Deadlocks

Gaurav Somani
gaurav@lnmiit.ac.in

Reference [Stallings] [Galvin]

Deadlocks

- The Deadlock Problem
- System Model
- Deadlock Characterization
- Methods for Handling Deadlocks
- Deadlock Prevention
- Deadlock Avoidance
- Deadlock Detection
- Deadlock Recovery
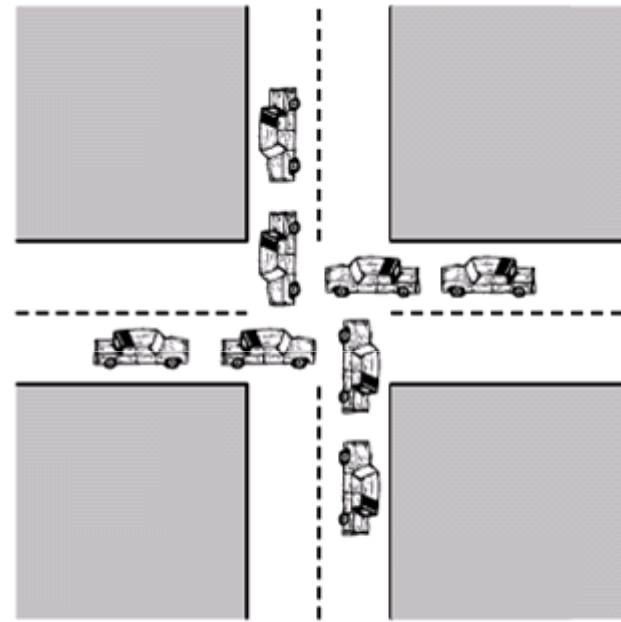
The Deadlock Problem

- A set of blocked processes each holding a resource and waiting to acquire a resource held by another process in the set

- Example
  - System has 2 disk drives
  - P_1 and P_2 each hold one disk drive and each needs another one

- Example
  - semaphores A and B, initialized to 1

P_0	P_1
wait (A);	wait(B)
wait (B);	wait(A)

Example
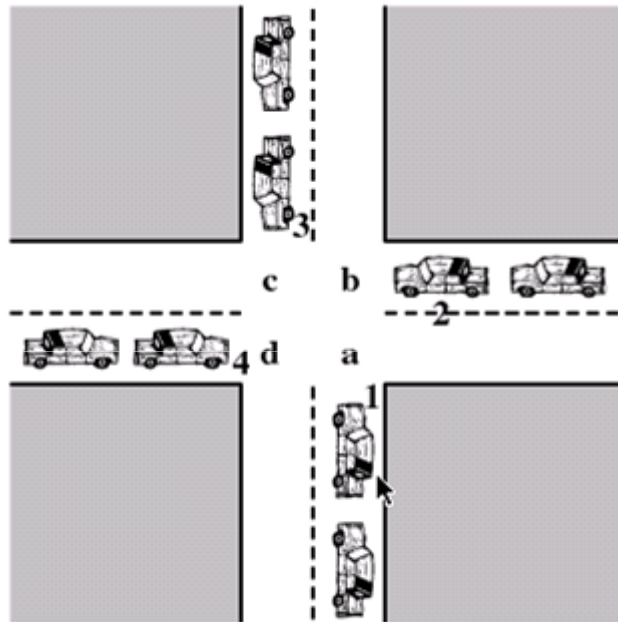
(a) Deadlock possible

(b) Deadlock

System Model

- Resource types $R_1, R_2, \ldots, R_m$

  CPU cycles, memory space, I/O devices

- Each resource type R_i has W_i instances.

- Each process utilizes a resource as follows:
  - **request**
  - **use**
  - **release**

Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously.

- **Mutual exclusion:** only one process at a time can use a resource
- **Hold and wait:** a process holding at least one resource is waiting to acquire additional resources held by other processes
- **No preemption:** a resource can be released only voluntarily by the process holding it, after that process has completed its task
- **Circular wait:** there exists a set $\{P_0, P_1, \ldots, P_n\}$ of waiting processes such that P_0 is waiting for a resource that is held by P_1, P_1 is waiting for a resource that is held by $P_2, \ldots, P_{n-1}$ is waiting for a resource that is held by P_n, and P_n is waiting for a resource that is held by P_0.

Resource-Allocation Graph

A set of vertices V and a set of edges E.

