Operating Systems: Deadlocks – PART II

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Deadlock Avoidance algorithm Outline

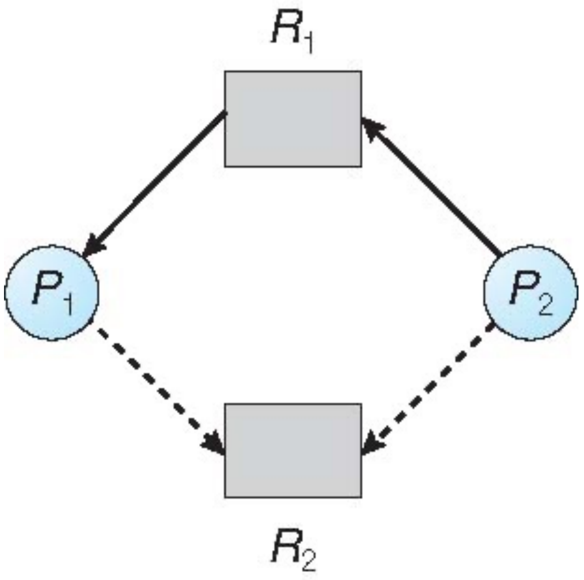
- Given the resource allocation state of a system,
  - The algorithm checks if the system is in a *safe state*.
  - If the system is in a safe state, whenever a process requests an instance of a resource type,
    - It checks to see if allocating the resources continues to have the system in a safe state.
      - If yes -- allocate the resources.
      - If no -- have the process wait.

Deadlock Avoidance Algorithms

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

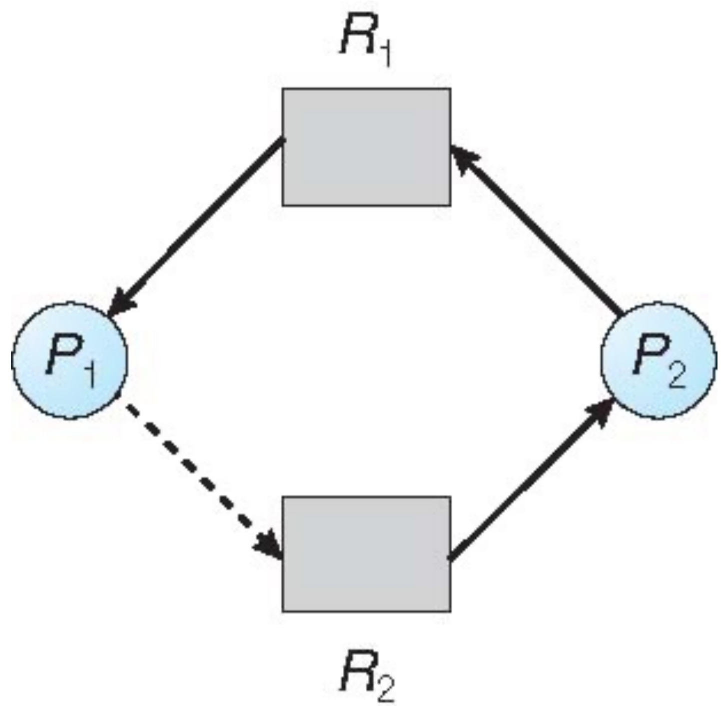
Resource-Allocation Graph Scheme

- Add claim edges to existing resource allocation graph.
- **Claim edge** $P_i \rightarrow R_j$ indicates 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 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
- We check for safety by using a cycle-detection algorithm.



Unsafe State In Resource-Allocation Graph

Although R_2 is free, we cannot allocate it to P_2 since this will create a cycle!

