Computer Security

02. Access Control

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Protection is essential to security

Protection

- The mechanism that provides and enforces controlled access of resources to processes (=users=subjects)
- A protection mechanism *enforces* security policies

Includes:

- User accounts & user authentication
- User privileges: access rights
  - File protection
- Resource scheduling & allocation
  - Thread priorities, memory pages
- Quotas (sometimes)

Co-located resources

- Earliest computers
  - Single-user batch processing – no shared resources
  - No need for access control – access control was physical
- Later … shared storage & timesharing systems
  - Multiple users share the same computer
  - User accounts & access control important
- Even later … PCs
  - Back to single-user systems
  - … but software is less trusted
- Now: networked PCs + mobile devices + IoT devices + …
  - Shared access: cloud computing, file servers, university systems
  - Program isolation on servers
  - Need to enforce access control

Access control

- Ensure that authorized users can do what they are permitted to do … *and no more*
- Real world
  - Keys, badges, guards, policies
- Computer world
  - Hardware
  - Operating systems
  - Web servers, databases & other multi-access software
  - Policies

OS controls access to resources

- CPU
- Memory
- Files & devices
- Network

Fundamental Mechanisms

- Protect the operating system from applications
- Protect applications from each other
- Allow the OS to stay in control

The OS and hardware are the
fundamental parts of the Trusted Computing Base (TCB)

Hardware timer

- OS kernel requests timer interrupts
  - One of several timer devices:
    - Programmable Interval Timer (PIT)
    - HPET (High Precision Event Timer)
    - or APIC timer (one per CPU)
  - Most current Intel Linux systems use APIC
- Applications cannot disable this

Ensures that the OS can always regain control

Processes

Timer interrupts ensure OS can examine processes while they are running

OS Process Scheduler

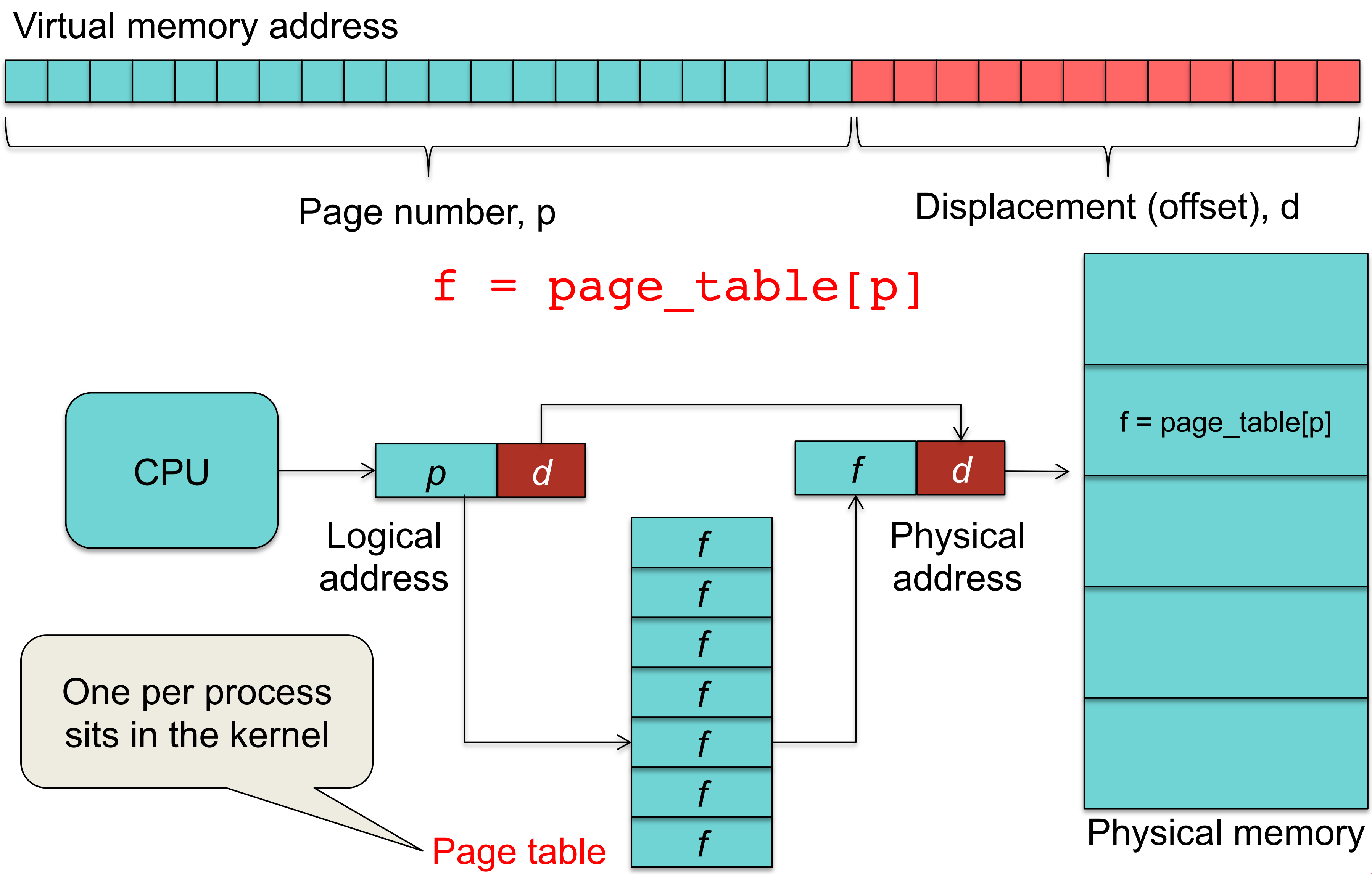
- Decides whether a process had enough CPU time and it is time for another process to run
- Avoid starvation: ensure all processes will get a chance to run
  - This would be an availability attack
- Prioritize threads
  - Based on user, user-defined priorities, interactivity, deadlines, “fairness”
  - One process should not adversely affect others

