CS 4410
Operating Systems

Deadlocks:
Avoidance – Detection - Recovery

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Cornell University

Today

- Can we avoid a deadlock? Can we detect and recover from a deadlock?
- Safe state
- Deadlock avoidance
- Banker's Algorithm
- Deadlock detection
- Deadlock recovery

Deadlock Avoidance

- The **system knows** the complete sequence of requests and releases for each process.
- The **system decides** for each request whether or not the process should wait in order to avoid a deadlock.
- Each **process declare** the maximum number of resources of each type that it may need.
- The system should always be at a **safe state**.
- Safe state → no deadlock
  - the inverse is not always true.

Safe State

- A state is said to be **safe**, if it has a process sequence
  - {P1, P2,…, Pn}, such that 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, where j < i.
- State is safe because OS can definitely avoid deadlock
  - by blocking any new requests until safe order is executed
- This avoids **circular wait** condition
  - Process waits until safe state is guaranteed

Safe State

- Suppose there are 12 tape drives

	Max Needs	Current Needs
p0	10	5
p1	4	2
p2	9	2

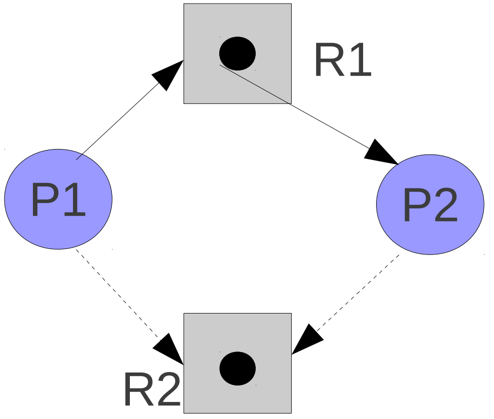
  - 3 drives remain

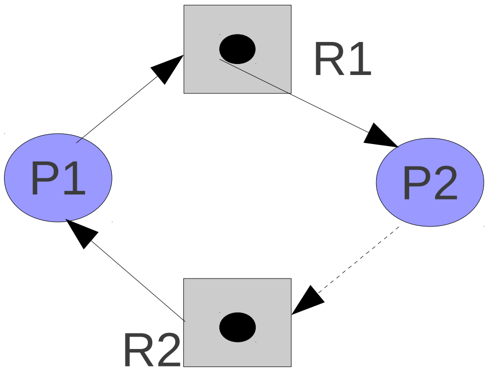
- Current state is safe because a safe sequence exists: <p1,p0,p2>
  - p1 can complete with current resources
  - p0 can complete with current+p1
  - p2 can complete with current +p1+p0

- If p2 requests 1 drive, then it must wait to avoid unsafe state.

Resource-Allocation Graph Algorithm

- Works only if each resource type has **one** instance.
- Algorithm:
  - Add a **claim edge**, Pi → Rj, if Pi can request Rj in the future
  - Represented by a dashed line in graph
- A request Pi → Rj can be granted only if:
  - Adding an assignment edge Rj → Pi does not introduce cycles
    - (since cycles imply unsafe state)





Banker's Algorithm

- Applicable to resources with **multiple instances**.
- Less efficient than the resource-allocation graph scheme.
- Each process declares its needs (number of resources)
- When a process requests a set of resources:
  - Will the system be at a safe state after the allocation?
    - Yes → Grant the resources to the process.
    - No → Block the process until the resources are released by some other process.

Banker's Algorithm

n: integer	# of processes
m: integer	# of resource-types
available[1..m]	available[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 # resource Rj that Pi may still request

Banker's Algorithm

- If request[i] > need[i] then
  - error (asked for too much)
- If request[i] > available[i] then
  - wait (can't supply it now)
- 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.

Banker's Algorithm

- **Safety Algorithm**

```
work[1..m] = available                /* how many resources are available */

finish[1..n] = false (for all i)      /* none finished yet */
```

Step 1:

```
Find an i such that finish[i]=false and need[i] <= work     /* find a proc that can complete*/
                                                            /*  its request now */

 If no such i exists, go to step 3                          /* we're done */
```

Step 2: Found an i:

```
finish [i] = true             /* done with this process */

work = work + allocation [i]          /* assume this process were to finish, */

                                     /*and its allocation  back to the available list */

go to step 1
```

Step 3: If finish[i] = true for all i, the system is safe. Else Not

Banker's Algorithm: Example

	Allocation			Max			Available		
	A	B	C	A	B	C	A	B	C
P0	0	1	0	7	5	3	3	3	2
P1	2	0	0	3	2	2			
P2	3	0	2	9	0	2			
P3	2	1	1	2	2	2			
P4	0	0	2	4	3	3			

- This is a safe state: safe sequence <P1, P3, P4, P2, P0>
- Suppose that P1 requests (1,0,2)
  - Add it to P1's allocation and subtract it from Available.

