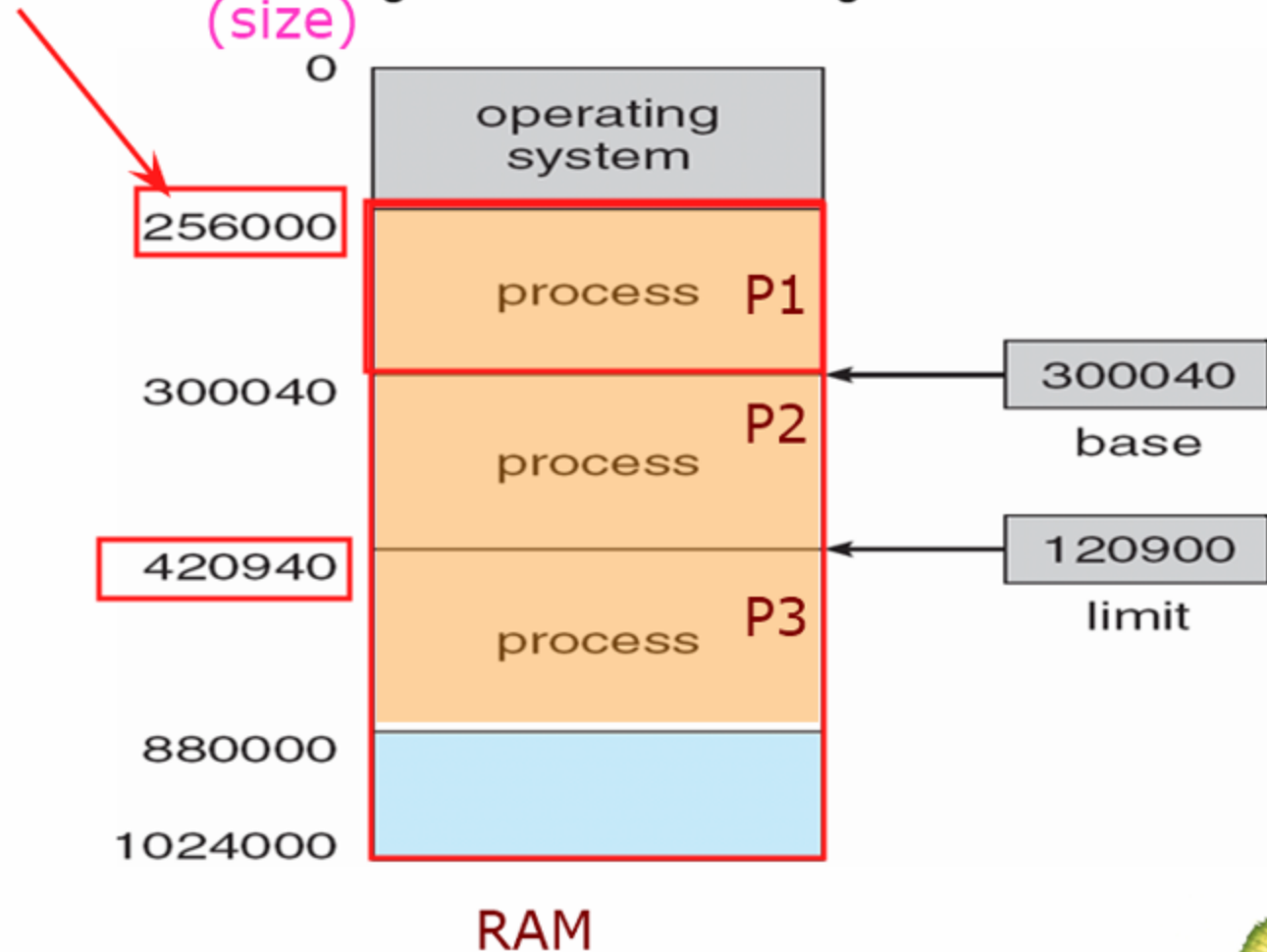




# Base and Limit Registers

$$200 + 330 = 530$$

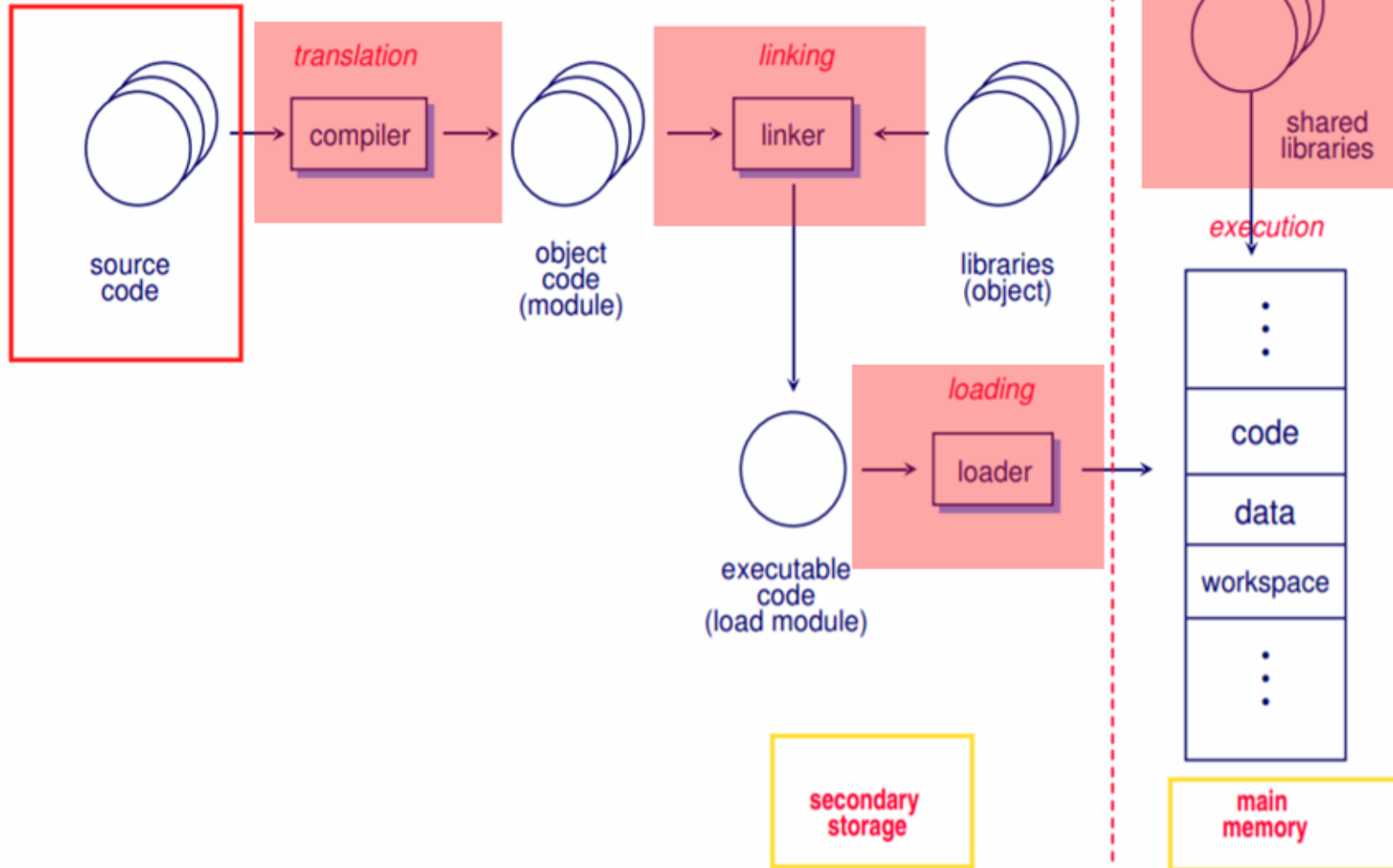
- A pair of **base** and **limit (size)** registers define the logical address space



# From *source* to *executable code*

Program

Process





# Binding of Instructions and Data to Memory

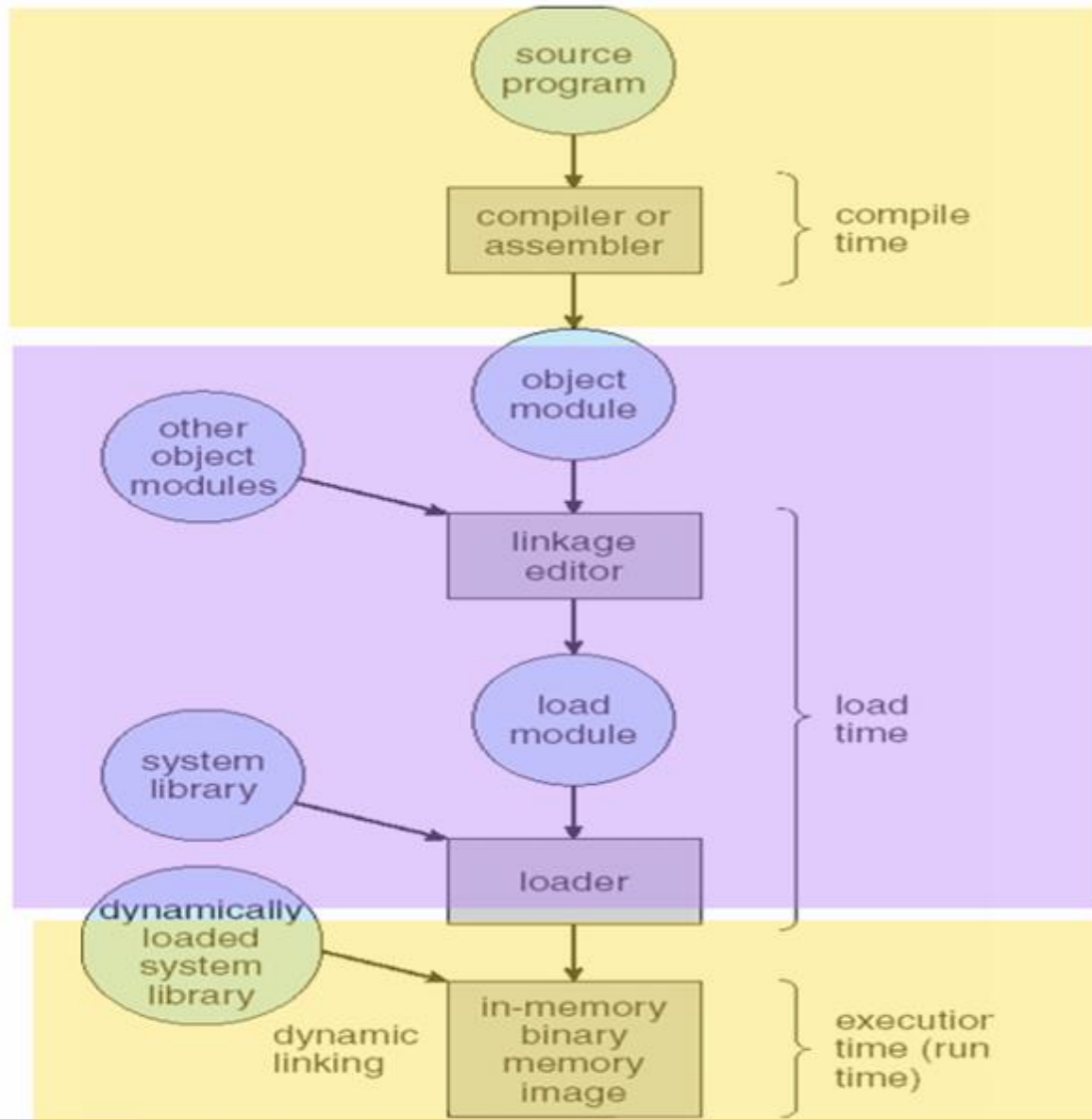
---

- Address binding of instructions and data to memory addresses can happen at three different stages
  - **Compile time:** If memory location known a priori, **absolute code** can be generated; must recompile code if starting location changes
  - **Load time:** Must generate **relocatable code** if memory location is not known at compile time
  - **Execution time:** Binding delayed until run time if the process can be moved during its execution from one memory segment to another. Need hardware support for address maps (e.g., base and limit registers)