Memory Management Unit

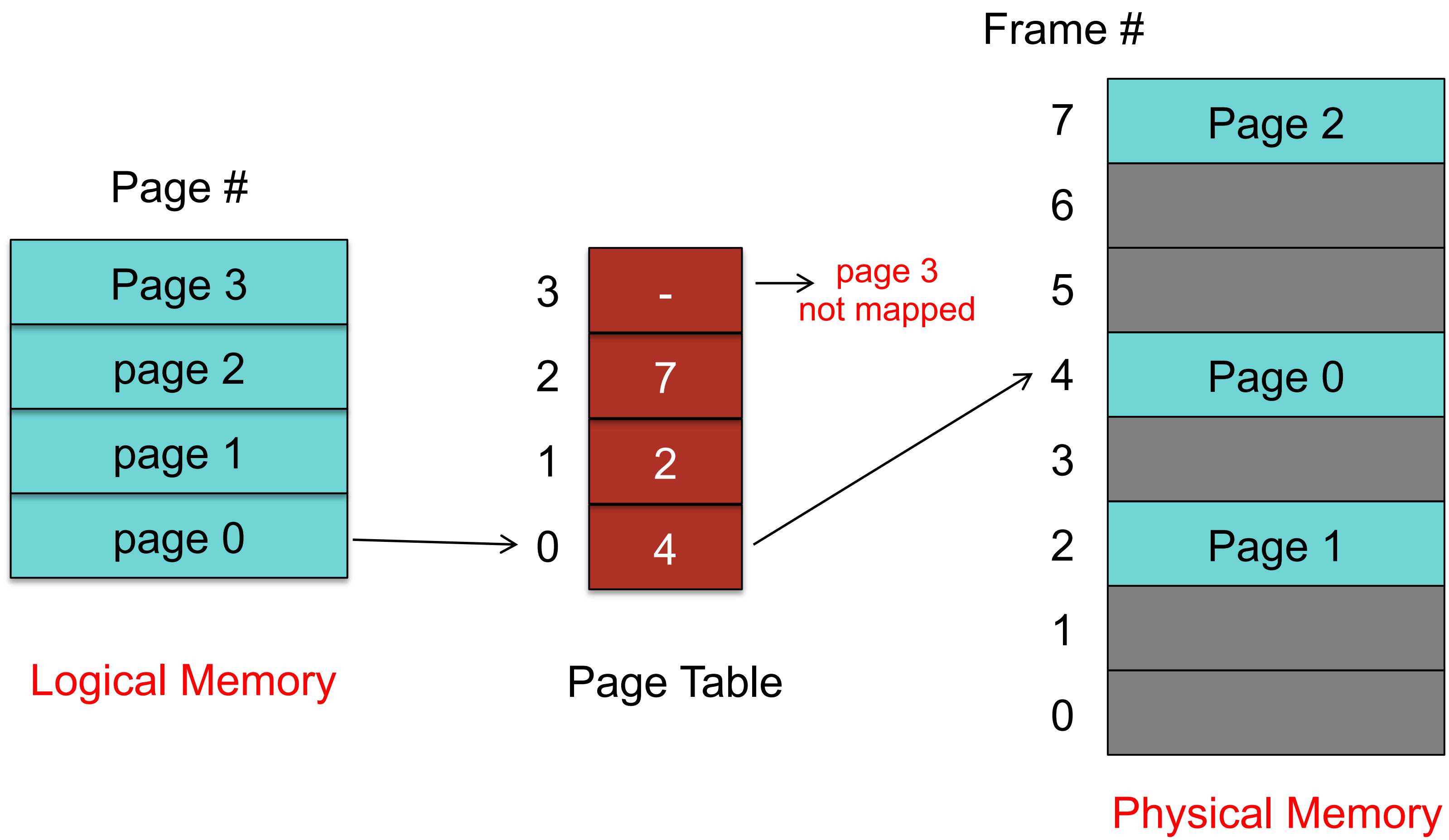
All modern CPUs have a Memory Management Unit (MMU)

- OS provides each process with virtual memory
  - Gives each process the illusion that it has the entire address space
  - One process cannot see another process' address space
  - Enforce access rights
    - Read-only
    - Read-write
    - Execute

Page translation



Logical vs. physical views of memory



User & kernel mode

Kernel mode = privileged, system, or supervisor mode

- Access restricted regions of memory
- Modify the memory management unit (page tables)
- Set timers
- Define interrupt vectors
- Halt the processor
- Etc.

- Getting into kernel mode
  - Trap: explicit instruction
    - Intel architecture: *INT* instruction (interrupt)
    - ARM architecture: *SWI* instruction (software interrupt)
  - Violation
  - Hardware interrupt (e.g., receipt of network data or timer)

Protection Rings

- All modern operating systems support two modes of operation: **user** & **kernel**

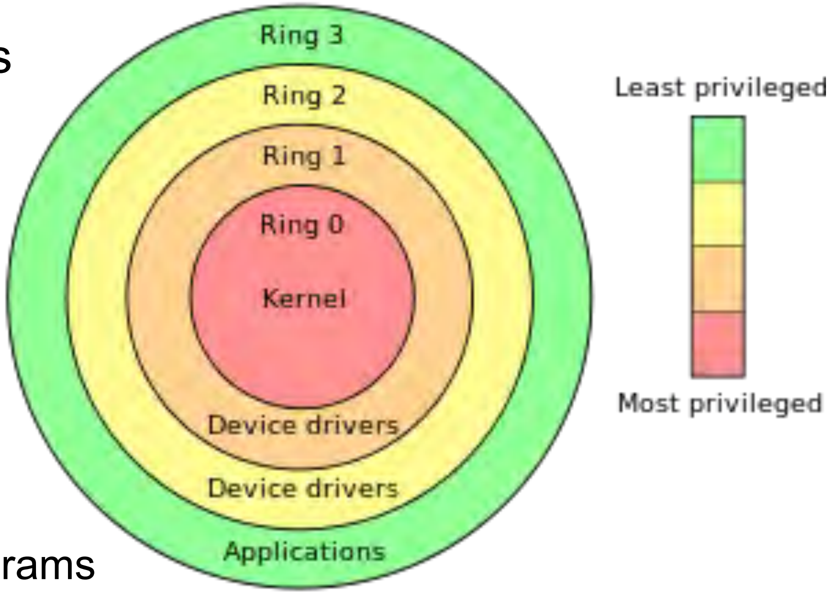
- *Multics* defined a ring structure with 6 different privilege levels
  - Each ring is protected from higher numbered rings
  - Special call (call gates) to cross rings: jump to predefined locations
  - Most of OS did not run in ring 0

- Intel x86, IA-32, and IA-64 support 4 rings

- Today's OSes only use
  - Ring 0: kernel
  - Ring 3: user

Note: hypervisors (virtual machine monitors) run at a 3rd privilege level

– In many systems, this is **ring -1** for the hypervisor, 0 for the kernel and 3 for user programs



https://en.wikipedia.org/wiki/Protection_ring

Subjects and Objects

- **Subject**: the thing that needs to access resources
  - Typically the user, also called the **principal**
- **Object**: the resource the subject may access
  - Typically the file
- **Access control**
  - Define what operations subjects can perform on objects

User authentication

Must be done before we can do access control

- Establish user identity – determine the *subject*
  - Operating system privileges are granted based on user identity

Steps

1. Get user credentials (e.g., name, password)
2. Authenticate user by validating the credentials
3. Access control: grant further access based on user ID

Domains of Protection

Domains of protection

- Subjects (users, processes) interact with objects
  - Objects include:
    hardware (CPU, memory, I/O devices)
    software: files, processes, semaphores, messages, signals

- A process should be allowed to access only objects that it is authorized to access
  - A process operates in a **protection domain**
  - Protection domain defines the objects the process may access and how it may access them

Modeling Protection: Access Control Matrix

Rows: domains (subjects or groups of subjects)

Columns: objects

Each entry represents an access right of a domain on an object

Objects

Subjects — *domains of protection*

	F_0	F_1	Printer
D_0	read	read-write	print
D_1	read-write-execute	read	
D_2	read-execute		
D_3		read	print
D_4			print

An Access Control Matrix is the primary abstraction for protection in computer security

We may need some more controls

- Domain transfers
  - Allow a process to run under another domain's permissions
  - Why?
    - Log a user in – how would you run the first user's process?
- Copy rights
  - Allow a user to grant certain access rights for an object
- Owner rights
  - Identify a subject as the owner of an object
  - Can change access rights on that object for any domain
- Domain control
  - A process running in one domain can change any access rights for another domain

