Deadlocks

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Deadlocks

- Conditions for a deadlock?
- Strategies to deal with deadlocks?

Definitions

- Use processes and threads interchangeably
- Resources
  - Preemptable: CPU (can be taken away)
  - Non-preemptable: Disk, files, mutex, ... (can't be taken away)
- Use a resource
  - Request, Use, Release
- Starvation
  - Processes wait indefinitely
- Deadlocks
  - A set of processes have a deadlock if each process is waiting for an event that only another process in the set can cause

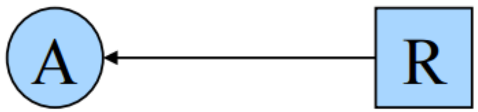
Preemptable and Nonpreemptable Resources

Sequence of events required to use a resource

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

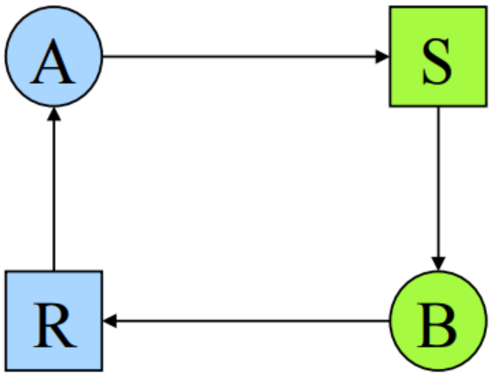
Resource Allocation Graph

- Process A is holding resource R



- Process B requests resource S

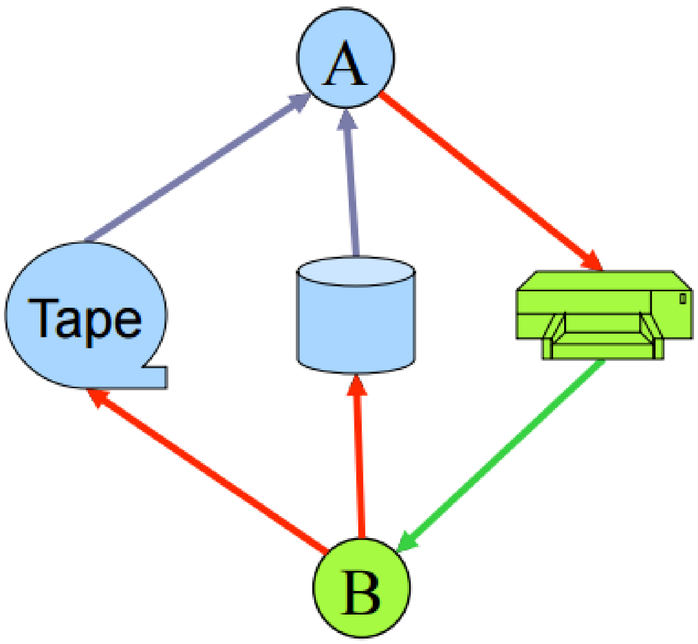
- A cycle in resource allocation graph ⇒ deadlock
- If A requests for S while holding R, and B requests for R while holding S, then



How do you deal with multiple instances of a resource?

An Example

- A utility program
  - Copy a file from tape to disk
  - Print the file to printer
- Resources
  - Tape
  - Disk
  - Printer
- A deadlock
  - **A** holds tape and disk, then requests for a printer
  - **B** holds printer, then requests for tape and disk



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 Deadlock

- Mutual exclusion condition
  - Each resource is assigned to exactly one process
- Hold and Wait
  - Processes holding resources can request new resources
- No preemption
  - Resources cannot be taken away
- Circular chain of requests
  - One process waits for another in a circular fashion

Deadlock Modeling (1)

