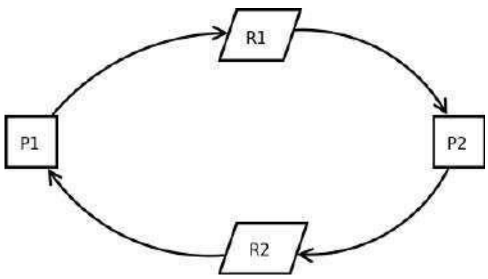
DEADLOCKS

Deadlock is a situation where a set of processes are blocked because each process is
→ holding a resource and
→ waiting for another resource held by some other process.

System Model

- ✓ A system consist of finite number of resources. (For ex: memory, printers, CPUs).
- ✓ These resources are distributed among number of processes.
- ✓ A process must
  → request a resource before using it and
  → release the resource after using it.
- ✓ The process can request any number of resources to carry out a given task.
- ✓ The total number of resource requested must not exceed the total number of resources available.
- ✓ In normal operation, a process must perform following tasks in sequence:
  - **Request**
    If the request cannot be granted immediately (for ex: the resource is being used by another process), then the requesting-process must wait for acquiring the resource.
    For example: open( ), malloc( ), new( ), and request( )
  - **Use**
    The process uses the resource.
    For example: prints to the printer or reads from the file.
  - **Release**
    The process releases the resource.
    So that, the resource becomes available for other processes.
    For example: close( ), free( ), delete( ), and release( ).
- ✓ A set of processes is deadlocked when every process in the set is waiting for a resource that is currently allocated to another process in the set.
- ✓ Deadlock may involve different types of resources.
- ✓ As shown in figure below,



- ✓ Both processes P1 & P2 need resources to continue execution.
- ✓ P1 requires additional resource R1 and is in possession of resource R2.
- ✓ P2 requires additional resource R2 and is in possession of R1.
  Thus, neither process can continue.
- ✓ Multithread programs are good candidates for deadlock because in figure they compete for shared resources.

Deadlock Characterization

In a deadlock, processes never finish executing, and system resources are tied up, preventing other jobs from starting.

Necessary Conditions

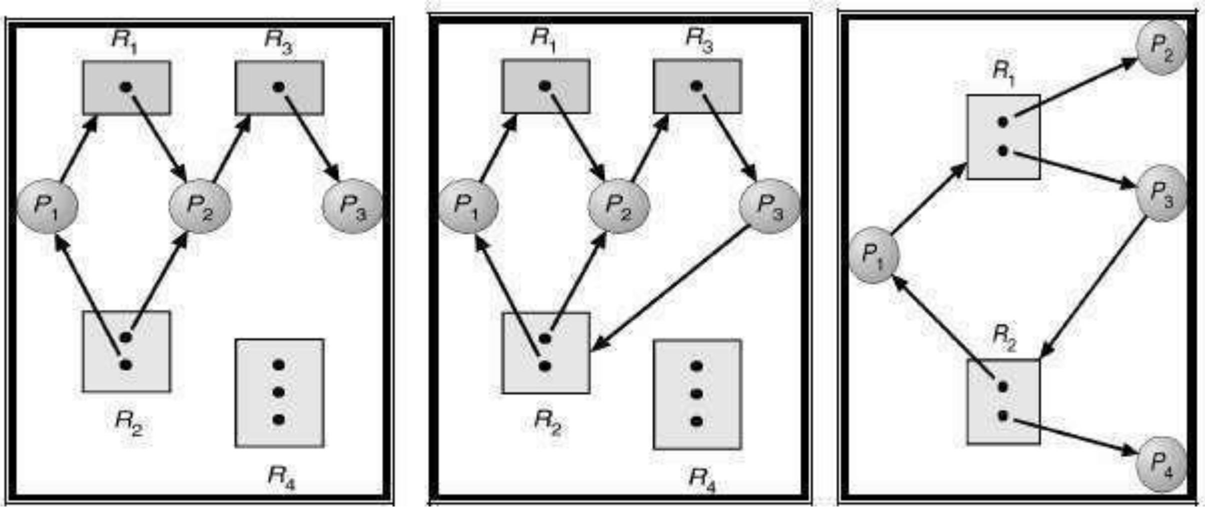
There are four conditions that are necessary to achieve deadlock:

1. **Mutual Exclusion**
   At least one resource must be held in a non-sharable mode.
   If any other process requests this resource, then the requesting-process must wait for the resource to be released.
2. **Hold and Wait**
   A process must be simultaneously
   → holding at least one resource and
   → waiting to acquire additional resources held by the other process.
3. **No Preemption**
   Once a process is holding a resource (i.e. once its request has been granted), then that resource cannot be taken away from that process until the process voluntarily releases it.
4. **Circular Wait**
   A set of processes { P0, P1, P2, . . ., PN } must exist such that P0 is waiting for a resource that is held by P1
   P1 is waiting for a resource that is held by P2, and so on

Resource-Allocation-Graph

- ✓ The resource-allocation-graph (RAG) is a directed graph that can be used to describe the deadlock situation.
- ✓ RAG consists of a
  → set of vertices (V) and
  → set of edges (E).
- ✓ V is divided into two types of nodes
  - P={P1,P2……..Pn} i.e., set consisting of all active processes in the system.
  - R={R1,R2……….Rn} i.e., set consisting of all resource types in the system.
- ✓ E is divided into two types of edges:
  - **Request Edge**
    A directed-edge Pi → Rj is called a request edge.
    Pi → Rj indicates that process Pi has requested a resource Rj.
  - **Assignment Edge**
    A directed-edge Rj → Pi is called an assignment edge.
    Rj → Pi indicates that a resource Rj has been allocated to process Pi.

- ✓ Suppose that process Pi requests resource Rj.
  Here, the request for Rj from Pi can be granted only if the converting request-edge to assignment-edge do not form a cycle in the resource-allocation graph.
- ✓ Pictorially,
  → We represent each process Pi as a circle.
  → We represent each resource-type Rj as a rectangle.
- ✓ As shown in below figures, the RAG illustrates the following 3 situation :
  - RAG with a deadlock
  - RAG with a cycle and deadlock
  - RAG with a cycle but no deadlock



(a) Resource allocation Graph (b) With a deadlock (c) with cycle but no deadlock Resource allocation graphs

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Methods for Handling Deadlocks

- ✓ There are three ways of handling deadlocks:
  - Deadlock prevention or avoidance - Do not allow the system to get into a deadlocked state.
  - Deadlock detection and recovery - Abort a process or preempt some resources when deadlocks are detected.
  - Ignore the problem all together - If deadlocks only occur once a year or so, it may be better to simply let them happen and reboot the system.
- ✓ In order to avoid deadlocks, the system must have additional information about all processes.
- ✓ In particular, the system must know what resources a process will or may request in the future.
- ✓ Deadlock detection is fairly straightforward, but deadlock recovery requires either aborting processes
- ✓ or preempting resources.
- ✓ If deadlocks are neither prevented nor detected, then when a deadlock occurs the system will gradually slow down.

Deadlock-Prevention

Deadlocks can be eliminated by preventing at least one of the four required conditions:

1. Mutual exclusion
2. Hold-and-wait
3. No preemption
4. Circular-wait.

Mutual Exclusion

- ✓ This condition must hold for non-sharable resources.
- ✓ For example:
  A printer cannot be simultaneously shared by several processes.
- ✓ On the other hand, shared resources do not lead to deadlocks.
- ✓ For example:
  Simultaneous access can be granted for read-only file.
- ✓ A process never waits for accessing a sharable resource.

- ✓ In general, we cannot prevent deadlocks by denying the mutual-exclusion condition because some resources are non-sharable by default.

