Reading:
See [Gollmann] Chapter 5 & 7
See [PF] Chapter 2.2 (pages 72 – 85)
See [Andersen] Chapter 4 up to 4.2.4
Read Wiki http://en.wikipedia.org/wiki/File_system_permissions

Lecture 7: Access Control

7.1 Overview of layering model in computer system design

7.2 Access control model

7.3 Access control in UNIX/Linux

7.4* UNIX/Linux: Elevated privilege (controlled invocation)

* **Warning**: This part could be the most abstract and *complicated* notion in the module.
Complexity is bad for security. See https://www.schneier.com/news/archives/2012/12/complexity_the_worst.html.

7.1 Overview of Layering Model in Computer System Design

Layers in Computer System

Applications	(e.g. browser, mail reader)
Services	(e.g. DBMS, Java Virtual Machine)
Operating System	(e.g. UNIX/Linux, Windows, iOS, macOS)
OS Kernel	(including system calls to handle memory, manage virtual memory, etc.)
Hardware	(including CPU, memory, storage, I/O)

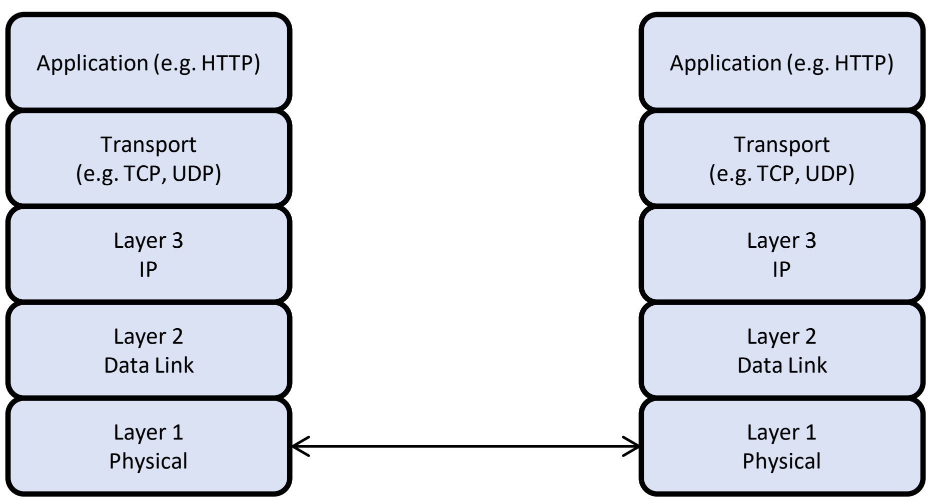
Remarks:

1. We can also view **OS kernel** as part of the OS
2. These layers are used as a *guideline:*
   actual systems typically don't have **distinct layers**
   (e.g., a **windowing system** may span across multiple "layers")

Compared to Layers in Communication Network

Network:

- The **boundary** is more well defined
- Information/data **flows** from the topmost layer down to the lowest layer, and is transmitted from the lowest layer to the topmost layer
- A **concern** of data confidentiality and integrity



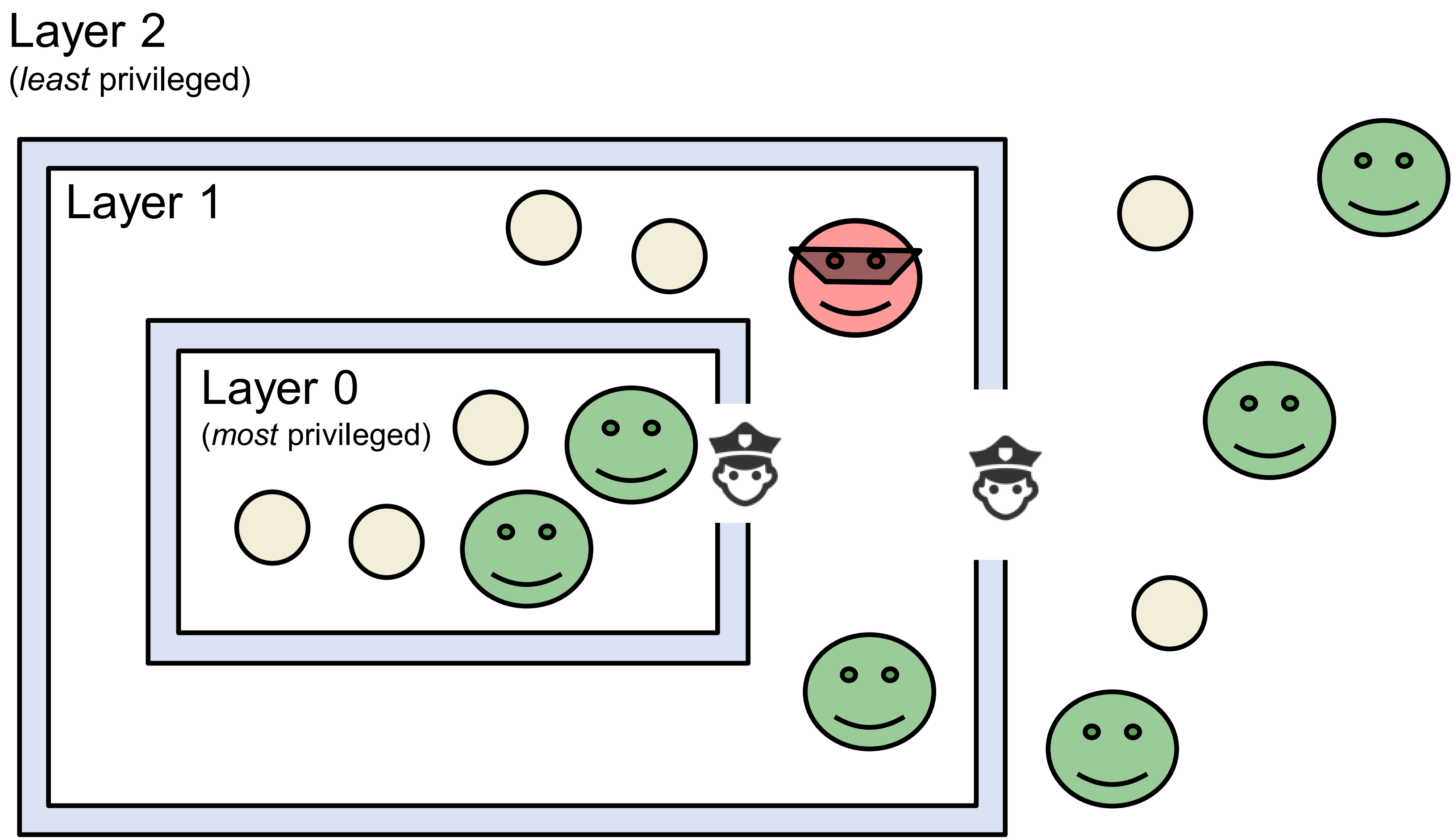
Compared to Layers in Communication Network

