Announcements/Reminders

- Homework 3 due Friday
- Friday: come prepared with any remaining questions about exam 1

Some More Lab 3 Hints

- No matter what your server implementation is, you must deal with synchronization issues. The java "synchronized" mechanism is very useful for this (but use with care).
- Implement game features incrementally: it is better to turn in something that you can demonstrate as partially working than not working at all or very late...

Monitors: A Dining Example

```
class Table {
   private int[] state; // Forks

   Table() {
     state = new int[5];
     for(i=0; i < 5; ++i) {
        state[i] = 0}; };

   synchronized void pickUp(int i){
     while(state[i] != 0 &&
            state[(i+1)%5] != 0)
        wait();
     state[i] = state[(i+1)%5] = 1;};

   synchronized void drop(int i) {
     state[i] = state[(i+1)%5] = 0;};
};
```

```
class Philosopher extends Thread {
   int i;
   Table tbl;

   Philospher(Table tb, int j) {
     tbl = tb; i=j};

   run() {
     while(1) {
       think();
       tbl.pickUp(i);
       eat();
       tbl.drop(i);
     }; }; };
```

Today: Deadlocks

- What are deadlocks?
- Conditions for deadlocks
- Deadlock prevention
- Deadlock detection

Deadlocks

- **Deadlock:** A condition where two or more threads are waiting for an event that can only be generated by these same threads.

- Example:

```
Process A:                    Process B:
 printer.Wait();               disk.Wait();
 disk.Wait();                  printer.Wait();

 // copy from disk             // copy from disk
 // to printer                 // to printer

 printer.Signal();             printer.Signal();
 disk.Signal();                disk.Signal();
```

Deadlocks: Terminology

- **Deadlock** can occur when several threads compete for a finite number of resources simultaneously
- **Deadlock prevention** algorithms check resource requests and possibly availability to prevent deadlock.
- **Deadlock detection** finds instances of deadlock when threads stop making progress and tries to recover.
- **Starvation** occurs when a thread waits indefinitely for some resource, but other threads are actually using it (making progress).

$\Rightarrow$ Starvation is a different condition from deadlock

Necessary Conditions for Deadlock

Deadlock can happen if all the following conditions hold.

1. **Mutual Exclusion:** at least one thread must hold a resource in non-sharable mode, i.e., the resource may only be used by one thread at a time.

2. **Hold and Wait:** at least one thread holds a resource and is waiting for other resource(s) to become available. A different thread holds the resource(s).

3. **No Preemption:** A thread can only release a resource voluntarily; another thread or the OS cannot force the thread to release the resource.

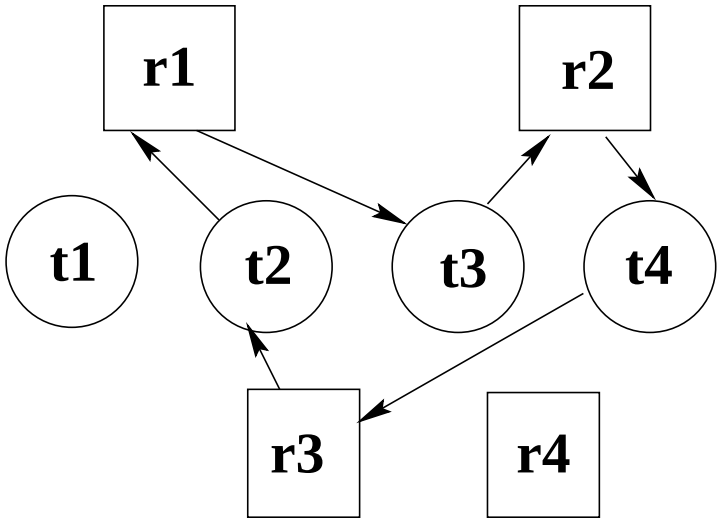
4. **Circular wait:** A set of waiting threads $\{t_1, \ldots, t_n\}$ where t_i is waiting on t_{i+1} $(i = 1\ to\ n)$ and t_n is waiting on t_1.

Deadlock Detection Using a Resource Allocation Graph

- We define a graph with vertices that represent both resources $\{r_1, \ldots r_m\}$ and threads $\{t_1, \ldots, t_n\}$.
  - A directed edge from a thread to a resource, $t_i \rightarrow r_j$ indicates that t_i has requested that resource, but has not yet acquired it (*Request Edge*)
  - A directed edge from a resource to a thread $r_j \rightarrow t_i$ indicates that the OS has allocated r_j to t_i (*Assignment Edge*)

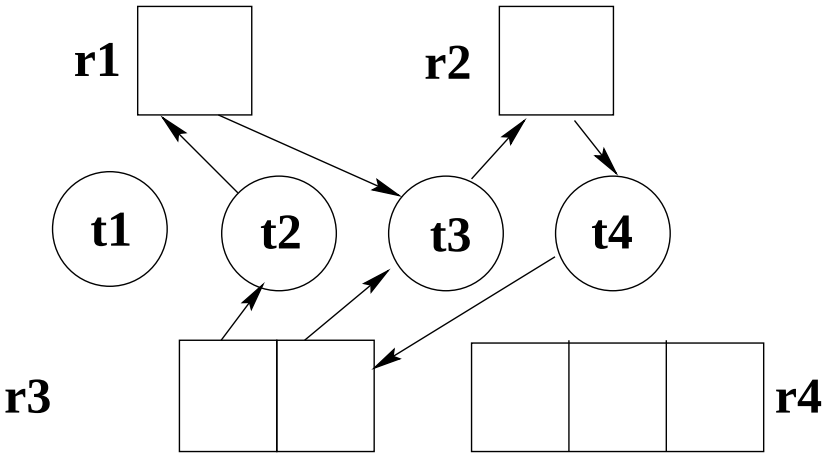
- If the graph has no cycles, no deadlock exists.