Hold and Wait

- ✓ To prevent this condition:
  The processes must be prevented from holding one or more resources while simultaneously waiting for one or more other resources.
- ✓ There are several solutions to this problem.
- ✓ For example:
  Consider a process that
  → copies the data from a tape drive to the disk
  → sorts the file and
  → then prints the results to a printer.
- ✓ **Protocol-1**
  - Each process must be allocated with all of its resources before it begins execution.
  - All the resources (tape drive, disk files and printer) are allocated to the process at the beginning.
- ✓ **Protocol-2**
  - A process must request a resource only when the process has none.
  - Initially, the process is allocated with tape drive and disk file.
  - The process performs the required operation and releases both tape drive and disk file.
  - Then, the process is again allocated with disk file and the printer
  - Again, the process performs the required operation & releases both disk file and the printer.
- ✓ **Disadvantages** of above 2 methods:
  - Resource utilization may be low, since resources may be allocated but unused for a long period.
  - Starvation is possible.

No Preemption

- ✓ To prevent this condition: the resources must be preempted.
- ✓ There are several solutions to this problem.
- ✓ **Protocol-1**
  - If a process is holding some resources and requests another resource that cannot be immediately allocated to it, then all resources currently being held are preempted.
  - The preempted resources are added to the list of resources for which the process is waiting.
  - The process will be restarted only when it regains the old resources and the new resources that it is requesting.
- ✓ **Protocol-2**
  - When a process request resources, we check whether they are available or not.
- ✓ These 2 protocols may be applicable for resources whose states are easily saved and restored, such
- ✓ as registers and memory.
- ✓ But, these 2 protocols are generally not applicable to other devices such as printers and tape drives.

```
If (resources are
available) then
{
        allocate resources to the process
}
else
{
        If (resources are allocated to waiting
        process) then
        {
                preempt the resources from the waiting
                process allocate the resources to the
                requesting-process the requesting-process
                must wait
        }
```

Circular-Wait

- ✓ Deadlock can be prevented by using the following 2 protocol:
- ✓ Protocol-1
  - Assign numbers all resources.
  - Require the processes to request resources only in increasing/decreasing order.
- ✓ Protocol-2
  - Require that whenever a process requests a resource, it has released resources with a lower number.
- ✓ One big challenge in this scheme is determining the relative ordering of the different resources.

Deadlock Avoidance

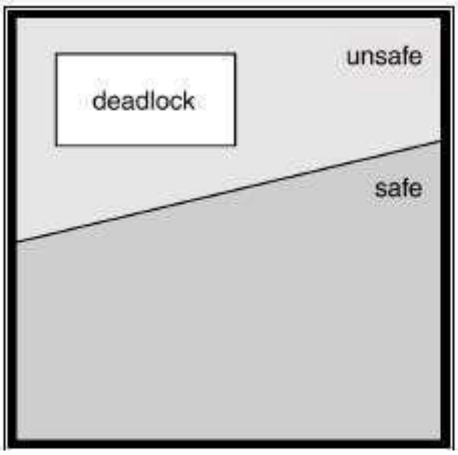
- ✓ The general idea behind deadlock avoidance is to prevent deadlocks from ever happening.
- ✓ Deadlock-avoidance algorithm
  → requires more information about each process, and
  → tends to lead to low device utilization.
- ✓ For example:
  - In simple algorithms, the scheduler only needs to know the maximum number of each resource that a process might potentially use.
  - In complex algorithms, the scheduler can also take advantage of the schedule of exactly what resources may be needed in what order.
- ✓ A deadlock-avoidance algorithm dynamically examines the resources allocation state to ensure that a circular-wait condition never exists.
- ✓ The resource-allocation state is defined by
  → the number of available and allocated resources and
  → the maximum demand of each process.

Safe State

- ✓ A state is safe if the system can allocate all resources requested by all processes without entering a deadlock state.
- ✓ A state is safe if there exists a safe sequence of processes {P0, P1, P2, ..., PN}

such that the requests of each process(Pi) can be satisfied by the currently available resources.