Computer system:

- The **boundary** is *less* well-defined
- Every layer has its own "**processes**" and "**data**"
(although ultimately, the raw processes/data are handled by hardware)
- The main security **concern** is about access to the processes & memory/storage
- Hence, besides **data confidentiality & integrity** (e.g. password file), there is also a concern of **process "integrity"**:
whether it deviates from its original execution path

Applications	(e.g. browser, mail reader)
Services	(e.g. DBMS, Java Virtual Machine)
Operating System	(e.g. UNIX/Linux, Windows, iOS, macOS)
OS Kernel	(including system calls to handle memory, manage virtual memory, etc.)
Hardware	(including CPU, memory, storage, I/O)

Attackers and System's Layers

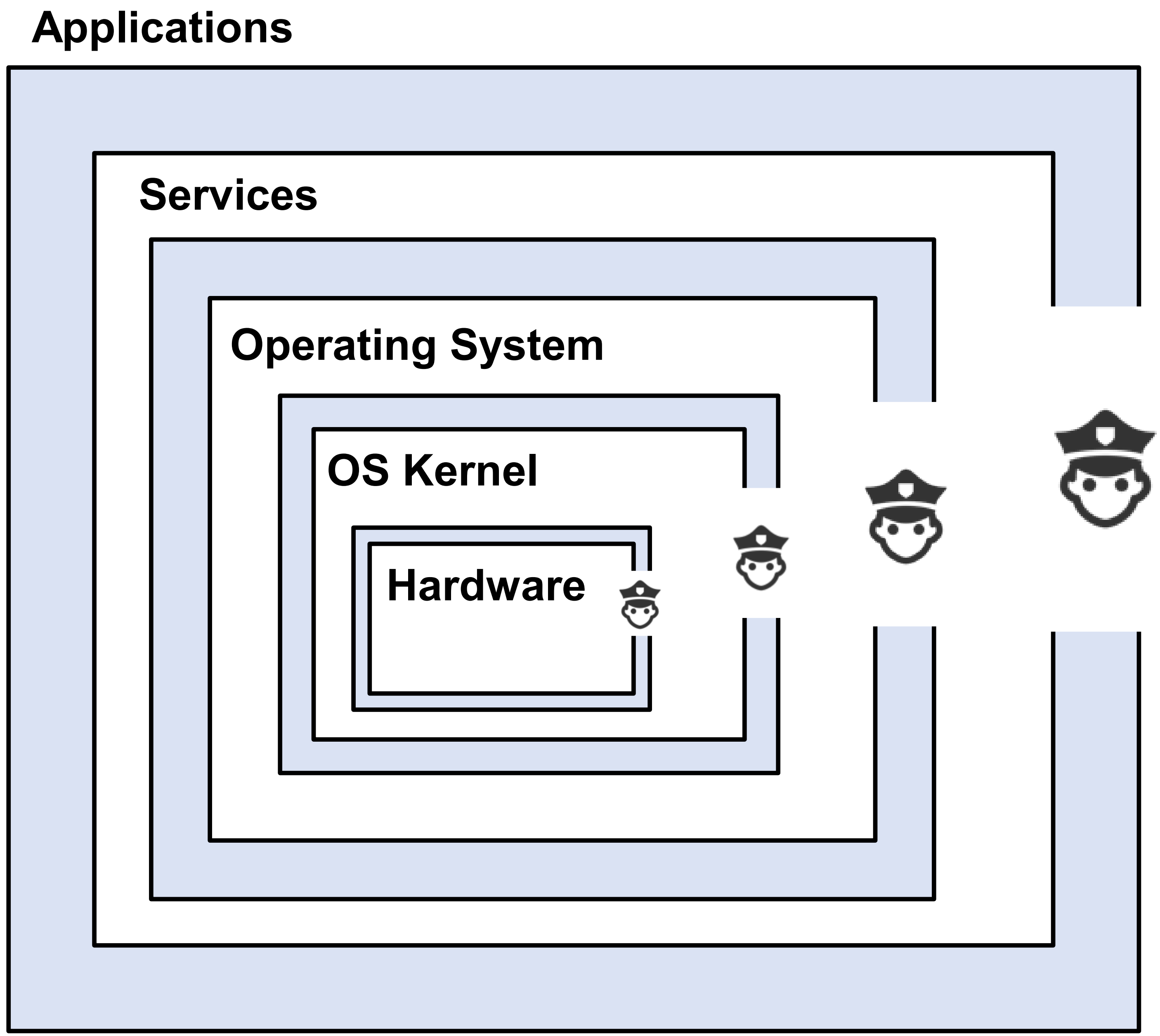


- Suppose an attacker sneaks into **Layer 1**
- The attacker must ***not*** be able to directly manipulate objects/data & processes in (more privileged) Layer 0
- Note that it is **very difficult** to ensure this requirement (due to possible implementation errors, overlooks in the design, etc.)

Security Mechanism

- It is insightful to figure out at ***what layer*** a security mechanism/attack resides
- A ***(layered-based) security mechanism*** should have a well-defined ***security perimeter/boundary***:
  - See [Gollmann] Section 3.5:
    "The parts of the system that can malfunction without compromising the protection mechanism ***lie outside*** this perimeter.
    The parts of the system that can be used to disable the protection mechanism ***lie within*** this perimeter."
- Nonetheless, quite often, it is difficult to determine the boundary

System's Layers: With Idealized Security Perimeter/Boundary



Security Mechanism

- An important **design consideration** of the security mechanism: **how to *prevent* attacker** from getting access to a *layer inside* the boundary
  - For example: **SQL injection attacks** target at the SQL DBMS. The **OS password management** (which is in a layer below) *should remain intact* even if an SQL injection attack has been successfully carried out.

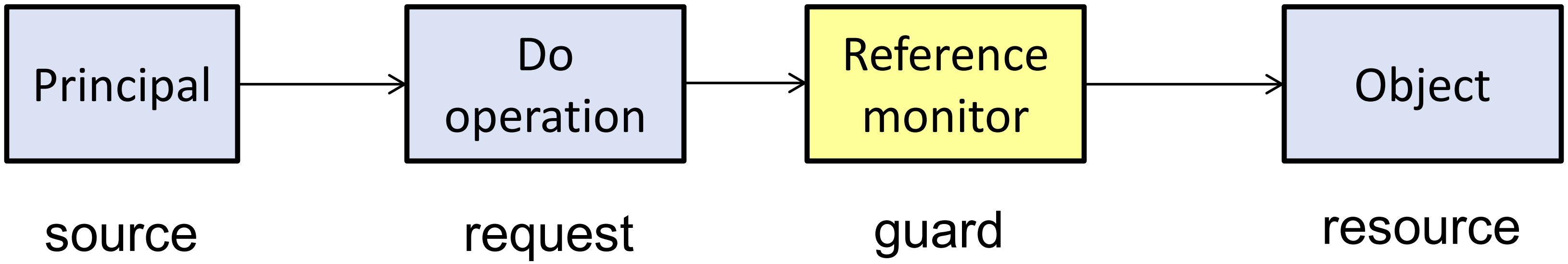
- It is also possible that an application takes care of **its own security** (i.e. ***self-secure*** itself):
  - For example: if an application **always encrypt its data** before writing them to the file system; so that even if the access control of the file system is compromised (e.g. malicious user can read someone else files), the confidentiality of the data will **still be preserved**

7.2 Access Control Model

Why Access Control?

