Secure Software Development: Theory and Practice

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MW 2:40-3:55pm
415 Schapiro [SCEP]

*Some slides are borrowed from Dan Boneh and John Mitchell

Software Security is a major problem!

Why writing secure code is hard?

Software bugs cost US economy $59.5 billion annually (NIST)

Not all bugs are equal!

Benign functional bugs

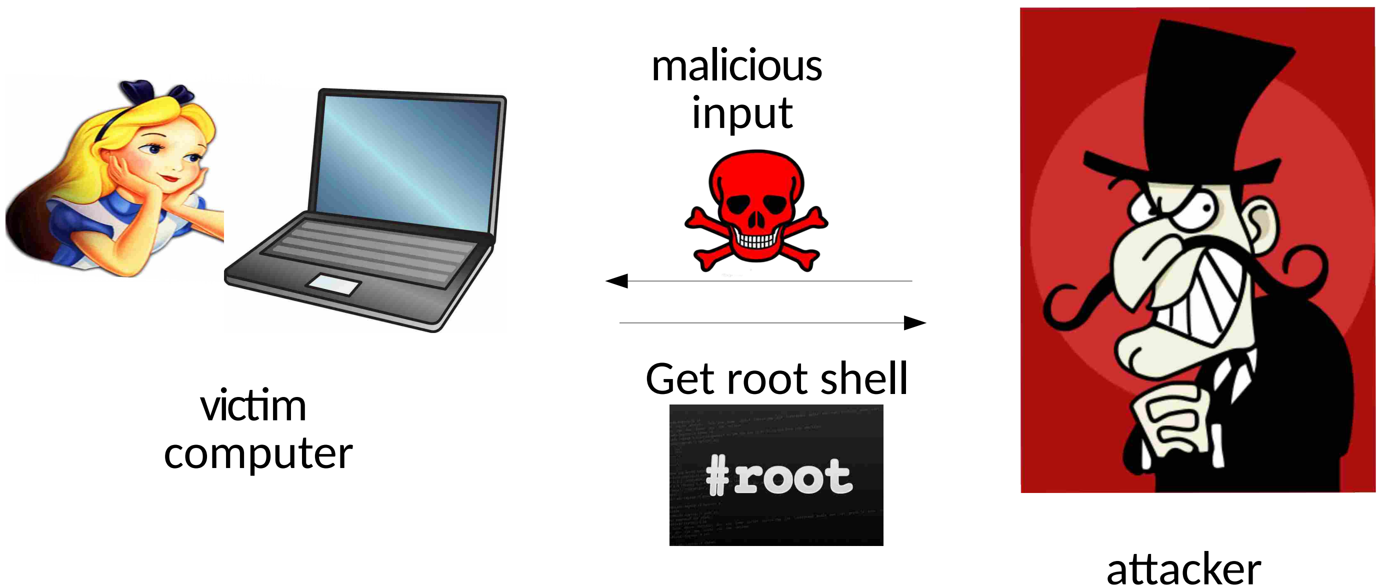
vs.

Security bugs

Why are security bugs more dangerous than other bugs?

Why security bugs are more dangerous?

- Security bugs allow attackers to cause serious damages: take over machines remotely, steal secrets, etc.



How do we deal with security bugs?

