CSCI262 : System Security

Operating Systems and Access Control

What is the OS used for?

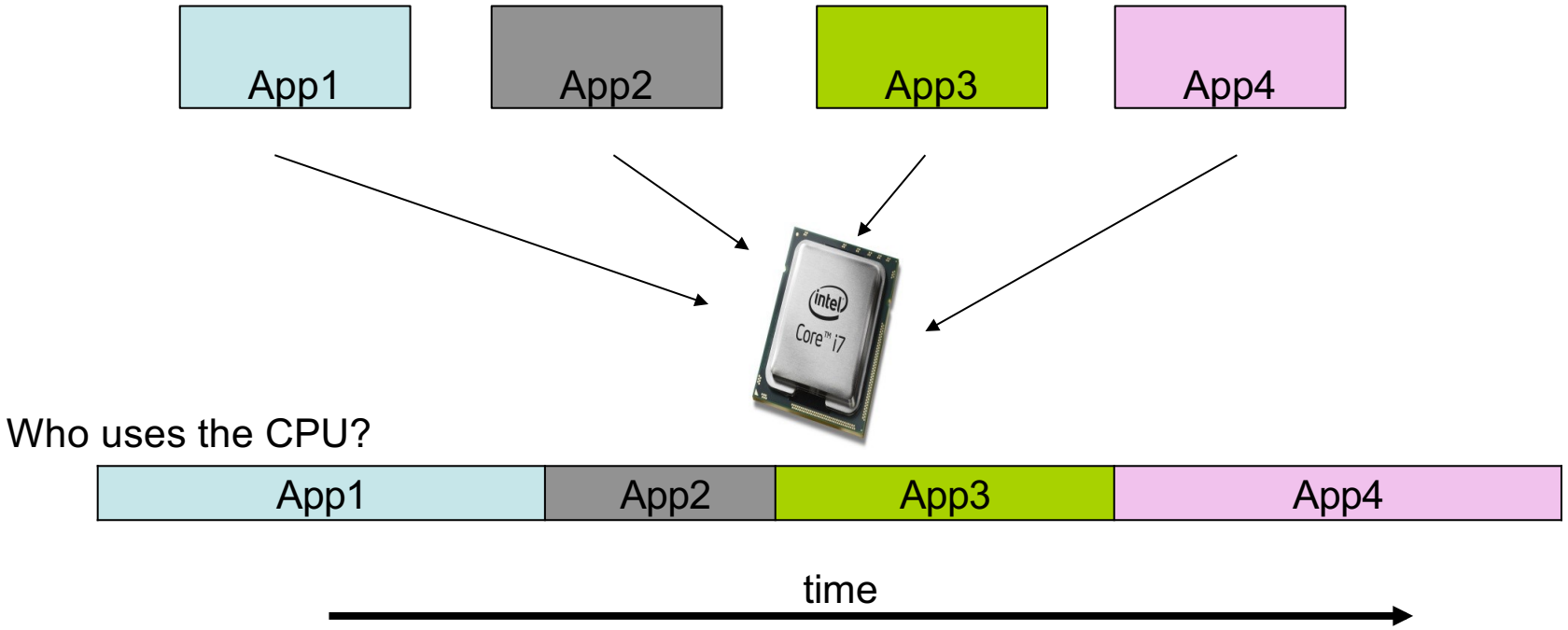
- Hardware Abstraction

  turns hardware into something that applications can use

- Resource Management

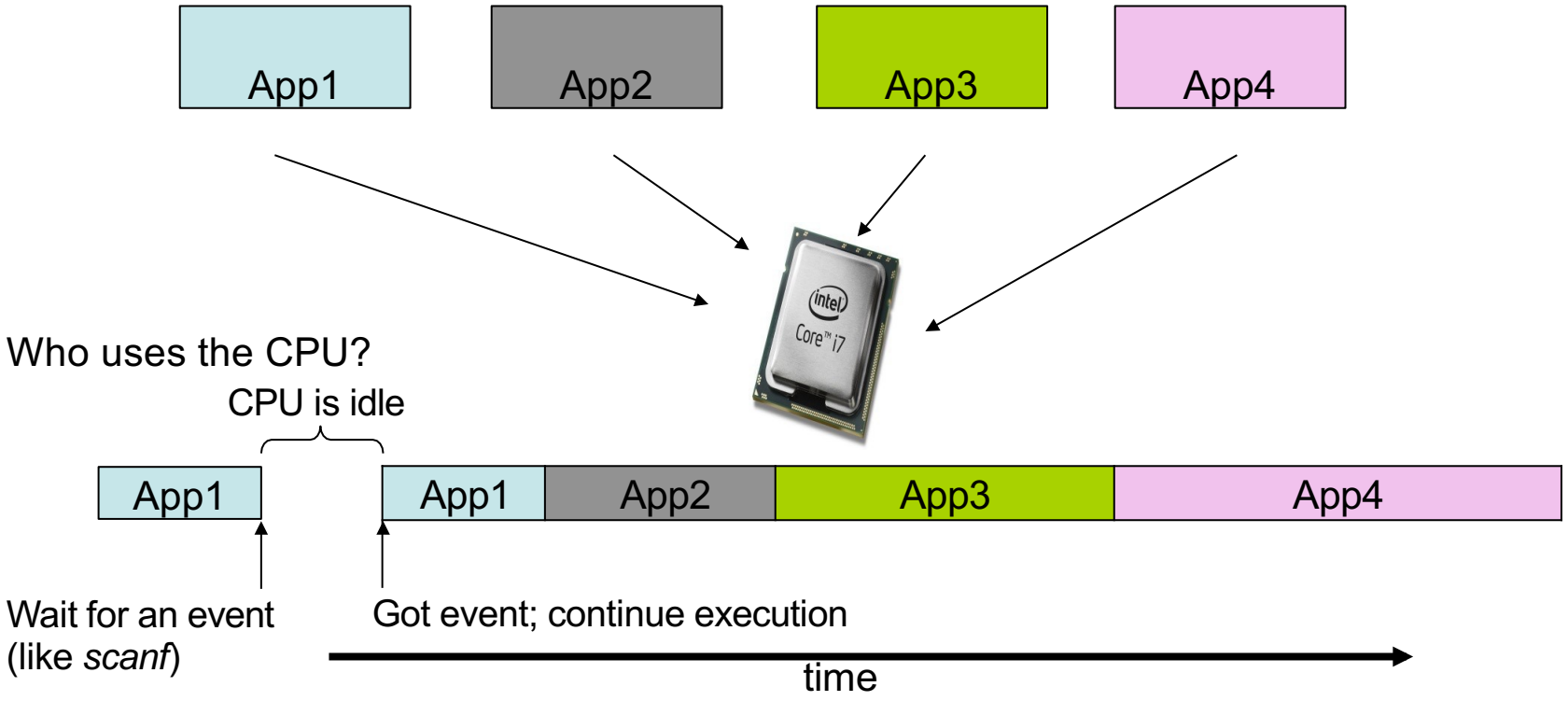
  manage system's resources

Sharing the CPU



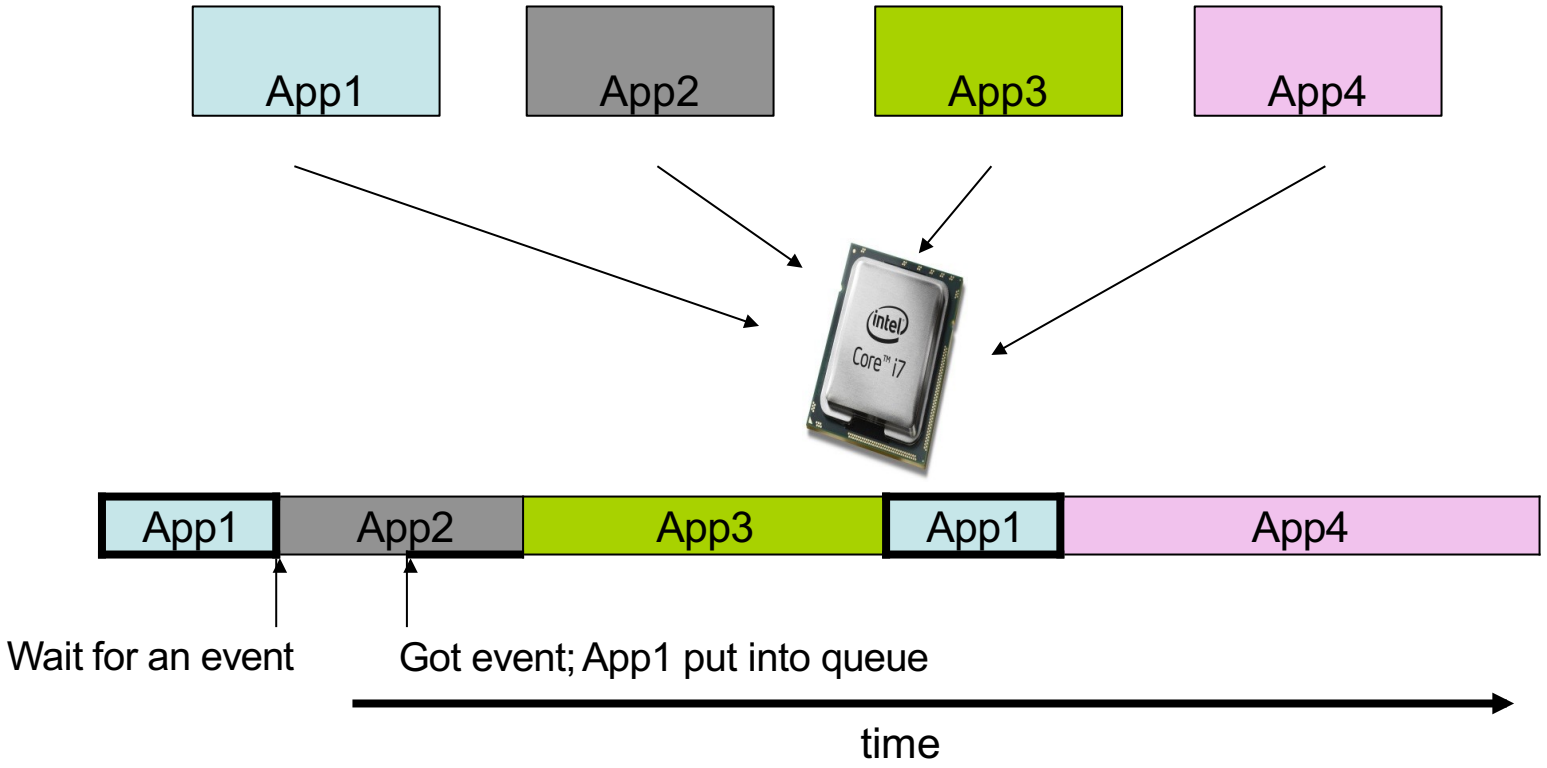
When one app completes the next starts

Idle CPU Cycles



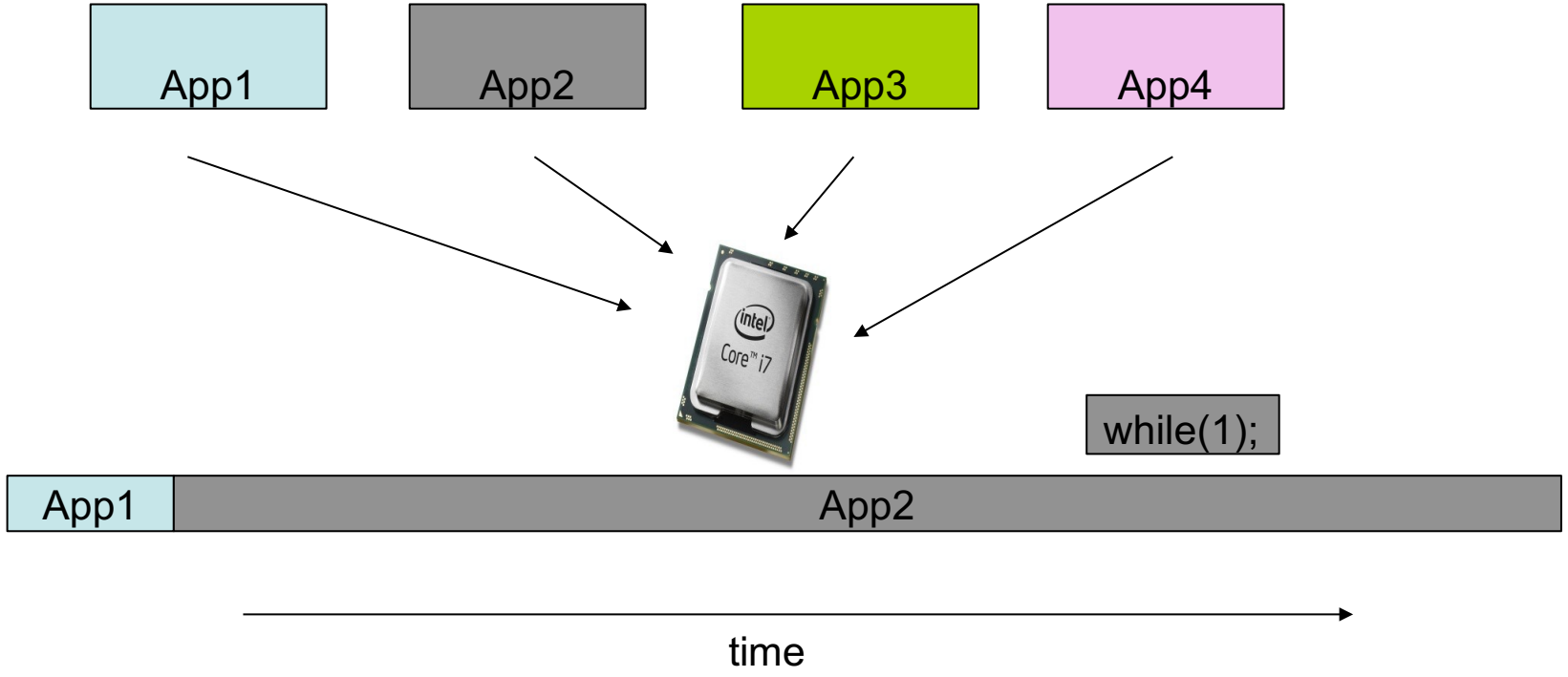
CPU is idle when executing app waits for an event.
Reduced performance.