- Access control is **required** in computer system, information system, and physical system
- Different application domains have different **requirements /interpretation**
- Examples of **application domains**:
  - OS
  - Social media (e.g. Facebook)
  - Documents in an organization (document can be classified as “restricted”, “confidential”, “secret”, etc.)
  - Physical access to different part of the building
- Generally, ***access control*** is about: “*selective restriction of access to a place or other resource*” (Wiki)
- The ***access control model/system*** gives a way to **specify & enforce** such restriction on the subjects, objects and actions

Principal/Subject, Operation, Object



- A ***principal*** (or ***subject***) wants to access an ***object*** with some ***operation***
- The ***reference monitor*** either grants or denies the access
- Some examples:
  - LumiNUS: a ***student*** wants to ***submit*** a ***forum post***
  - LumiNUS: a ***student*** wants to ***read*** the ***grade of another student***
  - File system: a ***user*** wants to ***delete*** a ***file***
  - File system: a ***user Alice*** wants to ***change*** a ***file's mode*** so that it can be ***read*** by ***another user named Bob***

Principal/Subject, Operation, Object

Principals vs subjects:

- ***Principals***: the **human** users
- ***Subjects***: the **entities** in the system that operate on behalf of the principals, e.g. processes, requests

Accesses to objects can be classified to the following:

- **Observe:** e.g. reading a file
  (In LumiNUS: downloading a file from File/Workbin)
- **Alter**: e.g. writing a file, deleting a file, changing properties
  (In LumiNUS: uploading a file to the File/Workbin)
- **Action:** e.g. executing a program

Object Access Rights and Ownership

Question: **Who** decides the access rights to an object?

There are two approaches:

1. ***Discretionary Access Control (DAC)***:
   the **owner** of the object decides the rights
2. ***Mandatory Access Control (MAC)***:
   a **system-wide policy** decides the rights, which must be followed by *everyone* in the system must follow

(**Question**: Does UNIX file system adopt DAC or MAC?)

Access Control Representation

Question: **How** does a system represent access control?

- **Access control matrix**: a matrix of principals vs objects
- The access control matrix can be represented in 2 ways:
  Access Control List (ACL) or ***capabilities***
- **Access Control List (ACL):**
  stores the **access rights to a particular <u>object</u>** as a list
- **Capabilities:**
  - **A <u>subject</u>** is given a list of *capabilities*,
    where each capability is the access rights to an object
  - "*A capability*: is an unforgeable token that gives the possessor certain rights to an object"
    (see [PG] pg. 82 on the description of "capability")

(**Question**: Does UNIX file system adopt ACL or capabilities?)

ACL and Capabilities: Examples

- **Access control matrix**:

	my.c	mysh.sh	sudo	a.txt
root	{r,w}	{r,x}	{r,s,o}	{r,w}
Alice	{}	{r,x,o}	{r,s}	{r,w,o}
Bob	{r,w,o}	{}	{r,s}	{}

- **ACL**: each object has a list of access rights to it

my.c	→ (root, {r,w}) → (Bob, {r,w,o})
mysh.sh	→ (root, {r,x}) → (Alice, {r,x,o})
sudo	→ (root, {r,s,o}) → (Alice, {r,s}) → (Bob, {r,s})
a.txt	→ (root, {r,w}) → (root, {r,w,o})

- **Capabilities**: each subject has a list of capabilities to objects

root	→ (my.c, {r,w}) → (mysh.sh, {r,x}) → (sudo, {r,s,o}) → (a.txt, {r,w})
Alice	→ (mysh.sh, {r,x,o})→ (sudo, {r,s}) → (a.txt, {r,w,o})
Bob	→ (my.c, {r,w,o}) → (sudo, {r,s})

Drawbacks of ACL and Capabilities

- **Drawback of ACL**:
  - It is difficult to get an overview of which objects that **a particular subject** has access rights to
  - I.e. it is hard to answer: "given a *particular subject*, which objects can this subject access?"
  - As an illustration: in UNIX, suppose the system admin wants to generate the list of file that the user **`alice012`** has "r" access to. How to quickly generate this list?
- **Drawbacks of capabilities**:
  - It is difficult to get an overview of the subjects who have access rights to a **particular object**
  - I.e. it is hard to answer: "given a *particular object*, which subjects can access this object?"

Drawbacks of ACL and Capabilities

- Drawbacks of **both** methods:
  - The size of the lists can still to be **too large** to manage
  - Hence, we need some ways to **simplify** the representation
  - One simple method is to "*group*" the subjects/objects and define the access rights on **the defined groups**
  - We need an ***intermediate control***

Intermediate Control: Group

In UNIX **file permission**, the ACL specifies the rights for the following ***user classes***:

- **user:** the owner
- **group**: the owner's group(s)
- **others:** world

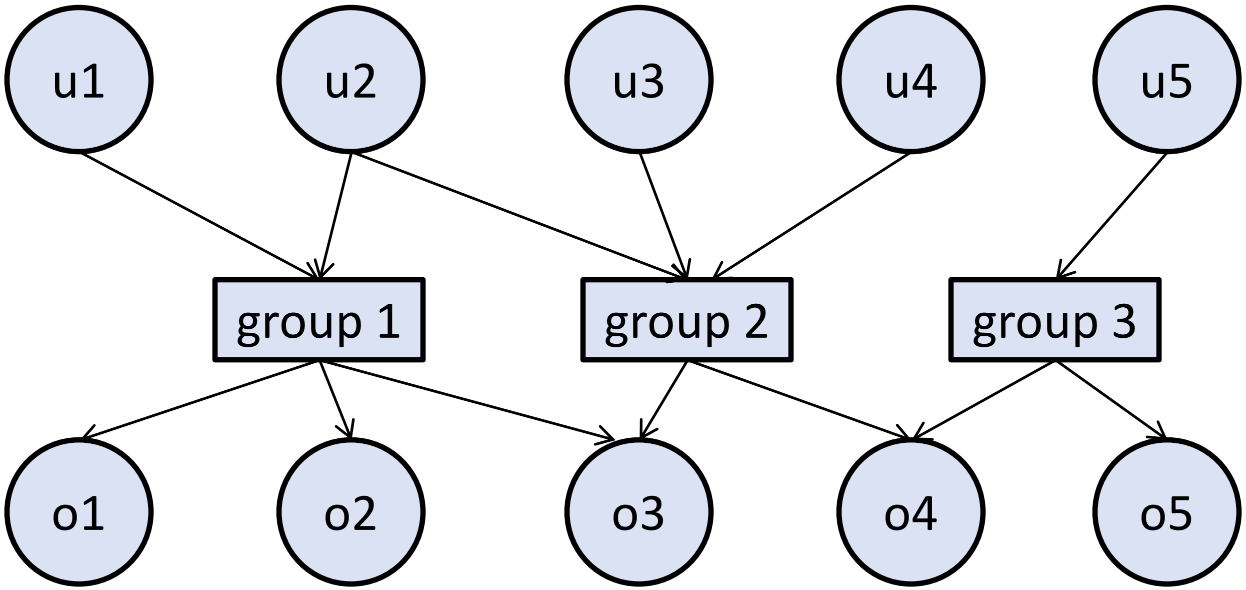
- Non-owner subjects **in the same group**: have the same access rights
- Some systems demand that a subject is in a **single** group, but some systems don't put such a restriction

