CENG 2034 - Operating Systems

Week 12: Deadlocks

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Outline

System Model

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  - release

Deadlock with Semaphores

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Deadlock with Semaphores

- Data:
  - A semaphore S_1 initialized to 1
  - A semaphore S_2 initialized to 1
- Two threads T_1 and T_2

  T_1:

  wait(s_1)
  wait(s_2)

  T_2:

  wait(s_2)
  wait(s_1)

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2. Hold and wait: a thread holding at least one resource is waiting to acquire additional resources held by others
3. No preemption: a resource can be released only voluntarily by the holding thread after the task completion
4. Circular wait: there exists a set $\{T_0, T_1, \dots, T_n\}$ of waiting threads such that

   T_0 is waiting for a resource that is held by T_1
   T_1 is waiting for a resource that is held by T_2
   $\dots$
   T_{n-1} is waiting for a resource that is held by T_n,
   and T_n is waiting for a resource that is held by T_0

Resource-Allocation Graph

A set of vertices V and a set of edges E

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- V is partitioned into two types:

$T = \{T_1, T_2, \ldots, T_n\}$	the set consisting of all the threads in the system
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- Edges:

request edge	directed edge $T_i \rightarrow R_j$
assignment edge	directed edge $R_j \rightarrow T_i$

Example (Resource Allocation Graph)

- One instance of R_1

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- One instance of R_1
- Two instances of R_2

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- One instance of R_1
- Two instances of R_2
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- Two instances of R_2
- One instance of R_3
- Three instance of R_4

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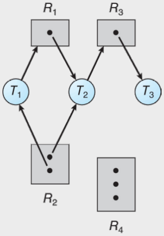
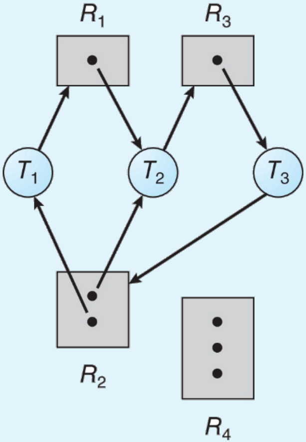
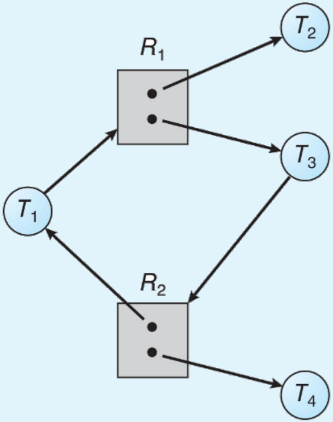


Resource-Allocation Graph with a Deadlock



Graph with a Cycle But no Deadlock



Basic Facts

- If graph contains no cycles $\Rightarrow$ no deadlock

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  - if several instances per resource type, possibility of deadlock

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  - Deadlock prevention
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- Ignore the problem and pretend that deadlocks never occur in the system

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  - Low resource utilization; starvation possible

Deadlock Prevention (cont'd)

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- Circular Wait:
  - Impose a total ordering of all resource types, and require that each thread requests resources in an increasing order of enumeration

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- Resources must be acquired in order

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- 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

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  - When T_i terminates, T_{i+1} can obtain its needed resources, and so on ...

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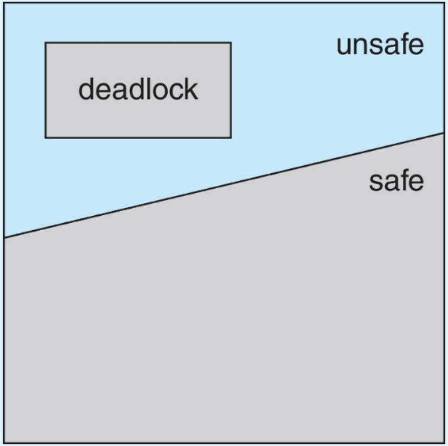
- Avoidance ⇒ ensure that a system will never enter an unsafe state

Safe, Unsafe, Deadlock State



Avoidance Algorithms

- Single instance of a resource type – Use a resource-allocation graph

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

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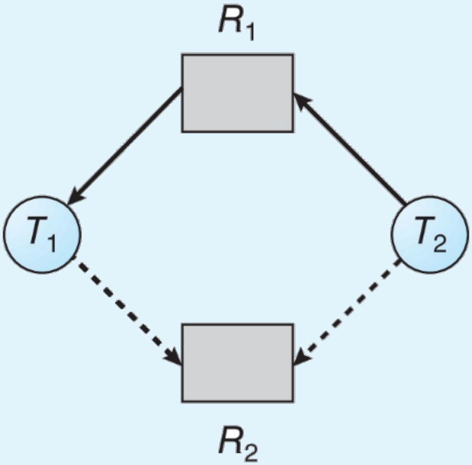
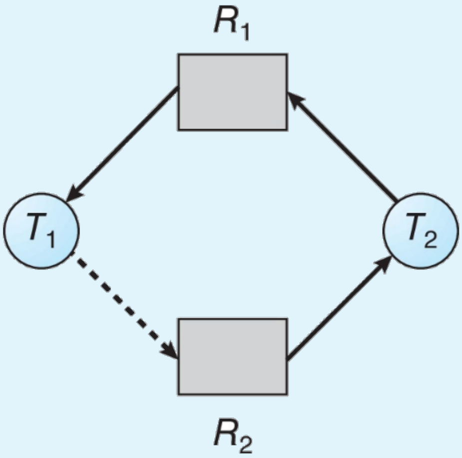
- Resources must be claimed a priori in the system