- Automatically find and fix bugs

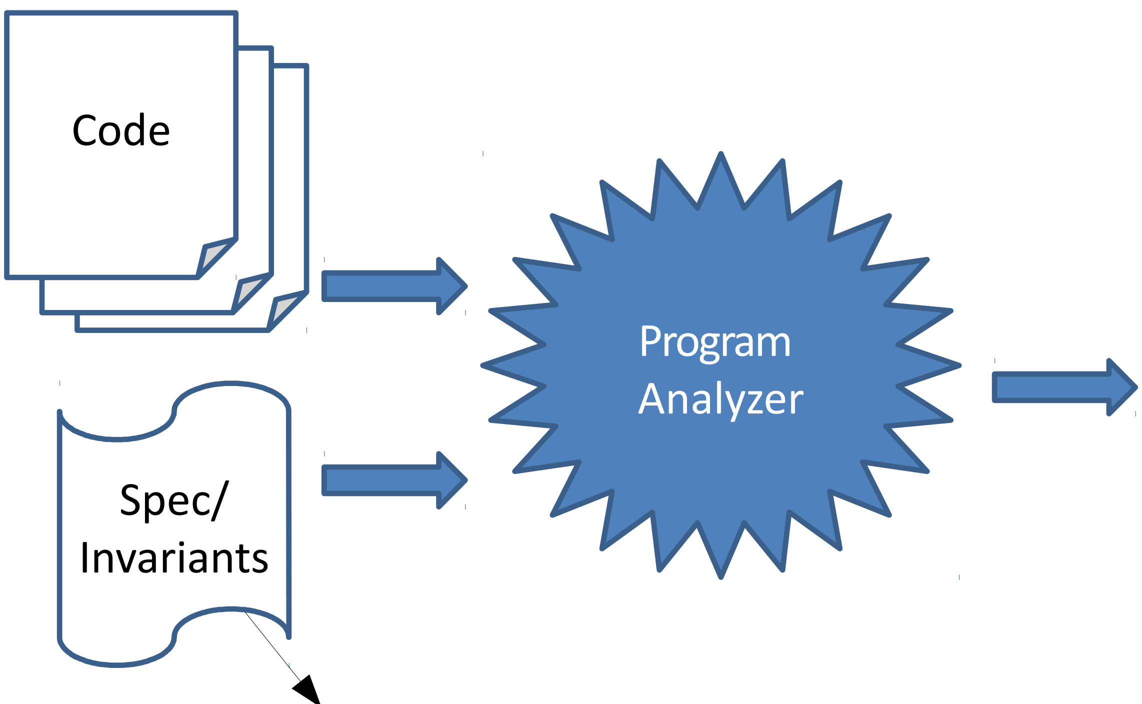
Topics of this class

- Monitor a system at runtime to detect and prevent exploits of bugs

- Accept that programs will have bugs and design the system to minimize damages
  - Example: Sandboxes, privilege separation

Theory of bug finding

Finding bugs with Program analyzers



Report	Type	Line
1	mem leak	324
2	buffer oflow	4,353,245
3	sql injection	23,212
4	stack oflow	86,923
5	dang ptr	8,491
…	…	…
10,502	info leak	10,921

Descriptions of different classes of bugs

Automated bug detection: main challenges

```
int main (int x, int y)
{
  if (2*y!=x)
    return -1;
  if (x>y+10)
    Return -1;
  ....
  ... /* buggy code*/
}
```

What values of x and y will cause the program to reach here

1. Too many paths (may be infinite)
2. How will program analyzer find inputs that will reach different parts of code to be tested?

Automated bug detection: two options

- Static analysis
  - Inspect code or run automated method to find errors or gain confidence about their absence
  - Try to aggregate the program behavior over a large number of paths without enumerating them explicitly

- Dynamic analysis
  - Run code, possibly under instrumented conditions, to see if there are likely problems
  - Enumerate paths but avoid redundant ones

Static vs dynamic analysis

- Static
  - Can consider all possible inputs
  - Find bugs and vulnerabilities
  - Can prove absence of bugs, in some cases
- Dynamic
  - Need to choose sample test input
  - Can find bugs and vulnerabilities
  - Cannot prove their absence