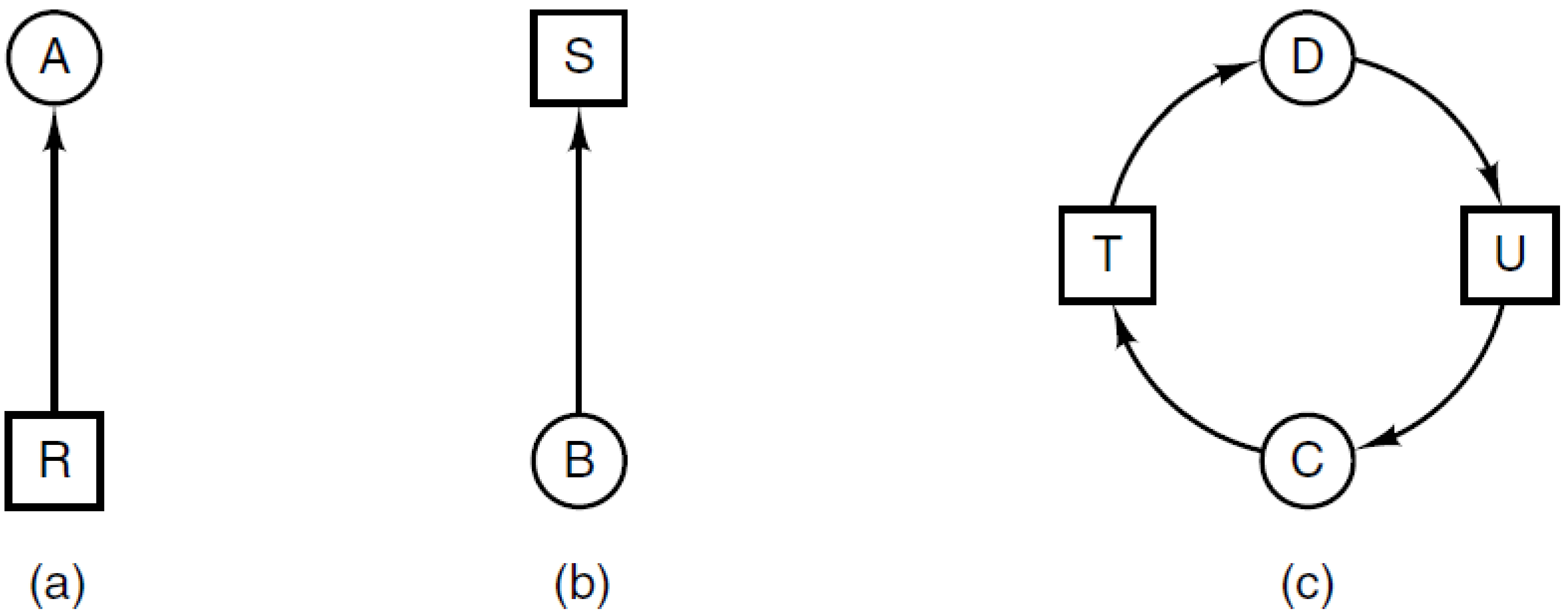


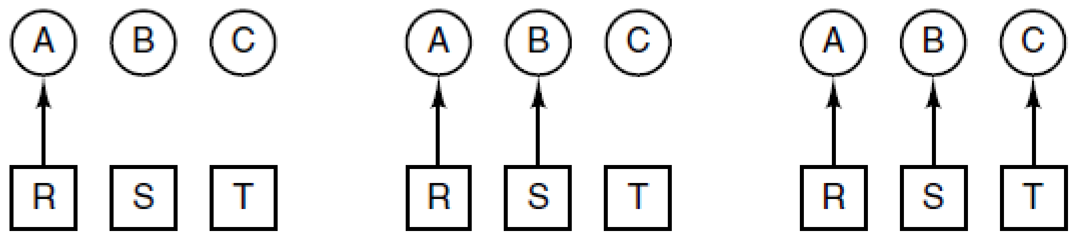
Figure 6-3. Resource allocation graphs. (a) Holding a resource. (b) Requesting a resource. (c) Deadlock.

