Operating System Concepts

Che-Wei Chang
chewei@mail.cgu.edu.tw
Department of Computer Science and Information Engineering, Chang Gung University

Contents

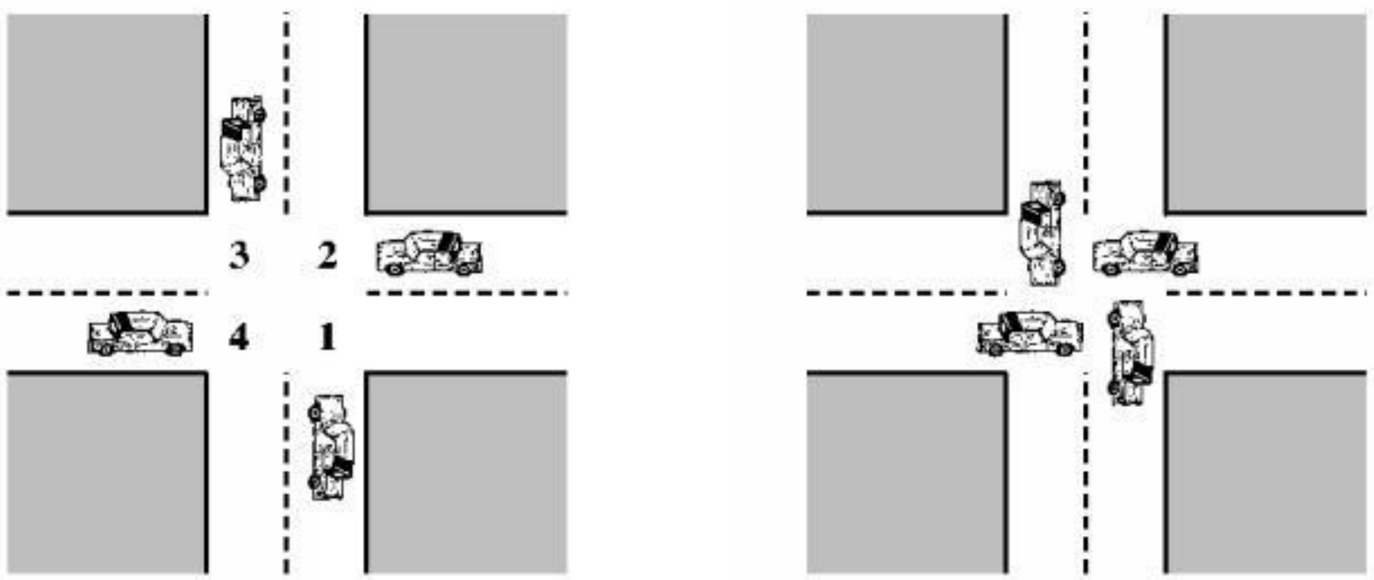
Chapter 7. Deadlocks

Objectives

- To develop a description of deadlocks, which prevent sets of concurrent processes from completing their tasks

- To present a number of different methods for preventing or avoiding deadlocks in a computer system

Illustration of Deadlock



(a) Deadlock possible

(b) Deadlock

Deadlocks

- A set of process is in a deadlock state when every process in the set is waiting for an event that can be caused by only another process in the set
- System Model
  - System consists of resources
  - Resource types R_1, R_2, . . ., R_m
    - e.g. CPU, 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

- **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
- **Circular wait:** there exists a set $\{P_0, P_1, \ldots, P_{n-1}\}$ of waiting processes such that each P_i is waiting for a resource that is held by $P_{((i+1)\%n)}$

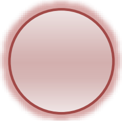
➔ Deadlock can arise if four conditions hold simultaneously