Soundness & Completeness

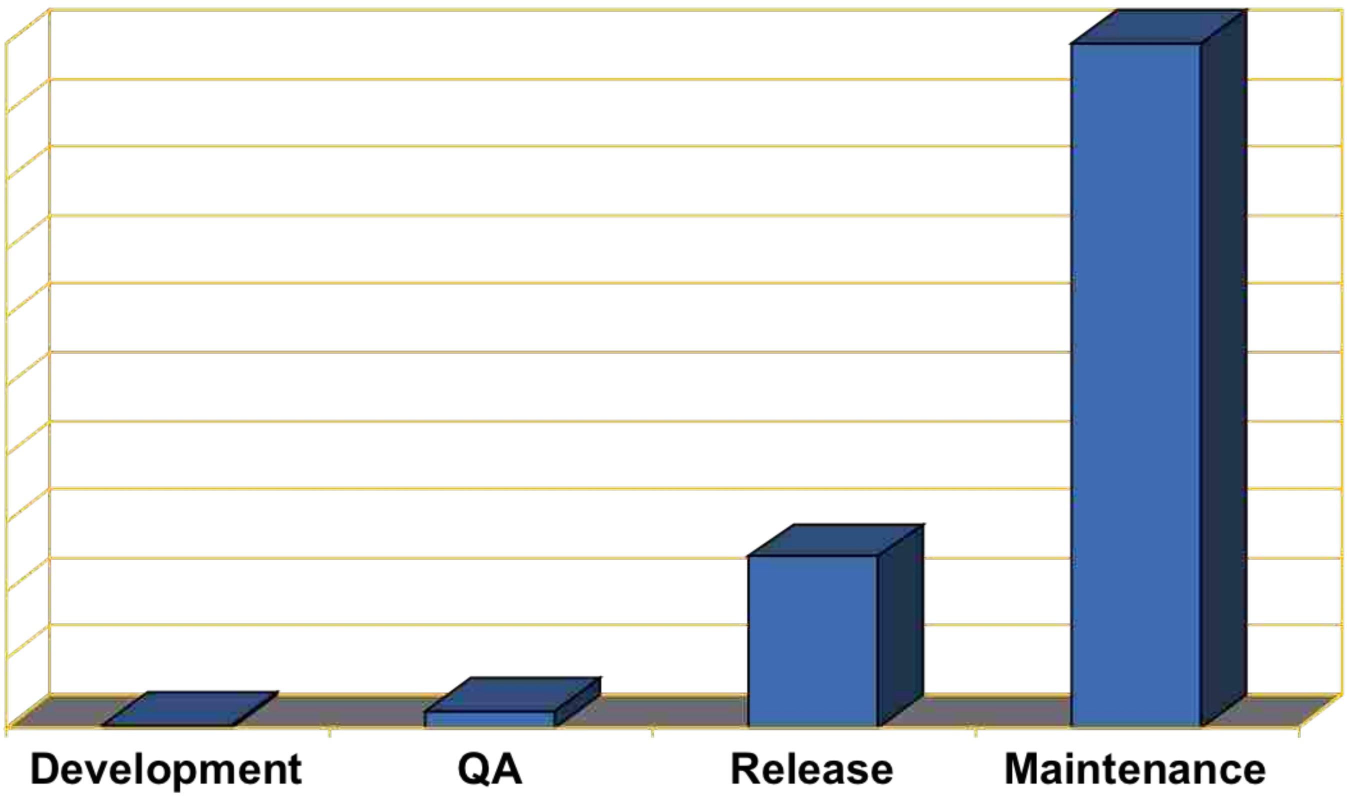
Property	Definition
Soundness	"Sound for reporting correctness" Analysis says no bugs $\rightarrow$ No bugs or equivalently There is a bug $\rightarrow$ Analysis finds a bug
Completeness	"Complete for reporting correctness" No bugs $\rightarrow$ Analysis says no bugs

Recall: $A \rightarrow B$ is equivalent to $(\neg B) \rightarrow (\neg A)$

Soundness & Completeness

	Complete	Incomplete
Sound	Reports all errors Reports no false alarms **Undecidable**	Reports all errors May report false alarms **Decidable**
Unsound	May not report all errors Reports no false alarms **Decidable**	May not report all errors May report false alarms **Decidable**

When to find bugs?

