CS-3103 : Operating Systems : Sec-A (NB) :

Deadlocks…..

CSEN3103: 3RD YEAR: SEC-A: Deadlocks

- System Model
- Deadlock Characterization
- Methods for Handling Deadlocks
- Deadlock Prevention
- Deadlock Avoidance
- Deadlock Detection
- Recovery from Deadlock
- Combined Approach to Deadlock Handling

Approaching Deadlock……

Let us consider the following scenario:

A process P1 is in execution. It requests for a printer. The operating system allocates the printer to process P1. A context switch happens: Process P1 is now in possession of the printer, but it has relinquished the CPU. The CPU is allotted to another process, P2. The process P2 now requests for the printer….

- In this situation, for the moment, neither P1 nor P2 can progress, because P1 has the printer but needs the CPU to generate data.
- *On the other hand P2 has the CPU and can generate data, but needs the printer to print it.*
- *We can say, both processes P1 and P2 are blocked at the moment and are in a deadlock situation.*
- ***Deadlock** is a situation in a computer system, where a set of processes is blocked, waiting for an event which will never happen.*
- ***Starvation** can be defined as a situation where a process waits for a resource, which is, for a prolonged time, made available to other processes.*

The Deadlock Problem

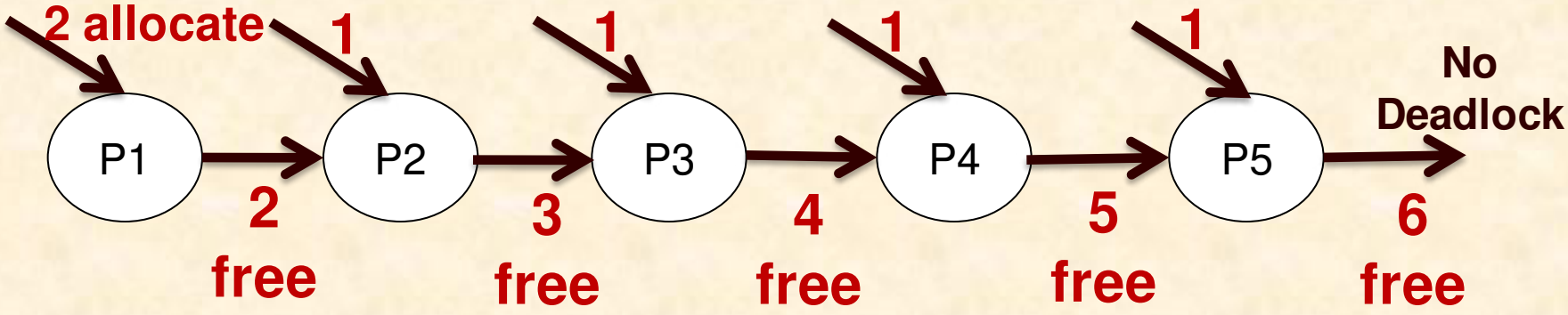
- A set of blocked processes each holding a resource and waiting to acquire a resource held by another process in the set. Couple of examples:
- Example -1
  - System has 2 printers.
  - P_1 and P_2 each hold one printer and each needs another one.
- Example-2
  - semaphores *A* and *B*, initialized to 1

P_1	P_2
wait (A);	*wait(B)*
wait (B);	*wait(A)*

DEADLOCK – Let's talk about Resource allocation to processes

- A computer system has 6 tape drives with ***n*** processes competing for them. Each process need 2 tape drives. The maximum value for ***n*** for which the system is guaranteed to be deadlock free is: a) 6 b) 5 c) 4 d) 3

5 processes can start with 1 tape drive (each). Processes are executing sequentially in the following way:



System Model

- Resource types $R_1, R_2, \ldots, R_m$

  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

Necessary conditions for a Deadlock to occur

Deadlock can arise if the following four conditions hold simultaneously.

- **Mutual exclusion:** A major cause of deadlock is that some resources are not shareable. Therefore, only one process can access such a resource at a time. This is a case of mutual exclusion, where, competing processes mutually exclude each other for the usage of the resource. Example: the chopstick is a non-shareable resource and therefore no two philosophers can simultaneously use the same chopstick.
- **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 $\{P_0, P_1, \ldots, P_0\}$ 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_0 is waiting for a resource that is held by P_0.

Resource-Allocation Graph

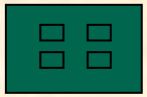
A set of vertices V and a set of edges E.

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

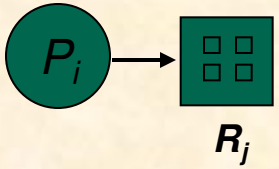
Resource-Allocation Graph (Cont.)

