Last Class: Deadlocks

- Necessary conditions for deadlock:
  - Mutual exclusion
  - Hold and wait
  - No preemption
  - Circular wait

- Ways of handling deadlock
  - Deadlock detection and recovery
  - Deadlock prevention
  - Deadlock avoidance

Deadlock Prevention with Resource Reservation

- Threads provide advance information about the maximum resources they may need during execution
- Define a sequence of threads $\{t_1, ..., t_n\}$ 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.
- Grant a resource to a thread is 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

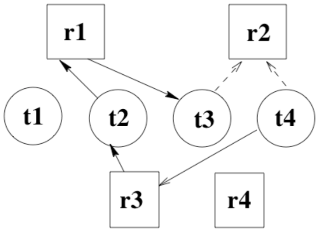
Example (contd)

- 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

Deadlock Avoidance using Resource Allocation Graph

- Claim edges: an edge from a thread to a resource that may be requested in the future
- Satisfying a request results in converting a claim edge to an allocation edge and changing its direction.
- A cycle in this extended resource allocation graph indicates an unsafe state.
- If the allocation would result in an unsafe state, the allocation is denied even if the resource is available.
  - The claim edge is converted to a request edge and the thread waits.
- This solution does not work for multiple instances of the *same* resource.



Banker's Algorithm

- This algorithm handles multiple instances of the same resource.
- Force threads to provide advance information about what resources they may need for the duration of the execution.
- The resources requested may not exceed the total available in the system.
- The algorithm allocates resources to a requesting thread if the allocation leaves the system in a safe state.
- Otherwise, the thread must wait.

Preventing Deadlock with Banker's Algorithm

```
class ResourceManager {
  int n;         // # threads
  int m;       // # resources
  int avail[m], // # of available resources of each type
  max[n,m],    // # of each resource that each thread may want
  alloc[n,m], //# of each resource that each thread is using
  need[n,m],    // # of resources that each thread might still
   request
```

Banker's Algorithm:Resource Allocation

```
public void synchronized allocate (int request[m], int i) {
  // request  contains the resources being requested
  // i is the thread making the request

  if (request > need[i])  //vector comparison
    error();  // Can't request more than you declared
  else while (request[i] > avail)
    wait();   // Insufficient resources available

  // enough resources exist to satisfy the requests
  // See if the request would lead to an unsafe state
  avail = avail - request;  // vector additions
  alloc[i] = alloc[i] + request;
  need[i] = need[i] - request;

  while ( !safeState () ) {
    // if this is an unsafe state, undo the allocation and wait
    <undo the changes to avail, alloc[i], and need[i]>
    wait ();
    <redo the changes to avail, alloc[i], and need[i]>
 } }
```

Banker's Algorithm: Safety Check

```
private boolean safeState () {
 boolean work[m] = avail[m];  // accommodate all resources
 boolean finish[n] = false;   // none finished yet

 // find a process that can complete its work now
 while (find i such that finish[i] == false
     and need[i] <= work) { // vector operations
   work = work + alloc[i]
   finish[i] = true;
 }

 if (finish[i] == true for all i)
    return true;
 else
    return false;
}
```

- Worst case: requires O(mn^2) operations to determine if the system is safe.

Example using Banker's Algorithm

System snapshot:

	Max	Allocation	Available
	A B C	A B C	A B C
P_0	0 0 1	0 0 1	
P_1	1 7 5	1 0 0	
P_2	2 3 5	1 3 5	
P_3	0 6 5	0 6 3	
Total		2 9 9	1 5 2

Example (contd)

- How many resources are there of type (A,B,C)?

- What is the contents of the Need matrix?

	A B C
P_0	
P_1	
P_2	
P_3	

- Is the system in a safe state? Why?

Example: solutions

- How many resources of type (A,B,C)? (3,14,11)

  resources = alloc + avail
- What is the contents of the need matrix?

  Need = Max - Allocation.

	A B C
P_0	0 0 0
P_1	0 7 5
P_2	1 0 0
P_3	0 0 2

- Is the system in a safe state? Why?
- Yes, because the processes can be executed in the sequence P_0, P_2, P_1, P_3, even if each process asks for its maximum number of resources when it executes.

Example (contd)

- If a request from process P_1 arrives for additional resources of (0,5,2), can the Banker's algorithm grant the request immediately?
- What would be the new system state after the allocation?

	Max	Allocation	Need	Available
	A B C	A B C	A B C	A B C
P_0	0 0 1			
P_1	1 7 5			
P_2	2 3 5			
P_3	0 6 5			
Total				

- What is a sequence of process execution that satisfies the safety constraint?