- V is partitioned into two types:
  - $P = \{P_1, P_2, \ldots, P_n\}$, the set consisting of all the processes in the system

  - $R = \{R_1, R_2, \ldots, R_m\}$, the set consisting of all resource types in the system

- Request edge – directed edge $P_i \rightarrow R_j$
- Assignment edge – directed edge $R_j \rightarrow P_i$

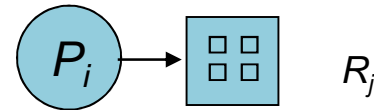# Resource-Allocation Graph (Cont.)

- Process

- Resource Type with 4 instances

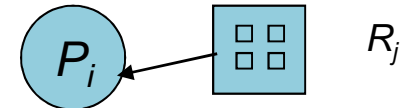- P_i requests instance of R_j $P_i \rightarrow R_j$

- P_i is holding an instance of R_j $P_i \leftarrow R_j$
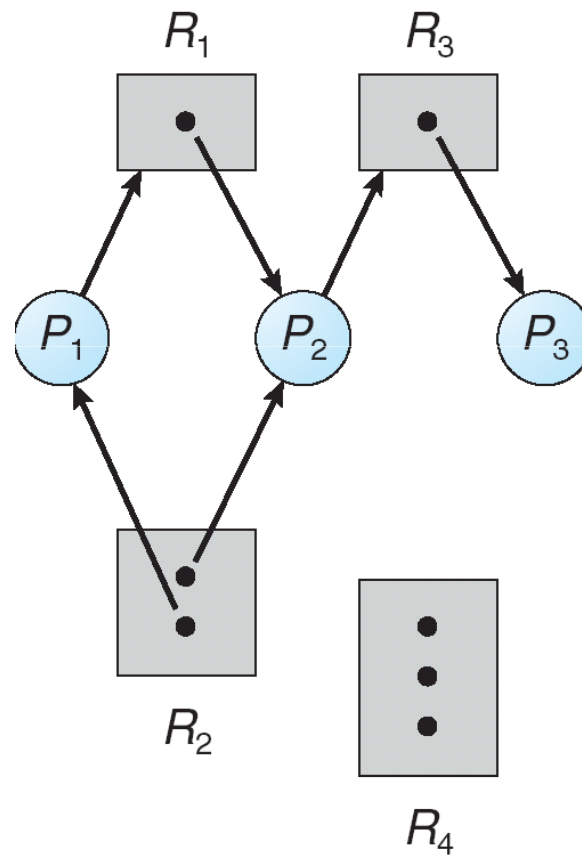
Example of a Resource Allocation Graph

