Lecture 13
Deadlock

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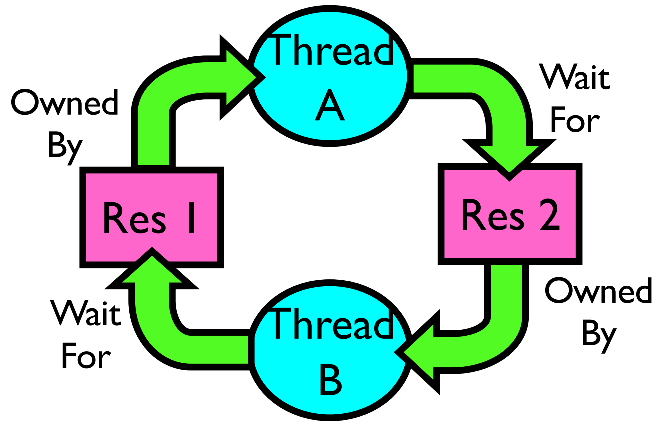
Starvation vs. Deadlock

- Starvation vs. Deadlock
  - Starvation: thread waits indefinitely
    - Low-priority thread waiting for resources constantly in use by high-priority threads
  - Deadlock: circular waiting for resources
    - Thread A owns Res 1 and is waiting for Res 2
      Thread B owns Res 2 and is waiting for Res 1
  - Deadlock ⇒ Starvation but not vice versa
    - Starvation can end (but does not have to)
    - Deadlock cannot end without external intervention



Conditions for Deadlock

- Deadlock will not always happen
    - Need the exactly right timing
    - Bugs may not exhibit during testing
- Deadlocks occur with multiple resources
    - Cannot solve deadlock for each resource independently
    - System with 2 disk drives and two threads
    - Each thread needs 2 disk drives to function
    - Each thread gets one disk and waits for another one

Process A	Process B
sem_wait(x)	sem_wait(y)
sem_wait(y)	sem_wait(x)
sem_post(y)	sem_post(x)
sem_post(x)	sem_post(y)

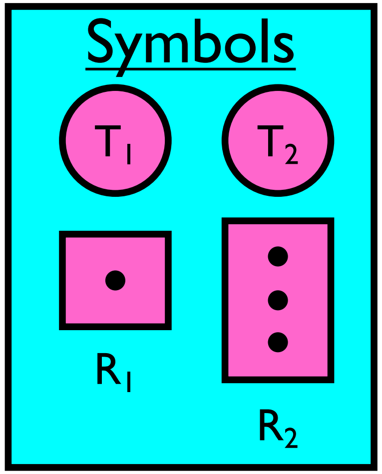
Four Requirements for Deadlock

- Mutual exclusion
  - Only one thread at a time can use a resource.
- Hold and wait
  - Thread holding at least one resource is waiting to acquire additional resources held by other threads
- No preemption
  - Resources are released only voluntarily by the thread holding the resource, after thread is finished with it
- Circular wait
  - There exists a set $\{T_1, \ldots, T_n\}$ of waiting threads
    - T_1 is waiting for a resource that is held by T_2
    - T_2 is waiting for a resource that is held by T_3
    - …
    - T_n is waiting for a resource that is held by T_1

Resource-Allocation Graph

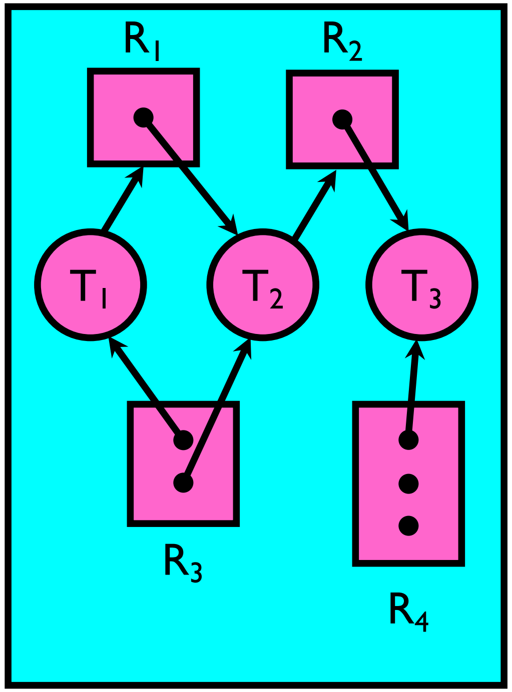
- System Model
  - A set of Threads $T_1, T_2, \ldots, T_n$
  - Resource types $R_1, R_2, \ldots, R_m$