- **Process**

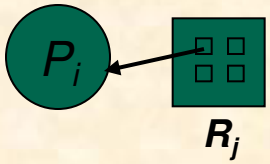
Resource Type with 4 instances



- P_i **requests instance of** R_j

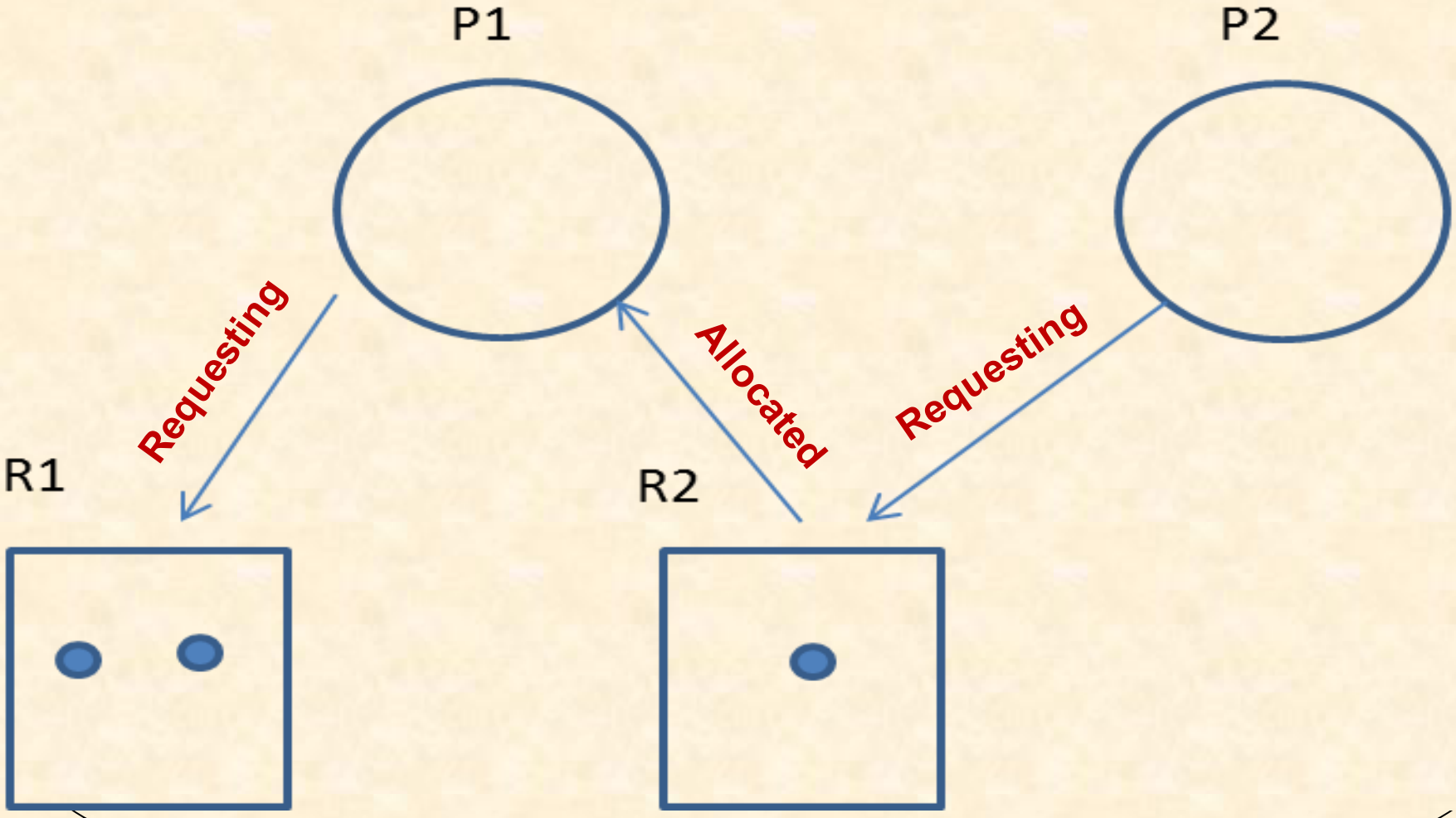


- P_i **is holding an instance of** R_j

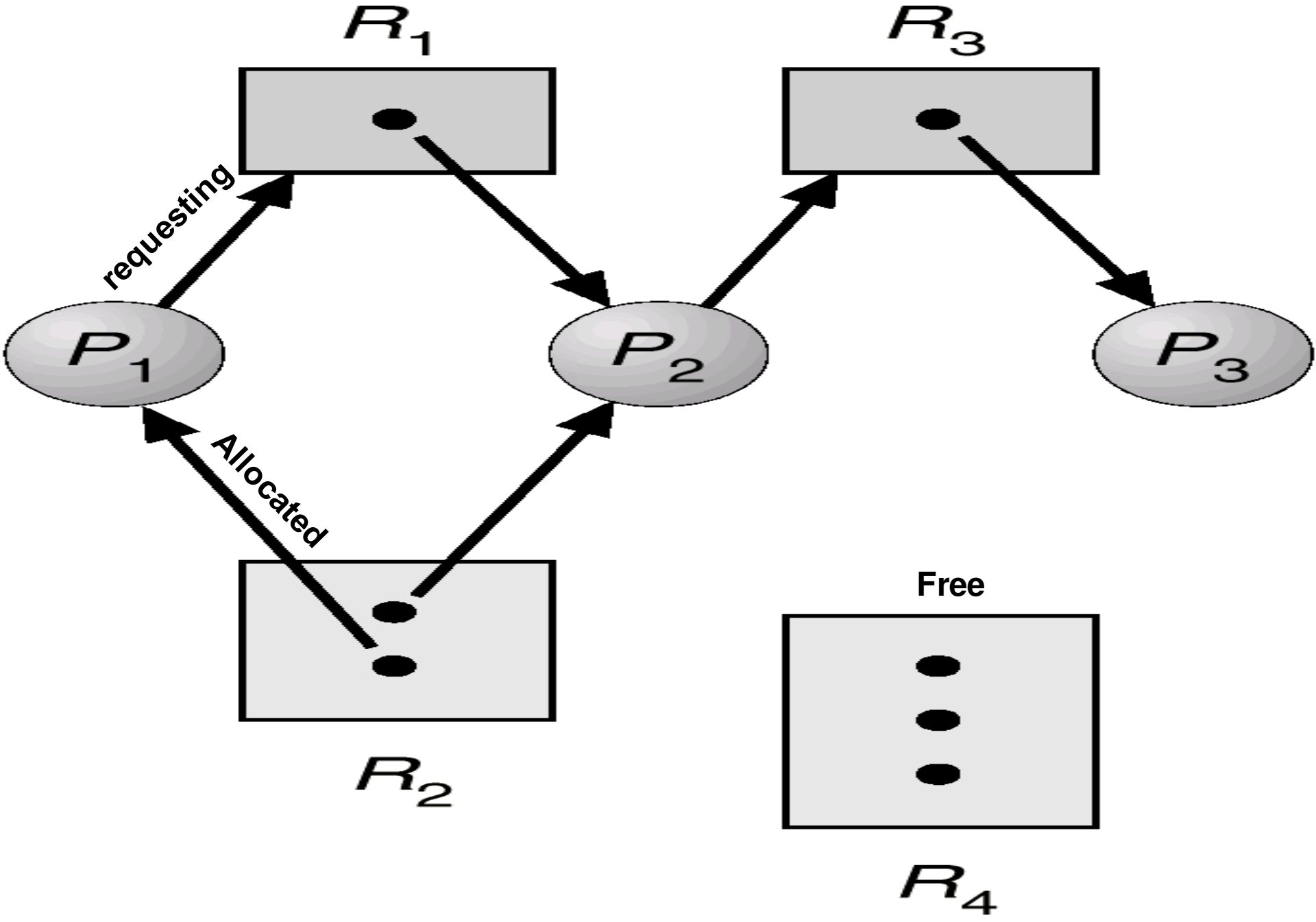


Resource-Allocation Graph (Cont.)

