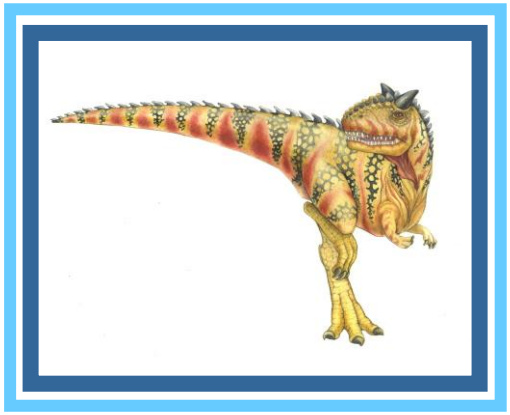
# UNIT 3 : Part-2, Deadlocks



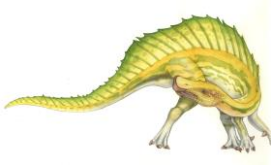
# UNIT – 3 : Deadlocks

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

# System Model

- System consists of resources
- Resource types $R_1, R_2, \ldots, R_m$

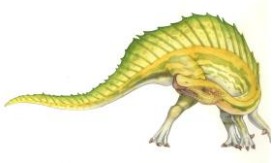
  *CPU cycles, memory space, I/O devices*
- Each resource type $R_i$ has $W_i$ instances.
- Each process utilizes a resource as follows:
  - **request**
  - **use**
  - **release**



# Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously.

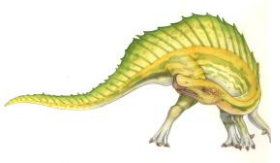
- **Mutual exclusion**: only one process at a time can use a resource
- **Hold and wait**: a process holding at least one resource is waiting to acquire additional resources held by other processes
- **No preemption**: a resource can be released only voluntarily by the process holding it, after that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



# System Resource-Allocation Graph

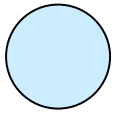
A set of vertices $V$ and a set of edges $E$.

- 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 $P_i \rightarrow R_j$
- **assignment edge** – directed edge $R_j \rightarrow P_i$