    CPU cycles, memory space, I/O devices
  - Each resource type R_i has W_i instances
  - Each thread utilizes a resource as follows:
    - Request() / Use() / Release()
- Resource-Allocation Graph:
  - V is partitioned into two types:
    - $T = \{T_1, T_2, \ldots, T_n\}$, the set threads in the system.
    - $R = \{R_1, R_2, \ldots, R_m\}$, the set of resource types in system
  - request edge – directed edge $T_1 \rightarrow R_j$
  - assignment edge – directed edge $R_j \rightarrow T_i$

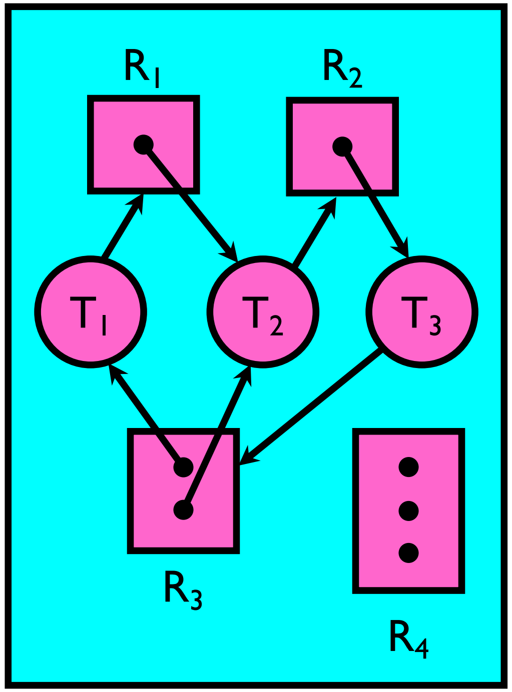


Resource Allocation Graph Examples

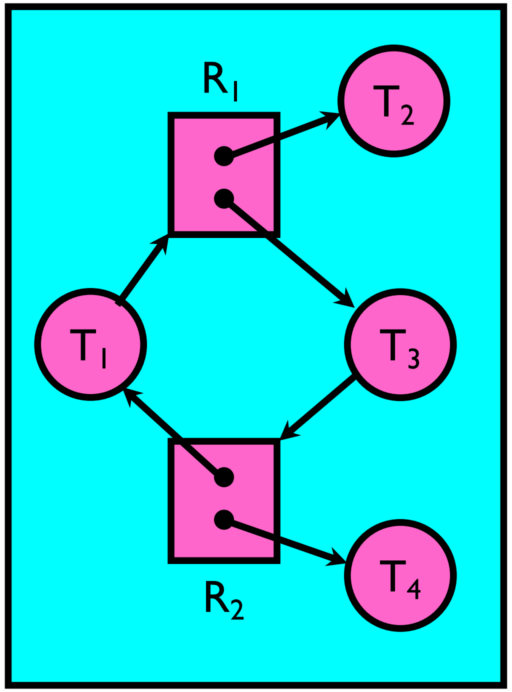
- Recall:
  - request edge – directed edge $T_1 \rightarrow R_j$
  - assignment edge – directed edge $R_j \rightarrow T_i$



Simple Resource Allocation Graph



Allocation Graph With Deadlock



Allocation Graph with Cycle, but No Deadlock

Methods for Handling Deadlocks

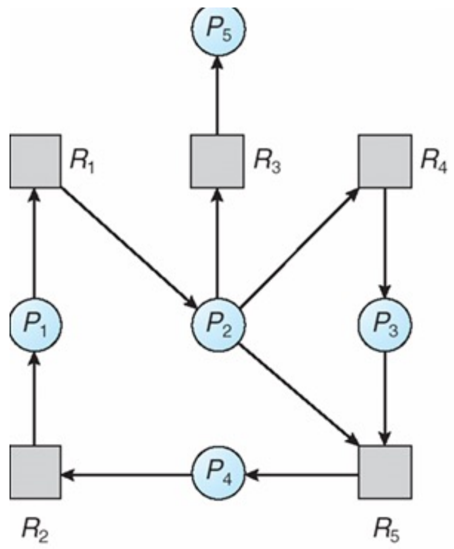
- Allow system to enter deadlock and then recover
  - **Deadlock detection**
  - Requires deadlock detection algorithm
  - Some technique for forcibly preempting resources and/or terminating tasks

- Ensure that system will never enter a deadlock
  - **Deadlock prevention**
  - Need to monitor all resource acquisitions
  - Selectively deny those that might lead to deadlock

- Ignore the problem and pretend that deadlocks never occur in the system
  - Used by most operating systems, including UNIX

Deadlock Detection with Resource Allocation Graphs

- Only one of each type of resource $\Rightarrow$ look for cycles
- More than one resource of each type
  - More complex deadlock detection algorithm
  - Next page



Several Instances per 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 $\mathbf{Allocation}_i \neq 0$, then
   Finish[i] = false; otherwise, **Finish**[i] = true
2. Find an index i such that both:
   (a) **Finish**[i] == false
   (b) $\mathbf{Request}_i \leq$ Work

   If no such i exists, go to step 4

3. **Work** = **Work** + $\mathbf{Allocation}_i$
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 $\langle P_0, P_2, P_3, P_1, P_4 \rangle$ 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 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 (not deadlocked), but insufficient resources to fulfill other processes; requests
  - Deadlock exists, consisting of processes P_1, P_2, P_3, and P_4

What if Deadlock Detected?

