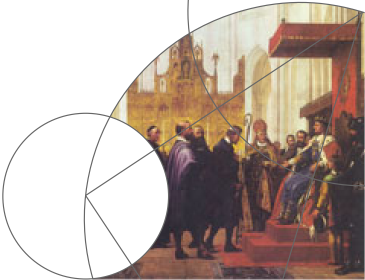
PWNIES INTRO WORKSHOP

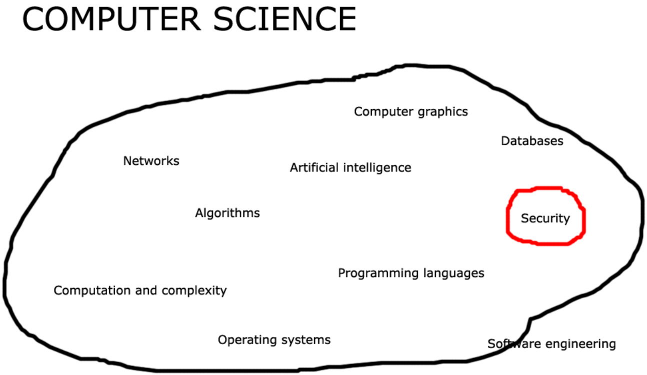
Day 1: Shellcode

Department of Computer Science, University of Copenhagen

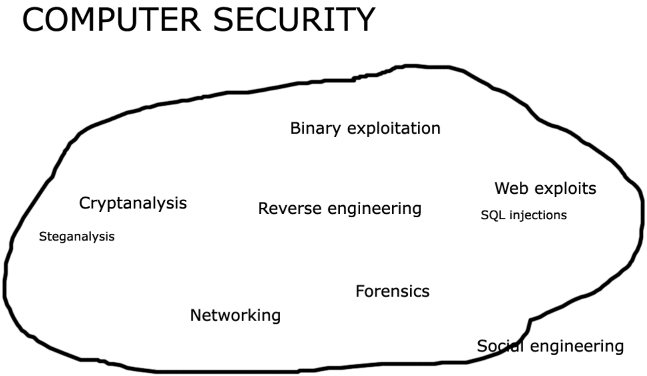


November 11, 2013

Computer and information security

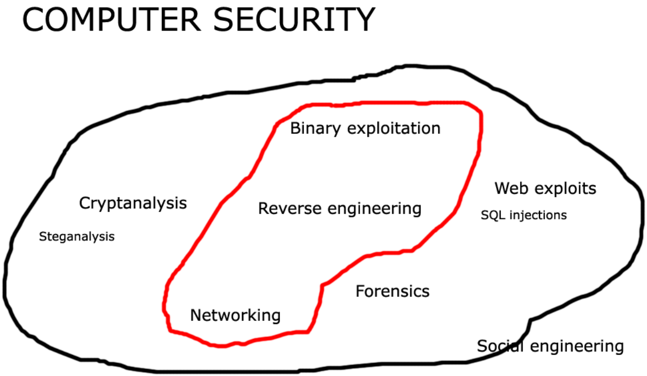


ZOOM; ENHANCE



Many of these are common categories in CTFs.

ZOOM; ENHANCE



Our focus in this workshop.

This week's program

- Shellcode and x86 assembly
- Reverse engineering and debugging
- Buffer overflow exploits
- Network-based exploits
- Advanced topics (format string, return-oriented programming)

Today's program

0. Hardware and lowlevel programming
1. CPU, x86 assembler instructions, and shellcode
2. Memory and the stack
3. Improving your shellcode
4. Extra exercises