Deadlock Modeling (2)

A	B	C
Request R	Request S	Request T
Request S	Request T	Request R
Release R	Release S	Release T
Release S	Release T	Release R
(a)	(b)	(c)

1. A requests R
2. B requests S
3. C requests T
4. A requests S
5. B requests T
6. C requests R
   deadlock

(d)



(e) (f) (g)

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

Deadlock Modeling (3)

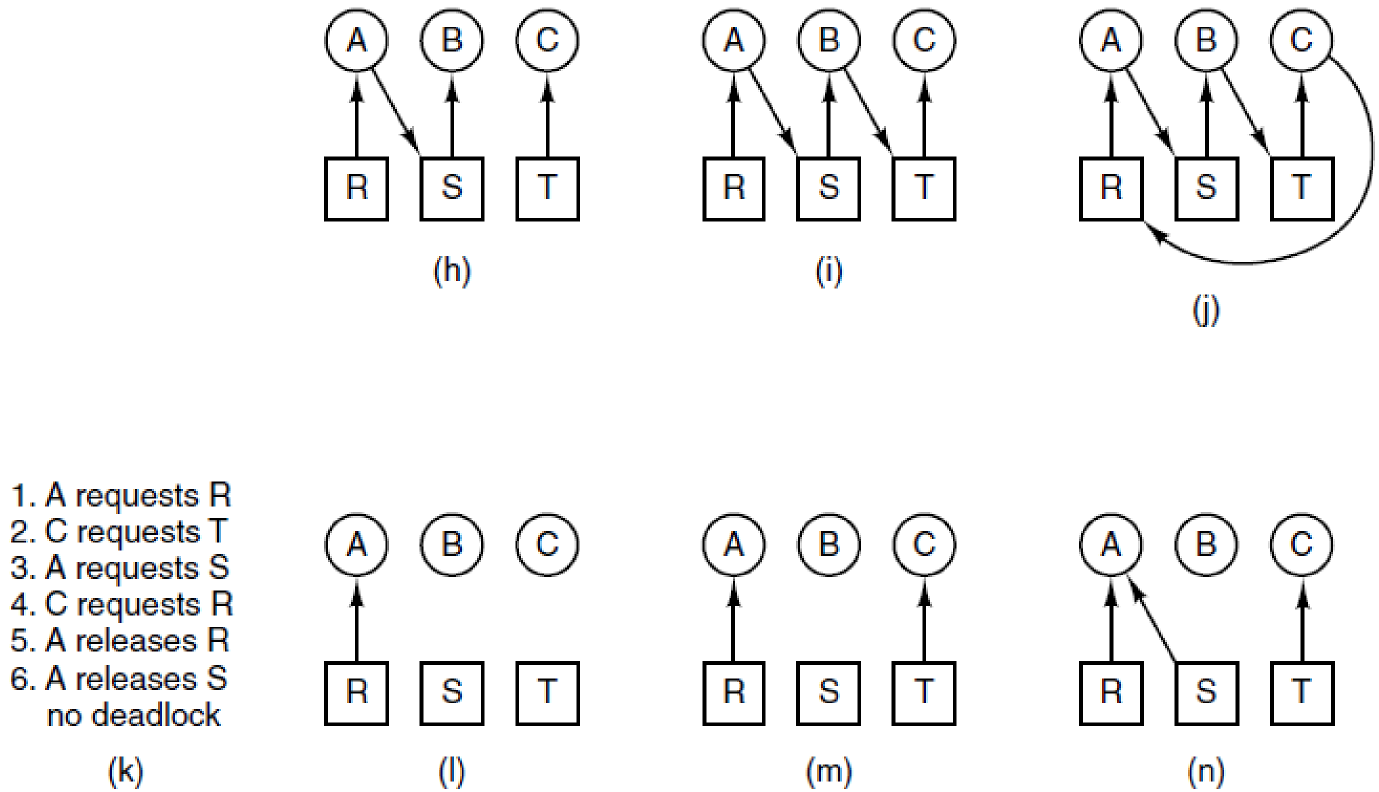


Figure 6-4. An example of how deadlock occurs and how it can be avoided.