- Terminate process, force it to give up resources
  - Shoot a dining philosopher !?
  - But, not always possible
- Preempt resources without killing off process
  - Take away resources from process temporarily
  - Does not always fit with semantics of computation
- Roll back actions of deadlocked process
  - Common technique in databases (transactions)
  - Of course, deadlock may happen once again

Deadlock Prevention

- Try to ensure at least one of the conditions cannot hold to prevent deadlock
  - Remove "Mutual Exclusion": not possible for non-sharable resources
  - Remove "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

- Try to ensure at least one of the conditions cannot hold to prevent deadlock
  - Remove “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

Deadlock Prevention

- Try to ensure at least one of the conditions cannot hold to prevent deadlock
  - Circular Wait – impose a total ordering of all resource types, and require that each process requests resources in an increasing order of enumeration
  - $R=\{R_1,R_2,\ldots,R_m\}$
  - One to one function F:R->N
  - If a process request a resource R_i, it can request another resource R_j if and only if $F(R_i) < F(R_j)$
  - Or, it must first release all resource R_i such that $F(R_i) \geq F(R_j)$

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**

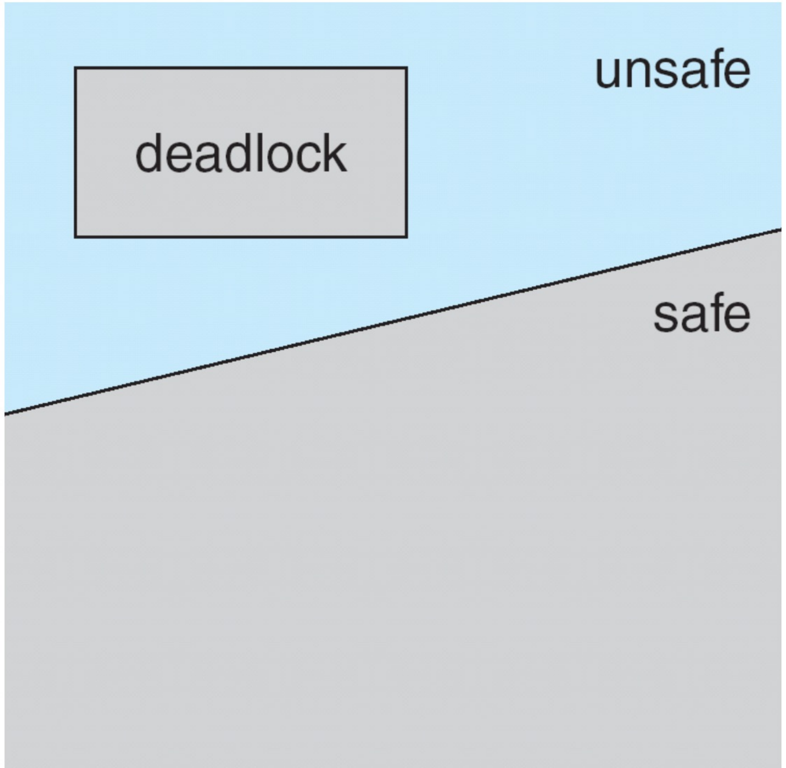
  - Resource-allocation state is defined by the number of available and allocated resources, and the maximum demands of the processes

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, …, 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 $j < i$**
  - If what 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

Safe, Unsafe, Deadlock State

- If a system is in safe state => no circular wait => no deadlocks
- If a system is in unsafe state => possibility of deadlock
- Deadlock avoidance => ensure that a system will never enter an unsafe state.



Banker's Algorithm

- Multiple instances of each resource type
- 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

Banker's Algorithm (Cont'd)

- 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]

Banker's Algorithm: 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 index i such that both:

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

   (b) $\mathbf{Need}_i \leq$ **Work** (i.e., for all k, $\mathbf{Need}_i[k] \leq \mathbf{Work}[k]$

   If no such i exists, go to step 4

3. $\mathbf{Work} = \mathbf{Work} + \mathbf{Allocation}_i$

   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 **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**;
   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

- 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:

	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'd)

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

	Allocation	*Need*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 4 3	3 3 2
P_1	2 0 0	1 2 2	
P_2	3 0 2	6 0 0	
P_3	2 1 1	0 1 1	
P_4	0 0 2	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)

- Check that **Request** ≤ **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 1	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 $<P_1, P_3, P_4, P_0, P_2>$ 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?

Thank you!