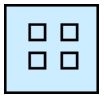


# Resource-Allocation Graph (Cont.)

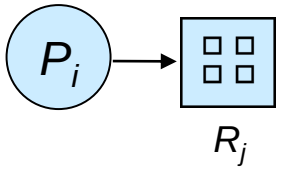
- Process



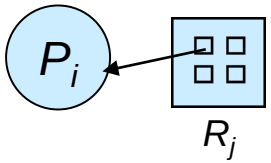
- Resource Type with 4 instances



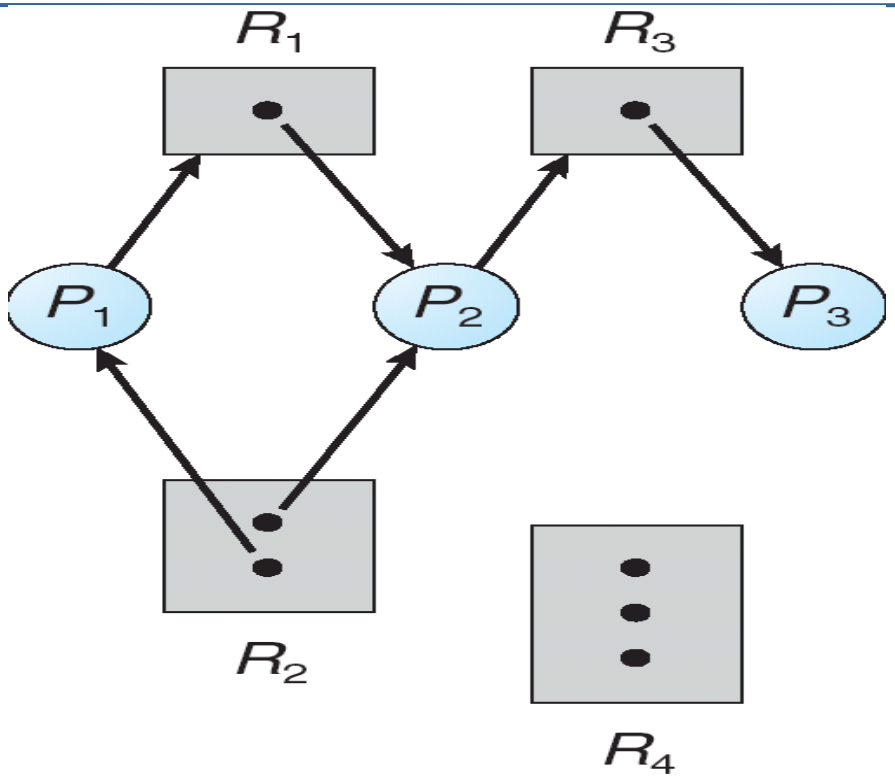
- $P_i$ requests instance of $R_j$




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



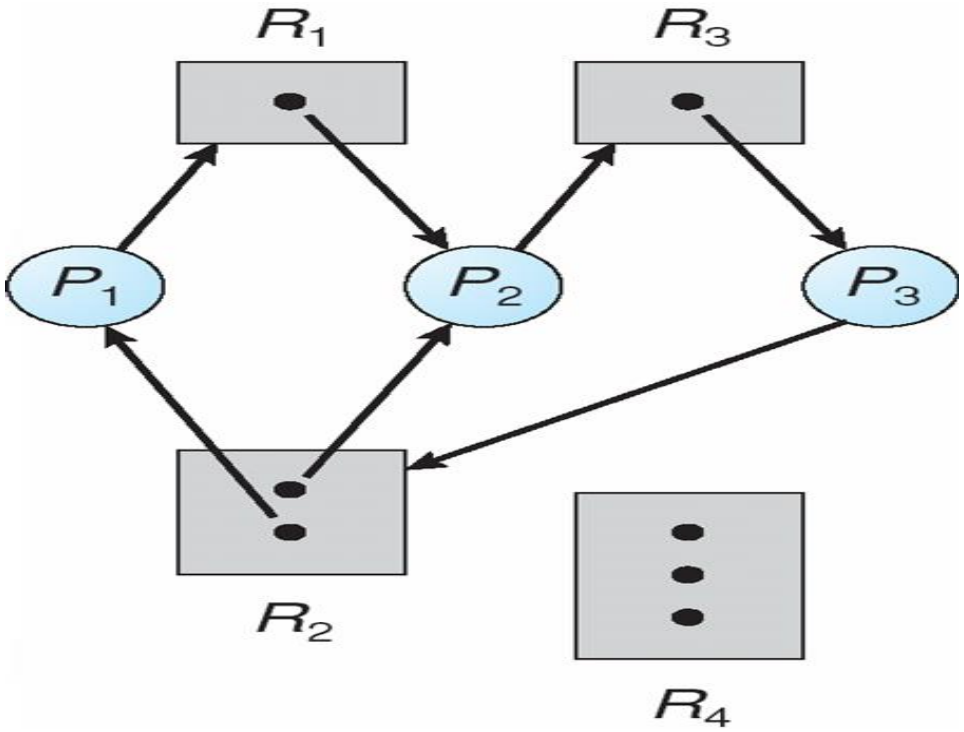

# Example of a Resource Allocation Graph




Process states:
- Process P1 is holding an instance of resource type R2 and is waiting for an instance of resource type R1.
- P2 holding instance of R1 & instance of R2,waiting for instance of R3.
- Process P3 is holding an instance of R3.

If no cycles exist in the system then no deadlock. If cycle, then there may exist a deadlock.

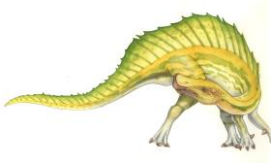
# Resource Allocation Graph With A Deadlock



