CSC 574
Computer and Network Security

Reverse Engineering

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(Derived from slides by Chris Kruegel)

Introduction

- Reverse engineering
  - process of analyzing a system
  - understand its structure and functionality
  - used in different domains (e.g., consumer electronics)

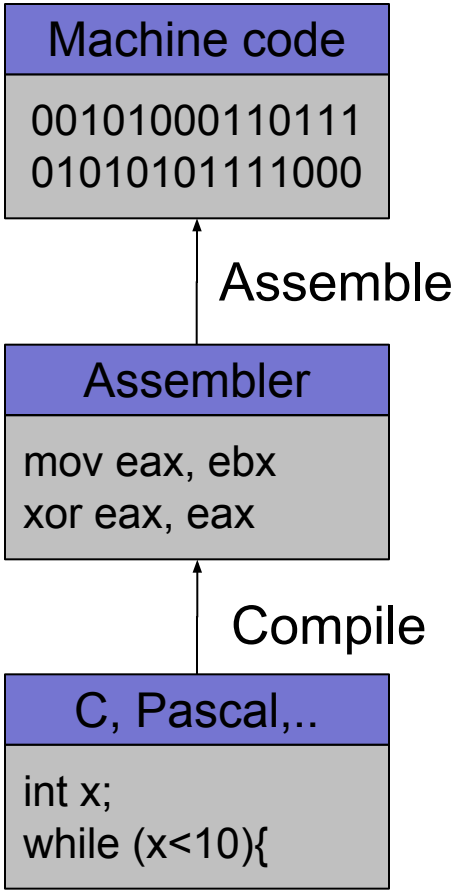
- Software reverse engineering
  - understand architecture (from source code)
  - extract source code (from binary representation)
  - change code functionality (of proprietary program)
  - understand message exchange (of proprietary protocol)

Software Engineering

First generation language

Second generation language

Third generation language

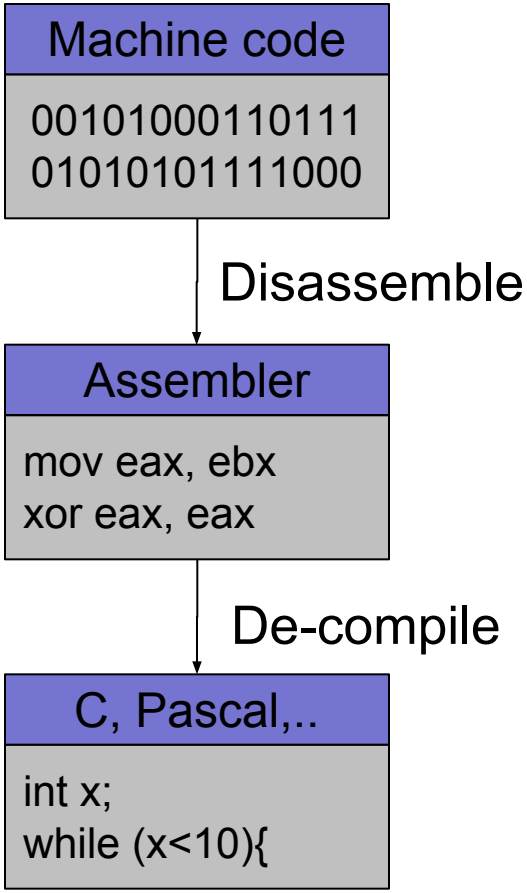


Software Reverse Engineering

First generation language

Second generation language

Third generation language



Going Back is Hard!

- Fully-automated disassemble/de-compilation of arbitrary machine-code is theoretically an undecidable problem
- Disassembling problems
  - hard to distinguish code (instructions) from data
- De-compilation problems
  - structure is lost
    - data types are lost, names and labels are lost
  - no one-to-one mapping
    - same code can be compiled into different (equivalent) assembler blocks
    - assembler block can be the result of different pieces of code

Why Reverse Engineering

- Software interoperability
  - Samba (SMB Protocol)
  - OpenOffice (MS Office document formats)
- Emulation
  - Wine (Windows API)
  - React-OS (Windows OS)
- Malware analysis
- Program cracking
- Compiler validation

Analyzing a Binary

Static Analysis

- Identify the file type and its characteristics
  - architecture, OS, executable format...
- Extract strings
  - commands, password, protocol keywords...
- Identify libraries and imported symbols
  - network calls, file system, crypto libraries
- Disassemble
  - program overview
  - finding and understanding important functions
    - by locating interesting imports, calls, strings...