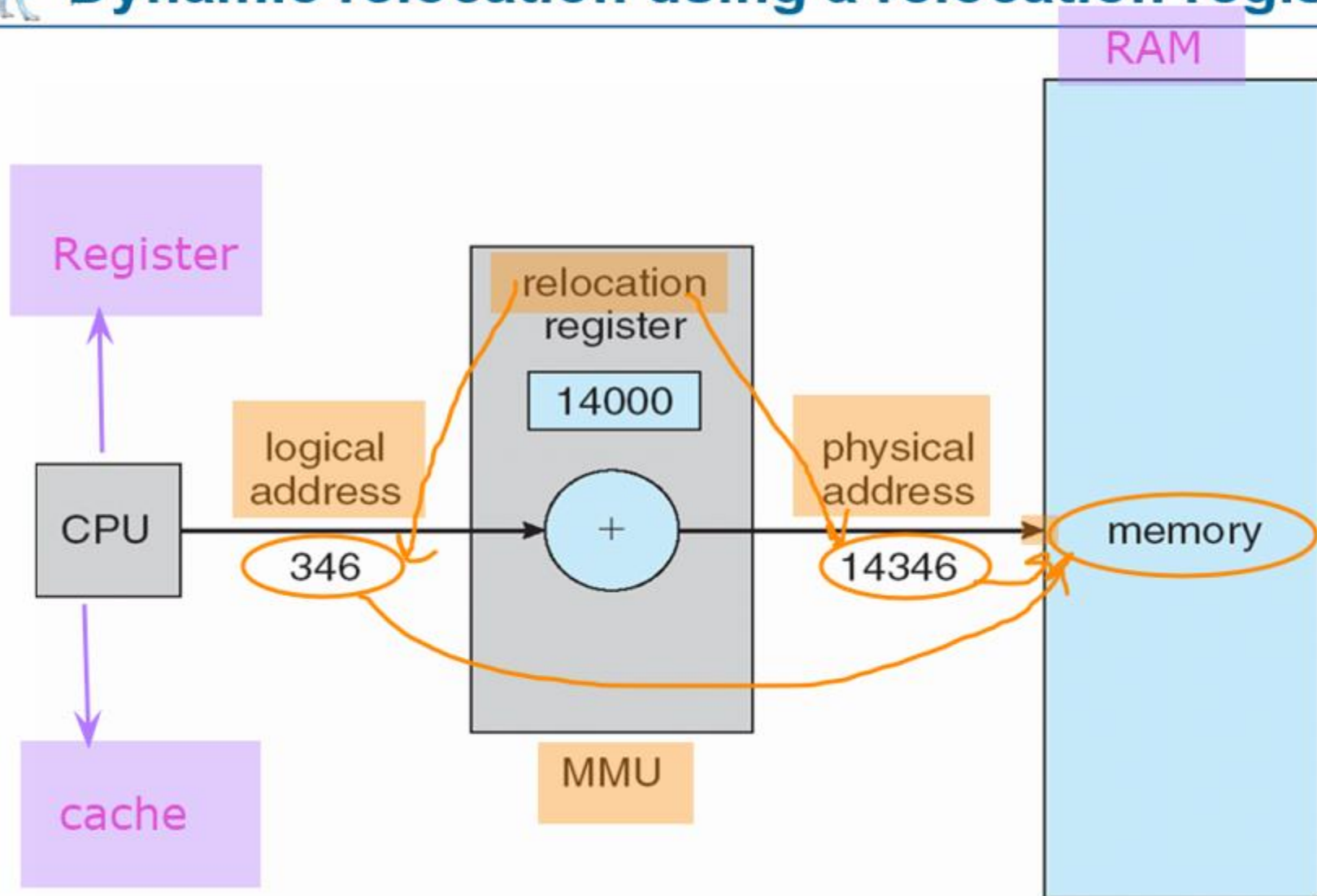


# Multistep Processing of a User Program





# Dynamic relocation using a relocation register



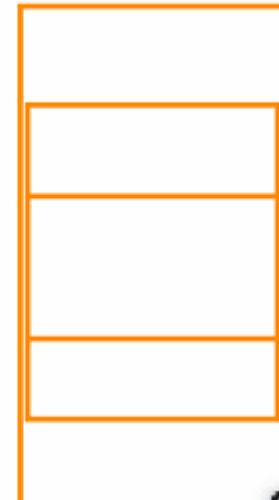


# Dynamic Loading

- ❑ Routine is not loaded until it is called
- ❑ Better memory-space utilization; unused routine is never loaded
- ❑ Useful when large amounts of code are needed to handle infrequently occurring cases
- ❑ No special support from the operating system is required implemented through program design

Static Loading →

Dynamic Loading →







# Dynamic Linking

- ❑ Linking postponed until execution time
- ❑ Small piece of code, *stub*, used to locate the appropriate memory-resident library routine
- ❑ Stub replaces itself with the address of the routine, and executes the routine
- ❑ Operating system needed to check if routine is in processes' memory address
- ❑ Dynamic linking is particularly useful for libraries
- ❑ System also known as **shared libraries**

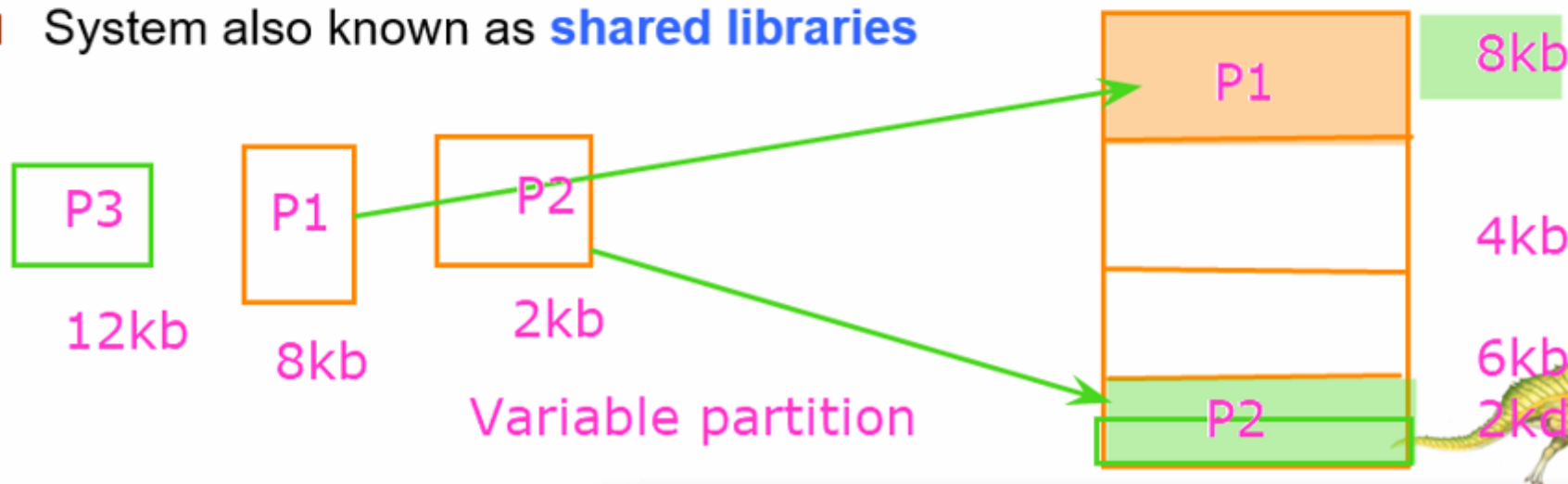
## Memory Management Techniques





# Dynamic Linking

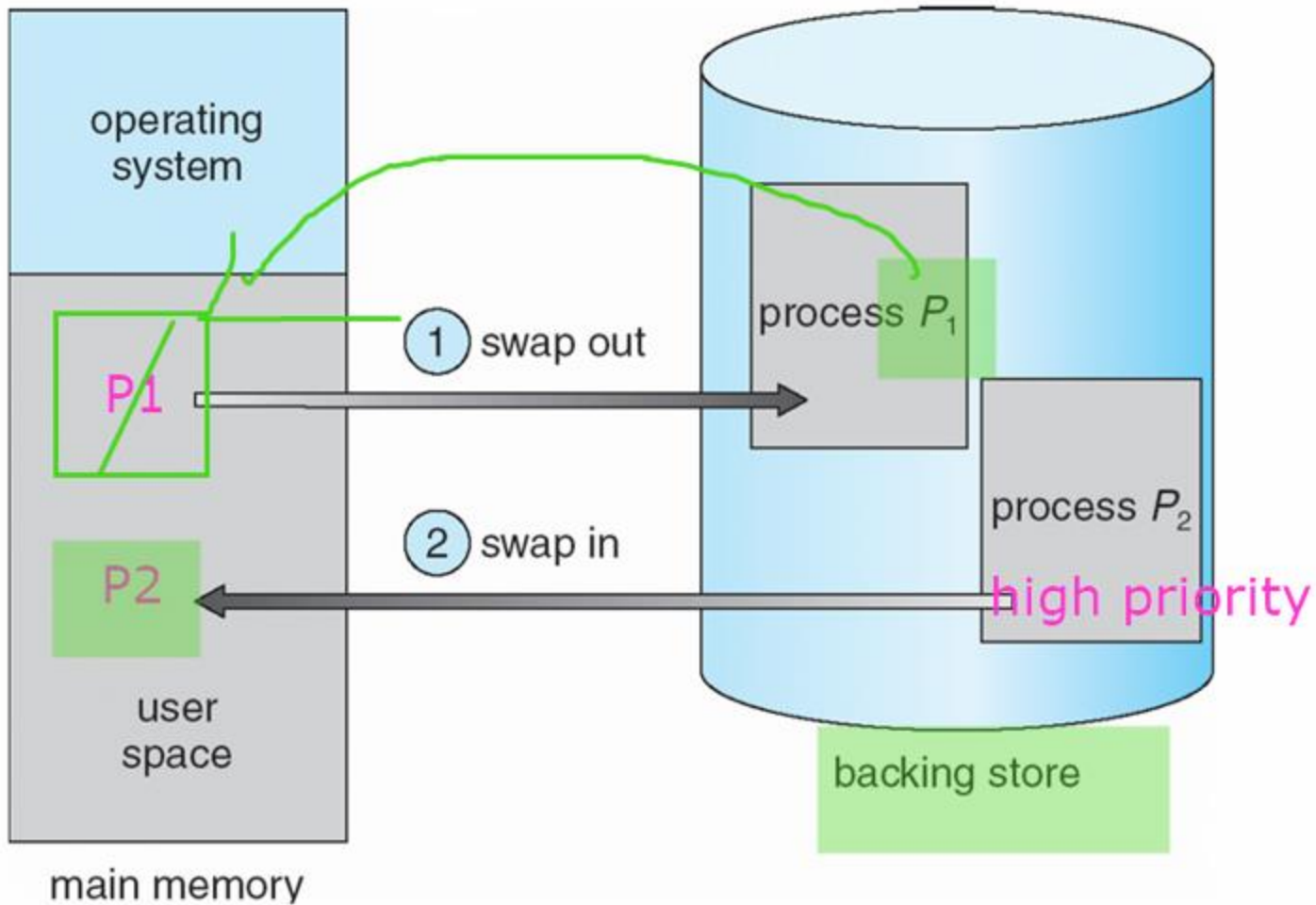
- ❑ Linking postponed until execution time
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- ❑ Operating system needed to check if routine is in processes' memory address
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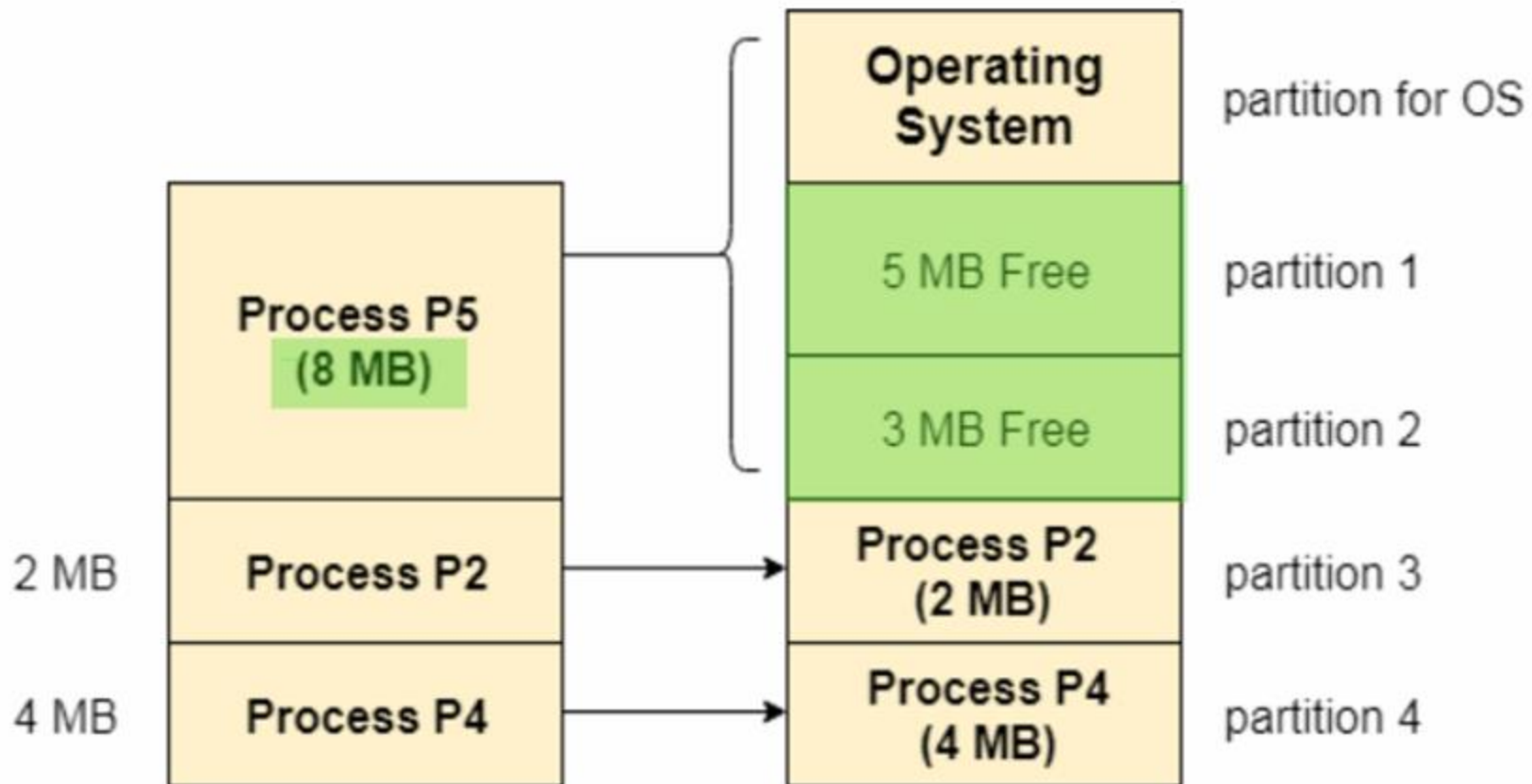