Access Control Matrix: Domain Transfers

Switching from one domain to another is a configurable policy

A process in D_0 can switch to running in domain D_1

objects

Subjects
domains of protection

	F_0	F_1	Printer	D_0	D_1	D_2	D_3	D_4
D_0	read	read-write	print	–	switch	switch		
D_1	read-write-execute	read			–			
D_2	read-execute				switch	–		
D_3		read	print					
D_4			print					

Access Control Matrix: Delegation of Access

Copy: allow delegation of rights

- Copy a specific access right on an object from one domain to another
  - Rights may specify either a copy or a transfer of rights

objects

Subjects
domains of protection

	F_0	F_1	Printer	D_0	D_1	D_2	D_3	D_4
D_0	read	read-write	print	–	switch	sv		
D_1	read-write-execute	read*						
D_2	read-execute				swtich	–		
D_3		read	print					
D_4			print					

A process executing in D_1 can give a *read* right on F_1 to another domain

Access Matrix: Object Owner

Owner: allow new rights to be added or removed

- An object may be identified as being *owned* by the domain
- Owner can add and remove any right in any column of the object

objects

Subjects
domains of protection

	F_0	F_1	Printer	D_0	D_1	D_2	D_3	D_4
D_0	read owner	read-write	print	–	switch	sw[illegible]		
D_1	read-write-execute	read*						
D_2	read-execute				swtich			
D_3		read	print					
D_4			print					

A process executing in D_0 owns F_0, so it can give a *read* right on F_0 to domain D_3 and remove the *execute* right from D_1

Access Control Matrix: Domain Control

Control: change entries in a row

– process executing in Domain *i* can change access rights for any object in Domain *j*

objects

Subjects
domains of protection

	F_0	F_1	Printer	D_0	D_1	D_2	D_3	D_4
D_0	read owner	read-write	print	–	switch	switch		
D_1	read-write-execute	read*			–			control
D_2	read-execute				switch	–		
D_3		read	print					
D_4			print					

A process executing in D_1 can modify any rights in domain D_4

This gets messy!

- An access control matrix does not address everything we may want
- Processes execute with the rights of the user (domain)
  - But sometimes they need extra privileges
    - Read configuration files
    - Read/write from/to a restricted device
    - Append to a queue
- We don’t want the user do be able to access these objects
  - So we need a 3-D access control matrix: (subjects, objects, processes)
- This gets messy!
  - One solution is to give an executable file a temporary domain transfer
    - Assumption is this is a trusted application that can access these resources
  - When run, it assumes the privileges of another domain

Implementing an access matrix

A single table to store an access matrix is impractical

- Big size: # domains (users) × # objects (files)
- Objects may come and go frequently
- Lookup needs to be efficient

Implementing an access matrix

Access Control List

– Associate a column of the table with each object

objects

Subjects
domains of protection

	F_0	F_1	F_2	F_3	F_3	Printer
D_0	read owner	read-write	read-execute	read		print
D_1	read-write-execute	read	read-execute	read	write	
D_2	read-execute		read-execute		write	
D_3		read	read-execute			print
D_4			read-execute		write	print

ACL for file F_0

Example: Limited ACLs in POSIX systems

Problem: an ACL takes up a varying amount of space

- Won't fit in a fixed-size inode

UNIX Compromise:

- A file defines access rights for three domains:
  - the owner, the group, and everyone else
- Permissions
  - Read, write, execute, directory search
  - Set user ID on execution
  - Set group ID on execution
- Default permissions set by the *umask* system call
- *chown* system call changes the object's owner
- *chgrp* system call changes the object's owner
- *chmod* system call changes the object's permissions

Example: Full ACLs in POSIX systems

What if we really want a full ACL?

- Extended attributes: stored outside of the inode
  - Hold an ACL
  - And other name:value attributes
- Enumerated list of permissions on users and groups
  - Operations on all objects:
    - *delete, readattr, writeattr, readextattr, writeextattr, readsecurity, writesecurity, chown*
  - Operations on directories
    - *list, search, add_file, add_subdirectory, delete_child*
  - Operations on files
    - *read, write, append, execute*
  - Inheritance controls

Implementing an access matrix

Capability List

– Associate a row of the table with each domain

objects

Subjects — *domains of protection*

	F_0	F_1	F_2	F_3	F_3	Printer
D_0	read owner	read-write	read-execute	read		print
D_1	read-write-execute	read	read-execute	read	write	
D_2	read-execute		read-execute		write	
D_3		read	read-execute			print
D_4			read-execute		[illegible]	[illegible]

Capability list for domain D_1

Capability Lists

- List of objects together with the operations allowed on the objects

- Each item in the list is a *capability*: the operations allowed on a specific object
  - Also called a ***ticket*** called or ***access token***

- A process presents the capability along with a request
  - Possessing the capability means that access is allowed

- The capability is a protected object
  - A process cannot modify its capability list

Capability Lists

- Advantages
  - Run-time checking is more efficient
  - Delegating rights is easy
- Disadvantages
  - Changing a file's permissions is hard
  - Hard to find all users that have access to a resource
- Not used in mainstream systems in place of ACLs
  - Limited implementations: Cambridge CAP, IBM AS/400
- BUT
  - Used for single sign-on services and other authorization services such as Oauth and Kerberos (sort of)
  - Access Tokens – used in Microsoft systems, including Azure
    - Identifies user's identity & rights associated with user's accounts (not objects!)

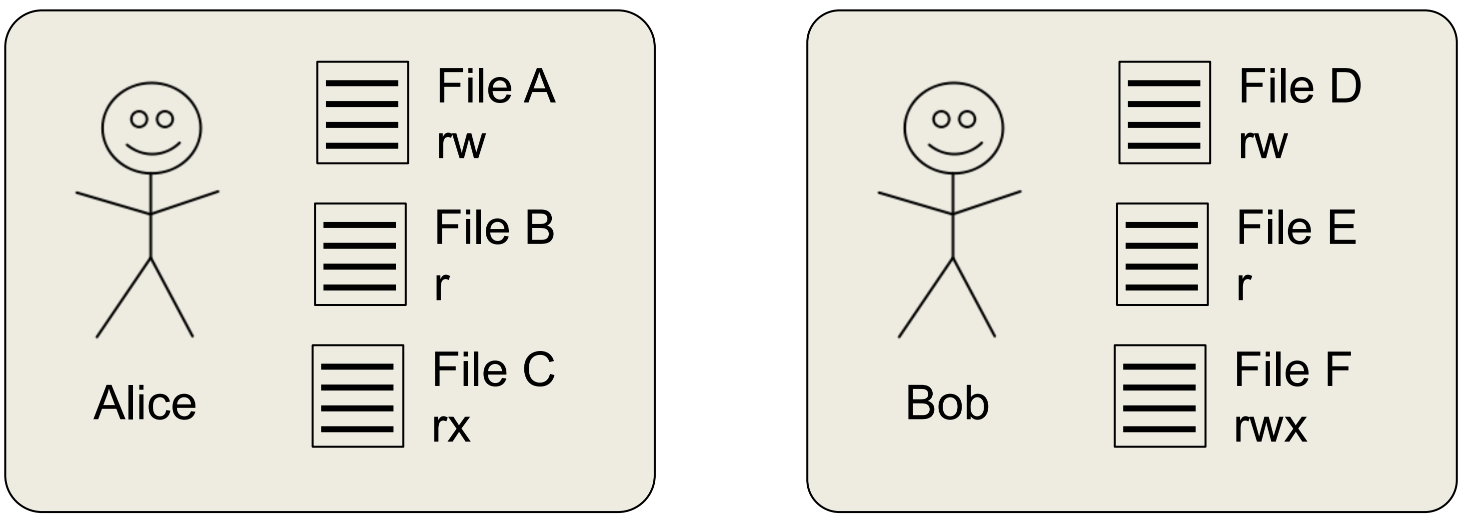
POSIX file permissions

File permissions

- Access isn't all or nothing
- Objects can have different access permissions

UNIX permission model

- Access permissions: read (r), write (w), execute (x)
  - All independently set
- Each file has an owner



How do you share files?

