ECE 650
Systems Programming & Engineering

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Protection & Security

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Slides are adapted from Brian Rogers (Duke)

Protection

- OS manages resources for users & user processes
  - Files, memory regions, I/O channels, CPU
- Protection is a critical part of this management
  - Ensure that resources can only be used with proper authorization from the OS
- Reasons for protection
  - Prevent users from malicious access to resources
  - Ensure processes use system resources only as consistent with allowed policies
- Protection is a ***mechanism***
  - Mechanism to enforce policies that define how resources should be used
  - As opposed to a ***policy*** (definition of how resources should be used)
  - Policies may adapt and change over time (or between different applications)
  - Thus mechanisms should be general to allow flexibility

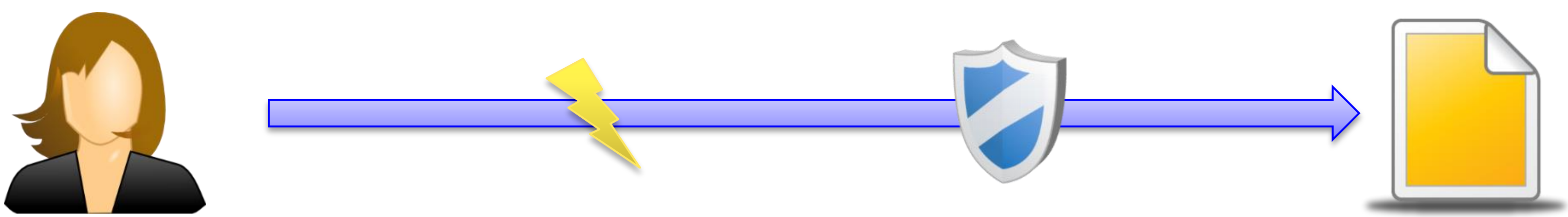
Engineering wisdom:
Always separate **mechanism** and **policy**

Basics of Protection

- Most protection mechanisms based on key principle
  - **Principle of least privilege**
  - Users, processes, etc. have the minimum level of access to resources and privileges needed to accomplish intended task
  - “Need to know basis”
- Minimizes damage from failed or compromised pieces
  - They can only affect a minimal set of components in the system
- OS designs provide support for this
  - System calls and services for apps to specify fine-grained permissions & controls
  - Apps enable and disable permissions as needed
  - Also applies to users (separate accounts, permissions)

Subjects, Objects, Actions, and Rights

Subject (initiator)	**Verb** (request)	**Right** (permission)	**Object** (target)
• The thing making the request (e.g. the user)	• The operation to perform (e.g., read, delete, etc.)	• A specific ability for the subject to do the action to the object.	• The thing that's being hit by the request (e.g., a file).



Protection Rules

- Think of all resources as an object
  - E.g., in UNIX – "everything is a file"
  - Hardware objects: CPU, memory spaces, disk, keyboard, display
  - Software objects: files, directories, programs
- Different objects have different possible operations, e.g.
  - Read & write memory regions; Read from a keyboard input
  - Execute on a CPU
  - Create, delete, open, close, read, write, append files
- Protection mechanism operates based on rules
  - Application or user (the <u>subject</u>) has permission to perform certain operations on certain <u>objects</u>

Protection Rules (2)

- Rules specifies objects (resources) the process has permission to access
- Access Right
  - A permission for a process to perform an operation on an object
- Access rights can be static or dynamic for a process
  - Dynamic rights achieved via either:
    - A mechanism to change an object's access rights
    - A mechanism for subject switching
      - Create new subject with desired access rights; then switch to it
  - For example, the user/supervisor mode we discussed for interrupts

```
$ whoami
tkb13
$ sudo whoami
[sudo] password for tkb13: ************
root
```

UNIX Example

- Happens via a protection mechanism using the file system
  - Remember, in UNIX, “everything” is a file
  - Every file has an owner ID and a setuid bit
    - "set user ID upon execution“
    - Set just like file read/write/execute permissions
  - When a user executes a file:
    - If setuid bit is on, user ID is changed to the owner of the file
    - If setuid bit is off, user ID does not change
  - Temporary user ID change ends after process exits
- Allows a privileged component to be used by general users
  - E.g. an application that accesses the network or change user password
- What if a user creates a file with user ID of root & setuid on?

