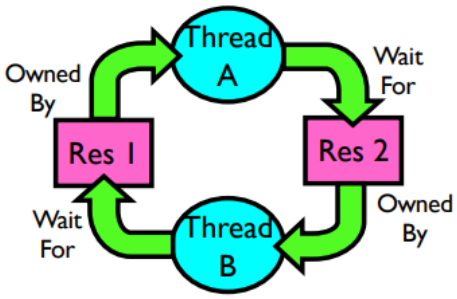
Lecture13 Deadlock

1. Background

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

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

Example

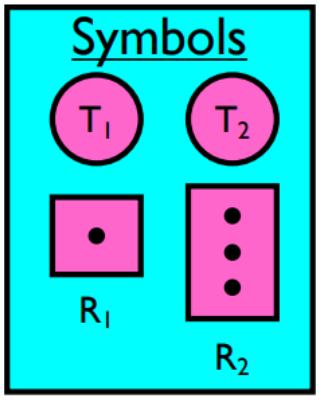
Process A	Process B
sem_wait(x)	sem_wait(y)
sem_wait(y)	sem_wait(x)
sem_post(y)	sem_post(x)
sem_post(x)	sem_post(y)

- 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

2. Resource-Allocation Graph

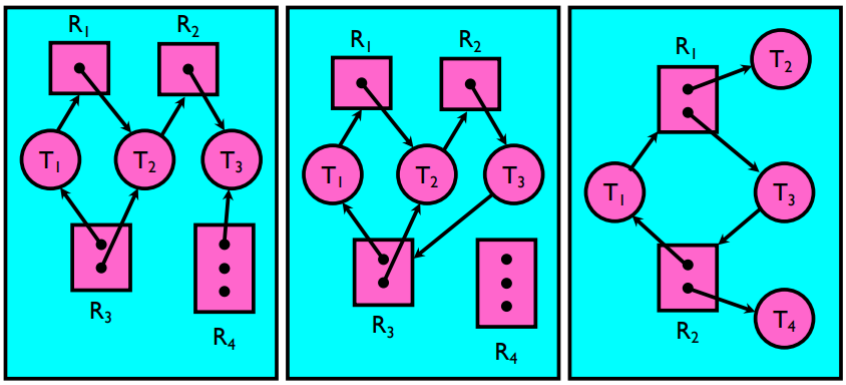
Graph Introduction

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



Simple Resource Allocation Graph | Allocation Graph With Deadlock | Allocation Graph with Cycle, but No Deadlock

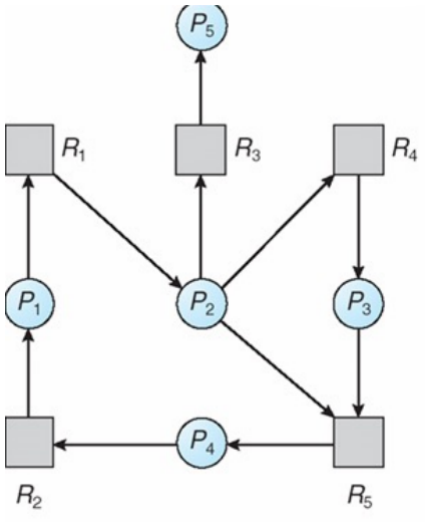
- V is partitioned into two types:
  - $T = \{T_1, T_2, \ldots, T_n\}$, the set threads in the system
  - $R = \{R_1, R_2, \ldots, R_m\}$, the set of resource types in system
- request edge – directed edge $T_1 \rightarrow R_j$
- assignment edge - directed edge $R_j \rightarrow T_i$

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

3. Deadlock Detection

One of each type of resource



- **Only one** of each type of resource -> **look for cycles**

Detection Algorithm: More than one resource of each type

- **Available**: A vector of length m indicates the number of available resources of each type
- **Allocation**: An $n \times m$ matrix defines the number of resources of each type currently allocated to each process
- **Request**: An $n \times m$ 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

Pseudocode

1. Let **Work** and **Finish** be vectors of length m and n, respectively. Initialize:
    - **Work** = **Available**
    - for i = 1, 2, ..., n, if **Allocation**[i] $\neq$ 0 then
        - **Finish**[i] = false, otherwise, **Finish**[i] = true
2. Find an index i such that both:
    - **Finish**[i] == false
    - **Request**[i] $\leq$ Work
    - 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] == false, then 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

If P_2 request an additional instance of type C

	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 1	
P_3	2 1 1	1 0 0	
P_4	0 0 2	0 0 2	

- 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

4. 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
- **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 Avoidance

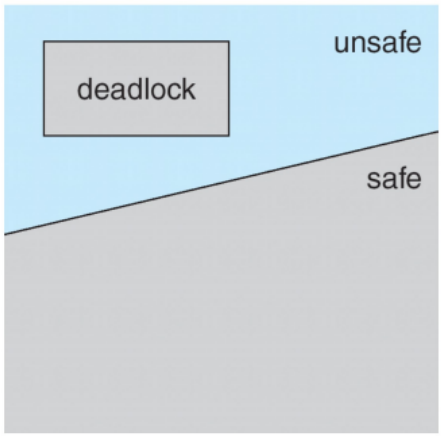
Requires that the system has some additional a priori information available

- 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

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 $F : R \to N$
- 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 the resource R_i such that $F(R_i) \geq F(R_j)$

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

- 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

Let n = number of processes, m = number of resources types

- **Available**: A vector of length m. If available[j] = k, there are k instances of resource type R_j available
- **Allocation**: An $n \times m$ matrix. If Max[i, j] = k, then process P_i may request at most k instances of resource type R_j

- **Need**: An $n \times m$ 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**
    - for i = 1, 2, ..., n, if **Allocation**[i] $\neq$ 0 then
        - **Finish**[i] = false, otherwise, **Finish**[i] = true
2. Find an index i such that both:
    - **Finish**[i] == false
    - **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

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 step2, Otherwise, raise error condition, since process has exceeded its maximum claim
2. If **Request**[i] $\leq$ **Available**[i] 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 save -> the resources are allocated to P_i
    - If unsafe -> P_i must wait, and old resource-allocation is restored

Example

- 5 process P_0 through P_4
- 3 resource types: A(10 instances), B(5 instances) and C(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	

P_1 Request (1, 0, 2), Need = Max - Allocation = (1, 2, 2)

- Check that **Request**[i] ≤ **Need**[i] (1, 0, 2) ≤ (1, 2, 2)
- Check that **Request**[i] ≤ **Available**[i] (1, 0, 2) ≤ (3, 3, 2)
- Available = (2, 0, 0) Allocation[1] = (3, 0, 2), Need[i] = (0, 2, 0)
- Executing safety algorithm show that, the sequence P_1, P_3, P_4, P_0, P_2 satisfy safety requirement