Lecture 2
Program Analysis
Computer and Network Security
October 7, 2019
Computer Science and Engineering Department


# Lecture 2
## Program Analysis

Computer and Network Security
October 7, 2019

Computer Science and Engineering Department

# Program Analysis

CNSO Program Analysis
- automatic analysis of programs
- property verification
- optimization (performance) or correctness
- static analysis or dynamic analysis



- automatic analysis of programs
- property verification
- optimization (performance) or correctness
- static analysis or dynamic analysis

CNSO
Program Model
- automaton
- control flow graph (CFG) (set of states and transitions)
- coverage: how much of the CFG can the analysis cover to ensure property validation

CNSO CTF crunch

# Program Model

- automaton
- control flow graph (CFG) (set of states and transitions)
- coverage: how much of the CFG can the analysis cover to ensure property validation

CNSO
Static and Dynamic Analysis
- do not execute or execute the program
- static analysis on source code or on binary program (executable)
- dynamic analysis on resource usage and behavior (process)
- symbolic execution is static analysis
- fuzzing is dynamic analysis
- static analysis: broad, may go into path explosion
- dynamic analysis: depth, may miss certain cases

CNSO CTF crunch

## Static and Dynamic Analysis

- do not execute or execute the program
- static analysis on source code or on binary program (executable)
- dynamic analysis on resource usage and behavior (process)
- symbolic execution is static analysis
- fuzzing is dynamic analysis
- static analysis: broad, may go into path explosion
- dynamic analysis: depth, may miss certain cases

CNSC CTF crunch Source Code vs Executable

# Source Code vs Executable

CNSO Source Code vs Executable
- extensive analysis on source code but ...

## Source Code vs Executable

- extensive analysis on source code but ...

CNSO Source Code vs Executable
- extensive analysis on source code but ...
- we don't know what the compiler / linker does to it, what optimizations happen, how it links to other components

## Source Code vs Executable

- extensive analysis on source code but ...
- we don't know what the compiler / linker does to it, what optimizations happen, how it links to other components

CNSO Source Code vs Executable
- extensive analysis on source code but ...
- we don't know what the compiler / linker does to it, what optimizations happen, how it links to other components
- it may not be available

## Source Code vs Executable

- extensive analysis on source code but ...
- we don't know what the compiler / linker does to it, what optimizations happen, how it links to other components
- it may not be available

CNSO Source Code vs Executable
- extensive analysis on source code but ...
- we don't know what the compiler / linker does to it, what optimizations happen, how it links to other components
- it may not be available
- we focus most on static binary analysis

CNSO CTF crunch

## Source Code vs Executable

- extensive analysis on source code but ...
- we don't know what the compiler / linker does to it, what optimizations happen, how it links to other components
- it may not be available
- we focus most on static binary analysis

CNSO Challenges of Static Binary Analysis
- more difficult to understand: requires reverse engineering
- may be subject to obfuscation, encryption, packing
- typically doubled by dynamic analysis

## Challenges of Static Binary Analysis

- more difficult to understand: requires reverse engineering
- may be subject to obfuscation, encryption, packing
- typically doubled by dynamic analysis

CNSO Outline
From Source Code to Process
The ELF Format
Linking
Tools of the Trade for Binary Static Analysis
Dynamic Analysis
Tools for Dynamic Analysis
GDB
Dynamic Linking and Loading
Conclusion

CNSO CTF crunch

# Outline

CNSO Process as a Goal
- provide functionality
- dynamic / run time
- allocate and use memory and other resources

CNSO CTF crunch

# Process as a Goal

- provide functionality
- dynamic / run time
- allocate and use memory and other resources

CNSO Steps from Source Code to Process

1. compile and assemble source code into object files
2. link object files into executable
3. load executable (disk image file) into process (memory + CPU)

CNSO CTF crunch

# Steps from Source Code to Process

1. compile and assemble source code into object files
2. link object files into executable
3. load executable (disk image file) into process (memory + CPU)