Resource Allocation Graph With A Deadlock
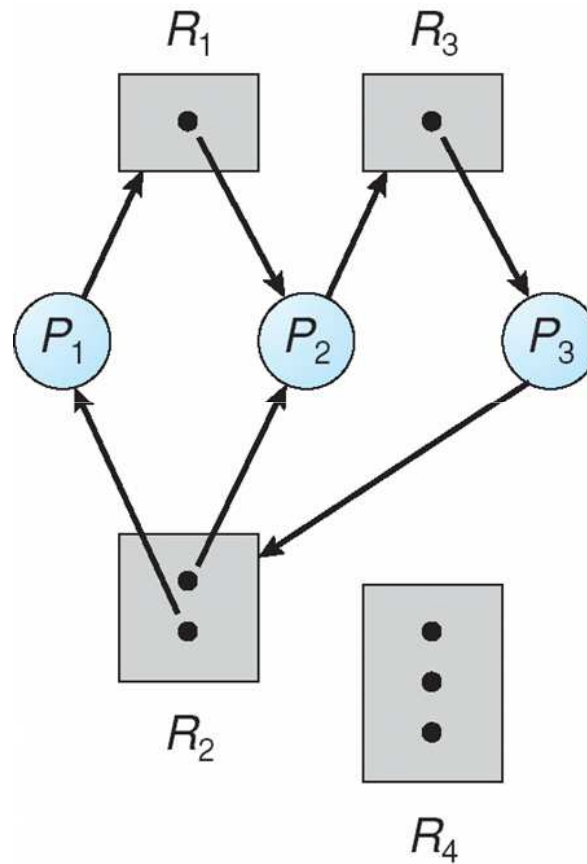
Graph With A Cycle But No Deadlock
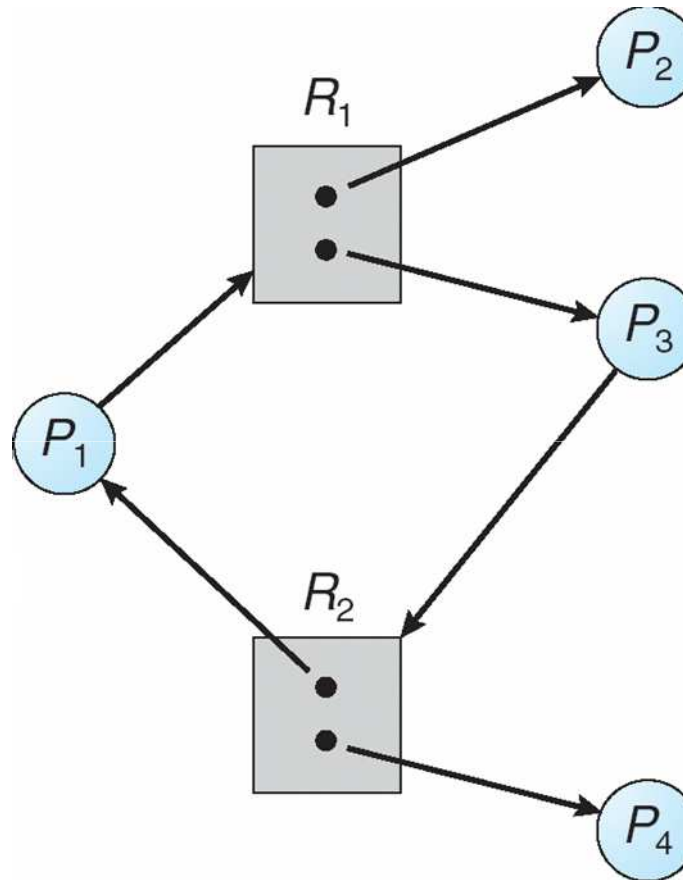
Basic Facts

- If graph contains no cycles $\Rightarrow$ no deadlock

- If graph contains a cycle $\Rightarrow$
  - if only one instance per resource type, then deadlock
  - if several instances per resource type, possibility of deadlock

Methods for Handling Deadlocks

- Ensure that the system will *never* enter a deadlock state

- Allow the system to enter a deadlock state and then recover

- Ignore the problem and pretend that deadlocks never occur in the system; used by most operating systems, including UNIX and windows.

Deadlock Prevention

Restrain the ways request can be made

- **Mutual Exclusion** – not required for sharable resources; must hold for non sharable resources

- **Hold and Wait** – must guarantee that whenever a process requests a resource, it does not hold any other resources
  - Require process to request and be allocated all its resources before it begins execution, or allow process to request resources only when the process has none
  - Low resource utilization; starvation possible

Deadlock Prevention (Cont.)

- **No Preemption** –
  - If a process that is holding some resources requests another resource that cannot be immediately allocated to it, then all resources currently being held are released
  - Preempted resources are added to the list of resources for which the process is waiting
  - Process will be restarted only when it can regain its old resources, as well as the new ones that it is requesting

- **Circular Wait** – impose a **total ordering** of all resource types, and require that each process requests resources in an increasing order of enumeration