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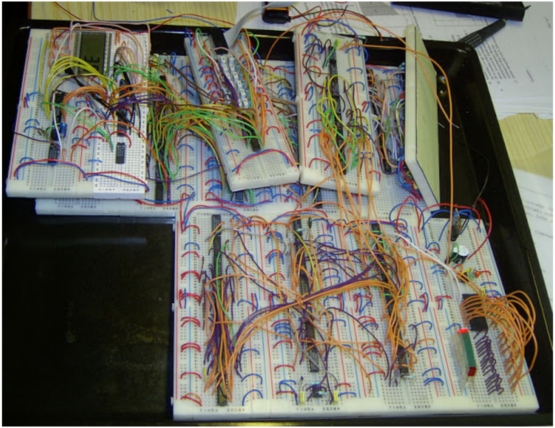
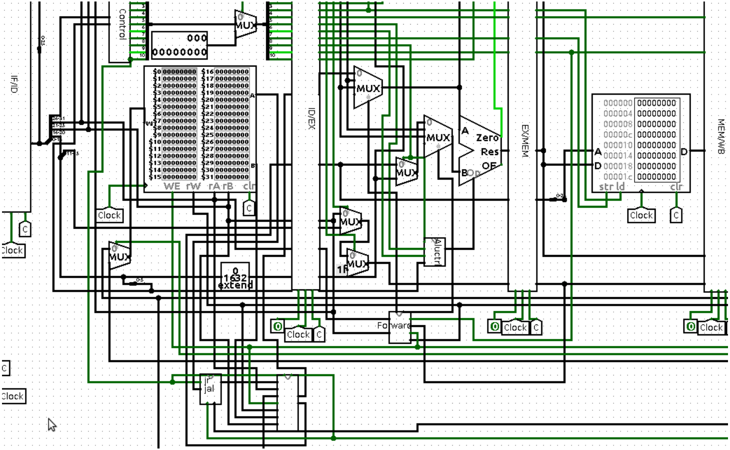
0. Hardware and lowlevel programming



At the base level, computers are just electronic components

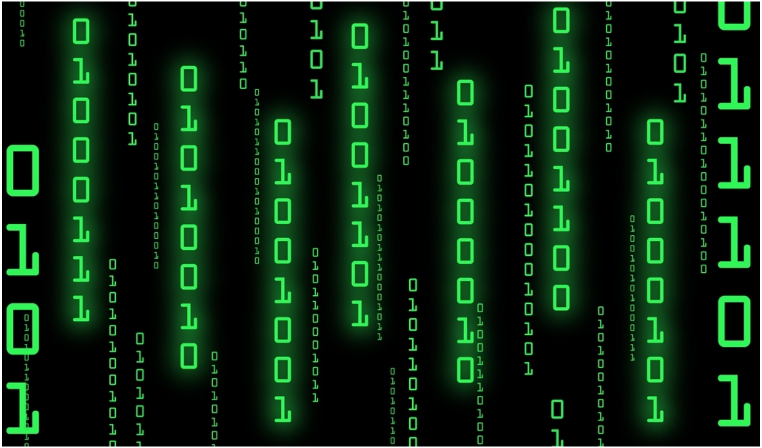
...

0. Hardware and lowlevel programming



. . . connected by logical circuits . . .

0. Hardware and lowlevel programming



...and mapped to 0's and 1's.

0. Hardware and lowlevel programming

- Everything the computer does is *really just numbers*.

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- What if we change *one* bit, 0**1**000000101011111000000000100000?
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- Everything the computer does is *really just numbers*.
- Example: In the MIPS architecture, the sequence 00000000101011111000000000100000 is an instruction for the computer to add two numbers.
- What if we change *one* bit, 0**1**000000101011111000000000100000?
- The meaning changes entirely - now it's a `jump` instruction.
- Going deeper: Binary sequences also represent numbers (the jump one is 1085243424), ascii values (@¯€), and more.

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- A CPU works by executing a flow of instructions.
- Sometimes, a CPU can be 'tricked' into executing your instructions instead of the original program.
- Today, you'll learn how to write these instructions in the Intel x86 architecture.

Today's program

0. Hardware and lowlevel programming
1. **CPU, x86 assembler instructions, and shellcode**
2. Memory and the stack
3. Improving your shellcode
4. Extra exercises

1.0 CPU, x86 assembler instructions, and shellcode

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- A CPU can only execute simple instructions like `add` or `mov`.
- Usually one line of c code will translate into several lines of assembler.

1.1 registers

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- EIP points to the next instruction.
- EFLAGS will not be discussed.

1.1 registers

32	24	16	8
E_X			
		_X	
		_H	_L

1.2 Example: mov instruction:

mov a, b

a = b

- mov register, value
  moves value (like 5) into register (like eax)
- mov register a, register b
  moves the content of reg. b into reg. a
- mov register a, [pointer]
  moves the content on the address "pointer" into reg. a

1.3 syscall:

Stops the instruction execution, and lets the operating system execute a function.
http://syscalls.kernelgrok.com/

- eax containes the syscall number.
- ebx, ecx and edx contains the arguments.
- 0x80 makes the call.