Access Matrix

- Protection model maps nicely to a matrix
- Rows = subjects; columns = objects
- A matrix entry lists the access rights
- Provides a general mechanism for specifying policies
  - Enforce specific access rights for a user or process

Access Matrix – Additional Functions

- Base access matrix allows
  - Defining and enforcing strict access control policy
- How can we provide dynamic rights?
  - Subject switching
    - Add access matrix entries to enforce “switch” operation rights
    - Examples: sudo, setuid
  - Allow controlled changing of the access matrix entries
    - Encode this permission in the access matrix as well!
    - New operations for **owner** of an object to allow creation of new rights in the access matrix
    - Examples: chmod, Google Drive sharing settings

Access Matrix Implementation

- In a real system, the matrix will be very sparse
  - But the way it is accessed & used cause special considerations
- Global Table
  - List of <subject, object, rights> tuples
  - Search for “right” when “subject” accesses “object”
  - Drawbacks:
    - Table is huge
    - Objects may have “global” rights, but still listed for every subject
- Access Lists
  - Maintain a list per object with <subject, rights> (column-based)
  - Can extend with a “default” set of rights for each object

Security

- Protection is a mechanism for internal problem
  - Controlled access to programs, data
- Security deals with the external environment
  - Protection can be thwarted if security is compromised
  - Protection works well only if users behave as intended
  - E.g., what if a user password is stolen or cracked?
- In a secure system…
  - All resources (objects) are used only according to policy
  - Cannot be achieved in reality, but strive to limit violations

Security and the OS

- Why is security important for systems programming?
- Many attacks target an "escalation of privilege"
  - This often involves attempting to gain "root" privilege in a system
  - For purposes of reading or tampering with data
    - Data not otherwise accessible via protection mechanism
  - Systems programmers should be aware of:
    - Types of attacks
    - Mechanisms by which attacks are attempted and operate

Some Definitions

- Threat: potential for a security violation
  - E.g. a **vulnerability** in a program
- Attack: attempt to break security
  - E.g. an **exploit** is an attempt to utilize a program vulnerability
- Categories of security violations
  - Confidentiality breach: data theft
    - E.g. credit card, account information; very common goal
  - Integrity breach: unauthorized modification of code or data
  - Availability breach: unauthorized destruction of data
    - E.g. deleting customer account info or defacing a website
  - Theft of service: unauthorized use of resources
  - Denial of service: prevent legitimate use of a system

Domains of Security Measures

- Physical
  - Need to secure the sites where computer systems reside
  - Only authorized administrators / users have physical access
- Human
  - Social engineering may trick authorized users into performing an inadvertent breach of security
  - Phishing obtain information
  - Executing malicious code
- OS
  - Mechanisms to protect from accidental or purposeful breaches
- Network
  - Protect network-transmitted data from interception or tampering

Types of Threats

- Threats to Running Programs
  - Trojan Horse
  - Trap Door
  - Logic Bomb
  - Stack (or Buffer) Overflow
  - Viruses
- Threats to System and Network Resources
  - Worms
  - Port Scanning
  - Denial of Service

Trojan Horse

- Malware code that misuses its environment
  - Often disguised as legitimate software
  - User unknowingly is tricked into executing the malware code
  - Often takes advantage of access rights of the executing user
- Example: Take advantage of search paths on UNIX OS
  - PATH environment variable specifies order of locations to search for executable files (e.g. ‘ls’ command)
  - PATH usually has things like: /bin:/usr/bin/:/usr/local/bin
  - Sometimes also has things like “.” (current directory)
  - Malicious user creates a Trojan program (e.g. with a common name like ‘cd’)
  - Unknowing user goes into the directory with this program and executes what they think is the “normal” cd command
  - Executes Trojan code
- NOTE: This is why ‘.’ is not in the PATH by default, and therefore why you have to say ./myprogram to run a program you just built

Trojan Horse (2)

- Emulate a login prompt
  - User enters a login ID and password
  - Trojan code captures user ID and password
  - Trojan code prints a login failure message & exits
    - Returning to the real login prompt
  - User thinks they have mistyped password; suspects nothing
  - Reason behind the <ctrl>+<alt>+<delete> Windows
    - Non-trappable key sequence
    - Trojan code cannot intercept this signal and ignore it
- Spyware
  - Code contained along with software to display ads
  - Or capture information and send it somewhere for mining
    - This is called a covert channel (e.g. by opening a network daemon)
  - Fundamental violation of principle of least privilege

Trap Door

- A security hole purposely left in legitimate software
  - Can be exploited by those with knowledge of the vulnerability
- Financial code might include tiny rounding errors
  - Route rounded money to a specific bank account

Trap Door (2)

- Tweak authentication procedures for an application
  - E.g. obscure user name and ID password combo is always valid
- Extra sneaky scenario:
  - Embed the trap door for an application in compiler(s)
  - Compiler checks to see if it is compiling the specific application
  - If so, it inserts the trap door code
  - Inspection of the application source code reveals no issues!
  - Additionally, if the application is re-compiled, problem still exists!