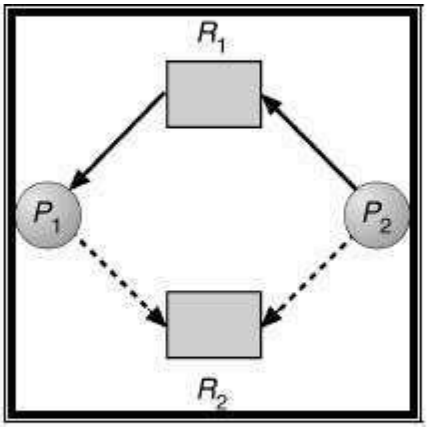
- ✓ If a safe sequence does not exist, then the system is in an unsafe state, which may lead to deadlock.
- ✓ All safe states are deadlock free, but not all unsafe states lead to deadlocks.

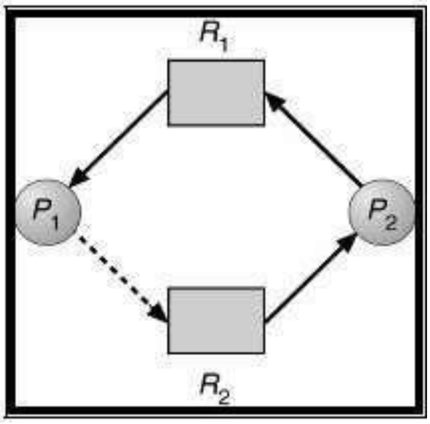


Safe, unsafe, and deadlock state spaces

<u>Resource-Allocation-Graph Algorithm</u>

- ✓ If resource categories have only single instances of their resources, then deadlock states can be detected by cycles in the resource-allocation graphs.
- ✓ In this case, unsafe states can be recognized and avoided by augmenting the resource-allocation graph with claim edges (denoted by a dashed line).
- ✓ Claim edge Pi → Rj indicated that process Pi may request resource Rj at some time in future.
- ✓ The important steps are as below:
  - ▪ When a process Pi requests a resource Rj, the claim edge Pi → Rj is converted to a request edge.
  - ▪ Similarly, when a resource Rj is released by the process Pi, the assignment edge Rj → Pi is reconverted as claim edge Pi → Rj.
  - ▪ The request for Rj from Pi can be granted only if the converting request edge to assignment edge do not form a cycle in the resource allocation graph.
- ✓ To apply this algorithm, each process Pi must know all its claims before it starts executing.
- ✓ Conclusion:
  - ▪ If no cycle exists, then the allocation of the resource will leave the system in a safe state.
  - ▪ If cycle is found, system is put into unsafe state and may cause a deadlock.
- ✓ For example: Consider a resource allocation graph shown in Figure 3.5(a).
  - ▪ Suppose P2 requests R2.
  - ▪ Though R2 is currently free, we cannot allocate it to P2 as this action will create a cycle in the graph as shown in Figure 3.5(b).
  - ▪ This cycle will indicate that the system is in unsafe state: because, if P1 requests R2 and P2 requests R1 later, a deadlock will occur.





Banker's Algorithm

- ✓ This algorithm is applicable to the system with multiple instances of each resource types.
- ✓ However, this algorithm is less efficient then the resource-allocation-graph algorithm.
- ✓ When a process starts up, it must declare the maximum number of resources that it may need.
- ✓ This number may not exceed the total number of resources in the system.
- ✓ When a request is made, the system determines whether granting the request would leave the system in a safe state.

    If the system in a safe state,
        the resources are allocated;
    else
        the process must wait until some other process releases enough resources.

- ✓ Assumptions:

    Let n = number of processes in the system
    Let m = number of resources types.

- ✓ Following data structures are used to implement the banker's algorithm.
    - Available [m]
        - This vector indicates the no. of available resources of each type.
        - If Available[j]=k, then k instances of resource type Rj is available.
    - Max [n][m]
        - This matrix indicates the maximum demand of each process of each resource.
        - If Max[i,j]=k, then process Pi may request at most k instances of resource type Rj.
    - Allocation [n][m]
        - This matrix indicates no. of resources currently allocated to each process.
        - If Allocation[i,j]=k, then Pi is currently allocated k instances of Rj.
    - Need [n][m]
        - This matrix indicates the remaining resources need of each process.
        - If Need[i,j]=k, then Pi may need k more instances of resource Rj to complete its task.
        - So, Need[i,j] = Max[i,j] - Allocation[i]

- ✓ The Banker's algorithm has two parts:
  1) Safety Algorithm
  2) Resource – Request Algorithm

Safety Algorithm

- ✓ This algorithm is used for finding out whether a system is in safe state or not.
- ✓ Assumptions:
  - Work is a working copy of the available resources, which will be modified during the analysis.
  - Finish is a vector of boolean values indicating whether a particular process can finish.