1.4 compiling, linking, and executing a program:

compile:	nasm -f elf32 <name>.asm
link:	ld -melf_i386 -o <name> <name>.o
run	./<name>

Replace <name> with the filename of your program.

1.5 x86 assembler template

```
[bits 32]
section .text
global _start



_start:
mov eax, str



section .data
str: db 'lolhej', 0x0
```

1. CPU, x86 assembler instructions, and shellcode

```
 ----------------------------------
| Exercise: Write a program        |
|           that executes /bin/sh! |
 ----------------------------------
              \
              (\^)
               o O\______-
               \_/      \\
                 \ ____ /\\
                 //\ ||\\ \\
                 ||\\|| \\
```

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- x86 is little endian (the 'least significant byte' is saved first). The number `0xDECAFBAD` consists of `0xAD`, `0xFB`, `0xCA`, `0xDE`, *in that order*!

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- x86 is little endian (the 'least significant byte' is saved first). The number `0xDECAFBAD` consists of `0xAD`, `0xFB`, `0xCA`, `0xDE`, *in that order*!
- The addresses are local for your program.

2. Memory and the stack

Example:

0x000c	...
0x0008	...
0x0004	0xDECAFBAD
0x0000	...

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Example:

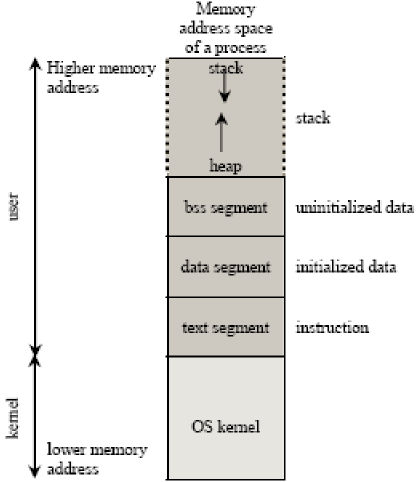
0x000c	...
0x0008	...
0x0004	0xDECAFBAD
0x0000	...

Zooming in at address 0x0004:

0x0007	0xDE
0x0006	0xCA
0x0005	0xFB
0x0004	0xAD

2. Memory and the stack

x86 memory is divided into segments:



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- Problem: We are using labels (why is this a problem?).
- Solution: We have plenty of space in dynamic memory! It's time to look at the stack.

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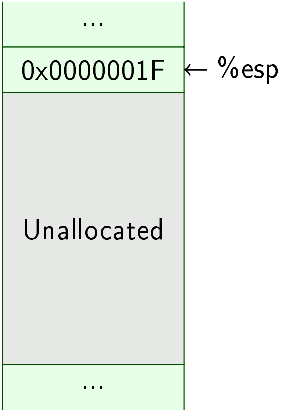
2. Memory and the stack

- The stack is a 'first in, last out' structure that grows *downwards*.
- ESP, the stack pointer, points to the top of the stack.
- The push instruction adds an element (4 bytes) to the top of the stack and decrements ESP.
- The pop instruction increments ESP by 4 (effectively removing the 4 bytes at the top).

2. Memory and the stack




```
->  push 0xDECAFBAD
    push 'heyy'
    push byte 0x42
    pop eax
```

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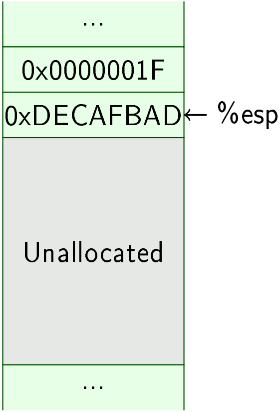


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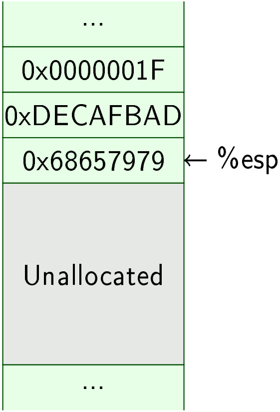
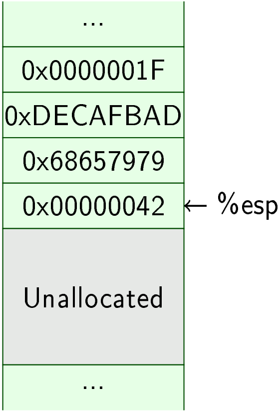



```
    push 0xDECAFBAD
    push 'heyy' ('h' = 0x68. Check man ascii.)
->  push byte 0x42
    pop eax
```