Resource-Allocation Graph

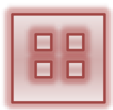
- A set of vertices V and a set of edges E
- V is partitioned into two types:
  - $P = \{P_1, P_2, \ldots, P_n\}$, the set consisting of all the processes in the system
  - $R = \{R_1, R_2, \ldots, R_m\}$, the set consisting of all resource types in the system
- E has two types:
  - Request edge : directed edge $P_i \rightarrow R_j$
  - Assignment edge : directed edge $R_j \rightarrow P_i$

Resource-Allocation Graph

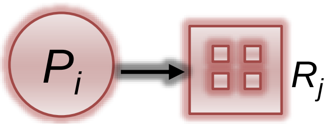
- Process



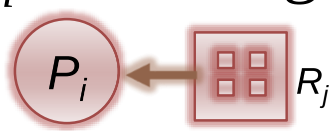
- Resource Type with 4 instances



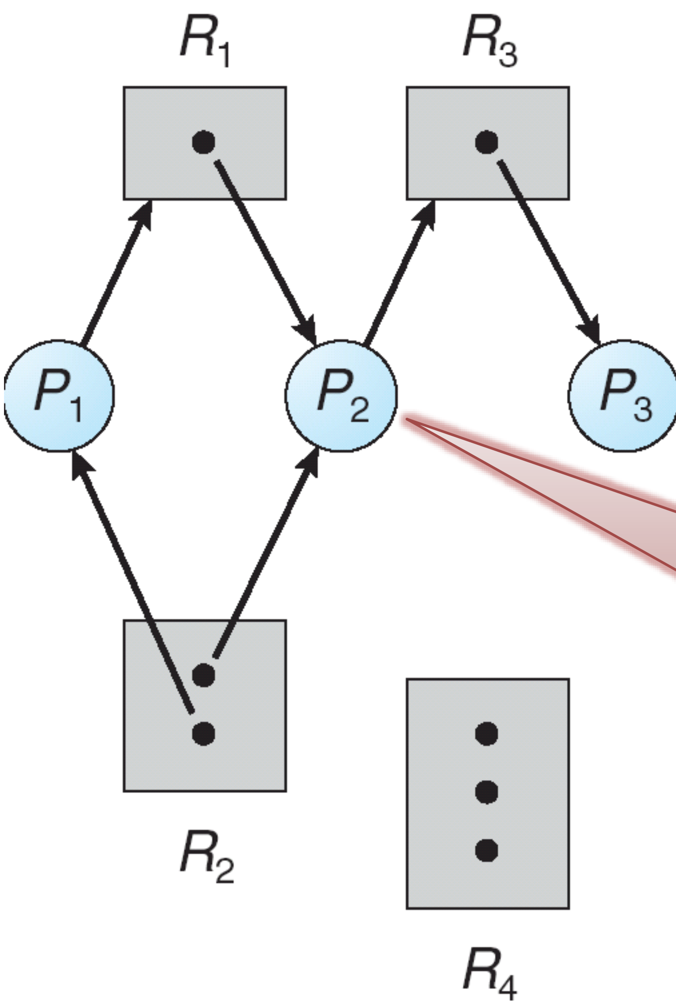
- P_i requests an instance of R_j



