Lecture 7: Deadlock

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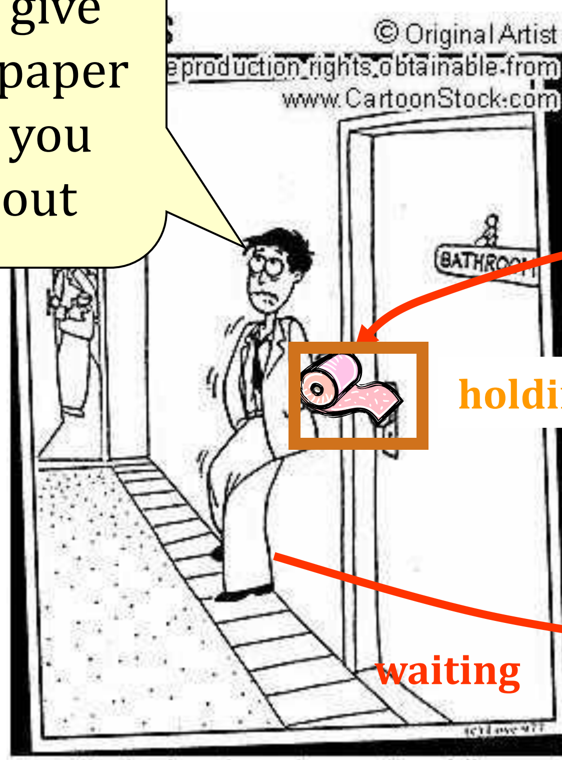
Deadlock

I won't come out unless you give me the paper

I won't give you the paper unless you come out



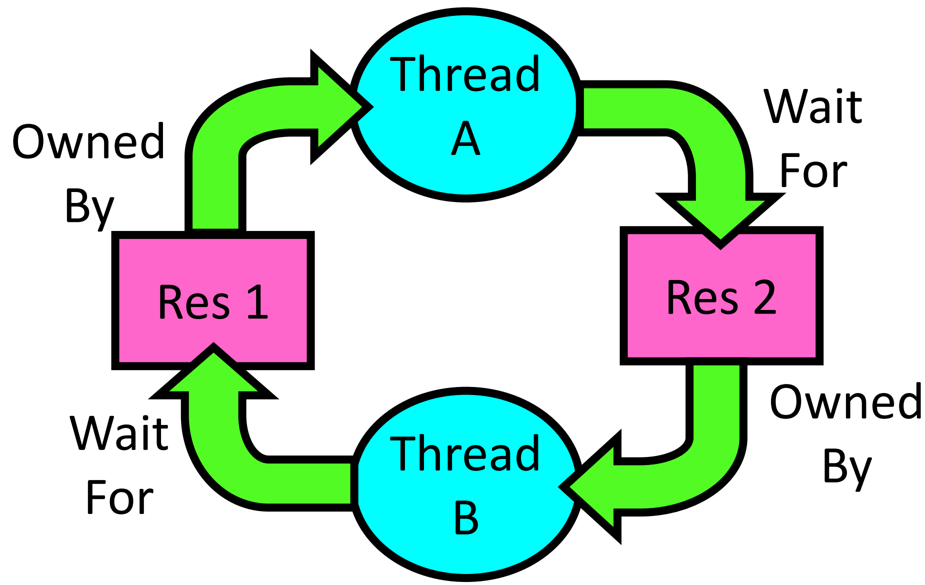
waiting

holding

waiting

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 not always deterministic

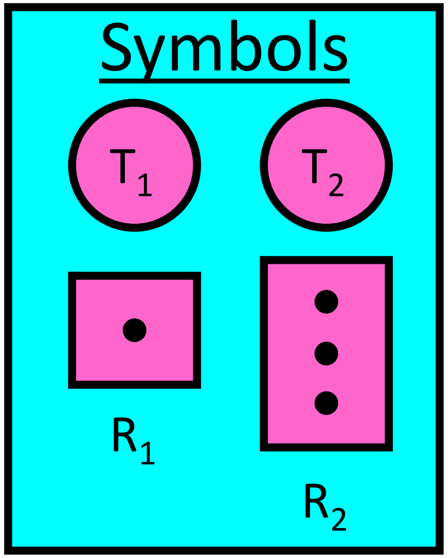
Thread A	Thread B
`sem_wait(x);`	`sem_wait(y);`
`sem_wait(y);`	`sem_wait(x);`
`sem_post(y);`	`sem_wait(x);`
`sem_post(x);`	`sem_wait(y);`