Circular wait
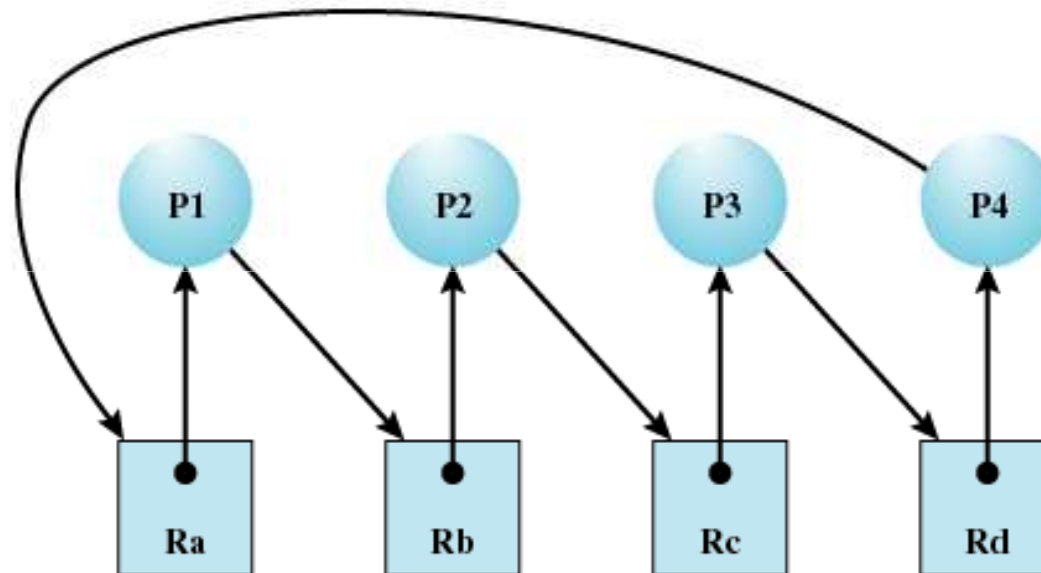
Deadlock Avoidance

- Requires that the system has some additional *a priori* information available

- Each process declare the *maximum number* of resources of each type that it may need

- The deadlock-avoidance algorithm dynamically examines the resource-allocation state to **ensure that there can never be a circular-wait condition**

Safe State

- When a process requests an available resource, system must decide if immediate allocation leaves the system in a safe state

- System is in safe state if there exists a sequence $<P_1, P_2, \ldots, P_n>$ of ALL the processes is the systems such that for each P_i, the resources that P_i can still request can be satisfied by currently available resources + resources held by all the P_j, with $j < i$

- That is:
    - If P_i resource needs are not immediately available, then P_i can wait until all P_j have finished
    - When P_j is finished, P_i can obtain needed resources, execute, return allocated resources, and terminate
    - When P_i terminates, P_{i+1} can obtain its needed resources, and so on

Basic Facts

- If a system is in safe state $\Rightarrow$ no deadlocks

- If a system is in unsafe state $\Rightarrow$ possibility of deadlock

- Avoidance $\Rightarrow$ ensure that a system will never enter an unsafe state.

Safe, Unsafe , Deadlock State
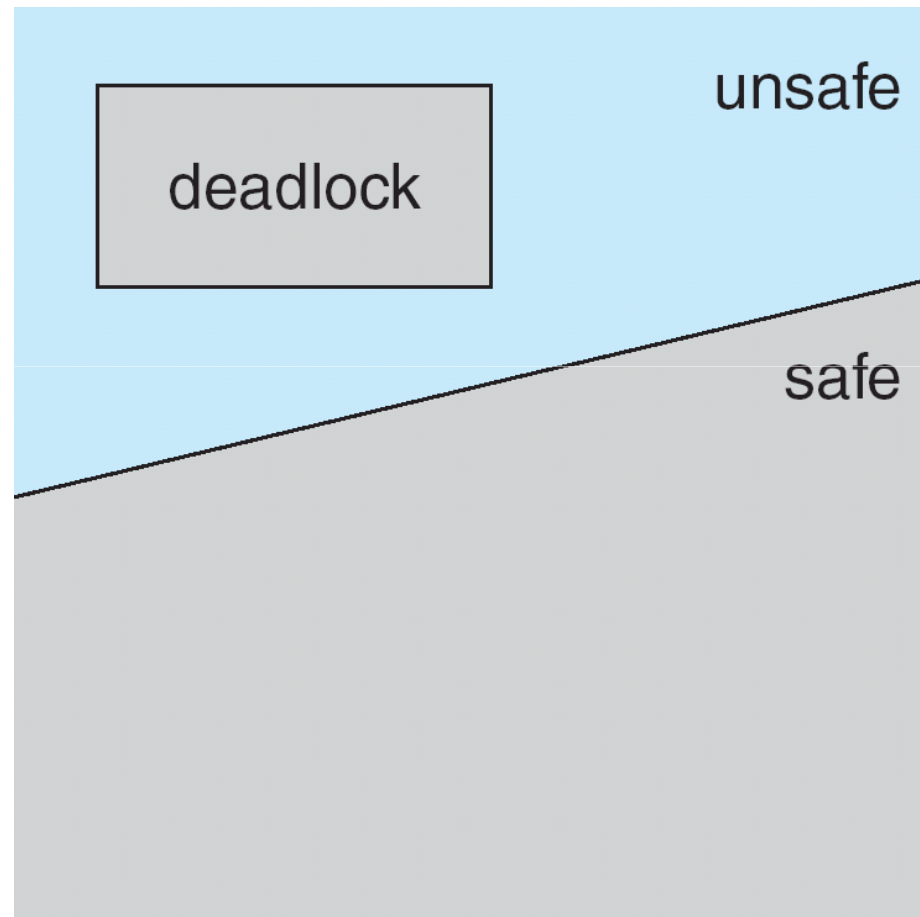
Avoidance algorithms