- P_i is holding an instance of R_j



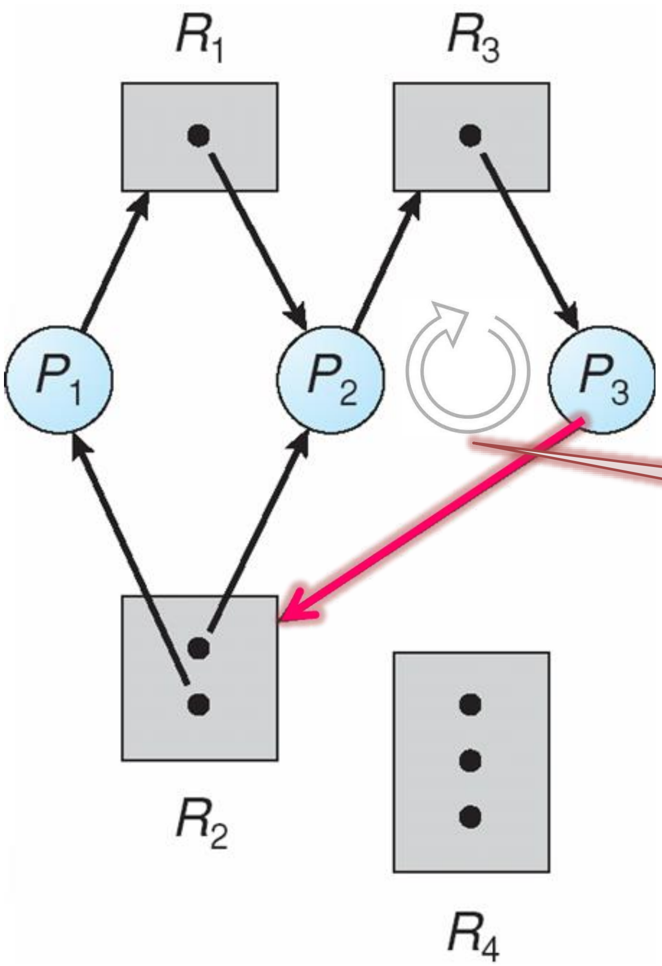
A Resource Allocation Graph



P_3 is holding an instance of R_3

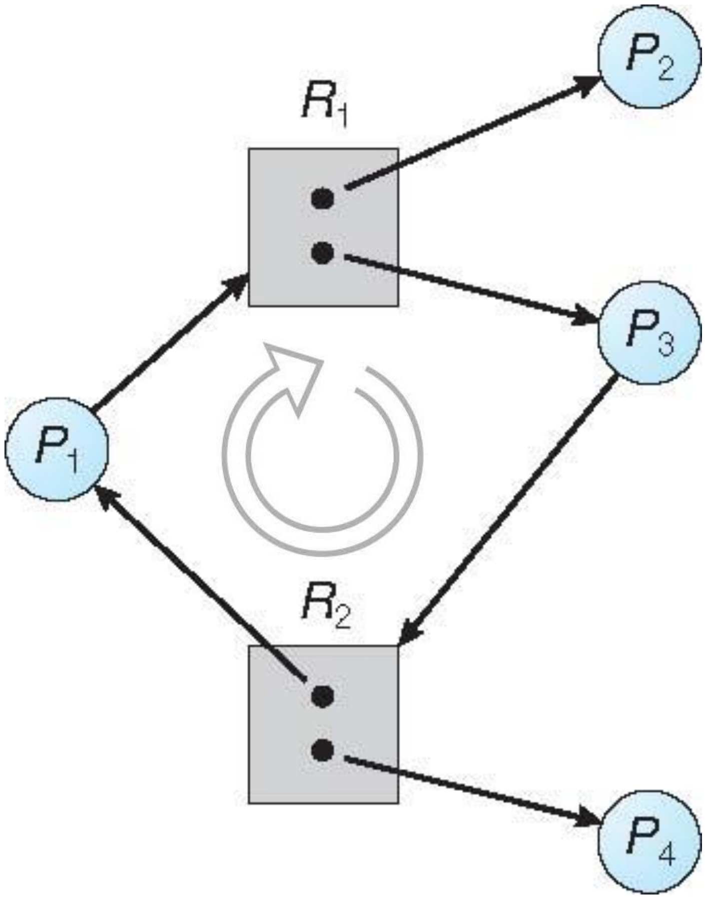
P_2 is holding an instance of R_1 and an instance of R_2 and requests an instance of R_3

A Deadlock in a Resource Allocation Graph



Deadlock

No Deadlock in a Cycle



The cycle will be broken after P_2 is finished

An Example of Deadlock

```
Code:
void transaction(Account from, Account to, double amount)
{
   mutex lock1, lock2;
   lock1 = get lock(from);
   lock2 = get lock(to);
   acquire(lock1);
      acquire(lock2);
         withdraw(from, amount);
         deposit(to, amount);
      release(lock2);
   release(lock1);
}
```