Analyzing a Binary

Dynamic Analysis

- Memory dump
  - extract code after decryption, find passwords...
- Library/system call/instruction trace
  - determine the flow of execution
  - interaction with OS
- Debugging running process
  - inspect variables, data received by the network, complex algorithms..
- Network sniffer
  - find network activities
  - understand the protocol

Static Techniques

- Gathering program information
  - get some rough idea about binary (`file`)

```
linux util # file sil
sil: ELF 32-bit LSB executable, Intel 80386, version 1
(SYSV), for GNU/Linux 2.6.9, dynamically linked (uses s
hared libs), not stripped
```

  - strings that the binary contains (`strings`)

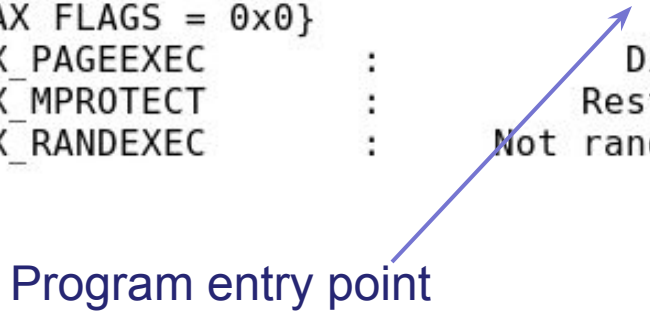
```
linux util # strings sil | head -n 5
/lib/ld-linux.so.2
_Jv_RegisterClasses
__gmon_start__
libc.so.6
puts
```

Static Techniques

- Examining the program (ELF) header (`elfsh`)

```
[ELF HEADER]
[Object sil, MAGIC 0x464C457F]

Architecture       :        Intel 80386   ELF Version         :              1
Object type        :  Executable object   SHT strtab index   :             25
Data encoding      :     Little endian   SHT foffset         :           4061
PHT foffset        :                52   SHT entries number :             28
PHT entries number :                 8   SHT entry size      :             40
PHT entry size     :                32   ELF header size     :             52
Entry point        :         0x8048500   [_start]
{PAX FLAGS = 0x0}
PAX_PAGEEXEC       :          Disabled   PAX_EMULTRAMP       :   Not emulated
PAX_MPROTECT       :        Restricted   PAX_RANDMMAP        :     Randomized
PAX_RANDEXEC       :    Not randomized   PAX_SEGMEXEC        :        Enabled
```



Static Techniques

- Used libraries
  - easier when program is dynamically linked (`ldd`)

Interesting "shared" library – used for (fast) system calls

```
linux util # ldd sil
        linux-gate.so.1 =>  (0xffffe000)
        libc.so.6 => /lib/libc.so.6 (0xb7e99000)
        /lib/ld-linux.so.2 (0xb7fcf000)
```

  - more difficult when program is statically linked

```
linux util # gcc -static -o sil-static simple.c
linux util # ldd sil-static
        not a dynamic executable
linux util # file sil-static
sil-static: ELF 32-bit LSB executable, Intel 80386, version 1
(SYSV), for GNU/Linux 2.6.9, statically linked, not stripped
```

Static Techniques

Looking at `linux-gate.so.1`

```
linux util # cat /proc/self/maps | tail -n 1
ffffe000-fffff000 r-xp 00000000 00:00 0          [vdso]
linux util # dd if=/proc/self/mem of=linux-gate.dso bs=4096 skip=1048574
 count=1 2> /dev/null
linux util # objdump -d linux-gate.dso | head -n 11

linux-gate.dso:     file format elf32-i386

Disassembly of section .text:

ffffe400 <__kernel_vsyscall>:
ffffe400:       51                      push   %ecx
ffffe401:       52                      push   %edx
ffffe402:       55                      push   %ebp
ffffe403:       89 e5                   mov    %esp,%ebp
ffffe405:       0f 34                   sysenter
```