- Single instance of a resource type
  - Use a resource-allocation graph

- Multiple instances of a resource type
  - Use the banker's algorithm

Resource-Allocation Graph Scheme

- Claim edge $P_i \rightarrow R_j$ indicated that process P_j may request resource R_j; represented by a dashed line

- Claim edge converts to request edge when a process requests a resource

- Request edge converted to an assignment edge when the resource is allocated to the process

- When a resource is released by a process, assignment edge reconverts to a claim edge

- Resources must be claimed *a priori* in the system

Resource-Allocation Graph
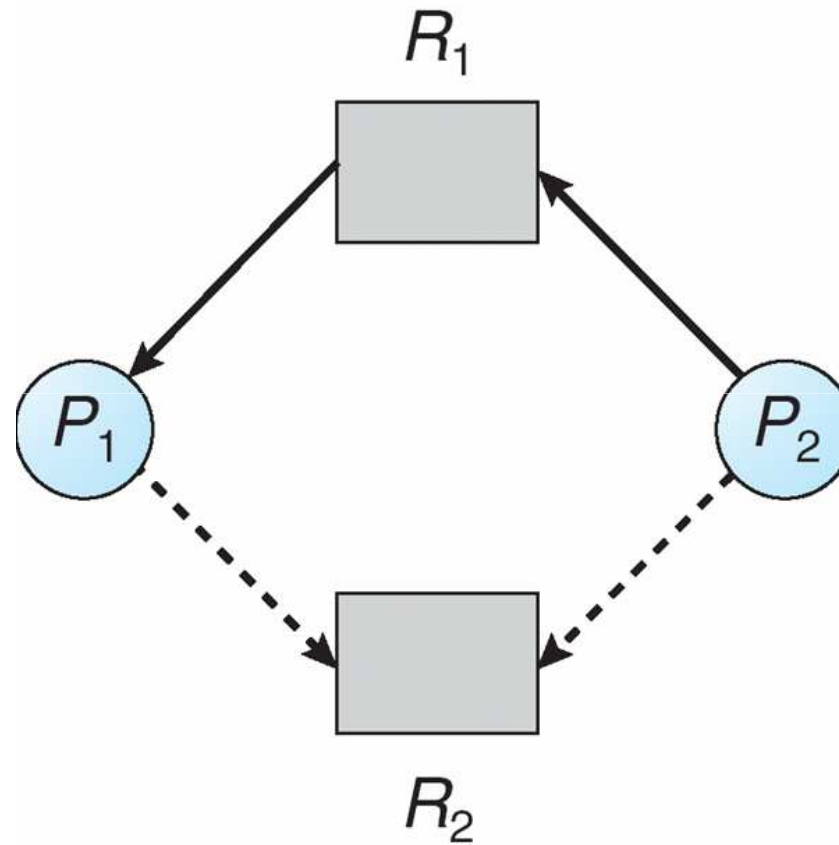
Unsafe State In Resource-Allocation Graph
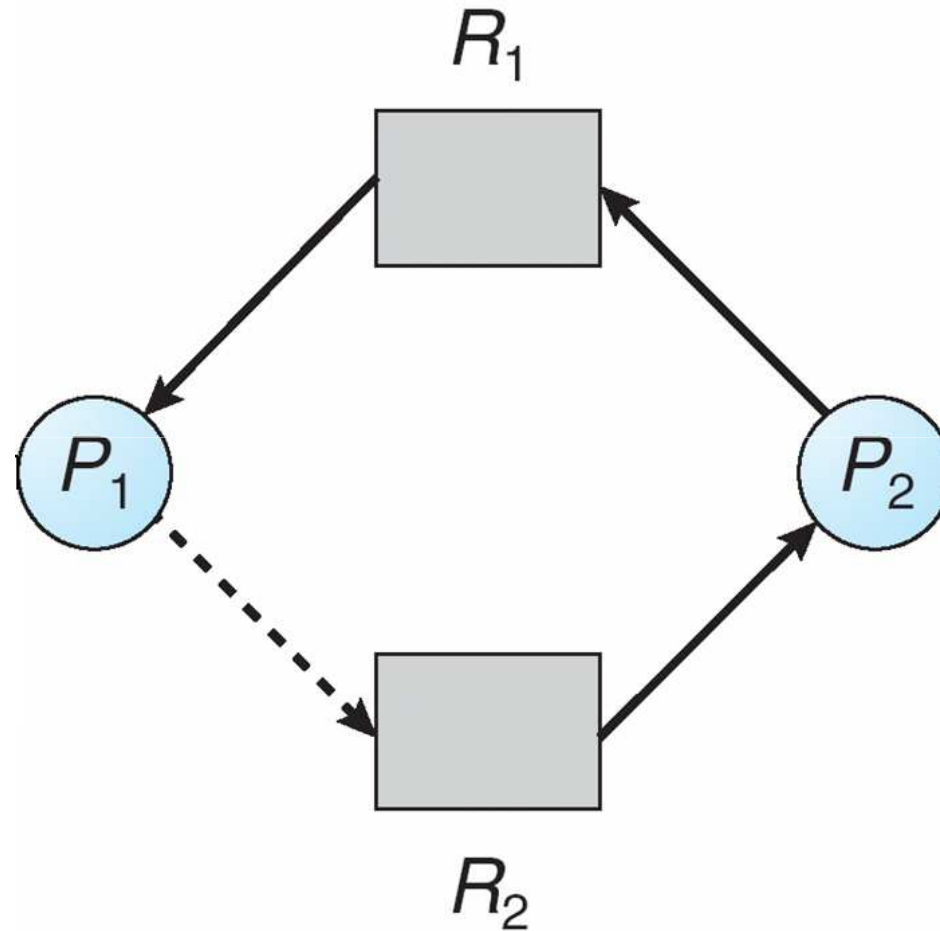
Resource-Allocation Graph Algorithm