Step 1:

Let Work and Finish be two vectors of length m and n respectively.
Initialize:
Work = Available
Finish[i] = false for i=1,2,3,…….n

Step 2:

Find an index(i) such that both
a) Finish[i] = false
b) Need i <= Work.
If no such i exist, then go to step 4

Step 3:

Set:
Work = Work +
Allocation(i) Finish[i]

Resource-Request Algorithm

- ✓ This algorithm determines if a new request is safe, and grants it only if it is safe to do so.
- ✓ When a request is made (that does not exceed currently available resources), pretend it has been granted, and then see if the resulting state is a safe one. If so, grant the request, and if not, deny the request.
- ✓ Let Request(i) be the request vector of process Pi.
- ✓ If Request(i)[j]=k, then process Pi wants K instances of the resource type Rj.

Step 1:

If Request(i) <=
Need(i) then
go to step 2
else
raise an error condition, since the process has exceeded its maximum claim.

Step 2:

If Request(i) <=
Available then
go to step 3
else
Pi must wait, since the resources are not available.

Step 3:

If the system want to allocate the requested resources to process Pi then modify the state as follows:
Available = Available – Request(i)
Allocation(i) = Allocation(i) +
Request(i) Need(i) = Need(i) –
Request(i)

Step 4:

If the resulting resource-allocation state is
safe, then i) transaction is
complete and
ii) Pi is allocated its resources.

Step 5:

If the new state is unsafe,
then i) Pi must wait for Request(i) and
ii) old resource-allocation state is restored.

Examples :

Question: Consider the following snapshot of a system:

	Allocation			Max			Available		
	A	B	C	A	B	C	A	B	C
P0	0	1	0	7	5	3	3	3	2
P1	2	0	0	3	2	2			
P2	3	0	3	9	0	2			
P3	2	1	1	2	2	2			
P4	0	0	2	4	3	3			

Answer the following questions using Banker's algorithm.

i) What is the content of the matrix need?
ii) Is the system in a safe state?
iii) If a request from process P1 arrives for (1 0 2) can the request be granted immediately?

Solution (i):

- The content of the matrix Need is given by
  Need = Max - Allocation
- So, the content of Need Matrix is:

	Need		
	A	B	C
P0	7	4	3
P1	1	2	2
P2	6	0	0
P3	0	1	1
P4	4	3	1

Solution (ii):

- Applying the Safety algorithm on the given system,

Step 1: Initialization

Work = Available i.e. Work =3 3 2

......P0.........P1........P2........P3......P4.....

Finish = | false | false | false | false | false |

Step 2: For i=0

Finish[P0] = false and Need[P0]<=Work i.e. (7 4 3)<=(3 3 2) ➔ false

So P0 must wait.

Step 2: For i=1

Finish[P1] = false and Need[P1]<=Work i.e. (1 2 2)<=(3 3 2) ➔ true

So P1 must be kept in safe sequence.

Step 3: Work = Work + Allocation[P1] =(3 3 2)+(2 0 0)=(5 3 2)

.......P0.........P1.......P2.......P3........P4......

Finish = | false | true | false | false | false |

Step 2: For i=2

Finish[P2] = false and Need[P2]<=Work i.e. (6 0 0)<=(5 3 2) ➔ false

So P2 must wait.

Step 2: For i=3

Finish[P3] = false and Need[P3]<=Work i.e. (0 1 1)<=(5 3 2) ➔ true

So P3 must be kept in safe sequence.

Step 3: Work = Work + Allocation[P3] = (5 3 2)+(2 1 1)=(7 4 3)

......P0.........P1......P2...........P3.......P4....