Example: solutions

- If a request from process P_1 arrives for additional resources of (0,5,2), can the Banker's algorithm grant the request immediately? Show the system state, and other criteria.

  Yes. Since

  1. (0,5,2) ≤ (1,5,2), the Available resources, and
  2. (0,5,2) + (1,0,0) = (1,5,2) ≤ (1,7,5), the maximum number P_1 can request.
  3. The new system state after the allocation is:

	Allocation	Max	Available
	A B C	A B C	A B C
P_0	0 0 1	0 0 1	
P_1	1 5 2	1 7 5	
P_2	1 3 5	2 3 5	
P_3	0 6 3	0 6 5	
			1 0 0

and the sequence P_0, P_2, P_1, P_3 satisfies the safety constraint.

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!!)

Computing Parable

- The Donkey that starved

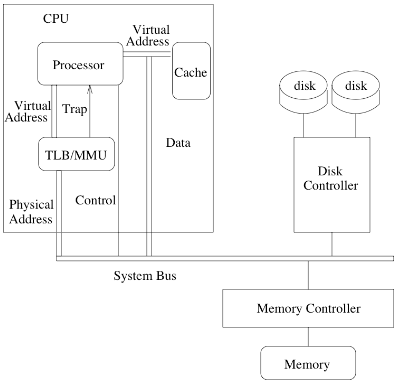
Where we are in the course

- Discussed:
  - Processes & Threads
  - CPU Scheduling
  - Synchronization & Deadlock
- Next up:
  - Memory Management
- Yet to come:
  - File Systems and I/O Storage
  - Distributed Systems

Memory Management

- Where is the executing process?
- How do we allow multiple processes to use main memory simultaneously?
- What is an address and how is one interpreted?

Background: Computer Architecture



- Program executable starts out on disk
- The OS loads the program into memory
- CPU fetches instructions and data from memory while executing the program

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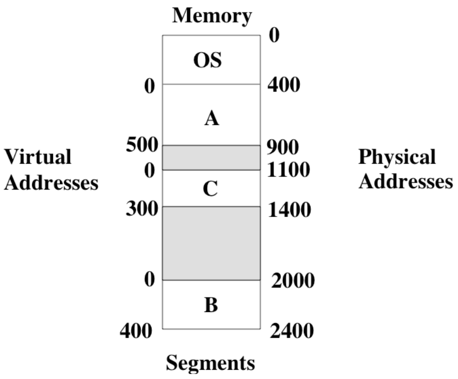
Memory Management: Terminology



- **Segment:** A chunk of memory assigned to a process.
- **Physical Address:** a real address in memory
- **Virtual Address:** an address relative to the start of a process's address space.

Where do addresses come from?

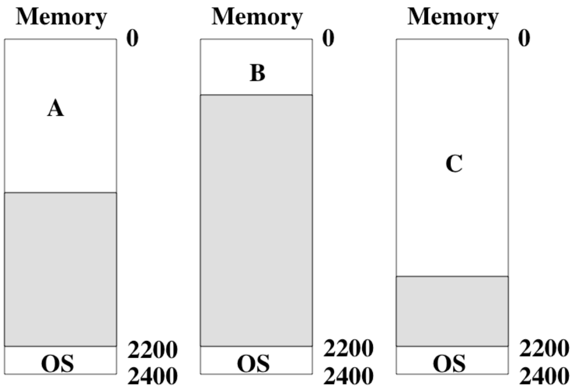
How do programs generate instruction and data addresses?

- **Compile time:** The compiler generates the exact physical location in memory starting from some fixed starting position k. The OS does nothing.
- **Load time:** Compiler generates an address, but at load time the OS determines the process' starting position. Once the process loads, it does not move in memory.
- **Execution time:** Compiler generates an address, and OS can place it any where it wants in memory.

Uniprogramming

- OS gets a fixed part of memory (highest memory in DOS).
- One process executes at a time.
- Process is always loaded starting at address 0.
- Process executes in a contiguous section of memory.
- Compiler can generate physical addresses.
- Maximum address = Memory Size - OS Size
- OS is protected from process by checking addresses used by process.

Uniprogramming



Processes A, B, C

⇒ Simple, but does not allow for overlap of I/O and computation.

Multiple Programs Share Memory

Transparency:

- We want multiple processes to coexist in memory.
- No process should be aware that memory is shared.
- Processes should not care what physical portion of memory they are assigned to.