- Groups & everyone else (other)
- A user has one **user ID** but may belong to multiple groups
  - One current default group ID for new objects
  - Multiple groups
- Other = all others (users who are not the owner or group members)
- File access permissions are expressed as:

```
rwxrwxrwx
```

user group other

```
$ ls -l /bin/ls
-rwxr-xr-x  1 root  wheel  38624 Dec 10 04:04 /bin/ls
```

Permission checking

if you are the owner of the file

only owner permissions apply

if you are part of a group the file belongs to

only group permissions apply

else “other” permissions apply

I cannot read this file even if I’m in the *localaccounts* group:

```
$ ls -l testfile
----rw----  1 paul  localaccounts  6 Jan 30 10:37 testfile
```

Execute permission

- Distinct from read
- You may have execute-only access
  - This takes away your right to copy the file
    … or inspect it
  - But the OS can load it & run it

Windows

- Windows has users & groups but more permissions
  - Read, write, execute
  - Also: delete, change permission, change ownership

- Users & resources can be partitioned into groups & domains
  - Each *domain* can have its own administrator
    - HR can manage users
    - Individual departments can manage printers

- Trust can be inherited in one or both directions
  - *Department resources* domains may trust the *user* domain
  - *User* domain may not trust *department resources* domains

What about directories?

- Directories are just files that map names to inode numbers
- Permissions have special meaning
  - Write = permission to create a file in the directory
  - Read = permission to list the contents of a directory
  - Execute = permission to search through the directory
- If you have *write* access to the directory of a file, you can *delete* the file
  - Even if you don't have write access to the file itself
- If you don't have *write* access to the directory
  - You cannot *create* or *delete* a file … even if you have *write* access to it

Where are user IDs and group IDs stored?

On Linux, user ID information in the password file, /etc/passwd
- (which does not contain passwords anymore!)

```
root:x:0:0:System Administrator:/root:/bin/sh
```

- User name
- (password)
- User ID
- Default group ID
- User's full name
- Home directory
- Login shell

- Group IDs are stored /etc/group
  - wheel:x:0:root
  - certusers:x:29:root,_jabber,_postfix,_cyrus,_calendar,_dovecot

Changing permissions

The **chmod** command

user = read, write, execute
group = read, execute
other = -none-

- Set permissions

```
$ chmod u=rwx,g=rx,o= testfile
$ ls -l testfile
-rwxr-x---  1 paul  localaccounts  6 Jan 30 10:37 testfile
```

- Add permissions

```
$ chmod go+w testfile
$ ls -l testfile
-rwxrwx-w-  1 paul  localaccounts  6 Jan 30 10:37 testfile
```

- Remove permissions

```
$ chmod o-w testfile
$ ls -l testfile
-r-xrwx---  1 paul  localaccounts  6 Jan 30 10:37 testfile
```

Changing permissions

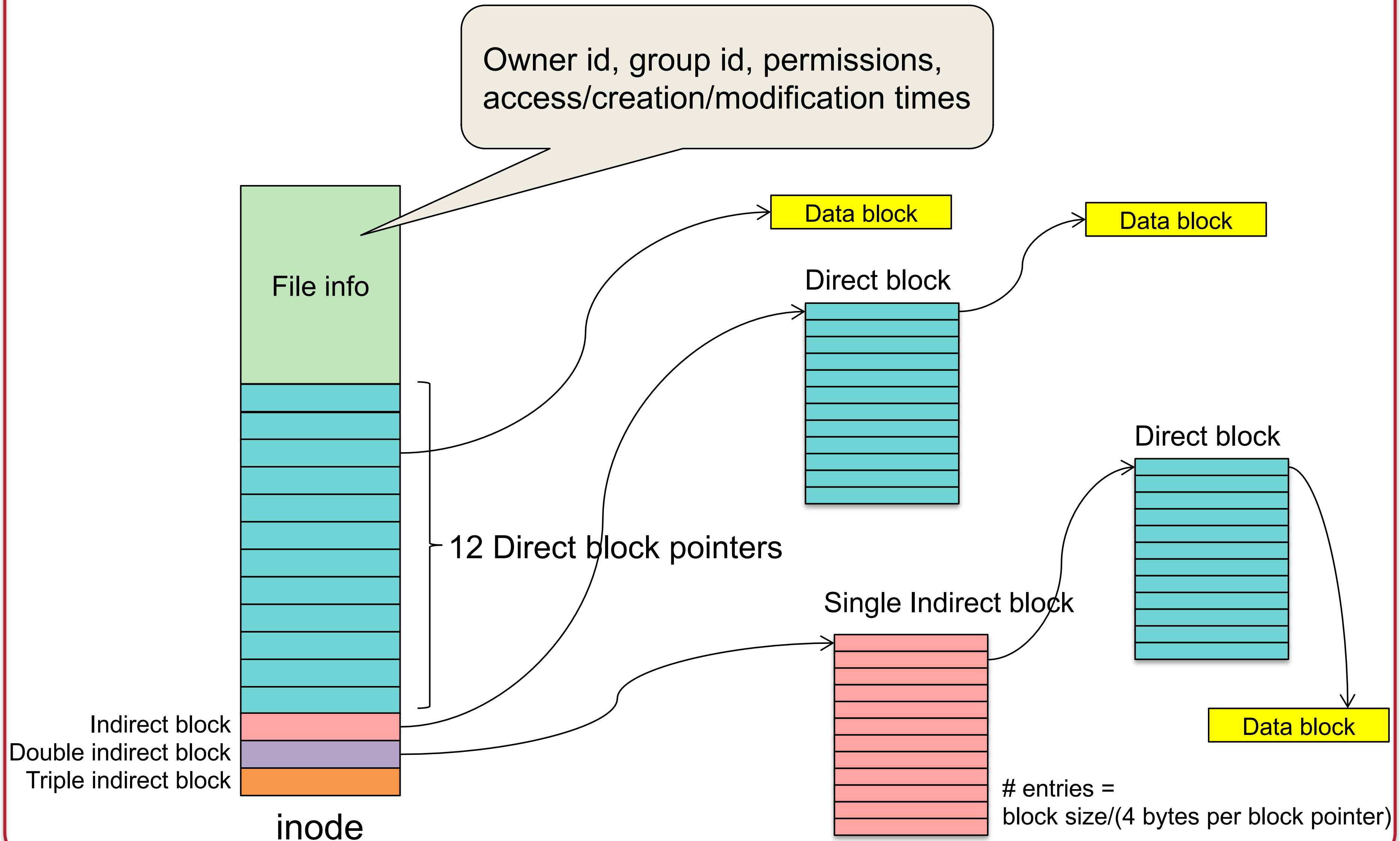
Or the old-fashioned way – specify an octal bitmask

- Set permissions

```
$ chmod 754 testfile
$ ls -l testfile
-rwxr-xr--  1 paul  localaccounts  6 Jan 30 10:37 testfile
```

