Deadlocks

Chapter 6

Introduction

- Resources used only by one process at a time
  - Process *A* requests permission to use X and is granted it
  - Process *B* requests Y first and is also granted it
  - *A* asks for Y, but the request is suspended until *B* releases it
  - Unfortunately, instead of releasing Y, *B* asks for X
  - At this point both processes are blocked and will remain so forever – **deadlock** conditions

Preemptable and Nonpreemptable Resources

- A **preemptable resource** can be taken away from the process owning it with no ill effects
  - Memory is an example of a preemptable resource
- A **nonpreemptable resource** cannot be taken away from its current owner without potentially causing failure
  - Blu-ray recorders are not preemptable
  - In general, deadlocks involve nonpreemptable resources.

Preemptable and Nonpreemptable Resources

Sequence of events required to use a resource

1. Request the resource.
2. Use the resource.
3. Release the resource.

Resource Acquisition (1)

```
typedef int semaphore;
semaphore resource_1;

void process_A(void) {
        down(&resource_1);
        use_resource_1( );
        up(&resource_1);
}
```

(a)

```
typedef int semaphore;
semaphore resource_1;
semaphore resource_2;

void process_A(void) {
        down(&resource_1);
        down(&resource_2);
        use_both_resources( );
        up(&resource_2);
        up(&resource_1);
}
```

(b)

Figure 6-1. Using a semaphore to protect resources. (a) One resource. (b) Two resources.

Resource Acquisition (2)

```
typedef int semaphore;
    semaphore resource_1;
    semaphore resource_2;

    void process_A(void) {
        down(&resource_1);
        down(&resource_2);
        use_both_resources( );
        up(&resource_2);
        up(&resource_1);
    }

    void process_B(void) {
        down(&resource_1);
        down(&resource_2);
        use_both_resources( );
        up(&resource_2);
        up(&resource_1);
    }
```

(a)

```
    semaphore resource_1;
    semaphore resource_2;

    void process_A(void) {
        down(&resource_1);
        down(&resource_2);
        use_both_resources( );
        up(&resource_2);
        up(&resource_1);
    }

    void process_B(void) {
        down(&resource_2);
        down(&resource_1);
        use_both_resources( );
        up(&resource_1);
        up(&resource_2);
    }
```

(b)

Figure 6-2. (a) Deadlock-free code.
(b) Code with a potential deadlock.

Deadlock Definition

A set of processes is deadlocked if …

- Each process in the set waiting for an event
- That event can be caused only by another process

Conditions for Resource Deadlocks

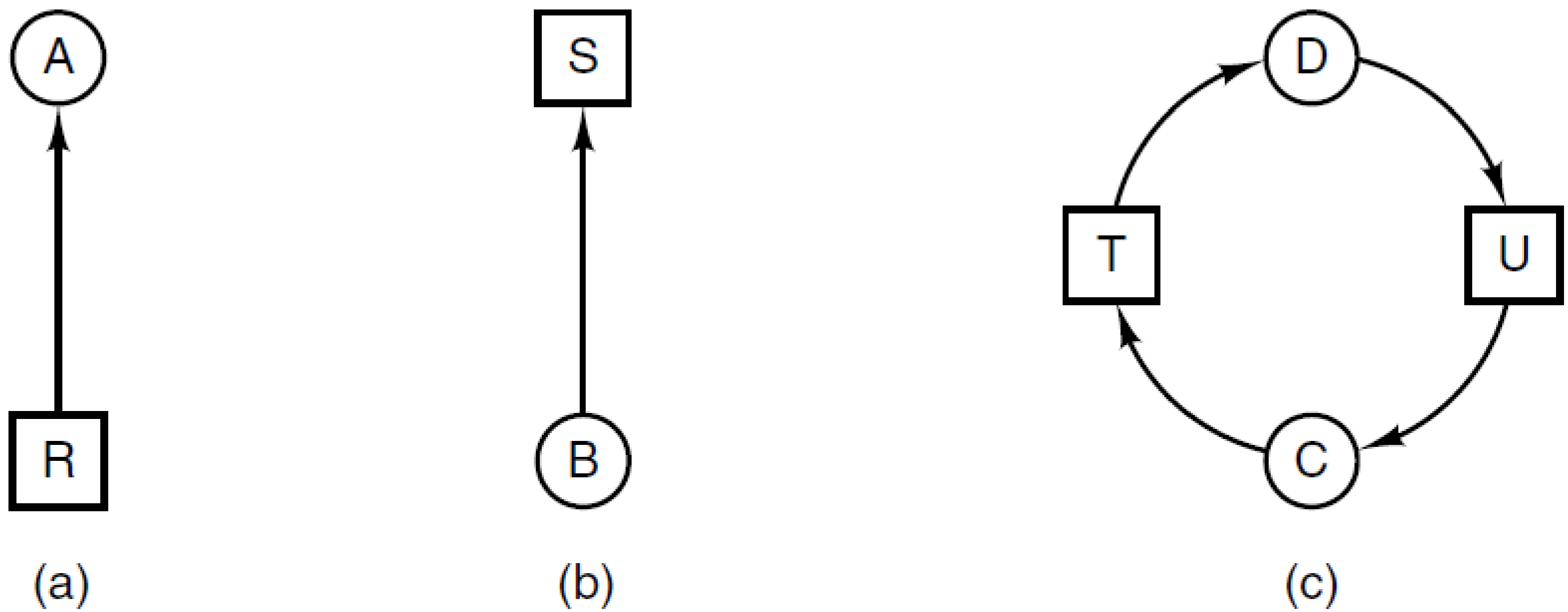
Four conditions that must hold:

1. Mutual exclusion
2. Hold and wait
3. No preemption
4. Circular wait condition

Conditions for Resource Deadlocks

- **Mutual exclusion** - each resource is either currently assigned to exactly one process or is available
- **Hold-and-wait** – processes currently holding resources that were granted earlier can request new resources
- **No-preemption** – resources previously granted cannot be forcibly taken away from a process. They must be explicitly released by the process holding them
- **Circular wait** – there must be a circular list of two or more processes, each of which is waiting for a resource held by the next member of the chain

Deadlock Modeling (1)



Cycle: C – T – D – U – C

Figure 6-3. Resource allocation graphs. (a) Holding a resource. (b) Requesting a resource. (c) Deadlock.

Deadlock Modeling (2)

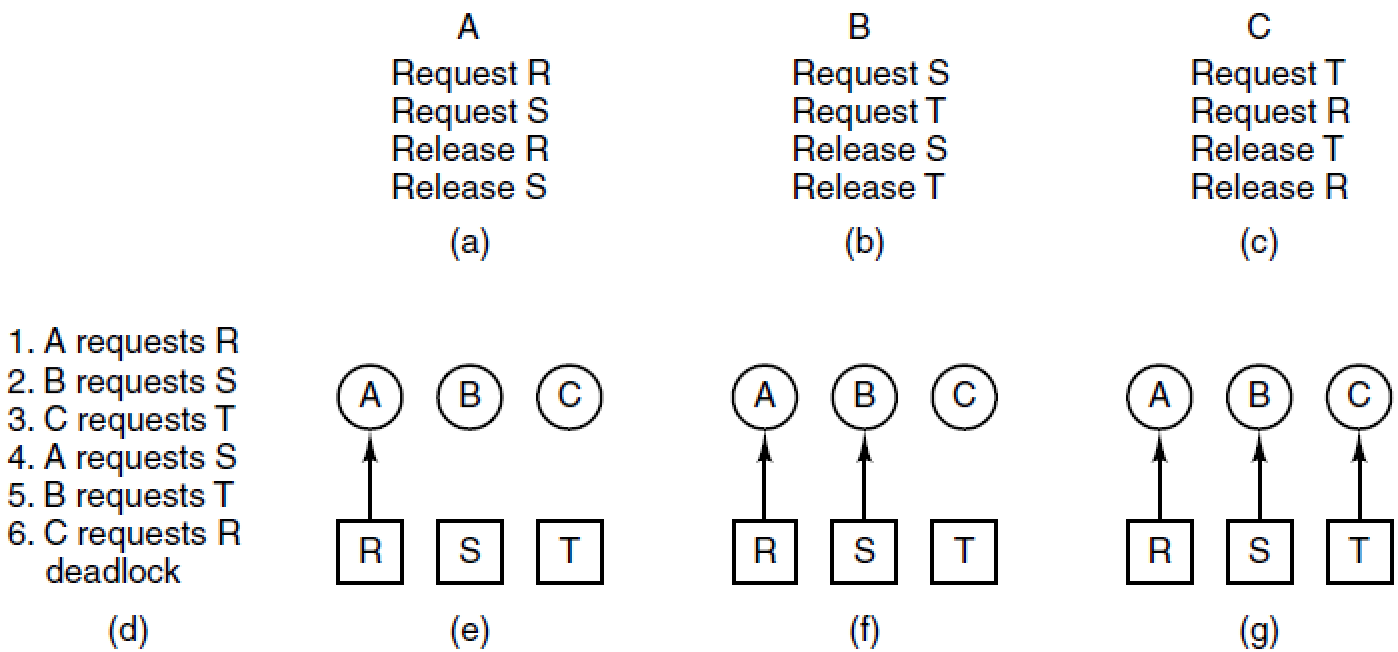


Figure 6-4. An example of how deadlock occurs and how it can be avoided.

