DEADLOCK

Deadlock

- processes which share resources or communicate are permanently blocked -> deadlock
- if processes request resources without releasing the resources they hold, deadlock may occur

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Deadlock

```
P1                  P2
req(D);             req(T);
lock(D);            lock(T);
  req(T);             req(D);
  lock(T);            lock(D);
    <……..>              <……..>
  unlock(T);          unlock(D);
unlock(D);          unlock(T);
```

Deadlock potential !

Deadlock

Example: 200K memory is available for processes in a system. Assume no other processes use the memory, the following series of requests have a deadlock potential.

P1	**P2**
req(80K);	req(70K);
...	...
req(60K);	req(80K);
...	...

Deadlock

Example: If *receive_msg* works in blocking mode, then the following scenario has a deadlock potential.

P1	**P2**
receive_msg(P2);	receive msg(P1);
...	...
send_msg(P2);	send_msg (P1);
...	...

Deadlock

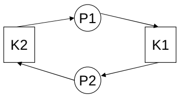
- if a resource is unavailable when requested:
  - process is blocked until resource becomes available
  - process receives an error message and tries later

Conditions for Deadlock

- mutual exclusion condition
  - only one process can use a shared resource at a time
- hold and wait condition
  - processes wait for a requested resource until it becomes available while holding onto its own resources
- no pre-emption condition
  - resources allocated to a process cannot be taken back without the process' consent
- circular wait condition
  - two or more processes wait for the other's resource while not releasing its own in a circular fashion

Conditions for Deadlock

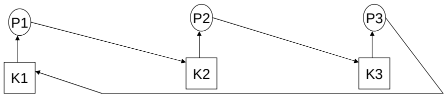
- a graph representation may be used
  - nodes in graph:
    - circle: process
    - square: resource
  - edges in graph:
    - process → resource : process requests resource
    - resource → process : resource allocated to process



Deadlock with circular wait.

Deadlock Example

```
P1                    P2                    P3
req(K1);             req(K2);              req(K3);
lock(K1);                     lock(K2);              lock(K3);
req(K2);              req(K3);             req(K1);
lock(K2);                     lock(K3);              lock(K1);
<…….>                <……..>                <………>
unlock(K2);           unlock(K3);           unlock(K1);
unlock(K1);           unlock(K2);           unlock(K3);
```



Deadlock

- strategies used for dealing with deadlock
  - prevention: structure the system negating one of the deadlock conditions
  - detection and recovery: let deadlocks occur, detect them and take action
  - avoidance
    - don't start processes whose requests may cause a deadlock
    - don't grant requests which may cause a deadlock
  - ignore

Deadlock Avoidance

- the Banker's algorithm
  - Dijkstra, 1965
  - fixed no. of processes and resources in the system
  - system state: current allocation of resources to processes
  - state: *resource* and *free* vectors, *has* and *max_request* matrices

Banker's Algorithm

- *resource*: shows all resources in system
- *free*: shows all free resources in system
- *has*: shows the amount of each resource allocated to each process
- *max_istek*: shows the maximum no. of requests a process will make during its lifetime for each type of resource

Banker’s Algorithm

safe state: a state is safe if it is not deadlocked and there exists some scheduling order in which every process can run to completion even if all of them request their maximum no. of resources immediately.

unsafe state: such a scheduling order cannot be found

Banker’s Algorithm

- when a process requests a resource, the request is granted if:
  - (resources process already has) + (resources it requests) ≤ (max_request)
  - if after granting this request, some scheduling order in which every process can run to completion even if all of them request their maximum no. of resources immediately still exists

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Banker’s Algorithm – Example One Type of Resource

Example 1: Total no. of resources = 12

Safe state √

1. give 2 resources to B
2. B releases 6 resources when it is completed
3. A and C can run to completion.

Process	**Has**	**Max_ Request**	**Remaining_ Request**
A	1	4	3
B	4	6	2
C	5	8	3

Allocated=10 *Free*=2

Banker’s Algorithm – Example One Type of Resource

Example 2: Total no. of resources = 12

Unsafe state X

- potential deadlock

Process	**Has**	**Max_ Request**	**Remaining_ Request**
A	8	10	2
B	2	5	3
C	1	3	2

Allocated=11 *Free*=1

Banker’s Algorithm – Example One Type of Resource

Example 3: Total no. of resources = 12

- system is in safe state of example 1.
- C requests one more resource

Q: Is this request granted?

- update the system state as if the request has been granted
- check if the new state is safe

Unsafe state X

- Request is NOT granted!

Process	**Has**	**Max_ Request**	**Remaining_ Request**
A	1	4	3
B	4	6	2
C	6	8	2

Allocated=11 *Free*=1

Banker’s Algorithm – Example One Type of Resource

Example 4: Total no. of resources = 12

- system is in safe state of example 1.
- B requests one more resource

Q: Is this request granted?