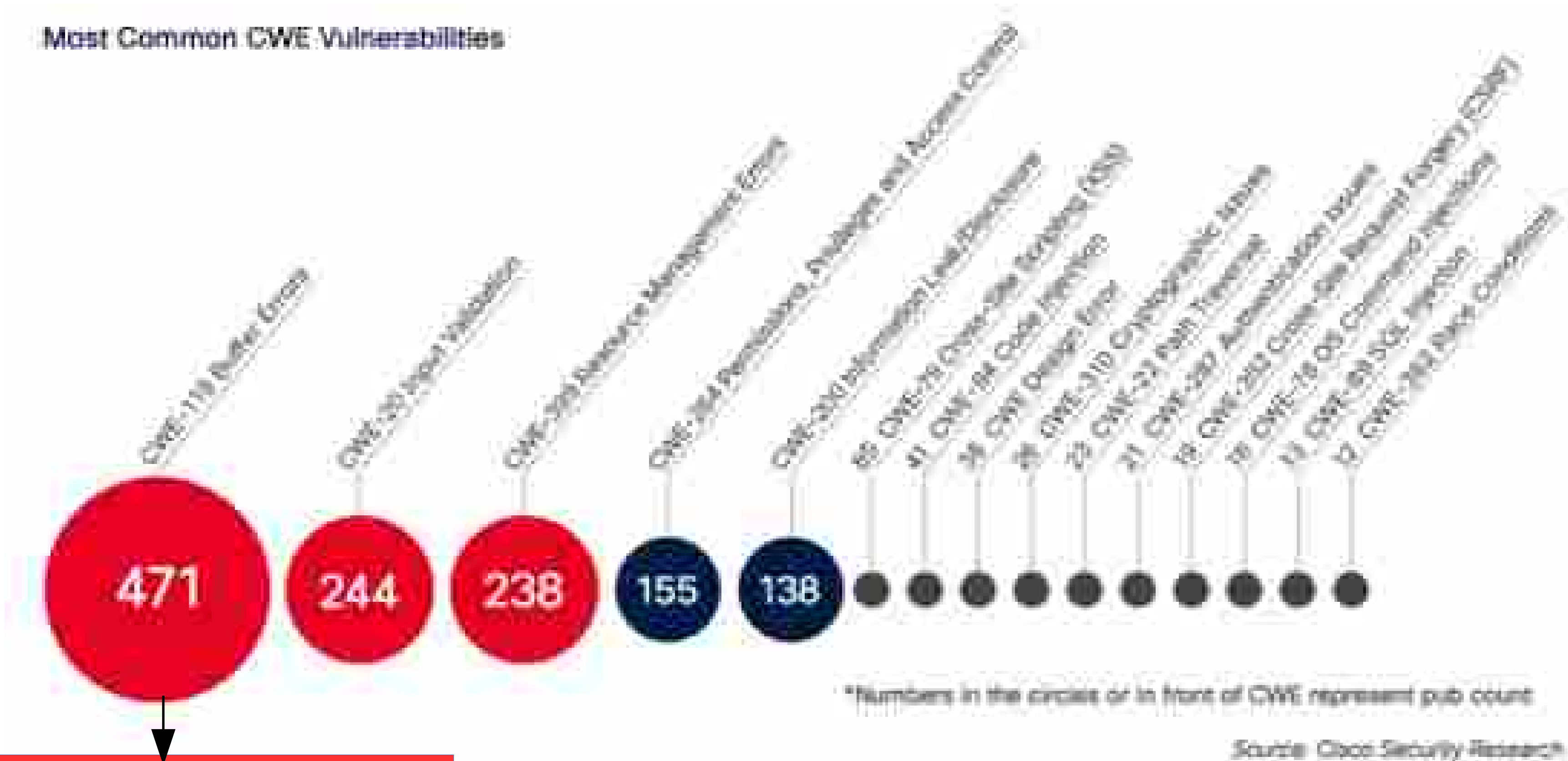


Cost of bug finding

Credit: Andy Chou, Coverity

Practice of bug finding

Popular classes of security bugs



Memory corruption attacks

Memory corruption attacks

- Attacker's goal:
  - Take over target machine (e.g., web server)
    - Execute arbitrary code on target by hijacking application control flow leveraging memory corruption

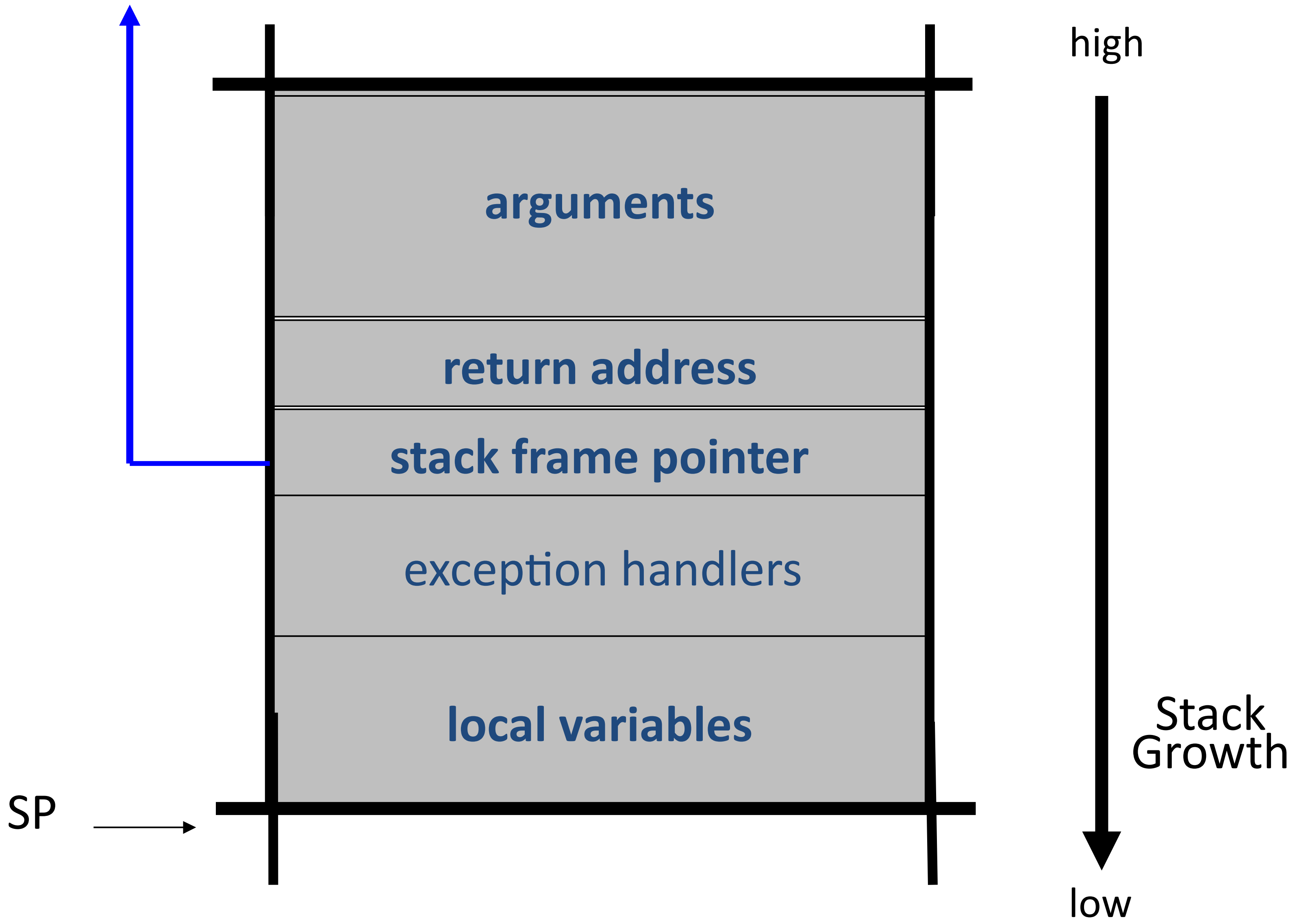
- Examples.
  - Buffer overflow attacks
  - Integer overflow attacks
  - Format string vulnerabilities