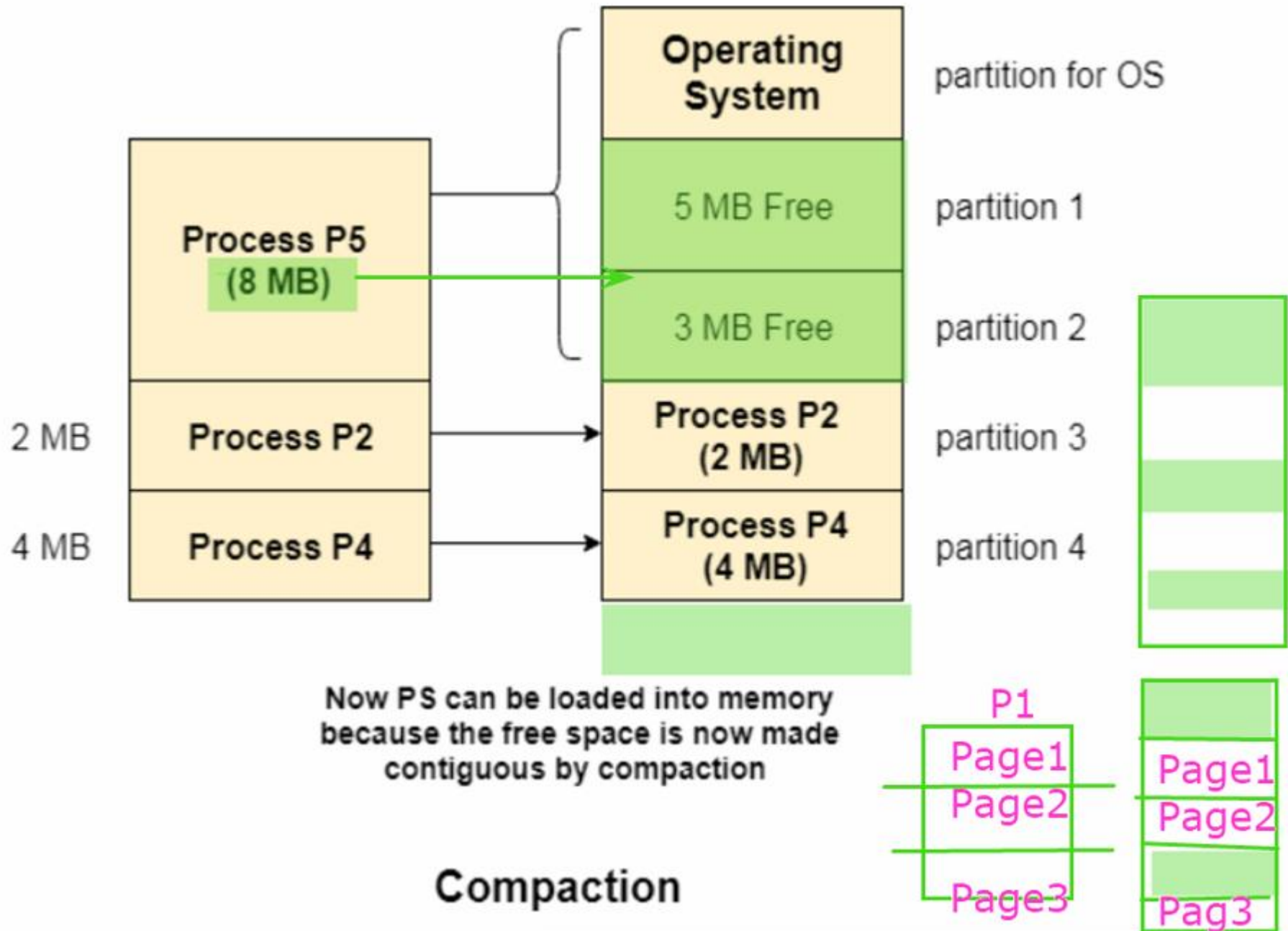
# Schematic View of Swapping

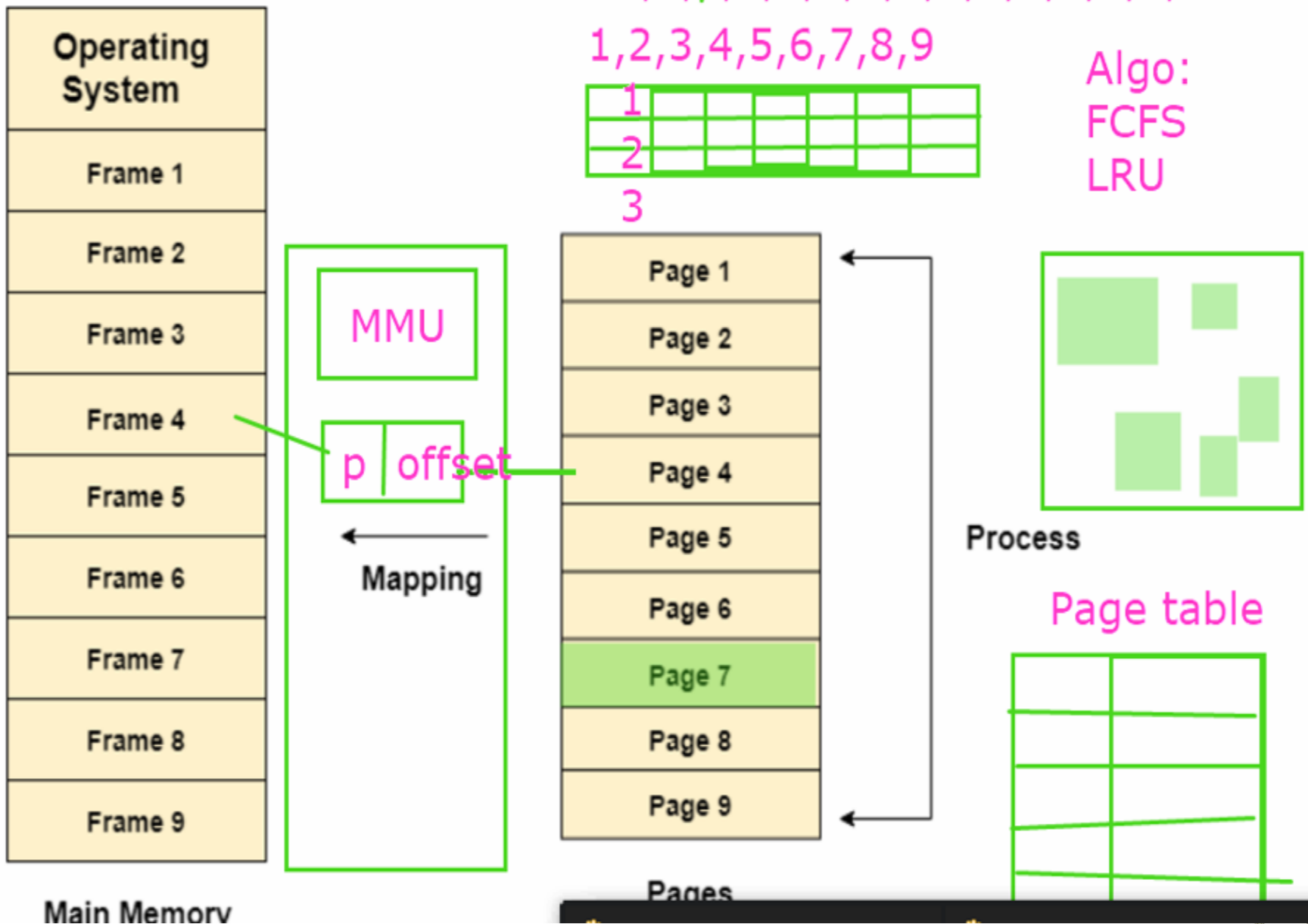




Now P5 can be loaded into memory  
because the free space is now made  
contiguous by compaction

## Compaction

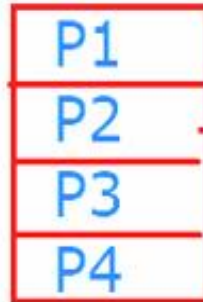




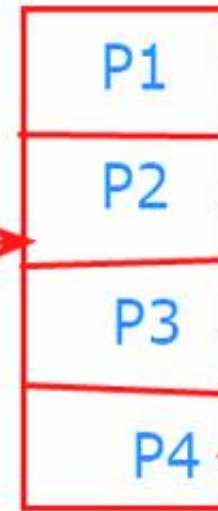


Page fault: miss the page  
Page hit: receive the page

Page



Frame



Ram

x6  
swap area

x1

P1

P2

x2

x3

P4

x5

P3

Virtual Mem



Page Replacement Algorithm

FCFS

LRU

Optimal

Kiran Wa



# Chapter 4: Threads

- Overview
- Multithreading Models
- Thread Libraries
- Threading Issues
- Operating System Examples
- Windows XP Threads
- Linux Threads

Program  
Process  
Threads

-path of execution within a process  
-multiple threads in parallel.  
-lightweight process  
-life cycle







# Chapter 4: Threads

- Overview
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Program  
Process  
Threads

-path of execution within a process  
-multiple threads in parallel.  
-lightweight process  
-life cycle