CNSO Object File
- binary files
- headers and binary code
- may be disassembled
- data and code
- sections

CNSO CTF crunch

# Object File

- binary files
- headers and binary code
- may be disassembled
- data and code
- sections

CNSO Library Files
- archive/collection of object files
- modularity
- static-linking and dynamic linking libraries
  - linking happens at link time
  - linking happens at load time

CNSO CTF crunch

# Library Files

- archive/collection of object files
- modularity
- static-linking and dynamic linking libraries
  - linking happens at link time
  - linking happens at load time

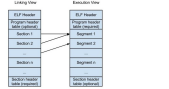
CNSO Executable Files
- binary files
- similar to object files, consist of object code
- may be disassembled
- created from object files
- static and dynamic executables
  - static: all object code is part of the executable
  - dynamic: library stubs to library functions

CNSO CTF crunch

# Executable Files

- binary files
- similar to object files, consist of object code
- may be disassembled
- created from object files
- static and dynamic executables
  - static: all object code is part of the executable
  - dynamic: library stubs to library functions

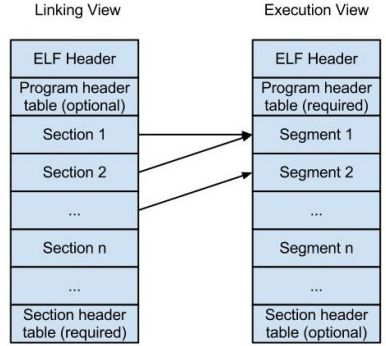
CNSO ELF




http://www.roman10.net/2012/11/28/an-intro-to-elf-file-formatpart-1-file-types-and-dual-views/

CNSO CTF crunch

# ELF




http://www.roman10.net/2012/11/28/an-intro-to-elf-file-formatpart-1-file-types-and-dual-views/

CNSO Outline
From Source Code to Process
The ELF Format
Linking
Tools of the Trade for Binary Static Analysis
Dynamic Analysis
Tools for Dynamic Analysis
GDB
Dynamic Linking and Loading
Conclusion

CNSO CTF crunch

# Outline

CNSO
Object File Format
- format of a file that contains object code: object file, executable files, dynamic-linking library files
- headers, sections
- data and code
- may be disassembled
- PE (Portable Executable) on Windows
- COFF (Common Object File Format) on Unix
- ELF (Executable and Linking Format) on Linux

CNSO CTF crunch

# Object File Format

- format of a file that contains object code: object file, executable files, dynamic-linking library files
- headers, sections
- data and code
- may be disassembled
- PE (Portable Executable) on Windows
- COFF (Common Object File Format) on Unix
- ELF (Executable and Linking Format) on Linux

CNSO Common Information in Executabile Files
- entry point
- program addresses (section addresses)
- section sizes
- symbols (names and addresses)
- permissions

## Common Information in Executabile Files

- entry point
- program addresses (section addresses)
- section sizes
- symbols (names and addresses)
- permissions

CNSO ELF Format
- header
- program headers
- sections
- segments
- symbols
- readelf, objdump, nm

CNSO CTF crunch

# ELF Format

- header
- program headers
- sections
- segments
- symbols
- `readelf`, `objdump`, `nm`

CNSO Sections
- storing data or code
- readelf -S program
- .text, .data, .bss
- .symtab, .strtab

CNSO CTF crunch

# Sections

- storing data or code
- `readelf -S program`
- `.text`, `.data`, `.bss`
- `.symtab`, `.strtab`

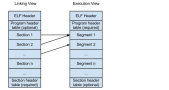
CNSO
Sections vs. Segments
- segments contain 0 ore more sections
- sections are used by linker, some sections may be ditched at runtime
- segments are used by the operating system (loaded into memory)