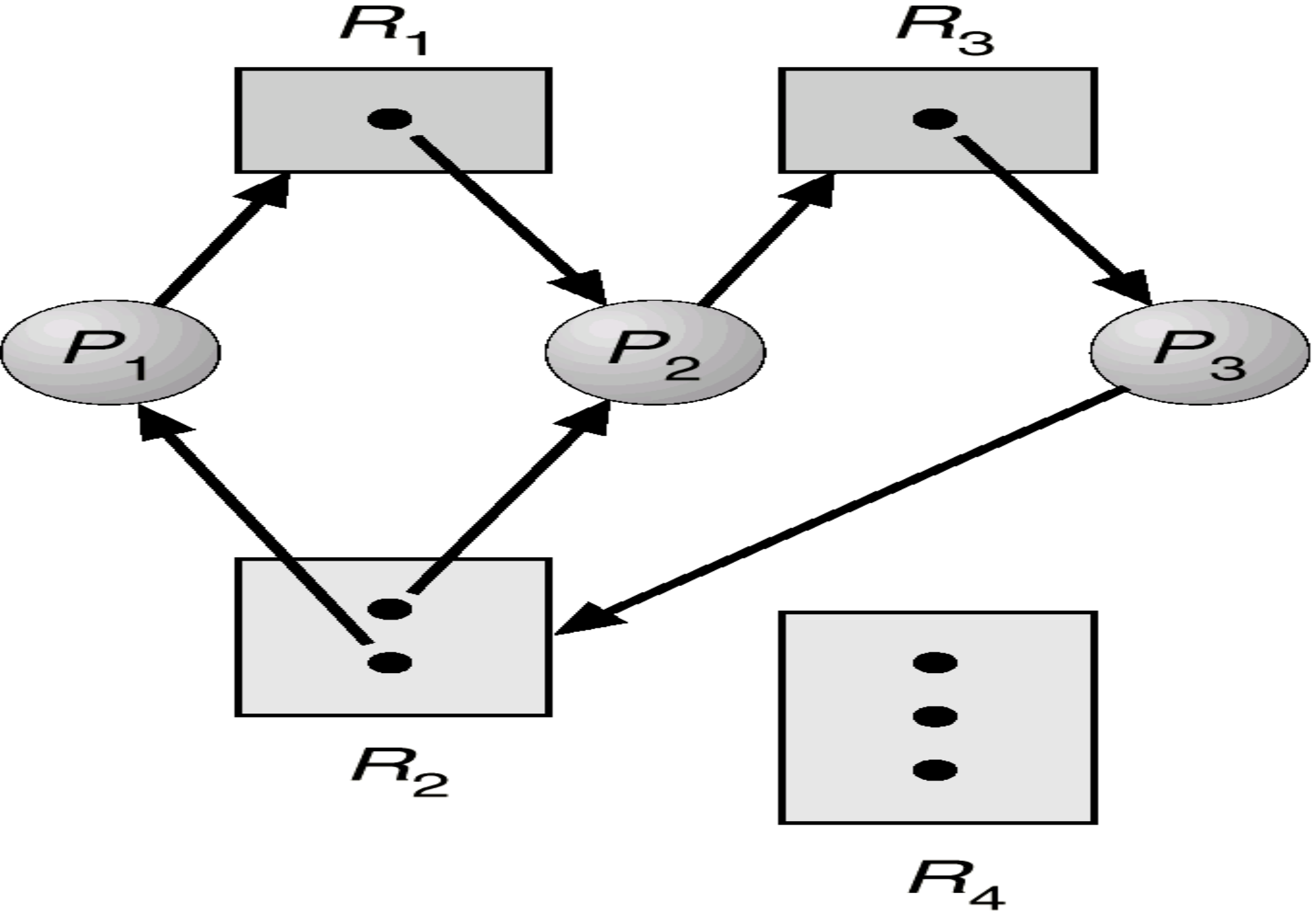
- An edge between two nodes can be of two types:
  - Request edge -- Allocation edge