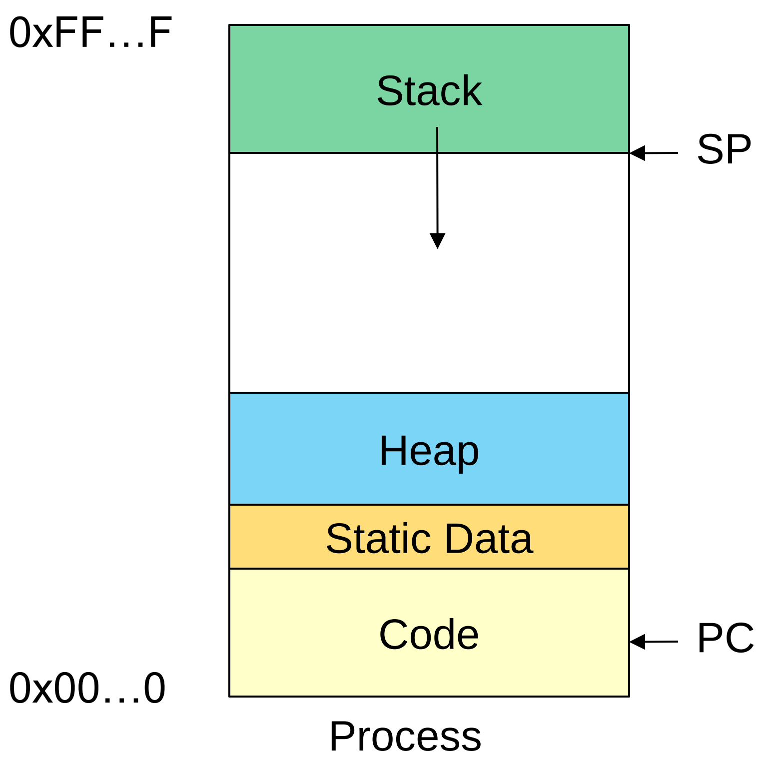
Logic Bomb

- Malware that is triggered only under certain conditions
  - E.g. causes a security incident only at a particular time
  - Application may run normally for a long period of time
- What kind of conditions? Almost anything…
  - Certain year, month, day, time
  - If certain information is present on the system
  - Check a database to see if the programmer is still employed

Stack (Buffer) Overflow

- Previous threats involve:
  - A programmer that can create malicious programs
  - A way to install or place malicious code in the system
- What if this is not possible?
  - How could an attacker execute malicious code?
- By far the most common way is through stack overflow
  - Takes advantage of the stack mechanism to:
    - Allow injection of malicious code
    - Force a process to execute the code
- As we will see, specific to architecture, OS, & application

Stack Overflow Mechanism



- Stack organized as frames
  - Every function call creates & pushes a new frame on stack
  - Function return pops frame from stack
- Frames may contain
  - Return address (PC)
  - Address of previous frame
  - Space for function args
  - Space for function local vars

Stack Overflow Mechanism

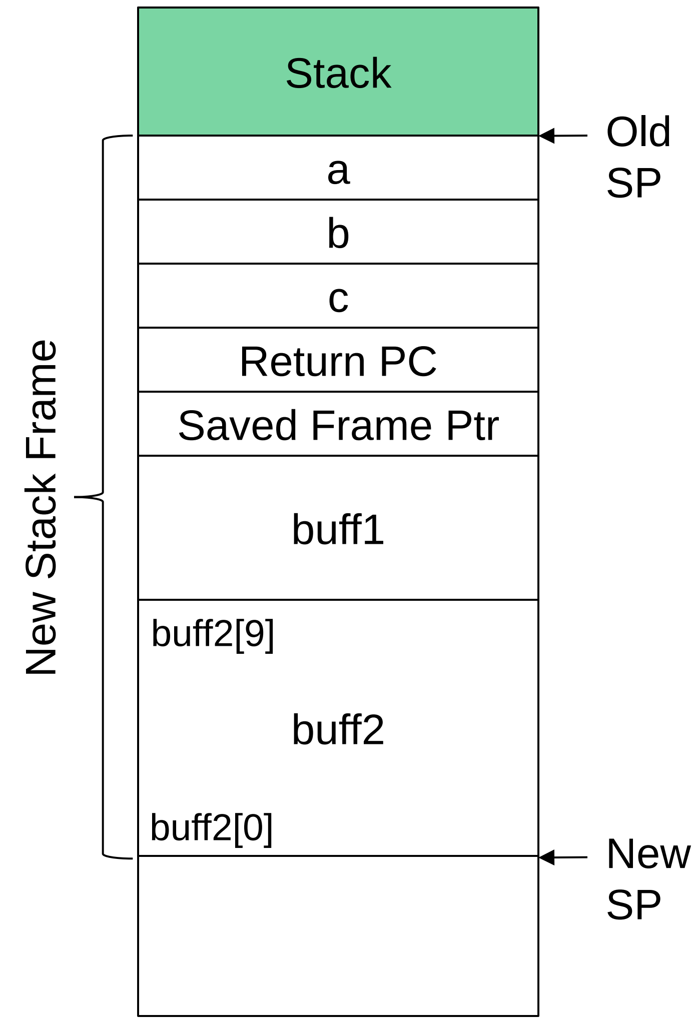
```
void func(int a, int b, char *c) {
   char buff1[5];
   char buff2[10];
   strcpy(buff2, c);
}

int main(int argc, char *argv[]) {
   func(1, 2,argv[1]);
}
```