- Suppose that process P_i requests a resource R_j

- The request can be granted only if converting the request edge to an assignment edge does not result in the formation of a cycle in the resource allocation graph

Banker's Algorithm

- Multiple instances

- Banking system analogy (Dikstra's)

- Each process must a priori claim maximum use

- When a process requests a resource it may have to wait

- When a process gets all its resources it must return them in a finite amount of time

Determination of a Safe State Initial State

	R1	R2	R3
P1	3	2	2
P2	6	1	3
P3	3	1	4
P4	4	2	2

Claim matrix C

	R1	R2	R3
P1	1	0	0
P2	6	1	2
P3	2	1	1
P4	0	0	2

Allocation matrix A

	R1	R2	R3
P1	2	2	2
P2	0	0	1
P3	1	0	3
P4	4	2	0

C – A

R1	R2	R3
9	3	6

Resource vector R

R1	R2	R3
0	1	1

Available vector V

(a) Initial state

- Is this a safe state?
  - Can anyone of the four processes can complete with the available resources?

Determination of a Safe State P2 Runs to Completion

	R1	R2	R3
P1	3	2	2
P2	0	0	0
P3	3	1	4
P4	4	2	2

Claim matrix C

	R1	R2	R3
P1	1	0	0
P2	0	0	0
P3	2	1	1
P4	0	0	2

Allocation matrix A

	R1	R2	R3
P1	2	2	2
P2	0	0	0
P3	1	0	3
P4	4	2	0

C – A

R1	R2	R3
9	3	6

Resource vector R

R1	R2	R3
6	2	3

Available vector V

(b) P2 runs to completion

Determination of a Safe State
P1 Runs to Completion

	R1	R2	R3
P1	0	0	0
P2	0	0	0
P3	3	1	4
P4	4	2	2

Claim matrix **C**

	R1	R2	R3
P1	0	0	0
P2	0	0	0
P3	2	1	1
P4	0	0	2

Allocation matrix **A**

	R1	R2	R3
P1	0	0	0
P2	0	0	0
P3	1	0	3
P4	4	2	0

C − A

R1	R2	R3
9	3	6

Resource vector **R**

R1	R2	R3
7	2	3

Available vector **V**

(c) P1 runs to completion

Determination of a Safe State
P3 Runs to Completion

	R1	R2	R3
P1	0	0	0
P2	0	0	0
P3	0	0	0
P4	4	2	2

Claim matrix **C**

	R1	R2	R3
P1	0	0	0
P2	0	0	0
P3	0	0	0
P4	0	0	2

Allocation matrix **A**

	R1	R2	R3
P1	0	0	0
P2	0	0	0
P3	0	0	0
P4	4	2	0

C − **A**

R1	R2	R3
9	3	6

Resource vector **R**

R1	R2	R3
9	3	4

Available vector **V**

(d) P3 runs to completion

Determination of an Unsafe State

Claim matrix C	R1	R2	R3
P1	3	2	2
P2	6	1	3
P3	3	1	4
P4	4	2	2

Allocation matrix A	R1	R2	R3
P1	1	0	0
P2	5	1	1
P3	2	1	1
P4	0	0	2

C − A	R1	R2	R3
P1	2	2	2
P2	1	0	2
P3	1	0	3
P4	4	2	0

Resource vector R	R1	R2	R3
	9	3	6

Available vector V	R1	R2	R3
	1	1	2

(a) Initial state

Determination of an Unsafe State

Claim matrix C	R1	R2	R3
P1	3	2	2
P2	6	1	3
P3	3	1	4
P4	4	2	2

Claim matrix **C**

Allocation matrix A	R1	R2	R3
P1	2	0	1
P2	5	1	1
P3	2	1	1