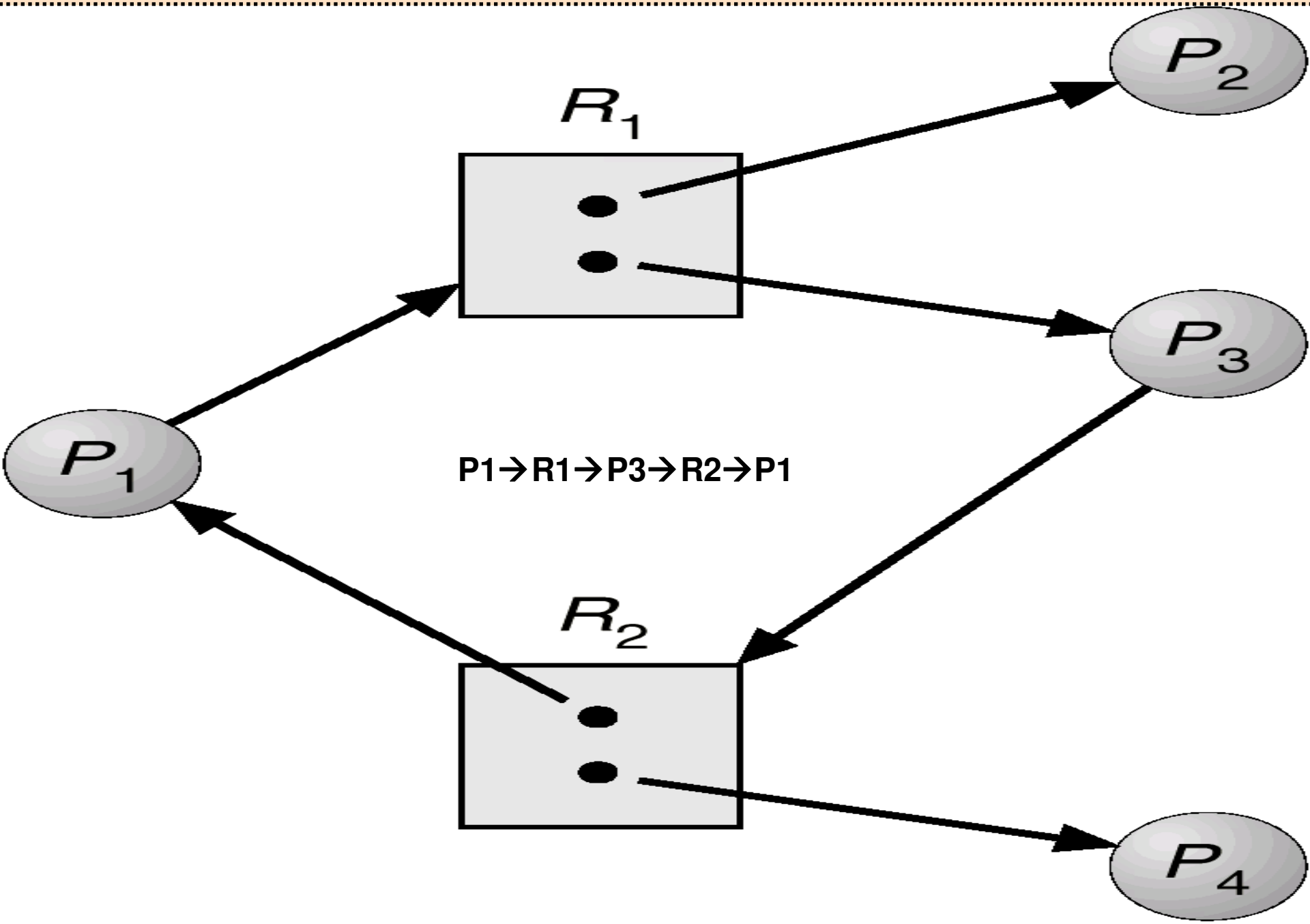
Example of a Resource Allocation Graph (Deadlock???)



Resource Allocation Graph (Deadlock ???)



Resource Allocation Graph (Deadlock ???)



Basic Facts

- Cycle is there: P1→R1→P3→R2→P1
- But, there is no deadlock. Process P4 may release its instance of resource type R2. That resource can then be allocated to P3, breaking the cycle.
- If graph contains no cycles ⇒ no deadlock.
- If graph contains a cycle ⇒
  - if only one instance per resource type, then deadlock.
  - if several instances per resource type, ***possibility*** of deadlock.

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 Strategies

- The deadlock problem is handled by using the following strategies:
  - Deadlock detection
  - Deadlock prevention
  - Deadlock avoidance

Deadlock Prevention

Restrain the ways request can be made.

- **Mutual Exclusion** – not required for sharable resources; must hold for non-sharable resources example. printer.
- **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.
  - *Adopt a policy wherein the resources allocated to a process can be preempted by the operating system. However, sometimes cost of preemption becomes very high. For instance, the resources like printers, plotters, etc., should not be forcefully taken by the OS from an executing process. In contrast, preempting a CPU for a short duration is tolerable.*
- **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.

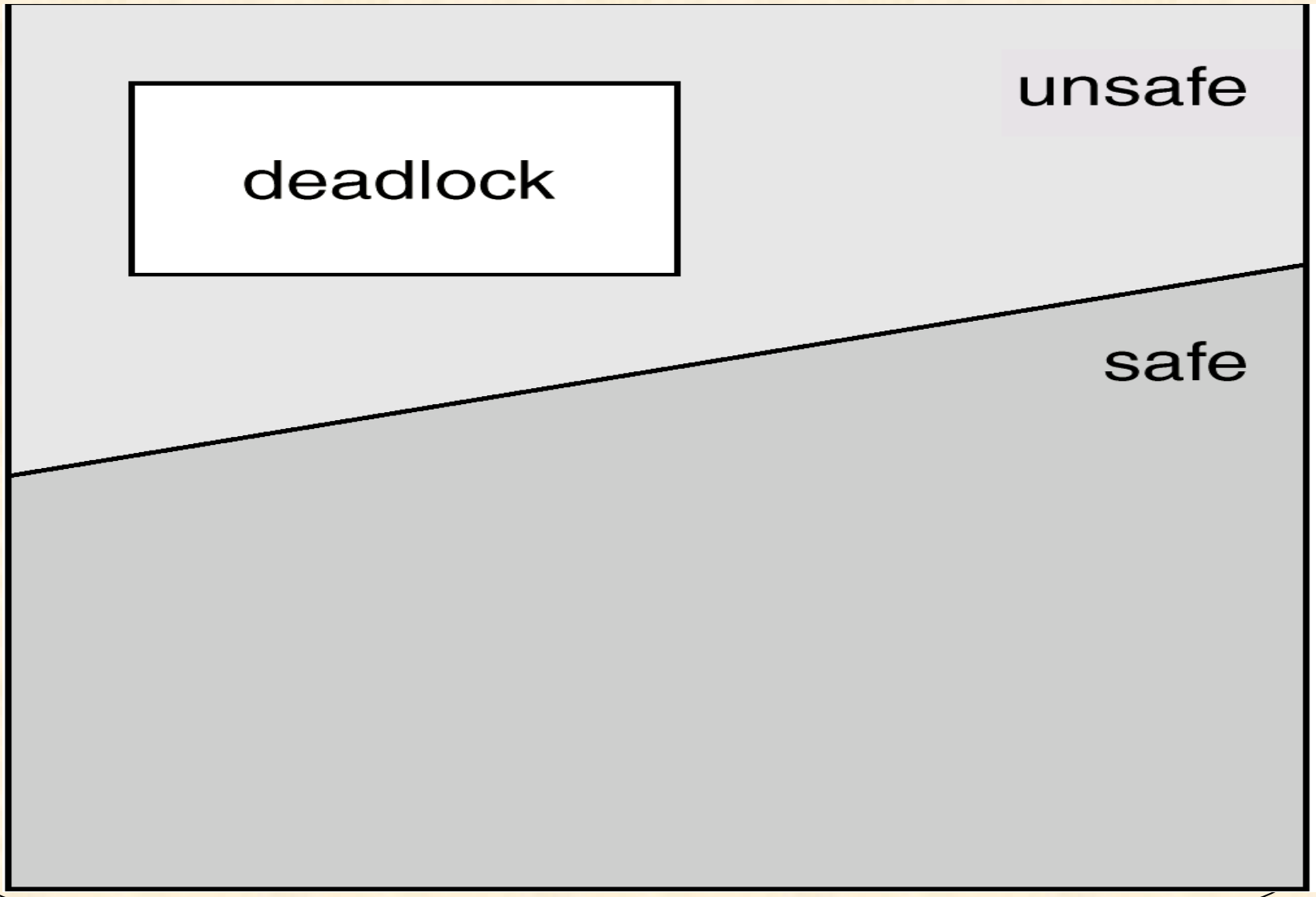
- Simplest and most useful model requires that **each process** declare the ***maximum number* of resources** of each type that it may need.
- The deadlock-avoidance algorithm dynamically examines the **resource-allocation state** to ensure that there can never be a **circular-wait condition**.
- ***Resource-allocation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