Hold   Wait

```
Use:
transaction(acc1, acc2, 1000);
transaction(acc2, acc1, 4000);
```

Methods for Handling Deadlocks

- Make sure that the system never has a deadlock
  - Deadlock Prevention: Prevent the necessary conditions
  - Deadlock Avoidance: Make sure that the system always stays at a "safe" state
- Do recovery if the system is deadlocked
  - Deadlock Detection
  - Recovery
- Ignore the possibility of deadlock occurrences
  - Restart the system manually if the system seems to be deadlocked or stops functioning
  - Note that the system may be frozen temporarily

Deadlock Prevention

- Goal:
  - Try to fail anyone of the necessary conditions
- The Necessary Conditions
  - Mutual Exclusion
    - Some resources, such as a printer, are intrinsically non-sharable
  - Hold and Wait
  - No Preemption
  - Circular Wait

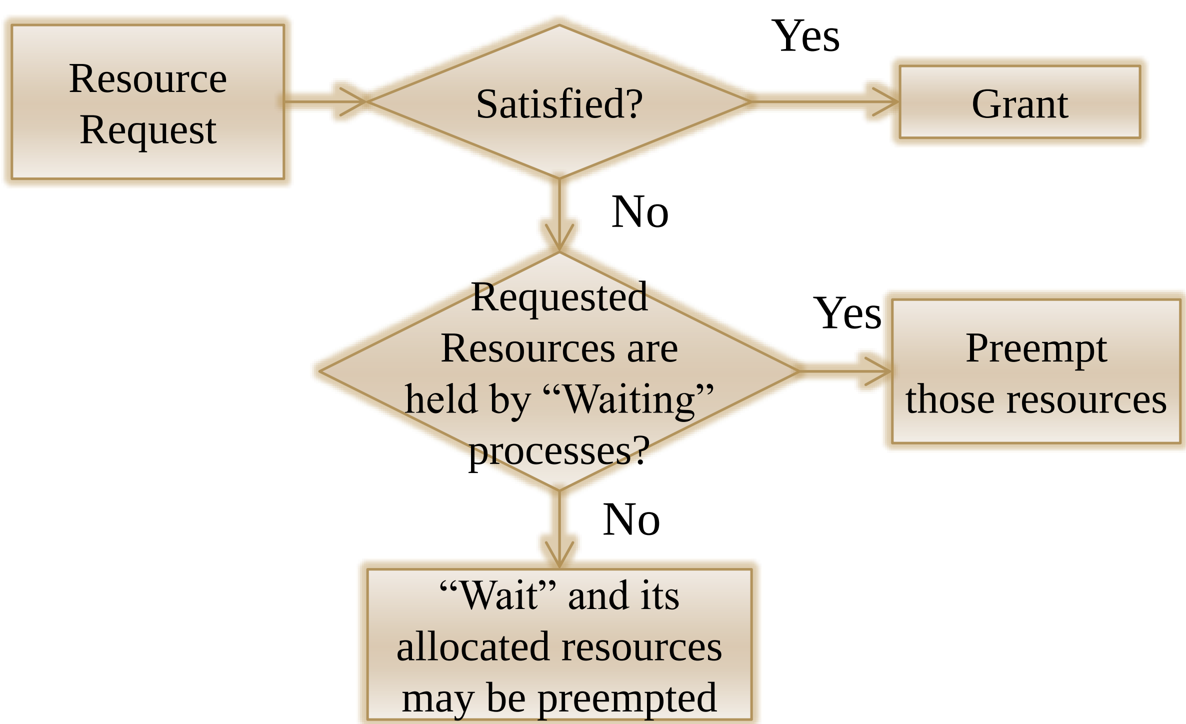
Deadlock Prevention—Hold and Wait

- Rules
  - Acquire all needed resources before its execution

    or
  - Release allocated resources before request additional resources
- Disadvantage
  - Low resource utilization
  - Starvation