When OS supports Multiprogramming



When CPU idle, switch to another app

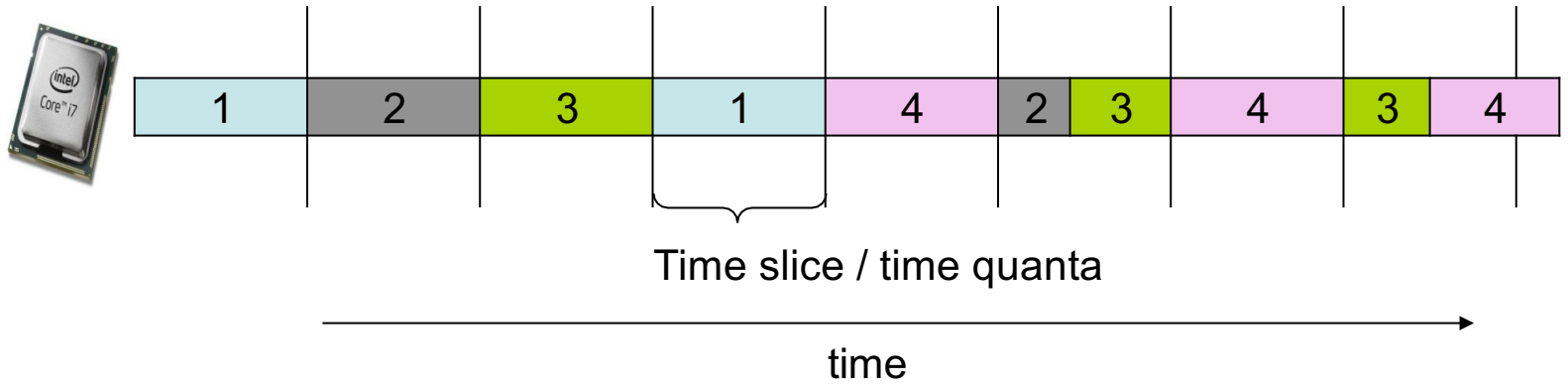
Multiprogramming could cause starvation



One app can hang the entire system

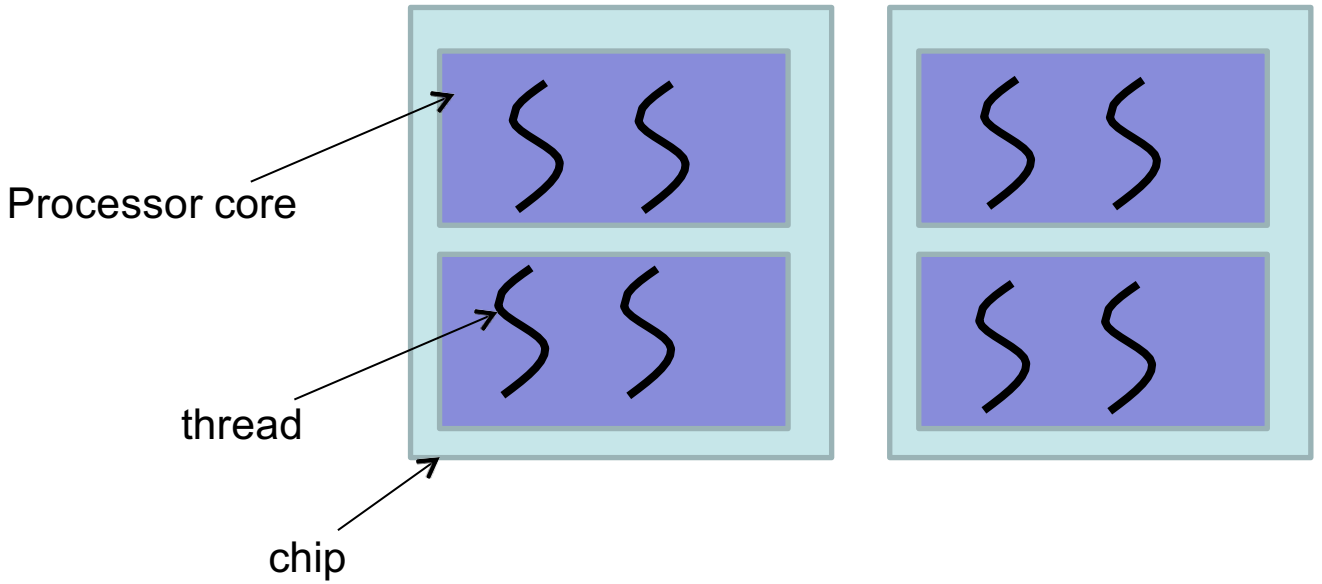
When OS supports Time Sharing (Multitasking)

- Time sliced
- Each app executes within a slice
- Gives impression that apps run concurrently
- No starvation. Performance improved



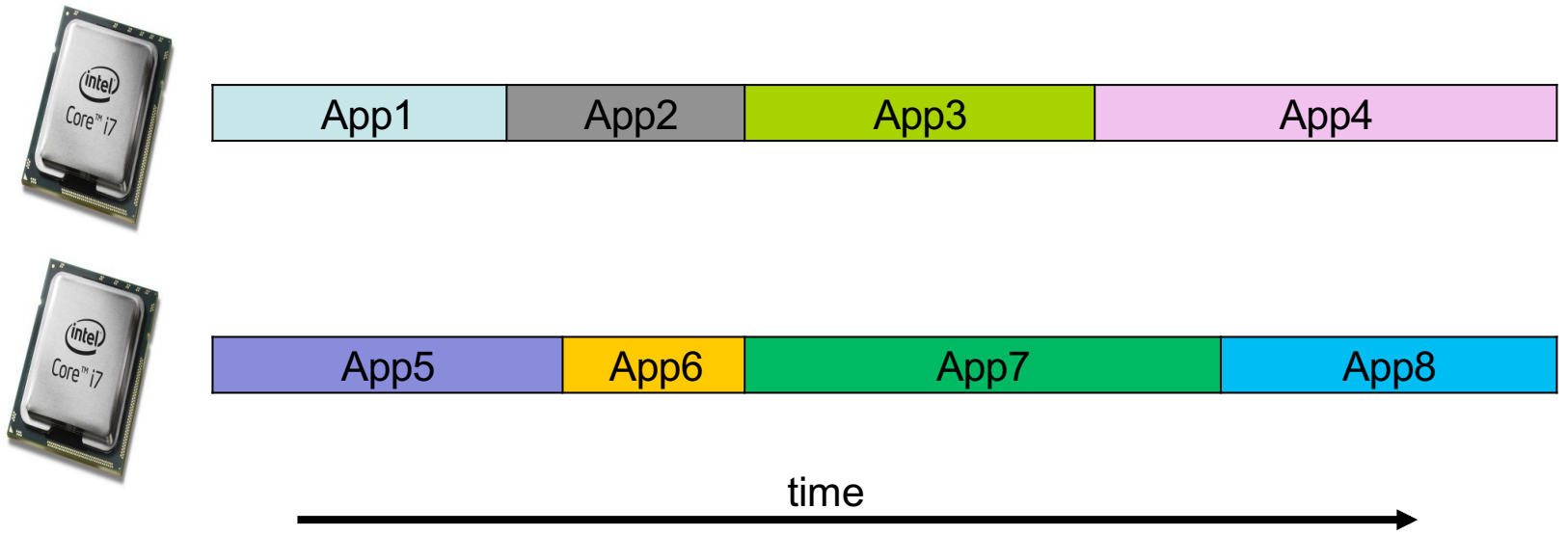
Multiprocessors

- Multiple processors chips in a single system
- Multiple cores in a single chip
- Multiple threads in a single core

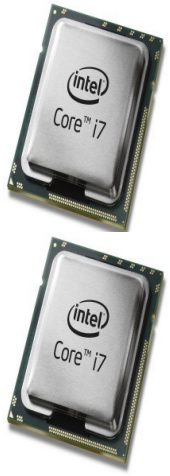


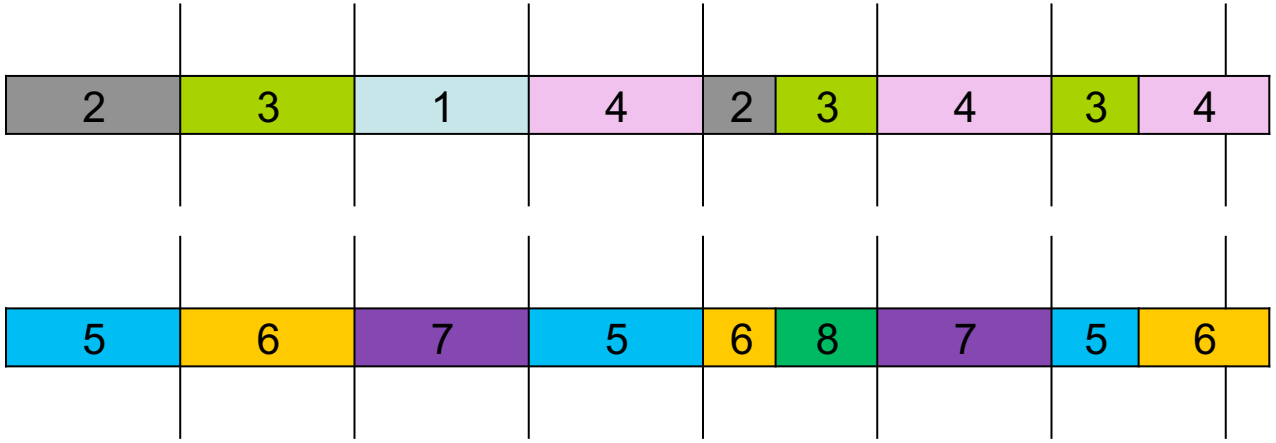
Multiprocessors

- Each processor can execute an app independent of the others

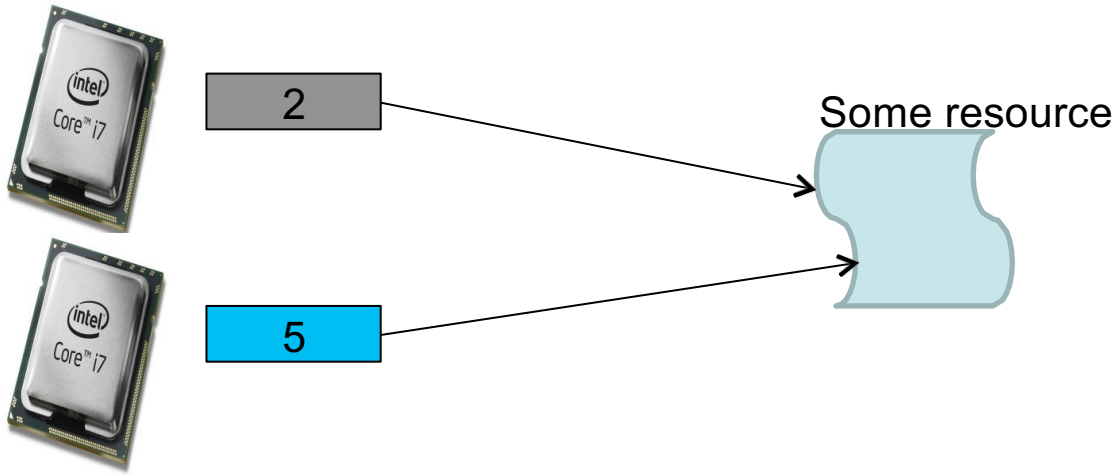


Multiprocessors and Multithreading



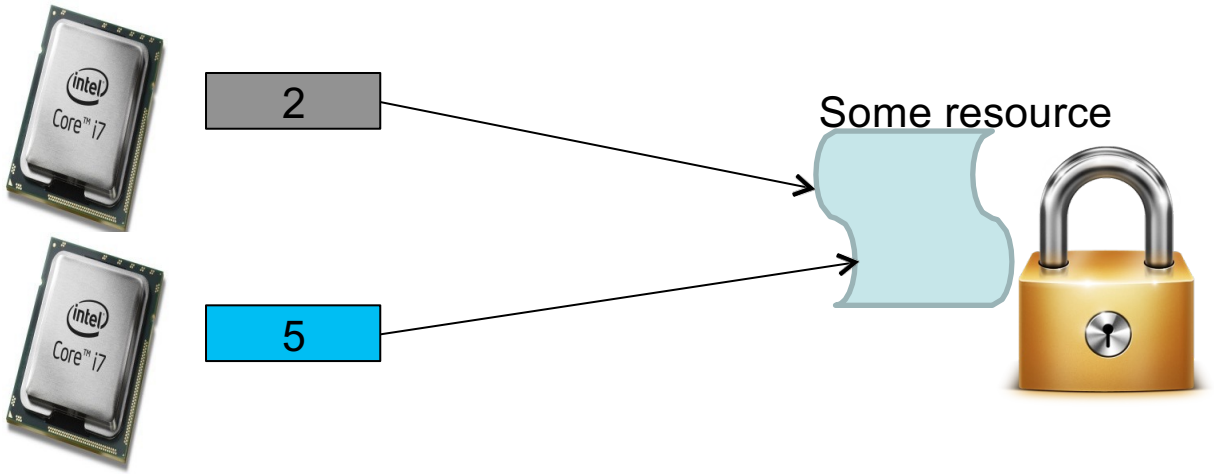


Race Conditions



- App2 and App5 want to write into some resource (like a file) simultaneously
- This results in a race condition
  - Need to synchronize between the two Apps

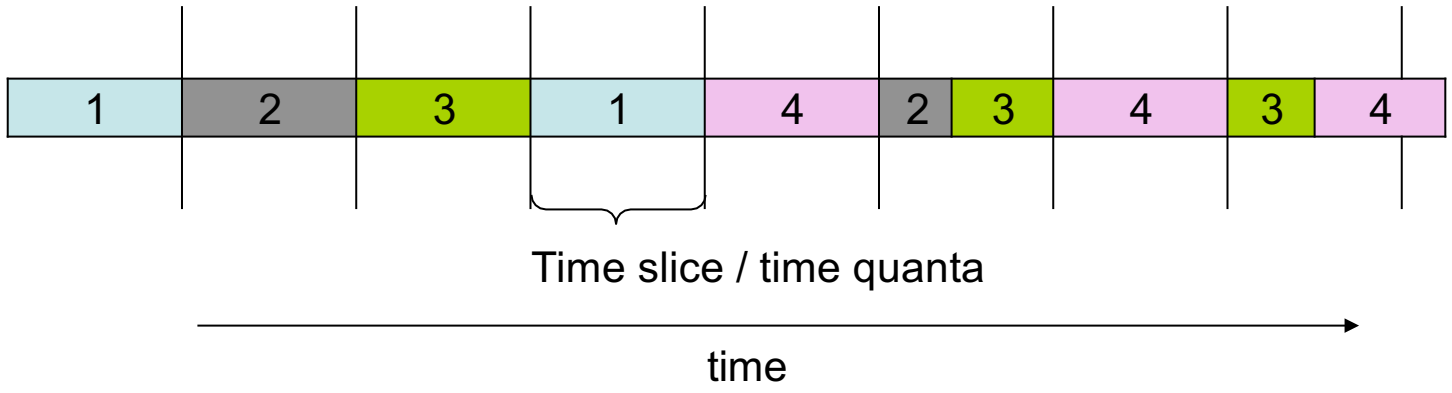
Synchronization



- The shared file is associated with a lock
- The lock ensures that only one App can access the resource at a time
- Sequence of Steps
  - App X locks the resource
  - App X accesses the resource, while App Y waits
  - App X unlocks the resource
  - App Y can now lock and then access the resource

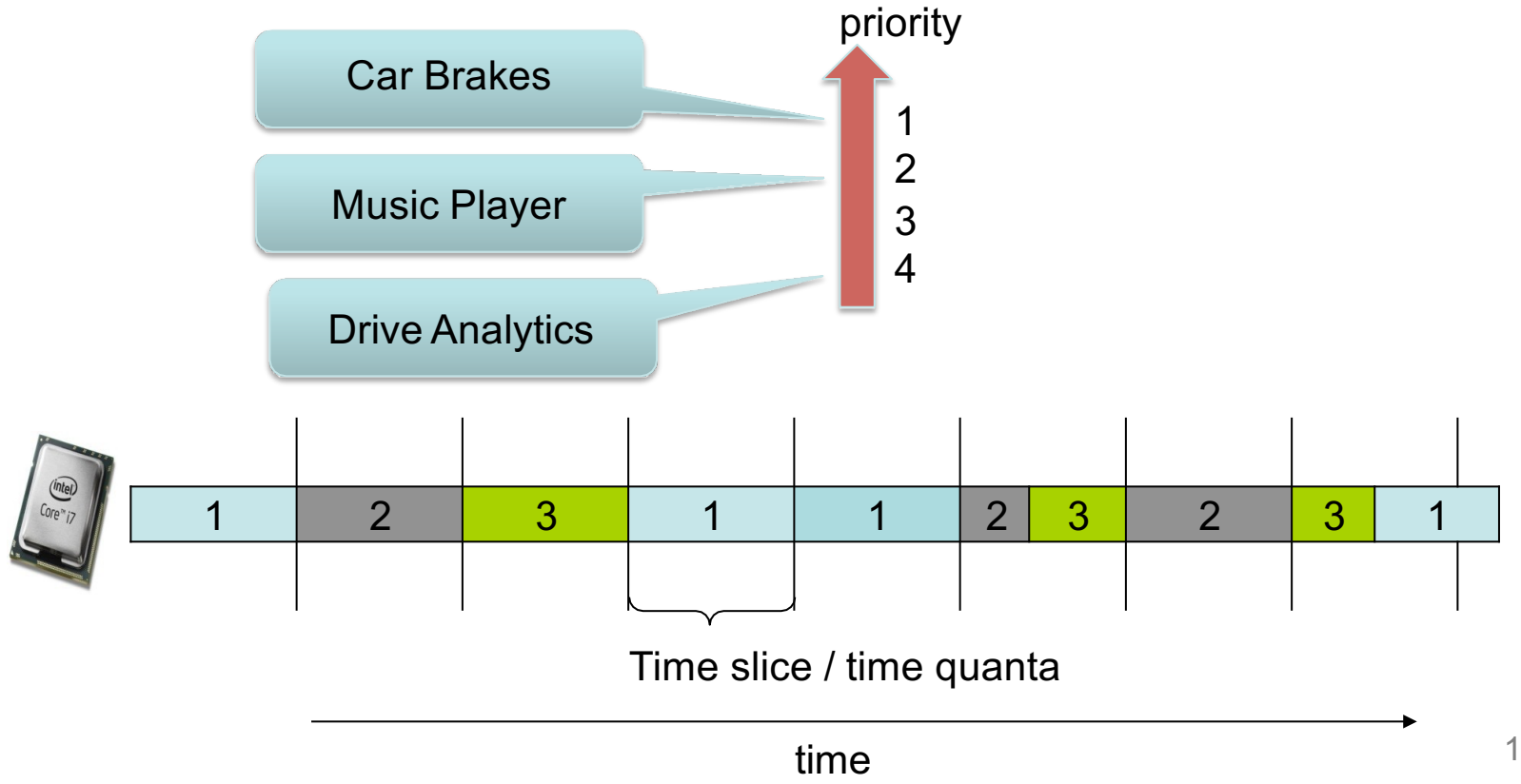
Who should execute next?