Deadlock Modeling (3)

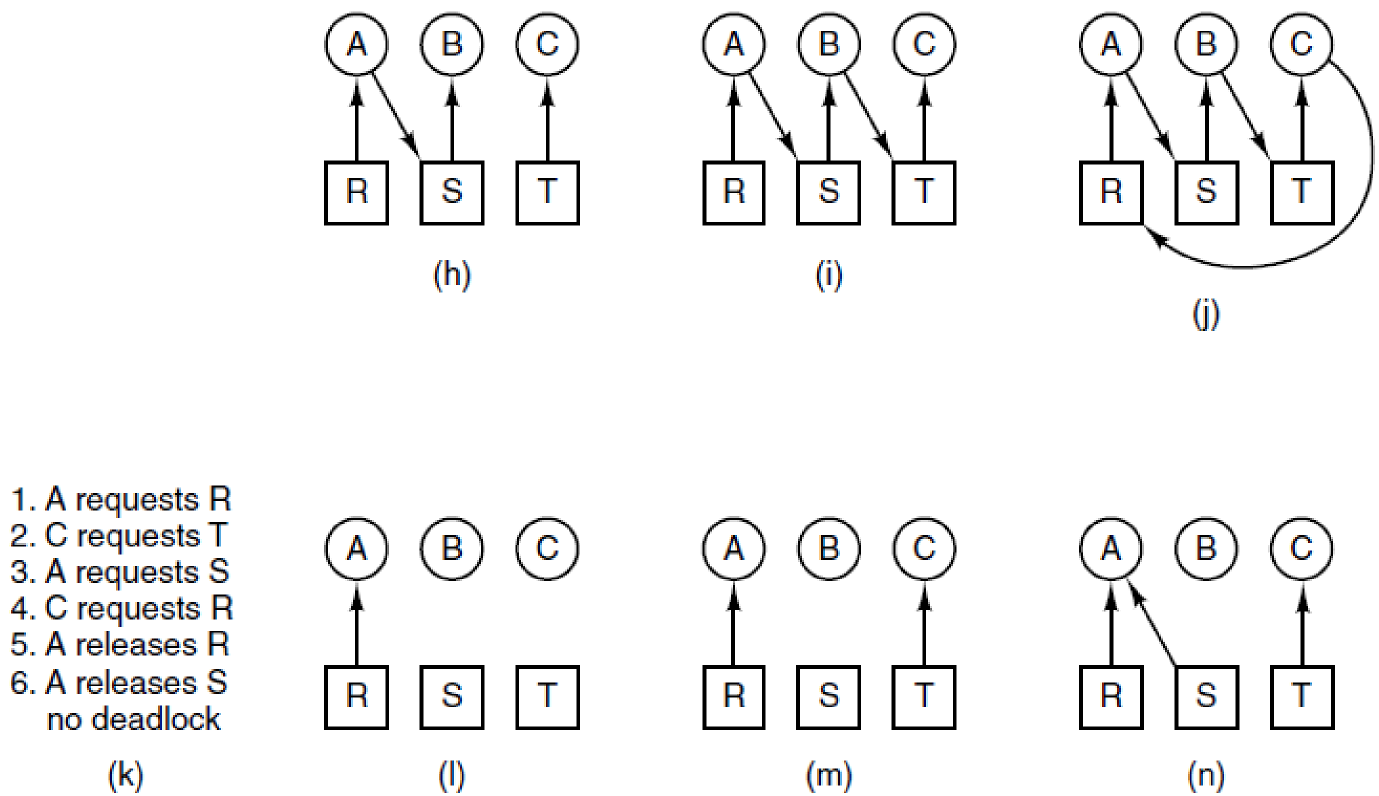


Figure 6-4. An example of how deadlock occurs and how it can be avoided.

Deadlock Modeling (4)