Deadlock Prevention—No Preemption

- Related protocols are only applied to resources whose states can be saved and restored, e.g., CPU registers & memory space, instead of printers or tape drives
- Example



Deadlock Prevention—Circular Wait

- Rule
  - Impose a total ordering of all resource types, and require that each process requests resources in an increasing order of enumeration
- Example

The order is not allowed

```
/* thread one runs in this function */
void *do work one(void *param)
{
   lock(&first mutex);
   lock(&second mutex);
   /** * Do some work */
   unlock(&second mutex);
   unlock(&first mutex);
   exit(0);
}
```

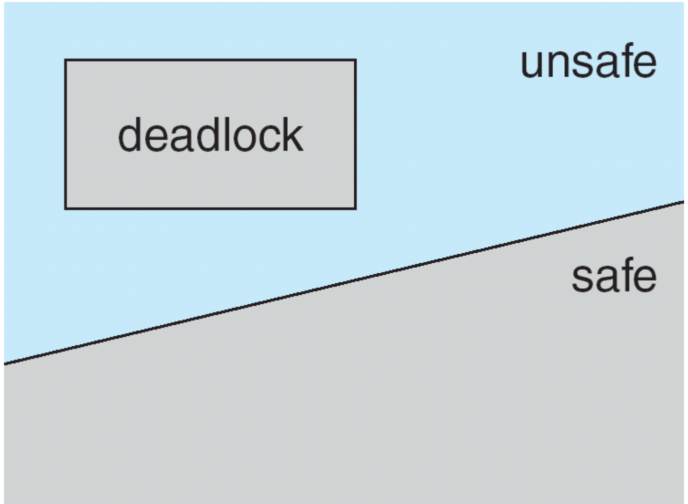
```
/* thread two runs in this function */
void *do work two(void *param)
{
   lock(&second mutex);
   lock(&first mutex);
   /** * Do some work */
   unlock(&first mutex);
   unlock(&second mutex);
   exit(0);
}
```

Deadlock Avoidance

- Goal:
  - Dynamically examines the resource-allocation state to ensure that there can never be a circular-wait condition
  - i.e., keep the system at a safe state
- Require that the system has some additional information
  - For each resource
    - Count the allocated amount
    - Log the available amount
  - For each process
    - Know the maximum demand of each resource
    - Count the allocated amount of each resource

Safe State (1/2)

- If a system is in safe state → no deadlocks
- If a system is in unsafe state → possibility of deadlock
- Avoidance → ensure that a system will never enter an unsafe state



Safe State (2/2)