- Scheduling
  - Algorithm that executes to determine which App should execute next
  - Needs to be fair
  - Needs to be able to prioritize some Apps over the others



Priority Based Systems

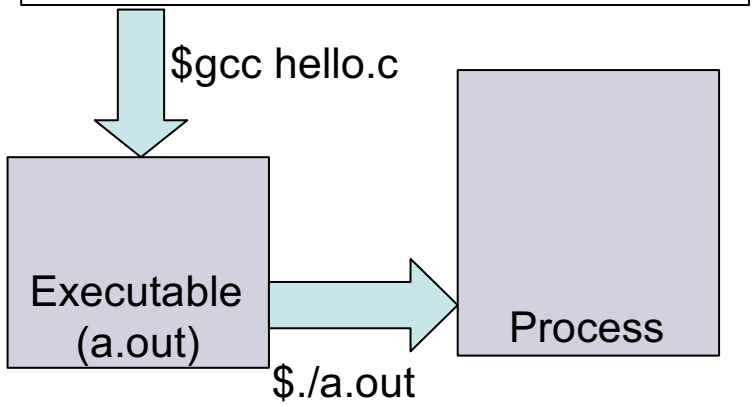
- Based on user choice or a heuristics, some apps are given higher priority compared to others.



Executing Apps (Process)

```c
#include <stdio.h>

int main(){
  char str[] = "Hello World\n";
  printf("%s", str);
}
```



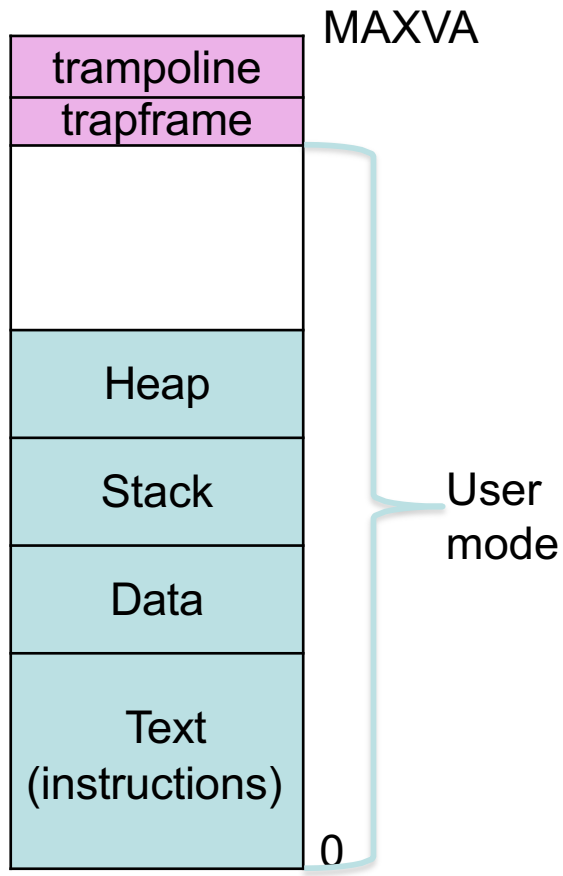
- Process
  - A program in execution
  - Comprises of
    - Executable instructions
    - Stack
    - Heap
    - State
  - State contains : registers, list of open files, related processes, etc.

Program ≠ Process

Program	Process
code + static and global data	Dynamic instantiation of code + data + heap + stack + process state
One program can create several processes	A process is unique isolated entity

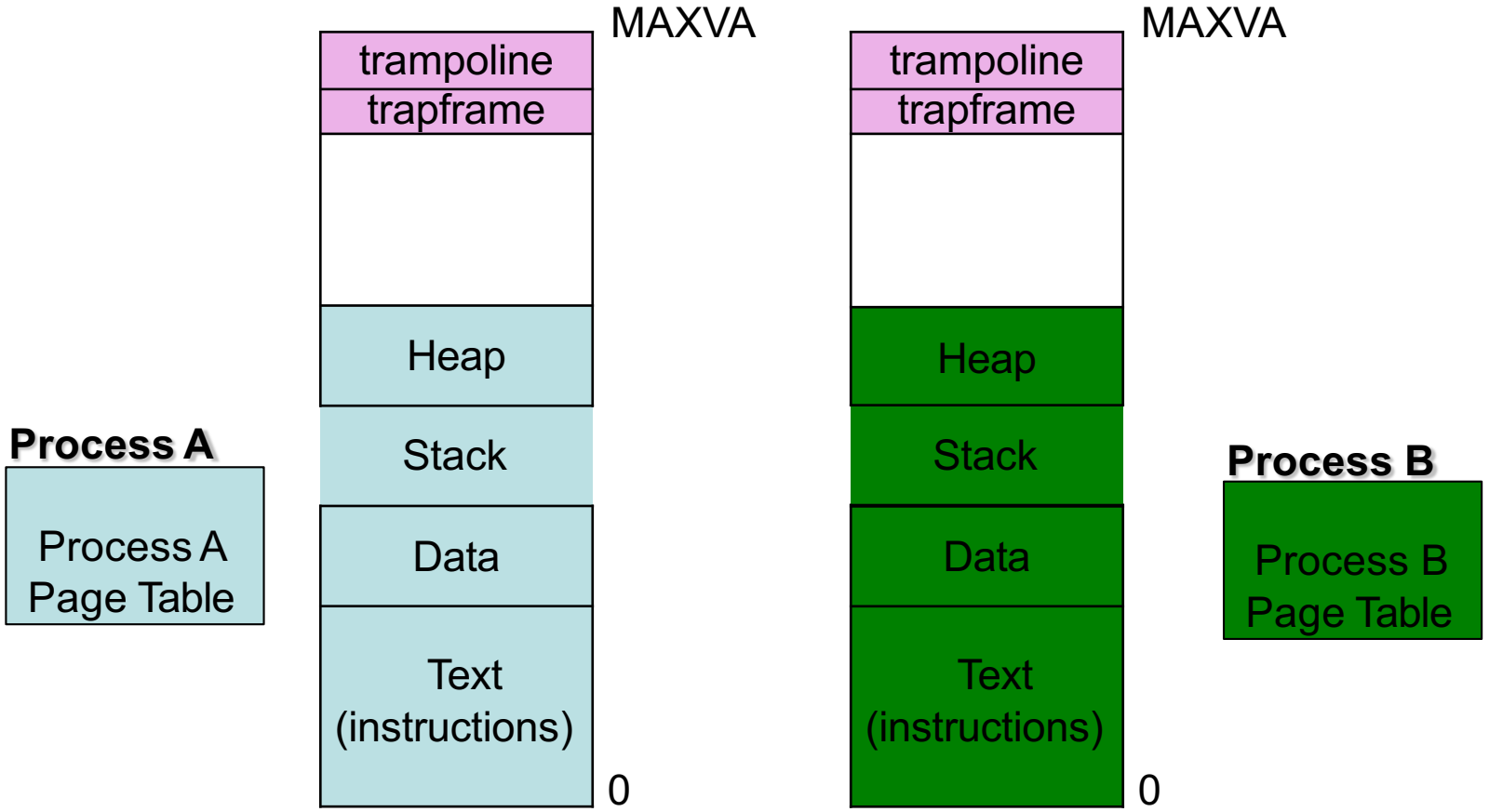
Process Address Space

- Virtual Address Map
  - All memory a process can address
  - Large contiguous array of addresses from 0 to MAXVA



Process Address Space

- Each process has a different address space
- This is achieved by the use of virtual memory
- Ie. 0 to MAXVA are virtual memory addresses



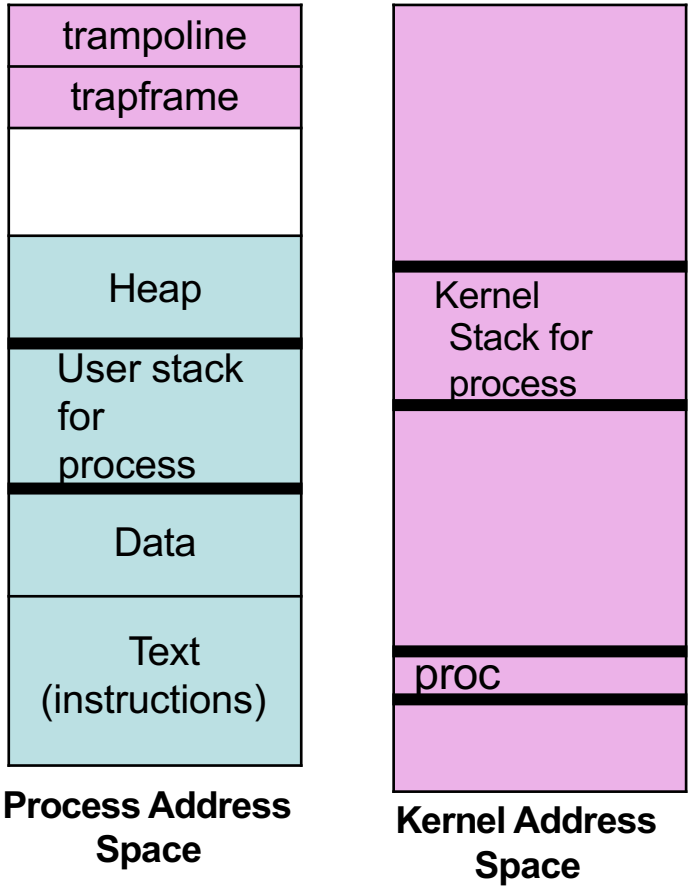
Advantages of Virtual Address Map

- Isolation (private address space)
  - One process cannot access another process' memory
- Relocatable
  - Data and code within the process is relocatable
- Size
  - Processes can be much larger than physical memory

Process Stacks

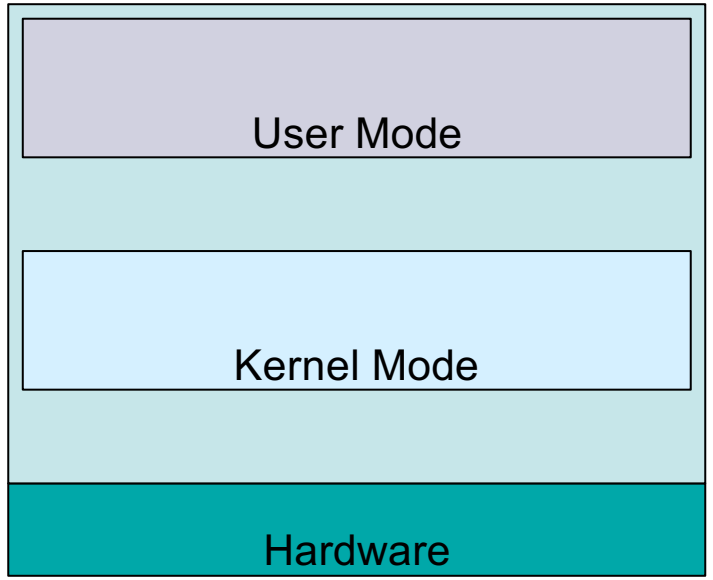
- Each process has 2 stacks
  - User space stack
    - Used when executing user code
  - Kernel space stack
    - Used when executing kernel code (for eg. during system calls)
  - Advantage : Kernel can execute even if user stack is corrupted

    (Attacks that target the stack, such as buffer overflow attack, will not affect the kernel)

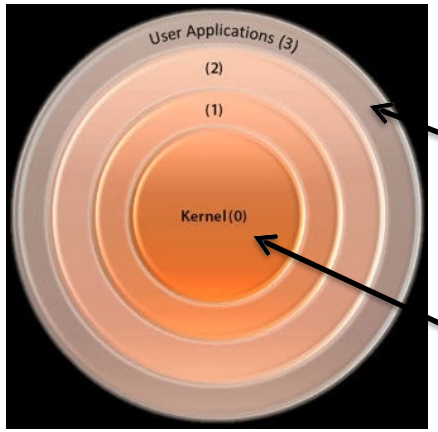


Operating Modes

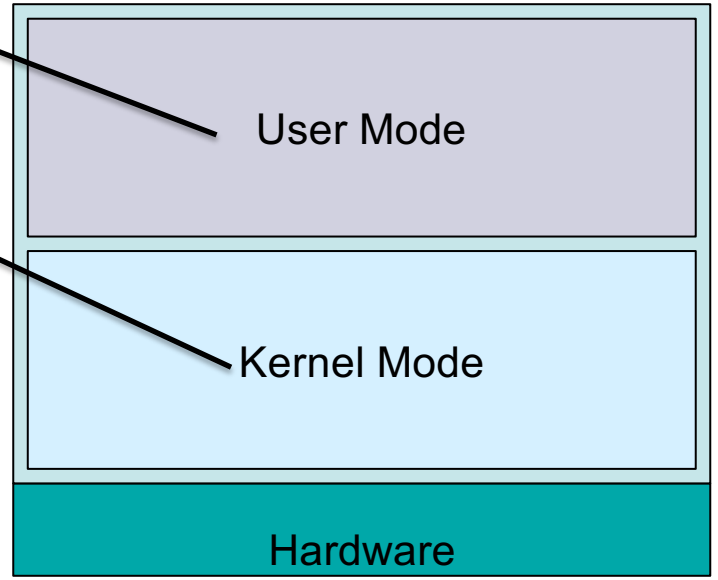
- User Mode
  - Where processes run
  - Restricted access to resources
  - Restricted capabilities
- Kernel mode a.k.a. Privileged mode
  - Where the OS runs
  - Privileged (can do anything)