Question: Is it possible in UNIX that an owner **does not** have a read access, but others have?

Answer: Strangely, yes. See Alice's file `temp` below:

```
--w-r--r--   1 alice   staff        3 Mar 13 00:27 temp
```

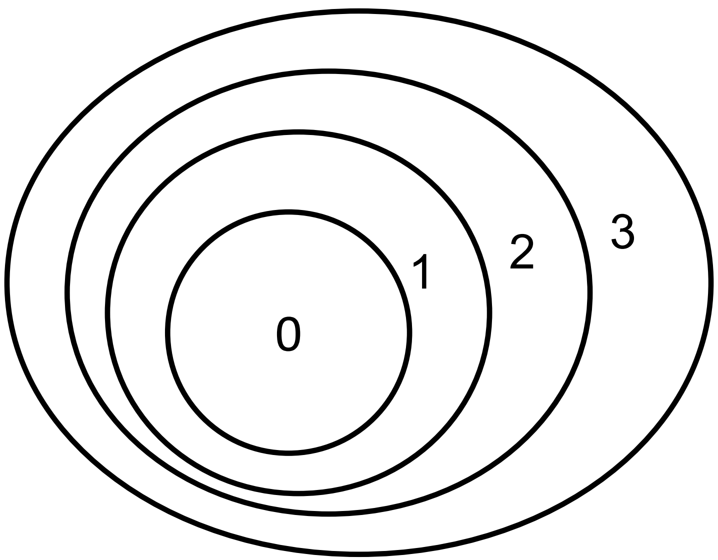
Users and Groups: Illustration



- In LumiNUS, **project groups** can be created:
  Objects created in a group can only be read by members of the group ***+ the lecturer(s)***
- In UNIX, groups can only be created by root:
  The extra groups info is stored in the file `/etc/group`

Intermediate Control: Protection Rings

- Here, each object (e.g. data) and subject (e.g. process) are assigned a **number**:
  - If a process is assigned a number *i*: it runs **in ring *i***
  - If an object is assigned a number *i*: it's accessible **in ring *i***
  - The **smaller** the number is, the **more important**: we can call processes with lower ring number as having "***higher privilege***"



7.3 Access Control in UNIX/Linux

Notes:

- An easy way to get UNIX-like environment on Windows is **Cygwin** (https://www.cygwin.com).
- Another way is by installing a **hypervisor** or **virtual machine monitor** (VMM): **VirtualBox** (https://www.virtualbox.org), or **VMWare** Player/Workstation (https://www.vmware.com). Then install Linux (e.g. **Ubuntu desktop**).
  Note: For VirtualBox, perform these additional installation steps as well:
  install VirtualBox Extension Pack and Guest Additions.
- Yet, another method: **Bash shell in Window 10**. (https://www.howtogeek.com/249966/how-to-install-and-use-the-linux-bash-shell-on-windows-10/).

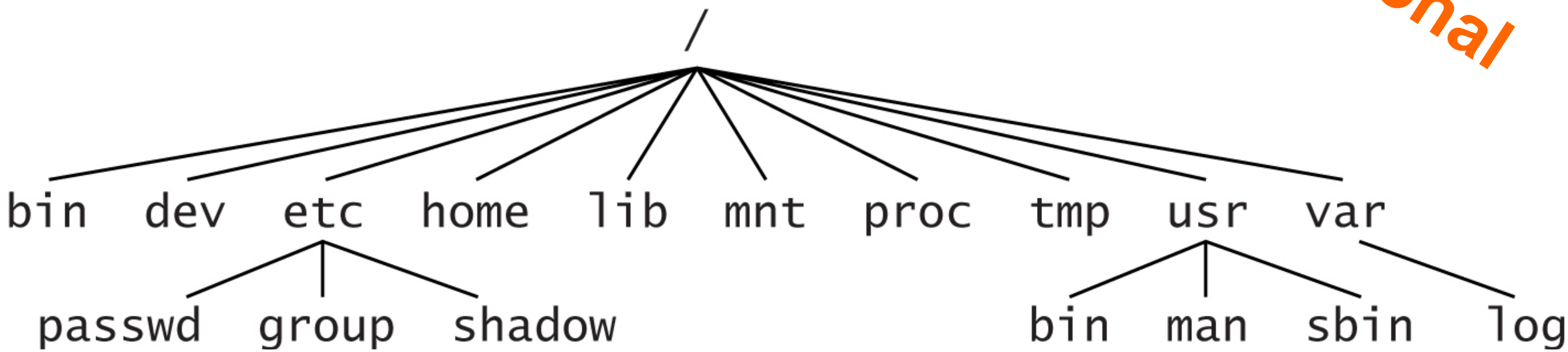
UNIX/Linux: Some Background

Optional

- History from 1970s
- Many versions:
  Solaris, AIX, Linux, Android, OS X + iOS
- Linux is open source (`http://www.kernel.org`)
- Many available tools (usually also open source)
- Many Linux distributions (distros):
  - Vary in setup, administration, kernel.
  - A popular choice: Ubuntu desktop

UNIX/Linux File System Structure

Optional



`/etc/passwd`: user database, password file

`/etc/shadow`: user database containing hashed user passwords, shadow password file

`/etc/group`: group database

`/bin/ls`

`man`

UNIX/Linux Manual Pages

Optional

- UNIX documentation using the **man** command
  - man is your friend!
  - Note: small variations in man with different UNIX

```
$ man ls
$ man man
```

- Organized in sections

```
$ man printf
$ man 1 printf
$ man 3 printf
```

- A free good resource to learning Linux commands:
  W. Shotts, "*The Linux Command Line*", `http://linuxcommand.org`

UNIX/Linux Access Control

- In Unix, **objects** of access control include: files, directories, memory devices, and I/O devices
- All these resources are treated as **file**! (a notion of "***universality of I/O***", read also tis Wiki: http://en.wikipedia.org/wiki/File_system_permissions)

```
%ls -al
-r-s--x--x  1 root   wheel   164560 Sep 10  2014 sudo
-rwxr-xr-x  2 root   wheel    18608 Nov  7 06:32 sum
-rw-r--r--  1 alice  staff      124 Mar  9 22:29 myprog.c
lr-xr-xr-x  1 root   wheel        0 Mar 12 16:29 stdin
```

Question: What are the files in the directory `/dev`?