Types of Threads

1. Single-threaded Process
2. Multi-threaded process

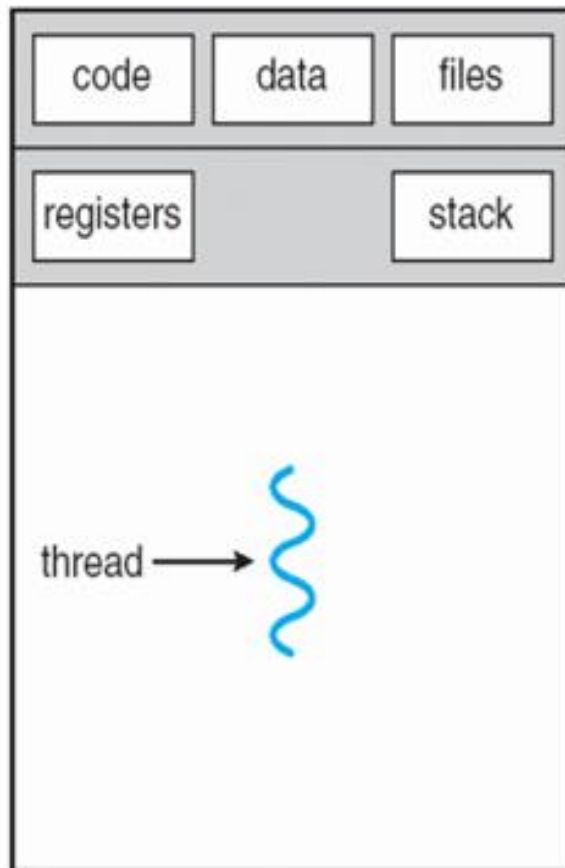
User Threads

Kernel Threads

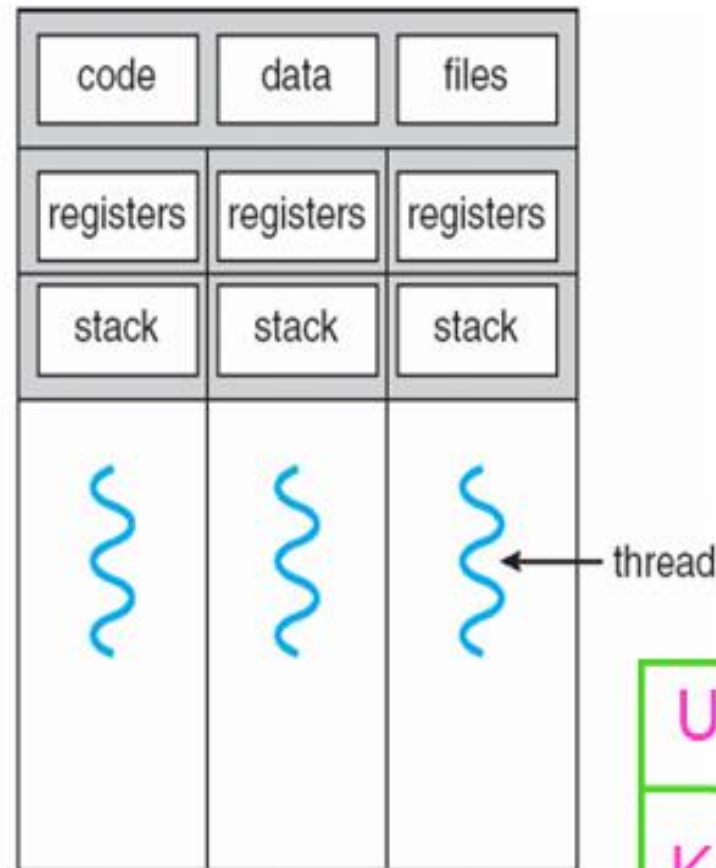




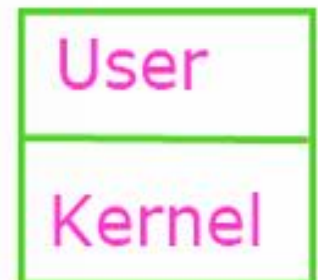
# Single and Multithreaded Processes



single-threaded process



multithreaded process



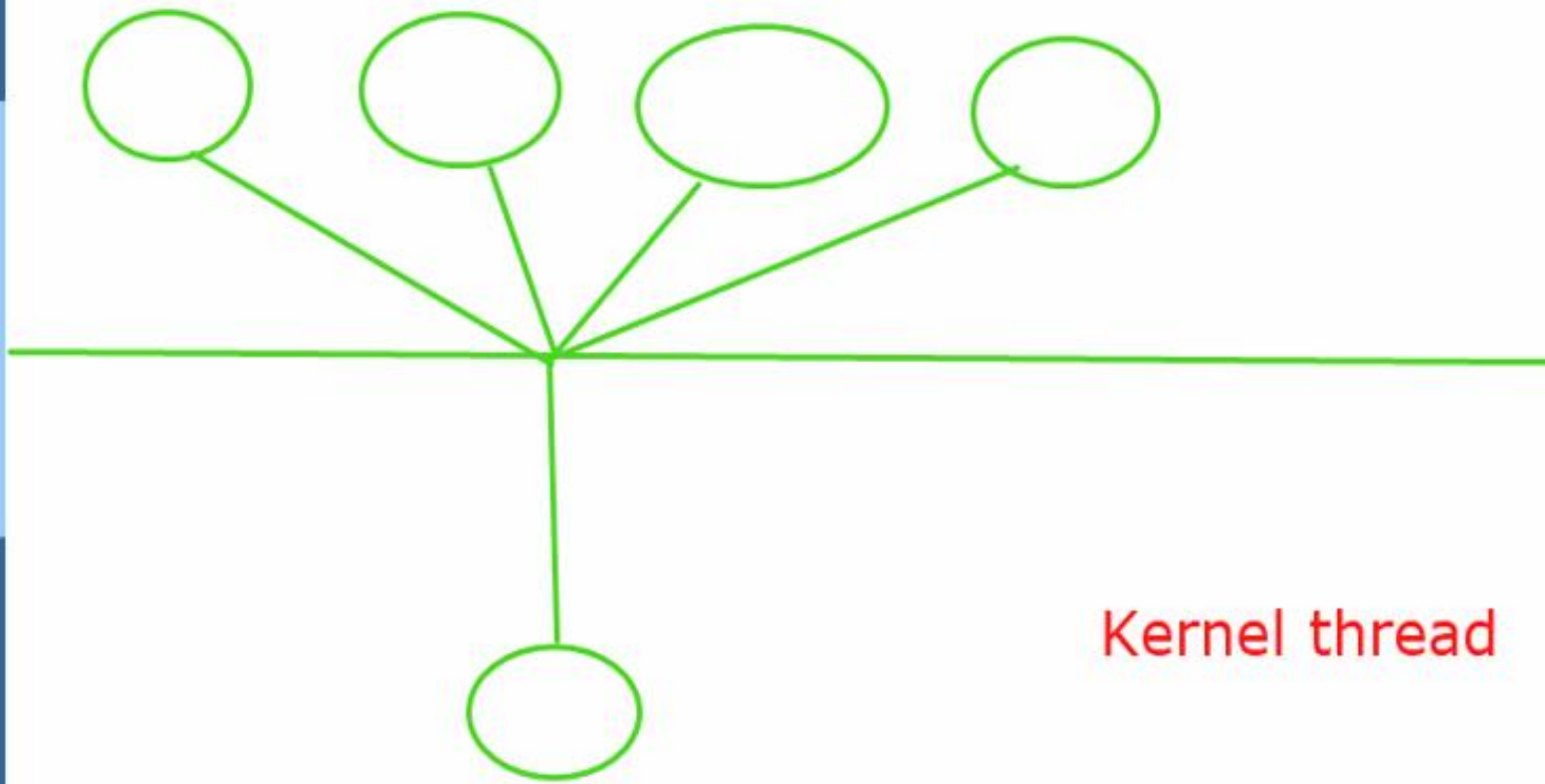


## Multithreading Models

Kiran Wagh...

Many to One Model

User thread



Kernel thread

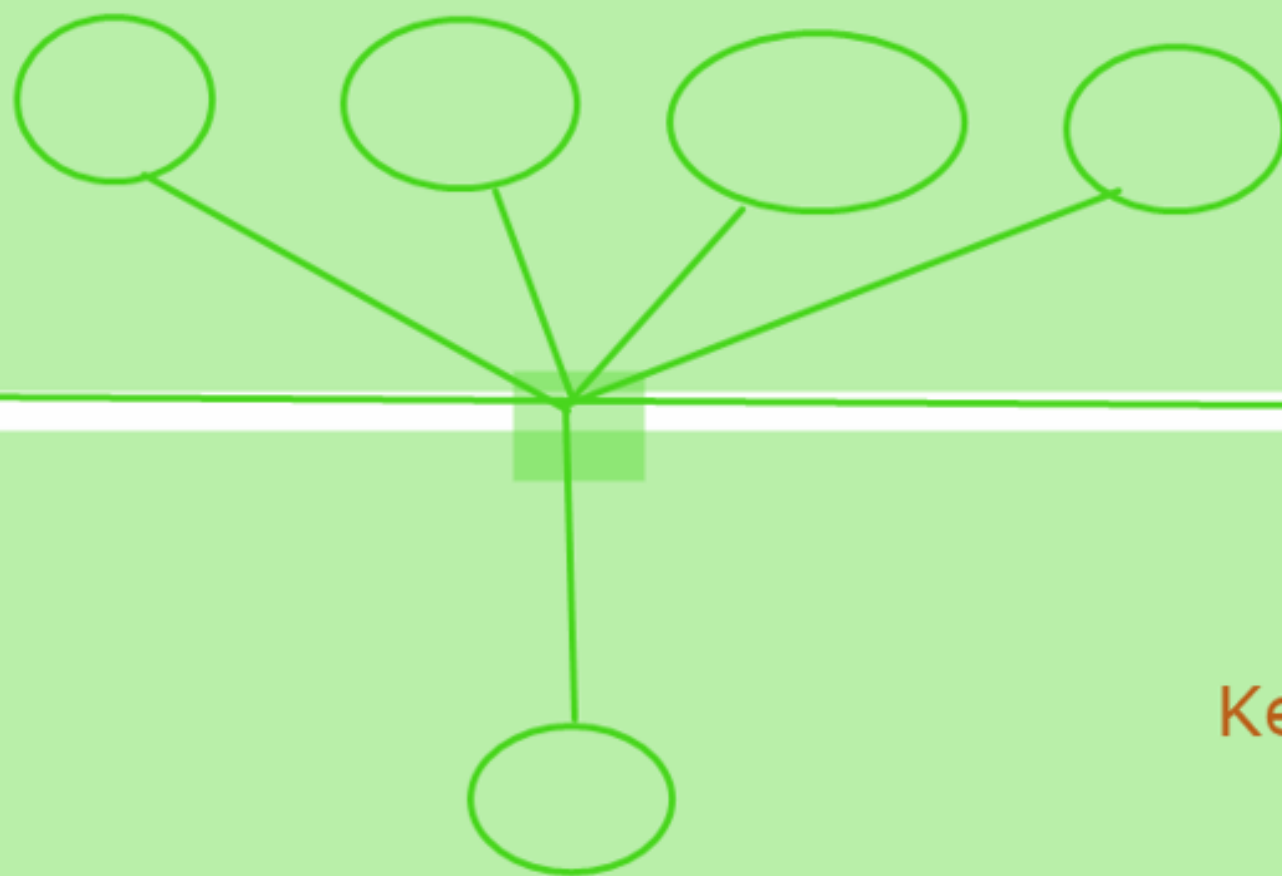




# Multithreading Models

Many to One Model

User thread



Kernel thread





# Multithreading Models

Many to Many Model

User thread



open()

close()

API

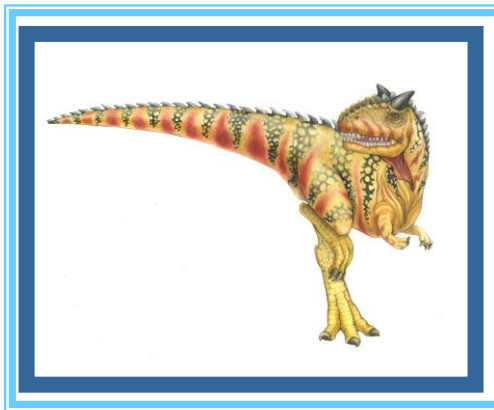


Kernel thread



# Deadlocks

---







# Deadlocks

---

- The Deadlock Problem
- System Model
- Deadlock Characterization
- Methods for Handling Deadlocks
- Deadlock Prevention
- Deadlock Avoidance
- Deadlock Detection
- Recovery from Deadlock





# Chapter Objectives

---

- To develop a description of deadlocks, which prevent sets of concurrent processes from completing their tasks
- To present a number of different methods for preventing or avoiding deadlocks in a computer system





# The Deadlock Problem

- A set of blocked processes each holding a resource and waiting to acquire a resource held by another process in the set
- Example
  - System has 2 disk drives
  - $P_1$  and  $P_2$  each hold one disk drive and each needs another one
- Example
  - semaphores  $A$  and  $B$ , initialized to 1