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

Deadlock Avoidance

- Example: for only one type of resources

	Max needs	Allocated		Available
P_0	10	5		3
P_1	4	2		
P_2	9	2		

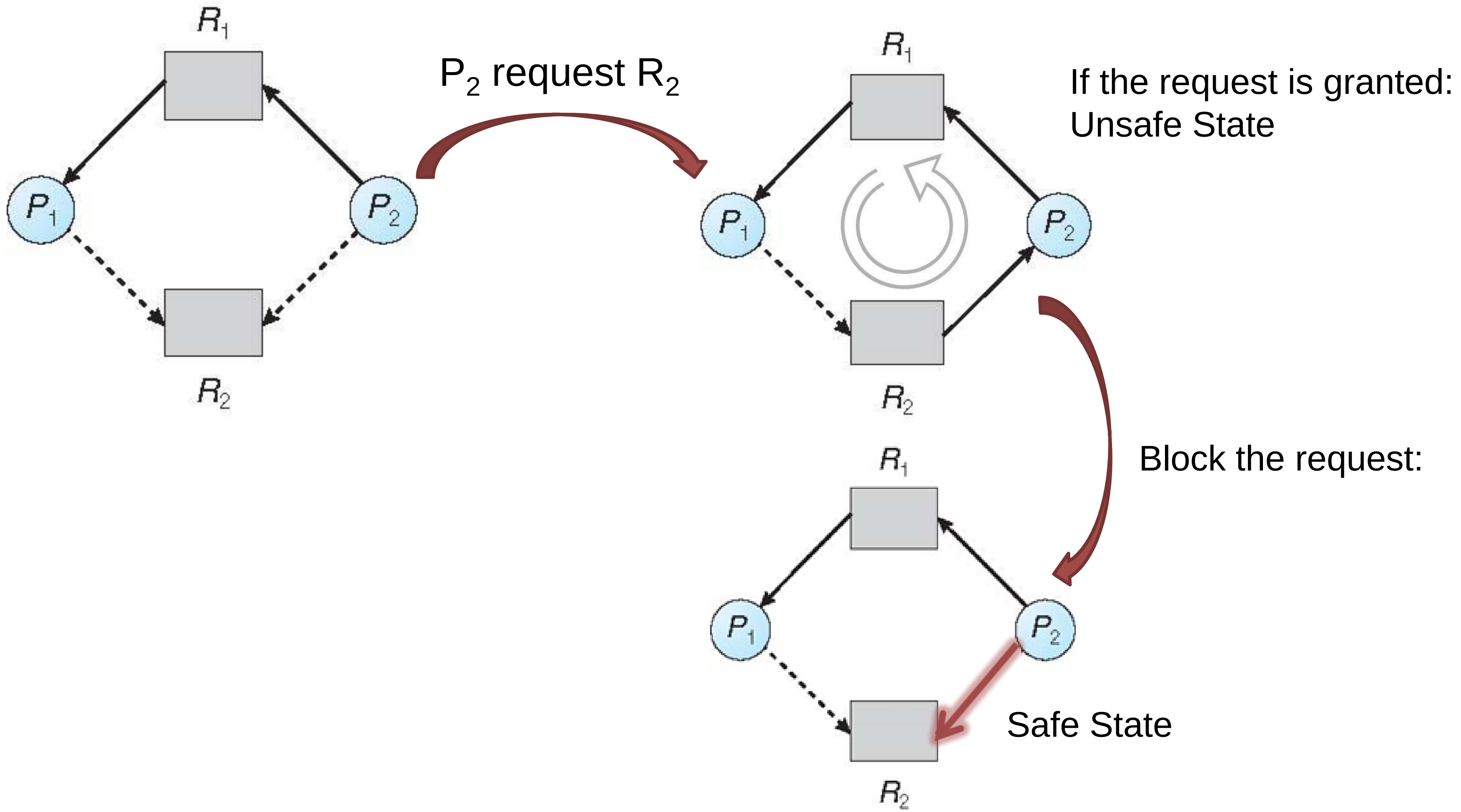
- The existence of a safe sequence <P_1, P_0, P_2>
- If P_2 got two more, the system state is unsafe

➔How to ensure that the system will always remain in a safe state?

Resource-Allocation Graph Scheme (1/2)

- **Claim edge** $P_i \rightarrow R_j$ indicated that process P_i 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

Resource-Allocation Graph Scheme (2/2)



Banker's Algorithm (1/3)

- Available [m]
  - If Available [i] = k, there are k instances of resource type R_i available
- Max [n,m]
  - If Max [i,j] = k, process P_i may request at most k instances of resource type R_j
- Allocation [n,m]
  - If Allocation [i,j] = k, process P_i is currently allocated k instances of resource type R_j
- Need [n,m]
  - If Need [i,j] = k, process P_i may need k more instances of resource type R_j

➔ Need [i,j] = Max [i,j] – Allocation [i,j]

n: number of processes

m: number of resource types

Banker's Algorithm (2/3) —Safe State Checking

1. Let **Work** and **Finish** be vectors of length m and n, respectively

   Initialize:

   Work[i]🡐 Available[i] for i = 0, 1, …, m-1, which means the current available instances of each resource