Deadlock Modeling (4)

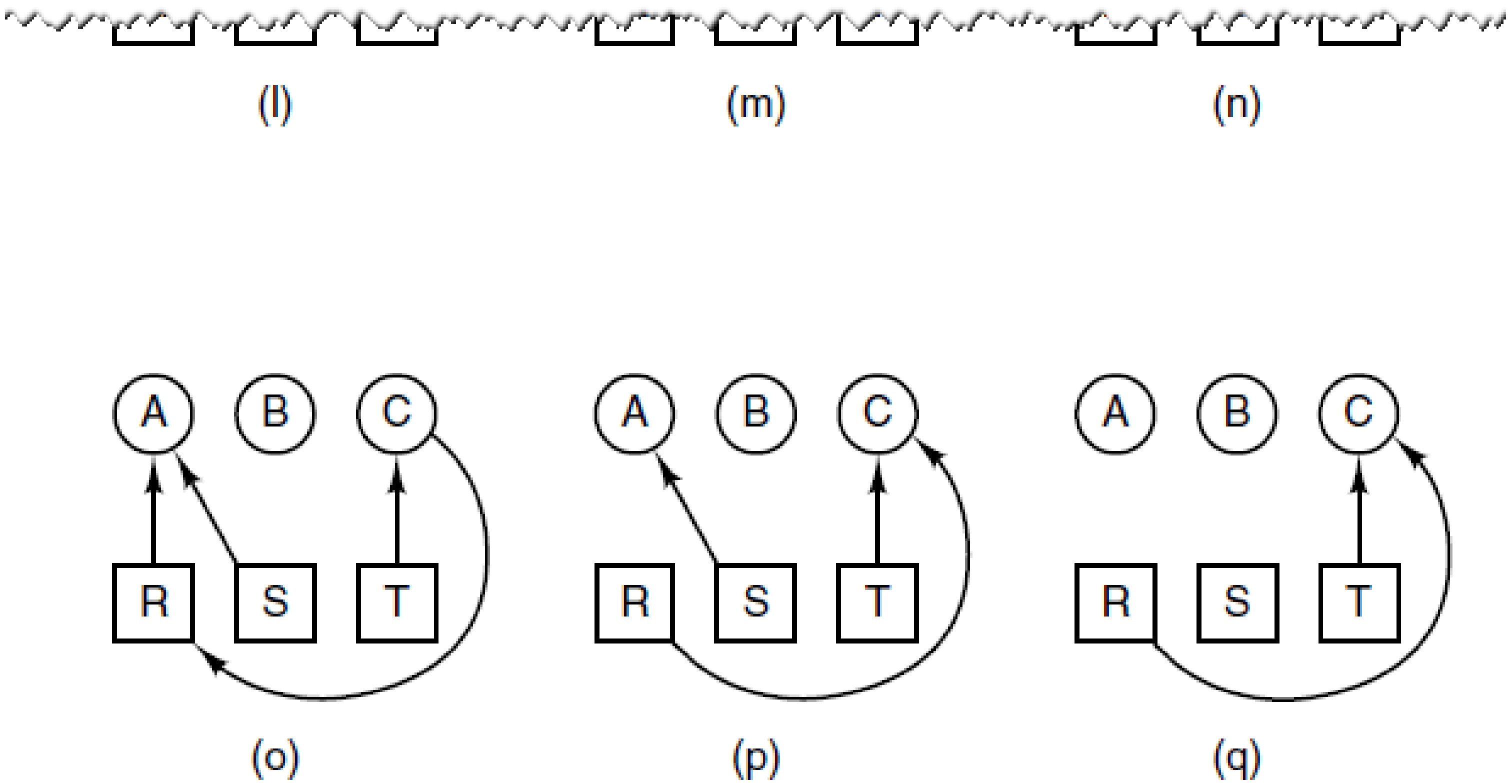


Figure 6-4. An example of how deadlock occurs and how it can be avoided.

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.

Strategies

- Ignore the problem
  - It is user's fault
- Detection and recovery
  - Fix the problem afterwards
- Dynamic avoidance
  - Careful allocation
- Prevention
  - Negate one of the four conditions

Ignore the Problem

- The OS kernel locks up
  - Reboot
- Device driver locks up
  - Remove the device
  - Restart
- An application hangs (“not responding”)
  - Kill the application and restart
  - Familiar with this?
- An application ran for a while and then hang
  - Checkpoint the application
  - Change the environment (reboot OS)
  - Restart from the previous checkpoint

Detection and Recovery

- Detection
  - Scan resource graph
  - Detect cycles
- Recovery (difficult)
  - Kill process/threads (can you always do this?)
  - Roll back actions of deadlocked threads
- What about the tape-disk-printer example?