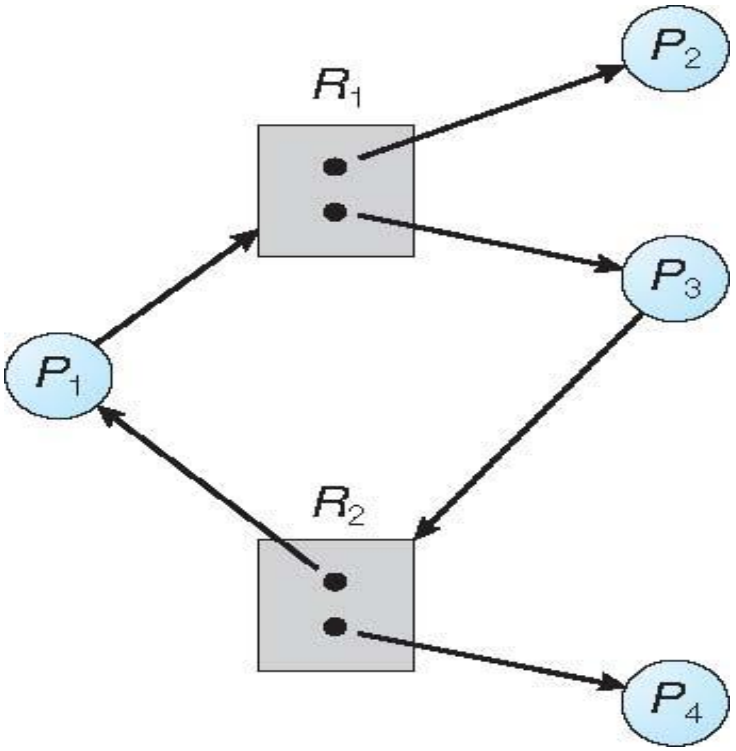

At this point, two minimal cycles exist in the system:

P1 -> R1 -> P2 -> R3 -> P3 -> R2 -> P1

P2 -> R3 -> P3 -> R2 -> P2



# Graph With A Cycle But No Deadlock




A cycles exists in the system:

P1 -> R1 -> P3 -> R2 -> P1

But no deadlock

# Basic Facts

- 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

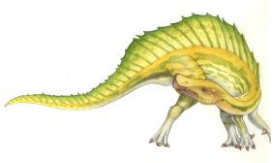
# Methods for Handling Deadlocks

Three methods :

1. Ensure that the system will ***never*** enter a deadlock state: use protocol for
   - 1.1. Deadlock prevention
   - 1.2. Deadlock avoidance

2. Allow the system to enter a deadlock state, detect it and recover

3. Ignore the problem and pretend that deadlocks never occur in the system; used by most operating systems, including UNIX



# 1.1. Deadlock Prevention

**Provides a set of methods for ensuring that at least one of the necessary conditions cannot hold.**

- **Mutual Exclusion** – not required for sharable resources (e.g., read-only files); must hold for non-sharable resources. Ex. a printer cannot be simultaneously shared by several processes. Sharable resources, in contrast, do not require mutually exclusive access and thus cannot be involved in a deadlock. Read-only files are a good examples. A process never needs to wait for a sharable resource.

- **Hold and Wait** – must guarantee that whenever a process requests a resource, it does not hold any other resources
  - **One protocol** is- Require each 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 allocated to it.
  - **Another protocol** is - it allows a process to request a resource only when it has no resources. Before it request any resource it must release all the resource that it is currently allocated.

# Deadlock Prevention (Cont.)

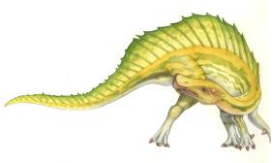
- **No Preemption** –
  - If a process that is holding some resources requests another resource that cannot be immediately allocated to it, then all resources currently being held are released(preempted)
  - Preempted resources are added to the list of resources for which the process is waiting
  - Process 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.

That is, a process can initially request any number of instances of a resource type— say, Rj. After that, the process can request instances of resource type Ri if and only if F(Rj ) > F(Ri)

F(tape drive) = 1,  F(disk drive) = 5,  F(printer) = 12

A process that wants to use the tape drive and printer at the same time must first request the tape drive and then request the printer.



# 1.2. 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 $<P_1, P_2, \ldots, P_n>$ of ALL the processes in 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

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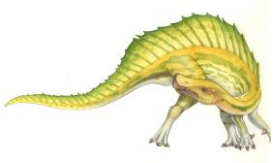


## Continued…..

Example:

- To illustrate, we consider a system with twelve magnetic tape drives and three processes: *Po,* P1, and P2. Process *Po* requires ten tape drives, process P1 may need as many as four tape drives, and process P2 may need up to nine tape drives. Suppose that, at time *to,* process *Po* is holding five tape drives, process P1 is holding two tape drives, and process P2 is holding two tape drives. (Thus, there are three free tape drives.).