   Finish[i] 🡐 false for i = 0, 1, …, n- 1, which means if process P_i is finished

2. Find a process $\mathbf{P_i}$ such that both:

   (a) **Finish[i] == false**

   (b) **Need[i] ≦ Work**

   If no such **i** exists, go to step 4

3. **Work 🡐 Work + Allocation[i]**

   Finish[i] 🡐 true

   go to Step 2

4. If **Finish [i] == true** for all **i**, then the system is in a safe state; otherwise, the system is unsafe

- X≦ Y if X[*k*] ≦ Y[*k*] for all *k*

- X🡐X+Y means X[*k*]🡐X[*k*] +Y[*k*] for all *k*

Banker's Algorithm (3/3) —Resource-Request Algorithm

Request[i] is the request vector for process $\mathbf{P_i}$. If **Request[i,j] = k** then process $\mathbf{P_i}$ wants **k** instances of resource type $\mathbf{R_j}$

1. If Request[i] ≦ Need[i], then goto Step 2; otherwise, Trap
2. If Request[i] ≦ Available, then goto Step3; otherwise, P_i must wait
3. Have the system pretend to have allocated resources to process P_i by setting:

   Available ← Available – Request[i];
   Allocation[i] ← Allocation[i] + Request[i];
   Need[i] ← Need[i] – Request[i];

4. Execute "**Safe State Checking**". If the system state is safe, the request is granted; otherwise, P_i must wait, and the old resource allocation state is restored

Deadlock Avoidance Example (1/2)

	Allocation			Max			Need			Available		
	A	B	C	A	B	C	A	B	C	A	B	C
P0	0	1	0	7	5	3	7	4	3	3	3	2
P1	2	0	0	3	2	2	1	2	2			
P2	3	0	2	9	0	2	6	0	0			
P3	2	1	1	2	2	2	0	1	1			
P4	0	0	2	4	3	3	4	3	1			

Is it in a safe state now?

Yes, a safe sequence is $\langle P_1, P_3, P_4, P_0, P_2 \rangle$

Department of Computer Science and Information Engineering, Chang Gung University

Deadlock Avoidance Demo

		Allocation			Max			Need			Available		
		A	B	C	A	B	C	A	B	C	A	B	C
4											3	3	2
1											5	3	2
	P2	3	0	2	9	0	2	6	0	0	7	4	3
2											7	4	5
3											7	5	5

Deadlock Avoidance Example (2/2)

	Allocation			Max			Need			Available		
	A	B	C	A	B	C	A	B	C	A	B	C
P0	0	1	0	7	5	3	7	4	3	3	3	2
P1	2	0	0	3	2	2	1	2	2			
P2	3	0	2	9	0	2	6	0	0			
P3	2	1	1	2	2	2	0	1	1			
P4	0	0	2	4	3	3	4	3	1			

Let P_1 make a request Request[1] = (1,0,2) Request[1] $\leqq$ Available (i.e., (1,0,2) $\leqq$ (3,3,2))

Should we grant it? Yes, there is still a safe sequence $<P_1,P_3,P_4,P_0,P_2>$

If Request[4] = (3,3,0) is asked later, it must be rejected

If Request[0] = (0,2,0) is asked later, it must be rejected because it results in an unsafe state