Banker’s Algorithm – One Type of Resource

```
free = total_resources;
for i= 1 to no_of_processes do
begin
  free = free – has[i],
  may_not_finish[i] = TRUE;
  remaining_request[i] = max_request[i] – has[i];
end;
flag = TRUE;
while (flag) do
begin
  flag = FALSE;
  for i=1 to no_of_processes do
  begin
    if ((may_not_finish[i]) AND
        (remaining_request[i] LE free)) then
    begin
      may_not_finish[i] = FALSE;
      free = free + has[i];
      flag = TRUE;
    end;
  end;
end;
if (free EQ total_resources) then
   ----- SAFE STATE ------
else
   ----- UNSAFE STATE -----
```

Banker’s Algorithm – Multiple Type of Resources

Example

Max_Request Matrix

	K1	K2	K3
P1	3	2	2
P2	6	1	3
P3	3	1	4
P4	4	2	2

Has Matrix

	K1	K2	K3
P1	1	0	0
P2	6	1	2
P3	2	1	1
P4	0	0	2

Remaining_Request Matrix

	K1	K2	K3
P1	2	2	2
P2	0	0	1
P3	1	0	3
P4	4	2	0

K1	K2	K3
9	3	6

Resource Vector

K1	K2	K3
0	1	1

Free Vector

if processes are executed in the order P2, P3, (P1 or P4) all may run to completion

⇒ SAFE STATE √

Banker’s Algorithm – Multiple Type of Resources

Example

Q: When the system is in the safe state given in the previous slide, if P3 requests one more K3, will this request be granted?

A: Granting this request will cause an unsafe state, so it will not be granted.

Application of the Banker’s Algorithm

1. Are there any rows in the *remaining_request* matrix ≤ *free* vector ?
   if not: unsafe state
2. Assume that the process corresponding to the row chosen above, requests all the resources it needs and finishes.
3. Mark the process as completed and add all its resources to the *free* vector
4. Repeat steps 1 and 2 until either all processes are marked as “completed” (safe state) or until a deadlock occurs (unsafe state)

Banker’s Algorithm

- to be able to apply the algorithm:
  - all processes must declare all their resource requests when they start execution
  - number of resources and processes must be fixed
  - order of process execution should not be important
  - any process holding a resource should not exit without releasing all its resources
- the algorithm grants or rejects requests based on the worst case sceario
  - not all rejected requests would cause a deadlock (inefficient use of resources)
- the algorithm is executed each time a request is made (high cost)

Deadlock Detection

- not as restrictive as avoidance strategies
- all requests are granted
- system is checked for deadlock periodically
  - if deadlock is detected:
    - terminate all deadlocked processes
    - or terminate processes one by one until deadlock is removed
    - or ...
- has lower cost since it is not executed on each request
- provides more efficient resource use
- period for checking for deadlock is set based on the frequency of deadlock on the system

Deadlock Detection

- *Has* matrix and *Free* vector used.
- Q *Request* matrix defined. qij shows the amount of j type resources process i requests
- algorithm determines processes which are not deadlocked and marks them
- initially all processes are unmarked

Deadlock Detection Steps

- **Step 1:** Mark all processes which correspond to rows with all `0`'s in the *Has* matrix
- **Step 2:** Create a temporary W vector to represent the *Free* vector
- **Step 3:** Find an *i* for which all corresponding values in the Q matrix are LE than those in the W vector (P_i must be unmarked).

  $Q_{ik} \leq W_k$, $1 \leq k \leq m$

Deadlock Detection Steps

- **Step 4:** Terminate algorithm if no such row exists
- **Step 5:** If such a row exists, mark the *i*th process and add the corresponding row in the *Has* matrix to the W vector

  $W_k = W_k + A_{ik}$, $1 \leq k \leq m$
- **Step6:** Return to step 3.

Deadlock Detection

- when algorithm terminates, if there are unmarked processes ⇒ Deadlock exists
  - unmarked processes are deadlocked
- algorithm only detectes if a deadlock exists in the current state or not

Deadlock Detection

	R1	R2	R3	R4	R5
P1	0	1	0	0	1
P2	0	0	1	0	1
P3	0	0	0	0	1
P4	1	0	1	0	1

Request Matrix Q

	R1	R2	R3	R4	R5
P1	1	0	1	1	0
P2	1	1	0	0	0
P3	0	0	0	1	0
P4	0	0	0	0	0

Allocation Matrix A

R1	R2	R3	R4	R5
2	1	1	2	1

Resource Vector

R1	R2	R3	R4	R5
0	0	0	0	1

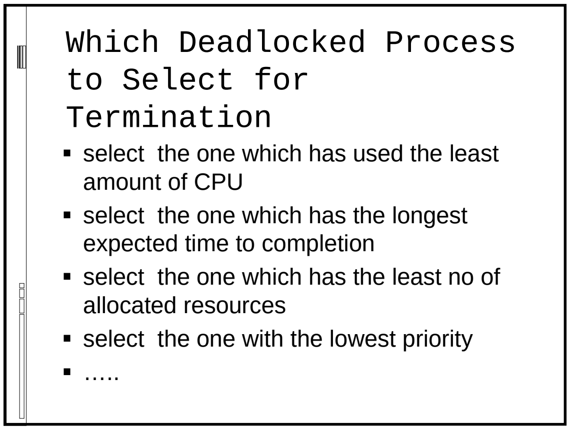
Available Vector

1) Mark P4
2) W = (0 0 0 0 1)
3) P3's request LE W ⇒ Mark P3
   W = W + (0 0 0 1 0) = (0 0 0 1 1)
4) No other such processes can be found ⇒ Terminate algorithm

P1 and P2 remain unmarked ⇒ deadlocked!

Strategies to Apply After Deadlock Detection

- terminate all deadlocked processes
- roll-back all deadlocked processes to a previous control point in time and resume from there
  - same deadlock may occur again
- terminate deadlocked processes one by one until deadlock no longer exists
- remove allocated resources from deadlocked processes one by one until deadlock no longer exists



Which Deadlocked Process to Select for Termination

- select the one which has used the least amount of CPU
- select the one which has the longest expected time to completion
- select the one which has the least no of allocated resources
- select the one with the lowest priority
- …..