BUCKNELL UNIVERSITY
Computer Science

CSCI 315 Operating Systems Design

Deadlock

Notice: The slides for this lecture have been largely based on those accompanying an earlier version of the course text *Operating Systems Concepts with Java*, by Silberschatz, Galvin, and Gagne. Many, if not all, the illustrations contained in this presentation come from this source.

Safe States

- Sequence **<P_1, P_2, …, P_n>** is ***safe*** if for each P_i, the resources that P_i can still request can be satisfied by currently available resources plus the resources held by all the P_j, with j<I.
  - 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.
- The system is in a ***safe state*** if there exists a safe sequence for all processes.
- When a process requests an available resource, the system must decide if immediate allocation leaves the system in a **safe state**.

Basic Facts

- If a system is in a safe state there can be no deadlock.
- If a system is in unsafe state, there exists the **possibility** of deadlock.
- **Avoidance** strategies ensure that a system will never enter an unsafe state.

Banker's Algorithm

- Applicable when there are multiple instances of each resource type.
- In a bank, the cash must never be allocated in a way such that it cannot satisfy the need of **all its customers**.
- Each process must state a priori the maximum number of instances of each kind of resource that it will ever need.
- 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.

Banker's Algorithm: Data Structures

Let ***n*** **= number of processes**, ***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.

  Note that:

  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* - 1,3, …, *n.*

2. Find an *i* such that both:
   (a) ***Finish*[i]** = ***false***
   (b) $\boldsymbol{Need_i} \leq \boldsymbol{Work}$
   If no such *i* exists, go to step 4.

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

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

Resource-Request Algorithm for Process P_i

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

1. If $\boldsymbol{Request_i} \leq \boldsymbol{Need_i}$, go to step 2. Otherwise, raise error condition, since process has exceeded its maximum claim.

2. If $\boldsymbol{Request_i} \leq \boldsymbol{Available}$, 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:

   $\boldsymbol{Available = Available - Request_i}$
   $\boldsymbol{Allocation_i = Allocation_i + Request_i}$
   $\boldsymbol{Need_i = Need_i - Request_i}$

   - *If **safe** ⇒ the resources are allocated to P_i.*
   - *If **unsafe** ⇒ P_i must wait, and the old resource-allocation state is restored*

Example of Banker's Algorithm

- 5 processes P_0 through P_4; 3 resource types *A* (10 instances),
  B (5instances, and *C* (7 instances).
- Snapshot at time T_0:

	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.

	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 P_1 Request (1,0,2) (Cont.)

- Check that Request $\leq$ Available (that is, $(1,0,2) \leq (3,3,2) \Rightarrow$ 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 2	6 0 0	
P_3	2 1 1	0 1 1	
P_4	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence <P1, P3, P4, P0, P2> satisfies safety requirement.
- Can request for (3,3,0) by P4 be granted?
- Can request for (0,2,0) by P0 be granted?

When Deadlock Happens

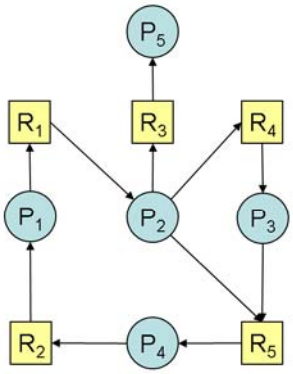
- Another way to deal with deadlock is not to use either prevention or avoidance. The system may enter a deadlock state; the OS will deal with that when [if] it happens.

- What is needed in such a system:
  - a **detection algorithm** to determine when deadlock states are entered, and
  - a **recovery scheme** to get the system back on a safe state.

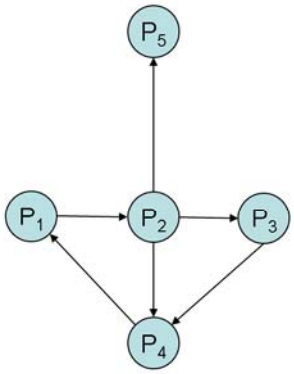
Single Instance of Each Resource Type

- Maintain a ***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* $[i_j] = k$, 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 $\boldsymbol{Allocation_i \neq 0}$, then
   Finish*[i] = false** , otherwise, ***Finish*[i] = *true.
2. Find an index *i* such that both:
   (a) ***Finish*[*i*] == *false***
   (b) $\boldsymbol{Request_i \leq Work}$
   If no such *i* exists, go to step 4.
3. ***Work* = *Work* + $\boldsymbol{Allocation_i}$**
   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 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*.

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 the system?
  - Can reclaim resources held by process P_0, but have insufficient resources to fulfill the requests of other processes.
  - 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 for 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.