2. Memory and the stack




```
    push 0xDECAFBAD
    push 'heyy'
    push byte 0x42
->  pop eax
```

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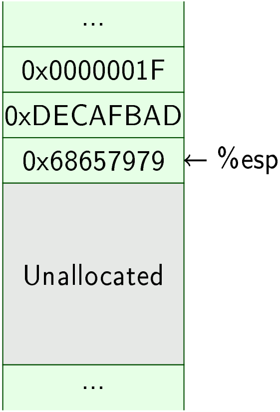

`push 0xDECAFBAD`

`push 'heyy'`

`push byte 0x42`

`pop eax` (`EAX` now contains `0x42`)

2. Memory and the stack

```
 -----------------------------------------
| Exercise: Write a program that executes |
|           /bin/sh without using labels! |
| Hint:     Strings are null-terminated.  |
 -----------------------------------------
              \
              (\^)
               o O\_____-
               \_/      \\
                 \ ____ /\\
                 //\ ||\\ \\
                 ||\\|| \\
```

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3. Improving your shellcode

- xor eax, eax
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3. Improving your shellcode

- xor eax, eax
  - set eax to 0.
- mul ecx
  - edx:eax = eax*ecx
- mov al, 5
  - move 5 to the least significant byte in eax.

3. Improving your shellcode

```
 ------------------------------------------
| Exercises:                                |
| a. Write shellcode that executes /bin/sh |
|    without null bytes!                    |
| b. Optimize your shellcode to using as    |
|    few bytes as possible!                 |
 ------------------------------------------
             \
             (\^)
              o O\_____-
              \_/      \\
                \ ____ /\\
                //\ ||\\ \\
                ||\\|| \\
```

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4. Extra exercises!

```
 --------------------------------------------
| You've found a vulnerability in a service  |
| run by <insert evil>, allowing you to      |
| execute shellcode.                         |
| You're interested in orienting yourself    |
| to find potentially interesting files...   |
|                                            |
| Write shellcode that executes /bin/ls with |
| '-l' as argument!                          |
 --------------------------------------------
             \
             (\^)
              o O\_____-
              \_/      \\
                \ ____ /\\
                //\ ||\\ \\
                ||\\|| \\
```

4. Extra exercises!

```
 ---------------------------------------------
| Huh. It seems they have a file called       |
| gold.txt lying around. Let's check it out.  |
|                                             |
| Write shellcode that writes the contents    |
| of a text file to standard output!          |
| Hint: sys_open, sys_read, sys_write.        |
|       For testing, create your own gold.txt |
|       file.                                 |
 ---------------------------------------------
             \
             (\^)
              o O\_____-
              \_/      \\
                \ ____ /\\
                //\ ||\\ \\
                ||\\|| \\
```

4. Extra! Compare instruction

cmp a, b
a ? b
compares a and b, the result is stored in a special register, and can be used by instructions like jeq, jne, jge, jle

- cmp register, value
  compares the value of register and value
- cmp register a, register b
  compares the value register a and b
- add register a, [register b + x]
  compares the value of register a and the value on the address of register b + x

4. Extra! Conditional jump instruction

j_ _ label
Used after compare, if the condition is true then the instruction pointer is moved to the address given by label.

- ja: jump if above
- jb: jump if below
- jeq: jump if equal
- jne: jump if not equal
- jae: jump if above or equal
- jbe: jump if below or equal
- jmp: always jump (does not have to be after a compare)

Compare and conditional jump instructions can be used to form loops.

4. Extra exercises!

```
 ----------------------------------------------
| a. Write a program that calculates the       |
|    factorial of some number n.               |
|    (For now, hardcode the number n in your   |
|    program. We'll get to function calls      |
|    another day.)                             |
| b. Write a program that calculates the nth   |
|    fibonacci number for some number n.       |
 ----------------------------------------------
             \
             (\^)
              o O\______-
              \_/       \\
                \ ____ /\\
                //\ ||\\ \\
                ||\\|| \\
```