CNSO CTF crunch

# Sections vs. Segments

- segments contain 0 ore more sections
- sections are used by linker, some sections may be ditched at runtime
- segments are used by the operating system (loaded into memory)

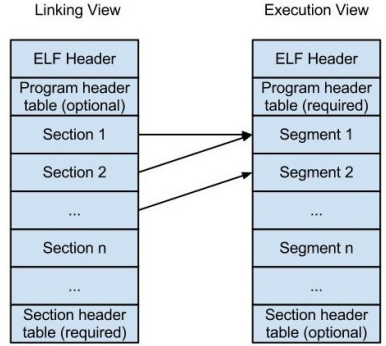
CNSS
View of ELF File




http://www.roman10.net/2012/11/28/an-intro-to-elf-file-formatpart-1-file-types-and-dual-views/

CNSS
CTF crunch

# View of ELF File




http://www.roman10.net/2012/11/28/an-intro-to-elf-file-formatpart-1-file-types-and-dual-views/

CNSO Symbols
- readelf -s program
- .dynsym and .symtab
- name, value, type, bind, size

# Symbols

- `readelf -s program`
- `.dynsym` and `.symtab`
- name, value, type, bind, size

CNSO Debugging Symbols
- Map Assembly instructions to variable, function or line in the source code
- Help mapping stack values with function parameters
- Optimize data flow analysis
- Optimize static and dynamic analysis
- On Linux, symbol table is embedded in the ELF file. PE files use an external symbols file

## Debugging Symbols

- Map Assembly instructions to variable, function or line in the source code
- Help mapping stack values with function parameters
- Optimize data flow analysis
- Optimize static and dynamic analysis
- On Linux, symbol table is embedded in the ELF file. PE files use an external symbols file

CNSO Stripping
- Removing symbol table from program executable
- Complicates reverse engineering
- Less space used by original binary

CNSO CTF crunch

# Stripping

- Removing symbol table from program executable
- Complicates reverse engineering
- Less space used by original binary

CNSO CTF crunch Outline
From Source Code to Process
The ELF Format
Linking
Tools of the Trade for Binary Static Analysis
Dynamic Analysis
Tools for Dynamic Analysis
GDB
Dynamic Linking and Loading
Conclusion

CNSO CTF crunch

# Outline

CNSO Overview of Linking
- All object files are linked together to produce an executable file
- Input: Object files, static libraries, dynamic libraries
- Output: Executable image
- The linker resolved external references from each object file

CNSO CTF crunch

# Overview of Linking

- All object files are linked together to produce an executable file
- Input: Object files, static libraries, dynamic libraries
- Output: Executable image
- The linker resolved external references from each object file

CNSO Using ld
- Command used in the last compiling phase
- Libraries are specified using -l option
- PIE option enables ASLR support

CNSO CTF crunch

# Using ld

- Command used in the last compiling phase
- Libraries are specified using `-l` option
- PIE option enables ASLR support

CNSO
Static Linking
- Linker copies library routines directly into executables image
- Executable is more portable because all data needed to execute resides in the file
- Faster execution because imports are not resolved at runtime
- Uses more space

CNSO CTF crunch

# Static Linking

- Linker copies library routines directly into executables image
- Executable is more portable because all data needed to execute resides in the file
- Faster execution because imports are not resolved at runtime
- Uses more space

CNSO Outline
From Source Code to Process
The ELF Format
Linking
Tools of the Trade for Binary Static Analysis
Dynamic Analysis
Tools for Dynamic Analysis
GDB
Dynamic Linking and Loading
Conclusion

CNSO CTF crunch

# Outline

CNSO Tools of Trade
- building machine code files
- inspecting machine code files
- disassembling machine code files

CNSO CTF crunch

# Tools of Trade

- building machine code files
- inspecting machine code files
- disassembling machine code files