compile

```
main:
  <snip>
  0x4 push $1
  0x8 push $2
  0xC push $3
  0x10 call func  #pushes pc=0x14
<snip>
```

Stack After Calling func()



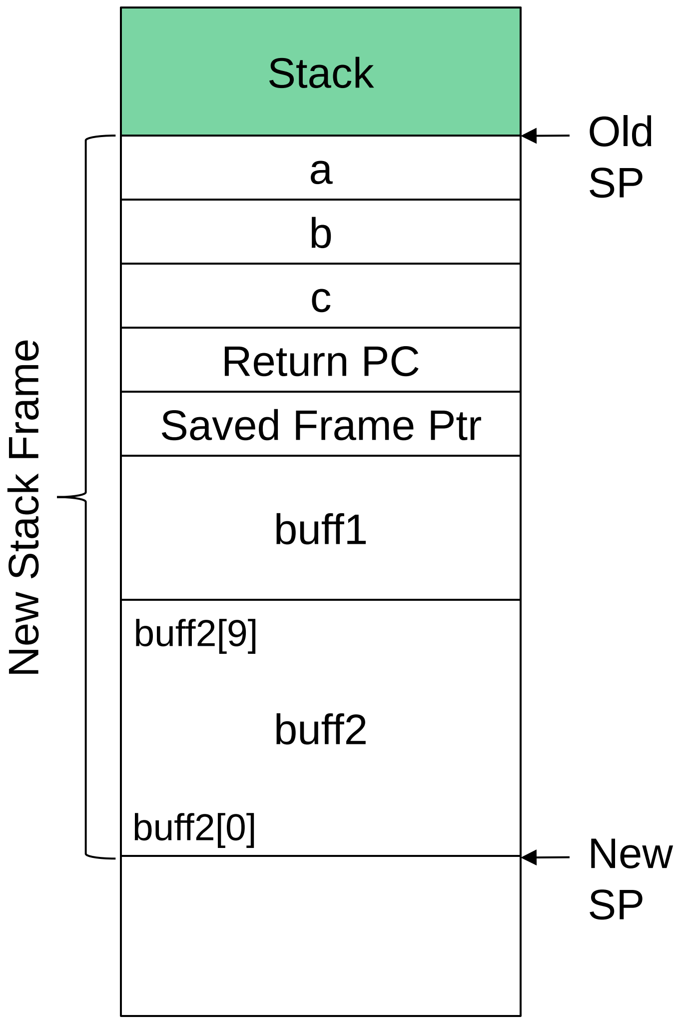
Stack Overflow Mechanism (2)

```
void func(int a, int b, char *c) {
   char buff1[5];
   char buff2[10];
   strcpy(buff2, c);
}

int main(int argc, char *argv[]) {
   func(1, 2,argv[1]);
}
```

- What if buffer c has more than 10 bytes?
- Lack of bounds checking means other stack addresses will be overwritten
- Including the Return PC!!!
- When a function exits (‘ret’ instruction)
  - This “Return PC” is placed in the CPU program counter

Stack After Calling func()



Stack Overflow

- If a stack buffer is filled based on user input:
  - A lack of bounds checking means the return PC can be changed
- What can the PC be changed to?
  - Where have we learned about PCs that point to specific code?
  - Or the attacker can fill the buffer with code!
  - Return PC will point back to the written buffer
- For example, code to execute a shell:

```
int main(int argc, char *argv[]) {
   execvp("/bin/sh", "/bin /sh", NULL);
   return 0;
}
```

- If this is interesting, read "Smashing the Stack for Fun and Profit": http://insecure.org/stf/smashstack.html