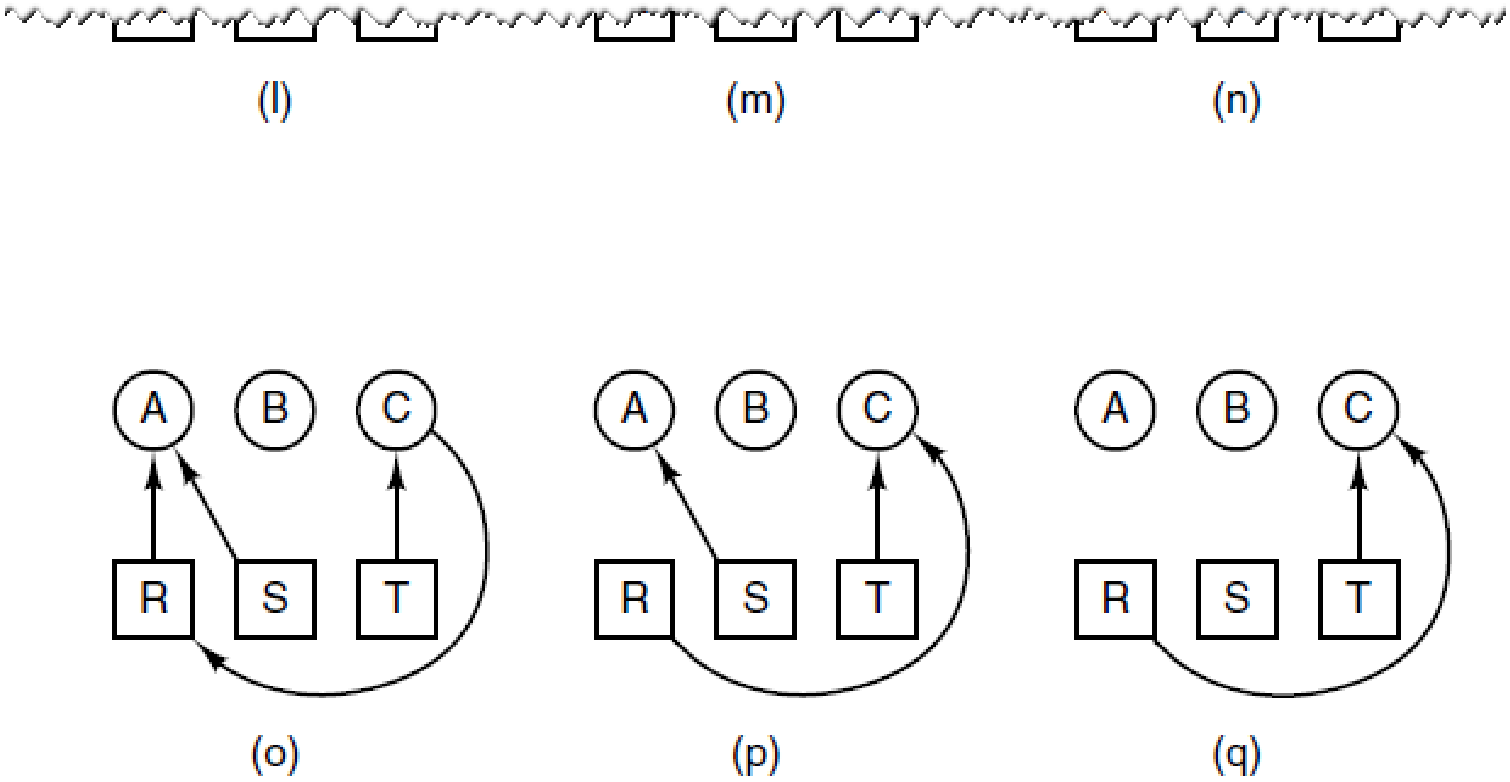


Figure 6-4. An example of how deadlock occurs and how it can be avoided.

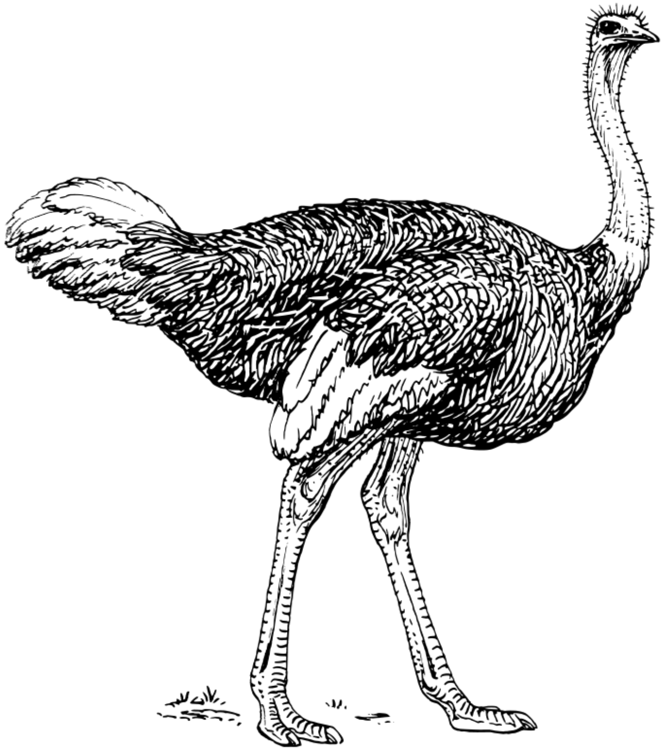
Deadlock Modeling (5)

Strategies are used for dealing with deadlocks:

1. Ignore the problem, maybe it will go away
2. Detection and recovery. Let deadlocks occur, detect them, and take action
3. Dynamic avoidance by careful resource allocation
4. Prevention, by structurally negating one of the four required conditions

The Ostrich Algorithm

Stick your head in the sand and pretend there is no problem.