Static Techniques

- Used library functions
  - again, easier when program is dynamically linked (`nm -D`)

```
linux util # nm -D sil | tail -n8
         U fprintf
         U fwrite
         U getopt
         U opendir
08049bb4 B optind
         U puts
         U readdir
08049bb0 B stderr
```

  - more difficult when program is statically linked

```
linux util # nm -D sil-static
nm: sil-static: No symbols
linux util # ls -la sil*
-rwxr-xr-x 1 root chris   8017 Jan 21 20:37 sil
-rwxr-xr-x 1 root chris 544850 Jan 21 20:58 sil-static
```

Static Techniques

Recognizing libraries in statically-linked programs

- Basic idea
  - create a checksum (hash) for bytes in a library function
- Problems
  - many library functions (some of which are very short)
  - variable bytes – due to dynamic linking, load-time patching, linker optimizations
- Solution
  - more complex pattern file
  - uses checksums that take into account variable parts
  - implemented in `IDA Pro` as:
    Fast Library Identification and Recognition Technology (FLIRT)

Static Techniques

- Program symbols
  - used for debugging and linking
  - function names (with start addresses)
  - global variables
  - use `nm` to display symbol information
  - most symbols can be removed with `strip`
- Function call trees
  - draw a graph that shows which function calls which others
  - get an idea of program structure

Static Techniques

Displaying program symbols

```
linux util # nm sil | grep " T"
080488c7 T __i686.get_pc_thunk.bx
08048850 T __libc_csu_fini
08048860 T __libc_csu_init
08048904 T _fini
08048420 T _init
08048500 T _start
080485cd T display_directory
080486bd T main
080485a4 T usage
linux util # strip sil
linux util # nm sil | grep " T"
nm: sil: no symbols
```

Static Techniques

- Disassembly
  - process of translating binary stream into machine instructions
- Different level of difficulty
  - depending on ISA (instruction set architecture)
- Instructions can have
  - fixed length
    - more efficient to decode for processor
    - RISC processors (SPARC, MIPS)
  - variable length
    - use less space for common instructions
    - CISC processors (Intel x86)

Static Techniques

- Fixed length instructions
  - easy to disassemble
  - take each address that is multiple of instruction length as instruction start
  - even if code contains data (or junk), all program instructions are found
- Variable length instructions
  - more difficult to disassemble
  - start addresses of instructions not known in advance
  - different strategies
    - linear sweep disassembler
    - recursive traversal disassembler
  - disassembler can be desynchronized with respect to actual code

Intel x86 Assembler Primer

- Assembler Language
  - human-readable form of machine instructions
  - must understand the hardware architecture, memory model, and stack

- AT&T syntax
  - mnemonic source(s), destination
  - standalone numerical constants are prefixed with a $
  - hexadecimal numbers start with 0x
  - registers are specified with %

Intel x86 Assembler Primer

- Registers
  - local variables of processor
  - six 32-bit general purpose registers
    - can be used for calculations, temporary storage of values, …

      `%eax, %ebx, %ecx, %edx, %esi, %edi`
  - several 32-bit special purpose registers