  - Deadlock will not always happen with this code
    - Have to have exactly the right timing
    - So you release a piece of software, and you tested it, and there it is, controlling a nuclear power plant…
- Deadlocks occur with multiple resources
  - Means you cannot decompose the problem
  - 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

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

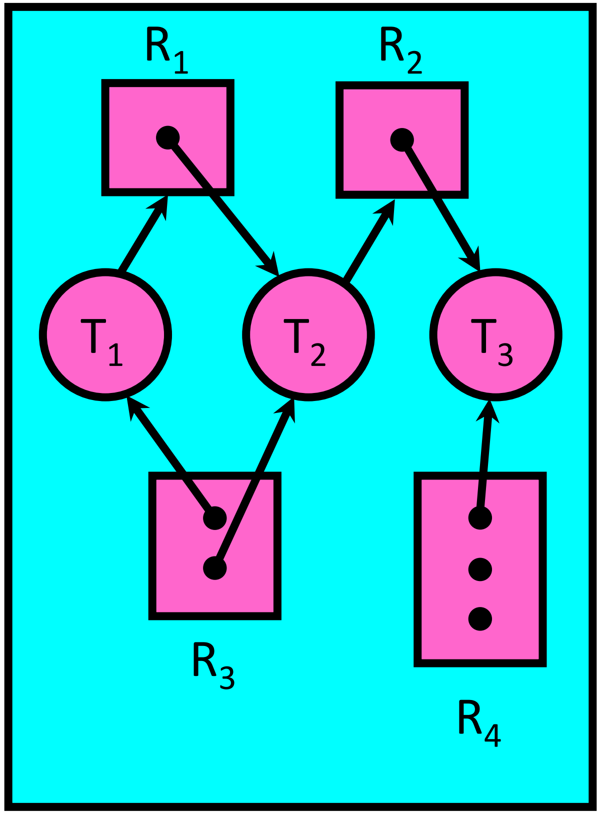


- System Model
  - A set of Threads $T_1, T_2, \ldots, T_n$
  - Resource types $R_1, R_2, \ldots, R_m$

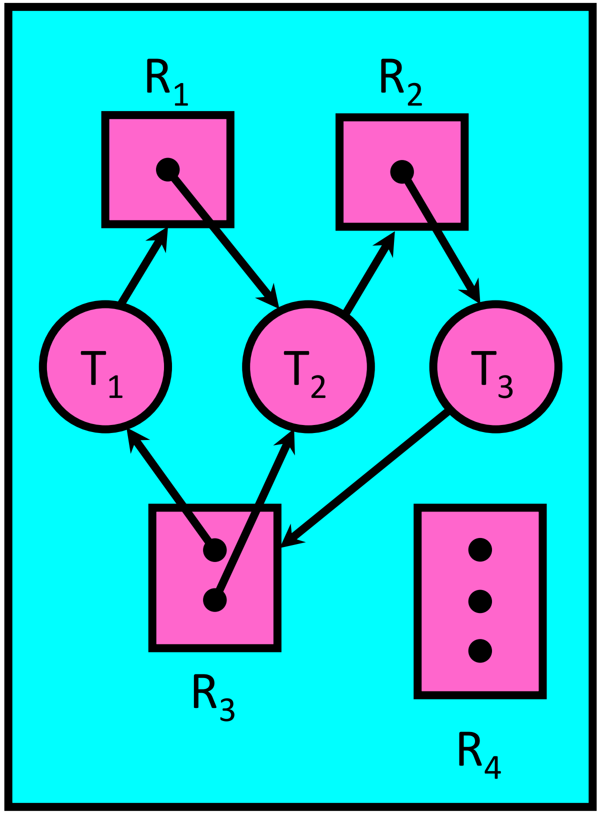
    CPU cycles, memory space, I/O devices
  - Each resource type R_i has W_i instances
  - Each thread utilizes a resource as follows:
    - `Request() / Use() / Release()`
- Resource-Allocation Graph:
  - V is partitioned into two types:
    - $T = \{T_1, T_2, \ldots, T_n\}$, the set threads in the system.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