Deadlock Detection with One Resource of Each Type (1)

Example of a system – is it deadlocked?

1. Process A holds R, wants S
2. Process B holds nothing, wants T
3. Process C holds nothing, wants S
4. Process D holds U, wants S and T
5. Process E holds T, wants V
6. Process F holds W, wants S
7. Process G holds V, wants U

Deadlock Detection with One Resource of Each Type (2)

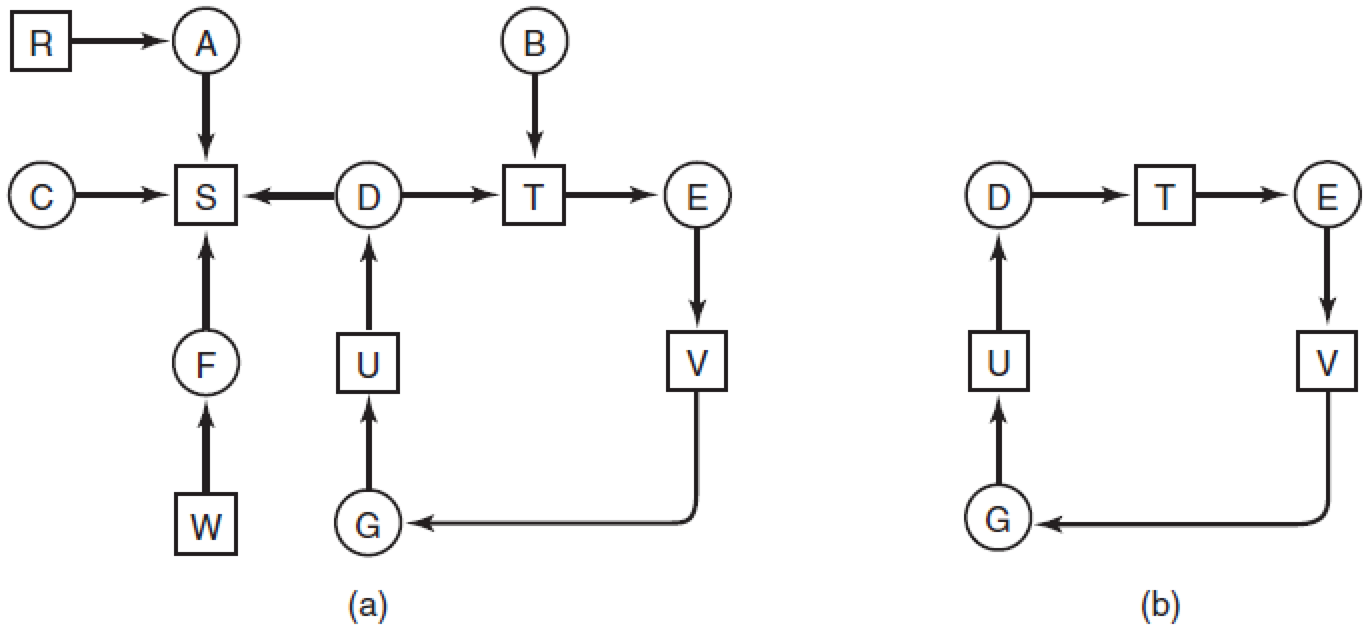


Figure 6-5. (a) A resource graph. (b) A cycle extracted from (a).

Algorithm to Detect Deadlocks (1)

1. For each node, *N* in the graph, perform following five steps with *N* as starting node.
2. Initialize *L* to empty list, and designate all arcs as unmarked.
3. Add current node to end of L, check to see if node now appears in L two times. If so, graph contains a cycle (listed in L) and algorithm terminates

Algorithm to Detect Deadlocks (2)

4. From given node, see if there are any unmarked outgoing arcs. If so, go to step 5; if not, go to step 6.
5. Pick unmarked outgoing arc at random, mark it. Then follow to new current node and go to step 3.
6. If this is initial node, graph does not contain cycles, algorithm terminates. Otherwise, dead end. Remove it and go back to the previous node.

Deadlock Detection with Multiple Resources of Each Type (1)

Resources in existence
$(E_1, E_2, E_3, \ldots, E_m)$

Resources available
$(A_1, A_2, A_3, \ldots, A_m)$

Current allocation matrix

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & \cdots & C_{1m} \\ C_{21} & C_{22} & C_{23} & \cdots & C_{2m} \\ \vdots & \vdots & \vdots & & \vdots \\ C_{n1} & C_{n2} & C_{n3} & \cdots & C_{nm} \end{bmatrix}$$

Row n is current allocation
to process n

Request matrix

$$\begin{bmatrix} R_{11} & R_{12} & R_{13} & \cdots & R_{1m} \\ R_{21} & R_{22} & R_{23} & \cdots & R_{2m} \\ \vdots & \vdots & \vdots & & \vdots \\ R_{n1} & R_{n2} & R_{n3} & \cdots & R_{nm} \end{bmatrix}$$

Row 2 is what process 2 needs

$$\sum_{i=1}^{n} C_{ij} + A_j = E_j$$

Figure 6-6. The four data structures needed
by the deadlock detection algorithm.