CNSC Building Executables
gcc, gas, nasm, ar, ld

CNSC CTF crunch

# Building Executables

- gcc, gas, nasm, ar, ld

CNSC ELF Inspection
- strings
- xxd
- readelf
- nm

CNSC CTF crunch

# ELF Inspection

- `strings`
- `xxd`
- `readelf`
- `nm`

CNSO Disassembling
IDA
objdump
radare2



- **IDA**
- objdump
- radare2

CNSO CTF crunch **Not** for Static Analysis
- pmap
- lsof
- ltrace
- strace
- GDB

# **Not** for Static Analysis

- pmap
- lsof
- ltrace
- strace
- GDB

CNSO Outline
From Source Code to Process
The ELF Format
Linking
Tools of the Trade for Binary Static Analysis
Dynamic Analysis
Tools for Dynamic Analysis
GDB
Dynamic Linking and Loading
Conclusion

CNSO CTF crunch

# Outline

CNSO Dynamic Analysis
- starts from executable files
- investigate processes
- requires process to run
- runtime analysis
- blackbox analysis

CNSO CTF crunch

# Dynamic Analysis

- starts from executable files
- investigate processes
- requires process to run
- runtime analysis
- blackbox analysis

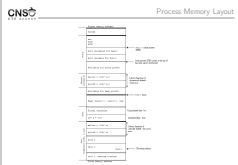
CNSO Processes
- unit of work in the operating system
- virtual memory address space, threads, resources
- isolated from each other
- at **load time** the executable gives birth to a process

CNSO CTF crunch

# Processes

- unit of work in the operating system
- virtual memory address space, threads, resources
- isolated from each other
- at **load time** the executable gives birth to a process

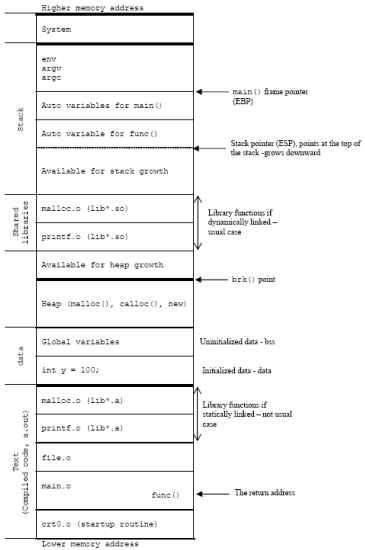
CNSO
Process Memory Layout



http://www.tenouk.com/Bufferoverflowc/Bufferoverflow1_files/image022.png

CNSO CTF crunch

# Process Memory Layout




http://www.tenouk.com/Bufferoverflowc/Bufferoverflow1_files/image022.png

CNSC Interesting Process Information
- the process memory map (virtual memory areas)
- memory addresses: code, variables
- memory region access rights
- machine code (to be disassembled)
- process state: registers, (call) stack, code

CNSC CTF crunch

## Interesting Process Information

- the process memory map (virtual memory areas)
- memory addresses: code, variables
- memory region access rights
- machine code (to be disassembled)
- process state: registers, (call) stack, code

CNSC Why Dynamic Analysis
- get output for input (blackbox)
- glimpse into the internals
- monitor/inspect resource usage
- debug execution and test attacks (step by step)

CNSC CTF crunch

# Why Dynamic Analysis

- get output for input (blackbox)
- glimpse into the internals
- monitor/inspect resource usage
- debug execution and test attacks (step by step)

CNSO CTF crunch
What Do We Investigate?
- code: system calls, library calls, function calls, step-by-step code
- state: thread information, process maps, open files, resources
- data: registers, variables, raw memory data

CNSO CTF crunch

# What Do We Investigate?

- code: system calls, library calls, function calls, step-by-step code
- state: thread information, process maps, open files, resources
- data: registers, variables, raw memory data

CNSO Inspecting Code
- function call tracing
- disassembling
- step by step instructions
- look into code where required in the process virtual address space