Banker’s Algorithm: Example

	Allocation	Max	Available
	A B C	A B C	A B C
P0	0 1 0	7 5 3	2 3 0
P1	3 0 2	3 2 2	
P2	3 0 2	9 0 2	
P3	2 1 1	2 2 2	
P4	0 0 2	4 3 3	

- This is still safe: safe seq <P1, P3, P4, P0, P2>
- In this new state,P4 requests (3,3,0)
  - Not enough available resources.
- P0 requests (0,2,0)
  - Let’s check resulting state...

Banker's Algorithm: Example

	Allocation			Max			Available		
	A	B	C	A	B	C	A	B	C
P0	0	3	0	7	5	3	2	1	0
P1	3	0	2	3	2	2			
P2	3	0	2	9	0	2			
P3	2	1	1	2	2	2			
P4	0	0	2	4	3	3			

- This is unsafe state (why?).
- So P0's request will be denied.

The story so far..

- We saw that you can **prevent** deadlocks.
  - By **negating** one of the four necessary conditions.
- We saw that the OS can schedule processes in a careful way so as to **avoid** deadlocks.
  - Using a resource allocation graph.
  - **Banker's algorithm**.
- What are the downsides to these?

Deadlock Detection

- If neither avoidance or prevention is implemented, deadlocks can (and will) occur.
- Coping with this requires:
  - **Detection**: finding out if deadlock has occurred
    - Keep track of **resource allocation** (who has what)
    - Keep track of **pending requests** (who is waiting for what)
  - **Recovery**: resolve the deadlock

Using the RAG Algorithm to detect deadlocks

- Suppose there is only one instance of each resource
- Example 1: Is this a deadlock?
  - P1 has R2 and R3, and is requesting R1
  - P2 has R4 and is requesting R3
  - P3 has R1 and is requesting R4
- Example 2: Is this a deadlock?
  - P1 has R2, and is requesting R1 and R3
  - P2 has R4 and is requesting R3
  - P3 has R1 and is requesting R4
- Use a **wait-for graph:**
  - Collapse resources
  - An edge Pi → Pk exists only if RAG has Pi → Rj & Rj → Pk
  - Cycle in wait-for graph → deadlock!

Detection Algorithm

- Multiple instances per resource.
- Data structures:

n: integer # of processes

m: integer # of resource-types

available[1..m] available[i] is # of avail resources of type i

request[1..n,1..m] current demand of each Pi for each Ri

allocation[1..n,1..m] current allocation of resource Rj to Pi

finish[1..n] true if Pi's request can be satisfied

Let request[i] be vector of # instances of each resource Pi wants

Detection Algorithm

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finish[1..n]	true if Pi's request can be satisfied

Let request[i] be vector of # instances of each resource Pi wants

Detection Algorithm

- work[]=available[]
- for all i < n, if allocation[i] != 0
  - then finish[i]=false else finish[i]=true
- find an index i such that:
  - finish[i]=false;
  - request[i]<=work
- if no such i exists, go to 7.
- work=work+allocation[i]
- finish[i] = true, go to 3
- if finish[i] = false for <u>some</u> i,
  - then system is deadlocked with Pi in deadlock

Detection Algorithm: Example

	Allocation A B C	Request A B C	Available A B C
P0	0 1 0	0 0 0	0 0 0
P1	2 0 0	2 0 2	
P2	3 0 3	0 0 0	
P3	2 1 1	1 0 0	
P4	0 0 2	0 0 2	

- The system is not in a deadlocked state.
- What will happen if P2 makes an additional request for a instance of type C?

Deadlock Recovery

- **Killing** one/all deadlocked processes
  - Keep killing processes, until deadlock broken
  - Repeat the entire computation
- **Preempt** resource/processes until deadlock broken
  - Selecting a victim (# resources held, how long executed)
  - Rollback (partial or total)
  - Starvation (prevent a process from being executed)

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