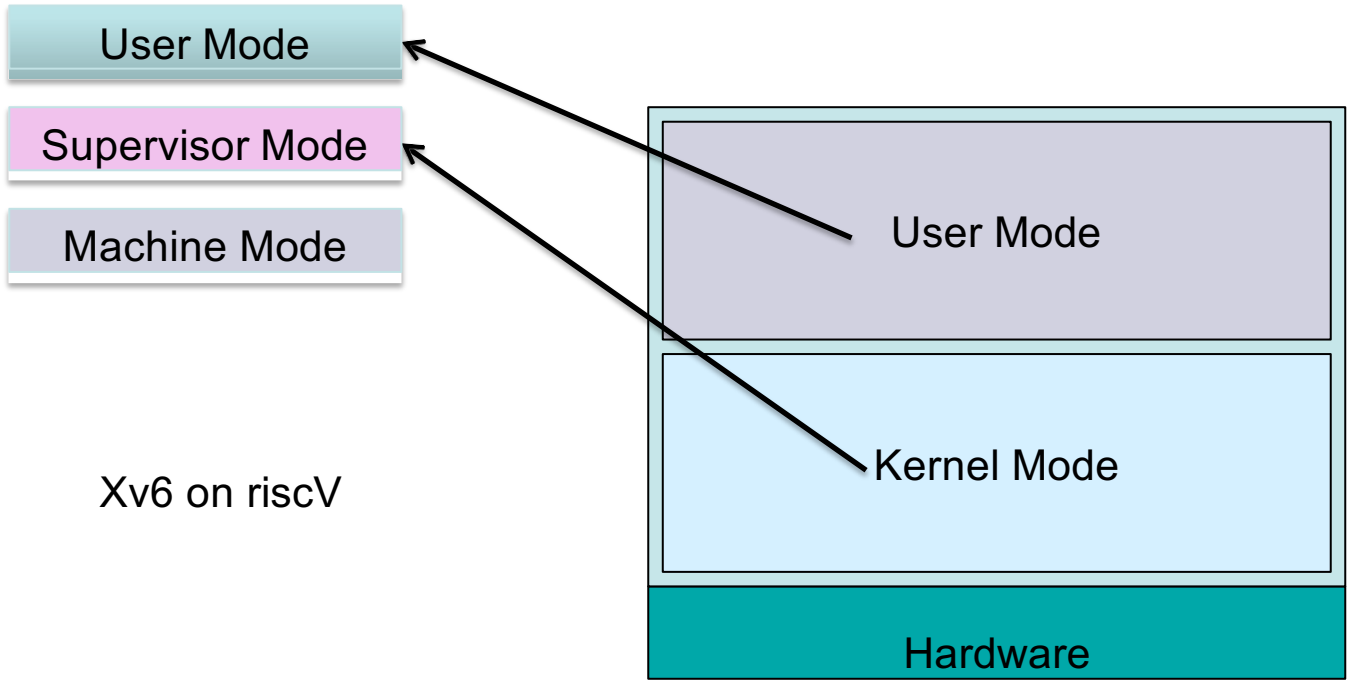
Operating Modes



Linux on x86

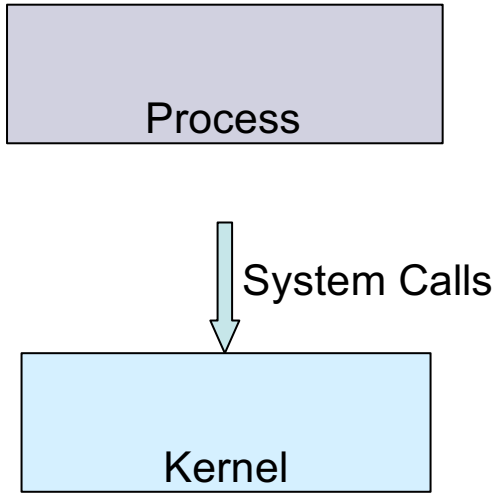


Operating Modes

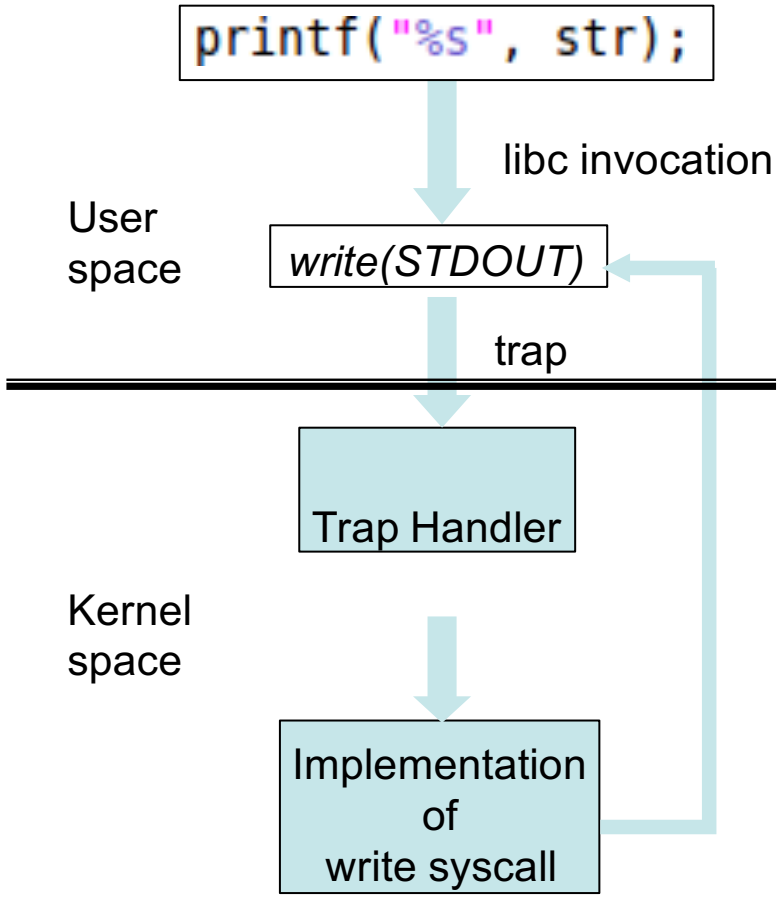


Communicating with the OS (System Calls)

- System call invokes a function in the kernel using a Trap
- This causes
  - Processor to shift from user mode to privileged mode
- On completion of the system call, the execution gets transferred back to the user mode process



Example (write system call)



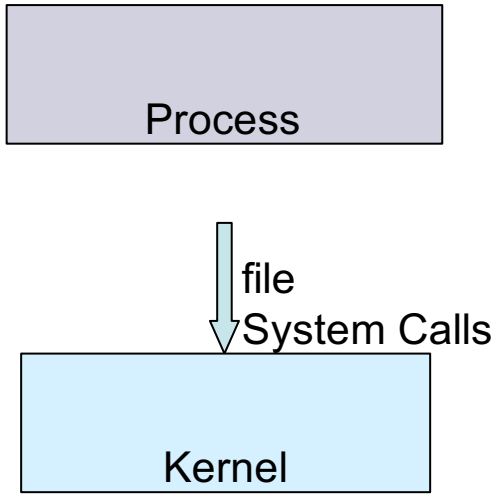
System Call Interfaces

- System calls provide users with interfaces into the OS.

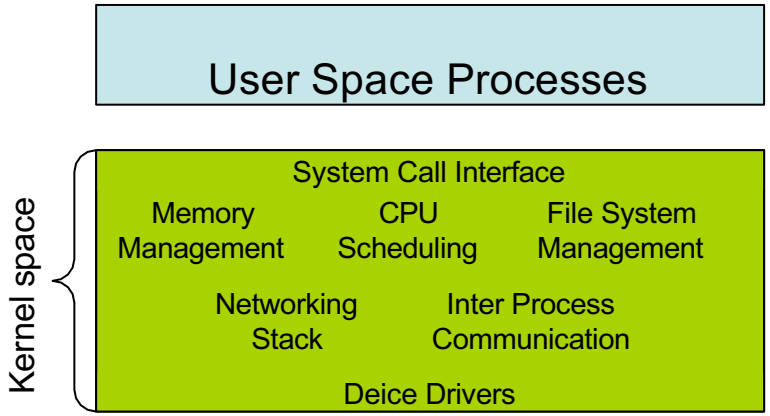
- What set of system calls should an OS support?
  - Offer sophisticated features
  - But yet be simple and abstract whatever is necessary
  - General design goal : rely on a few mechanisms that can be combined to provide generality

Files

- Data persistent across reboot
- What should the file system calls expose?
  - Open a file, read/write file, creation date, permissions, etc.
  - More sophisticated options like seeking into a file, linking, etc.
- What should the file system calls hide?
  - Details about the storage media.
  - Exact locations in the storage media.

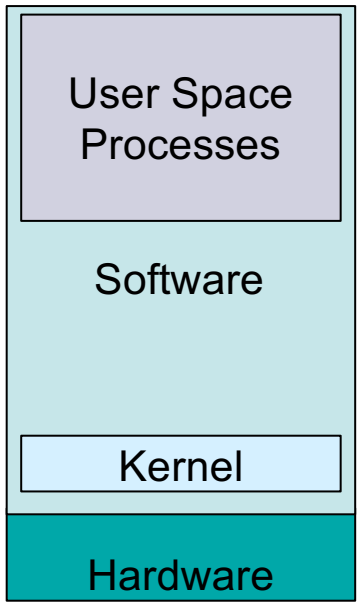


OS Structure : Monolithic Structure

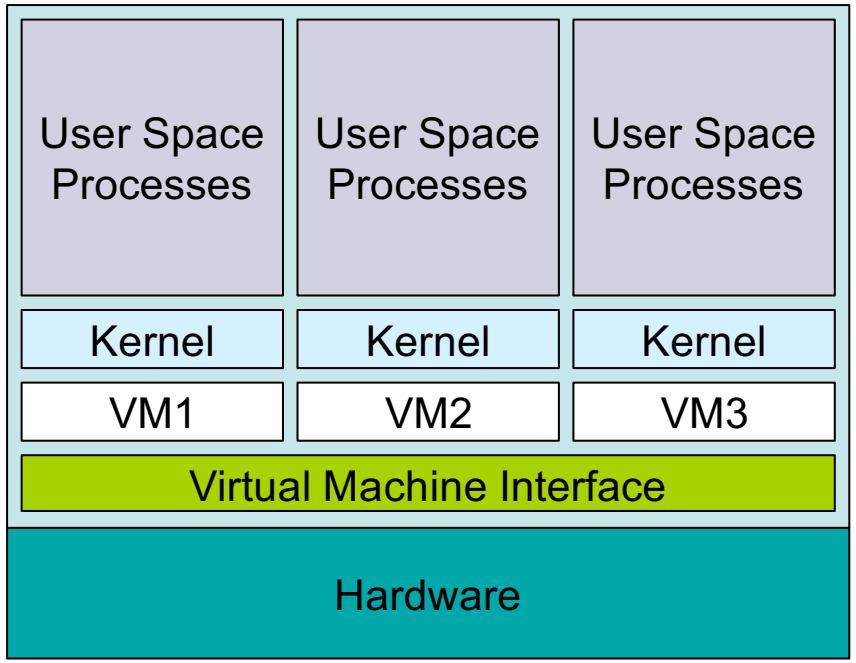


- Linux, MS-DOS, xv6
- All components of OS in kernel space
- Cons : Large size, difficult to maintain, likely to have more bugs, difficult to verify
- Pros : direct communication between modules in the kernel by procedure calls

Virtual Machines



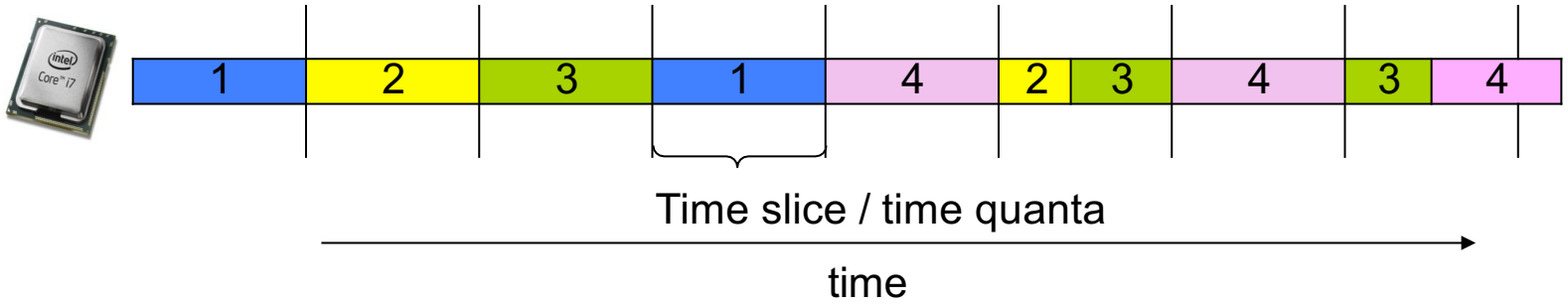
No virtual Machines



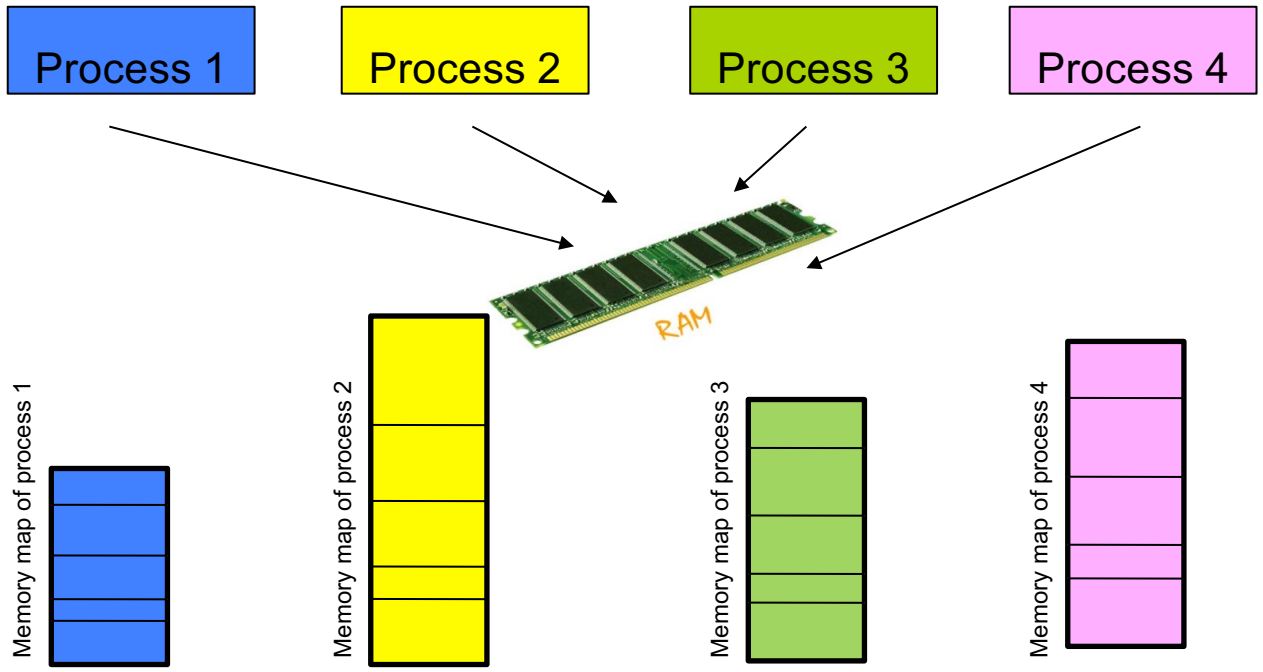
With virtual Machines

Multitasking

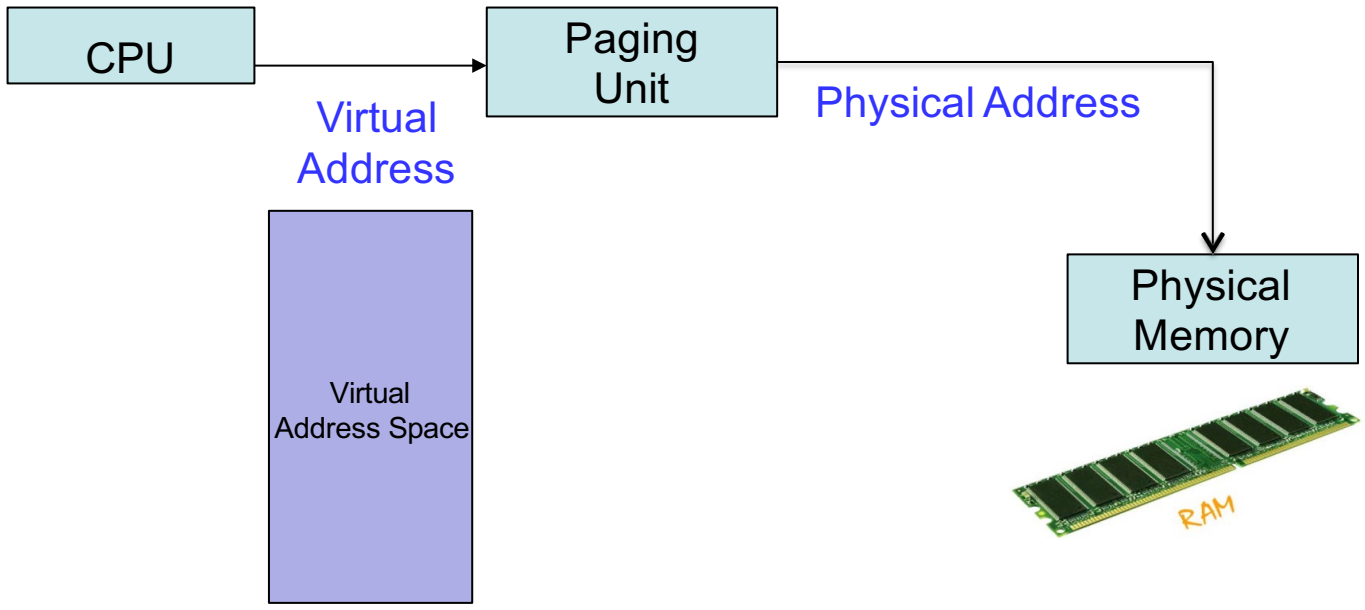
- Multiple programs execute in a time-multiplexed manner