Finish = | false | true | false | true | false |

Step 2: For i=4
Finish[P4] = false and Need[P4]<=Work i.e. (4 3 1)<=(7 4 3) → true
So P4 must be kept in safe sequence.
Step 3: Work = Work + Allocation[P4] =(7 4 3)+(0 0 2)=(7 4 5)

......P0.........	P1......	P2.........	P3.......	P4.....
false	true	false	true	true

Finish= | false | true | false | true | true |

Step 2: For i=0
Finish[P0] = false and Need[P0]<=Work i.e. (7 4 3)<=(7 4 5) → true
So P0 must be kept in safe sequence.
Step 3: Work = Work + Allocation[P0] =(7 4 5)+(0 1 0)=(7 5 5)

.....P0.......P1.........P2.......P3.......P4....
Finish= | true | true | false | true | true |

Step 2: For i=2
Finish[P2] = false and Need[P2]<=Work i.e. (6 0 0) <=(7 5 5) → true
So P2 must be kept in safe sequence.
Step 3: Work = Work + Allocation[P2] =(7 5 5)+(3 0 2)=(10 5 7)

.....P0.......P1.........P2.......P3.......P4....
Finish= | true | true | true | true | true |

Step 4: Finish[Pi] = true for 0<=i<=4
Hence, the system is currently in a safe state.
The safe sequence is <P1, P3, P4, P0, P2>.
the system is currently in a safe state.

Solution (iii): P1 requests (1 0 2) i.e. Request[P1]=1 0 2

- To decide whether the request is granted, we use Resource Request algorithm.
  - Step 1: Request[P1]<=Need[P1] i.e. (1 0 2)<=(1 2 2) → true.
  - Step 2: Request[P1]<=Available i.e. (1 0 2)<=(3 3 2) → true.
  - Step 3: Available = Available – Request[P1] = (3 3 2) - (1 0 2)= (2 3 0)
    Allocation[P1] = Allocation[P1] + Request[P1] = (2 0 0) + (1 0 2)= (3 0 2)
    Need[P1] = Need[P1] – Request[P1] = (1 2 2) - (1 0 2)= (0 2 0)
- We arrive at the following new system state:

	Allocation			Max			Available		
	A	B	C	A	B	C	A	B	C
P0	0	1	0	7	5	3	2	3	0
P1	3	0	2	3	2	2			
P2	3	0	2	9	0	2			
P3	2	1	1	2	2	2			
P4	0	0	2	4	3	3			

- The content of the matrix Need is given by Need = Max - Allocation
- So, the content of Need Matrix is:

	Need		
	A	B	C
P0	7	4	3
P1	0	2	0
P2	6	0	0
P3	0	1	1
P4	4	3	1

- To determine whether this new system state is safe, we again execute Safety algorithm.

Step 1: Initialization

Here, m=3, n=5

Work = Available i.e. Work =2 3 0

.....P0.........P1........P2..........P3.......P4....

Finish = | false | false | false | false | false |

Step 2: For i=0

Finish[P0] = false and Need[P0]<=Work i.e. (7 4 3)<=(2 3 0) ➔ false

So P0 must wait.

Step 2: For i=1

Finish[P1] = false and Need[P1]<=Work i.e. (0 2 0)<=(2 3 0) ➔ true

So P1 must be kept in safe sequence.

Step 3: Work = Work + Allocation[P1] =(2 3 0)+(3 0 2)=(5 3 2)

......P0.........P1.......P2.........P3.......P4......

Finish = | false | true | false | false | false |

Step 2: For i=2

Finish[P2] = false and Need[P2]<=Work i.e. (6 0 0) <=(5 3 2) ➔ false

So P2 must wait.

Step 2: For i=3

Finish[P3] = false and Need[P3]<=Work i.e. (0 1 1)<=(5 3 2) ➔ true

So P3 must be kept in safe sequence.

Step 3: Work = Work + Allocation[P3] = (5 3 2)+(2 1 1)=(7 4 3)

.....P0..........P1......P2........P3.......P4......