P4	0	0	2

Allocation matrix **A**

C − A	R1	R2	R3
P1	1	2	1
P2	1	0	2
P3	1	0	3
P4	4	2	0

C − A

R1	R2	R3
9	3	6

Resource vector **R**

R1	R2	R3
0	1	1

Available vector **V**

(b) P1 requests one unit each of R1 and R3

Deadlock Avoidance Logic

```
struct state
{
        int resource[m];
        int available[m];
        int claim[n][m];
        int alloc[n][m];
}
```

(a) global data structures

```
if (alloc [i,*] + request [*] > claim [i,*])
      < error >;                                  /* total request > claim*/
else if (request [*] > available [*])
      < suspend process >;
else                                              /* simulate alloc */
{
      < define newstate by:
      alloc [i,*] = alloc [i,*] + request [*];
      available [*] = available [*] - request [*] >;
}
if (safe (newstate))
      < carry out allocation >;
else
{
      < restore original state >;
      < suspend process >;
}
```

(b) resource alloc algorithm

Deadlock Avoidance Logic

```
boolean safe (state S)
{
    int currentavail[m];
    process rest[<number of processes>];
    currentavail = available;
    rest = {all processes};
    possible = true;
    while (possible)
    {
        <find a process Pk in rest such that
            claim [k,*] - alloc [k,*] <= currentavail;>
        if (found)                              /* simulate execution of Pk */
        {
            currentavail = currentavail + alloc [k,*];
            rest = rest - {Pk};
        }
        else
            possible = false;
    }
    return (rest == null);
}
```

(c) test for safety algorithm (banker's algorithm)

Deadlock Avoidance : restrictions

- Maximum resource requirement must be stated in advance

- Processes under consideration must be independent; no synchronization requirements

- There must be a fixed number of resources to allocate

- No process may exit while holding resources

Deadlock Detection

- Allow system to enter deadlock state

- Detection algorithm

- Recovery scheme

Single Instance of Each Resource Type

- Maintain *wait-for* graph
  - Nodes are processes
  - $P_i \rightarrow P_j$ if P_i is waiting for P_j

- Periodically invoke an algorithm that searches for a cycle in the graph. If there is a cycle, there exists a deadlock

- An algorithm to detect a cycle in a graph requires an order of n^2 operations, where n is the number of vertices in the graph

Resource-Allocation Graph and Wait-for Graph

(a)