Banker's Algorithm Outline for *multiple instances* of a resource type

- The algorithm consists of two parts
  - **PART 1 - Safety Algorithm** – checks whether a system is in a safe state or not.
  - **PART 2 - Resource-Request Algorithm** – checks to see if resources requested by a process can be satisfied or not.
- Each process must a priori claim maximum use
- When a process gets all its resources it must return them in a *finite amount of time*
- When a process requests a resource, it *may have to wait*

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

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

Example of Data Structures for Banker's Algorithm

- 5 processes P_0 through P_4;

  3 resource types:

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

Resource allocation state at time T_0:

	Max. Need			Allocation			Available		
	A	B	C	A	B	C	A	B	C
P_0	7	5	3	0	1	0	3	3	2
P_1	3	2	2	2	0	0			
P_2	9	0	2	3	0	2			
P_3	2	2	2	2	1	1			
P_4	4	3	3	0	0	2			

Need matrix for Banker's Algorithm

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

- 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:

	Max. Need			**Allocation**			**Need**			**Available**		
	A	B	C	A	B	C	**A**	**B**	**C**	A	B	C
P_0	7	5	3	0	1	0	**7**	**4**	**3**	3	3	2
P_1	3	2	2	2	0	0	**1**	**2**	**2**			
P_2	9	0	2	3	0	2	**6**	**0**	**0**			
P_3	2	2	2	2	1	1	**0**	**1**	**1**			
P_4	4	3	3	0	0	2	**4**	**3**	**1**			

Part 1 - Safety Algorithm outline explained with an example

Step 1: Maintain ***Work*** and ***Finish*** vectors of length *m* and *n*, respectively.

Initialize:

Work* = *Available

***Finish* [*i*] = *false*, *i* ∈ [0, *n*- 1]**

Work. = (3 3 2)

Finish =

False	False	False	False	False

Step 2: Find a process **P_i** such that both:

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

(b) **$Need_i \leq Work$**

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

P_1 satisfies conditions (a) and (b)

Part 1 - Safety Algorithm outline explained with an example – contd…

Step 3:

Work = Work + Allocation$_i$

Finish[i] = true

Go to step 2

Work $= Work + Allocation_1$

$= (3\ 3\ 2) + (2\ 0\ 0) = (5\ 3\ 2)$

Finish[1] = true

Finish =

False	True	False	False	False

Next, we see that process P_3, P_4, P_2, and P_0 all satisfy the conditions in step 2.

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

Finish =

True	True	True	True	True

Therefore, the system is in a safe state and the sequence of processes satisfying the safety requirement is -

<P_1, P_3, P_4, P_2, P_0>

Part – 2 Resource-Request Algorithm for Process P_i

- $\boldsymbol{Request_i}$ = request vector for process $\boldsymbol{P_i}$. If $\boldsymbol{Request_i[j] = k}$ then process $\boldsymbol{P_i}$ wants $\boldsymbol{k}$ instances of resource type $\boldsymbol{R_j}$
- **Step 1:** If $\boldsymbol{Request_i \le Need_i}$ go to step 2. *Otherwise, raise error condition*, since process has exceeded its maximum claim
- **Step 2:** If $\boldsymbol{Request_i \le Available}$, go to step 3. *Otherwise,* $\boldsymbol{P_i}$ *must wait*, since resources are not available
- **Step 3:** Pretend to allocate requested resources to $\boldsymbol{P_i}$ and update the system 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 $\boldsymbol{P_i}$
  - If unsafe $\Rightarrow$ $\boldsymbol{P_i}$ must wait, and the old resource-allocation state is restored

PART 2 - Resource-Request Algorithm Explained with an Example

- **P_1 requests resources (1 0 2)**
- Check if **$Request_1 \leq Need_1$**
  - $(1\ 0\ 2) \leq (\ 1\ 2\ 2) \Rightarrow$ true
- Check if **$Request_1 \leq Available$**
  - $(1\ 0\ 2) \leq (\ 3\ 2\ 2) \Rightarrow$ true
- Pretend that resources requested have be granted.
- Update system state. Max need, $Allocation_1$ and $Need_1$ data structures
  - $Available_1 = (3\ 2\ 2) - (1\ 0\ 2) = (2\ 2\ 0)$
  - $Allocation_1 = (2\ 0\ 0) + (1\ 0\ 2) = (3\ 0\ 2)$
  - $Need_1 = (1\ 2\ 2) - (1\ 0\ 2) = (0\ 2\ 0)$