START

Basic Facts

- 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 spaces



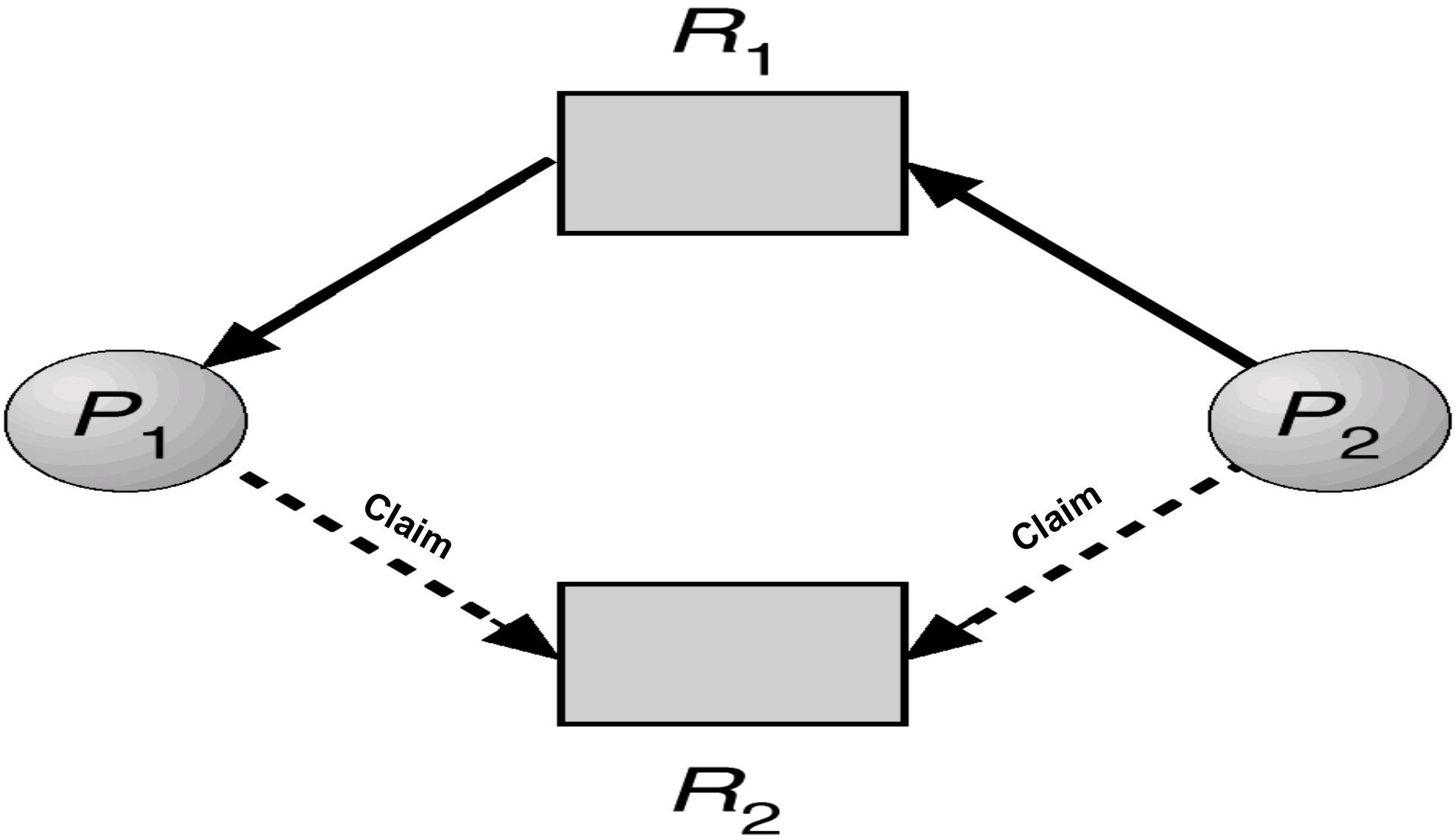
Safe State

- *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 safe sequence of all processes.**
- **Sequence <P_1, P_2, …, P_n> is safe if for each P_i, the resources that *Pi* can still request can be satisfied by currently available resources + resources held by all the P_j, with $j<i$.**
  - **If P_i 's 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.**