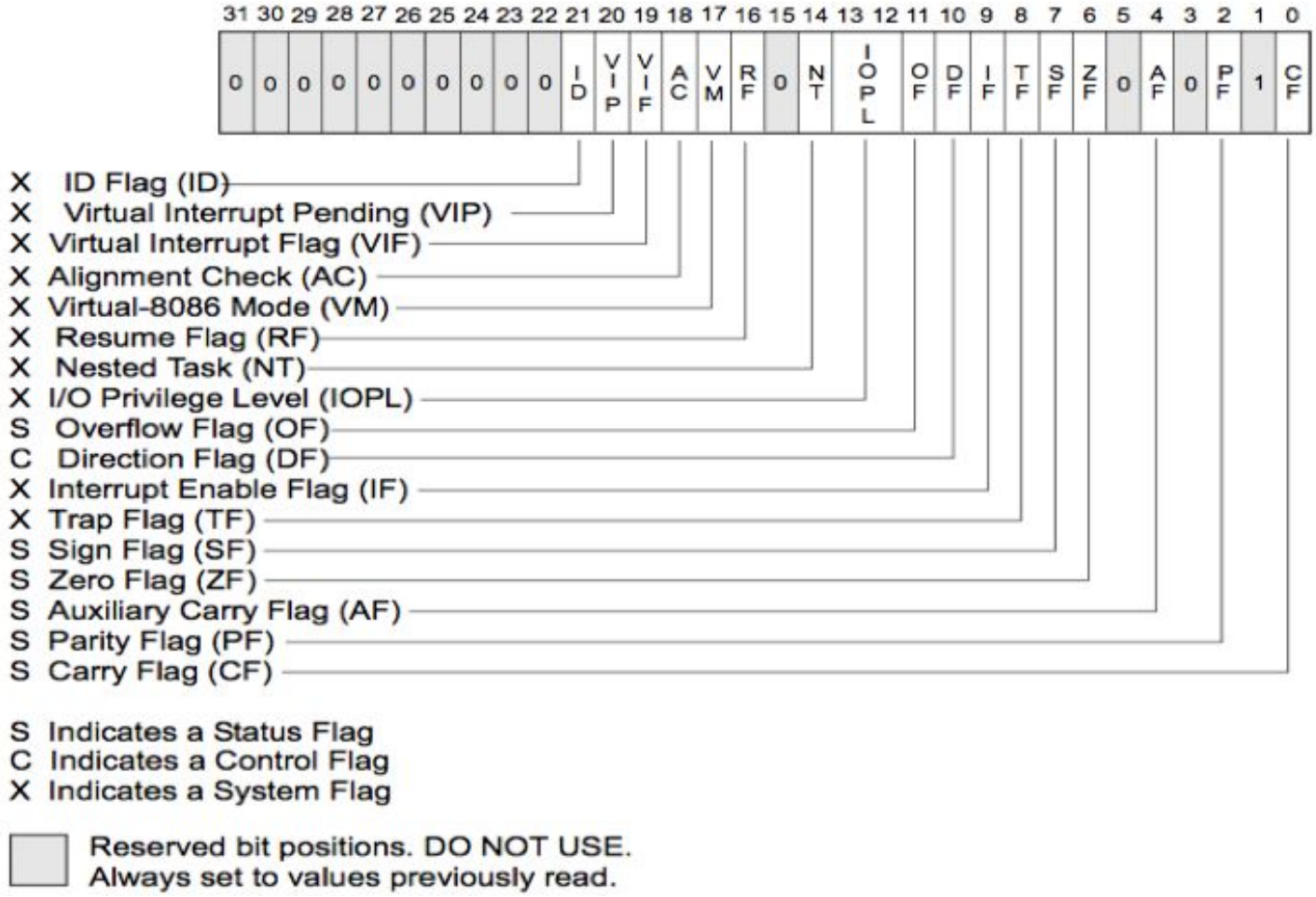
      `%esp- stack pointer`
      `%ebp- frame pointer`
      `%eip- instruction pointer`

- Important mnemonics (instructions)

  `mov` data transfer
  `add` / `sub` arithmetic
  `cmp` / `test` compare two values and set control flags
  `je` / `jne` conditional jump depending on control flags (branch)
  `jmp` unconditional jump

Intel x86 Assembler Primer

Status (EFLAGS) Register



Intel x86 Assembler Primer

- Status (EFLAGS) Register
  - used for control flow decision
  - set implicit by many operations (arithmetic, logic)

- Flags typically used for control flow
  - CF (carry flag)
    - set when operation “carries out” most significant bit
  - ZF (zero flag)
    - set when operation yields zero
  - SF (signed flag)
    - set when operation yields negative result
  - OF (overflow flag)
    - set when operation causes 2’s complement overflow
  - PF (parity flag)
    - set when the number of ones in result of operation is even

Intel x86 Assembler Primer

Instruction	Synonym	Jump condition	Description
jmp label		1	direct jump
jmp *operand		1	indirect jump
je label	jz	ZF	equal/zero
jne label	jnz	~ZF	not equal/zero
js label		SF	negative
jns label		~SF	non-negative
jg label	jnle	~(SF ^ OF) & ~ZF	greater than (signed)
jge label	jnl	(~SF ^ OF)	greater or equal (signed)
jl label	jnge	SF ^ OF	less than (signed)
jle label	jng	(SF ^ OF) | ZF	less or equal (signed)
ja label	jnbe	~CF & ~ZF	above (unsigned)
jae label	jnb	~CF	above or equal (unsigned)
jb label	jnae	CF	below (unsigned)
jbe label	jna	CF | ZF	below or equal (unsigned)