What is needed

- Understanding C functions, the stack, and the heap.
- Know how system calls are made
- The exec() system call

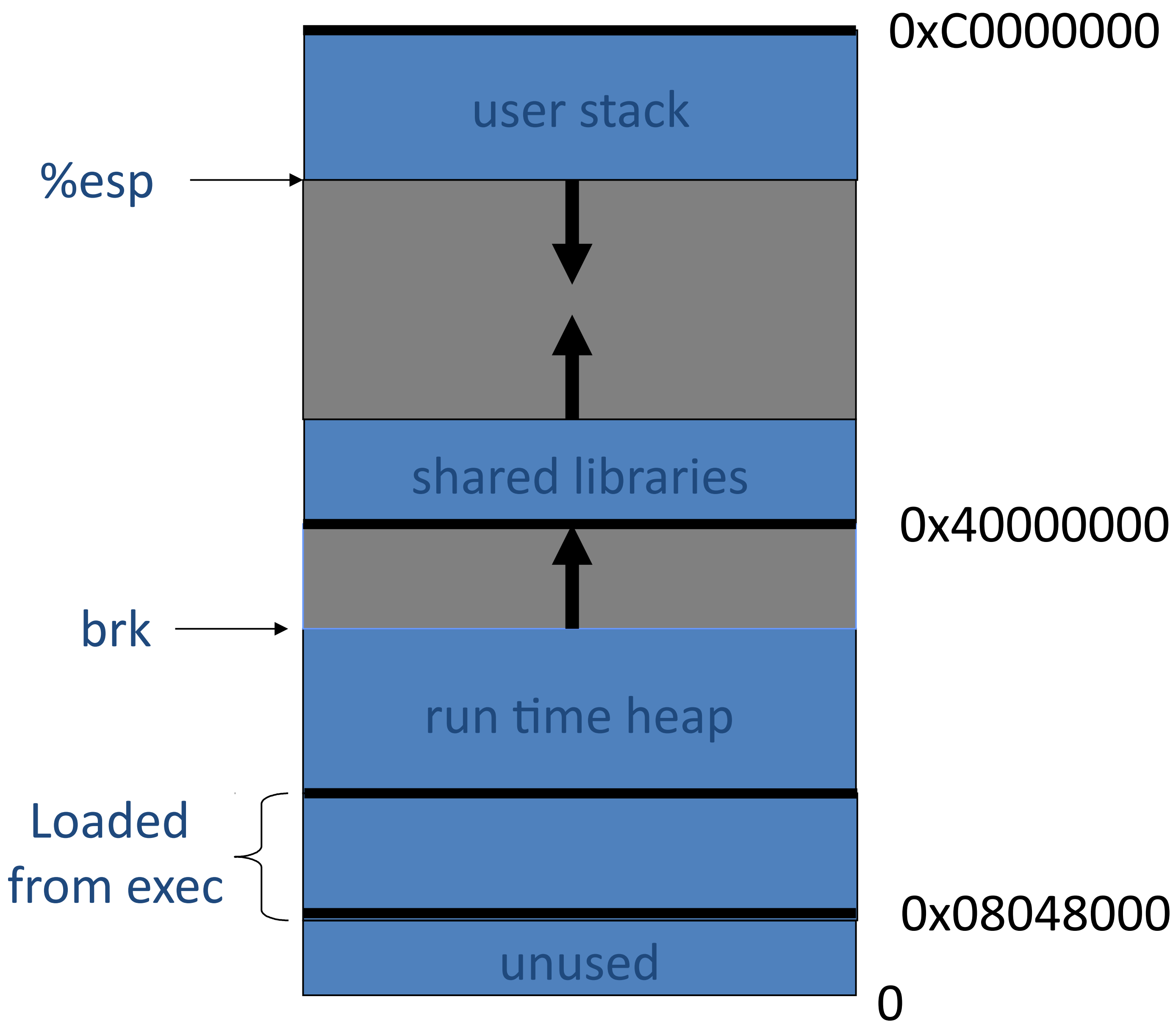
- Attacker needs to know which CPU and OS used on the target machine:
  - Our examples are for x86 running Linux or Windows
  - Details vary slightly between CPUs and OSs:
    - Little endian vs. big endian (x86 vs. Motorola)
    - Stack Frame structure (Unix vs. Windows)