UNIX/Linux User and Groups

- Each **user**:
  - Has a unique **user/login name**
  - Has a numeric user identifier (**UID**): stored in `/etc/passwd`
  - Can belong to one or more groups:
    the **first group** is stored in `/etc/passwd`,
    additional group(s) are stored in `/etc/group`
- Each **group**:
  - Has a unique **group name**
  - Has a numeric group identifier (**GID**)
- Main **purposes** of UIDs and GIDs *(more on this later)*:
  - To determine **ownership** of various system resources, e.g. files
  - To determine the **credentials** of running processes
  - To control the **permissions** granted to processes that
    wish to access the resources

UNIX/Linux Principals

- **Principals**:
  ***user identities* (UIDs)** and ***group identities* (GIDs)**

- Information of the user accounts are stored in the **password file** `/etc/passwd`

  E.g. `root:*:0:0:System Administrator:/var/root:/bin/sh`

  (Read Wiki page for details of these fields: https://en.wikipedia.org/wiki/Passwd)

- Additional group information of a user is stored in `/etc/group`

- A special user is the ***superuser***, with **UID 0**, and usually the username **`root`**:
  - All security checks are **turned off** for `root`
    (UNIX users' protection rings with 2 rings: superuser, users)

Remarks on the Password File Protection

- The file is made **world readable** because some information in `/etc/passwd` is needed by **non-root processes**

- Note that in the **older versions** of UNIX, the location of "*" was the hashed password $H(pw)$.
  As a result, all users can have access to this hashed-password field.

- The availability of the hashed password allows attackers to carry out an **offline password guessing**.

- Since passwords are typically short, exhaustive search are able to get many passwords.

- To prevent this, it is now replaced by "*", and the actual password is stored somewhere else, and it is **not** world-readable.
  The actual location depends on different versions of UNIX
  (e.g. the **shadow password file** `/etc/shadow`).

The Shadow Password File

The fields of an entry (separated by “:”):

- login name, hashed password, date of last password change, minimum password age, maximum password age, password warning period, password inactivity period, account expiration date, reserved field
- Example:

  user1:6yonrs//S$bUdht9fglwJW0LduAxEJpcExtMfKokFMJoT8tGkKLx5
  xFGJk22/trPstOHXr4PdBlD0AV1xko5LfFVDwW.aJS.:17275:0:99999:7:::

The **second** field (**hashed password**), which is shown in red, has the following format: idsalt$hashed-key

- **id**: ID of the hash-method used (5=SHA-256, 6= SHA-512, …)
- **salt**: up to 16 chars drawn from the set [a-zA-Z0-9./]
- **hashed-key**: hash of the password (e.g. 43 chars for SHA-256, 86 chars for SHA-512)

UNIX/Linux Subjects

- Subjects: ***processes***
- A **new process**: created by invoking an executable file, or due to a "fork" by an existing process
- Each process has a **process ID (PID)**:
  use the command `ps aux` or `ps -ef` to display a list of running processes

```
dave@howtogeek:~$ ps -ef | less
UID        PID  PPID  C STIME TTY          TIME CMD
root         1     0  0 Nov15 ?        00:00:03 /sbin/init splash
root         2     0  0 Nov15 ?        00:00:00 [kthreadd]
root         3     2  0 Nov15 ?        00:00:00 [rcu_gp]
root         4     2  0 Nov15 ?        00:00:00 [rcu_par_gp]
root         6     2  0 Nov15 ?        00:00:00 [kworker/0:0H-kb]
root         8     2  0 Nov15 ?        00:00:00 [mm_percpu_wq]
root         9     2  0 Nov15 ?        00:00:00 [ksoftirqd/0]
root        10     2  0 Nov15 ?        00:00:02 [rcu_sched]
root        11     2  0 Nov15 ?        00:00:00 [migration/0]
root        12     2  0 Nov15 ?        00:00:00 [idle_inject/0]
root        14     2  0 Nov15 ?        00:00:00 [cpuhp/0]
root        15     2  0 Nov15 ?        00:00:00 [cpuhp/1]
root        16     2  0 Nov15 ?        00:00:00 [idle_inject/1]
root        17     2  0 Nov15 ?        00:00:00 [migration/1]
root        18     2  0 Nov15 ?        00:00:00 [ksoftirqd/1]
root        20     2  0 Nov15 ?        00:00:00 [kworker/1:0H-kb]
root        21     2  0 Nov15 ?        00:00:00 [kdevtmpfs]
root        22     2  0 Nov15 ?        00:00:00 [netns]
root        23     2  0 Nov15 ?        00:00:00 [rcu_tasks_kthre]
:
```

Source: https://www.howtogeek.com/448271/how-to-use-the-ps-command-to-monitor-linux-processes/

Selected Issues: Search Path

- When a user types in the **command** to execute a program, say "`su`" without specifying the full path, **which program** would be executed:

  `/usr/bin/su` or `./su`?

- The program to be executed is searched through the directories specified in the ***search path***.
  Use a command `echo $PATH` to display the search path.

- When a program with the name is found in a directory, the search **stops** and the program will be **executed**.

- Suppose an attacker somehow stored a malicious program in the directory that appears in the **beginning** of the search path, and the malicious program has a **common name**, say "`su`".
  When a user executes "`su`", the **malicious program** will be invoked instead.

- To prevent such attack, specify the **full path**

- Also **avoid** putting the current directory ("`.`") in the search path: *Why*?

Files and File System Permission

indicates whether it is a file (-) or directory (d)

owner's group

date & time of last modification

```
-rw-r--r--  1 alice  staff  124 Mar  9 22:29 my.c
```

file permission

owner

file size

filename

link count (not relevant in this module)

The **file permission** are grouped **into 3 triples**, that define the **read**, **write**, **execute** access for classes: **owner** (**"user"**), **group** & **others** (**the "world"**):

'-' indicates access not granted

r: read

w: write (including delete)

x: execute (**s**: allow a user to execute with the permission of the *file owner*)

Changing File Permission Bits

- Use **`chmod`** command:
  `chmod` [options] mode[,mode] file1 [file2 ...]
- Useful options:
  - `-R`: Recursive, i.e. include objects in subdirectories
  - `-f`: force processing to continue if errors occur
  - `-v`: verbose, show objects changed (unchanged objects are not shown)
- Two notations for mode:
  - *Symbolic mode* notation
  - *Octal mode* notation
- See also : https://en.wikipedia.org/wiki/Chmod

Changing File Permission Bits

- **Symbolic mode** notation:
  - **Syntax**: [references][operator][modes]
  - *Reference*: u (user), g (group), o (others), a (all)
  - *Operator*: + (add), - (remove), = (set)
  - *Mode*:
    r (read), w (write), x (execute), s (setuid/gid), t (sticky)
  - Examples:
    `chmod g+w shared_dir`
    `chmod ug=rw groupAgreements.txt`
  - What are the file permission bits of `shared_dir` and `groupAgreements.txt`?