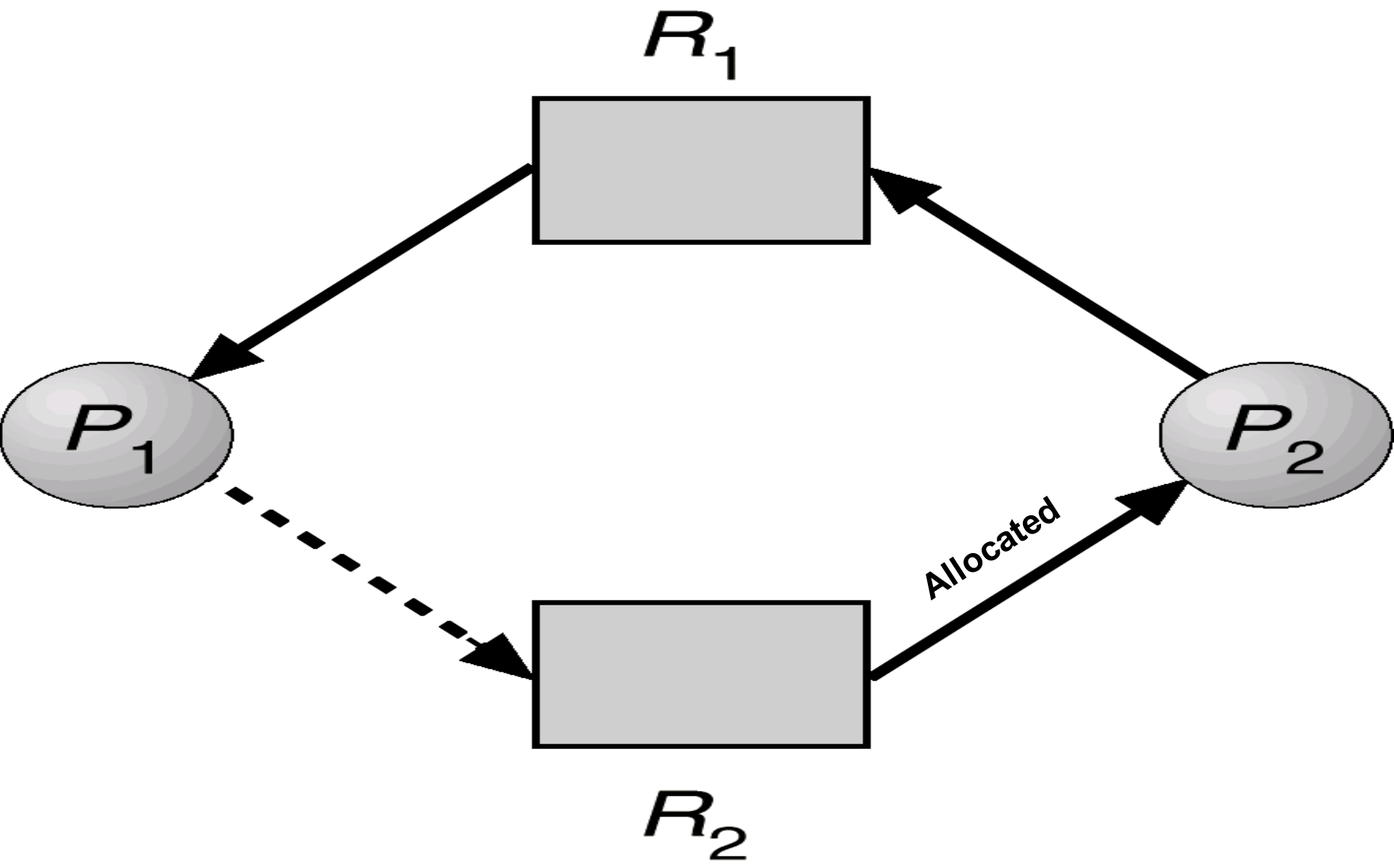
Resource-Allocation Graph Algorithm

- *Claim edge* $P_i \dashrightarrow R_j$ 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.
- 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 For Deadlock Avoidance



A Resource-Allocation Graph



Banker's Algorithm (the deadlock avoidance 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 *Work* and *Finish* be vectors of length *m* and *n*, respectively. Initialize:

   Work := *Available*

   Finish [*i*] = *false* for *i* - 1,2,3, …, *n.*

2. Find an *i* such that both:

   (a) *Finish* [*i*] = *false*

   (b) $Need_i \leq Work$

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

3. *Work* := *Work* + $Allocation_i$

   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

$Request_i$ = 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

Q : Suppose we have two resources, A, and B. A has 6 instances and B has 3 instances. Can the system execute the following processes without deadlock occurring?

Already Allocated

DONE

….

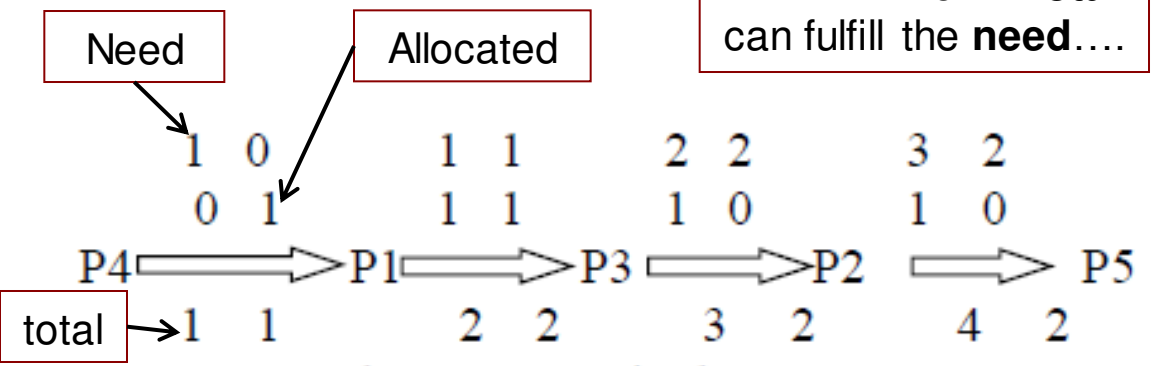
Process	Allocate		Maximum need		Sum of max. need per row.
	A	B	A	B	
P1	1	1	2	2	4
P2	1	0	4	2	6
P3	1	0	3	2	5
P4	0	1	1	1	2 ← **Min.**
P5	2	1	6	3	9