Finish = | false | true | false | true | false |

Step 2: For i=4

Finish[P4] = false and Need[P4]<=Work i.e. (4 3 1)<=(7 4 3) ➔ true

So P4 must be kept in safe sequence.

Step 3: Work = Work + Allocation[P4] =(7 4 3)+(0 0 2)=(7 4 5)

......P0.........P1......P2.........P3.......P4....

Finish = | false | true | false | true | true |

Step 2: For i=0

Finish[P0] = false and Need[P0]<=Work i.e. (7 4 3)<=(7 4 5) ➔ true

So P0 must be kept in safe sequence.

Step 3: Work = Work + Allocation[P0] =(7 4 5)+(0 1 0)=(7 5 5)

......P0.......P1.........P2......P3........P4....

Finish = | true | true | false | true | true |

Step 2: For i=2

Finish[P2] = false and Need[P2]<=Work i.e. (6 0 0) <=(7 5 5) ➔ true

So P2 must be kept in safe sequence.

Step 3: Work = Work + Allocation[P2] =(7 5 5)+(3 0 2)=(10 5 7)

.....P0.......P1.........P2.......P3.......P4....

Finish= | true | true | true | true | true |

Step 4: Finish[Pi] = true for 0<=i<=4

Hence, the system is in a safe state.

The safe sequence is <P1, P3, P4, P0, P2>.

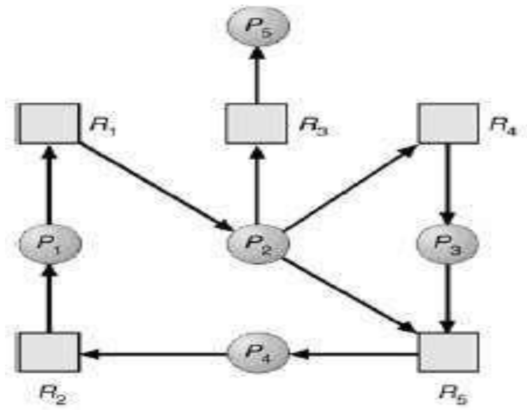
Since the system is in safe sate, the request can be granted.

Deadlock Detection

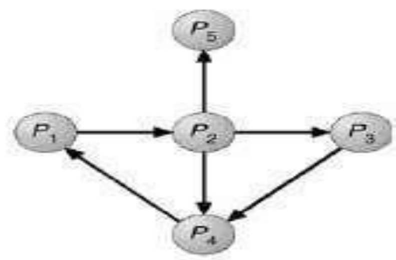
- ✓ If a system does not use either deadlock-prevention or deadlock-avoidance algorithm then a deadlock may occur.
- ✓ In this environment, the system must provide
  - An algorithm to examine the system-state to determine whether a deadlock has occurred.
  - An algorithm to recover from the deadlock.

Single Instance of Each Resource Type

- ✓ If all the resources have only a single instance, then deadlock detection-algorithm can be defined using a wait-for-graph.
- ✓ The wait-for-graph is applicable to only a single instance of a resource type.
- ✓ A wait-for-graph (WAG) is a variation of the resource-allocation-graph.
- ✓ The wait-for-graph can be obtained from the resource-allocation-graph by
  → removing the resource nodes and
  → collapsing the appropriate edges.
- ✓ An edge from Pi to Pj implies that process Pi is waiting for process Pj to release a resource that Pi needs.
- ✓ An edge Pi → Pj exists if and only if the corresponding graph contains two edges
  Pi → Rq and
  Rq → Pj.
- ✓ For example:
  Consider resource-allocation-graph and Corresponding wait-for-graph shown in below figure,



Resource-allocation-graph



Corresponding wait-for-graph.

- ✓ A deadlock exists in the system if and only if the wait-for-graph contains a cycle.
- ✓ To detect deadlocks, the system needs to
  → maintain the wait-for-graph and
  → periodically execute an algorithm that searches for a cycle in the graph.