Deadlock Detection with Multiple Resources of Each Type (2)

Deadlock detection algorithm:

1. Look for unmarked process, P_i , for which the i-th row of R is less than or equal to A.
2. If such a process is found, add the i-th row of C to A, mark the process, go back to step 1.
3. If no such process exists, algorithm terminates.

Deadlock Detection with Multiple Resources of Each Type (3)

$$
\begin{array}{ccccc}
 & \text{Tape drives} & \text{Plotters} & \text{Scanners} & \text{CD Roms} \\
E = (& 4 & 2 & 3 & 1 \,)
\end{array}
\qquad
\begin{array}{ccccc}
 & \text{Tape drives} & \text{Plotters} & \text{Scanners} & \text{CD Roms} \\
A = (& 2 & 1 & 0 & 0 \,)
\end{array}
$$

Current allocation matrix

$$
C = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 2 & 0 & 0 & 1 \\ 0 & 1 & 2 & 0 \end{bmatrix}
$$

Request matrix

$$
R = \begin{bmatrix} 2 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 2 & 1 & 0 & 0 \end{bmatrix}
$$

Figure 6-7. An example for the deadlock detection algorithm.

Deadlock Detection with Multiple Resources of Each Type (3)

- When to look for a deadlock to come up?
- Check every time a resource request is made.
  - This is certain to detect them as early as possible, but expensive in terms of CPU time
- Check every k minutes
- Check when CPU utilization has dropped below some threshold

Recovery from Deadlock

Possible Methods of recovery (though none are “attractive”):

1. Preemption
2. Rollback
3. Killing processes

Deadlock Avoidance
Resource Trajectories

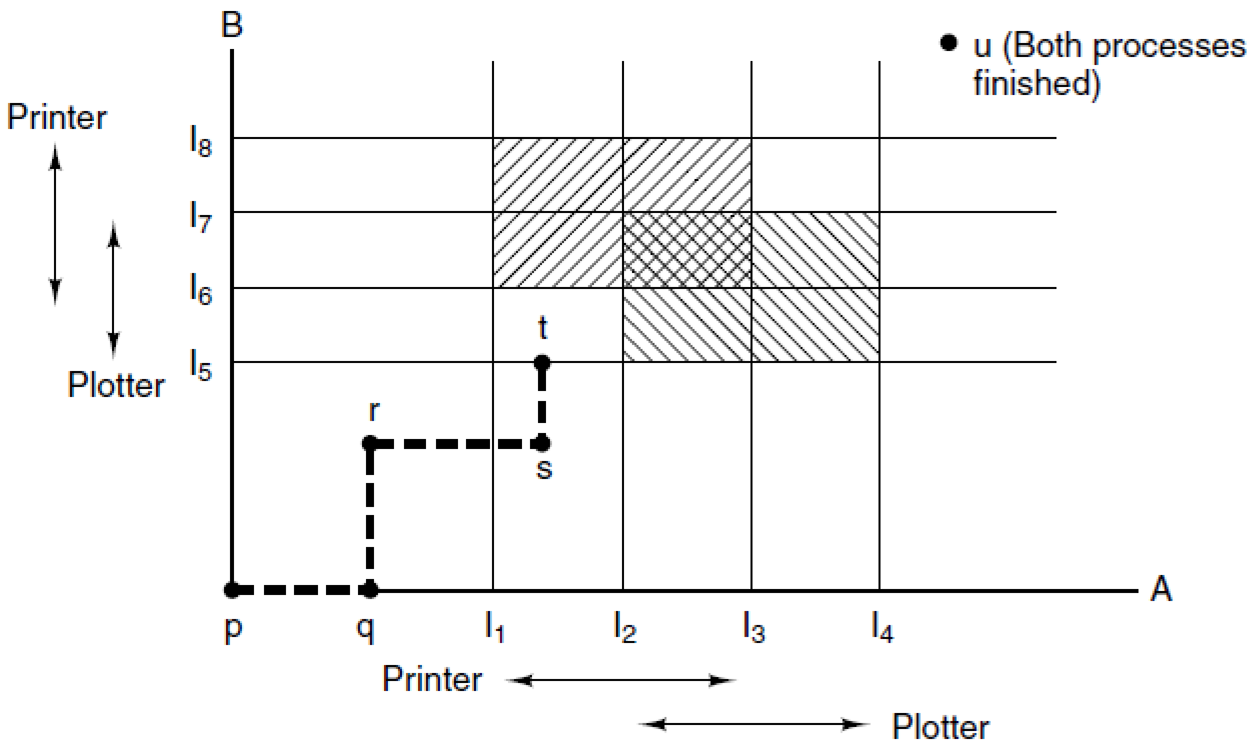


Figure 6-8. Two process resource trajectories.