Answer

Available: A → 6 instances,
Already allocated → 5;
available → 6-5 = 1;
For B → 0

Total freed up resources can be allocated to awaiting processes.. Starting from P4 → P1 → P3 → P2 → P5…. **Total** can fulfill the **need**….

Process	Need	
	A	B
P1	1	1
P2	3	2
P3	2	2
P4	1	0
P5	4	2



We can execute the processes in the sequence <P4, P1, P3, P2, P5> without deadlock.

Q : Consider we have five processes P0, P1, . . . P5 and three resources A, B, and C. Is the executing the following processes in the safe state?

Process	Allocation			Maximum need			Available		
	A	B	C	A	B	C	A	B	C
P0	1	2	0	2	2	2	0	1	0
P1	1	0	0	1	1	0			
P2	1	1	1	1	4	3			
P3	0	1	1	1	1	1			
P4	0	0	1	1	2	2			
P5	1	0	0	1	5	1			

DONE

....

Answer

We find the resources that need for each process

Process	Need		
P0	1	0	2
P1	0	1	0
P2	0	3	2
P3	1	0	0
P4	1	2	1
P5	0	5	1

Allocation

0 1 0 | 1 1 0 | 1 2 1 | 1 2 2 | 2 4 2

1 0 0 | 0 1 1 | 0 0 1 | 1 2 0 | 1 1 1

1 1 0 | 1 2 1 | 1 2 2 | 2 4 2 | 3 5 3

P1 ⟹ p3 ⟹ p4 ⟹ p0 ⟹ p2 ⟹ p5

Q : Suppose we have five processes and three resources, A, B, and C. A has 2 instances, B has 5 instances and C has 4 instances. Can the system execute the following processes without deadlock occurring, where we have the following?

Try this….

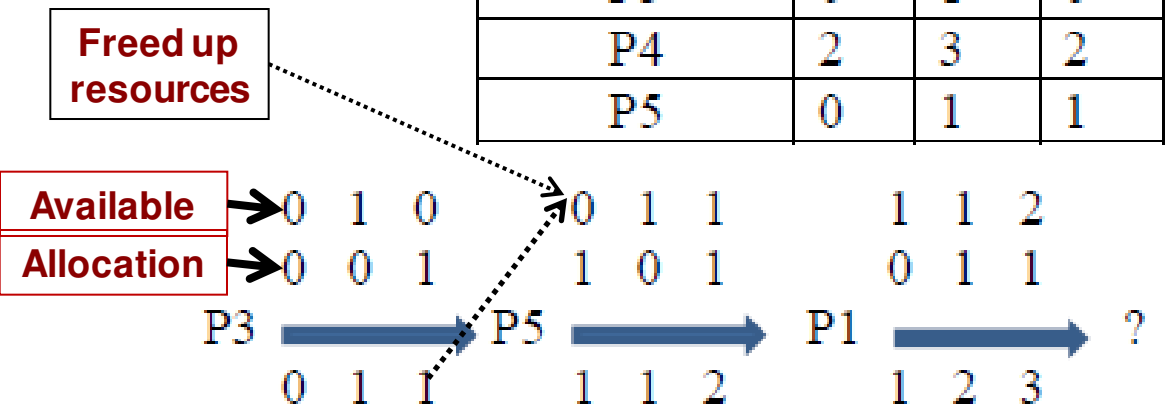
Process	Maximum need			Allocation		
	A	B	C	A	B	C
P1	1	2	3	0	1	1
P2	2	2	0	0	1	0
P3	0	1	1	0	0	1
P4	3	5	3	1	2	1
P5	1	1	2	1	0	1

Answer

The available is A=0, B=1, C=0.

The current need is

Process	Current need		
	A	B	C
P1	1	1	2
P2	2	1	0
P3	0	1	0
P4	2	3	2
P5	0	1	1



For P2: freed up resources : 1 2 3

Allocation : 0 1 0

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1 3 3

The deadlock is occurred since the available resources is less than the needs of P2 and P4.

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:

Try this in H.W

	Allocation	*Max*	*Available*
	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).

Try this in H.W

	Need
	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 < P_1, P_3, P_4, P_2, P_0> satisfies safety criteria.

Example (Cont.): P_1 request (1,0,2)

- Check that Request ≤ Available (that is, (1,0,2) ≤ (3,3,2) ⇒ *true.*

	Allocation	*Need*	*Available*
	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	

Try this in H.W

- Executing safety algorithm shows that sequence <P_1, P_3, P_4, P_0, P_2> 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?