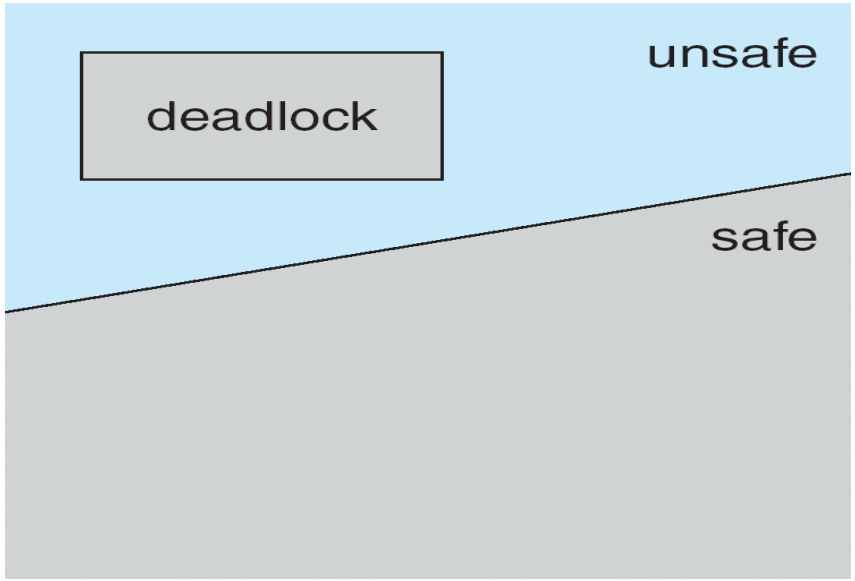
| | Maximum Needs | Current Needs |
|---|---|---|
| P0 | 10 | 5 |
| P1 | 4 | 2 |
| P2 | 9 | 2 |

- At time *t0,* the system is in a safe state. The sequence <P1, *P0,* P2> satisfies the safety condition. Process P1 can immediately be allocated all its tape drives and then return them (the system will then have five available tape drives); then process *Po* can get all its tape drives and return them (the system will then have ten available tape drives); and finally process *P2* can get all its tape drives and return them (the system will then have all twelve tape drives available).