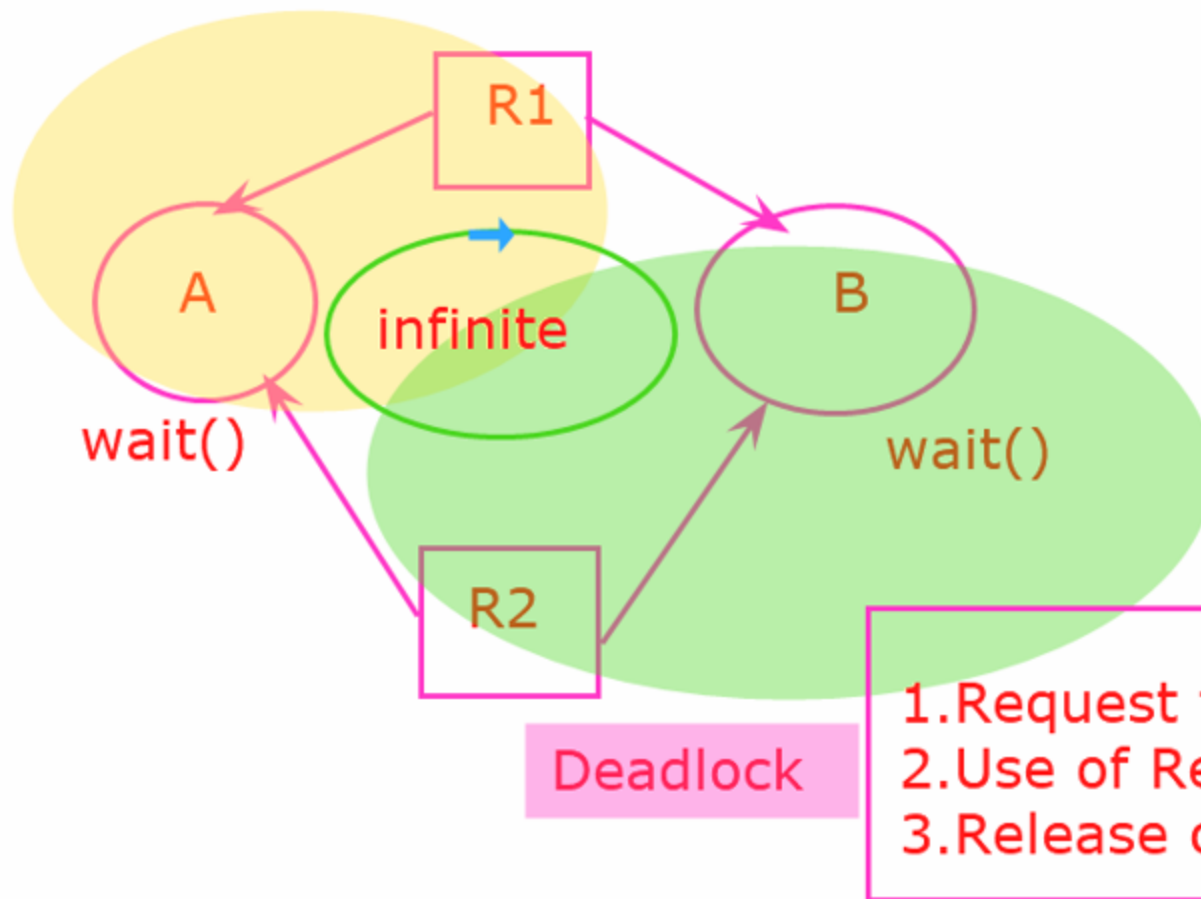
$P_0$	$P_1$
wait (A);	wait(B)
wait (B);	wait(A)





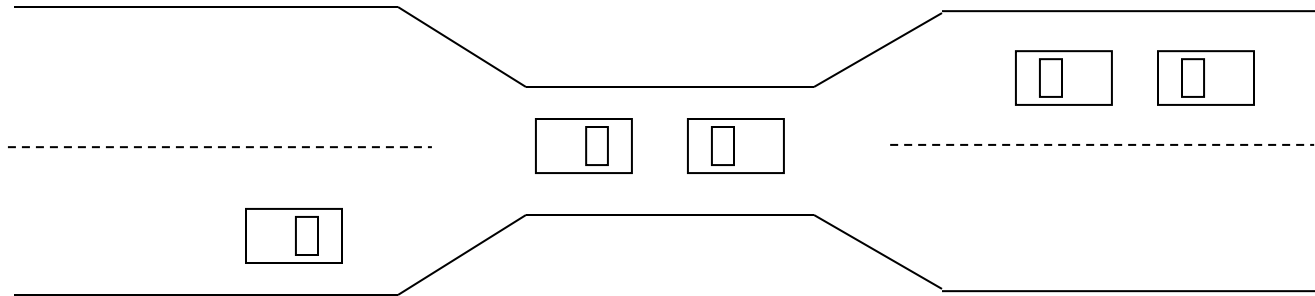
# Deadlock

Uses some resources and used resources.





# Bridge Crossing Example



- ❑ Traffic only in one direction
- ❑ Each section of a bridge can be viewed as a resource
- ❑ If a deadlock occurs, it can be resolved if one car backs up (preempt resources and rollback)
- ❑ Several cars may have to be backed up if a deadlock occurs
- ❑ Starvation is possible
- ❑ Note – Most OSes do not prevent or deal with deadlocks





# System Model

---

- Resource types  $R_1, R_2, \dots, R_m$   
*CPU cycles, memory space, I/O devices*
- Each resource type  $R_i$  has  $W_i$  instances.
- Each process utilizes a resource as follows:
  - **request**
  - **use**
  - **release**







# Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously.

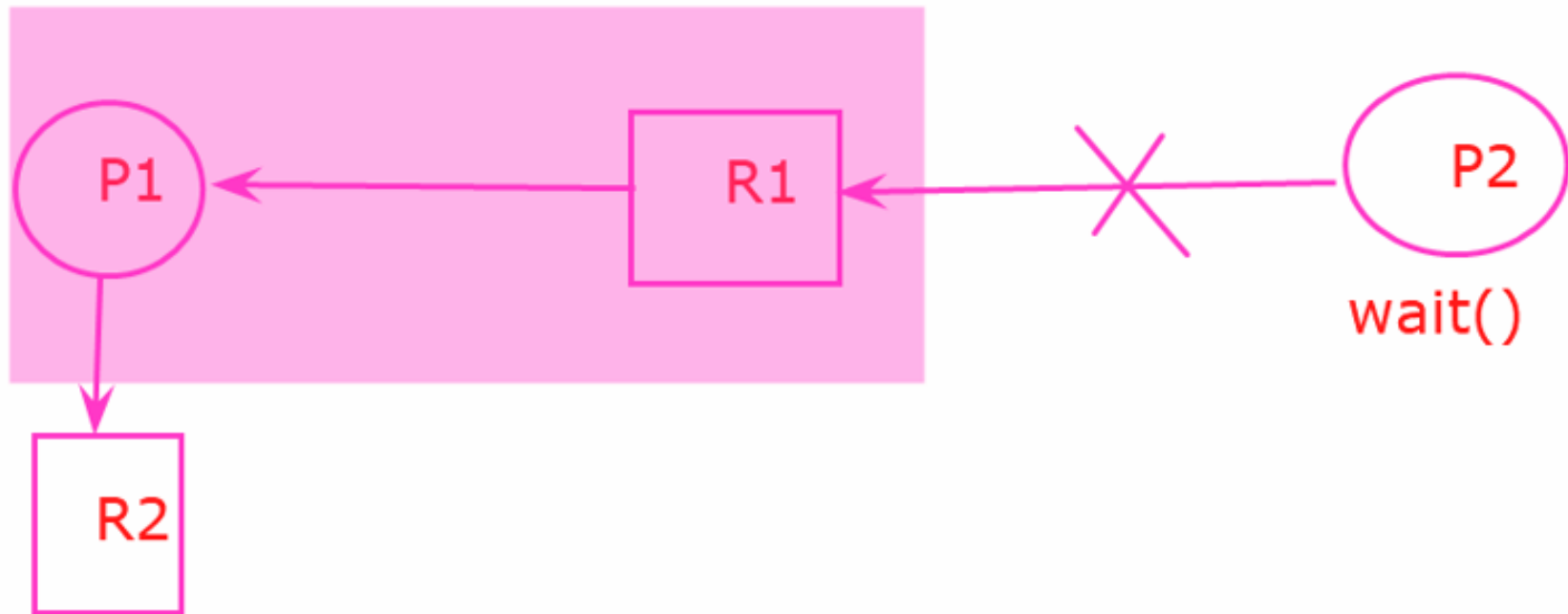
- **Mutual exclusion:** only one process at a time can use a resource
- **Hold and wait:** a process holding at least one resource is waiting to acquire additional resources held by other processes
- **No preemption:** a resource can be released only voluntarily by the process holding it, after that process has completed its task
- **Circular wait:** there exists a set  $\{P_0, P_1, \dots, P_n\}$  of waiting processes such that  $P_0$  is waiting for a resource that is held by  $P_1$ ,  $P_1$  is waiting for a resource that is held by  $P_2$ , ...,  $P_{n-1}$  is waiting for a resource that is held by  $P_n$ , and  $P_n$  is waiting for a resource that is held by  $P_0$ .





