CSE451 Deadlocks
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Your job this week

- Readings in Silberschatz
  - Chapter 7
- No homework this week instead there is a midterm exam on Friday

But First a Brief Word About Monitors (Section 6.7)

- The term *monitor* used in this context is not to be confused with *monitor mode* used to describe a hardware protection
- A synchronization monitor is a programming language construct that supports controlled access to shared data
- Essentially it is an ADT that encapsulates
  - Some shared data structures
  - Procedures/methods to access the data
  - Synchronization build into the procedures (using *condition variables*)

Today

- All these various synchronization methods are great for keeping concurrent processes/threads from mangling each other
- However they do introduce another problem
- Synchronization does not stop them from starving each other
- And that’s the topic of deadlocks
- We need to look at what deadlocks are and how to deal with them

Deadlock

- Deadlock is a problem that can exist when a group of processes compete for access to fixed resources.
- Def: deadlock exists among a set of processes if every process is waiting for an event that can be caused only by another process in the set.
- Example: two processes share 2 resources that they must *request* (before using) and *release* (after using). Request either gives access or causes the proc. to block until the resource is available.

```
Proc1:                        Proc2:
    request tape                  request printer
    request printer               request tape
    … <use them>                  … <use them>
    release printer               release tape
    release tape                  release printer
```

Four Conditions for Deadlock

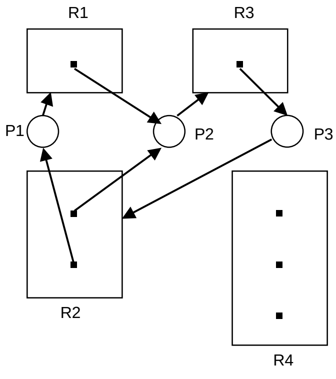
- Deadlock can exist if and only if 4 conditions hold simultaneously:

1. mutual exclusion: at least one process must be held in a non-sharable mode.
2. hold and wait: there must be a process holding one resource and waiting for another.
3. No preemption: resources cannot be preempted.
4. circular wait: there must exist a set of processes [p1, p2, …, pn] such that p1 is waiting for p2, p2 for p3, and so on….

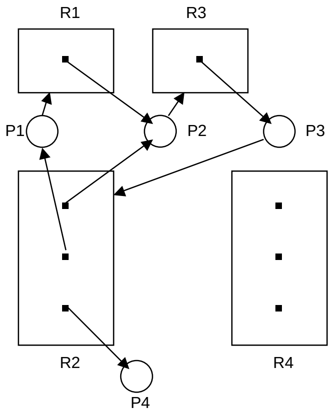
Resource Allocation Graph

- Deadlock can be described through a *resource allocation graph*.
- The RAG consists of a set of vertices $P=\{P_1,P_2,\ldots,P_n\}$ of processes and $R=\{R_1,R_2,\ldots,R_m\}$ of resources.
- A directed edge from a processes to a resource, $P_i \text{->} R_j$, implies that P_i has requested R_j.
- A directed edge from a resource to a process, $R_j \text{->} P_i$, implies that R_j has been allocated by P_i.
- If the graph has no cycles, deadlock cannot exist. If the graph has a cycle, deadlock may exist.

Resource Allocation Graph Example



There are two cycles here: P1-R1-P2-R3-P3-R2-P1 and P2-R3-P3-R2-P2, and there is *deadlock*.



Same cycles, but no deadlock.

Possible Approaches

- Deadlock Prevention: ensure that at least 1 of the necessary conditions cannot exist.
  - Mutual exclusion: make resources shareable (isn’t really possible for some resources)
  - hold and wait: guarantee that a process cannot hold a resource when it requests another, or, make processes request all needed resources at once, or, make it release all resources before requesting a new set
  - circular wait: impose an ordering (numbering) on the resources and request them in order

More Possible Approaches

- Deadlock Avoidance
  - General idea: provide information in advance about what resources will be needed by processes to guarantee that deadlock will not exist.
- E.g., define a sequence of processes <P1,P2,..Pn> as *safe* if for each Pi, the resources that Pi can still request can be satisfied by the currently available resources plus the resources held by all Pj, j < i.
  - This avoids circularities.
  - When a process requests a resource, the system grants or forces it to wait, depending on whether this would be an unsafe state.

Example:

- Processes p0, p1, and p2 compete for 12 tape drives

	max need	current usage	could ask for
p0	10	5	5
p1	4	2	2
p2	9	2	7

3 drives remain

- Current state is safe because a safe sequence exists: <p1,p0,p2>
  - p1 can complete with current resources
  - p0 can complete with current+p1
  - p2 can complete with current +p1+p0
- If p2 requests 1 drive, then it must wait because that state would be unsafe.