7	5	4
111	101	100
rwx	r-x	r--
user	group	other

File permissions are stored in the file's inode



Sometimes groups aren't enough

Access Control Lists (ACL)

- Explicit list of permissions for users
- Supported by most operating systems
  - Windows ≥ XP
  - macOS ≥ 10.4
  - Linux ≥ ext3 file system + acl package

ACLs and ACEs

Access Control List (**ACL**) = list of **Access Control Entries** (**ACE**)

- ACE identifies a user or group & permissions
  - Files: read, write, execute, append
  - Directories:
    list, search, read attributes, add file, add sub-directory, delete contents
- "*Inheritance*" permission
  - directory's file contents can inherit one set of ACLs
  - Directories inherit another set of ACLs
- Wildcards are often supported
- See *chmod* on macOS or *setfacl* on Linux

Example ACL

```
pxk.*         rwx
419-ta.*      rwx
*.faculty     rx
*.*           x
```

- `Users pxk and 419-ta have` *`read-write-execute`* access
- Users in the faculty group have *read-execute* access
- Others only have *execute* access

Search order

ACEs are evaluated in the order they are entered into the ACL

In this case, I don't have write access to the file:

`419-ta.*`	`rwx`	
`*.faculty`	`rx`	← This is me ← This appears first & has priority
`pxk.*`	`rwx`	← So is this
`*.*`	`x`	← So is this

Search order: ACLs + permissions

In systems like Linux that integrate ACLs with 9-bit permissions:

1. If you are the owner of the file, *only* owner permissions apply
2. If you are part of a group the file belongs to, only group permissions apply
3. Else search through the ACL entries to find an applicable entry
4. Else other permissions apply

Initial file permissions

On Unix-derived systems (Linux, macOS, Android, *BSD):

- umask = set of permissions applications cannot set on files
  - Bitmask (octal) of bits that will be turned off
- To disallow read-write-execute for everyone but the owner
  - umask = 000 111 111 = 077
- Default umask on macOS & Ubuntu is 022
  - 022 = 000 010 010 = --- -w- -w-
  - This takes away *write* access from group & other
  - By default new files are readable by all and writable only by the owner

See the *umask* command and *umask* system call man pages

Watch out for race conditions!

- Suppose we create a file readable by all: `rwxr--r--`

  `rwx, r, r`

- But then we change the permissions to `rwx------`

  `rwx, -, -`

GOOD	BAD
Create a file: `rwx-r--r-` Change permissions to `rwx------` *[Attacker opens the file for reading]* *Do your work*	Create a file: `rwx-r--r-` *[Attacker opens the file for reading]* Change permissions to `rwx------` *Do your work*

- We don't know when the attacker will hit
- Once the attacker has the file open, changing permissions does not take access away
  – Access rights are only checked when the file is opened!

Giving files away

- You can change the owner of a file

  `chown alice testfile`

  – Changes the file's owner to alice

- You can change the group of a file too

  `chgrp accounting testfile`

  – Changes the file's group to accounting

… but you have to be the owner to do either

Changing user & group IDs

- root = uid 0 = super user
  - Access to everything
- How do you log in?
  - login program runs as uid=0
  - Gets your credentials
  - Authenticates you
  - Then:

```
chdir(home_directory);
setgid(group_id);
setuid(user_id);
execve(user_shell, …);
```

Changing user ID temporarily

- What if some files need special access?
  - A print program needs to access the printer queue
  - A database needs to access its underlying files
- An executable file normally runs under the user's ID
- A special permission bit, the "**setuid bit**" changes this
  - **Executable files** with the setuid bit
    will run with the *effective UID* set to the owner of the file
  - **Directories** with the setuid bit set
    will force all files and sub-directories created in them to be owned by the directory owner
- Same thing with groups – the **setgid** permission bit
  - Executable files with this bit set will run with effective gid set to the gid of the file.

Principle of Least Privilege

At each abstraction layer, every element (user, process, function) should be able to access ***only*** the resources necessary to perform its task

- Even if an element is compromised, the scope of damage is limited

- Consider:
  - Good: You cannot kill another user's process
  - Good: You cannot open the `/etc/hosts` file for writing
  - Good: Private member functions & local variables in functions limit scope

  - Violation: a compromised print daemon allows someone to add users
  - Violation: a process can write a file even though there is no need to
  - Violation: admin privileges set by default for any user account

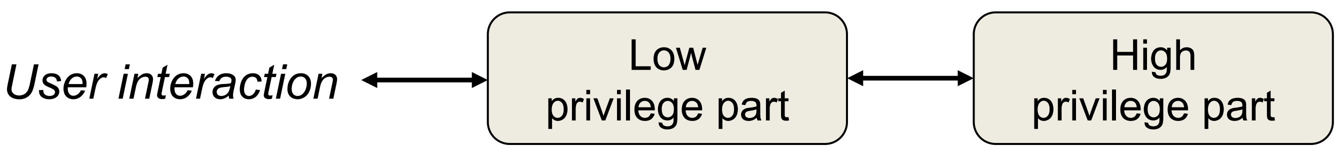
Least privilege is often difficult to define & enforce

Privilege Separation

Divide a program into multiple parts: high & low privilege components

Example on POSIX systems

- Each process has a *real* and *effective* user ID
- Privileges are evaluated based on the effective user ID
  - Normally, `uid == euid`
- An executable file may be tagged with a *setuid bit*
  - **`chmod +sx filename`**
  - When run: uid = user's ID
    euid = file owner's ID (without setuid, runs with user's ID)
- Separating a program
  1. Run a *setuid* program
  2. Create a communication link to self (*pipe*, *socket*, shared memory)
  3. *fork*
  4. One of the processes will call `seteuid(getuid())` to lower its privilege



Setuid can get you into trouble!

- Most *setuid* programs ran as root
- If they were compromised, the whole system was compromised
- This was one of the best attack vectors for Unix/Solaris/Linux systems

Other Access Control Models

What's wrong with ACLs?

- Users are in control

```
chmod o+rw secret.docx
```

  – Now everyone can read and modify `secret.docx`

- Doesn't work well in environments where management needs to define access permissions

- No ability to give time-based or location-based permissions

- Access is associated with objects
  – **Hard to turn off access for a subject** - except by locking the user
  – Otherwise have to go through each object and remove user from the ACL
    - … but you're still stuck with default access permissions and wondering how other users will set access rights in the future

Access Control Models: MAC vs. DAC

DAC: Discretionary Access Control

- A subject (domain) can pass information onto any other subject
- In some cases, access rights may be transferred
  e.g., chown
- *Users are in charge of access permissions*
- *Most systems use this*

MAC: Mandatory Access Control

- Policy is centrally controlled
- Users cannot override the policy
- *Administrators are in charge of access permissions*