# Conditions for Deadlock to occur

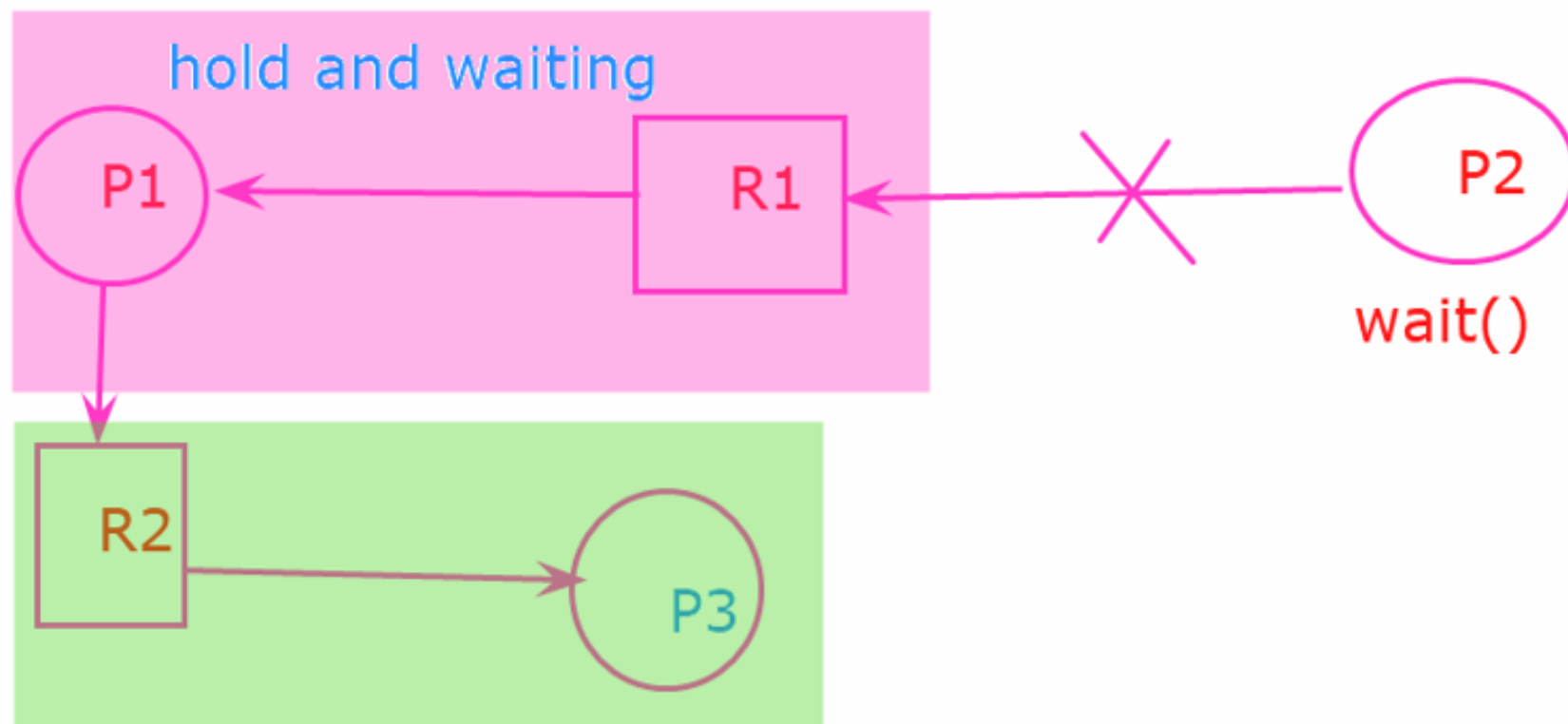
## 1. Mutual Exclusion





# Conditions for Deadlock to occur

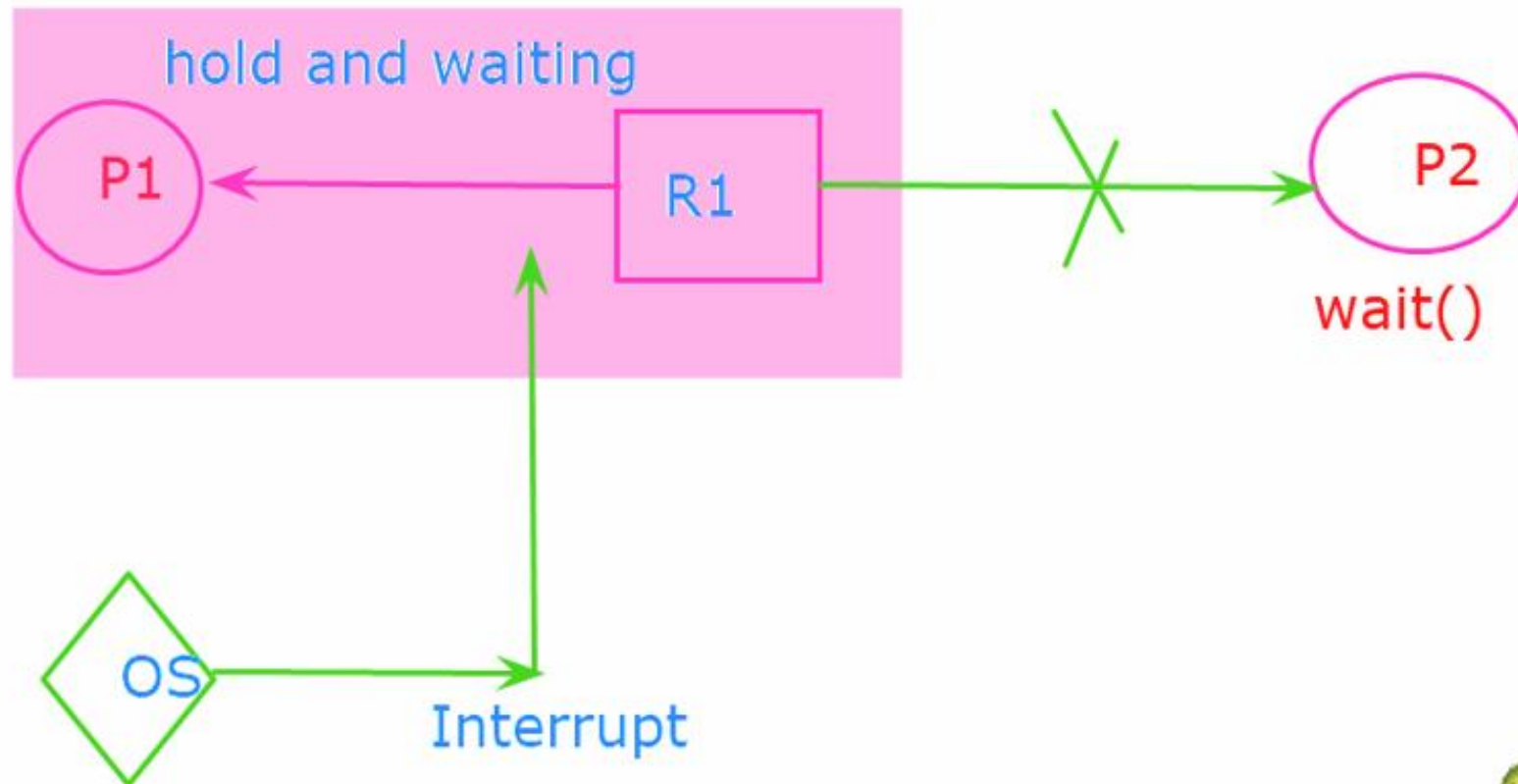
## 2. Hold and Wait





# Conditions for Deadlock to occur

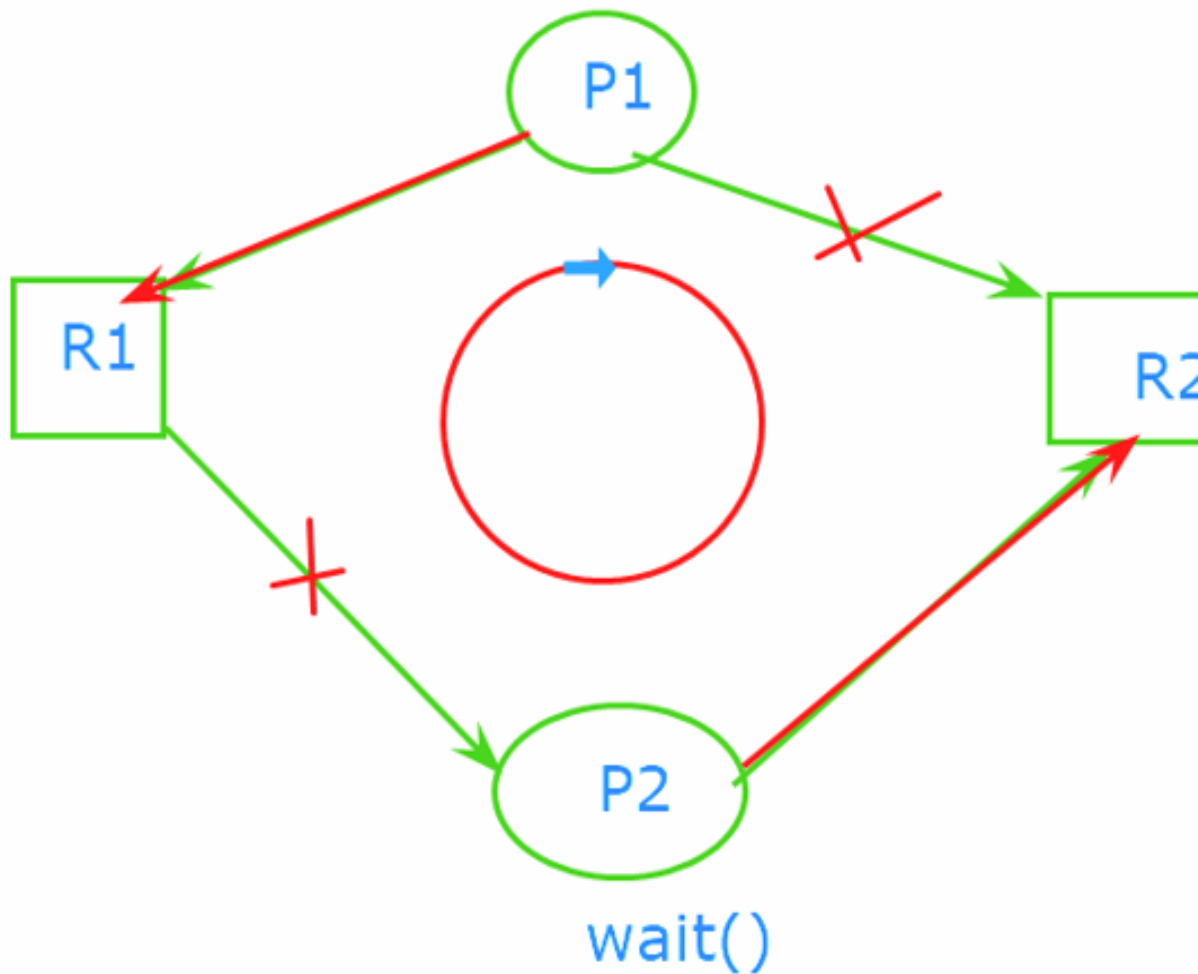
## 3. No Pre-emption





# Conditions for Deadlock to occur

## 4. Circular wait





# Resource-Allocation Graph

A set of vertices  $V$  and a set of edges  $E$ .

- $V$  is partitioned into two types:
  - $P = \{P_1, P_2, \dots, P_n\}$ , the set consisting of all the processes in the system
  - $R = \{R_1, R_2, \dots, R_m\}$ , the set consisting of all resource types in the system
- **request edge** – directed edge  $P_i \rightarrow R_j$
- **assignment edge** – directed edge  $R_j \rightarrow P_i$