PART 2 - Resource-Request Algorithm Explained with an Example contd…

Updated resource allocation state:

	Max. Need			Allocation			Need			Available		
	A	B	C	A	B	C	A	B	C	A	B	C
P_0	7	5	3	0	1	0	7	4	3	**2**	**2**	**0**
P_1	3	2	2	**3**	**0**	**2**	**0**	**2**	**0**			
P_2	9	0	2	3	0	2	6	0	0			
P_3	2	2	2	2	1	1	0	1	1			
P_4	4	3	3	0	0	2	4	3	1			

PART 2 - Resource-Request Algorithm Explained with an Example contd…

- Run safety algorithm on the updated resource allocation state.
- System is in safe state and the sequence of processes satisfying the safety requirement is **<P_1, P_3, P_4, P_2, P_0>**

Updated Resource allocation state after request has been granted for P_1

	Max. Need			Allocation			Need			Available		
	A	B	C	A	B	C	A	B	C	A	B	C
P_0	7	5	3	0	1	0	7	4	3	**2**	**2**	**0**
P_1	3	2	2	**3**	**0**	**2**	**0**	**2**	**0**			
P_2	9	0	2	3	0	2	6	0	0			
P_3	2	2	2	2	1	1	0	1	1			
P_4	4	3	3	0	0	2	4	3	1			

Resource-Request Algorithm Example – Cont...

- When system in this state, can request for (3 3 0) by P_4 be granted?
  - Check if **Request$_4$** $\leq$ **Available**
    - (3 3 0) $\leq$ (2 2 0) $\Rightarrow$ false
    - The request cannot be granted.
- When system in this state, can request for (0 2 0) by P_0 be granted?
  - Check if **Request$_0$** $\leq$ **Need$_0$**
    - (0 2 0) $\leq$ (7 4 3) $\Rightarrow$ true
  - Check if **Request$_0$** $\leq$ **Available**
    - (0 2 0) $\leq$ (2 2 0) $\Rightarrow$ true
  - Pretend to grant the resources requested.

Resource-Request Algorithm Example – Cont…

Updated Resource allocation state

	Max. Need			Allocation			Need			Available		
	A	B	C	A	B	C	A	B	C	A	B	C
P_0	7	5	3	**0**	**3**	**0**	**7**	**2**	**3**	**2**	**0**	**0**
P_1	3	2	2	3	0	2	0	2	0			
P_2	9	0	2	3	0	2	6	0	0			
P_3	2	2	2	2	1	1	0	1	1			
P_4	4	3	3	0	0	2	4	3	1			

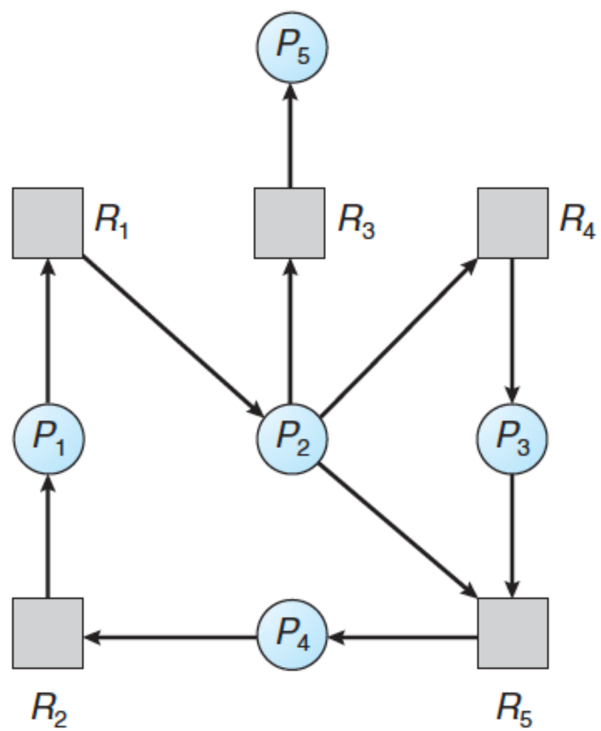
- However, since no sequence of processes exist that satisfies the safe state requirement, P_0's request cannot be granted as doing so will leave the system in an unsafe state.