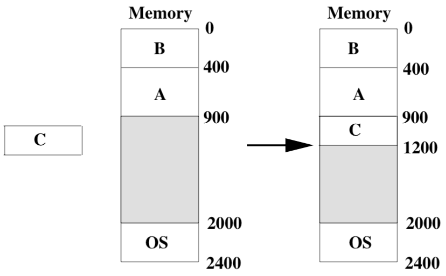
Safety:

- Processes must not be able to corrupt each other.
- Processes must not be able to corrupt the OS.

Efficiency:

- Performance of CPU and memory should not be degraded badly due to sharing.

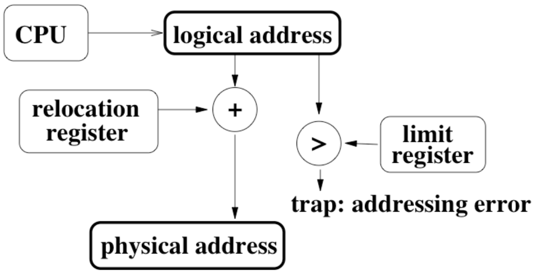
Relocation



- Put the OS in the highest memory.
- Assume at compile/link time that the process starts at 0 with a maximum address = memory size - OS size.
- Load a process by allocating a contiguous segment of memory in which the process fits.
- The first (smallest) physical address of the process is the *base* address and the largest physical address the process can access is the *limit* address.

Relocation

- **Static Relocation:**
  - at load time, the OS adjusts the addresses in a process to reflect its position in memory.
  - Once a process is assigned a place in memory and starts executing it, the OS cannot move it. (Why?)
- **Dynamic Relocation:**
  - hardware adds relocation register (base) to virtual address to get a physical address;
  - hardware compares address with limit register (address must be less than limit).
  - If test fails, the processor takes an address trap and ignores the physical address.



Dynamic Relocation

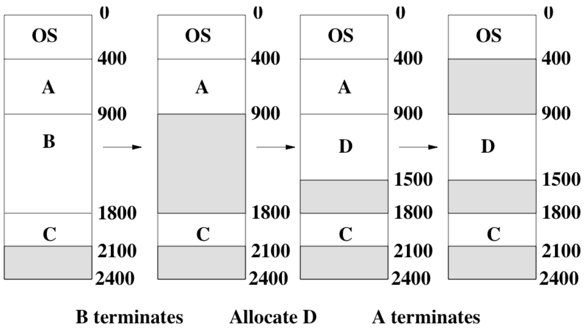
- **Advantages:**
  - OS can easily move a process during execution.
  - OS can allow a process to grow over time.
  - Simple, fast hardware: two special registers, an add, and a compare.
- **Disadvantages:**
  - Slows down hardware due to the add on every memory reference.
  - Can't share memory (such as program text) between processes.
  - Process is still limited to physical memory size.
  - Degree of multiprogramming is very limited since all memory of all active processes must fit in memory.
  - Complicates *memory management*.

Relocation: Properties

- **Transparency:** processes are largely unaware of sharing.
- **Safety:** each memory reference is checked.
- **Efficiency:** memory checks and virtual to physical address translation are fast as they are done in hardware, BUT if a process grows, it may have to be moved which is very slow.

Memory Management: Memory Allocation

As processes enter the system, grow, and terminate, the OS must keep track of which memory is available and utilized.



- **Holes:** pieces of free memory (shaded above in figure)
- Given a new process, the OS must decide which hole to use for the process

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Memory Allocation Policies

- **First-Fit:** allocate the first one in the list in which the process fits. The search can start with the first hole, or where the previous first-fit search ended.
- **Best-Fit:** Allocate the smallest hole that is big enough to hold the process. The OS must search the entire list or store the list sorted by size hole list.
- **Worst-Fit:** Allocate the largest hole to the process. Again the OS must search the entire list or keep the list sorted.
- Simulations show first-fit and best-fit usually yield better storage utilization than worst-fit; first-fit is generally faster than best-fit.

Fragmentation

- **External Fragmentation**
  - Frequent loading and unloading programs causes free space to be broken into little pieces
  - External fragmentation exists when there is enough memory to fit a process in memory, but the space is not contiguous
  - *50-percent rule:* Simulations show that for every 2*N* allocated blocks, *N* blocks are lost due to fragmentation (i.e., 1/3 of memory space is wasted)
  - We want an allocation policy that minimizes wasted space.
- **Internal Fragmentation:**
  - Consider a process of size 8846 bytes and a block of size 8848 bytes
  - ⇒ it is more efficient to allocate the process the entire 8848 block than it is to keep track of 2 free bytes
  - Internal fragmentation exists when memory internal to a partition that is wasted