Lecture 12
Deadlock

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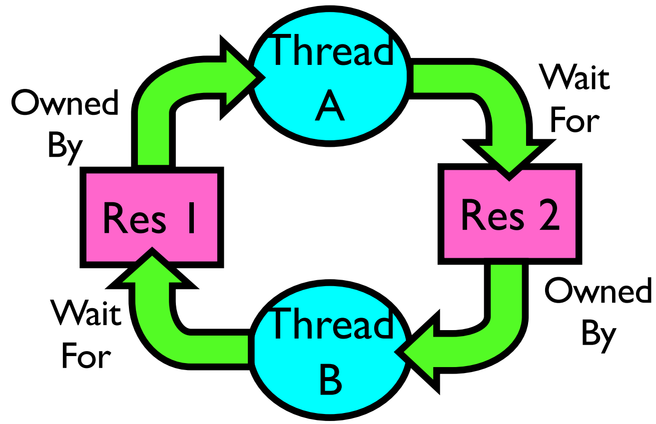
Starvation vs. Deadlock

- 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 $\Rightarrow$ 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)

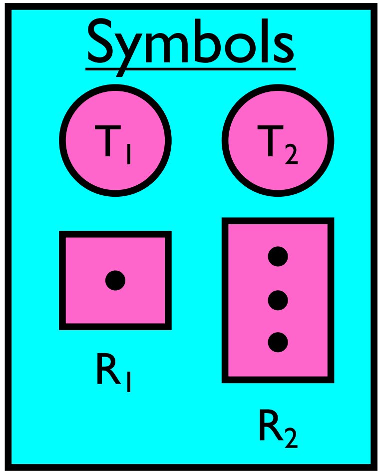
Four Requirements for Deadlock

- 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

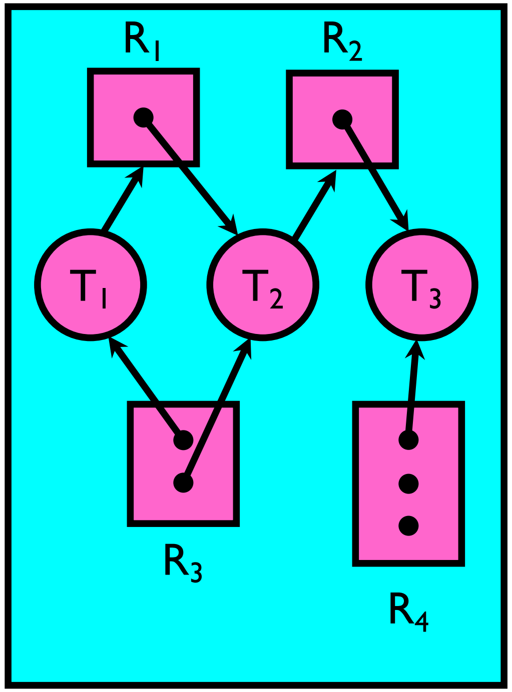
- System Model
  - A set of Threads $T_1, T_2, \ldots, T_n$
  - Resource types $R_1, R_2, \ldots, R_m$