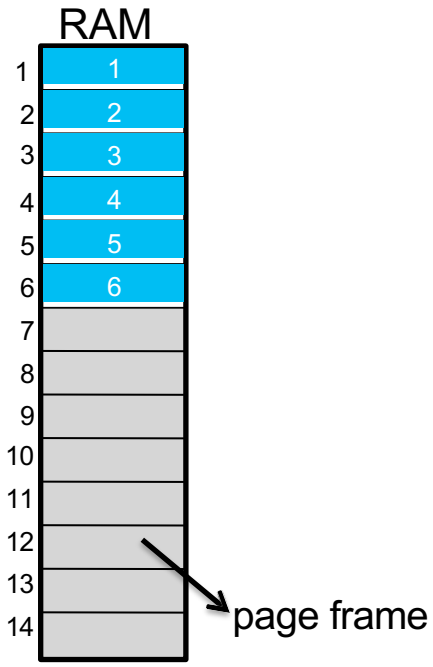
Sharing RAM


Process 1
Process 2
Process 3
Process 4
RAM
Memory map of process 1
Memory map of process 2
Memory map of process 3
Memory map of process 4

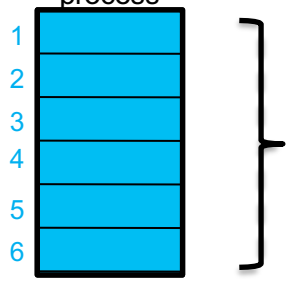
Address Translation



Virtual Memory



Virtual address space of process



Memory in a process divided into fixed size blocks (typically of 4KB)

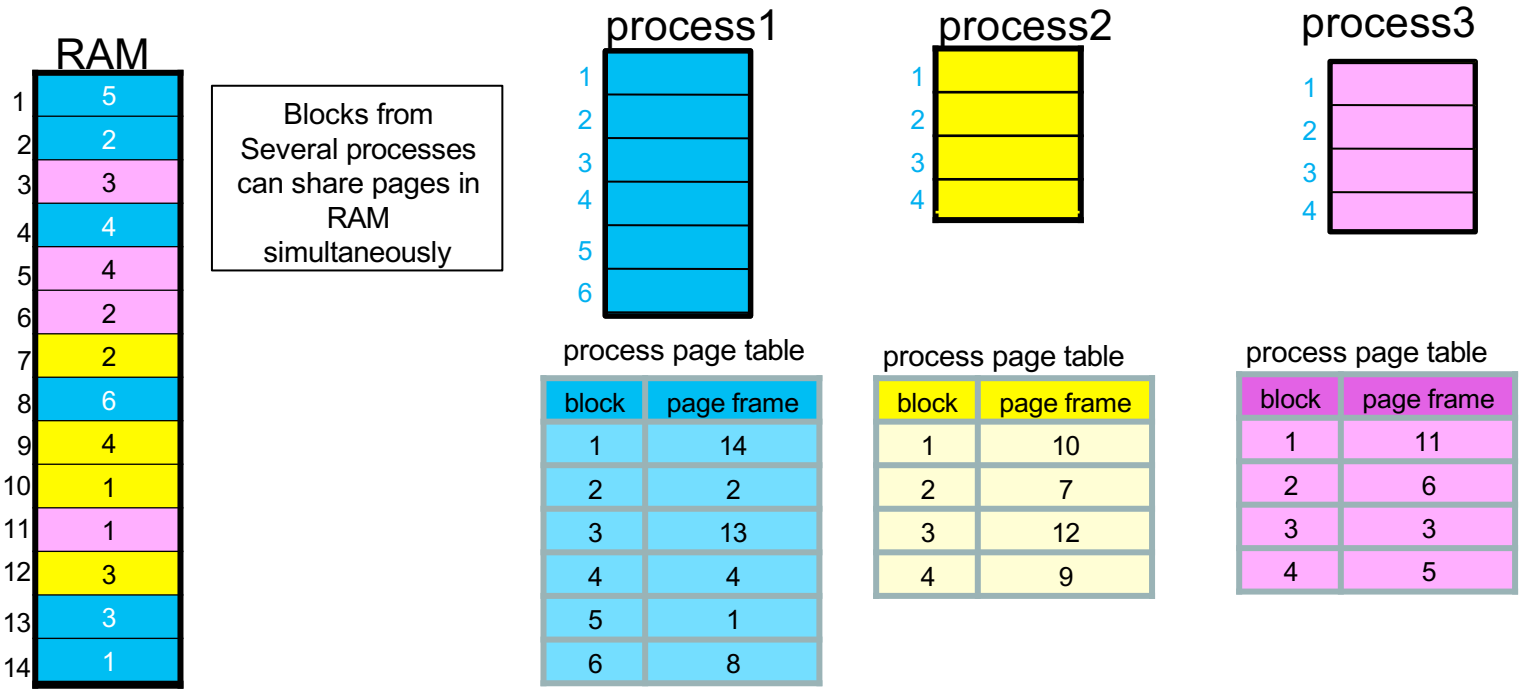
process page table

block	page frame
1	1
2	2
3	3
4	4
5	5
6	6

Every time a memory location is accessed, the processor looks into the page table to identify the corresponding page frame number.

Frames do not have to be contiguous

Virtual Memory



process page table

block	page frame
1	14
2	2
3	13
4	4
5	1
6	8

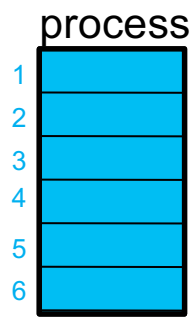
process page table

block	page frame
1	10
2	7
3	12
4	9

process page table

block	page frame
1	11
2	6
3	3
4	5

Virtual Memory



process page table

block	page frame
1	14
2	2
3	13
4	4
5	1
6	8

Do we really need to load all blocks into memory before the process starts executing?

No.

Not all parts of the program are accessed simultaneously.
Infact, some code may not even be executed.

Virtual memory takes advantage of this by using a concept called demand paging.

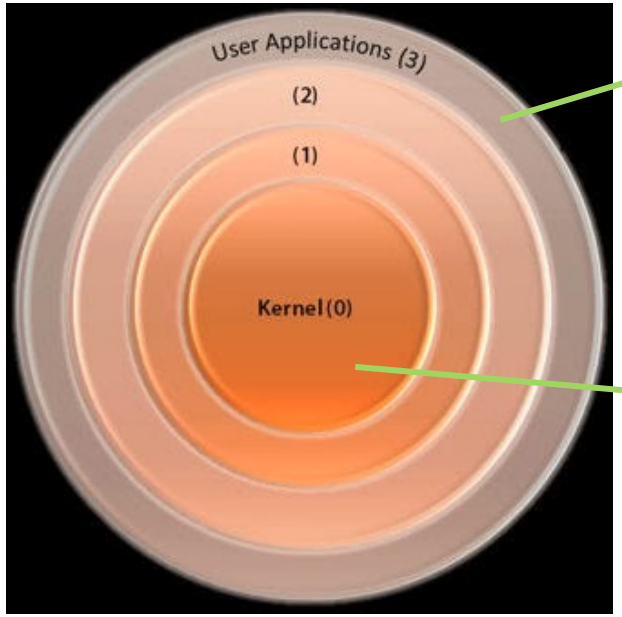
OS and Isolation

- **Why is it needed?**
  - Multiple apps execute concurrently, each app could be from a different user. Therefore needs isolation.
  - Preventing a malfunctioning app from affecting other apps

OS Isolation

- Ensure that the OS itself runs in a protected mode

X86 model

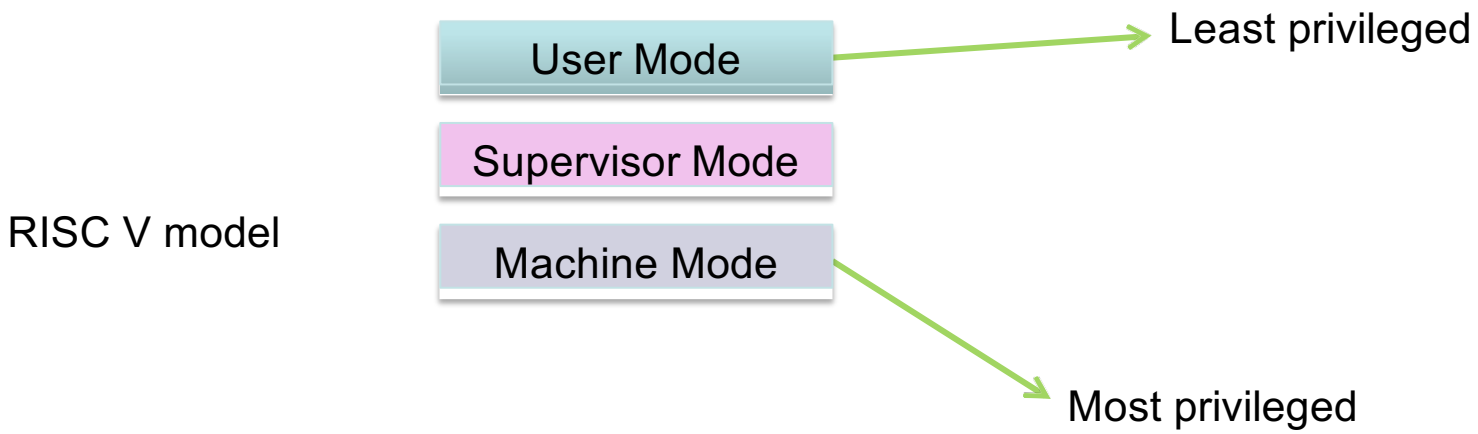


Least privileged

Most privileged

OS Isolation

- Ensure that the OS itself runs in a protected mode



Program Isolation

- Use virtual memory to ensure programs are isolated from each other
- Set page permissions
  - Execute, read only, read-write

OS and Security

- Why is it needed?
  - Defend against internal or external attacks from viruses, worms, identity theft, theft of service.

- How is it achieved?
  - Access Control
  - Passwords and Cryptography
  - Biometrics
  - Security assessment

Access Control

- Only authorized users can access files and other resources

	File 1	File 2	File 3	Program 1
Ann	own read write	read write		execute
Bob	read		read write	
Carl		read		execute read

CSCI262 : System Security

Access Control 1

Schedule

- What is access control?
- Access control policies
- Role-based access control
- Attribute-based access control

What is access control?

- Access:
  - Able to do something, perhaps get somewhere.
  - Carry out an action
- Control:
  - To restrict or allow,
- **Access control**: being able to restrict or allow particular actions
- [SB18]: Access control implements a security policy that specifies who or what (e.g., in the case of a process) may have access to each specific system resource, and the type of access that is permitted in each instance.

Access control context

- **Authentication:** Verification that the credentials of a user or other system entity are valid.
- **Authorisation:** The granting of a right or permission to a system entity to access a system resource.
- **Audit:** review and exam of system records and activities to ensure compliance with policies

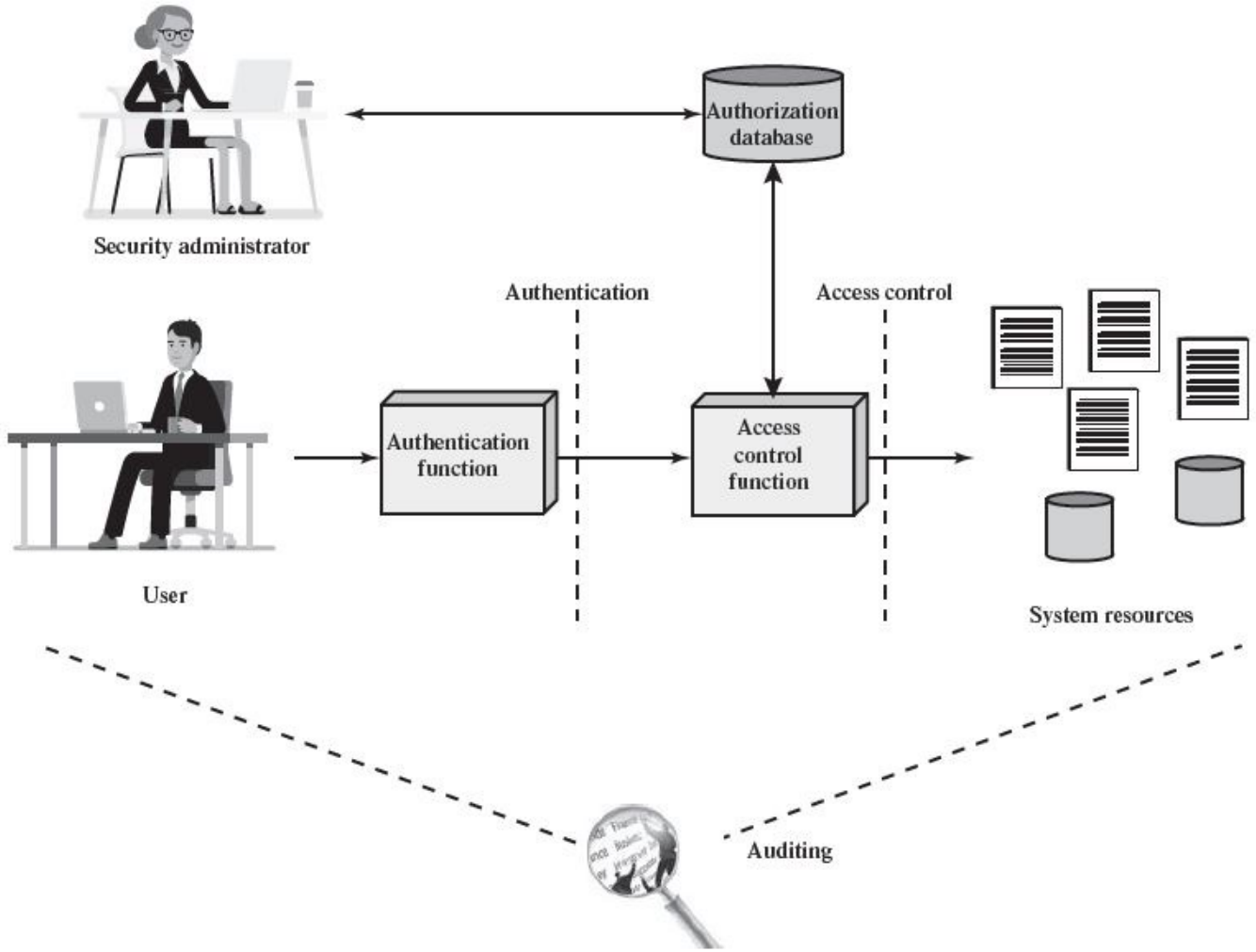


Figure 4.1 **Relationship Among Access Control and Other Security Functions**

Question

- Do we always need both authentication and access control?
- Are there any circumstances where we might apply one but not the other?

Access control policies

- An access control policy dictates what types of access are permitted, under what circumstances, and by whom.
- Categories:
  - **Discretionary access control (DAC):** Users use their own discretion to specify who can access what
  - **Mandatory access control (MAC):** control access based on comparing security labels with security clearances
  - **Role-based access control (RBAC):** control access based on users' roles
  - **Attribute-based access control (ABAC):** control access based on users' attributes

Subjects, objects, access rights

- Subject: entities capable of accessing objects → active
  - Includes users and processes
- Object: entities (resources) that are used → passive
  - Includes files, directories, memory
- Access right: describe the way in which a subject may access an object.
  - read, write, execute, delete, create, search

Access control matrices

- The concept was developed independently by researchers in operating systems and databases.
- An **access control matrix** (ACM) model is defined in terms of state and state transitions.
- The **state** of a system is defined by a triplet (S, O, A):
  - S: A set of subjects.
  - O: A set of objects.
  - A: An access control matrix, A[S, O] with entries a(s,o).
    - a(s,o) lists the access rights of s on o.
    - Access rights specify the kind of access allowed for a subject on each object.

Example: Access Control Matrix

Objects / Subjects	**File$_1$**	**File$_2$**	**Process$_1$**	…	…
Process$_1$	Read	Read Write			
Alice		Read	Execute		
Bob	Write		Execute		
Carol					
…					

Translate please

- $Process_1$ can read $File_1$:
  - If $A(Process_1, File_1) \supseteq Read$
- Alice can execute $Process_1$:
  - If $A(Alice, Process_1) \supseteq Execute$
- …

Advantages and Disadvantages of ACM?