Intel x86 Assembler Primer

- When are flags set?
  - implicit, as a side effect of many operations
  - can use explicit compare / test operations
- Compare

  `cmp b, a` [note the order of operands]
  - computes (a – b) but does not overwrite destination
  - sets ZF (if a == b), SF (if a < b) [and also OF and CF]
- How is a branch operation implemented
  - typically, two step process

    first, a compare/test instruction

    followed by the appropriate jump instruction

Intel x86 Assembler Primer

- Program can access data stored in memory
  - memory is just a linear (flat) array of memory cells (bytes)
  - accessed in different ways (called addressing modes)

- Most general fashion
  - `address: displacement(%base, %index, scale)`

    where the result address is `displacement + %base + %index*scale`

- Simplified variants are also possible
  - use only displacement → direct addressing
  - use only single register → register addressing

Intel x86 Assembler Primer

- Stack
  - managed by stack pointer (%esp) and frame pointer (%ebp)
  - special commands (push, pop)
  - used for
    - function arguments
    - function return address
    - local arguments
- Byte ordering
  - important for multi-byte values (e.g., four byte long value)
  - Intel uses *little endian* ordering
  - how to represent `0x03020100` in memory?

```
0x040   0
0x041   1
0x042   2
0x043   3
```

Intel x86 Assembler Primer

```
# no input
# returns a status code, you can view it by typing echo $?
# %ebx holds the return code
.section .text
.globl _start

_start:
movl   $1, %eax    # This is the system call for exiting program
movl   $0, %ebx    # This value is returned as status
int    $0x80  # This interrupt calls the kernel, to execute sys call
```

Intel x86 Assembler Primer

- So how do we create the application?
  - we need to assemble and link the code
  - this can be done by using the assembler *as (or gcc)*

- Assemble

```
as exit.s –o exit.o |
  gcc –c –o exit.o exit.s
```

- Link

```
ld –o exit exit.o |
  gcc –nostartfiles –o exit exit.o
```

Intel x86 Assembler Primer

- `If` statement

```
#include <stdio.h>

int main(int argc, char **argv)
{
  int a;

  if(a < 0) {
    printf("A < 0\n");
  }
  else {
    printf("A >= 0\n");
  }
}
```

```
.LC0:
        .string "A < 0\n"
.LC1:
        .string "A >= 0\n"
.globl main
        .type   main, @function
main:
          [ function prologue ]
        cmpl    $0, -4(%ebp) /* compute: a - 0    */
        jns     .L2          /* jump, if sign bit
                                not set: a >= 0  */
        movl    $.LC0, (%esp)
        call    printf
        jmp     .L3
.L2:
        movl    $.LC1, (%esp)
        call    printf
.L3:
        leave
        ret
```

Intel x86 Assembler Primer

- `While` statement

```
#include <stdio.h>

int main(int argc, char **argv)
{
    int i;

    i = 0;
    while(i < 10)
    {
        printf("%d\n", i);
        i++;
    }
}
```

```
.LC0:
        .string "%d\n"
main:
        [ function prologue ]
        movl    $0, -4(%ebp)
.L2:
        cmpl    $9, -4(%ebp)
        jle     .L4
        jmp     .L3
.L4:
        movl    -4(%ebp), %eax
        movl    %eax, 4(%esp)
        movl    $.LC0, (%esp)
        call    printf
        leal    -4(%ebp), %eax
        incl    (%eax)
        jmp     .L2
.L3:
        leave
        ret
```

Intel x86 Assembler Primer

Task: Find the maximum of a list of numbers

- Questions to ask:
  - Where will the numbers be stored?
  - How do we find the maximum number?
  - How much storage do we need?
  - Will registers be enough or is memory needed?

- Let us designate registers for the task at hand:
  - %edi holds position in list
  - %ebx will hold current highest
  - %eax will hold current element examined