# Basic Facts

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

# Safe, Unsafe, Deadlock State

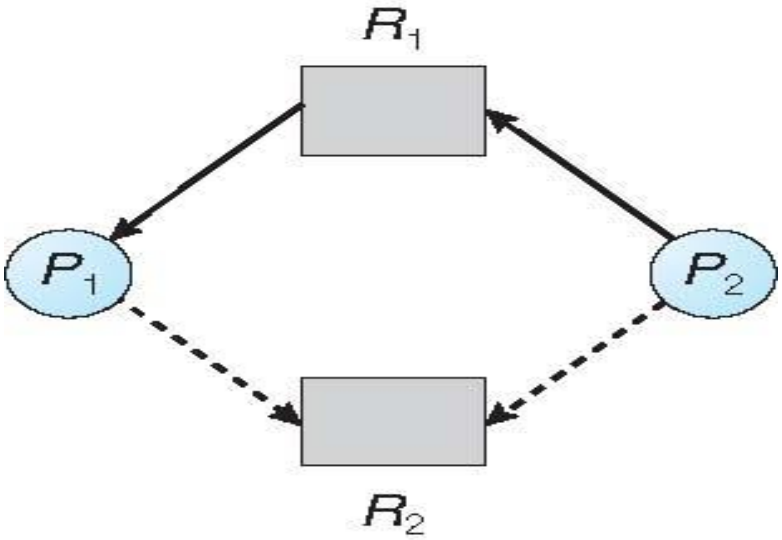



# Avoidance Algorithms

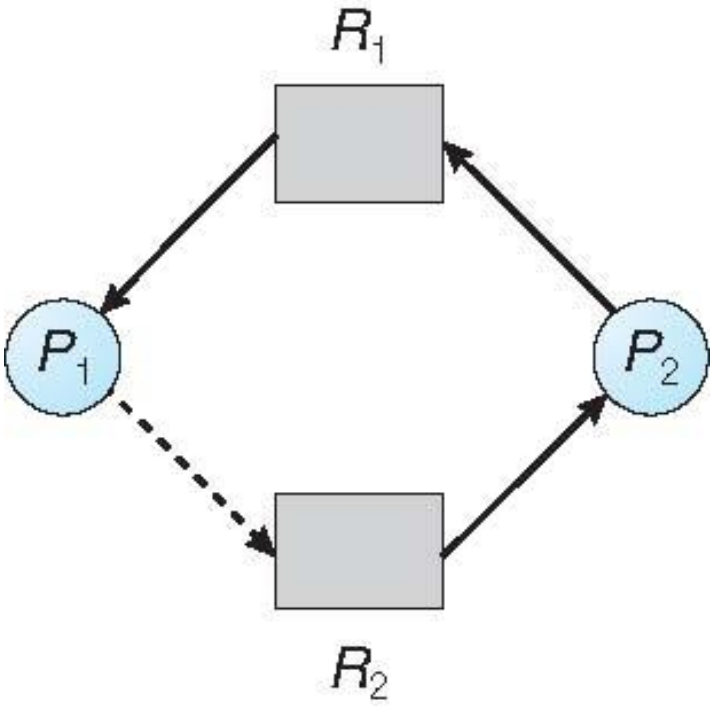
- Single instance of a resource type
  - Use a resource-allocation graph
- Multiple instances of a resource type
  - Use the banker's algorithm

# Resource-Allocation Graph Scheme

- **Claim edge** $P_i \rightarrow R_j$ indicated that process $P_j$ 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

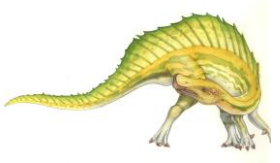



# Unsafe State In Resource-Allocation Graph



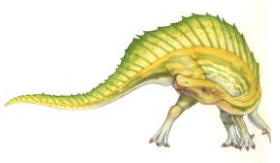

# Resource-Allocation Graph Algorithm

- 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

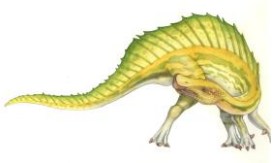


# Data Structures for the Banker's Algorithm

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**: $n$ x $m$ matrix. If $Max$ [$i,j$] = $k$, then process $P_i$ may request at most $k$ instances of resource type $R_j$
- **Allocation**: $n$ x $m$ matrix. If Allocation[$i,j$] = $k$ then $P_i$ is currently allocated $k$ instances of $R_j$
- **Need**: $n$ x $m$ 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* = 0, 1, …, *n*- 1**

2. Find an ***i*** such that both:

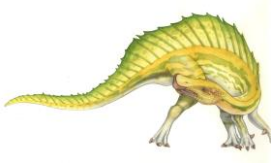
   (a) ***Finish* [*i*] = *false***

   (b) $\boldsymbol{Need_i \leq Work}$

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

3. $\boldsymbol{Work = Work + Allocation_i}$
   ***Finish*[*i*] = *true***
   go to step 2

4. If ***Finish* [*i*] == *true*** for all ***i***, then the system is in a safe state



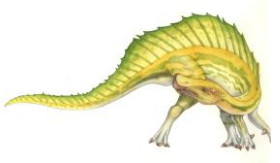
# Example of Banker's Algorithm

- Consider the following system snapshot.

| | *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 | |

i) Calculate the content of need matrix

ii) Determine whether the system is in the safe state. If so find the safe sequence.



# Example (Cont.)

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

| | *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 |

# Continued..

- P0 need0 <= available 7, 4, 3 <= 3, 3, 2
- P1 need1<= available 1, 2, 2 <= 3, 3, 2

  available= available+allocation

  3, 3, 2 + 2 ,0, 0

  available= 5,3,2
- P2 need2 <= available 6,0,0 <= 5,3,2
- P3 need3<= available 0,1,1<=5,3,2

  available= available+allocation

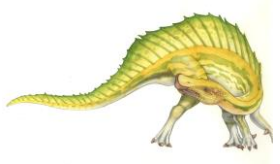
  5,3,2+2,1,1

  available= 7,4,3
- P4 need4<= available 4,3,1 <= 7,4,3

  available= available+allocation

  7,4,3+0, 0, 2

  available= 7,4,5



# Continued..

- P0 need0 <= available 7, 4, 3 <= 7,4,5

  available= available+allocation

  = 7,4,5+0,1,0

  available = 7,5,5

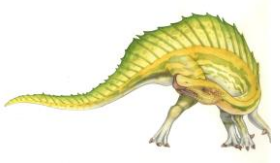
- P2 need2 <= available 6,0,0 <=7,5,5

  available= available+allocation

  = 7,5,5+3,0,2

  available= 10,5,7

Safe sequence p1, p3, p4, p0, p2 or p1, p3, p4, p2, p0



# 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: $P_1$ 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 | |
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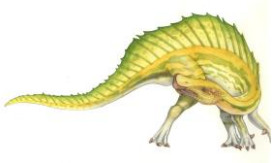
| $P_3$ | 2 1 1 | 0 1 1 | |
| $P_4$ | 0 0 2 | 4 3 1 | |