    `shared_dir: drwxr-xr-x → drwxrwxr-x`

Changing File Permission Bits

- **Octal mode** notation:
  - 3-4 octal digits
  - 3 rightmost digits refer to permissions for: the file **user**, the **group**, and **others**
  - Optional leading digit, when 4 digits are given, specifies: **the *special file permissions*** (setuid, setgid and sticky bit)
  - Examples:
    `chmod 664 sharedFile`
    `chmod 4755 setCtrls.sh`
  - `-rw-rw-r-` and `-rwsr-xr-x`

Octal	Binary	rwx
7	111	rwx
6	110	rw-
5	101	r-x
4	100	r--
3	011	-wx
2	010	-w-
1	001	--x
0	000	---

File System Permission: Additional Notes

- ***Directory*** permissions:
  - **r**: allows the contents of the directory to be **listed** if the x attribute is also set
  - **w**: allows files within the directory to be created, deleted, or renamed if the x attribute is also set
  - **x**: allows a directory to be **entered** (i.e. `cd dir`)

- ***Special file*** permissions:
  - **Set-UID**: the process' ***effective user ID*** of is the **owner** of the executable file (usually root), rather than the user **running** the executable
    `-r-sr-sr-x   3 root     sys       104580 Sep 16 12:02 /usr/bin/passwd`

File System Permission: Other Notes

- **Set-GID**: the process' ***effective group ID*** is the group **owner** of the executable file
  `-r-sr-sr-x   3 root      sys          104580 Sep 16 12:02 /usr/bin/passwd`
- ***Sticky bit**: (optional)*
  If a **directory** has the sticky bit set,
  its file can be deleted *only by* the owner of the file,
  the owner of the directory, or by root.
  This prevents a user from deleting other users' files from public directories such as `/tmp`:
  `drwxrwxrwt 7  root   sys    400 Sep  3 13:37 tmp`
- See also: https://docs.oracle.com/cd/E19683-01/816-4883/secfile-69/index.html

Objects and Their Access Control

- Recall that the objects are **files**:
  each file is owned by a **user** and a **group**
- Also recall that each file is associated with a **9-bit permission**
- When a **non-root user** (subject) wants to access a file (object), the following are checked in order:
  1. If the user is the **owner**, the permission bits for **owner** decide the access rights
  2. If the user is not the owner, but the user’s group (GID) owns the file, the permission bits for **group** decide the access rights
  3. If the user is not the owner, nor member of the group that own the file, then the permission bits for **other** decide
- The **owner** of a file or **superuser** can change the permission bits

Controlled Invocation (More on this in next section)

- The following is an **important** access control issue in UNIX/Linux
- Certain resources in UNIX/Linux can be accessed **only by superuser**, e.g.:
  - Listening at the trusted port 0—1023
  - Accessing `/etc/shadow` file
- Sometimes, a non-root user **needs** those resources for certain operations: e.g. changing password
- For security reasons, it is **not** advisable to promote the user status/privilege to superuser:
  - The non-root user may **abuse** the granted superuser privilege
- ***So, how?***

Controlled Invocation (More on this in next section)

- A **solution** is ***controlled invocation***:
  Provide a predefined **set of operations (programs)** in a ***superuser mode***, and the non-root user can then run those operations with the superuser mode

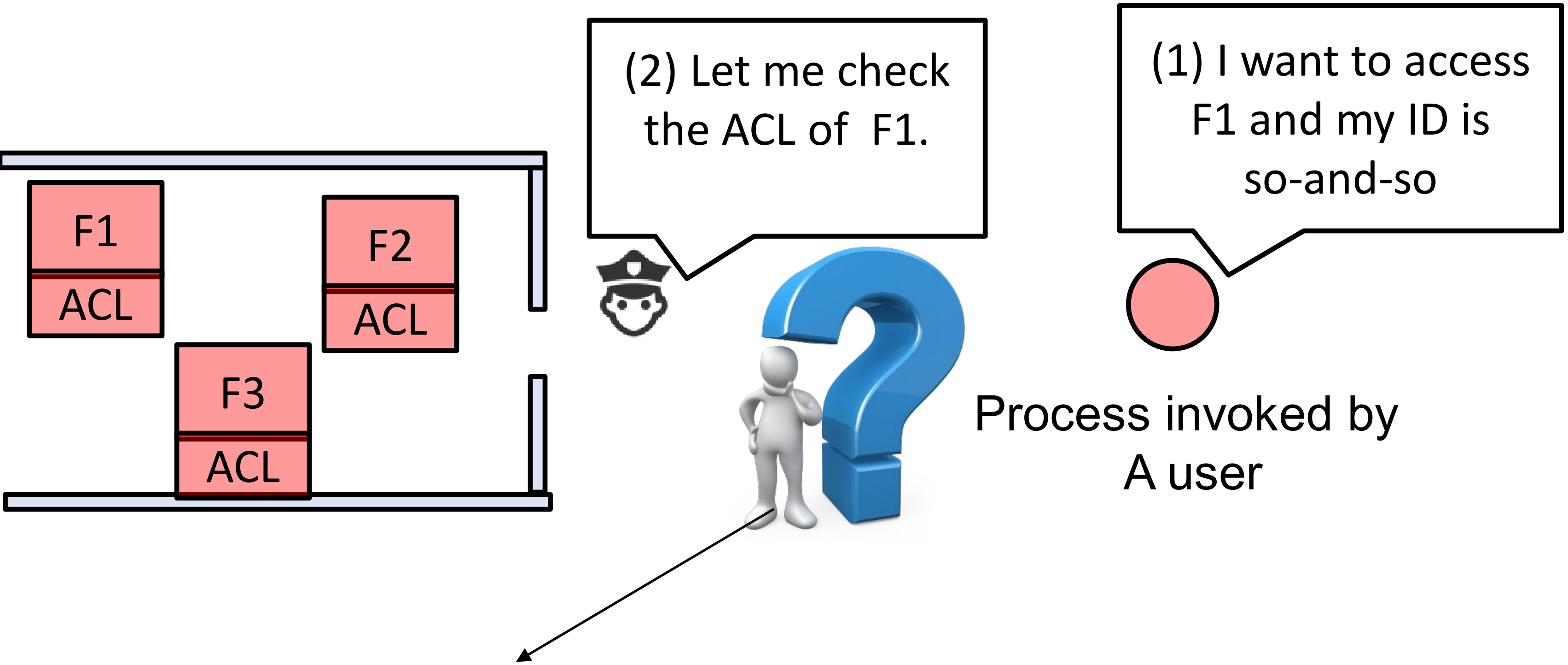
- The OS supports this solution using the **set-UID bit** of an executable

