Deadlock

- Definition
- Motivation
- Conditions for deadlocks
- Deadlock prevention & detection

Deadlocks

- **Deadlock** = condition where multiple threads/processes wait on each other

process A	*process B*

`printer->wait();`
`disk->wait();`
`  do stuffs …`
`disk->signal();`
`printer->signal();`
	`disk->wait();`
	`printer->wait();`
	` do stuffs …`
	`printer->signal();`
	`disk->signal();`

Binary semaphore: printer, disk. Both initialized to be 1.

Deadlocks - Terminology

- **Deadlock**:
  - Can occur when several processes compete for finite number of resources simultaneously
- **Deadlock prevention** algorithms:
  - Check resource requests & availability
- **Deadlock detection**:
  - Finds instances of deadlock when processes stop making progress
  - Tries to recover

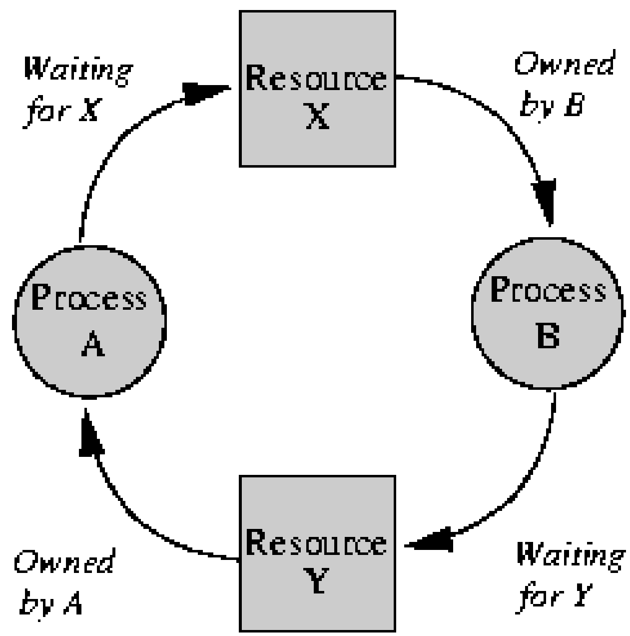
- **Note: Deadlock ≠ Starvation**

When Deadlock Occurs

All of below *must* hold:

1. **Mutual exclusion**:
   - An instance of resource used by one process at a time
2. **Hold and wait**
   - One process holds resource while waiting for another; other process holds that resource
3. **No preemption**
   - Process can only release resource *voluntarily*
   - No other process or OS can force thread to release resource
4. **Circular wait**
   - Set of processes $\{t_1, \ldots, t_n\}$: t_i waits on t_{i+1}, t_n waits on t_1

Deadlock: Example



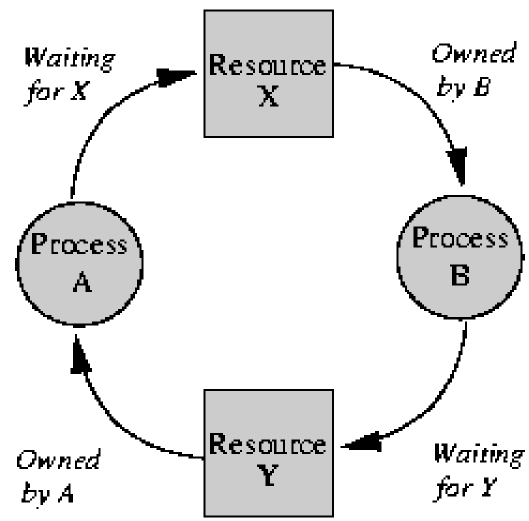
- If no way to free resources *(preemption)*, deadlock

Deadlock Detection: Resource Allocation Graph

- Define graph with vertices:
  - Resources = $\{r_1, \ldots, r_m\}$
  - Processes/threads = $\{t_1, \ldots, t_n\}$
- *Request edge* from process to resource

  $t_i \rightarrow r_j$
  - Process requested resource but not acquired it
- *Assignment edge* from resource to process

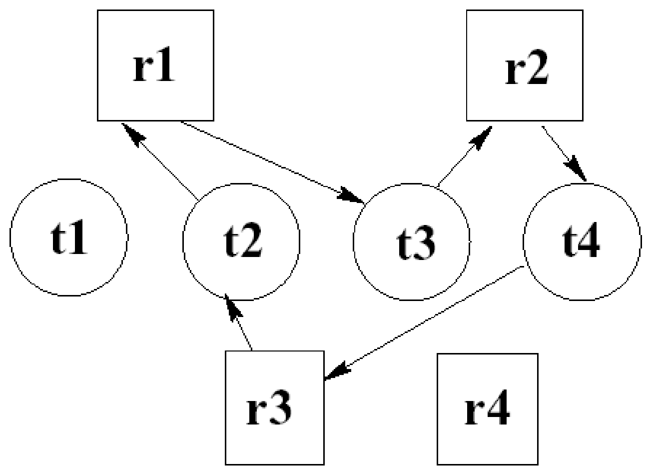
  $r_j \rightarrow t_i$
  - OS has allocated resource to process
- Deadlock detection
  - No cycles → no deadlock
  - Cycle → might be deadlock



Resource Allocation Graph: Example

- Deadlock or not?