Deadlock Detection

- Approach:
  - Allow system to enter deadlock state

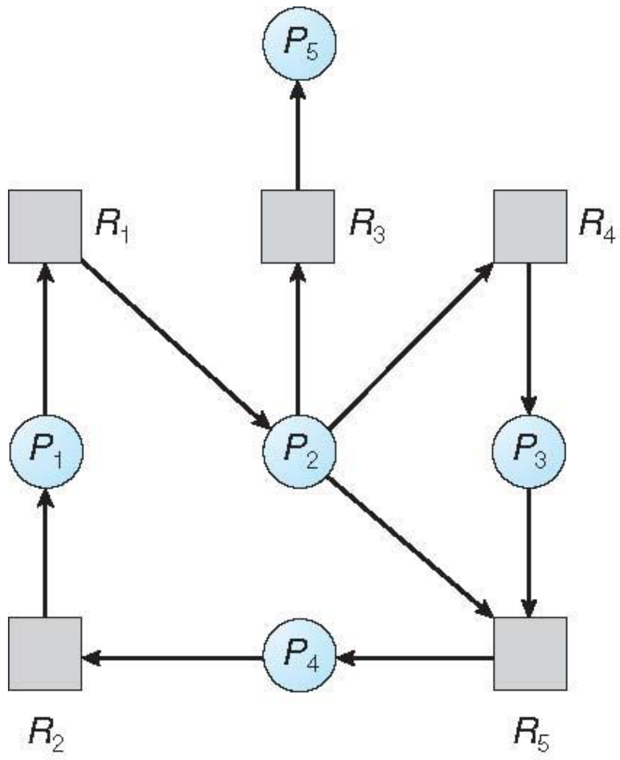
- Thus, we need:
  - Detection algorithm
  - Recovery scheme

Single Instance of Each Resource Type (1/2)

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

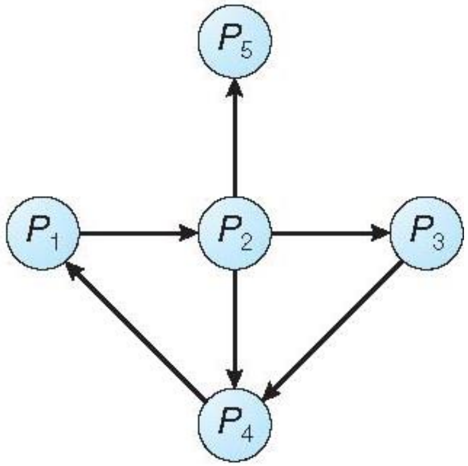
- Periodically invoke an algorithm that searches for a cycle in the graph
  - If there is a cycle, there exists a deadlock

Single Instance of Each Resource Type (2/2)



(a)

Resource-Allocation Graph



(b)

Corresponding wait-for graph

Multiple Instances of Each Resource Type (1/2)

n: number of processes, *m*: number of resource types

- Data Structures
  - Available[1..m]: number of available resource instances
  - Allocation[1..n, 1..m]: current resource allocation to each process
  - Request[1..n, 1..m]: the current request of each process
  - If Request[i,j] = k, P_i is now requesting k more instances of resource type R_j

Multiple Instances of Each Resource Type (2/2)

1. Work[1..m] 🡐 Available[1..m]
   Finish[1..n] 🡐 False

2. Find a process P_i such that both
   a. Finish[i] = False
   b. Request[i] ≦ Work
   If no such i, **goto** Step 4

3. Work 🡐 Work + Allocation[i]
   Finish[i] := True
   goto Step 2

4. **If** Finish[i] = False for some P_i, **then** the system is in a deadlock state
   If Finish[i] = False, then process P_i is deadlocked

Deadlock Detection Example

	Allocation			Request			Available		
	A	B	C	A	B	C	A	B	C
P0	0	1	0	0	0	0	0	2	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			

- Find a sequence <P0, P2, P3, P1, P4> such that Finish[i] = True for all i
- If Request[2] = (0,0,1) is issued, then P1, P2, P3, and P4 are deadlocked

Deadlock Detection Demo

		Allocation			Request		
		A	B	C	A	B	C
1	P0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	P1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	P2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	P3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	P4	0	0	2	0	0	2

Available		
A	B	C
0	2	0
0	3	0
3	3	3
5	4	4
7	4	4

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 deadlocked processes "caused" the deadlock

Recovery from Deadlock: Process Termination

- Abort all deadlocked processes
- Abort one process at a time until the deadlock cycle is eliminated
- In which order should we choose to abort?
  1. Priority of the process
  2. How long process has computed, and how much longer to completion
  3. Resources the process has used
  4. Resources process needs to complete
  5. How many processes will need to be terminated
  6. 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