Several Instances of a Resource Type

- ✓ The wait-for-graph is applicable to only a single instance of a resource type.
- ✓ However, the wait-for-graph is not applicable to a multiple instance of a resource type.
- ✓ The following detection-algorithm can be used for a multiple instance of a resource type.
- ✓ Assumptions:

Let 'n' be the number of processes in the system
Let 'm' be the number of resources types.

- ✓ Following data structures are used to implement this algorithm.

1. **Available [m]**
   This vector indicates the no. of available resources of each type.
   If Available[j]=k, then k instances of resource type Rj is available.
2. **Allocation [n][m]**
   This matrix indicates no. of resources currently allocated to each process.
   If Allocation[i,j]=k, then Pi is currently allocated k instances of Rj.
3. **Request [n][m]**
   This matrix indicates the current request of each process.
   If Request [i, j] = k, then process Pi is requesting k more instances of resource type Rj.

Step 1:

Let Work and Finish be vectors of length m and n respectively.
a) Initialize Work = Available b) For i=0,1,2……….n
if Allocation(i) != 0 then
Finish[i] = false;
else
Finish[i] = true;

Step 2:

Find an index(i) such that both
a) Finish[i] = false
b) Request(i) <= Work.
If no such i exist, goto step 4.

Step 3:

Set:
Work = Work + Allocation(i) Finish[i] = true
Go to step 2.

Step 4:

If Finish[i] = false for some i where 0 < i < n, then the system is in a deadlock state.

Detection-Algorithm Usage

- ✓ The detection-algorithm must be executed based on following factors:
  1. The frequency of occurrence of a deadlock.
  2. The no. of processes affected by the deadlock.
- ✓ If deadlocks occur frequently, then the detection-algorithm should be executed frequently.
- ✓ Resources allocated to deadlocked-processes will be idle until the deadlock is broken.
- ✓ Deadlock occurs only when some processes make a request that cannot be granted immediately.
- ✓ The deadlock-algorithm must be executed whenever a request for allocation cannot be granted immediately.

- ✓ In this case, we can identify set of deadlocked-processes and specific process causing the deadlock.
- ✓ The deadlock-algorithm must be executed in periodic intervals.
  For example: once in an hour, whenever CPU utilization drops below certain threshold

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Recovery from deadlock

Three approaches to recovery from deadlock:

- ➢ Inform the system-operator for manual intervention.
- ➢ Terminate one or more deadlocked-processes.
- ➢ Preempt(or Block) some resources.

Process Termination

- ✓ There are two methods to remove deadlocks:
  - ➢ Terminate all deadlocked-processes:
    This method will definitely break the deadlock-cycle. However, this method incurs great expense. This is because, Deadlocked-processes might have computed for a long time. Results of these partial computations must be discarded. Probably, the results must be re-computed later.
  - ➢ Terminate one process at a time until the deadlock-cycle is eliminated:
    This method incurs large overhead. This is because after each process is aborted, deadlock-algorithm must be executed to determine if any other process is still deadlocked
- ✓ For process termination, following factors need to be considered:
  - The priority of process.
  - The time taken by the process for computation & the required time for complete execution.
  - The no. of resources used by the process.
  - The no. of extra resources required by the process for complete execution.
  - The no. of processes that need to be terminated for deadlock-free execution.
  - The process is interactive or batch.

Resource Preemption

- ✓ Some resources are taken from one or more deadlocked-processes.
- ✓ These resources are given to other processes until the deadlock-cycle is broken.
- ✓ Three issues need to be considered:
- ➢ **Selecting a victim**
  - Which resources/processes are to be pre-empted (or blocked)?
  - The order of pre-emption must be determined to minimize cost.
  - Cost factors includes
  - The time taken by deadlocked-process for computation.
  - The no. of resources used by deadlocked-process.
- ➢ **Rollback**
  - If a resource is taken from a process, the process cannot continue its normal execution.
  - In this case, the process must be rolled-back to break the deadlock.
  - This method requires the system to keep more info. about the state of all running processes.
- ➢ **Starvation**
  - In a system where victim-selection is based on cost-factors, the same process

may be always picked as a victim.

- As a result, this process never completes its designated task.
- Ensure a process is picked as a victim only a (small) finite number of times.