- *Request edge* from process to resource $t_i \rightarrow r_j$
  - Process requested resource but not acquired it
- *Assignment edge* from resource to process $r_j \rightarrow t_i$
  - OS has allocated resource to process

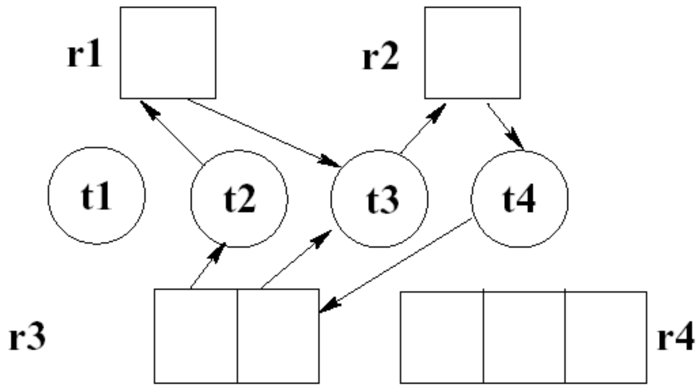


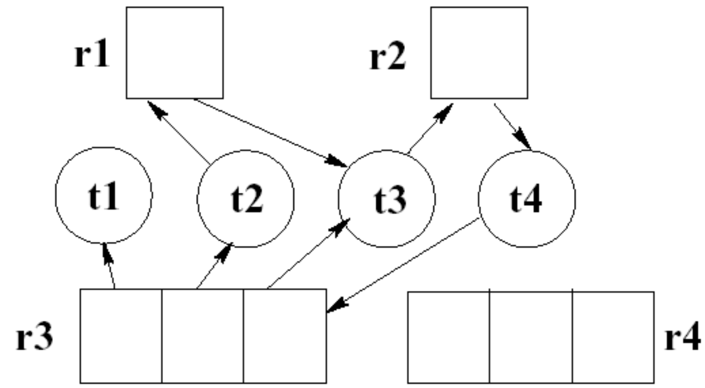
Deadlock Detection: Multiple Instances of Resource

- What if there are *multiple instances* of a resource?
  - Cycle → deadlock *might* exist
  - If any instance held by process outside cycle, progress is possible when process releases resource

Deadlock Detection

- Deadlock or not?

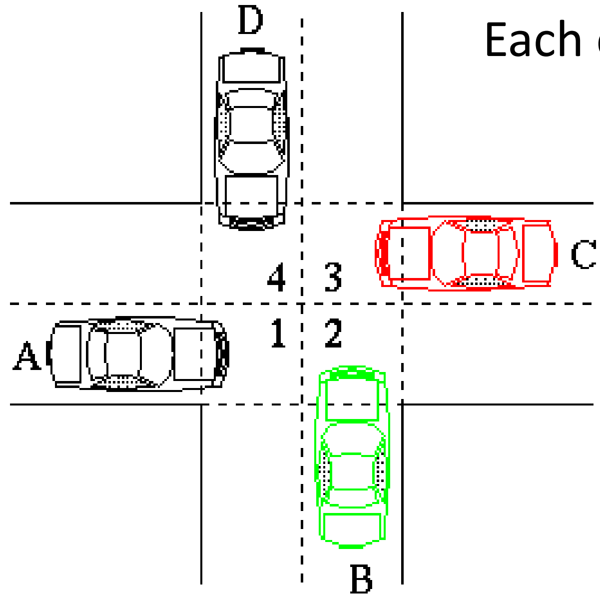




Resource Allocation Graph: Example

- Draw a graph for the following event:

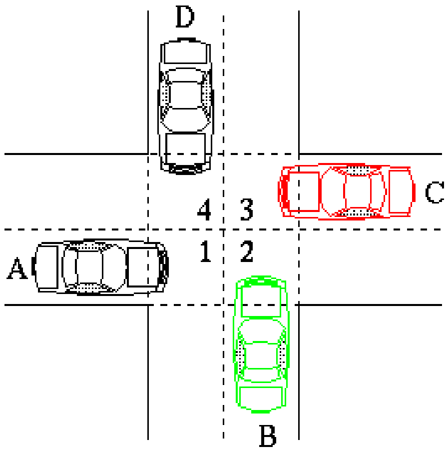
- *Request edge* from process to resource $t_i \rightarrow r_j$
  - Process: requested resource but not acquired it
- *Assignment edge* from resource to process $r_j \rightarrow t_i$
  - OS has allocated resource to process