# Resource-Allocation Graph (Cont.)

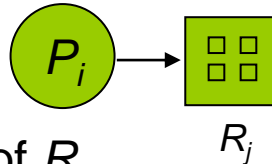
- Process



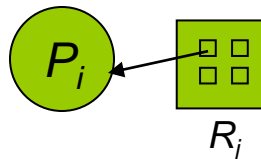
- Resource Type with 4 instances



- $P_i$  requests instance of  $R_j$

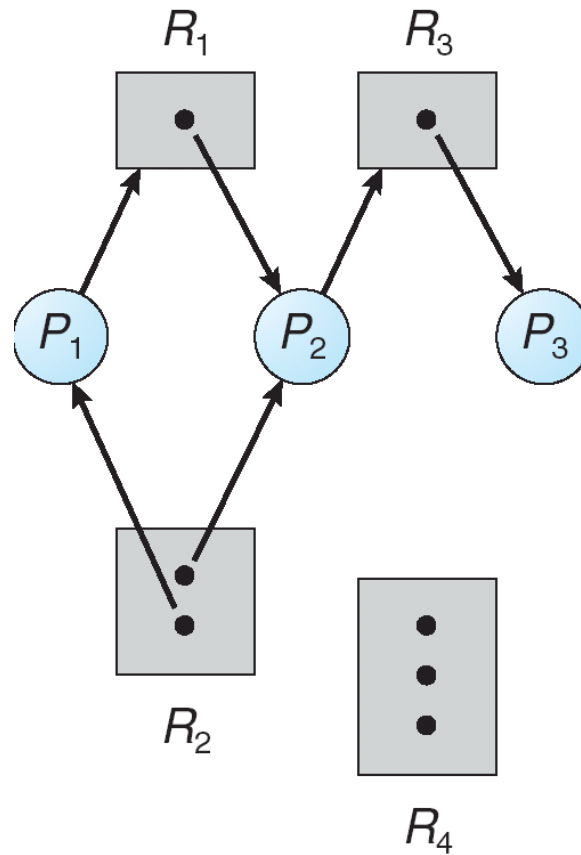


- $P_i$  is holding an instance of  $R_j$



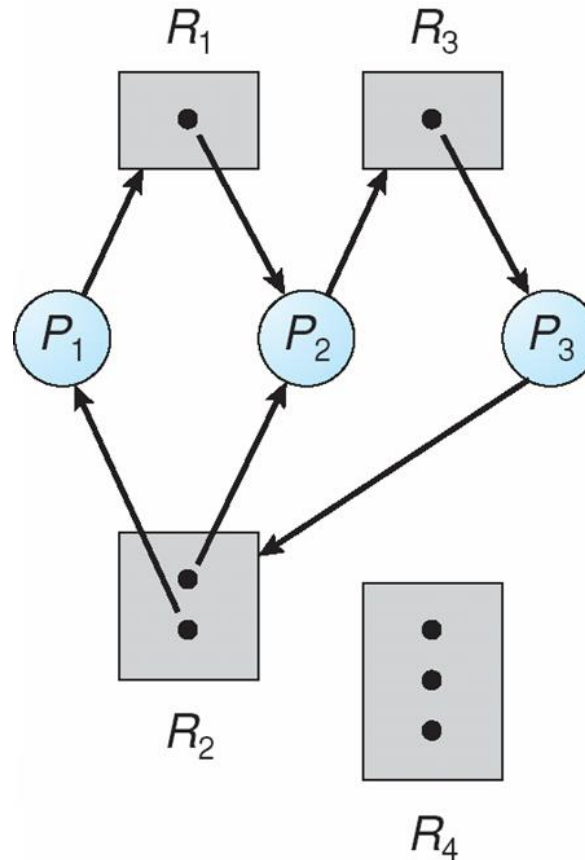


# Example of a Resource Allocation Graph



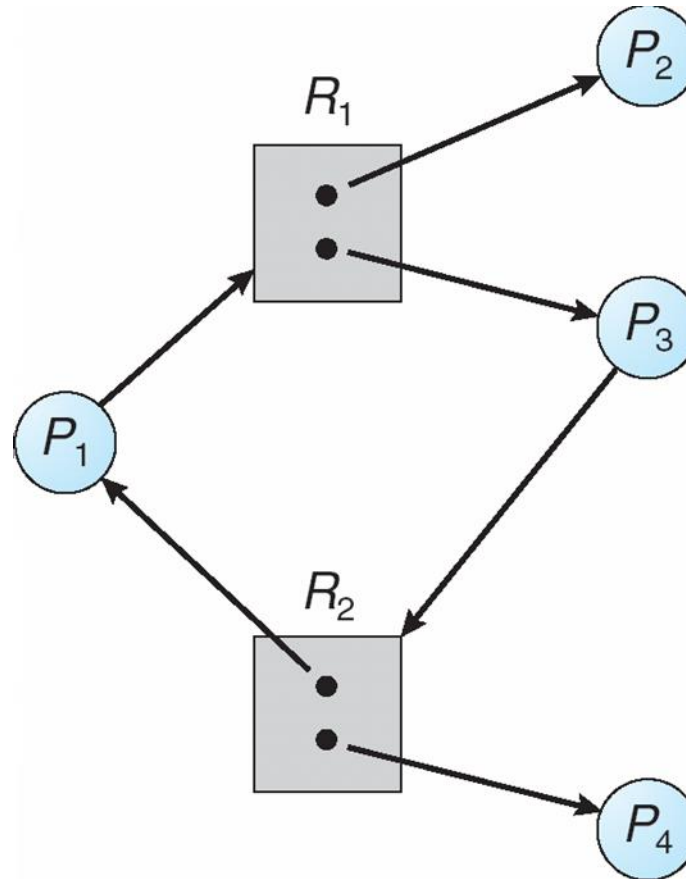


# Resource Allocation Graph With A Deadlock





# Graph With A Cycle But No Deadlock





# Basic Facts

---

- If graph contains no cycles  $\Rightarrow$  no deadlock
- If graph contains a cycle  $\Rightarrow$ 
  - if only one instance per resource type, then deadlock
  - if several instances per resource type, possibility of deadlock



## → Methods for handling Deadlock

1. Deadlock Prevention and avoidance
2. Deadlock detection and recovery
3. Ignore the problem

p1	3	
P2	1	
P3	2	
P4	3	

## Deadlock handling strategies

1. Pre-emption
2. Roll back
3. Kill the process

## Banker's Algorithm

1. no of resources, Process
2. duration of resources
3. available resources.





# Methods for Handling Deadlocks

---

- Ensure that the system will *never* enter a deadlock state
- Allow the system to enter a deadlock state and then recover
- Ignore the problem and pretend that deadlocks never occur in the system; used by most operating systems, including UNIX







# Deadlock Prevention

---

Restrain the ways request can be made

- ❑ **Mutual Exclusion** – not required for sharable resources; must hold for nonsharable resources
- ❑ **Hold and Wait** – must guarantee that whenever a process requests a resource, it does not hold any other resources
  - ❑ Require process to request and be allocated all its resources before it begins execution, or allow process to request resources only when the process has none
  - ❑ Low resource utilization; starvation possible





# Deadlock Prevention (Cont.)

---

## □ **No Preemption** –

- If a process that is holding some resources requests another resource that cannot be immediately allocated to it, then all resources currently being held are released
- Preempted resources are added to the list of resources for which the process is waiting
- Process will be restarted only when it can regain its old resources, as well as the new ones that it is requesting

## □ **Circular Wait** – impose a total ordering of all resource types, and require that each process requests resources in an increasing order of enumeration





# Deadlock Avoidance

---

Requires that the system has some additional *a priori* information available

- Simplest and most useful model requires that each process declare the *maximum number* of resources of each type that it may need
- The deadlock-avoidance algorithm dynamically examines the resource-allocation state to ensure that there can never be a circular-wait condition
- Resource-allocation *state* is defined by the number of available and allocated resources, and the maximum demands of the processes





# Safe State

- When a process requests an available resource, system must decide if immediate allocation leaves the system in a safe state
- System is in **safe state** if there exists a sequence  $\langle P_1, P_2, \dots, P_n \rangle$  of ALL the processes is the systems such that for each  $P_i$ , the resources that  $P_i$  can still request can be satisfied by currently available resources + resources held by all the  $P_j$ , with  $j < i$
- That is:
  - If  $P_i$  resource needs are not immediately available, then  $P_i$  can wait until all  $P_j$  have finished
  - When  $P_j$  is finished,  $P_i$  can obtain needed resources, execute, return allocated resources, and terminate
  - When  $P_i$  terminates,  $P_{i+1}$  can obtain its needed resources, and so on





# Basic Facts

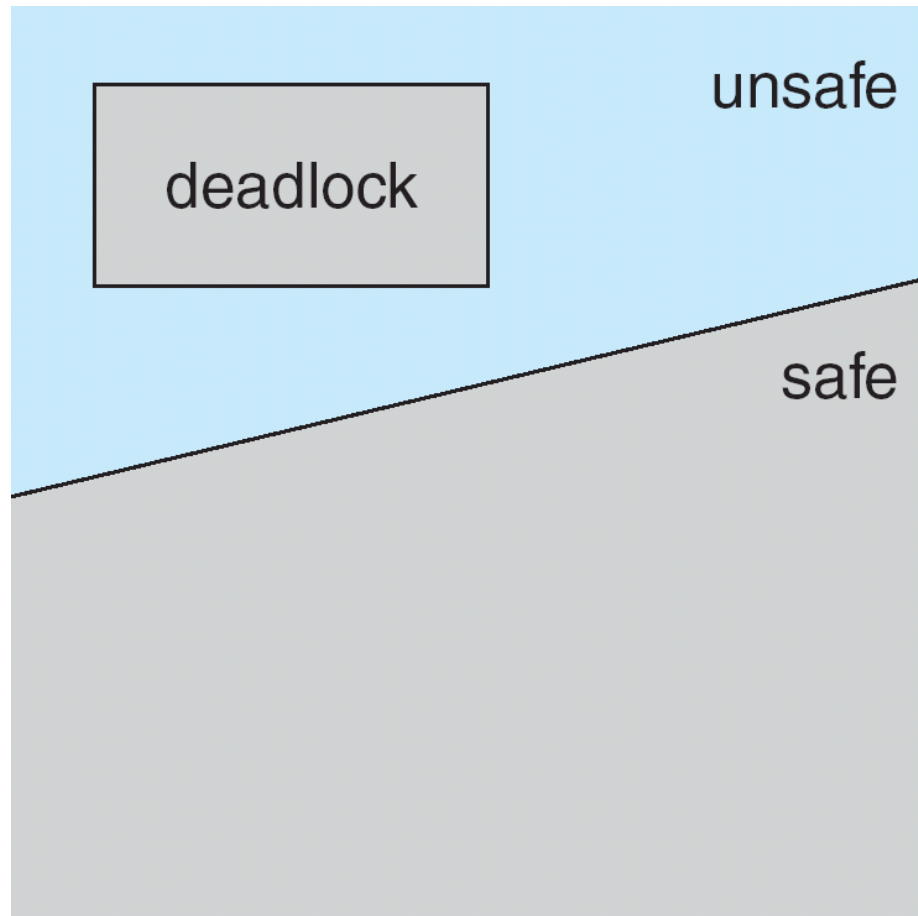
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- If a system is in safe state  $\Rightarrow$  no deadlocks
- If a system is in unsafe state  $\Rightarrow$  possibility of deadlock
- Avoidance  $\Rightarrow$  ensure that a system will never enter an unsafe state.





# Safe, Unsafe , Deadlock State





# Avoidance algorithms

---

- Single instance of a resource type
  - Use a resource-allocation graph
  
- Multiple instances of a resource type
  - Use the banker's algorithm





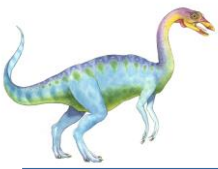


# Resource-Allocation Graph Scheme

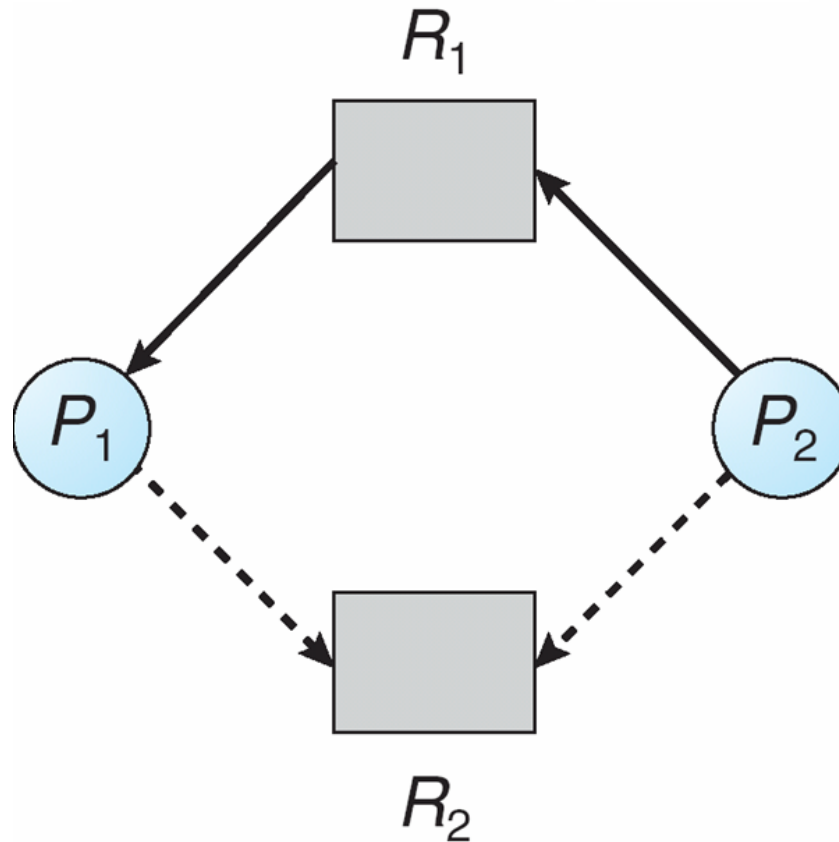
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- **Claim edge**  $P_i \rightarrow R_j$  indicated that process  $P_i$  may request resource  $R_j$ ; represented by a dashed line
- Claim edge converts to request edge when a process requests a resource
- Request edge converted to an assignment edge when the resource is allocated to the process
- When a resource is released by a process, assignment edge reconverts to a claim edge
- Resources must be claimed *a priori* in the system