The Banker's Algorithm

- Banker's algorithm decides whether to grant a resource request. Define data structures.

```
int n;                // # of processes
int m;                // # of resources
int available[m];     // # of avail resources of type i
int max[n][m];        // max demand of each Pi for each Rj
int allocation[n][m]; // current allocation of resource Rj
                      // to Pi
int need[n][m];       // max # of resources that Pi may
                      // still request of Rj
```

let request[i] be a vector of the # of instances of resource Rj that Process Pi wants.

The Basic Banker's Algorithm

```
if (request[i] > need[i]) {
    // error, asked for too much
}

if (request[i] > available[i]) {
    // wait until resources become available
}

//  resources are available to satisfy request, assume
//  that we satisfy the request, we would then have

available = available – request[i];
Allocation[i] = allocation[i] + request[i];
need[i] = need[i] – request[i];

//  now check if this would leave us in a safe state
//  if yes then grant the request otherwise the process
//  must wait
```

Safety Check in Banker's Algorithm

```
int work[m] = available;       // to accumulate resources
boolean finish[n] = {FALSE,…}; // non finished yet

do {
    find an i such that (finish[i]==FALSE) && (need[i]<work)

    // process i can complete all of its requests

    finish[i] = TRUE;            // done with this process

    work = work + allocation[i]; // assume this process gave
                                 // all its allocation back
} until (no such i exists);

if (all finish entries are TRUE) {
    // system is safe.  i.e., we found a sequence a processes
    // that will lead to everyone finishing
}
```

Deadlock Detection

- If there is neither deadlock prevention nor avoidance, then deadlock may occur.
- In this case, we must have:
  - an algorithm that determines whether a deadlock has occurred
  - an algorithm to recover from the deadlock
- This is doable, but it’s costly

Deadlock Detection Algorithm

```
int work[m] = available;       // to accumulate resources
boolean finish[n] = {FALSE,…}; // non finished yet

for (i = 0; i < n; i++) {
    if (allocation[i] is zero) { finish[i] = TRUE; }
}

do {
    find an i such that (finish[i]==FALSE && request[i]<work)

    // process I can finish with currently available resources

    finish[i] = TRUE;            // done with this process

    work = work + allocation[i]; // assume this process gave
                                 // all its allocation back
} until (no such i exists);

if (finish[i] == FALSE for some i) {
    // System is deadlocked with Pi in the deadlock cycle
}
```

Deadlock Detection

- Deadlock detection algorithm is expensive. How often we invoke it depends on:
  - how often or likely is deadlock
  - how many processes are likely to be affected when deadlock occurs

Deadlock Recovers

- Once a deadlock is detected, there are 2 choices:
  1. abort all deadlocked processes (which will cost in the repeated computations necessary)
  2. abort 1 process at a time until cycle is eliminated (which requires re-running the detection algorithm after each abort)
- Or, could do process preemption: release resources until system can continue. Issues:
  - selecting the victim (could be clever based on R’s allocated)
  - rollback (must rollback the victim to a previous state)
  - starvation (must not always pick same victim)
- These are common database inspired methods, within an interactive OS none are really that acceptable

Real Life Deadlock Prevention

- Fewer resources (locks) means less deadlock potential, but also less potential concurrency. So there is a trade off here
- For really simple applications acquiring all the resources up front is fairly common, but not always practical.
- Programmers most often use common sense in the ordering of resources acquisition and releases
  - Resource levels is one area that helps development
- In complicated software systems resource levels are not practical. (e.g., memory management and the file system often recursively call each other), and deadlock prevention is far more a matter of fine tuning the locks and understanding the exact scenario in which locks are acquired

Important Points to Remember About Deadlocks

- When a deadlock does happen, by definition, it will not go away; therefore debugging deadlocks is somewhat simpler because all the processes are stuck and can’t squirm out of the way.
- Identifying a deadlock is sometimes easier then understanding how to prevent the deadlock
- No magic bullet here, but a lot of common sense

Next Time

- Review on Wednesday and
- Midterm on Friday
  - Closed book
  - Closed notes
  - Closed neighbor
  - Open mind
  - Roughly 10 questions covering
    - Hardware Support
    - OS Architecture
    - Processes and Threads
    - Scheduling Algorithms
    - Synchronization, and
    - The Linux Projects