Deadlock Detection

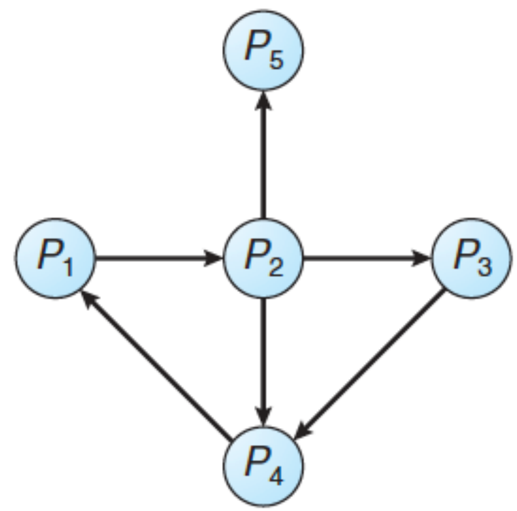
- Allow system to enter deadlock state
- Use deadlock detection algorithm to check if a deadlock exists
- If deadlock exists, use a recovery scheme to recover from the deadlock

Deadlock Detection - Single Instance of Each Resource Type

- A variant of the resource-allocation graph if all resources have only **a single instance** - used for deadlock detection
- Nodes are processes, and an edge $\boldsymbol{P_i \rightarrow P_j}$ in the wait for graph implies that $\boldsymbol{P_i}$ is waiting for $\boldsymbol{P_j}$ to release a resource that P_j needs.