CNSO CTF crunch

# Inspecting Code

- function call tracing
- disassembling
- step by step instructions
- look into code where required in the process virtual address space

CNSO Inspecting Data
- variables: global (data) and local (stack)
- runtime metadata: return addresses, function arguments, command line arguments, GOT and PLT (to be discussed later)
- registers
- raw memory data: heap, stack, random address

CNSO CTF crunch

# Inspecting Data

- variables: global (data) and local (stack)
- runtime metadata: return addresses, function arguments, command line arguments, GOT and PLT (to be discussed later)
- registers
- raw memory data: heap, stack, random address

CNSO Inspecting State
process memory map
thread state
open file descriptors

CNSO CTF crunch

# Inspecting State

- process memory map
- thread state
- open file descriptors

CNSO Outline
From Source Code to Process
The ELF Format
Linking
Tools of the Trade for Binary Static Analysis
Dynamic Analysis
Tools for Dynamic Analysis
GDB
Dynamic Linking and Loading
Conclusion

CNSO CTF crunch

# Outline

CNSO Types of Tools
- blackbox inspection: function call tracers (strace, ltrace, dtrace/dtruss), fuzzers
- profilers: most often for performance: perf, callgrind, vTune
- debugging: GDB, LLDB, valgrind

CNSO CTF crunch

# Types of Tools

- blackbox inspection: function call tracers (strace, ltrace, dtrace/dtruss), fuzzers
- profilers: most often for performance: perf, callgrind, vTune
- debugging: GDB, LLDB, valgrind

CNSO Fuzzing
- generate "random" input and detect program flaws
- program is run
- smart fuzzer try to direct
- AFL, libfuzzer

CNSO CTF crunch

# Fuzzing

- generate "random" input and detect program flaws
- program is run
- smart fuzzer try to direct
- AFL, libfuzzer

CNSO strace/ltrace
- strace ./a.out
- strace -e read,write ./a.out
- strace -e file ./a.out
- strace -e file -f ./a.out
- strace -e file -s 512 -f ./a.out
- similar options for ltrace

CNSO CTF crunch

# strace/ltrace

- `strace ./a.out`
- `strace -e read,write ./a.out`
- `strace -e file ./a.out`
- `strace -e file -f ./a.out`
- `strace -e file -s 512 -f ./a.out`
- similar options for `ltrace`

CNSO lsof/pmap
- PID as argument
- lsof -p 12345
- pmap 12345

## lsof/pmap

- PID as argument
- `lsof -p 12345`
- `pmap 12345`

CNSO perf
- default profiler on Linux
- sampling profiler, doesn't instrument the code
- uses events sampling
- perf stat -e cache-misses -a ./mem-walk
- sudo perf list
- some actions and events may require privileged access

CNSO CTF crunch

# perf

- default profiler on Linux
- sampling profiler, doesn't instrument the code
- uses events sampling
- `perf stat -e cache-misses -a ./mem-walk`
- `sudo perf list`
- some actions and events may require privileged access

CNSO GDB
- default debugger on GNU/Linux distributions
- command line; there are some GUI front-ends
- incorporated in Linux-based IDEs
- debugging, dynamic analysis / process investigation
- gdb ./a.out
- gdb -q ./a.out

CNSO CTF crunch

# GDB

- default debugger on GNU/Linux distributions
- command line; there are some GUI front-ends
- incorporated in Linux-based IDEs
- debugging, dynamic analysis / process investigation
- `gdb ./a.out`
- `gdb -q ./a.out`

CNSO LLDB
- LLVM Debugger
- used on Mac OS X
- similar features to GDB
- command line; most commands are equivalent to GDB
- http://lldb.llvm.org/lldb-gdb.html

CNSO CTF crunch

# LLDB

- LLVM Debugger
- used on Mac OS X
- similar features to GDB
- command line; most commands are equivalent to GDB
- `http://lldb.llvm.org/lldb-gdb.html`