- An example file:
  `-rws—x--x  3 root  bin  59808 Nov 17 07:21 /usr/bin/passwd`

- The **"s" (set-UID) bit** indicates that the privilege is **escalated** to the file **owner** (`root`) while a user is running this process

7.4 UNIX/Linux: Privilege Escalation (Controlled Invocation)

Access Control and Reference Monitor



See Slide 37 again for the checking rules

Process Credentials and Set User ID (Set-UID)

- A process is a **subject**: it has an identification (PID)
- A process is associated with ***process credentials***:
  a ***real UID*** and an ***effective UID***
- The **real UID** is inherited from the user who invokes the process:
  it identifies the **real owner** of the process
  E.g. if the user is `alice`, the process' real UID is `alice`*
- For processes created by executing a file, there are 2 cases:
  - If the set-User-ID (set-UID) is disabled (the permission bit is displayed as "**x**"), then the process' **effective UID** is same as **real UID**
  - If the set-User-ID (set-UID) is enabled (the permission bit is displayed as "**s**"), then the process' **effective UID** is inherited from the UID of the **file's owner**

* Note: A process' real & effective UIDs are **integers**, but we simply refer to the **usernames**

Real UID and Effective UID: Examples

- If `alice` creates the process by executing the file:

  `-r-`**`x`**`r-xr-x   1 root  staff       6 Mar 18 08:00 check`

  Then the process' real UID is `alice`,

  whereas its effective UID is `alice`

- If the process is created by executing the following file:

  `-r-`**`s`**`r-xr-x   1 `**`root`**`  staff       6 Mar 18 08:00 check1`

  Then the process' real UID is `alice`,

  but its effective UID is **`root`**

This indicates that set-UID is enabled

When a Process (Subject) Wants to Read a File (Object)

- When a process wants to access a file,
  the ***effective UID*** of the process is treated as the "**subject**" and **checked** against the file permission to decide whether it will be granted or denied access

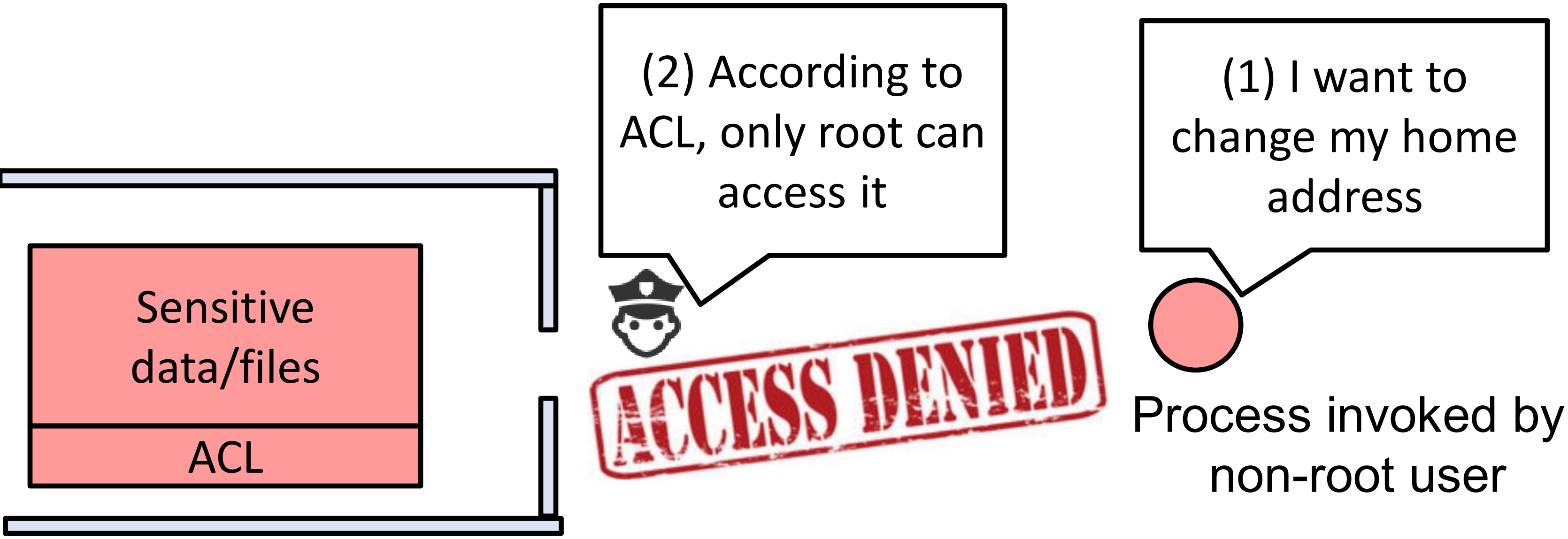
- Example:
  Consider a **file** owned by the root:
  `-rw-------   1 root  staff     6 Mar 18 08:00 sensitive.txt`

  - If the effective UID of a process is **`alice`**,
    then the process will be **denied** reading the file
  - If the effective UID of a process is **`root`**,
    then the process will be **allowed** to read the file

Use Case Scenario of “s” (Set-UID)

- Consider a scenario where the file `employee.txt` contains personal information of the users
- This is **sensitive** information, hence, the system administrator set it to **non-readable** except by root:
  `-rw-------   1 root  staff     6 Mar 18 08:00 employee.txt`
- However, users should be allowed to **self-view** and even **self-edit** some fields (for e.g. postal address) of their own profile
- Since the file permissible is set to “-” for all users (except root), a **process** created by any user (except root) **cannot** read/write it
- Now, we are stuck: there are data in the file that we want to **protect**, and data that we want the user to **access**
- *What can we do?*

Access Control and Reference Monitor



Solution

- Create an executable file `editprofile` owned by `root`:

```
-r-sr-xr-x   1 root  staff      6 Mar 18 08:00 editprofile
```

- The program is made **world-executable**:
  any user can execute it
- Furthermore, the **set-UID bit** is set (“s”):
  when it is executed, its effective UID will be “root”
- This is an example of a ***set-UID-root*** program/executable
- Now, if `alice` executes the file, the process’ real UID is `alice`, but its effective UID is `root`:
  this process now **can read/write** the file `employee.txt`


Sensitive data/files
ACL
(2) Ok
ACCESS GRANTED
(1) My effective UID is root
Process invoked by non-root user, but it is a **set-UID-root** process

Comparison: When Set-UID is *Disabled*

- If the user `alice` invokes the executable, the process will has its **effective ID** as **`alice`**
- When this process wants to read the file `employee.txt`, the OS (reference monitor) will **deny** the access

Process info: name (`editprofile`) real ID (`alice`) effective ID (`alice`)


```
-rw-------   1 root  staff    6 Mar 18 08:00 employee.txt
-r-xr-xr-x   1 root  staff    6 Mar 18 08:00 editprofile
```