- **Advantages:**
  - Allows for fast and easy determination of the access control rights for any subject-object pair
    - Just go to the cell of the matrix corresponding to this subject's row and object's column.
  - Gives administrators a simple, visual way of seeing the entire set of access control relationships all at once
  - The degree of control is as specific as the granularity of subject-object pairs.
- **Disadvantages:**
  - It is too big : n subjects and m objects result in a matrix with nm cells

Representations of Access Control

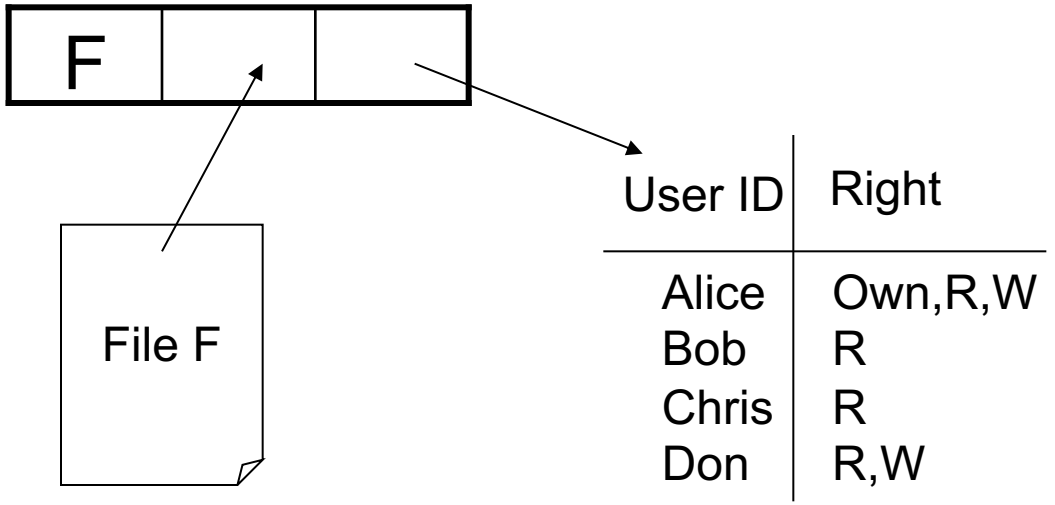
- **Access Control Lists (ACL):**
  - Contain access from the viewpoint of an object.
  - In other words, a column of the ACM.
  - For example:
    - File F : (A, Write), (B, Read).
- **Capabilities:**
  - These correspond to the viewpoint of a subject.
  - In other words, a row of the ACM.
  - For example:
    - ((Read, F1), (Write, F2)….)
  - Subject presents a capability to an object.

Access Control Lists

- A list of subjects that are authorised to access an object.
- Identity-based policies (such as individual-based and role-based policies) can be realised in a straightforward way.
- Maintenance of the list and enforcement of the access control are essentially the responsibility of the systems and environment surrounding the object.
- Access control list:

s1	s2	s3	...
r1	r2	r3	...

- What does it mean?
  - Subject s1, s2, s3 … have rights r1, r2, r3 … for this object.
  - The subjects could be individuals or roles (team leaders, managers…)



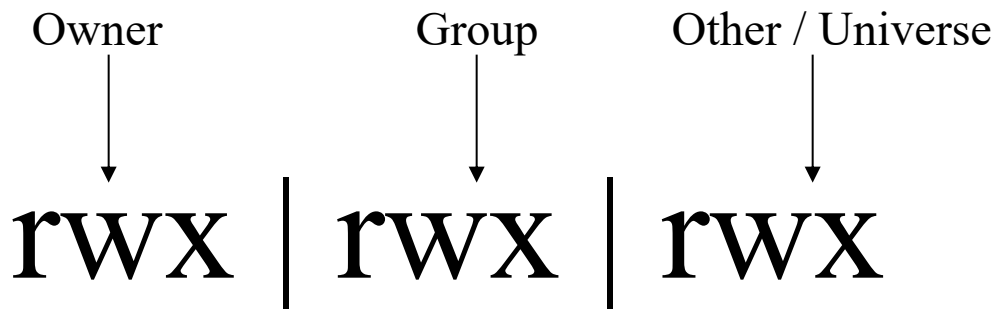
Access control lists are used to protect owned objects. The owner can confer/invoke rights by adding, deleting or modifying the entry for a user.

- In **Unix** a file has an access control list with three entries: owner, group, and other users.
- The type of access can be r, w, x (roughly).

```
$ ls -l | more
total 152
drwxr-xr-x   4 wsusilo  cs-uow       512 Aug 14  2007 111
drwxr-x---   5 greg     cs-uow       512 Nov  8  2004 112
drwxr-x---   2 david    csstf        512 Sep  8  2004 114.old
drwxr-x---   7 txia     other        512 Oct 18  2004 121
drwxr-x---   8 dfs      csstf        512 Dec  2  2003 121.2003
drwxr-x---   5 wsusilo  cs-uow       512 Sep  9  2003 121.old
drwxrwx---   4 koren    other        512 Apr  4  2006 124
lrwxrwxrwx   1 root     other         37 Jan  7 15:43 131 -> /web/itacs/documents/subjects/csci131
drwxr-x---   4 jrg      cs-uow       512 Jun  7  2001 1999.235
drwxrwxr-x   2 ian      csci203m    1024 May 30 11:46 203
drwxr-x---  10 greg     uowugc       512 Sep 20  1999 203.old
drwxr-sr-x   7 lukemc   csci204m     512 May 16 17:14 204
drwxr-x---   2 dfs      root         512 Jul 21  2007 204.dfs
drwxr-xr-x   7 lei      cs-uow       512 May 28 13:33 212
…
```

The permission string…

- The permission string - --- --- --- can be (if we ignore the first element) written in terms of permissions for the three classes:



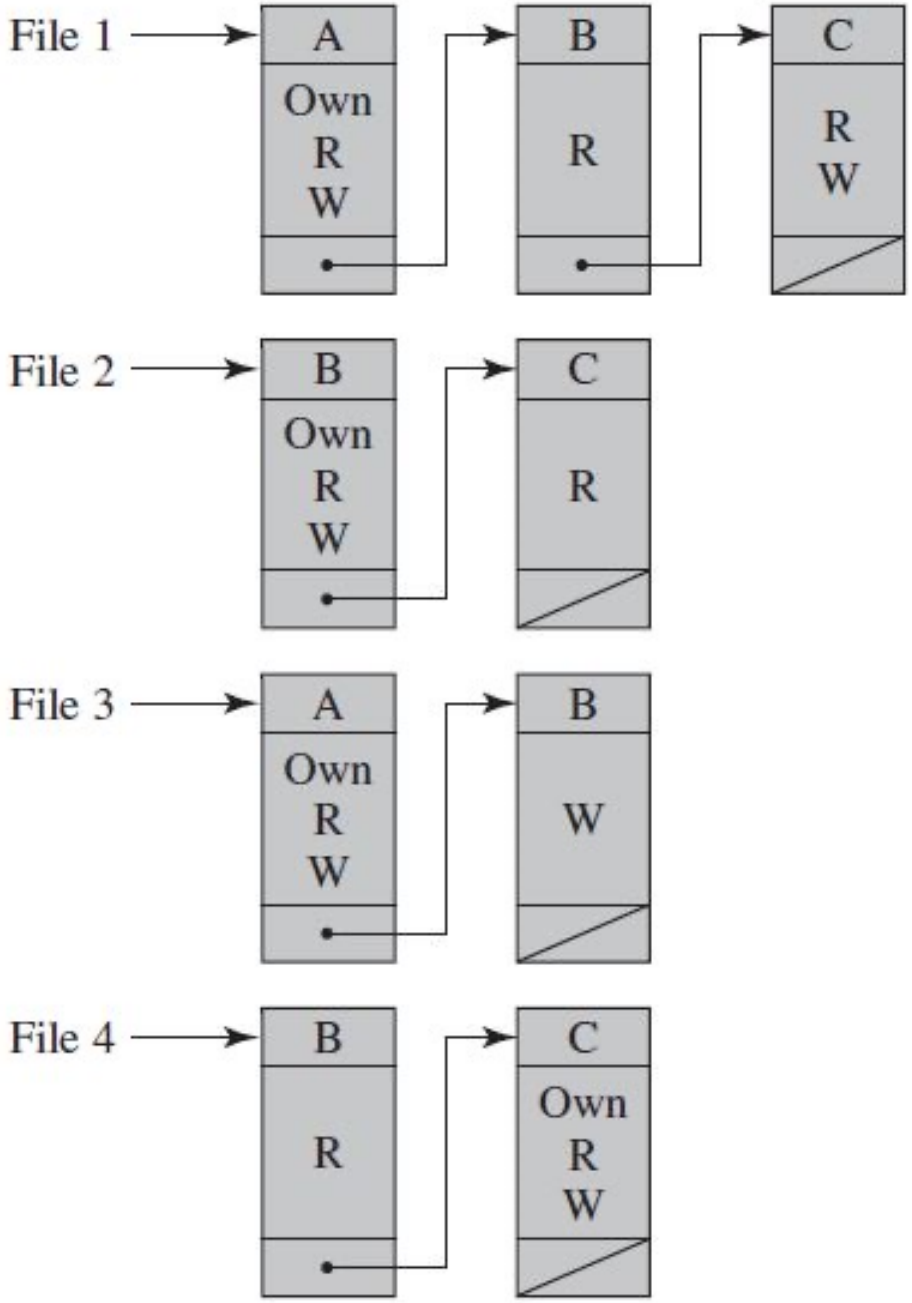
- The ‘R’ permission means read.
- The ‘W’ permission means write.
- The ‘X’ permission means execute on a file. In the context of a directory it means the directory can be searched.

- These permissions can also be described as a 3 digit octal (base 8) number. The *read* flag contributes a 4, the *write* flag contributes a 2 and the *execute* flag contributes a 1.

- So the following would yield the octal permission 744.

-rwxr--r--

4 (r) + 2 (w) + 1 (x) for owner	7
4 (r) for group	4
4 (r) for others/ universe	4



SUBJECTS	OBJECTS: File 1	File 2	File 3	File 4
User A	Own Read Write		Own Read Write	
User B	Read	Own Read Write	Write	Read
User C	Read Write	Read		Own Read Write

Figure 4.2 in [SB18]

- File 1: (A,Own/R/W), (B,R), (C,R/W)
- File 2: (B,Own/R/W), (C,R)
- File 3: (A,Own/R/W), (B,W)
- File 4: (B,R), (C,Own/R/W)

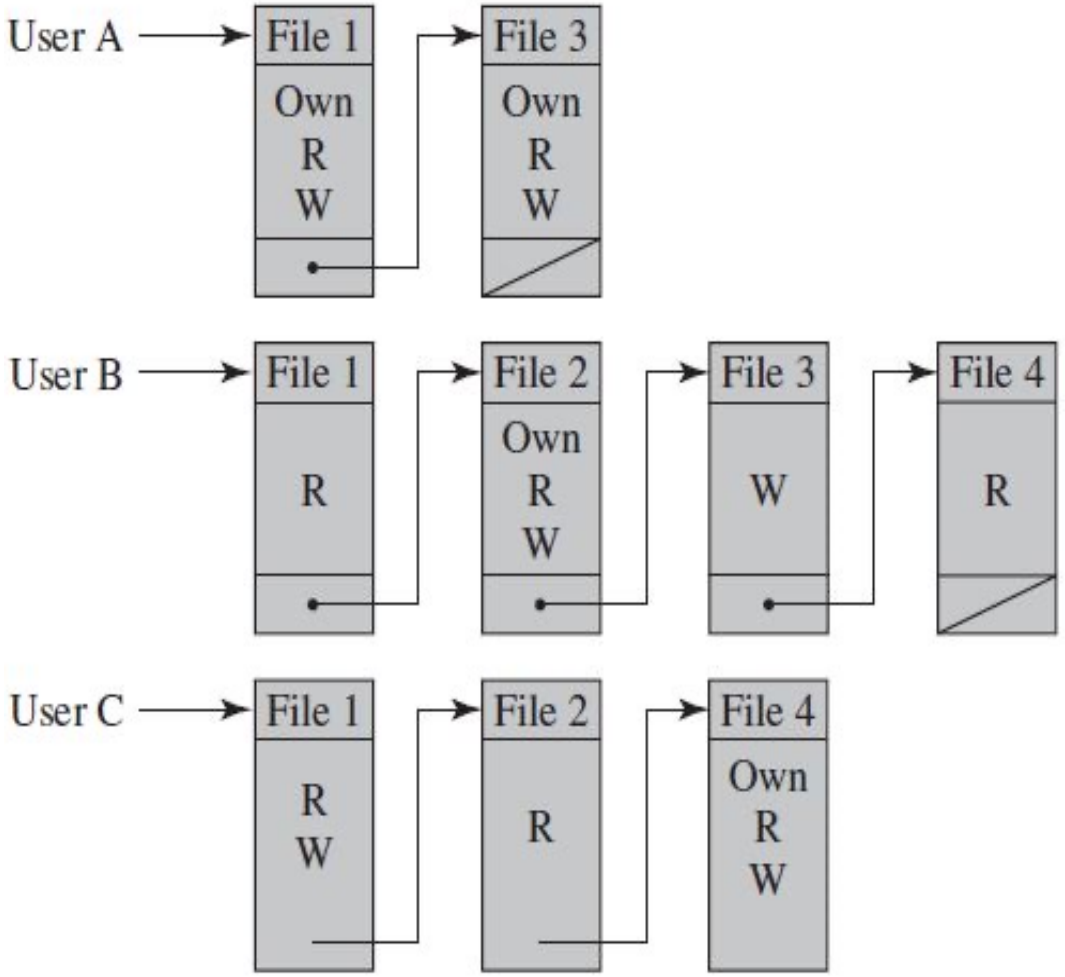
Advantages & disadvantages of ACL

- **Advantages:**
- The main advantage of ACLs over access control matrices is size
- the ACL for an object can be stored directly with that object as part of its metadata, which is particularly useful for file systems.
  - The header blocks for files and directories can directly store the access control list of that file or directory
    - Thus, if the operating system is trying to decide if a user or process requesting access to a certain directory or file in fact has that access right, the system need only consult the ACL of that object.
- **Disadvantages:**
- Don’t provide an efficient way to enumerate all the access rights of a given subject.
  - In order to determine all the access rights for a given subject, s, a secure system based on ACLs would have to search the access control list of every object looking for records involving s.
  - Unfortunately, this computation is sometimes necessary

Capabilities

- Describes what a subject is capable of doing.
- Subject : With a list of (Object, Rights)
- Classical Capability System:
  - Capability : A triplet: <Object, Rights, Check>
  - Check = f(Object, Rights).
- We can think of a capability as a ticket that authorises the holder to access an object in a particular way.
  - The Check is there for authentication. It could be something like a message authentication code or digital signature (see CSCI361).
  - Capabilities are difficult to revoke.

- To obtain access an access request and the capability are transmitted to the appropriate server.
- Access Decision:
  - When the access request and capability arrive, the function f is applied to detect tampering.
  - If the capability passes => access is granted!