(b)
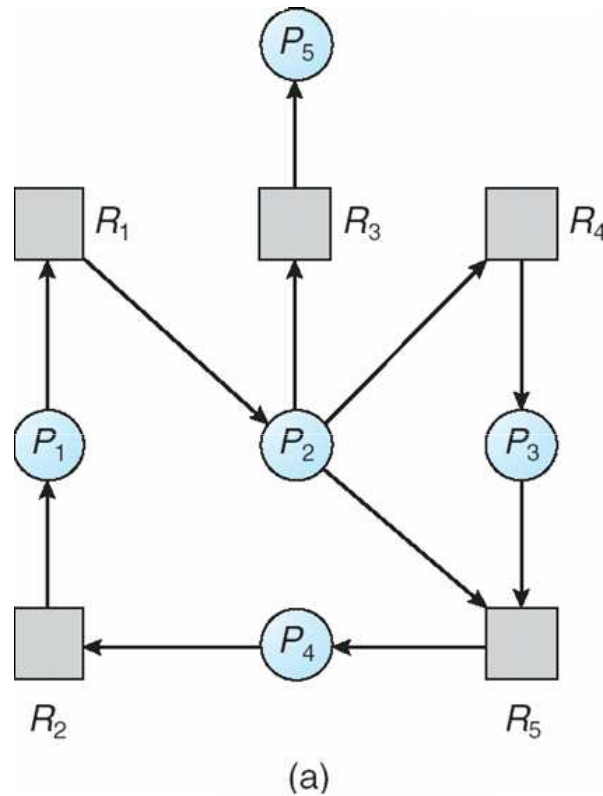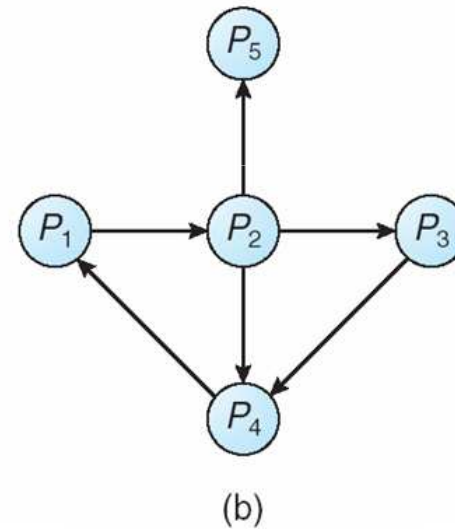
Resource-Allocation Graph   Corresponding wait-for graph

Several Instances of a Resource Type

- **Available**: A vector of length m indicates the number of available resources of each type.

- **Allocation**: An n x m matrix defines the number of resources of each type currently allocated to each process.

- **Request**: An n x m matrix indicates the current request of each process. If $Request[i_j] = k$, then process P_i is requesting k more instances of resource type. R_j.

Detection Algorithm

1. Let *Work* and *Finish* be vectors of length m and n, respectively Initialize:
   (a) *Work* = *Available*
   (b) For $i = 1,2, \ldots, n$, if $Allocation_i \neq 0$, then
       $Finish[i]$ = false; otherwise, $Finish[i]$ = *true*

2. Find an index i such that both:
   (a) $Finish[i] == false$
   (b) $Request_i \leq Work$

   If no such i exists, go to step 4

3. $Work = Work + Allocation_i$ // *Simulate Execution Here ….Pi is executed*
   $Finish[i]$ = *true*
   go to step 2

4. If $Finish[i] == false$, for some i, $1 \leq i \leq n$, then the system is in deadlock state.
   Moreover, if $Finish[i] == false$, then P_i is deadlocked

Algorithm requires an order of O(m x $n^{2)}$ operations to detect whether the system is in deadlocked state

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

Figure 6.10   Example for Deadlock Detection

Detection-Algorithm Usage

- When, and how often, to invoke depends on:
    - How often a deadlock is likely to occur?
    - How many processes will need to be rolled back?
        - one for each disjoint cycle

- If detection algorithm is invoked arbitrarily, there may be many cycles in the resource graph and so we would not be able to tell which of the many deadlocked processes "caused" the deadlock

Strategies once Deadlock Detected

- Abort all deadlocked processes
- Back up each deadlocked process to some previously defined checkpoint, and restart all process
  - Original deadlock may occur
- Successively abort deadlocked processes until deadlock no longer exists
- Successively preempt resources until deadlock no longer exists

Recovery from Deadlock: Process Termination

- In which order should we choose to abort?
  - Priority of the process
  - How long process has computed, and how much longer to completion
  - Resources the process has used
  - Resources process needs to complete
  - How many processes will need to be terminated
  - Is process interactive or batch?

Recovery from Deadlock: Resource Preemption

- Selecting a victim – minimize cost

- Rollback – return to some safe state, restart process for that state

- Starvation – same process may always be picked as victim, include number of rollback in cost factor