Prevention Mechanisms

- Historically this type of attack has dominated incidents
  - Lack of bounds checking is the vulnerability
  - Stack overflow is the exploit
- What can be done? Lots of R&D on this:
  - strncpy()!! (i.e. more careful programming)
  - Non-executable stacks
    - But attackers just become more sophisticated
    - Use chains of system calls to perform attacks
  - Address space randomization
  - Stack meta-data to record modifications to stack information
  - And on and on

Virus

- Malware embedded in a legitimate program
- Replicates itself and actively spreads
  - Key distinction from the threats we have thus far seen
- Typically spread via social engineering
  - Users execute programs via spam email or internet downloads
- One common source
  - Microsoft office files, as they can execute macros
  - Attacker can embed malicious macro code in a file
- A delivery program (usually a Trojan horse) contains a program called a virus dropper
  - Virus dropper executes and injects virus into the system
  - E.g. copies to memory & starts executing virus program

Some Common Virus Categories

- File
  - Virus appends to a file
  - Changes start of program to jump to virus
  - After executing, returns control to program so virus is not noticed
- Boot
  - Infect boot sector; execute every time system is booted
  - Also infects other bootable media such as USB
  - Viruses don’t appear in the file system
- Macro
  - Macro: programming language available in some document formats, e.g. Microsoft office files
  - Attacker can embed malicious macro code in a file, have it add same macro to other files
- Source code
  - Modifies source of programs to include the virus & help spread

More Common Virus Categories

- Lots of variants geared to avoiding detection
- Polymorphic
  - Changes each time it is installed to change its “signature”
  - Helps defeat virus scanners that look for patterns in code
- Stealth
  - Virus modifies parts of a system that check for virus existence
  - E.g. modify the read() system call
- Tunneling
  - Virus bypasses detection by installing itself in interrupt handler or device drivers
- Encrypted
  - Virus includes decryption code to decrypt itself and then execute

Worms

- Essentially a virus that uses network resources to spread
- Does not attach to existing program like a virus
- Often consist of 2 pieces
  - "Grappling hook"
    - Initial code that is established and executes on a machine
    - It communicates with an established machine & requests the worm
  - Main worm malware

Morris Worm

- Robert Morris – 1998, graduate student at Cornell
- First internet worm
- Worm attempted 3 network attack methods
  - Try to exploit ‘rsh’ to execute a task remotely
    - Searched for host-login name pairs in special files
  - Exploit vulnerability in ‘finger’ program
    - Buffer overflow of a stack frame to execute /bin/sh
  - Exploit vulnerability in ‘sendmail’ program
    - Debugging option commonly left enabled by system admins
    - Worm mailed itself & executed grappling hook program

Port Scanning

- Attempt TCP/IP connections to host on range of ports
- Each attempt tries to connect to a vulnerable service
  - E.g. sendmail
- If successful, this indicates an exploit opportunity
  - E.g. to exploit a buffer overflow

Denial of Service

- Not aimed at stealing or modifying information
- Goal is to disrupt legitimate use of a system or service
- Usually network-based attacks
  - E.g. initiate but do not complete many TCP/IP connections
  - Results in no new legitimate connections being serviced
- Distributed Denial of Service (DDOS)
  - Launched from multiple sites at a common target
  - Sometimes the multiple sites are infected machines (zombies)
- Sometimes security measures introduce DOS vulnerabilities
  - E.g. increasing delays between unsuccessful login attempts

Rootkits

- Malware that acquires privileged access to the OS
  - Also maintains that access
  - By hiding its presence from normal OS activity
- Goals of a rootkit
  - Run (without restriction) on a target system
    - Use social engineering or vulnerabilities in protection (e.g. ACLs)
  - Remain invisible to security software, OS, users
  - Perform malicious action (called the payload)
    - Steal information or access to resources; install other malware

How do Rootkits Hide?

- Processes (including security software) depend on the OS to provide information about the environment
  - E.g. through APIs that expose system calls
- Rootkit software can monitor these API questions to OS
  - Rootkit intercepts questions related to its existence
    - E.g. an ‘ls’ of the directory where the rootkit program exists
    - E.g. an ‘ls’ of the /proc/ directory containing info on all processes
    - E.g. a ‘read’ request on a file modified by the Rootkit

Rootkit Subversion Mechanisms

- "Hooking" OS APIs
  - Change address of OS APIs by pointing to own malware code
  - Can be done for user or supervisor mode
  - In response to system calls, the code at modified address is run
- Hide in unused disk space
  - Unused disk space is not visible to normal file system APIs
  - Modify device driver(s) to execute rootkit code when loaded
- Infect the Master Boot Record (MBR)
  - Control what is loaded into memory before OS is even booted