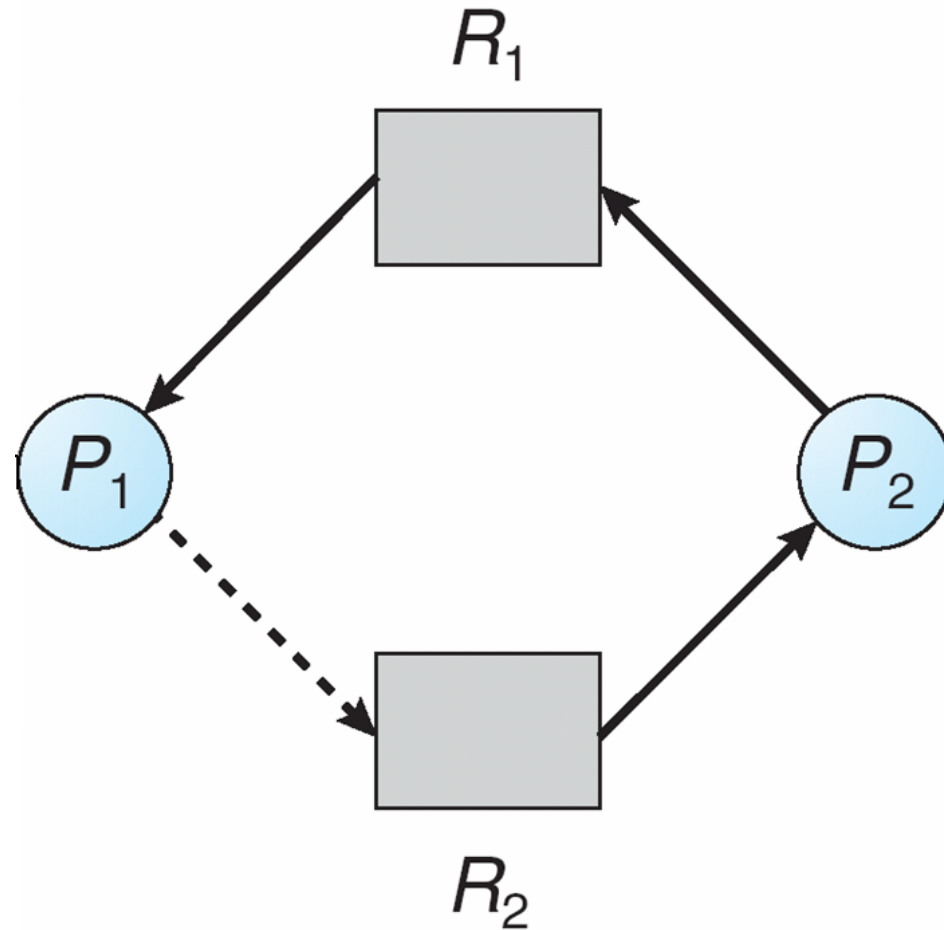


# Resource-Allocation Graph





# Unsafe State In Resource-Allocation Graph





# Resource-Allocation Graph Algorithm

---

- Suppose that process  $P_i$  requests a resource  $R_j$
- The request can be granted only if converting the request edge to an assignment edge does not result in the formation of a cycle in the resource allocation graph





# Banker's Algorithm

---

- ❑ Multiple instances
- ❑ Each process must a priori claim maximum use
- ❑ When a process requests a resource it may have to wait
- ❑ When a process gets all its resources it must return them in a finite amount of time





# Data Structures for the Banker's Algorithm

Let  $n$  = number of processes, and  $m$  = number of resources types.

- **Available:** Vector of length  $m$ . If  $available[j] = k$ , there are  $k$  instances of resource type  $R_j$  available
- **Max:**  $n \times m$  matrix. If  $Max[i,j] = k$ , then process  $P_i$  may request at most  $k$  instances of resource type  $R_j$
- **Allocation:**  $n \times m$  matrix. If  $Allocation[i,j] = k$  then  $P_i$  is currently allocated  $k$  instances of  $R_j$
- **Need:**  $n \times m$  matrix. If  $Need[i,j] = k$ , then  $P_i$  may need  $k$  more instances of  $R_j$  to complete its task

$$Need[i,j] = Max[i,j] - Allocation[i,j]$$





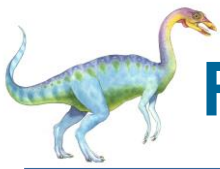
# Safety Algorithm

---

1. Let *Finish* be vector of length *n*. Initialize:  
 $Finish[i] = false$  for  $i = 0, 1, \dots, n-1$
2. Find an *i* such that both:
  - (a)  $Finish[i] = false$
  - (b)  $Need_i \leq Available[j]$If no such *i* exists, go to step 4
3.  $Available[j] = Available[j] + Allocation_i$   
 $Finish[i] = true$   
go to step 2
4. If  $Finish[i] == true$  for all *i*, then the system is in a safe state.







# Resource-Request Algorithm for Process $P_i$

$Request$  = request vector for process  $P_i$ . If  $Request_i[j] = k$  then process  $P_i$  wants  $k$  instances of resource type  $R_j$

1. If  $Request_i \leq Need_i$  go to step 2. Otherwise, raise error condition, since process has exceeded its maximum claim
2. If  $Request_i \leq Available$ , go to step 3. Otherwise  $P_i$  must wait, since resources are not available
3. Pretend to allocate requested resources to  $P_i$  by modifying the state as follows:

$$Available = Available - Request_i;$$

$$Allocation_i = Allocation_i + Request_i;$$

$$Need_i = Need_i - Request_i;$$

- If safe  $\Rightarrow$  the resources are allocated to  $P_i$
- If unsafe  $\Rightarrow P_i$  must wait, and the old resource-allocation state is restored





# Example of Banker's Algorithm

□ 5 processes  $P_0$  through  $P_4$ ;

3 resource types:

$A$  (10 instances),  $B$  (5 instances), and  $C$  (7 instances)

Snapshot at time  $T_0$ :

	<u>Allocation</u>	<u>Max</u>	<u>Available</u>
	$A \ B \ C$	$A \ B \ C$	$A \ B \ C$
$P_0$	0 1 0	7 5 3	3 3 2
$P_1$	2 0 0	3 2 2	
$P_2$	3 0 2	9 0 2	
$P_3$	2 1 1	2 2 2	
$P_4$	0 0 2	4 3 3	





## Example (Cont.)

- The content of the matrix *Need* is defined to be *Max – Allocation*

	<u>Need</u>
	A B C
$P_0$	7 4 3
$P_1$	1 2 2
$P_2$	6 0 0
$P_3$	0 1 1
$P_4$	4 3 1

- The system is in a safe state since the sequence  $\langle P_1, P_3, P_4, P_2, P_0 \rangle$  satisfies safety criteria





## Example: $P_1$ Request (1,0,2)

- Check that Request  $\leq$  Available (that is,  $(1,0,2) \leq (3,3,2) \Rightarrow$  true

	<u>Allocation</u>	<u>Need</u>	<u>Available</u>
	A B C	A B C	A B C
$P_0$	0 1 0	7 4 3	2 3 0
$P_1$	3 0 2	0 2 0	
$P_2$	3 0 1	6 0 0	
$P_3$	2 1 1	0 1 1	
$P_4$	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence  $\langle P_1, P_3, P_4, P_0, P_2 \rangle$  satisfies safety requirement
- Can request for (3,3,0) by  $P_4$  be granted?
- Can request for (0,2,0) by  $P_0$  be granted?





# Deadlock Detection

---

- Allow system to enter deadlock state
- Detection algorithm
- Recovery scheme





# Single Instance of Each Resource Type

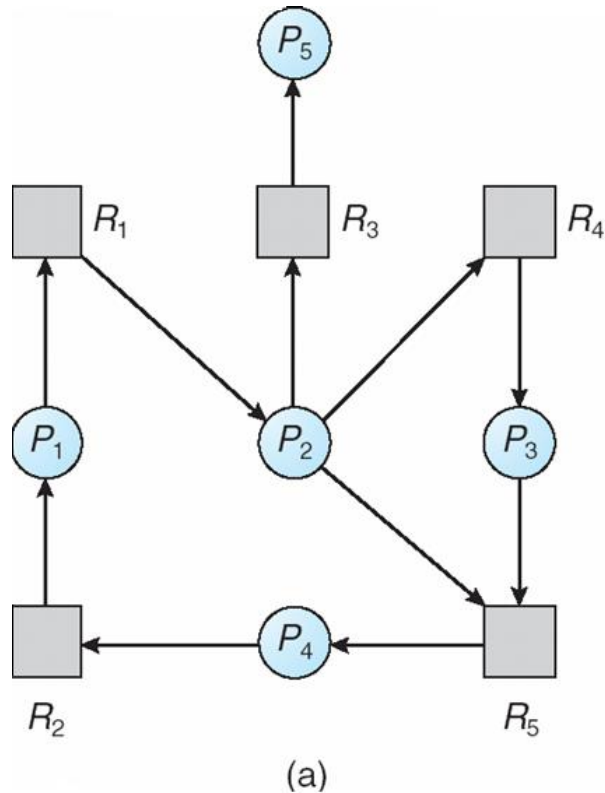
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- Maintain *wait-for* graph
  - Nodes are processes
  - $P_i \rightarrow P_j$  if  $P_i$  is waiting for  $P_j$
- Periodically invoke an algorithm that searches for a cycle in the graph. If there is a cycle, there exists a deadlock
- An algorithm to detect a cycle in a graph requires an order of  $n^2$  operations, where  $n$  is the number of vertices in the graph

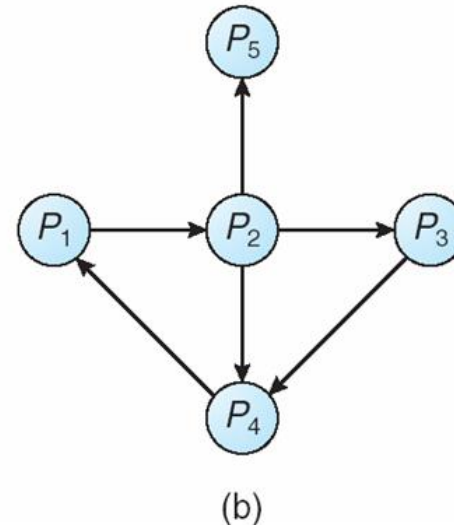




# Resource-Allocation Graph and Wait-for Graph



Resource-Allocation Graph



Corresponding wait-for graph







# Several Instances of a Resource Type

---

- **Available:** A vector of length  $m$  indicates the number of available resources of each type.
- **Allocation:** An  $n \times m$  matrix defines the number of resources of each type currently allocated to each process.
- **Request:** An  $n \times m$  matrix indicates the current request of each process. If  $Request[i_j] = k$ , then process  $P_i$  is requesting  $k$  more instances of resource type  $R_j$ .





# Detection Algorithm

---

1. Let *Work* and *Finish* be vectors of length *m* and *n*, respectively Initialize:
  - (a) *Work* = *Available*
  - (b) For  $i = 1, 2, \dots, n$ , if  $Allocation_i \neq 0$ , then  
 $Finish[i] = \text{false}$ ; otherwise,  $Finish[i] = \text{true}$
2. Find an index *i* such that both:
  - (a)  $Finish[i] == \text{false}$
  - (b)  $Request_i \leq Work$

If no such *i* exists, go to step 4





# Detection Algorithm (Cont.)

---

3.  $Work = Work + Allocation_i$   
 $Finish[i] = true$   
go to step 2
4. If  $Finish[i] == false$ , for some  $i$ ,  $1 \leq i \leq n$ , then the system is in deadlock state. Moreover, if  $Finish[i] == false$ , then  $P_i$  is deadlocked

**Algorithm requires an order of  $O(m \times n^2)$  operations to detect whether the system is in deadlocked state**





# Example of Detection Algorithm

- Five processes  $P_0$  through  $P_4$ ; three resource types A (7 instances), B (2 instances), and C (6 instances)
- Snapshot at time  $T_0$ :

	<u>Allocation</u>			<u>Request</u>			<u>Available</u>		
	A	B	C	A	B	C	A	B	C
$P_0$	0	1	0	0	0	0	0	0	0
$P_1$	2	0	0	2	0	2			
$P_2$	3	0	3	0	0	0			
$P_3$	2	1	1	1	0	0			
$P_4$	0	0	2	0	0	2			

- Sequence  $\langle P_0, P_2, P_3, P_1, P_4 \rangle$  will result in  $Finish[i] = \text{true}$  for all  $i$





## Example (Cont.)

- $P_2$  requests an additional instance of type C

	<u>Request</u>		
	A	B	C
$P_0$	0	0	0
$P_1$	2	0	1
$P_2$	0	0	1
$P_3$	1	0	0
$P_4$	0	0	2

- State of system?
  - Can reclaim resources held by process  $P_0$ , but insufficient resources to fulfill other processes; requests
  - Deadlock exists, consisting of processes  $P_1$ ,  $P_2$ ,  $P_3$ , and  $P_4$





# Detection-Algorithm Usage

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- When, and how often, to invoke depends on:
  - How often a deadlock is likely to occur?
  - How many processes will need to be rolled back?
    - ▶ one for each disjoint cycle
- If detection algorithm is invoked arbitrarily, there may be many cycles in the resource graph and so we would not be able to tell which of the many deadlocked processes “caused” the deadlock





# Recovery from Deadlock: Process Termination

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- Abort all deadlocked processes
- Abort one process at a time until the deadlock cycle is eliminated
- In which order should we choose to abort?
  - Priority of the process
  - How long process has computed, and how much longer to completion
  - Resources the process has used
  - Resources process needs to complete
  - How many processes will need to be terminated
  - Is process interactive or batch?





# Recovery from Deadlock: Resource Preemption

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- Selecting a victim – minimize cost
- Rollback – return to some safe state, restart process for that state
- Starvation – same process may always be picked as victim, include number of rollback in cost factor





# End of Chapter 7

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