Resource-Allocation Graph



Unsafe State In Resource-Allocation Graph



Resource-Allocation Graph Algorithm

- Suppose that thread T_i requests a resource R_j

Resource-Allocation Graph Algorithm

- Suppose that thread T_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

Banker's Algorithm

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- When a thread gets all its resources it must return them in a finite amount of time

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- Allocation: $n \times m$ matrix. If $\mathtt{Allocation}[i, j] = k$ then T_i is currently allocated k instances of R_j
- Need: $n \times m$ matrix. If $\mathtt{Need}[i, j] = k$, then T_i may need k more instances of R_j to complete its task

$$\mathtt{Need}[i, j] = \mathtt{Max}[i, j] - \text{Allocation}[i, j]$$

Safety Algorithm

1. Let `Work` and `Finish` be vectors of length m and n, respectively. Initialize:

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3. - `Work` = `Work` + $\texttt{Allocation}_i$
   - `Finish[i]` = true

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

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3. Pretend to allocate requested resources to T_i by modifying the state as follows:

$$\begin{aligned}
\texttt{Available} &= \texttt{Available} - \texttt{Request}_i; \\
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- If safe $\Rightarrow$ the resources are allocated to T_i
- If unsafe $\Rightarrow$ T_i must wait, and the old resource-allocation state is restored

Example (Banker's Algorithm)

- 5 threads T_0 through T_4;

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- Current state snapshot:

	Allocation	Max	Available
	$A\ B\ C$	$A\ B\ C$	$A\ B\ C$
T_0	0 1 0	7 5 3	3 3 2
T_1	2 0 0	3 2 2	
T_2	3 0 2	9 0 2	
T_3	2 1 1	2 2 2	
T_4	0 0 2	4 3 3	

Example (Banker's Algorithm (cont'd))

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- Current-state snapshot:

	Need
	A B C
T_0	7 4 3
T_1	1 2 2
T_2	6 0 0
T_3	0 1 1
T_4	4 3 1

Example (Banker's Algorithm (cont'd))

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- The system is in a safe state since the sequence

$$< T_1, T_3, T_4, T_2, T_0 >$$

satisfies safety criteria

Outline

Deadlock Detection

- Allow system to enter deadlock state

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- Recovery scheme

Single Instance of Each Resource Type

- Maintain wait-for graph

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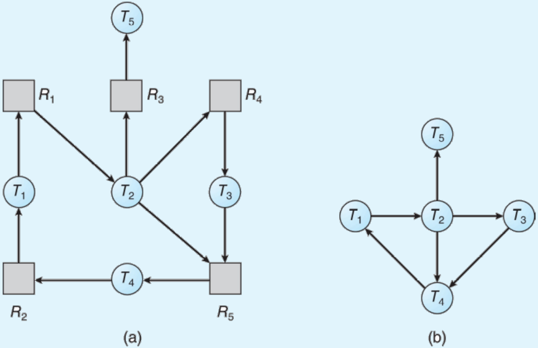
- Periodically invoke an algorithm that searches for a cycle in the graph
- If there is a cycle, there exists a deadlock
- An algorithm to detect a cycle in a graph requires an order of n^2 operations, where n is the number of vertices in the graph

Resource-Allocation Graph and Wait-for Graph



Resource-Allocation Graph Corresponding wait-for graph

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- `Allocation`: An $n \times m$ matrix defines the number of resources of each type currently allocated to each thread
- `Request`: An $n \times m$ matrix indicates the current request of each thread. If $\texttt{Request}[i][j] = k$, then thread T_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:

`Work`	=	`Available`	
`Finish[i]`	=	`false`	if `Allocation` $\neq 0$ for $i = 1, 2, \dots n$
`Finish[i]`	=	`true`	otherwise

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4. If Finish[i] == false, for some i s.t. $1 \leqslant \texttt{i} \leqslant n$, then the system is in deadlock state. Moreover, if Finish[i] == false, then T_i is deadlocked

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- Sequence

$$< T_0, T_2, T_3, T_4, T_1 >$$

will result in `Finish[i] = true` for all i

Example (Detection Algorithm (cont'd))

- T_2 requests an additional instance of type C

	Request
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T_0	0 0 0
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- State of system?
  - Can reclaim resources held by thread T_0, but insufficient resources to fulfill other threads; requests
  - Deadlock exists, consisting of threads T_1, T_2, T_3, and T_4

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- When, and how often, to invoke depends on:
  - How often a deadlock is likely to occur?
  - How many threads will be affected by deadlock when it happens?
- 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 threads “caused” the deadlock.

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- Abort all deadlocked threads

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  5. How many threads will need to be terminated
  6. Is the thread interactive or batch?

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- Selecting a victim – minimize cost
- Rollback – return to some safe state, restart the thread for that state
- Starvation – same thread may always be picked as victim, include number of rollback in cost factor

Thanks! & Questions?