Safe and Unsafe States (1)

	Has	Max
A	3	9
B	2	4
C	2	7

Free: 3
(a)

	Has	Max
A	3	9
B	4	4
C	2	7

Free: 1
(b)

	Has	Max
A	3	9
B	0	–
C	2	7

Free: 5
(c)

	Has	Max
A	3	9
B	0	–
C	7	7

Free: 0
(d)

	Has	Max
A	3	9
B	0	–
C	0	–

Free: 7
(e)

Figure 6-9. Demonstration that the state in (a) is safe.

Safe and Unsafe States (2)

	Has	Max
A	3	9
B	2	4
C	2	7

Free: 3
(a)

	Has	Max
A	4	9
B	2	4
C	2	7

Free: 2
(b)

	Has	Max
A	4	9
B	4	4
C	2	7

Free: 0
(c)

	Has	Max
A	4	9
B	—	—
C	2	7

Free: 4
(d)

From a safe state the system can guarantee that all processes will finish
From an unsafe state, no such guarantee can be given

Figure 6-10. Demonstration that the state in (b) is not safe.

Banker's Algorithm

- Proposed by Dijkstra in 1965
- Modeled on how a banker might deal with a group of customers to whom he has granted loans (1 unit like 1K dollars)
- Based on safe and unsafe state
- Customers are processes, units are resources, banker is the OS

Banker's Algorithm for Single Resource

	Has	Max
A	0	6
B	0	5
C	0	4
D	0	7

Free: 10

(a)

	Has	Max
A	1	6
B	1	5
C	2	4
D	4	7

Free: 2

(b)

	Has	Max
A	1	6
B	2	5
C	2	4
D	4	7

Free: 1

(c)

Figure 6-11. Three resource allocation states:
(a) Safe. (b) Safe. (c) Unsafe.

Banker's Algorithm for Multiple Resources (1)

Process	Tape drives	Plotters	Printers	CD ROMs
A	3	0	1	1
B	0	1	0	0
C	1	1	1	0
D	1	1	0	1
E	0	0	0	0

Resources assigned

Process	Tape drives	Plotters	Printers	CD ROMs
A	1	1	0	0
B	0	1	1	2
C	3	1	0	0
D	0	0	1	0
E	2	1	1	0

Resources still needed

E = (6342)
P = (5322)
A = (1020)

Figure 6-12. The banker's algorithm with multiple resources.

Banker's Algorithm for Multiple Resources (2)

1. Look for a row, R, whose unmet resource needs are all smaller than or equal to A. If no such row exists, system will eventually deadlock.
2. Assume the process of row chosen requests all resources needed and finishes. Mark that process as terminated, add its resources to the A vector.
3. Repeat steps 1 and 2 until either all processes are marked terminated (safe state) or no process is left whose resource needs can be met (deadlock)

Deadlock Prevention

Assure that at least one of conditions is never satisfied

- Mutual exclusion
- Hold and wait
- No Preemption
- Circular wait

Attacking Mutual Exclusion

- Spooling printer output and one printer daemon process can eliminate deadlock on the printer
- But daemons normally print only after a complete file is available
  - That could lead to deadlock due to limited spooling space

Attacking Hold and Wait

- All process will request all their recourses before starting execution
  - If everything is available, the process will be allocated whatever it needs and can finish
  - Many processes don't know how many resources they will need
- A process requesting a resource will temporarily release all the recourses it holds and tries to get everything it needs all at once

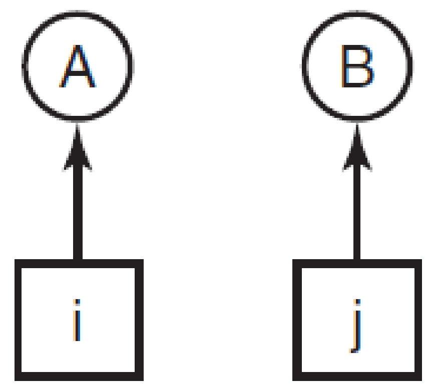
Attacking No Preemption

- Some resources can be virtualized
- Spooling printer output to the disk and one printer daemon process can eliminate deadlock on the printer
- However, not all resources can be virtualized like this

Attacking Circular Wait Condition

1. Imagesetter
2. Printer
3. Plotter
4. Tape drive
5. CD-ROM drive

(a)



(b)

Figure 6-13. (a) Numerically ordered resources.
(b) A resource graph

Deadlock Prevention

Condition	Approach
Mutual exclusion	Spool everything
Hold and wait	Request all resources initially
No preemption	Take resources away
Circular wait	Order resources numerically

Figure 6-14. Summary of approaches to deadlock prevention.