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)

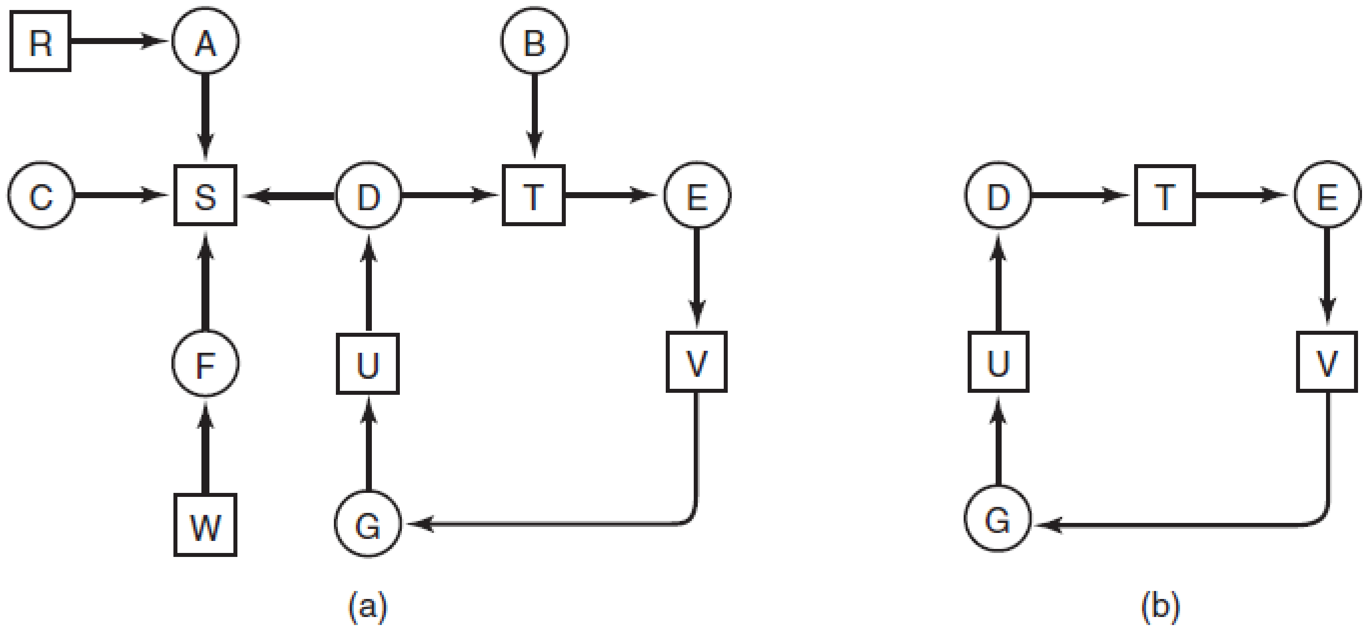


Figure 6-5. (a) A resource graph. (b) A cycle extracted from (a).

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

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)

$$\begin{array}{cccccc} & \text{Tape drives} & \text{Plotters} & \text{Scanners} & \text{CD Roms} & \\ E = (& 4 & 2 & 3 & 1 &) \end{array}$$

$$\begin{array}{cccccc} & \text{Tape drives} & \text{Plotters} & \text{Scanners} & \text{CD Roms} & \\ A = (& 2 & 1 & 0 & 0 &) \end{array}$$

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.