Stack Frame



high
arguments
return address
stack frame pointer
exception handlers
local variables
Stack Growth
SP
low

Linux process memory layout



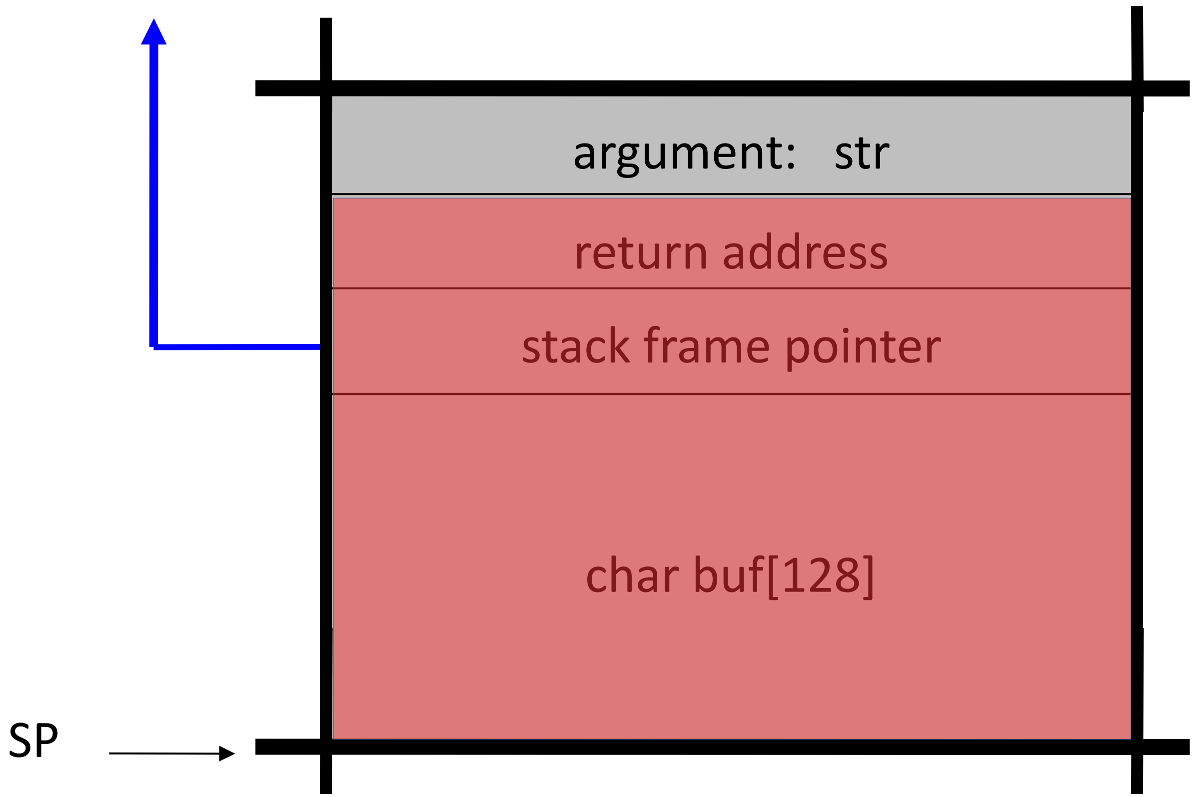
What are buffer overflows?