- Executing safety algorithm shows that sequence < $\boldsymbol{P_1}$, $\boldsymbol{P_3}$, $\boldsymbol{P_4}$, $\boldsymbol{P_0}$, $\boldsymbol{P_2}$> satisfies safety requirement

- Can request for (3,3,0) by $\boldsymbol{P_4}$ be granted?

- Can request for (0,2,0) by $\boldsymbol{P_0}$ be granted?



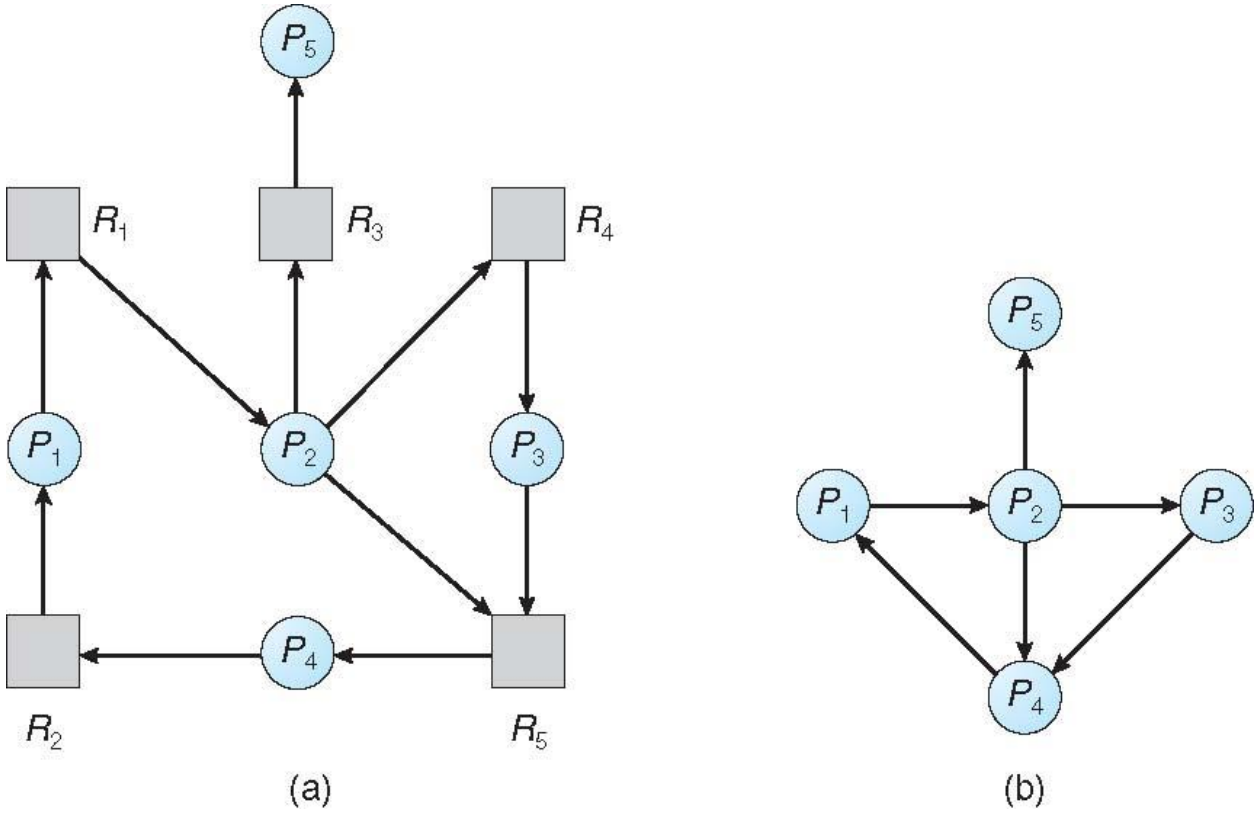
# 2 Deadlock Detection

- 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. 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