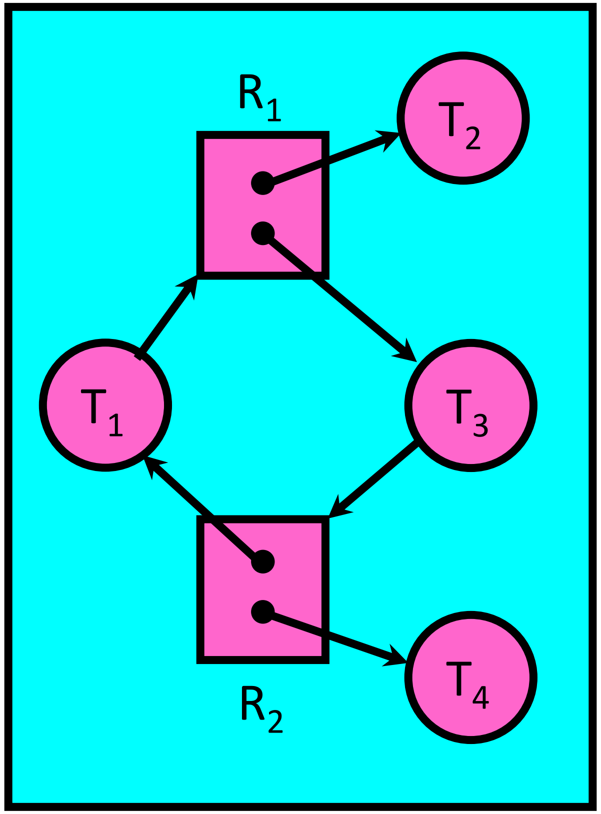
- Recall:
  - request edge – directed edge $T_1 \rightarrow R_j$
  - assignment edge – directed edge $R_j \rightarrow T_i$



Simple Resource Allocation Graph



Allocation Graph With Deadlock



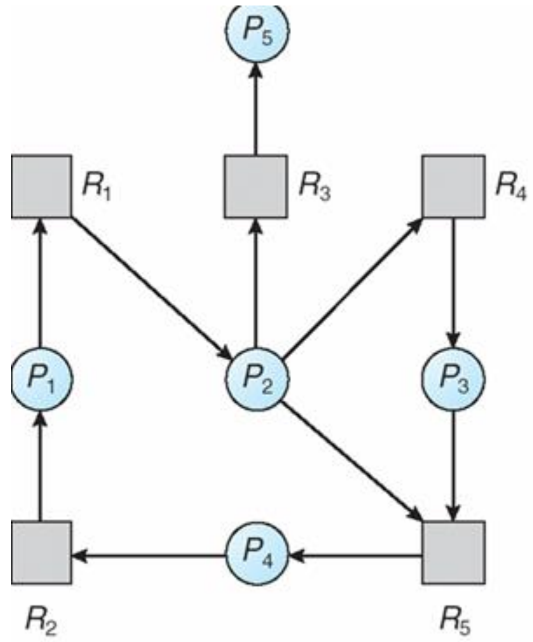
Allocation Graph with Cycle, but No Deadlock

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 Algorithm

- Only one of each type of resource ⇒ look for cycles



- More than one resource of each type
  - More deadlock detection algorithm
  - Next page

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 $i = 1,2, \ldots, n$, if $Allocation_i \neq 0$, then *Finish*[i] = false; otherwise, *Finish*[i] = *true*
2. Find an index i such that both:
   (a) $Finish[i] == false$
   (b) $Request_i \leq Work$

   If no such i exists, go to step 4

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 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 to do when detect deadlock?

- Terminate thread, force it to give up resources
  - In Bridge example, Godzilla picks up a car, hurls it into the river. Deadlock solved!
  - Shoot a dining philosopher
  - But, not always possible
- Preempt resources without killing off thread
  - Take away resources from thread temporarily
  - Does not always fit with semantics of computation
- Roll back actions of deadlocked threads
  - For bridge example, make one car roll backwards (may require others behind him)
  - Common technique in databases (transactions)
  - Of course, if you restart in exactly the same way, may reenter deadlock once again
- Many operating systems use other options

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 threads)
  - 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
    - Don not leave home until we know no one is using any intersection between home and SUSTech; only one car on the Bay Bridge at a time
- 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

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***:* $n \times m$ matrix. If *Max* $[i,j] = k$, then process P_i may request at most k instances of resource type R_j
- **Allocation***:* $n \times m$ matrix. If Allocation$[i,j] = k$ then P_i is currently allocated k instances of R_j
- **Need***:* $n \times m$ matrix. If $Need[i,j] = k$, then P_i may need k more instances of R_j to complete its task

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

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) $Need_i \leq Work$ (*i.e., for all k,* $Need_i[k] \leq$ 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.)

- 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 ≤ 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!