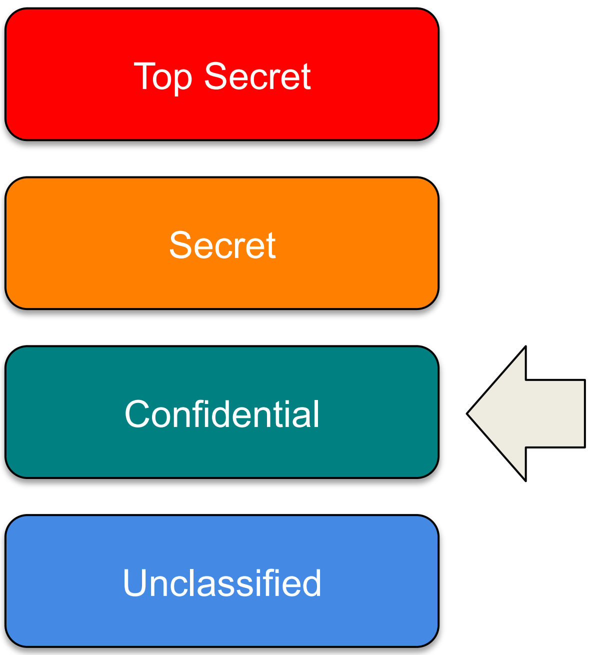
MLS: Multi-Level Security Systems

Handle multiple levels of classified data in one system

Bell-LaPadula Model

– Designed for the military
– Based on U.S. military classification levels

Motivation:
Preserve confidentiality. If one program gets hacked, it will not be able to access data at higher levels of classification



If you have confidential clearance:

– You can **access** confidential & unclassified data

– You can **create** confidential, secret, and top-secret data

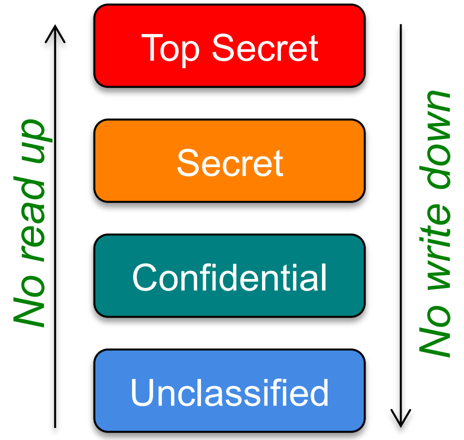
Bell-LaPadula Base OS Model

Designed to address security concerns in the Air Force

- Reference Monitor
  - Component of the OS that would manage access control decisions
- Trusted Computing Base (TCB)
  - Set of components whose correct functioning is sufficient to ensure the security policy is being enforced
  - If the TCB fails, the security policy could be breached

Bell-LaPadula (BLP) Access Model

- Objects are classified into a hierarchy of sensitivity levels
  – Unclassified, Confidential, Secret, Top Secret
- Each user is assigned a clearance
- "No read up; no write down"
  – Cannot read from a higher clearance level
  – Cannot write to a lower clearance level
- Assumes vulnerabilities exist and staff may be careless
- Need a "trusted subject" to declassify files



Confidential cannot read Secret
Confidential cannot write Unclassified

Bell-LaPadula (BLP) Model Properties

Every subject & object gets a security **label** (e.g., confidential, secret)

1. **The Simple Security Property** – *mandatory rules for reading*
   - No Read Up (NRU)
     A subject cannot read from a higher security level

2. ***-Property** (star-property) – *mandatory rules for writing*
   - No Write Down (NWD)
     A subject cannot write to a lower security level

3. **The Discretionary Security Property**
   - Access control matrix can be used for **DAC** *after* MAC is enforced

BLP Tranquility Principle

- **Tranquility principle**: security labels never change during operation
- **Weak tranquility principle**: labels may change but in a way that does not violate security policy
  - Implements the principle of least privilege
  - If owner has *Top Secret* clearance, a program will run at the lowest clearance level and get upgraded only when it needs to access data at a higher level
- BLP gets complicated
  - Changes in security policy in real time can result in access being revoked – even in the middle of an operation
- Difficult to use BLP in practice
  - Networking, servers, collaborative work

No Write Down?

If you can write up, can a Confidential user overwrite Secret data?

– That's an attack on availability

- Usually: allow overwriting files when the process' security labels match exactly

Type Enforcement Model (TE)

Secondary <u>Access Control Matrix</u> that gives MAC priority over DAC

- Domains and Types
  - Assigns subjects to domains
  - Assigns objects to types
  - Matrix defines permitted domain-domain and domain-type interactions
- SE Linux = Security-Enhanced Linux
  - Both subjects and objects are *types*
  - Matrix defines allowed *type pairs*
  - Each process has a security ID, user ID, and group ID
  - Security modules may be added with rules that operate on SIDs

Role-Based Access Control (RBAC)

- More general than Bell-LaPadula
- Designed to allow enforcement of both MAC & DAC properties
- Access decisions do not depend on user IDs but on **roles**
  - Administrators define roles for various job functions
  - Each role contains permissions to perform certain operations
  - Users are assigned one or more roles
- Roles are *job functions*, not *permissions*
  - “update customer information” is a role
  - “write to the database” is <u>not</u> a role
- Enables fine-grained access
  - Roles may be defined in application specific ways (e.g., “move funds”)

RBAC Rules

- Role assignment
  - A subject can execute an operation only if the subject has been assigned a role
- Role authorization
  - A subject's active role must be authorized for that subject
  - Ensures that users can only take on roles for which they have been authorized
- Transaction authorization
  - A subject can execute a transaction only if the transaction is authorized through the subject's role membership

RBAC is essential to database security

Aren't roles == groups?

- **Group** = collection of users
  - Does not enable management of user-permission relationships
- **Role** = collection of permissions
  - Permissions can be associated with users and groups
- Roles have a **session**
  - Users can activate a role
- In SE Linux, RBAC is built on top of TE (type enforcement)
  - Users mapped to roles at login time
  - Roles are authorized for domains
  - Domains are given permissions to types

RBAC Benefits

- RBAC is hugely popular in large companies
  - Driven by regulations such as HIPAA and Sarbanes-Oxley
- Makes it easy to manage movement of employees
- Makes it easy to manage “separation of duty” requirements
- Can manage complex relationships
  - Doctor X wants to view records of Patient Y
  - Doctor needs roles of “Doctor” and “attending doctor with respect to Y”
  - Roles allow specification of only if, not if or if and only if relations
- RBAC can simulate MAC and DAC

See http://csrc.nist.gov/groups/SNS/rbac/faq.html

Biba Integrity Model

- Bell-LaPadula was designed to address confidentiality
- Biba is designed to ensure data integrity

Confidentiality = constraints on who can *read* data

Integrity = constraints on who can *write* data

Motivation:
Preserve data integrity.
If one program gets hacked, it will not be able to modify data at higher levels of integrity

Biba model properties

- **Simple Security Property** = A subject cannot read an object from a lower integrity level
  Subjects may not be corrupted by objects from a lower level
  (no read down)
- **Star property** = A subject cannot write to an object at a higher integrity level
  Subjects may not corrupt objects at a higher level than the subject
  (no write up)
- A process cannot request higher access

An example of where Biba is useful

The Biba model fits many real-world applications

- ECG device
  - Runs a calibration process, which stores a calibration file
  - Runs user processes, that run ECG tests
- Normal users cannot write the calibration file but can read it
  - Can read data at higher levels (calibration = higher data level)
    - User process can read calibration data – but cannot modify it
- Calibration process can write data to lower levels
    - Calibration process can write to the user process – but cannot read user data
- Works well when you need to get data from a trusted device