    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 $R_j \rightarrow T_i$

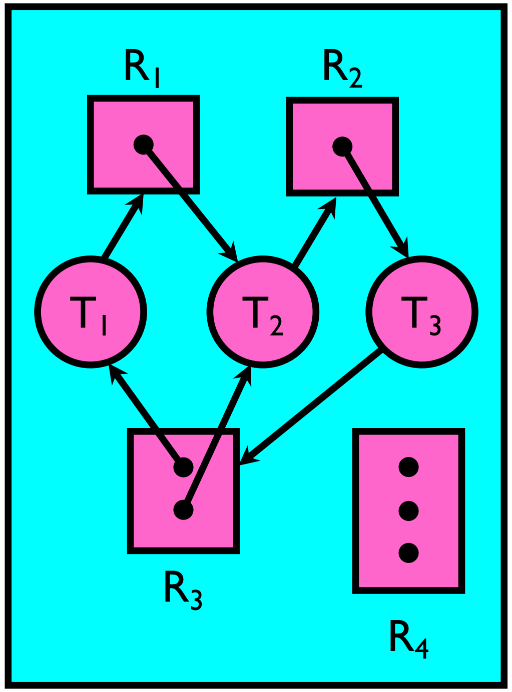


Resource Allocation Graph Examples

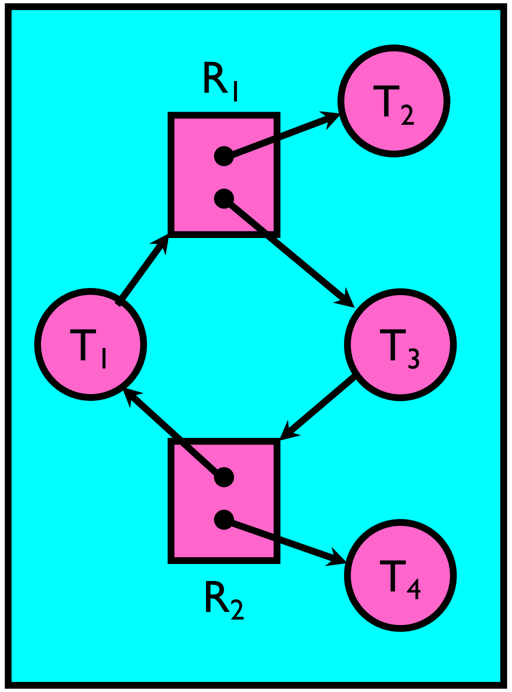
- Recall:
  - request edge – directed edge $T_1 \rightarrow R_j$
  - assignment edge – directed edge $R_j \rightarrow T_i$



Simple Resource Allocation Graph



Allocation Graph With Deadlock



Allocation Graph with Cycle, but No Deadlock

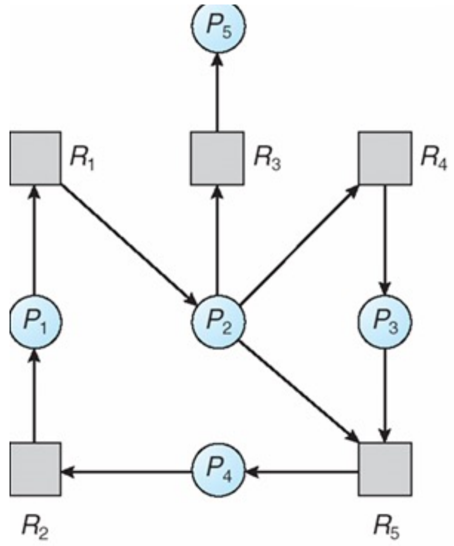
Methods for Handling Deadlocks

- Allow system to enter deadlock and then recover
  - Requires deadlock **detection** algorithm
  - Some technique for forcibly preempting resources and/or terminating tasks
- Ensure that system will **never** enter a deadlock
  - 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 ⇒ 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 $\textbf{Allocation}_i \neq 0$, then
   Finish[i] = false; otherwise, **Finish**[i] = true
2. Find an index i such that both:
   (a) **Finish**[i] == false
   (b) $\textbf{Request}_i \leq \text{Work}$

   If no such i exists, go to step 4

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

Techniques for Preventing Deadlock

- Infinite resources
  - Include enough resources so that no one ever runs out of resources. Examples:
    - Bay bridge with 12,000 lanes. Never wait!
    - Infinite disk space (not realistic yet?)
- No sharing of resources (totally independent processes)
  - Not very realistic
- Do not allow waiting
  - Technique used in Ethernet/some multiprocessor nets
    - Everyone speaks at once. On collision, back off and retry
  - Inefficient, since have to keep retrying
    - Consider: driving to SUSTech; when hit traffic jam, suddenly you are transported back home and told to retry!

Techniques for Preventing Deadlock

- Make all threads request everything they will need at the beginning
  - Problem: Predicting future is hard, tend to over-estimate resources. Example:
    - If need 2 chopsticks, request both at same time
    - Do not leave home until we know no one is using any intersection between home and SUSTech
- Force all threads to request resources in a particular order preventing any cyclic use of resources
  - Thus, preventing deadlock
  - Example (x.P, y.P, z.P,…)
    - Make tasks request disk, then memory, then…
    - Keep from deadlock on freeways around SF by requiring everyone to go clockwise

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) **Need**$_i$ ≤ **Work** (i.e., for all k, **Need**$_i$[k] ≤ **Work**[k]
   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] == 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**

	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)

- 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 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!