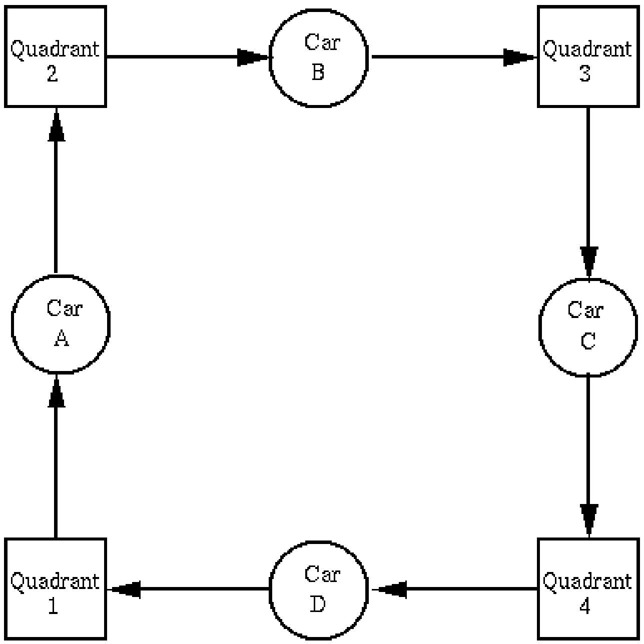


Each car going straight

Resource Allocation Graph : Example

- Draw a graph for the following event:





Detecting & Recovering from Deadlock

- Single instance of resource
  - Scan resource allocation graph for cycles & break them!
  - Detecting cycles takes $O(n^2)$ time
    - $n = |T| + |R|$
  - When to detect:
    - When request cannot be satisfied
    - On regular schedule, e.g. every hour
    - When CPU utilization drops below threshold

Detecting & Recovering from Deadlock (cont'd)

- How to recover? - break cycles:
  - Kill all processes in cycle
  - Kill processes one at a time
    - Force each to give up resources
  - Preempt resources one at a time
    - Roll back thread state to before acquiring resource
    - Common in database transactions
- Multiple instances of resource
  - No cycle → no deadlock
  - Otherwise, check whether processes can proceed

Deadlock Prevention

- Ensure at least one of necessary conditions doesn't hold
  - **Mutual exclusion**
  - **Hold and wait**
  - **No preemption**
  - **Circular wait**

Deadlock Prevention

- **Mutual exclusion**:
  - Make resources shareable (but not all resources can be shared)
- **Hold and wait**
  - Guarantee that process cannot hold one resource when it requests another
  - Make processes request all resources they need at once and release all before requesting new set

Deadlock Prevention, continued

- **No preemption**
  - If process requests resource that cannot be immediately allocated to it
    - OS preempts (releases) all resources the process currently holds
  - When all resources available:
    - OS restarts the process

- *Problem*: not all resources can be preempted

Deadlock Prevention, continued

- **Circular wait**
  - Impose ordering (numbering) on resources and request them in order

Deadlock Prevention with Resource Reservation

- With future knowledge, we can prevent deadlocks:
  - Processes provide advance information about maximum resources they may need during execution
- Resource-allocation *state*:
  - Number of available & allocated resources, maximum demand of each process

Deadlock Prevention with Resource Reservation (cont'd)

- Main idea: grant resource to process if new state is *safe*
  - Define sequence of processes $\{t_1, \ldots, t_n\}$ as *safe:*
    - For each t_i, the resources that t_i can still request can be satisfied by currently available resources plus resources held by all t_j, $j < i$
  - *Safe state* = state in which there is safe sequence containing all threads
- If new state unsafe:
  - Process waits, even if resource available

Guarantees no circular-wait condition

Resource Reservation Example 1

- Processes t_1, t_2, and t_3
  - Competing for 12 tape drives
- Currently 11 drives allocated
- Question: is current state safe?

- Yes: there exists safe sequence $\{t_1, t_2, t_3\}$ where all threads may obtain maximum number of resources without waiting

- t_1 can complete with current allocation
- t_2 can complete with current resources, + t_1's resources & unallocated tape drive
- t_3 can complete with current resources, + t_1's and t_2's, & unallocated tape drive

	max need	in use	could want
t_1	4	3	1
t_2	8	4	4
t_3	12	4	8

Resource Reservation Example II

- If t1 requests one more drive:
  - Should OS grant it?