SUBJECTS	OBJECTS: File 1	File 2	File 3	File 4
User A	Own Read Write		Own Read Write	
User B	Read	Own Read Write	Write	Read
User C	Read Write	Read		Own Read Write

Figure 4.2 in [SB18]

- User A: (File 1,Own/R/W), (File 3, Own/R/W)

Advantages & Disadvantages

- **Advantages**
  - Has the same advantage in space over the access control matrix as ACL
    - A system administrator only needs to create and maintain access control relationships for subject-object pairs that have nonempty access control rights
  - Makes it easy for an administrator to quickly determine for any subject all the access rights that that subject has.
    - Just read off the capabilities list for that subject
- **Disadvantages**
  - not associated directly with objects
    - Thus, the only way to determine all the access rights for an object o is to search all the capabilities lists for all the subjects

Sandhu & Samarati's authorization table

- The access control matrix may be sparse.
  - A more concise representation, but less common, is the authorization table.
- One row of the table is used for each allowed access triplet.
- The table can be sorted by Subject or Object to give equivalence to a capability list or an ACL, respectively.
- A relational database can easily implement an authorization table of this type. (More about relational database later)

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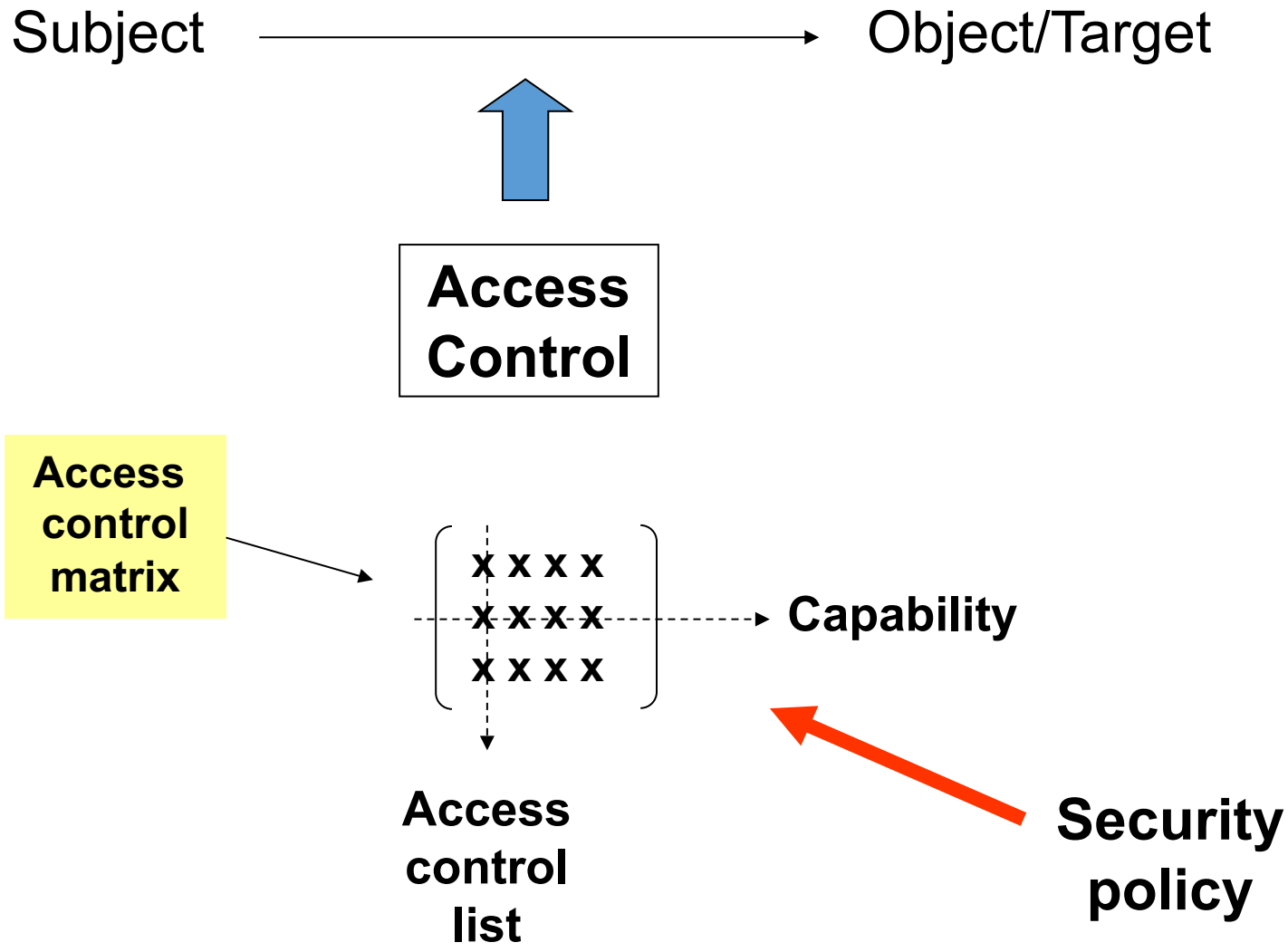
		OBJECTS			
		File 1	File 2	File 3	File 4
SUBJECTS	User A	Own Read Write		Own Read Write	
	User B	Read	Own Read Write	Write	Read
	User C	Read Write	Read		Own Read Write

Table 4.2 Authorization Table for Files in Figure 4.2

Subject	Access Mode	Object
A	Own	File 1
A	Read	File 1
A	Write	File 1
A	Own	File 3
A	Read	File 3
A	Write	File 3
B	Read	File 1
B	Own	File 2
B	Read	File 2
B	Write	File 2
B	Write	File 3
B	Read	File 4
C	Read	File 1
C	Write	File 1
C	Read	File 2
C	Own	File 4
C	Read	File 4
C	Write	File 4

A brief summary to now …



Intermediate Controls

- Group-based access control
- Previleges
- Role-based access control
- Protection ring

Group-based access control

- Users are assigned to groups.
  - Depending on the system policy, a user might be allowed to be a member of one group or multiple groups.
- Groups are given permissions to access objects.
- Each user has the permissions assigned to the group or groups it is a member of.
- We can think of grouping as being always on structures, relative to the roles we will look at soon.
  - For example, you are in a group whether you are logged in or not.

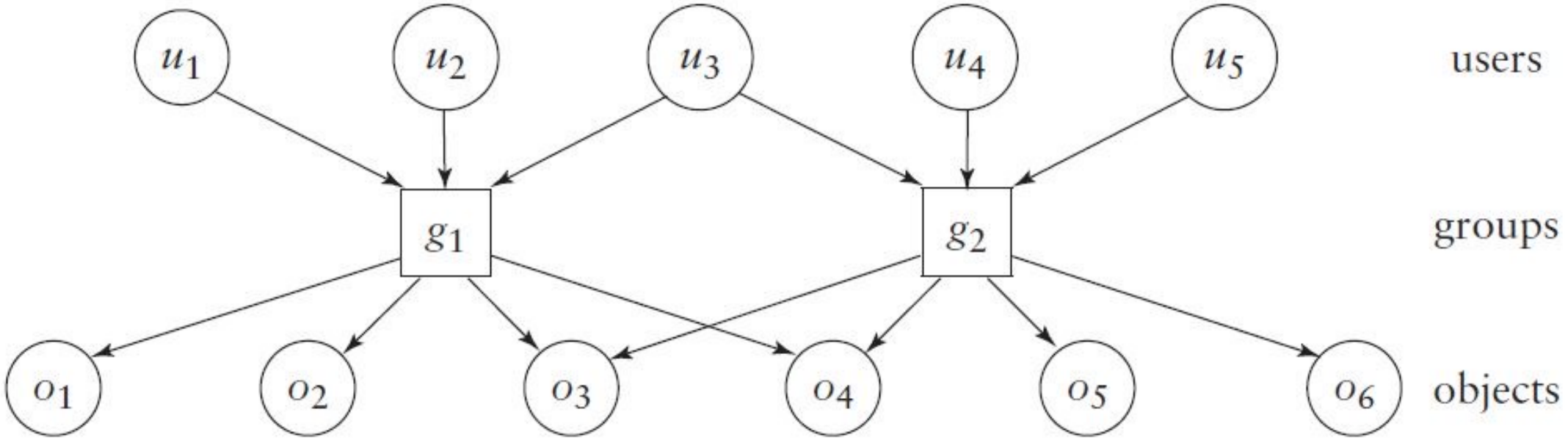


Figure 5.6 in [G11]: Groups serve as an intermediate access control layer

- All access permissions can be mediated through group membership
- For example: user u2 can access object o1 (being in group g1) and object o6 (being in group g2)

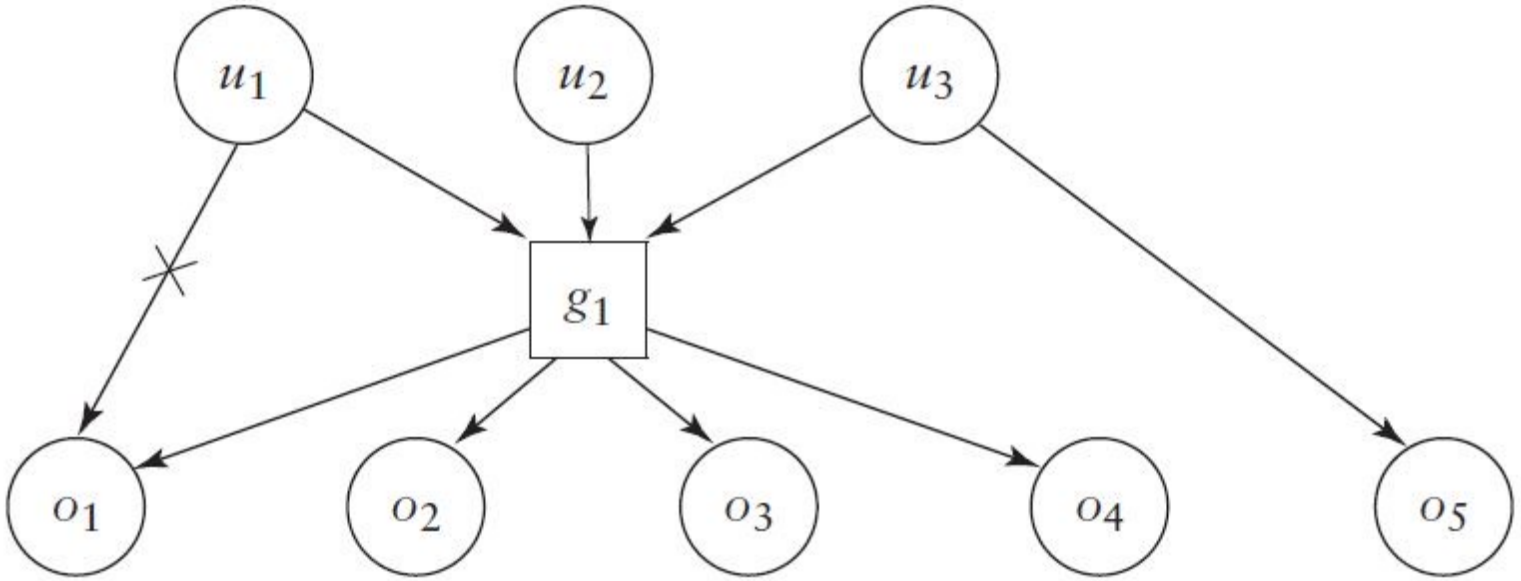
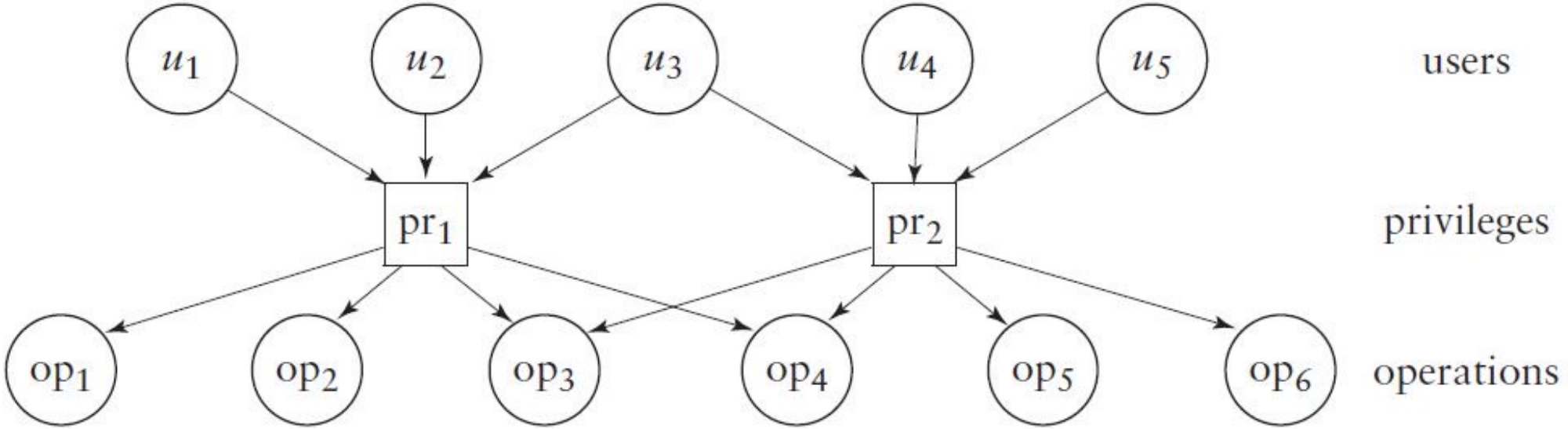


Figure 5.7 in [G11]: Access Control with Negative Permissions

- Notice the negative permission.
- A negative permission is an entry in an access control structure that specifies the access operations a user is not allowed to perform
- There is a conflict in the policies associated with s_1.
  - There would need to be a reference monitor policy to resolve this conflict.

Privileges : action grouping

- Privileges can be viewed as intermediate between subjects and actions or operations.
  - A subject is assigned privileges that allow the subject to execute certain operations, probably on certain objects.
  - Typically, privileges are associated with OS functions and relate to activities like system administration, or network access.



Role based access: An example

- In a banking environment there are several appropriate roles: Teller, Branch Manager, Customer, System Administrator, Auditor.
- A **Teller** has permission to modify a customer account with a deposit, carry out withdrawal transactions up to a specified limit, and query all account log entries.
- A **Branch Manager** has the same permissions as a teller but can also create and terminate accounts.

- A **Customer** is allowed to query the account log for his/her own account.
- A **System Administrator** can query all system log entries, activate/deactivate the system, but cannot read or modify customer account information.
- An **Auditor** can read any data in the system but modify nothing.

Role-based access cont

- Assign access rights to roles instead of individual users.
- Users are assigned to different roles.
  - A single user may be assigned multiple roles.
  - Multiple users may be assigned to a single role.