Biba Problems

- Like Bell-LaPadula, it doesn't always fit the real world
- Microsoft offers Mandatory Integrity Control (Biba model)
  - User's access token gets assigned an integrity level
  - File objects are marked with an integrity level:
    - ***System***: Critical files
    - ***Medium***: Regular users and objects
    - ***High***: Elevated users
    - ***Low***: Internet Explorer, Adobe Reader, etc.
    - New process gets the *minimum* of the user integrity level and the file integrity level
  - Default policy = *NoWriteUp*
    - Goal: Anything downloaded with IE can read files but cannot write them – limit damage done by malware
    - Trusted subjects would have to overwrite the security model
      - Users get used to the pop-up dialog boxes asking for permission!
  - Microsoft dropped the *NoReadDown r*estriction
    - Did not end up protecting the system from users

Access Models: Summary

- Discretionary Access Control
  - Works great when it's ok to put the user is in charge
- Mandatory Access Control
  - Needed when an organization needs to define policies
  - **Bell-LaPadula** (BLP)
    - Oldest & most widely studied model – synonymous with MLS
    - Designed to protect confidentiality
    - Doesn't work well outside of the DoD … and is clunky within the DoD
  - **Type Enforcement** (TE)
    - Simple MAC model to override DAC
  - **Role-Based Access Control** (RBAC)
    - Identifies roles and assigns users to roles
    - Made popular by business needs
    - Most actively used MAC model
  - **Biba Model**
    - Opposite of Bell-LaPadula: concerned with integrity, not confidentiality

Security Risks

- Even if the mechanisms work perfectly, policies may fail
  - DAC: you're trusting the users or a sysadmin to set everything up correctly
  - MAC
    - User or role assignment may be incorrect
    - Collaboration needs to be considered
    - Models like Bell-LaPadula and Biba require overrides to function well
- Corruption
  - Attacks may change the definition of roles or the mapping of users to roles
  - This is an attack on the Trusted Computing Base
- Users
  - Most malware is installed willingly
  - Users thus give it privileges of – at least – normal applications
  - As far as the operating system is concerned, it is enforcing defined policy

Security Risks

- Even administrators should not be able to read all files
  - Many security systems enforce this
  - Edward Snowden should not have been able to copy sensitive documents onto a thumb drive … even if NSA policy banned thumb drives
- General assumption has been that programs are trusted and run with the user's privileges
- Worked well for system programs
- Do you trust the game you installed on your phone?
- Need to consider better application isolation
  - Android turned Linux into a single-user system
  - User IDs are used on a per-application bases

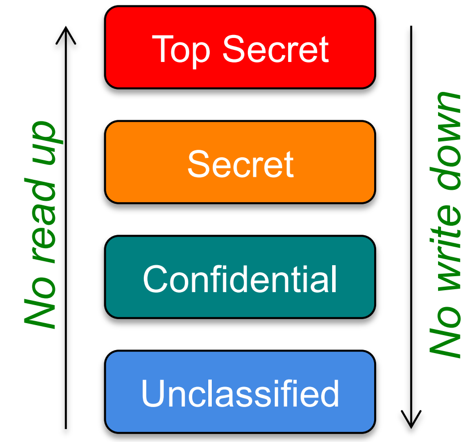
Program-Based Control

- A lot of access decisions must be handled by programs, not the OS
  - Database users and the access each user has within the database
  - Microsoft Exchange & Active Directory administrators
  - Mail readers
  - Web services: users are unlikely to have accounts on the system
  - Movement of data over a network
    - How do you send access permissions to another system?
    - Digital rights management = requires trusted players
- Programs may implement RBAC (e.g., Exchange) or other mechanisms
  - But the OS does not help

Multi-Lateral Security

Multi-Level Security

- Subjects and objects have assigned classification labels
- Rules control what you can read or write

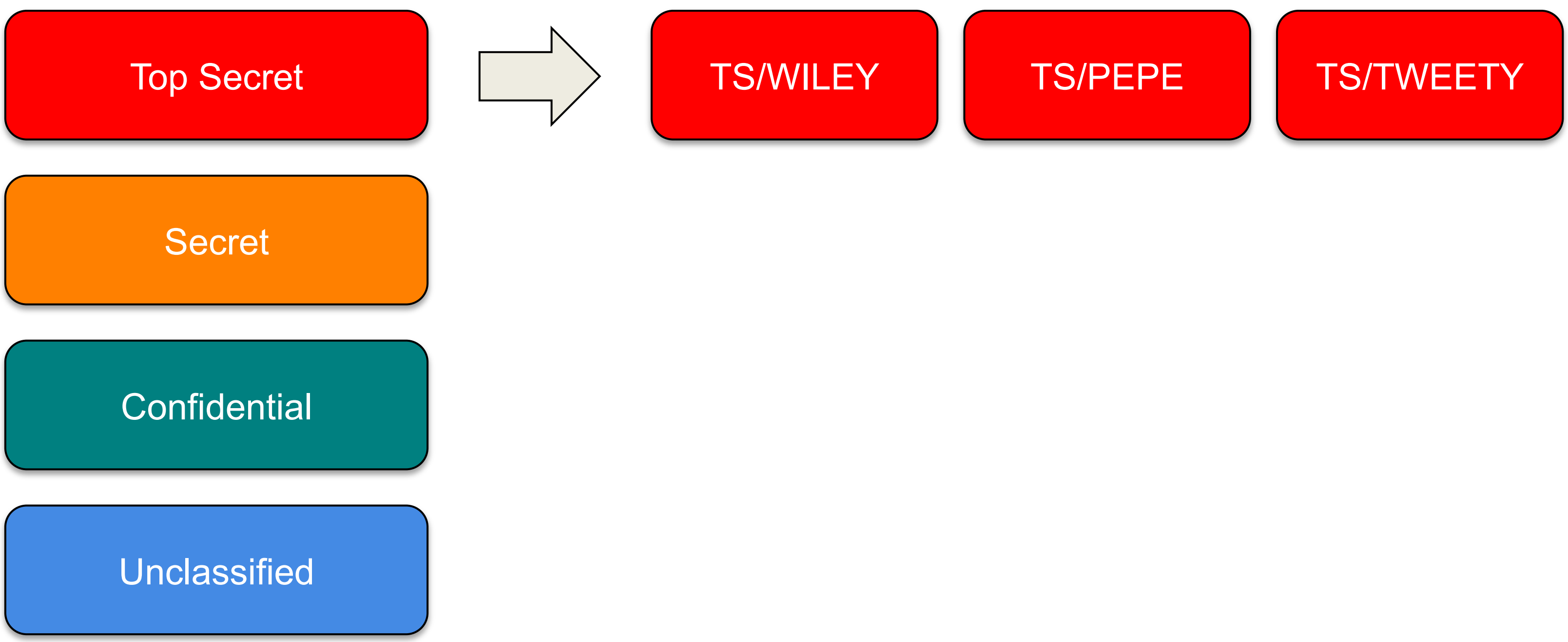


Bell-LaPadula

Multilateral Security

Each security level may be divided into compartments

- Usually applied to the top-secret level
- TS/SCI = Top-Secret / Special Compartmentalized Intelligence
- You will be granted access to specific compartments
  - Formalized description of "need to know"