	max need	in use	could want
t_1	4	3	1
t_2	8	4	4
t_3	12	4	8

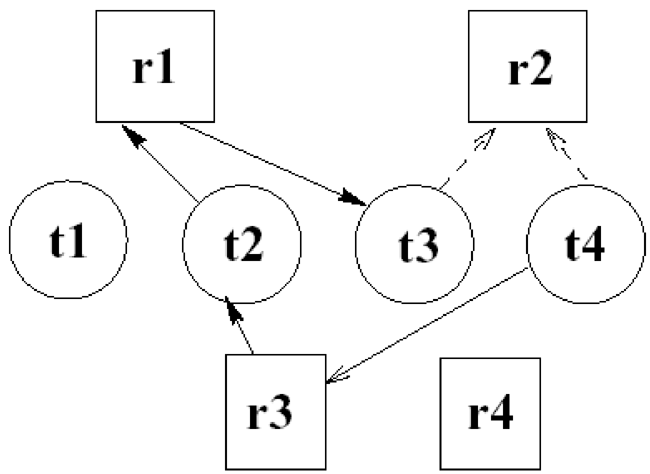
Resource Reservation Example III

- If t3 requests one more drive:
  - Must wait because allocating drive would lead to unsafe state: 0 available drives, but each thread might need at least one more drive

	max need	in use	could want
t_1	4	3	1
t_2	8	4	4
t_3	12	4	8

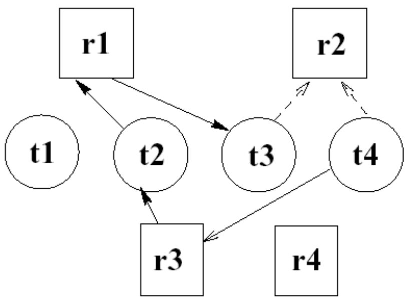
Single-Instance Resources: Deadlock Avoidance via Claim Edges

- Add *claim edges*:
  - Edge from process to resource that may be requested in future

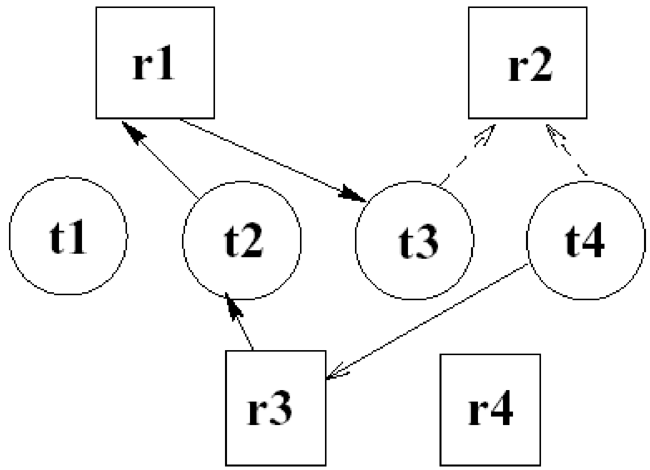


Single-Instance Resources: Deadlock Avoidance via Claim Edges (cont'd)

- To determine whether to satisfy a request:
  - convert claim edge to allocation edge
  - No cycle: grant request
  - Cycle: unsafe state; Deny allocation, convert claim edge to request edge, block process



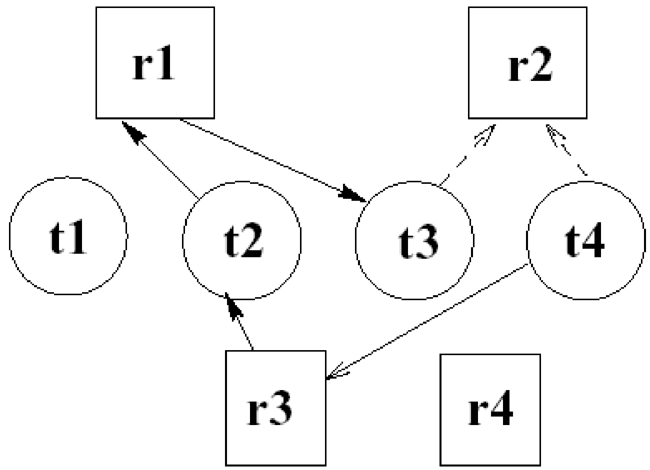
Single-Instance Resources: Deadlock Avoidance via Claim Edges (cont'd)



resource-allocation graph at time T

Q1: suppose t3 requests r2 at time T1 (T1>T), should OS grant it?

Single-Instance Resources: Deadlock Avoidance via Claim Edges (cont'd)



resource-allocation graph at time T

Q2: suppose t4 requests r2 at time T1 (T1>T), should OS grant it??

Multiple-Instance Resources: Banker's Algorithm (Dijkstra)

- Give processes as much as possible while avoiding deadlock

- Process specifies maximum amount of resource it ever needs
  - Can never ask for more
  - Total resources given < total number of available resources

- Process must wait for resource (block) if it will:
  - prevent first process from finishing, and
  - given that first process finishes & releases all of its resource, prevent second process from finishing, and
  - given that first through *k*th-1 processes finish & release all resources, prevent *k*th process from finishing