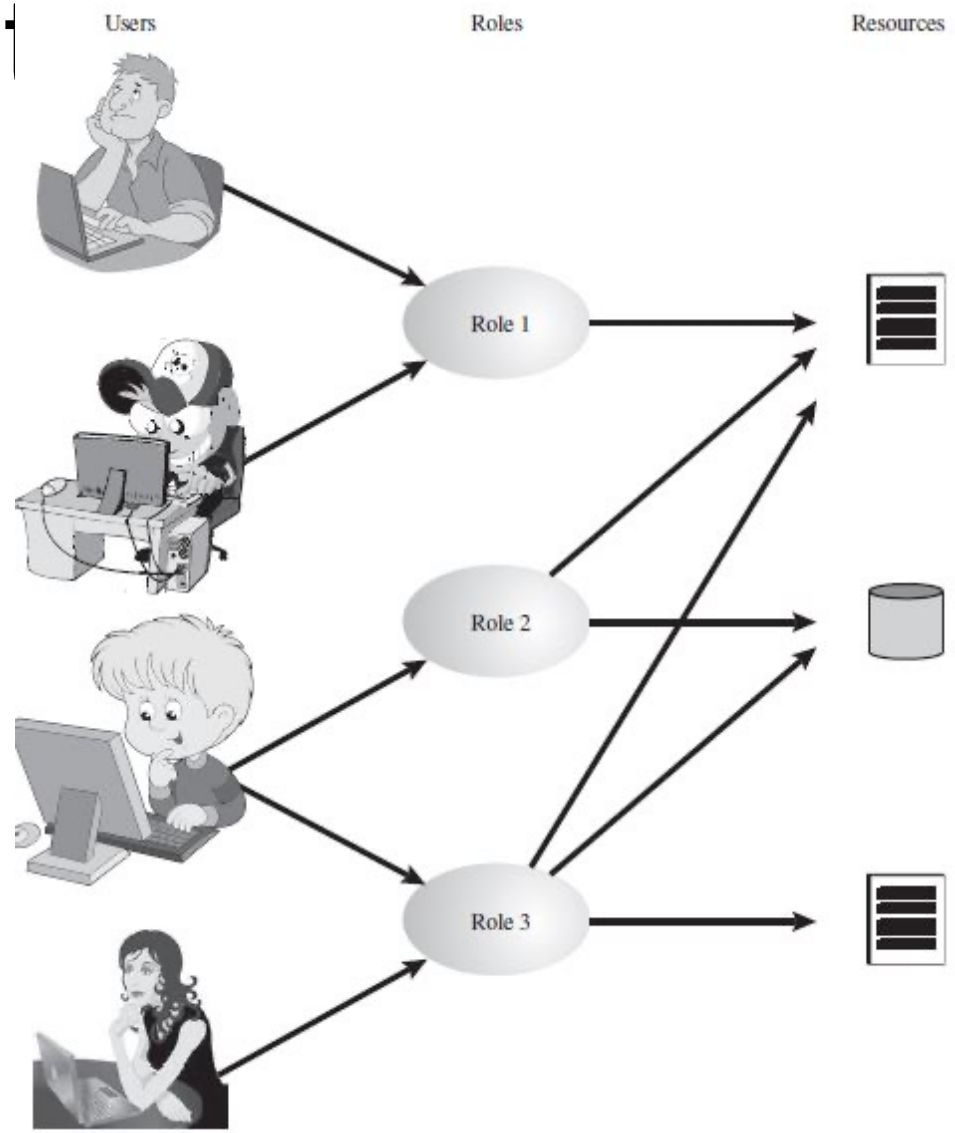


Figure 4.6 in [SB18]: Users, Roles, and Resources

ACM for RBAC

	R_1	R_2	• • •	R_n
U_1	✕			
U_2	✕			
U_3		✕		✕
U_4				✕
U_5				✕
U_6				✕
• • •				
U_m	✕			

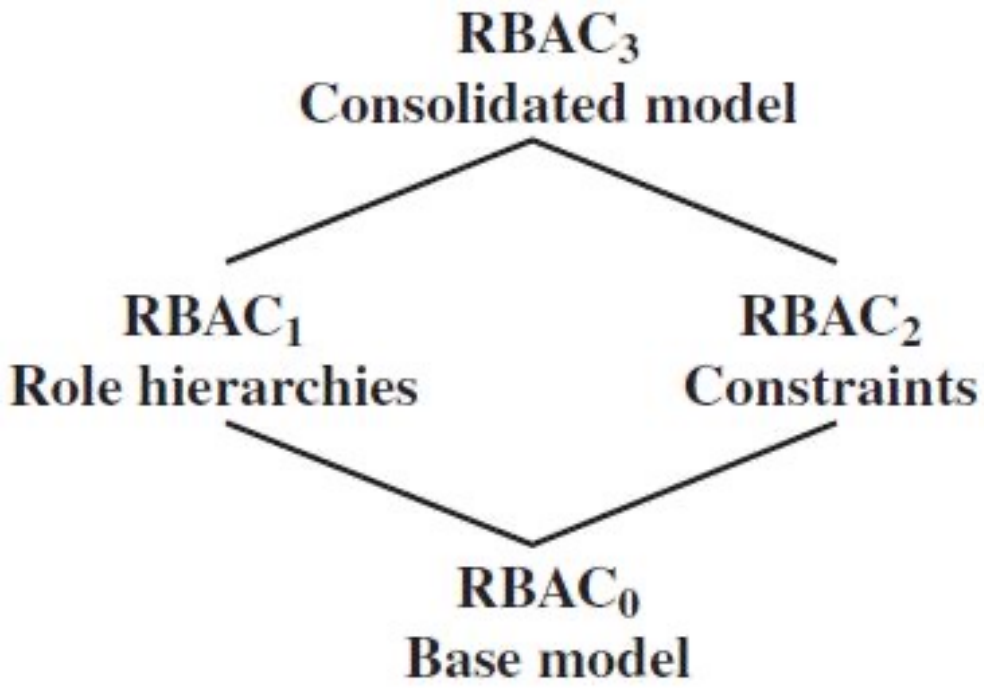
		OBJECTS							
		R_1	R_2	R_n	F_1	F_2	P_1	P_2	D_1	D_2
ROLES	R_1	control	owner	owner control	read *	read owner	wakeup	wakeup	seek	owner
	R_2		control		write *	execute			owner	seek *
	• • •									
	R_n			control		write	stop			

Figure 4.7 Access Control Matrix Representation of RBAC

- RBAC implements **principle of least privilege**:
  - Each role should contain minimum set of access rights needed for that role
  - A users is assigned to a role that enables him/her to perform only what is required for that role.
  - Multiple users assigned to the same role enjoy the same minimal set of access rights.

RBAC Models

- There are four models that are related to each other.



(a) Relationship among RBAC models

Table 4.4 **Scope RBAC Models**

Models	Hierarchies	Constraints
$RBAC_0$	No	No
$RBAC_1$	Yes	No
$RBAC_2$	No	Yes
$RBAC_3$	Yes	Yes

Figure 4.8 in [SB18]

$RBAC_1$

- Role hierarchies:
  - Can reflect the hierarchical structure of roles in an organization.
  - Makes use of the concept of inheritance.

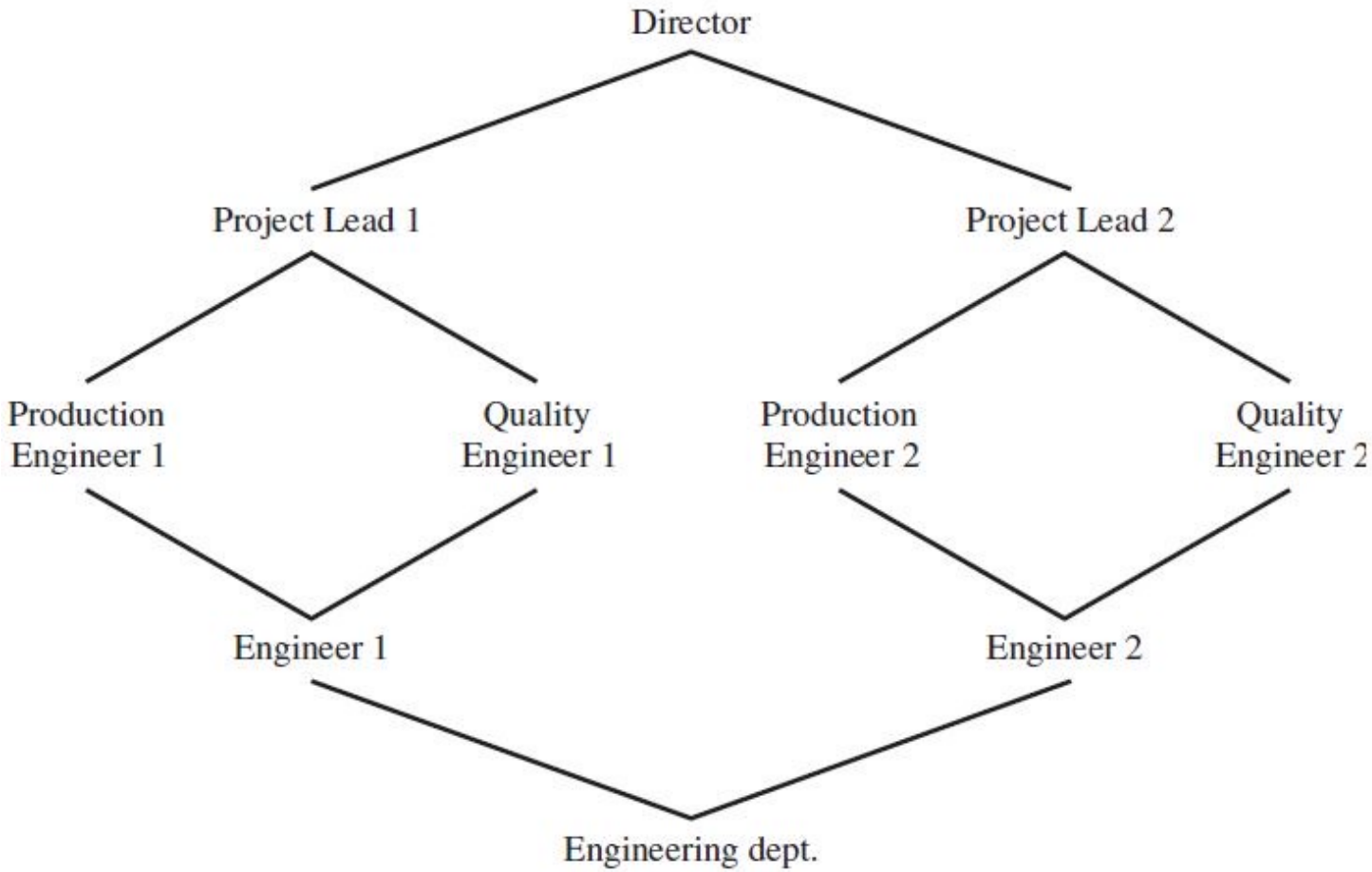


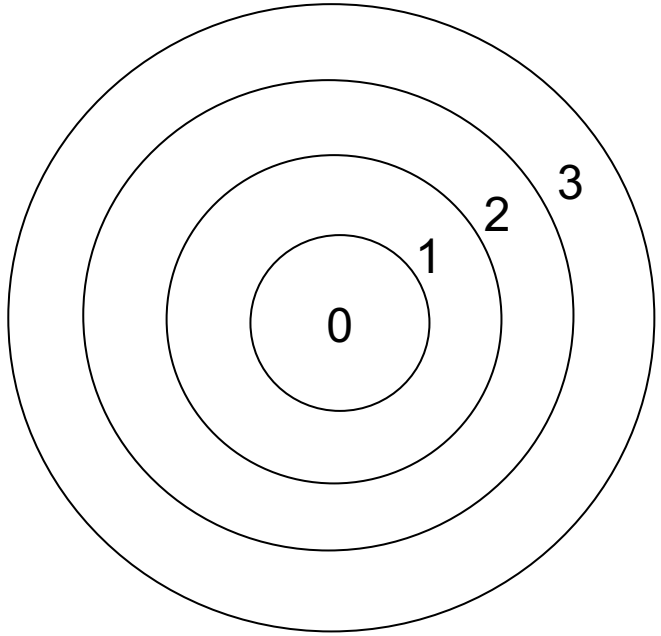
Figure 4.9 Example of Role Hierarchy

$RBAC_2$

- Constraints: mutually exclusive roles, cardinality, and prerequisite roles.
- **Mutually exclusive roles:**
  - A user can only be assigned to one role in the set (either during a session or statically).
  - Any permission (access right) can be granted to only one role in the set.
- **Cardinality:** set a maximum number with respect to roles.
  - Maximum number of users for a given role.
  - Maximum number of roles for a given user.
  - Maximum number of roles for a permission.
- **Prerequisite:** a user can only be assigned to a particular role if if it is already assigned to some other specified role.

Protection rings

- Each subject or each object is assigned a number depending on its importance.
  - For an OS, it could be:
    0: OS kernel.
    1: OS.
    2: Utilities.
    3: User processes.
  - The numbers are compared to make decisions about access control.
  - Unix, Intel processors, etc. adopt this method.



Multilevel access control

- Protection rings are a special case of multilevel.
- The numbers are generalized into **security labels**.
- Subjects and objects have these security labels assignment to them, possibly using the same name but generally with different meanings.
- For subjects the labels correspond to clearances.
  - Think of every user having a clearance.
- For objects the labels correspond to classifications or sensitivity.
- The access relationship between security labels of the two types are governed by a series of rules.
- Multilevel/multilayer models are also referred to as *data flow models*
  → This is somewhat restrictive.

- A **Security label** is a set of information security attributes bound to an object or a subject.
  - The most common use is in supporting multilevel access control policies.
- When a subject makes an access request, a label is generated and attached to the request, by a trusted process.
  - Each object has a label bound to it, identifying it with a classification level.
- To process a request, a security server in the object environment compares the request label with the object label and applies policy rules, such as the Bell-LaPadula rules, to decide whether to grant or deny access.
  - We will talk about this later.

- Labels generated in one security domain may or may not be significant in another domain:
  - Consider, for example, labels of identical format in two different organizations or in parts of a single organization.
  - Information classified as confidential in the first organization, or part thereof, should generally not be disclosed to the persons with confidential clearance in the other organization, or other part thereof.
  - Access control models taking into account “horizontal” structures are referred to as multi-lateral, more on this later.

Multilevel policies: An example

- We need to describe whether a particular attempted action will be allowed as a function of the relevant labels, using policies.
- Example:
  - Labels: Our sensitivity levels are

    Top secret
    Secret
    Confidential
    Unclassified
  - Policy: An object can only be accessed by a subject with a clearance level as high as the object classification.
    - This is somewhat vague … we will look at BLP very soon and this will be clarified.

Attribute-based Access Control (ABAC)

- This is a relatively new approach to access control.
- In this approach we can construct more complex authorisation statements based on attributes associated with subjects, objects, operations, and the environment.
  - It doesn’t have the subject focus on RBAC.
- The flexibility is it’s upside, the performance cost, checks per access, it’s downside.

ABAC elements

- **Attributes**: Defined for entities.
- **Policy Model**: Defines the policies – so the rules and relationships for governing what's allowed and what's disallowed.
- **Architecture**: This is the infrastructure used to manage requests, at the policy and enforcement levels, and carry out the interactions with the sources of attributes.

Type of ABAC Attributes

- Attributes are characteristics defining specific aspects.
- Subject attributes:
  - Define identity and characteristics of the subject.
  - Examples: Name, age, job title, roles, …
- Object attributes:
  - As above but for an object.
  - Examples: File name, file title, creation date, …
- Environment attributes:
  - Largely only lightly used.
  - Examples: Date, time, attacker activity,…

ABAC Logical Architecture

1. A subject requests to an object
2. The access control mechanism is governed by a set of rules (2a) that are defined by a preconfigured access control policy to determine authorisation.
3. Allow/deny access.

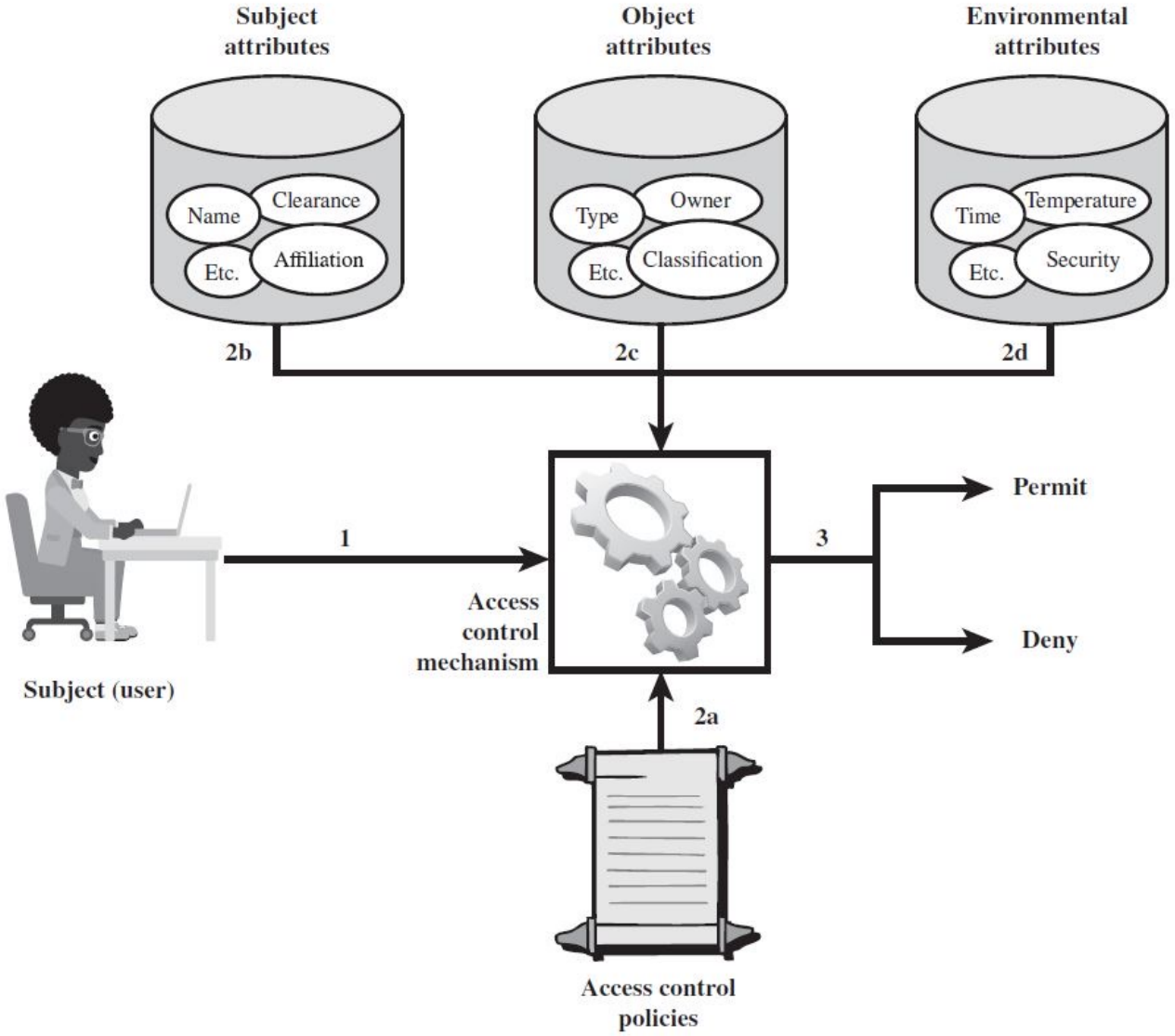


Figure 4.10 in [SB18]