Communication Deadlocks

- Communication systems
  - A sends a request message to B
  - Blocks until B sends back a reply message
  - The request message gets lost
  - A is blocked waiting for the reply
  - B is blocked waiting for a request asking it to do something
  - Not classical resource deadlock
- Timeouts to break communication deadlocks

Communication Deadlocks

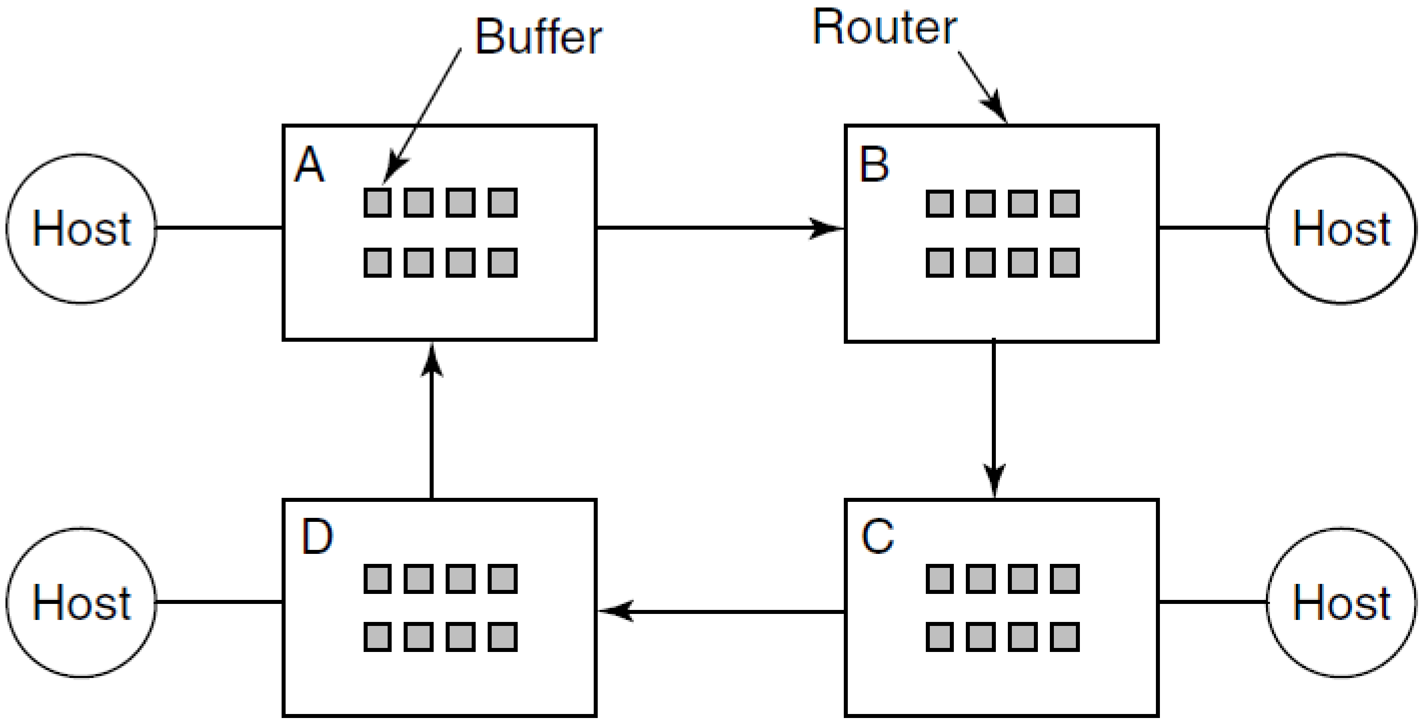


Figure 6-15. A resource deadlock in a network.

Livelock

```
acquire_lock(&resource_1);
while (try_lock(&resource_2) == FAIL) {
    release_lock(&resource_1);
    wait_fixed_time();
    acquire_lock(&resource_1);
}
use_both_resources( );
release_lock(&resource_2);
release_lock(&resource_1);
```

```
acquire_lock(&resource_2);
while (try_lock(&resource_1) == FAIL) {
    release_lock(&resource_2);
    wait_fixed_time();
    acquire_lock(&resource_2);
}
use_both_resources( );
release_lock(&resource_1);
release_lock(&resource_2);
```

Figure 6-16. Polite processes that may cause livelock

Starvation

- Some policy is needed to make a decision about who gets which resource when
- This seemingly reasonable policy may lead to some processes never getting service even though they are not deadlocked
- Can be avoided by using a first-come, first-served resource allocation policy

End

Chapter 6