20
Patched:	e9	XX	XX	48	83	c0	20

`jmpq 0x8348XXXX` *(punned)*

Inserting/removing code

Inserting new (or removing old) code is extremely hard, quoting [And18]:

> *... new code will shift existing code to different addresses, thereby breaking references to that code. It's practically impossible to locate and patch all existing references after moving ...*

So, manually patching it's possible, but *tough* ... interesting read:
Did Microsoft just manually patch their equation editor executable? Why yes, yes they did. (CVE-2017-11882)

Instrumentation framework

For more complex scenarios, there are Instrumentation frameworks

- tools for building program analysis tools
- they allow you to choose what to instrument and how

We can't cover them now; the most prominent are *Frida* `https://www.frida.re/`:

- "Unlocking secrets of proprietary software using Frida" @ NDC 2018
  `https://www.youtube.com/watch?v=QC2jQI7GLus`
- "The engineering behind the reverse engineering" @ OSDC 2015
  `https://www.youtube.com/watch?v=uc1mbN9EJKQ`

and Intel's *Pin* `http://www.intel.com/software/pintool`

Restricted area, again *and again*!

Let's solve `restricted_area_v2` by patching the executable

Demo/exercise: restricted-area v3.0

We promise this is the last variant!
→ `restricted_area_v3`

…you know what to do, don't you? ☺

Start the server by running:
`restricted_area_v3_run_server.sh`
The server listen at port 6001/tcp, that can be reached by running:
`nc 127.0.0.1 6001`

Outline

Demo/exercises

Exercises:

→ `math_is_4_fun`

→ `minions`, port 6002

→ `jurassic_park`

→ `slow_printer`

→ `easter_egg`

→ `lucky-numb3rs`, port 6003

→ `the_maze`, port 6004

→ `unbreakable_aes`

Demo/exercise:

→ `pacman4console`

References I

[ACvdV+16] Dennis Andriesse, Xi Chen, Victor van der Veen, Asia Slowinska, and Herbert Bos.
An in-depth analysis of disassembly on full-scale x86/x64 binaries.
In *25th USENIX Security Symposium (USENIX Security 16)*, pages 583–600, Austin, TX, 2016. USENIX Association.

[And18] Dennis Andriesse.
Practical Binary Analysis.
No Starch Press, 2018.

[ASB17] Dennis Andriesse, Asia Slowinska, and Herbert Bos.
Compiler-agnostic function detection in binaries.
In *Security and Privacy (EuroS&P), 2017 IEEE European Symposium on*, pages 177–189. IEEE, 2017.

References II

[DGR20] Gregory J. Duck, Xiang Gao, and Abhik Roychoudhury.
Binary Rewriting without Control Flow Recovery.
In *Proceedings of the 41st ACM SIGPLAN Conference on Programming Language Design and Implementation*, PLDI 2020, page 151–163, New York, NY, USA, 2020. Association for Computing Machinery.

[Eag12] Michael J Eager.
Introduction to the DWARF debugging format, 2012.

[JLH13] Christopher Jamthagen, Patrik Lantz, and Martin Hell.
A new instruction overlapping technique for anti-disassembly and obfuscation of x86 binaries.
In *Anti-malware Testing Research (WATeR), 2013 Workshop on*, pages 1–9. IEEE, 2013.

References III

[JRM11] Emily R Jacobson, Nathan Rosenblum, and Barton P Miller.
Labeling library functions in stripped binaries.
In *Proceedings of the 10th ACM SIGPLAN-SIGSOFT workshop on Program analysis for software tools*, pages 1–8. ACM, 2011.

[JZL+20] Muhui Jiang, Yajin Zhou, Xiapu Luo, Ruoyu Wang, Yang Liu, and Kui Ren.
An empirical study on ARM disassembly tools.
In *Proceedings of the 29th ACM SIGSOFT International Symposium on Software Testing and Analysis*, pages 401–414, 2020.

References IV

[LD03] Cullen Linn and Saumya Debray.
Obfuscation of executable code to improve resistance to static disassembly.
In *Proceedings of the 10th ACM conference on Computer and communications security*, pages 290–299. ACM, 2003.

[MM16] Xiaozhu Meng and Barton P Miller.
Binary code is not easy.
In *Proceedings of the 25th International Symposium on Software Testing and Analysis*, pages 24–35. ACM, 2016.