CNSO Hardware Support for Debugging
- useful for debugging embedded devices
- JTAG: Joint Test Action Group
  - uses dedicated debug port
- Lauterbach Trace32: in circuit debugger (device using JTAG)

CNSO CTF crunch

# Hardware Support for Debugging

- useful for debugging embedded devices
- JTAG: Joint Test Action Group
  - uses dedicated debug port
- Lauterbach Trace32: in circuit debugger (device using JTAG)

CNSO CTF crunch Outline
From Source Code to Process
The ELF Format
Linking
Tools of the Trade for Binary Static Analysis
Dynamic Analysis
Tools for Dynamic Analysis
GDB
Dynamic Linking and Loading
Conclusion

CNSO CTF crunch

# Outline

CNSO GDB and Security
- not just for debugging
- follow what a process does (step instructions)
- inspect data (memory, registers)

CNSO CTF crunch

# GDB and Security

- not just for debugging
- follow what a process does (step instructions)
- inspect data (memory, registers)

CNSO GDB for Dynamic Analysis
- process state inspection
- register inspection
- (machine) code inspection
- memory inspection
- memory alteration
- function call tracing

# GDB for Dynamic Analysis

- process state inspection
- register inspection
- (machine) code inspection
- memory inspection
- memory alteration
- function call tracing

CNSO GDB Basics
- starting a process
- stepping instructions
- breakpoints
- disassemble
- show registers
- display data
- trace function calls
- alter data

CNSO CTF crunch

# GDB Basics

- starting a process
- stepping instructions
- breakpoints
- disassemble
- show registers
- display data
- trace function calls
- alter data

CNSO Starting a Process
- run
- run < input file
- run arg1 arg2 arg3
- set args arg1 arg2 arg3 and then issue run
- start: breakpoint at main / starting point

CNSO CTF crunch

## Starting a Process

- `run`
- `run < input file`
- `run arg1 arg2 arg3`
- `set args arg1 arg2 arg3` and then issue `run`
- `start`: breakpoint at main / starting point

CNSO Stepping Instructions

- si and ni
- ni doesn't go into nested functions
- very useful for understanding programs and validating attacks

CNSO CTF crunch

# Stepping Instructions

- `si` and `ni`
- `ni` doesn't go into nested functions
- very useful for understanding programs and validating attacks

CNSO Breakpoints

- b symbol-name
- b *address: b *0x80123456
- continue: continue until the next breakpoint
- help breakpoints

CNSO CTF crunch

# Breakpoints

- `b symbol-name`
- `b *address`: `b *0x80123456`
- `continue`: continue until the next breakpoint
- `help breakpoints`

CNSO Disassembling
during runtime
disass symbol-name: disass printf
help disassemble

CNSO CTF crunch

# Disassembling

- during runtime
- `disass symbol-name: disass printf`
- `help disassemble`

CNSO CTF crunch Displaying Data
- show memory data or registers
- info registers
- p $eax
- p *0x80123456
- x/10x 0x12345678: examine memory and display in hex
- x/10s 0x12345678: examine memory and display in string
- x/10i 0x12345678: examine memory and display in instructions
- help p
- help x

CNSO CTF crunch

# Displaying Data

- show memory data or registers
- `info registers`
- `p $eax`
- `p *0x80123456`
- `x/10x 0x12345678`: examine memory and display in hex
- `x/10s 0x12345678`: examine memory and display in string
- `x/10i 0x12345678`: examine memory and display in instructions
- `help p`
- `help x`

CNSC Find Data in Memory
- find "sh"
- find 0x01020304
- find 0x400000, 100000, "sh"

CNSC CTF crunch

# Find Data in Memory

- `find "sh"`
- `find 0x01020304`
- `find 0x400000, 100000, "sh"`

CNSC Trace Function Calls
- backtrace: show function trace
- up, down: update current call stack
- http://web.mit.edu/gnu/doc/html/gdb_8.html

