Debugging

An introduction

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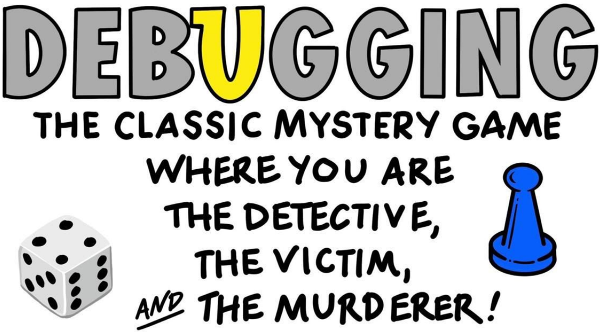
Outline

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
- ...

Debuggers



https://twitter.com/lucacarettoni/status/1200538741946929153

"Debuggers don't remove bugs.
They only show them in slow motion."
(unknown)

Kind of debuggers

We can distinguish between:

- Source-level vs Assembly-level debuggers
- Local vs Remote
- User-mode vs Kernel debuggers

credo : vs / gdb

In both Linux and Windows

- you can start a debugging session by either
  - starting a new process from the debugger
  - attaching a debugger to a running process
- each process can have at most one debugger attached

Outline

Linux: Gdb

- Documentation: "Debugging with GDB"
  `https://sourceware.org/gdb/download/onlinedocs/`
- GEF `https://hugsy.github.io/gef/`
  - and the extras: `https://hugsy.github.io/gef-extras/`
  - My cheatsheet for GDB+GEF: `https://github.com/zxgio/gdb_gef-cheatsheet`
- generally solid; however, if you encounter strange behaviours, try to compile a newer version, e.g. *x.y*, from sources:
  - `wget https://ftp.gnu.org/gnu/gdb/gdb-`*x.y*`.tar.xz`
  - install Python development headers (in Ubuntu: `python3-dev`)
  - extract the archive, create a build directory, and then invoke `configure` from it:
    - *where-gdb-has-been-extracted*`/configure --prefix=$HOME/bin/gdb`*x.y*
      `--with-python=/usr/bin/python3`
    - `make && make install`
- ret-sync `https://github.com/bootleg/ret-sync`

Windows: x64dbg

x64dbg `https://x64dbg.com/`, that can be enhanced with plugins; e.g.

- ret-sync `https://github.com/bootleg/ret-sync`
- xAnalyzer `https://github.com/ThunderCls/xAnalyzer`
- ScyllaHide `https://github.com/x64dbg/ScyllaHide`
- ...

WinDbg can be used for (local) kernel-debugging too

Outline

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] (`https://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 3rd-party utilities, can download symbols and store them in the cache

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

Common features for controlling the execution

Debugger typically allow you to

- set breakpoints; two kinds:
  - software breakpoints (the default)
    - Unlimited number
    - On execution only
  - hardware breakpoints
    - Limited number, four on x86/64. Set by writing into *debug registers*: `https://en.wikipedia.org/wiki/X86_debug_register` These registers cannot be *directly* accessed by user-code
    - Can be on Read, Write or Execute
- single-step: the debugger stops after every (machine) instruction
  - step-into or step-over `CALL` instructions
- step-out/finish/execute-till-return functions
- ...

→ `c-examples/buggy_factorial`

Software breakpoints

On x86 the one byte opcode 0xCC corresponds to instruction `INT3`, intended for calling the debug exception handler

In general, `int` $n \leftrightarrow$ `0xcd` n however, `int3` $\leftrightarrow$ `0xcc`

To implement a (software) breakpoint at address α, a debugger:

1. saves the content of address α: $t \leftarrow [\alpha]$
2. replaces such a byte with `0xcc`: $[\alpha] \leftarrow$ `0xcc`

When an exception/signal is triggered, the debugger:

3. restores the original content: $[\alpha] \leftarrow t$
4. decrements the instruction pointer: $\texttt{IP} \leftarrow \texttt{IP} - 1$
5. allows the user to inspect/change the debugged process
6. if the breakpoint should persist:
    - executes a single-step
    - if $\texttt{IP} = \alpha$ then go to (5), else go to (1)

Single-step (on x86/64)

You could implement single-stepping with software breakpoints; *however* you'd need to

- decode the current instruction to find out its length
- handle instructions that jump to themselves, even indirectly (e.g. `JMP RAX`, when `RAX==RIP`)

Better approach: setting the trap flag in the flag register

- issues an `INT 1` after a single instruction, and
- reset itself

See "17.3.1.4 Single-Step Exception Condition" in the *System Programming Guide* by Intel for more details

Outline

Backtraces

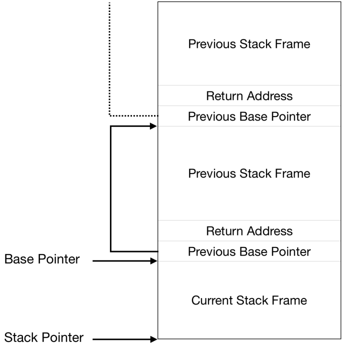
Backtraces/call-stacks help you understand how the execution got to a certain point, by listing all callers

Issues:

- who's my caller?
- where are the functions?

They can be tackled differently, depending whether we have:

- frame pointers
- debug information
- frame (exception handling) info



Taken from: `https://techno-coder.github.io/example_os/2018/06/04/A-stack-trace-for-your-OS.html`

Can be tricky; see, e.g., Demystifying Thread Call Stack Spoofing by Alessandro Magnosi
`https://www.youtube.com/watch?v=dl-AuN2xsbg`

Demo/exercise

1. Set a breakpoint
   - at the beginning of function `fact`
   - with the condition that the argument value is 0

   Then, start the program...

   When the breakpoint is hit, check the backtrace/call-stack
2. Verify what happens when you set a breakpoint:

   Linux You can read `/proc/`*`pid`*`/mem` with `dd`/`xxd`

   Windows You can use *System Infomer* (successor of Process Hacker)
   `https://systeminformer.sourceforge.io/`
   `https://github.com/winsiderss/systeminformer/`

References

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