Recovery from Deadlock

Possible Methods of recovery (though none are "attractive"):

1. Preemption
2. Rollback
3. Killing processes

Avoidance

- Safety Condition:
  - It is not deadlocked
  - There is some scheduling order in which every process can run to completion (even if all request their max resources)

- Banker's algorithm (Dijkstra 65)
  - Single resource
    - Each process has a credit
    - Total resources may not satisfy all credits
    - Track resources assigned and needed
    - Check on each allocation for safety
  - Multiple resources
    - Two matrices: allocated and needed
    - See textbook for details

Deadlock Avoidance Resource Trajectories

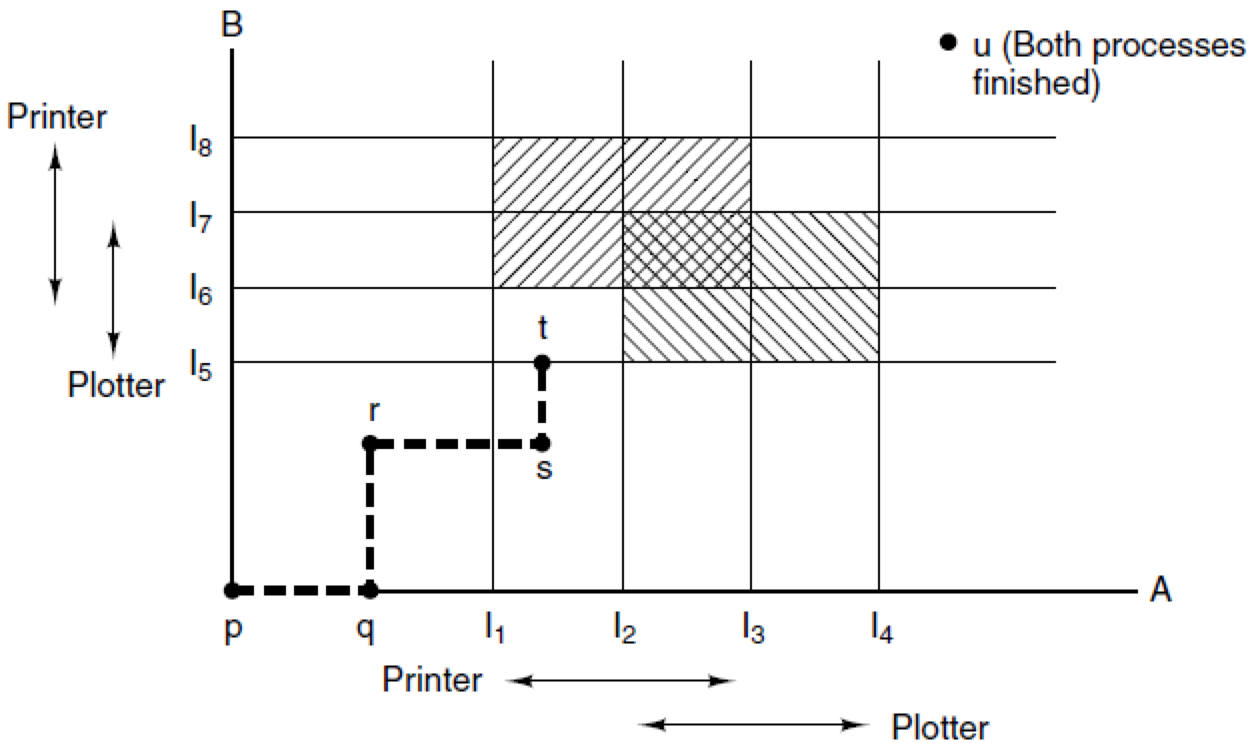


Figure 6-8. Two process resource trajectories.

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)

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

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

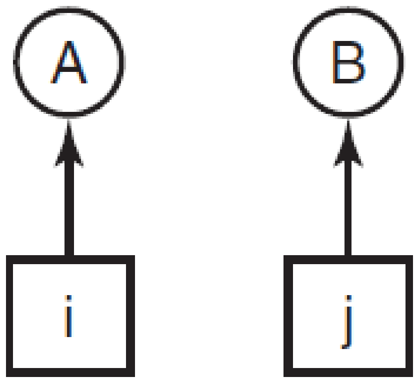
Assure that at least one of conditions is never satisfied

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

Attacking Circular Wait Condition (1)

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

Attacking Circular Wait Condition (2)