Suppose a web server contains a function:

```
void func(char *str) {
    char buf[128];

    strcpy(buf, str);
    do-something(buf);
}
```

When func() is called stack looks like:



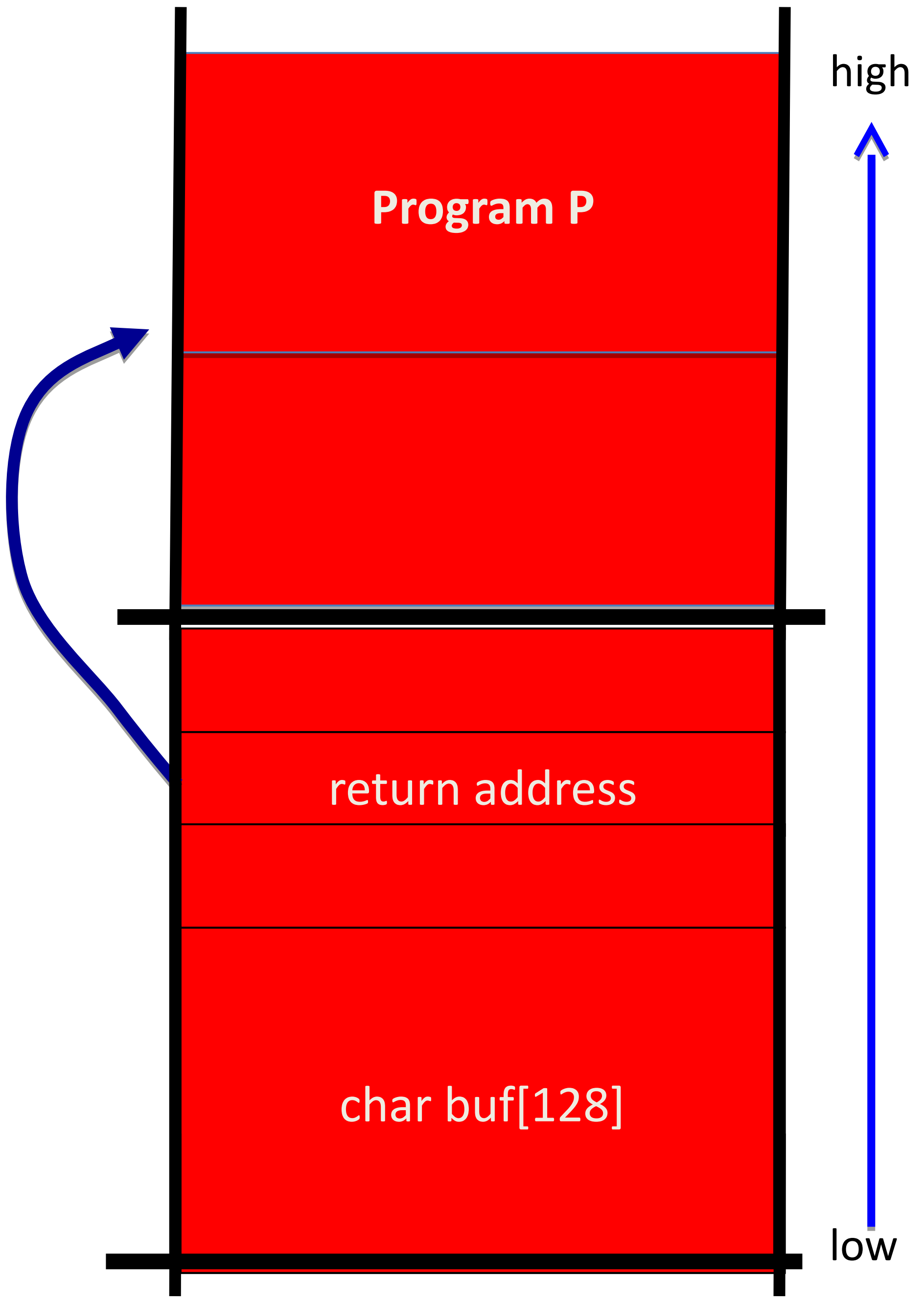
What happens if str is larger than 128?

Basic stack exploit

Suppose *str is such that
after strcpy stack looks like:

Program P: exec("/bin/sh")

When func() exits, the user gets shell!
Note: attack code P runs *in stack*.