# Trace Function Calls

- `backtrace`: show function trace
- `up`, `down`: update current call stack
- `http://web.mit.edu/gnu/doc/html/gdb_8.html`

CNSO Alter Data
- set variable num = 10
- set {int}0x8038290 = 10
- set $eax = 0x12345678

CNSO CTF crunch

# Alter Data

- `set variable num = 10`
- `set {int}0x8038290 = 10`
- `set $eax = 0x12345678`

CNSO PEDA
- Python Exploit Development Assistance
- enhancement for GDB
- create cyclic patterns
- Return Oriented Programming features
- custom view: code, registers, stack
- shellcode features
- telescope an address (follow pointers)

CNSO CTF crunch

# PEDA

- *Python Exploit Development Assistance*
- enhancement for GDB
- create cyclic patterns
- Return Oriented Programming features
- custom view: code, registers, stack
- shellcode features
- telescope an address (follow pointers)

CNSO Outline
From Source Code to Process
The ELF Format
Linking
Tools of the Trade for Binary Static Analysis
Dynamic Analysis
Tools for Dynamic Analysis
GDB
Dynamic Linking and Loading
Conclusion

CNSO CTF crunch

# Outline

CNSO Times in Getting from Source Code to Process
- compile time: when translating source code to object code in object files (using gcc, gas, nasm)
- link time: when aggregating multiple object files into an executable file (using gcc, ld)
- load time: when executable is loaded in memory and a process is created (using ./program)
- run time: while the process is running (using strace -p, lsof -p)

CNSO CTF crunch

# Times in Getting from Source Code to Process

- compile time: when translating source code to object code in object files (using gcc, gas, nasm)
- link time: when aggregating multiple object files into an executable file (using gcc, ld)
- load time: when executable is loaded in memory and a process is created (using ./program)
- run time: while the process is running (using strace -p, lsof -p)

CNSO
Linking and Loading
- linking is getting object files together into an executable or dynamic-linking file
- for the linker, object files are input and executables are output
- loading is getting an executable into memory and starting a process
- for the loader, executable file is input, process is output

CNSO CTF crunch

## Linking and Loading

- linking is getting object files together into an executable or dynamic-linking file
- for the linker, object files are input and executables are output
- loading is getting an executable into memory and starting a process
- for the loader, executable file is input, process is output

CNSO
Static linking
all symols are solved at link time
all code is part of the executable
static executables
large executable files, but with no dependencies, highly portable

CNSO CTF crunch

# Static linking

- all symols are solved at link time
- all code is part of the executable
- static executables
- large executable files, but with no dependencies, highly portable

CNSO
Load Time Dynamic Linking
- symbols are marked as stubs inside the executable file
- symbols are solved at load time, the moment the process is created
- symbols are picked from dynamic-linking library files
- provides reduced size executable files but requires dependencies to be satisfied

CNSO CTF crunch

# Load Time Dynamic Linking

- symbols are marked as stubs inside the executable file
- symbols are solved at load time, the moment the process is created
- symbols are picked from dynamic-linking library files
- provides reduced size executable files but requires dependencies to be satisfied

CNSO
Run Time Dynamic Linking
linking (and loading) is done at runtime
it may be implicit (lazy binding) or explicit
dlopen, dlsym for the explicit case: explicitly load a library and locate a symbol

CNSO CTF crunch

# Run Time Dynamic Linking

- linking (and loading) is done at runtime
- it may be implicit (lazy binding) or explicit
- dlopen, dlsym for the explicit case: explicitly load a library and locate a symbol

CNSO
Lazy Binding
- postpone linking of a symbol until it is called
- usually done for functions through the use of a trampoline section (PLT for ELF)
- the first time a function is called, the dynamic linker also does the binding

CNSO CTF crunch

# Lazy Binding

- postpone linking of a symbol until it is called
- usually done for functions through the use of a trampoline section (PLT for ELF)
- the first time a function is called, the dynamic linker also does the binding