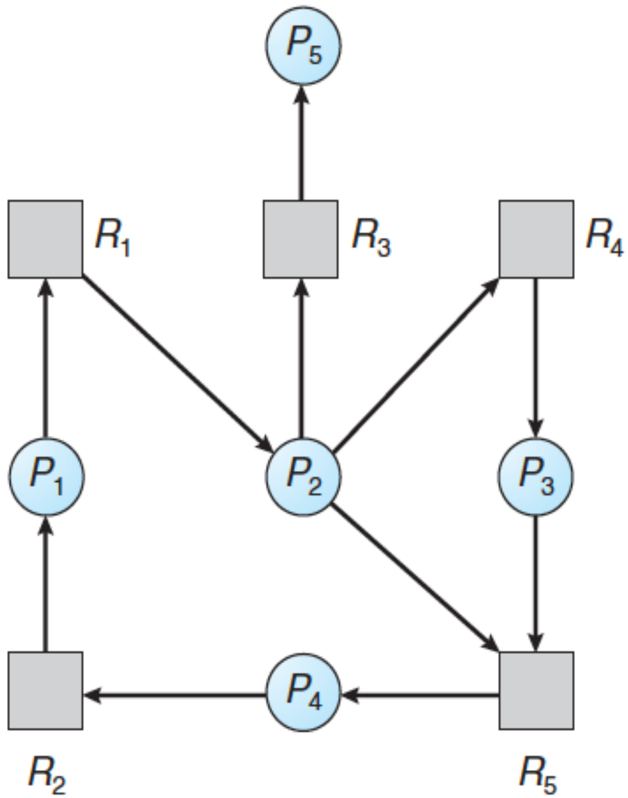
Resource-Allocation Graph



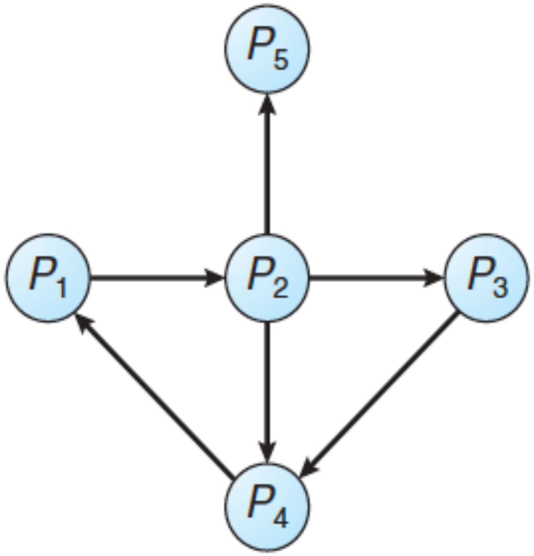
Corresponding wait-for graph

Deadlock Detection - Single Instance of Each Resource Type

If a cycle exists in the wait-for graph, then the system is in deadlock.



Resource-Allocation Graph



Corresponding wait-for graph

Deadlock Detection Algorithm for Multiple Instances of a Resource Type

- The algorithms needs to know
  - The number of *available resources and allocated resources* for each resource type.
  - The number of *requested resources* by all processes in the system.
- Given the above,
  - The deadlock detection algorithm checks whether the system is ***in a deadlocked*** state or not.
  - If the system is in a deadlocked state, then the algorithm also identifies the processes involved in the deadlock.

Deadlock Detection Algorithm for Multiple Instances of a Resource Type Data Structures

- **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*** instances of resource type R_j.

Deadlock 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***,

      i. if $\boldsymbol{Allocation_i \neq 0}$, then ***Finish*[i] = *false***;

      ii. otherwise, ***Finish*[i] = *true***

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

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

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

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

Items in red highlight the differences in Deadlock detection algorithm and the safety algorithm described under Banker's algorithm.

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.

Example for Deadlock Detection Algorithm

- Five processes P_0 through P_4
- Three resource types

  A (7 instances), B (2 instances), and C (6 instances)
- Snapshot of the system 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			

Example of Detection Algorithm Cont…

Step 1:

1. Work = Available = (0 0 0)

   Since $Allocation_i \neq 0$, for all $i \in [1, n]$

   Finish =

False	False	False	False	False

Step 2: Find an index **i** such that both:

1. Finish[i] == false
2. $Request_i \leq Work$

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

P_0 satisfies the above two conditions.

Example of Detection Algorithm Cont…

- Step 3:
  - **Work = Work + Allocation$_0$ = (0 0 0) + (0 1 0) = (0 1 0)**

    Finish[1] = true

    go to step 2

- We see that process P_2, P_3, P_1, and P_4 all satisfy the conditions in step 2.

- Finally, in **Step 4: Finish =**

True	True	True	True	True

- Therefore, the system is ***not in a deadlocked state,*** as the following sequence of processes results in all values of the **Finish** vector to be **True**: **<P_0, P_2, P_3, P_1, P_4>**

Example of Detection Algorithm Cont…

- *Suppose P_2* requests an additional instance of type *C.*
- *Then below is the updated snapshot of the system including this request:*

	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 1	
P_3	2 1 1	1. 0 0	
P_4	0. 0 2	0 0 2	

- Can reclaim resources held by process $\boldsymbol{P_0}$, but insufficient resources to fulfill other processes' requests
- **Deadlock exists, consisting of processes $\boldsymbol{P_1}$, $\boldsymbol{P_2}$, $\boldsymbol{P_3}$, and $\boldsymbol{P_4}$**

Recovery from Deadlock

- **Process Termination**
  - Abort all deadlocked processes
  - Abort one process at a time until the deadlock cycle is eliminated

- **Resource Preemption**
  - **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. Possible solution - include number of rollback in cost factor