Deadlock

Emin Gun Sirer

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

---

4 Conditions for Deadlock

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

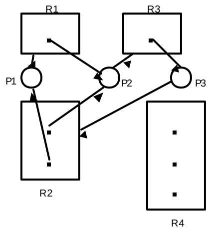
1. mutual exclusion: at least one resource must be held in a non-sharable mode.
2. hold and wait: there must be a process holding one resource and waiting for another.
3. no preemption: resources cannot be preempted.
4. circular wait: there must exist a set of processes

   [p1, p2, …, pn] such that p1 is waiting for p2, p2 for p3, and so on and pn waits for p1….

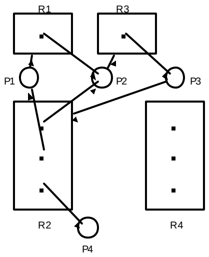
Resource Allocation Graph

- 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->R_j, implies that P_i has requested R_j.
- A directed edge from a resource to a process, R_j->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.

Dealing with Deadlocks

- *Deadlock Prevention & Avoidance*: Ensure that the system will never enter a deadlock state
- *Deadlock Detection & Recovery*: Detect that a deadlock has occurred and recover
- *Deadlock Ignorance*: Pretend that deadlocks will never occur

---

Deadlock Prevention

- **Deadlock Prevention: ensure that at least one of the necessary conditions cannot exist.**
  - Mutual exclusion: make resources shareable
    - Not 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
    - Low utilization, starvation
  - Preemption: take resources back if there is contention
    - Not always possible, hard model to write applications for
  - Circular wait: impose an ordering (numbering) on the resources and request them in order

---

Deadlock Prevention

- **Most real systems use deadlock prevention through resource ordering**
- **The resource order is a convention that the OS designers must know and follow**
  - These conventions complicate system programming
- **E.g. must always acquire a buffer cache lock before acquiring the file system lock, before acquiring the disk lock**
- **What happens when you get a page fault ?**

Problems with Deadlock Prevention

- **Prevention works by restraining how requests are made**
- **Might yield low utilization and low throughput**
  - Certain resource request sequences are not allowed, limiting functionality

- **With sufficient information about future behavior, we could allow any process to perform any set of resource accesses**
- **As long as their actions would not lead to a deadlock in the future**

Deadlock Avoidance

- **Deadlock Avoidance**
  - general idea: provide info in advance about what resources will be needed by processes to guarantee that deadlock will not exist.
- **E.g., define a set of processes < P_1, P_2,... P_n> as *safe* if for each P_i, the resources that P_i can still request can be satisfied by the currently available resources plus the resources held by all P_j, where $j < i$.**
  - this avoids circular waiting
  - when a process requests a resource, the system grants or forces it to wait, depending on whether this would be an unsafe state
- **All deadlock states are unsafe. An unsafe state may lead to deadlock. By avoiding unsafe states, we avoid deadlock**

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.**

n: integer	# of processes
m: integer	# of resources
available[1..m]	avail[i] is # of avail resources of type i
max[1..n,1..m]	max demand of each Pi for each Ri
allocation[1..n,1..m]	current allocation of resource Rj to Pi
need[1..n,1..m]	max # of resource Rj that Pi may still request

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

The Basic Algorithm

1. **If request[i] > need[i] then error (asked for too much)**
2. **If request[i] > available[i] then wait (can't supply it now)**
3. **Resources are available to satisfy the request:**
   Let's *assume* that we satisfy the request. Then we would 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, grant the request, if no, then leave the state as is and cause process to wait.

Safety Check

```
1. free[1..m] = available          ;  how many resources are available
   finish[1..n] = false (for all i)  ; none finished yet
2. Find an i s.t. finish[i]=false and need[i] <= work
       (find a proc that can complete its request now)
       if no such i exists, go to step 4 (we're done)
3. Found an i:
   finish [i] = true  ; done with this process
   free = free + allocation [i] (assume this process were to finish,
   and its allocation back to the available list)
   go to step 2
4. If finish[i] = true for all i, the system is safe.
```

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

```
available[1..m] ; # of available resources
allocation[1..n,1..m] ;# of resource of each  Ri allocated to  Pj
request[1..n,1..m] ; # of resources of each  Ri requested by  Pj

1.  work=available
    for all i < n, if allocation [i] not 0
            then finish[i]=false else finish[i]=true
2.  find an index i such that:
    finish[i]=false;
    request[i]<=work
    if no such i exists, go to 4.
3.  work=work+allocation[i]
    finish[i] = true, go to 2
4.  if finish[i] = false for some i, then system is deadlocked with Pi in deadlock
```

Deadlock

- **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
- **Running the deadlock detection algorithm often will catch deadlock cycles early**
  - Few processes will be affected
  - Note: there is no single process that caused the deadlock
  - May incur large overhead

Deadlock Recovery

- **Once a deadlock is detected, there are two choices:**
  1. abort all deadlocked processes (which will cause some computations to be repeated)
  2. abort one 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 resources allocated)
  - rollback (must rollback the victim to a previous state, may require a transactional programming model, or functional apps)
  - starvation (must not always pick same victim)