CNSO CTF crunch Locating Libraries

- for stating linking, use the -L argument to gcc
- for dynamic linking, the dynamic linker/loader is used: ld-linux.so
- man ld-linux.so
- searches for
  1. values in LD_LIBRARY_PATH
  2. the /etc/ld.so.cache file; populated by ldconfig
  3. the default /lib and /usr/lib library folders

## Locating Libraries

- for stating linking, use the -L argument to gcc
- for dynamic linking, the dynamic linker/loader is used: ld-linux.so
- `man ld-linux.so`
- searches for
  1. values in `LD_LIBRARY_PATH`
  2. the `/etc/ld.so.cache` file; populated by `ldconfig`
  3. the default `/lib` and `/usr/lib` library folders

CNSO PLT
- used for external library function calls
- generic trampoline code to jump to initially jump to per-function binder (.plt in ELF)
- writable data area storing function pointers (.got.plt)
  - initially store pointers to binder code (symbol solver)
  - after the first call store actual pointer to function call

CNSO CTF crunch

# PLT

- used for external library function calls
- generic trampoline code to jump to initially jump to per-function binder (`.plt` in ELF)
- writable data area storing function pointers (`.got.plt`)
  - initially store pointers to binder code (symbol solver)
  - after the first call store actual pointer to function call

CNSO GOT
- Global Offset Table
- .got in ELF for global variables
- .got.plt in ELF for external library function pointers
- local uses of external library symbol point to GOT
- GOT if filled by the dynamic linker at the beginning

CNSO CTF crunch

# GOT

- Global Offset Table
- `.got` in ELF for global variables
- `.got.plt` in ELF for external library function pointers
- local uses of external library symbol point to GOT
- GOT if filled by the dynamic linker at the beginning

CNSO CTF crunch Outline
From Source Code to Process
The ELF Format
Linking
Tools of the Trade for Binary Static Analysis
Dynamic Analysis
Tools for Dynamic Analysis
GDB
Dynamic Linking and Loading
Conclusion

CNSO CTF crunch

# Outline

CNSO CTF crunch Keywords

- static analysis
- dynamic analysis
- executable
- ELF
- readelf
- section
- segment
- disassembling
- objdump
- symbols
- linker
- process
- strace / ltrace
- lsof / pmap
- perf
- GDB
- breakpoint
- info
- examine
- ni, si
- backtrace, up, down
- write
- searchmem
- dynamic linking
- dynamic loading
- lazy binding
- trampoline

CNSO CTF crunch

# Keywords

- static analysis
- dynamic analysis
- executable
- ELF
- readelf
- section
- segment
- disassembling
- objdump
- symbols
- linker
- process
- strace / ltrace
- lsof / pmap
- perf
- GDB
- breakpoint
- `info`
- `examine`
- `ni`, `si`
- `backtrace`, `up`, `down`
- `write`
- `searchmem`
- dynamic linking
- dynamic loading
- lazy binding
- trampoline

CNSO Useful Links
- http://www.skyfree.org/linux/references/ELF_Format.pdf
- ftp://ftp.gnu.org/old-gnu/Manuals/ld-2.9.1/html_node/ld_3.html
- https://msdn.microsoft.com/en-us/library/windows/desktop/ee416588(v=vs.85).aspx
- https://www.technovelty.org/linux/plt-and-got-the-key-to-code-sharing-and-dynamic-libraries.html

# Useful Links

- http://www.skyfree.org/linux/references/ELF_Format.pdf
- ftp://ftp.gnu.org/old-gnu/Manuals/ld-2.9.1/html_node/ld_3.html
- https://msdn.microsoft.com/en-us/library/windows/desktop/ee416588(v=vs.85).aspx
- https://www.technovelty.org/linux/plt-and-got-the-key-to-code-sharing-and-dynamic-libraries.html