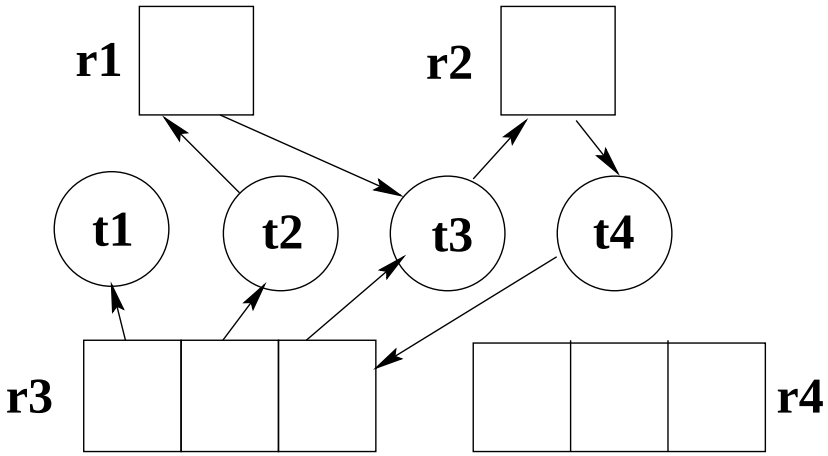
- If the graph has a cycle, deadlock might exist.



Deadlock Detection Using a Resource Allocation Graph

- What if there are multiple interchangeable instances of a resource?
  - Then a cycle indicates only that deadlock *might* exist.
  - If any instance of a resource involved in the cycle is held by a thread not in the cycle, then we can make progress when that resource is released.





Detect Deadlock and Then Correct It

- Scan the resource allocation graph for cycles, and then break the cycles.
- Different ways of breaking a cycle:
  - Kill all threads in the cycle.
  - Kill the threads one at a time, forcing them to give up resources.
  - Preempt resources one at a time rolling back the state of the thread holding the resource to the state it was in prior to getting the resource. This technique is common in database transactions.

Detect Deadlock and Then Correct It (cont)

- Detecting cycles takes O(n^2) time, where n is $|T| + |R|$. When should we execute this algorithm?
  - Just before granting a resource, check if granting it would lead to a cycle? (Each request is then O(n^2).)
  - Whenever a resource request can't be filled? (Each failed request is O(n^2).)
  - On a regular schedule (hourly or ...)? (May take a long time to detect deadlock)
  - When CPU utilization drops below some threshold? (May take a long time to detect deadlock)

Deadlock Prevention

Prevent deadlock: ensure that at least one of the necessary conditions doesn't hold.

1. **Mutual Exclusion:** make resources shareable (but not all resources can be shared)

2. **Hold and Wait:**

   - Guarantee that a thread cannot hold one resource when it requests another
   - Make threads request all the resources they need at once and make the thread release all resources before requesting a new set.

Deadlock Prevention (cont)

3. **No Preemption:**
   - If a thread requests a resource that cannot be immediately allocated to it, then the OS preempts (releases) all the resources that the thread is currently holding.
   - Only when all of the resources are available, will the OS restart the thread.
   - *Problem:* not all resources can be easily preempted, like printers.

4. **Circular wait:** impose an ordering (numbering) on the resources and request them in order.

Deadlock Prevention with Resource Reservation

- Threads provide advance information about the maximum resources they may need during execution
- Define a sequence of threads $\{t_1, \ldots, t_n\}$ as *safe* if for each t_i, the resources that t_i can still request can be satisfied by the currently available resources plus the resources held by all $t_j, j < i$.
- A *safe state* is a state in which there is a safe sequence for the threads.
- An unsafe state is not equivalent to deadlock, it just may lead to deadlock, since some threads might not actually use the maximum resources they have declared.

Deadlock Prevention with Resource Reservation (cont)

- Grant a resource to a thread if the new state is safe
- If the new state is unsafe, the thread must wait even if the resource is currently available.
- This algorithm ensures no circular-wait condition exists.

Example

- Threads t_1, t_2, and t_3 are competing for 12 tape drives.
- Currently, 11 drives are allocated to the threads, leaving 1 available.
- The current state is *safe* (there exists a safe sequence, $\{t_1, t_2, t_3\}$ where all threads may obtain their maximum number of resources without waiting)
  - t_1 can complete with the current resource allocation
  - t_2 can complete with its current resources, plus all of t_1's resources, and the unallocated tape drive.
  - t_3 can complete with all its current resources, all of t_1 and t_2's resources, and the unallocated tape drive.

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

Example (cont)

- If t_3 requests one more drive, then it must wait because allocating the drive would lead to an unsafe state.
- There are now 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	5	7

Summary

- Deadlock: situation in which a set of threads/processes cannot proceed because each requires resources held by another member of the set.
- Detection and recovery: recognize deadlock after it has occurred and break it.
- Avoidance: don't allocate a resource if it would introduce a cycle.
- Prevention: design resource allocation strategies that guarantee that one of the necessary conditions never holds
- Code concurrent programs very carefully. This only helps prevent deadlock over resources managed by the program, not OS resources.
- Ignore the possibility! (Most OSes use this option!!)

Next Classes

- Friday: Discussion Section (lots to cover, so please come on time).
- Next Monday: Deadlock Avoidance (last half of Chapter 8)