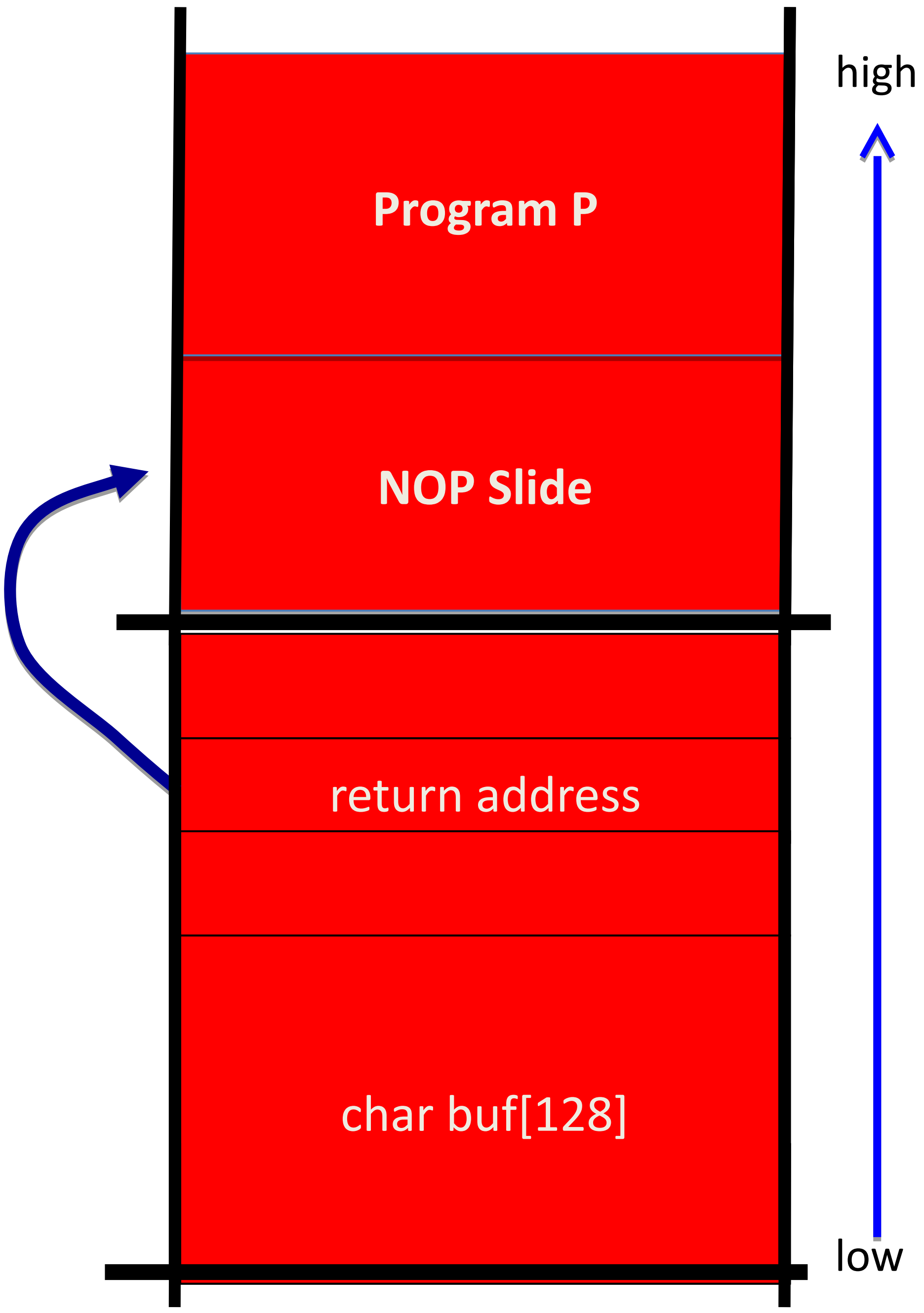


The NOP slide

Problem: how does attacker determine ret-address?

Solution: NOP slide

- Guess approximate stack state when func() is called
- Insert many NOPs before program P:
  nop , xor eax,eax , inc ax



How to avoid buffer overflows?

- Rewrite software in a type safe language (Java, Rust)
  - Difficult for existing (legacy) code …
- Use safer functions like strncpy instead of strcpy
  - Developer may make mistakes
  - Confusing semantics for terminating NULL characters
- Automatically find them
  - Static analysis tools: Coverity, CodeSoner...
  - Dynamic analysis tools: AFL, libfuzzer...

More details about detection techniques later in the semester

Structure of the class

1. Control & data flow analysis
2. Symbolic Execution
3. Fuzzing

Program analysis
Fundamentals

Build tools for detecting
classes of bugs

Memory corruption attacks

Web Attacks:
XSS, SQL injection, and CSRF

Semantic/logic bugs

Side channel leaks

DOS attack vectors

Different classes of security bugs

Logistics

Class webpage
http://sumanj.info/secure_sw_devel.html

TAs: Eugene Ang and Plaban Mohanty)

Reading
No text book, slides, and one/two papers per class

Grading :
Quizzes/programming assignments - 35%
Midterm - 30%
Group Project (3-4 students) - 30%
Class participation - 5%

Summary

In this class you will learn about:

1. Different classes of security bugs and their implications
2. State-of-the art of bug finding techniques
3. Using and customizing existing bug finding tools