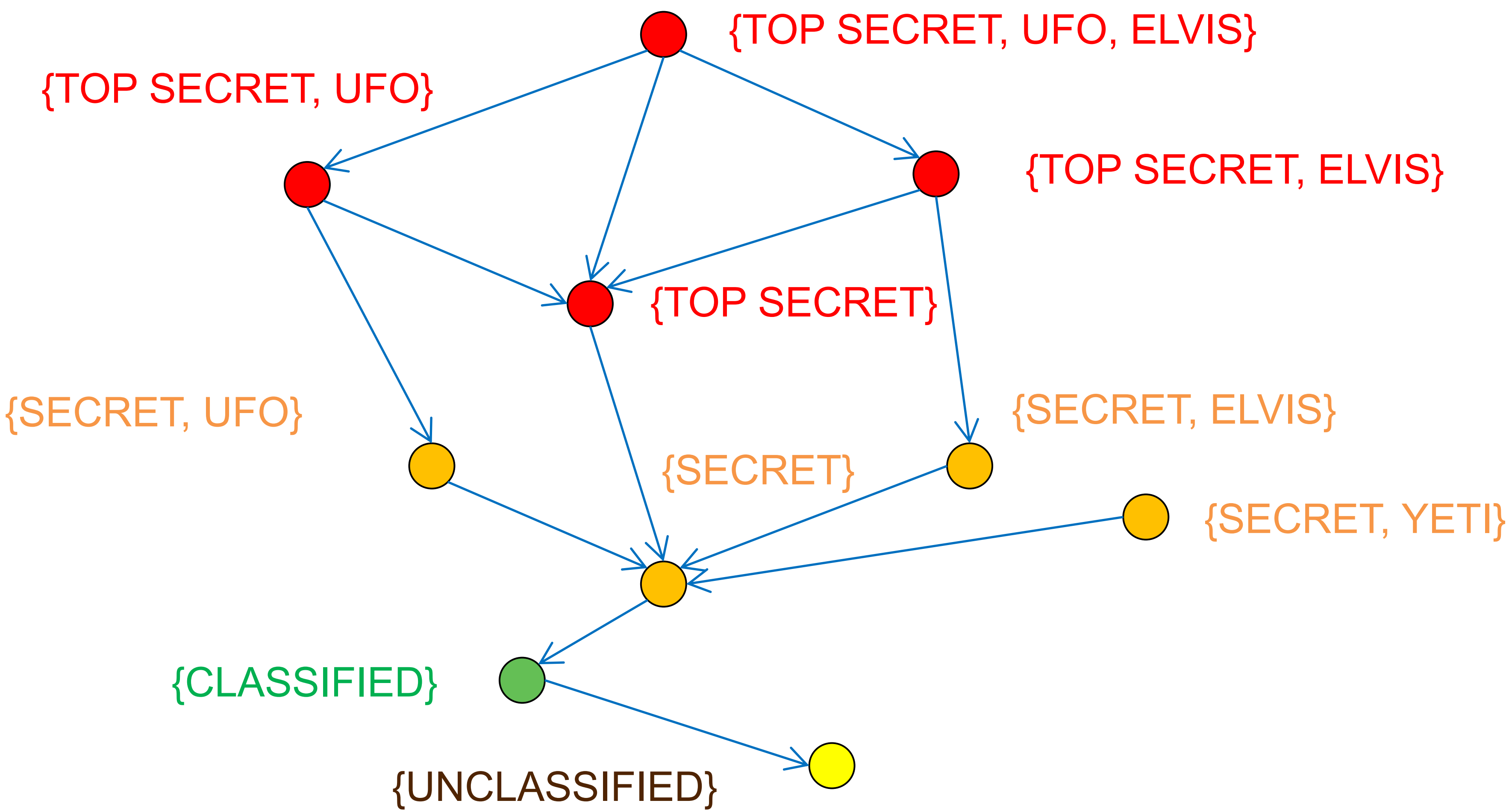


Compartmentalization

- Subjects & objects get security labels (compartments) in addition to security classification labels
- If you do not have clearance for the label, you cannot access the data
  - {TOP SECRET, UFO} cannot be read by someone with {TOP SECRET} clearance
  - Neither can {SECRET, UFO}

Lattice Model

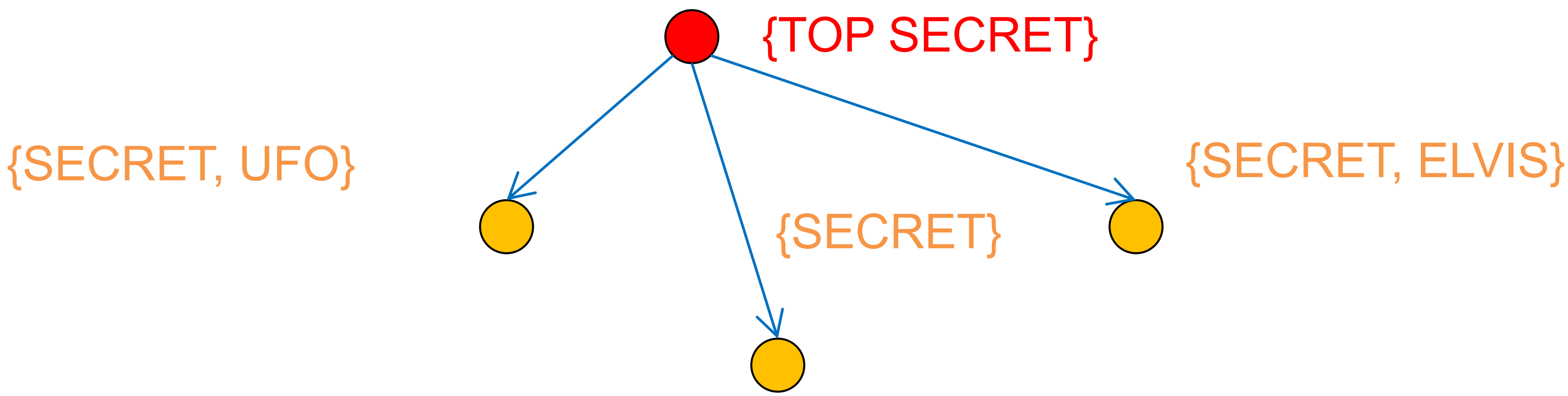
Graph representing access rights of different labels & levels



Lattice model

- Data from two compartments ⇒ third compartment
  - Creates more isolation
  - Does not help with sharing

- One option
  - Allow multiple compartments at a lower level to be readable by a higher level



Multi-level & Lattice models

- Do not help downgrading data
  - Need special roles to re-label or declassify data
- Handing searches across compartments is difficult
  - No single entity will likely have rights to everything

Chinese Wall model

Chinese wall = rules designed to prevent conflicts of interest

- Common in financial industry
  - E.g., separate corporate advisory & brokerage groups
- Also in law firms and advertising agencies

- Separation of duty
  - A user can perform transaction *A* or *B* but not both

- Three layers of abstraction
  - Objects: files that contain resources about one company
  - Company groups = set of files relating to one company
  - Conflict classes: groups of competing company groups:

    { Coca-cola, Pepsi }

    { American Airlines, United, Delta, Alaska Air }

Chinese Wall model

Basic rule

A subject can access objects from a company as long as it never accessed objects from competing companies.

Simple Security property

– A subject *s* can be granted access to an object *o* only if the object
  - Is in the same company group as objects already accessed by s

  or
  - *o* belongs to a different conflict class

***-property**

– Write access is allowed only if
  - Access is permitted by the simple security property

  and
  - No object was read which is in a different company dataset than the one for which write access is requested *and* contains unsanitized information
    - *Sanitization* = disguising a company's identify
    - This means that you could read data across the wall ONLY if it's anonymized

The end