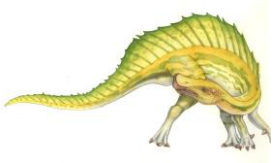
# Resource-Allocation Graph and Wait-for Graph




Resource-Allocation Graph Corresponding wait-for graph

# Several Instances of a Resource Type

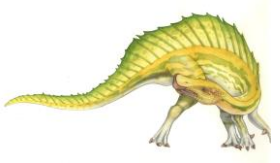
- **Available**: A vector of length ***m*** indicates the number of available resources of each type
- **Allocation**: An ***n*** **x** ***m*** matrix defines the number of resources of each type currently allocated to each process
- **Request**: An ***n*** **x** ***m*** matrix indicates the current request of each process. If ***Request*** **[*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, …, *n***, if ***Allocation*$_i$ ≠ 0**, then ***Finish*[i] = *false***; otherwise, ***Finish*[i] = *true***
2. Find an index ***i*** such that both:
   (a) ***Finish*[*i*] == *false***
   (b) ***Request*$_i$ ≤ *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] == false***, for some ***i***, $1 \le i \le n$, then the system is in deadlock state. Moreover, if ***Finish*[*i*] == *false***, then $P_i$ is deadlocked.

**Algorithm requires an order of O($m$ x $n^2$) 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 | |

- Sequence <$P_0$, $P_2$, $P_3$, $P_1$, $P_4$> will result in ***Finish[i] = true*** for all ***i***

# Deadlock detection Solution

1. In this, Work = [0, 0, 0] & Finish = [false, false, false, false, false]

2. i=0 is selected as both Finish[0] = false and Request<=Work, ie [0, 0, 0]<=[0, 0, 0].

   Work =[0, 0, 0]+[0, 1, 0] =>[0, 1, 0] & Finish = [true, false, false, false, false].

3. i=2 is selected as both Finish[2] = false and [0, 0, 0]<=[0, 1, 0].

   Work =[0, 1, 0]+[3, 0, 3] =>[3, 1, 3] & Finish = [true, false, true, false, false].

4. i=3 is selected as both Finish[3] = false and [1, 0, 0]<=[3, 1, 3].

   Work =[3, 1, 3]+[2, 1, 1] =>[5, 2, 4] & Finish = [true, false, true, true, false].

5. i=1 is selected as both Finish[1] = false and [2, 0, 2]<=[5, 2, 4].

   Work =[5, 2, 4]+[2, 0, 0] =>[7, 2, 4] & Finish = [true, true, true, true, false].

6. i=4 is selected as both Finish[4] = false and [0, 0, 2]<=[7, 2, 4].

   Work =[7, 2, 4]+[0, 0, 2] =>[7, 2, 6] & Finish = [true, true, true, true, true].

Sequence is <P0, P2, P3, P1, P4>Since Finish is a vector of all true, there is no deadlock.

# Example (Cont.)

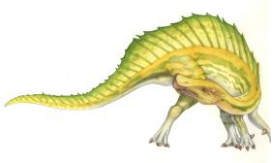
$P_2$ requests an additional instance of type ***C***

| | *Request* |
|---|---|
| | *A B C* |
| $P_0$ | 0 0 0 |
| $P_1$ | 2 0 2 |
| $P_2$ | 0 0 1 |
| $P_3$ | 1 0 0 |
| $P_4$ | 0 0 2 |

State of system?

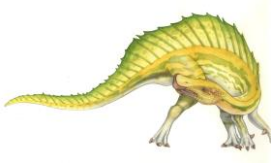
Can reclaim resources held by process $P_0$, but insufficient resources to fulfill other processes; requests

Deadlock exists, consisting of processes $P_1$, $P_2$, $P_3$, and $P_4$



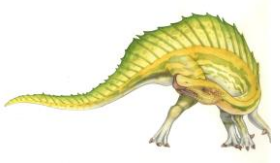
# Recovery from Deadlock: Process Termination

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



# Recovery from Deadlock: Resource Preemption

- **Selecting a victim** – minimize cost i.e which resource and which process are to be preempted.
- **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