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

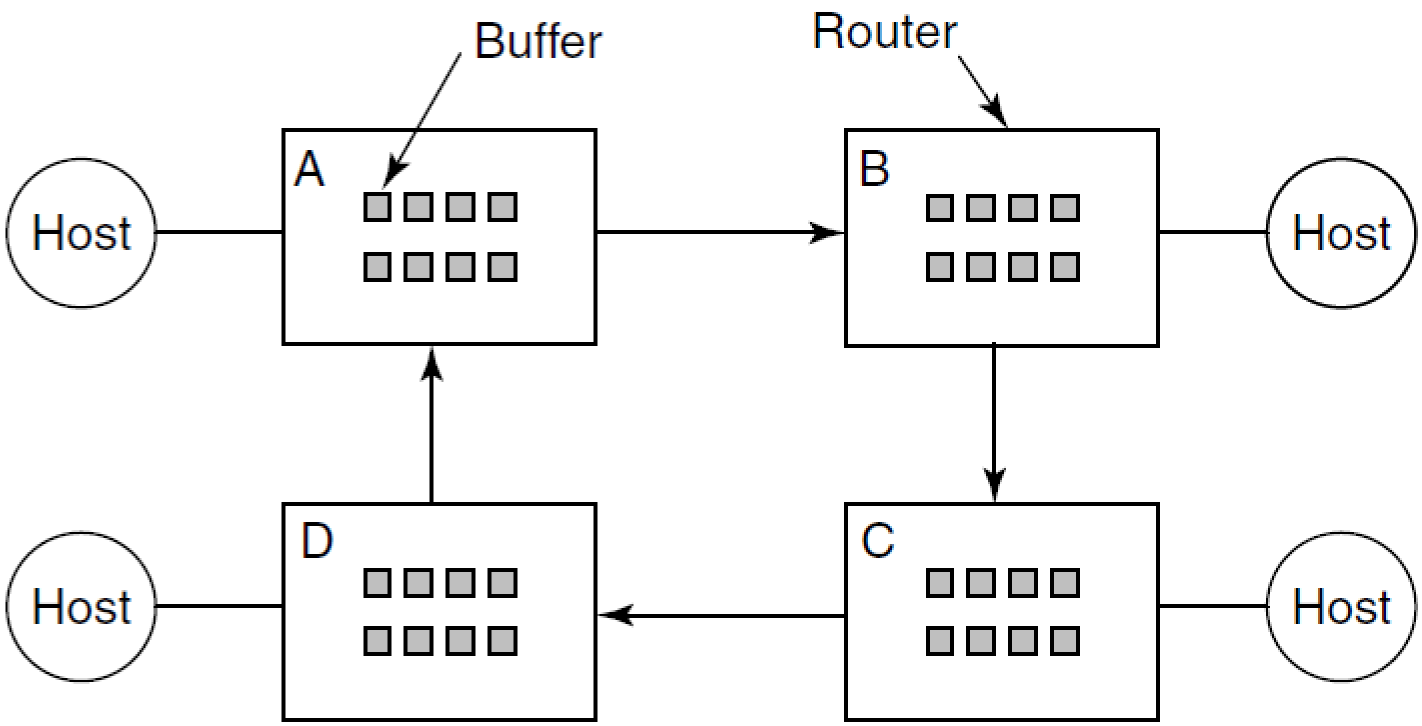


Figure 6-15. A resource deadlock in a network.

Livelock

```
void process_A(void) {
        enter_region(&resource_1);
        enter_region(&resource_2);
        use_both_resources( );
        leave_region(&resource_2);
        leave_region(&resource_1);
}
```

Figure 6-16. Busy waiting that can lead to livelock.

```
void process_B(void) {
        enter_region(&resource_2);
        enter_region(&resource_1);
        use_both_resources( );
        leave_region(&resource_1);
        leave_region(&resource_2);
}
```

Which Is Your Favorite?

- Ignore the problem
  - It is user’s fault
- Detection and recovery
  - Fix the problem afterwards
- Dynamic avoidance
  - Careful allocation
- Prevention (Negate one of the four conditions)
  - Avoid mutual exclusion
  - Avoid hold and wait
  - No preemption
  - No circular wait

End

Chapter 3