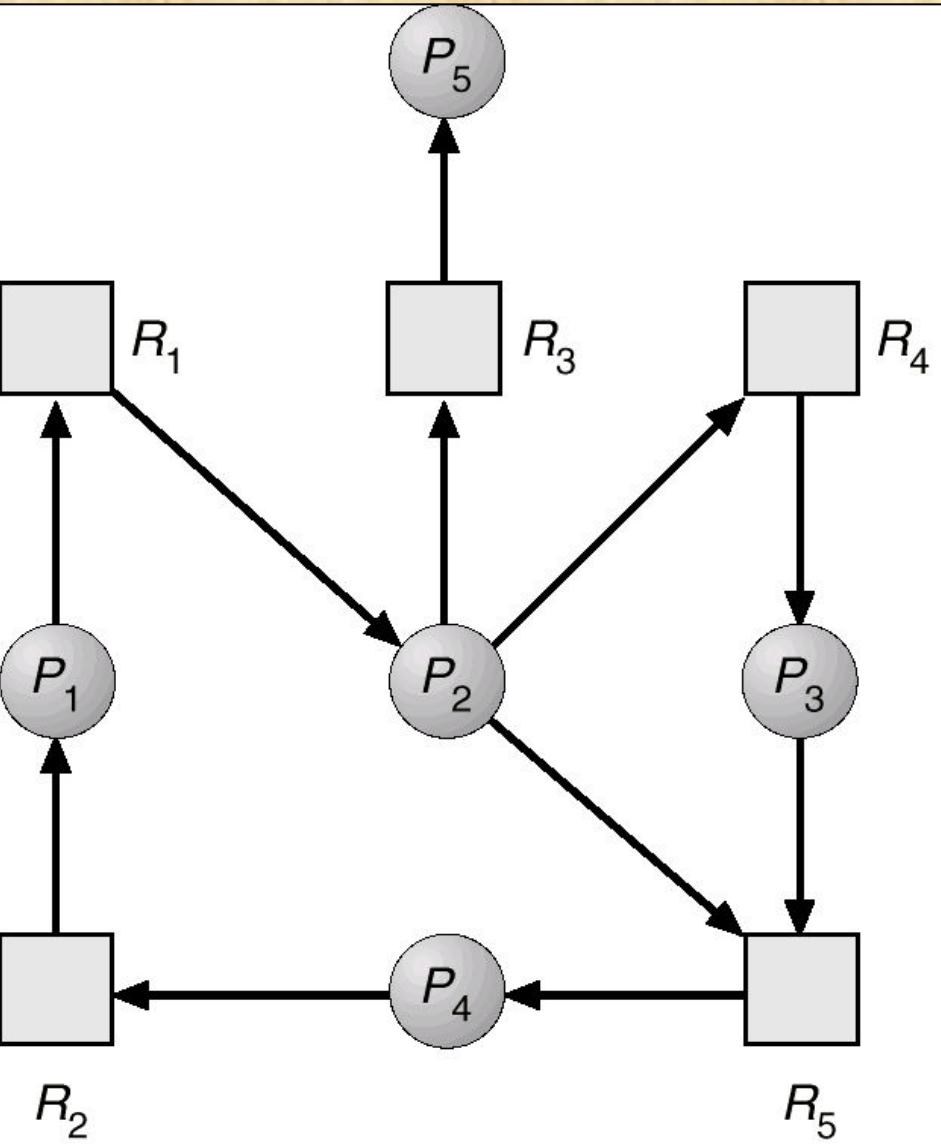
Deadlock Detection

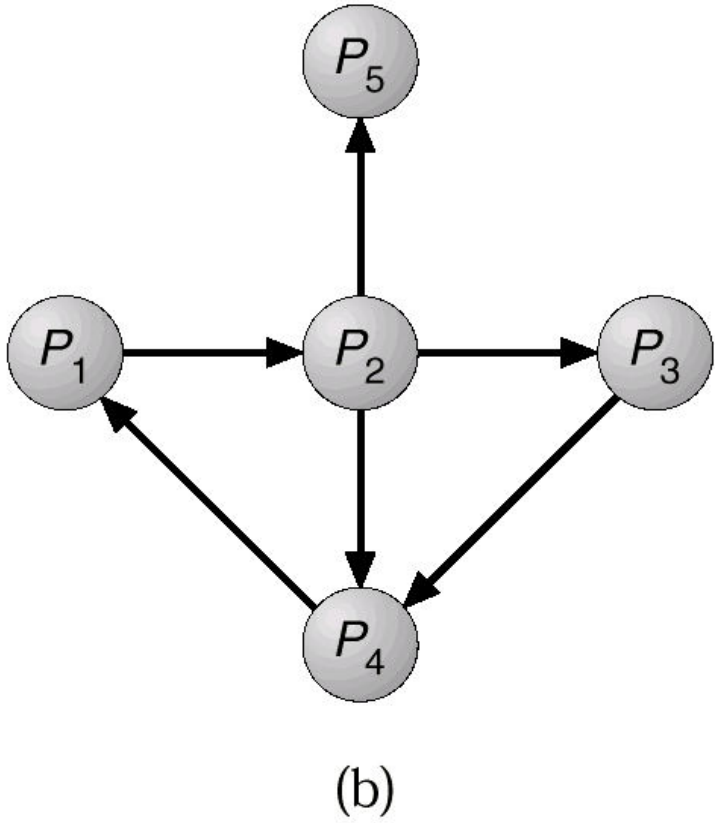
- Allow system to enter deadlock state
- Detection algorithm
- Recovery scheme

Single Instance of Each Resource Type

- 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.
- 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 x m* matrix defines the number of resources of each type currently allocated to each process.
- ***Request***: An *n x m* matrix indicates the current request of each process. If *Request* [*ij*] = *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 $i = 1,2, \ldots, n$, if $Allocation_i \neq 0$, then *Finish*[i] := false ; otherwise, *Finish*[i] := *true*.
2. Find an index *i* such that both:
   (a) *Finish*[*i*] = *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 $m \times n^2$ 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:

	Allocation	*Request*	*Available*
	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	
	7 2 6		

No resources are available for P0 to P4 processes

- Sequence <P_0, P_2, P_3, P_1, P_4> will result in *Finish*[*i*] = true for all *i*. After completion of P0 and P2, we have different ways to arrange P3, P1 and P4. Try, (P1, P3, P4) or (P4, P1, P3) or (P3, P1, P4)……

Example (Cont.)

- P_2 requests an additional instance of type *C*.

	Request
	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

- 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

- 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

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

Combined Approach to Deadlock Handling

- Combine the three basic approaches
  - prevention
  - avoidance
  - detection

  allowing the use of the optimal approach for each of resources in the system.
- Partition resources into hierarchically ordered classes.
- Use most appropriate technique for handling deadlocks within each class.


Time for
a Break