Comparison: When Set-UID is *Enabled*

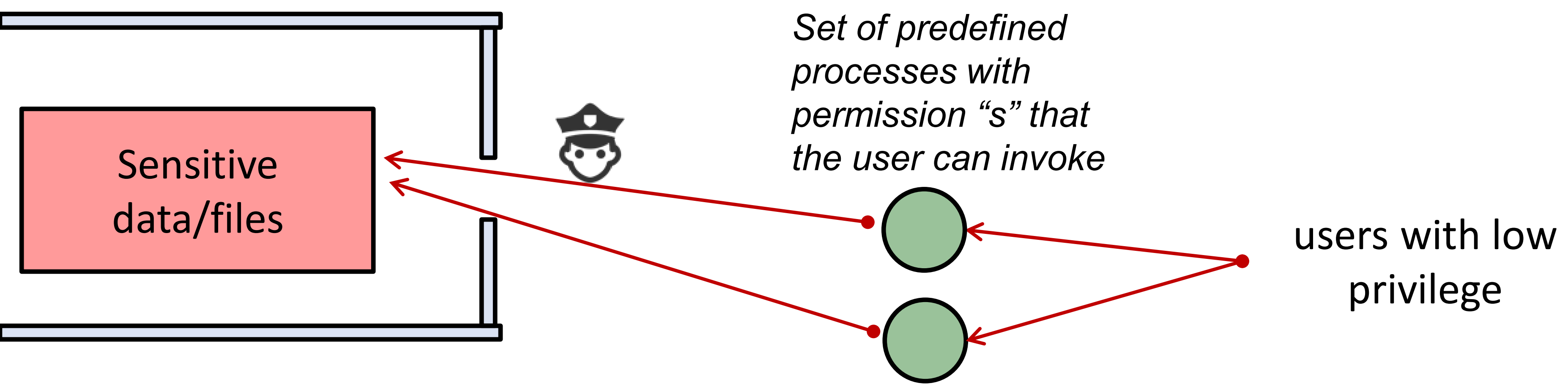
- But if the permission of the executable is “s” instead of “x”, then the invoked process will has **`root`** as its effective ID
- Hence the OS **grants** the process to read the file
- Now, the process invoked by `alice` can access `employee.txt`

Process info: name (`editprofile`) real ID (`alice`) effective ID (`root`)


```
-rw-------   1 root   staff      6 Mar 18 08:00 employee.txt
-r-sr-xr-x   1 root   staff      6 Mar 18 08:00 editprofile
```

Elevated Privilege

- In this example, the process `editprofile` is temporarily **elevated** to superuser (i.e. root), so as to access the sensitive data
- We can view the elevated process as the ***interfaces*** where a user can access the "sensitive" information:
  - They are the predefined "***bridges***" for the user to access the data
  - Note that the "bridge" can only be built by **the root**
- So, it is important that these "bridges" are correctly implemented and do not leak more than required!



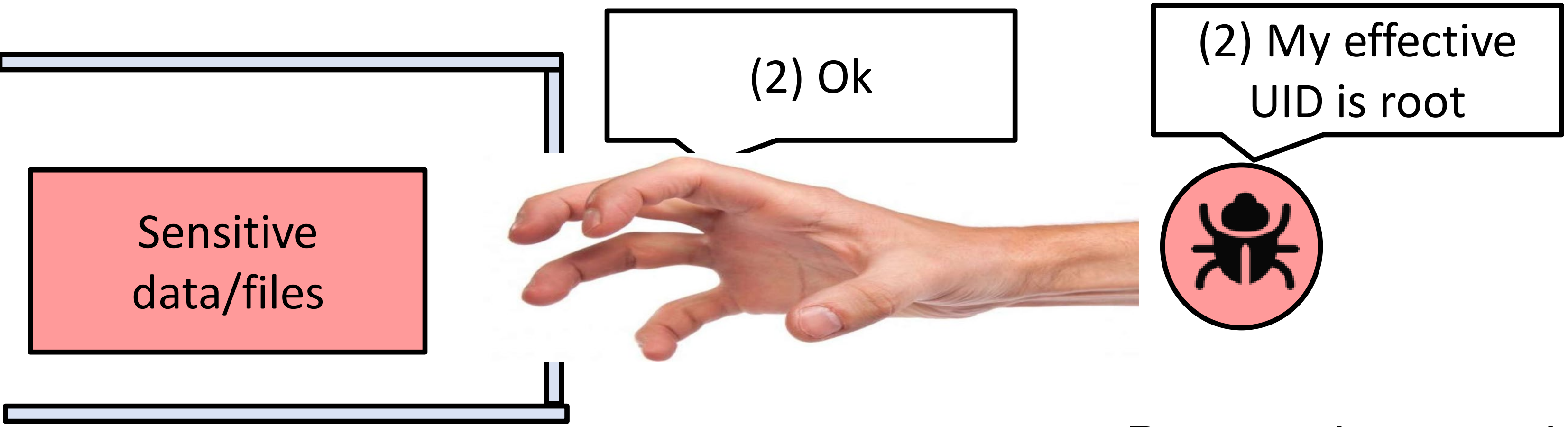
Privilege Escalation Go Wrong

- Suppose a “bridge” is ***not*** implemented correctly, and contains **exploitable vulnerability**
- An attacker, by feeding the bridge with a carefully-crafted input, can cause it to perform **malicious operations**
- This could have serious implication, since the process is now running with ***elevated privilege***
- Attacks of such form also known as ***privilege escalation*** attacks

  (Read https://en.wikipedia.org/wiki/Privilege_escalation on privilege escalation:

  Privilege escalation *is the act of exploiting a bug, design flaw or configuration oversight in an operating system or software application to gain elevated access to resources that are normally protected from an application or user. The result is that an application with more privileges than intended by the application developer or system administrator can perform unauthorized actions.*)

- This leads us to another important security topic: **secure programming** and **software security**



Program has permission “s”, and the program has a ”bug”!

Footnote: More Complications (Real UID, Effective UID, Saved UID)

- The OS actually maintains three IDs for a process:
  real UID, effective UID, and **saved UID**
- **Saved UID** is like a "temp" container and is useful for a process running with elevated privileges to **drop privilege temporarily**: a good set-UID programming practice
- A process removes its privileged user ID from its effective UID, but stores it in its saved UID.
  Later, the process may restore privilege by restoring the saved privileged UID into its effective UID.
  (See https://en.wikipedia.org/wiki/User_identifier#Saved_user_ID)
- The details may easily ***confuse*** many programmers
  (Read http://stackoverflow.com/questions/8499296/realuid-saved-uid-effective-uid-whats-going-on)
- Different UNIX versions may have ***different*** behaviors:
  complexity is bad for security!
  (Optional: Chen et al., "Setuid Demystified", USENIX Security, 2002)