Operating System

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Chapter 06

Concurrency: Deadlock and Starvation

并发性：死锁和饥饿

Learning Objectives

- List and explain the conditions for deadlock
- Define deadlock prevention and describe deadlock prevention strategies related to each of the conditions for deadlock
- Explain the difference between deadlock prevention and deadlock avoidance
- Understand two approaches to deadlock avoidance
- Explain the fundamental difference in approach between deadlock detection and deadlock prevention or avoidance
- Analyze the dining philosophers problem

Outline

- **Principles of Deadlock**
  - Reusable resources
  - Consumable resources
  - Resource allocation graphs
  - The conditions for deadlock
- **Deadlock Prevention**
  - Mutual exclusion
  - Hold and wait
  - No preemption
  - Circular wait
- **Deadlock Avoidance**
  - Process initiation denial
  - Resource allocation denial
- **Deadlock Detection**
  - Deadlock detection algorithm
  - Recovery
- **Dining Philosophers Problem**
  - Solution using semaphores
  - Solution using a monitor

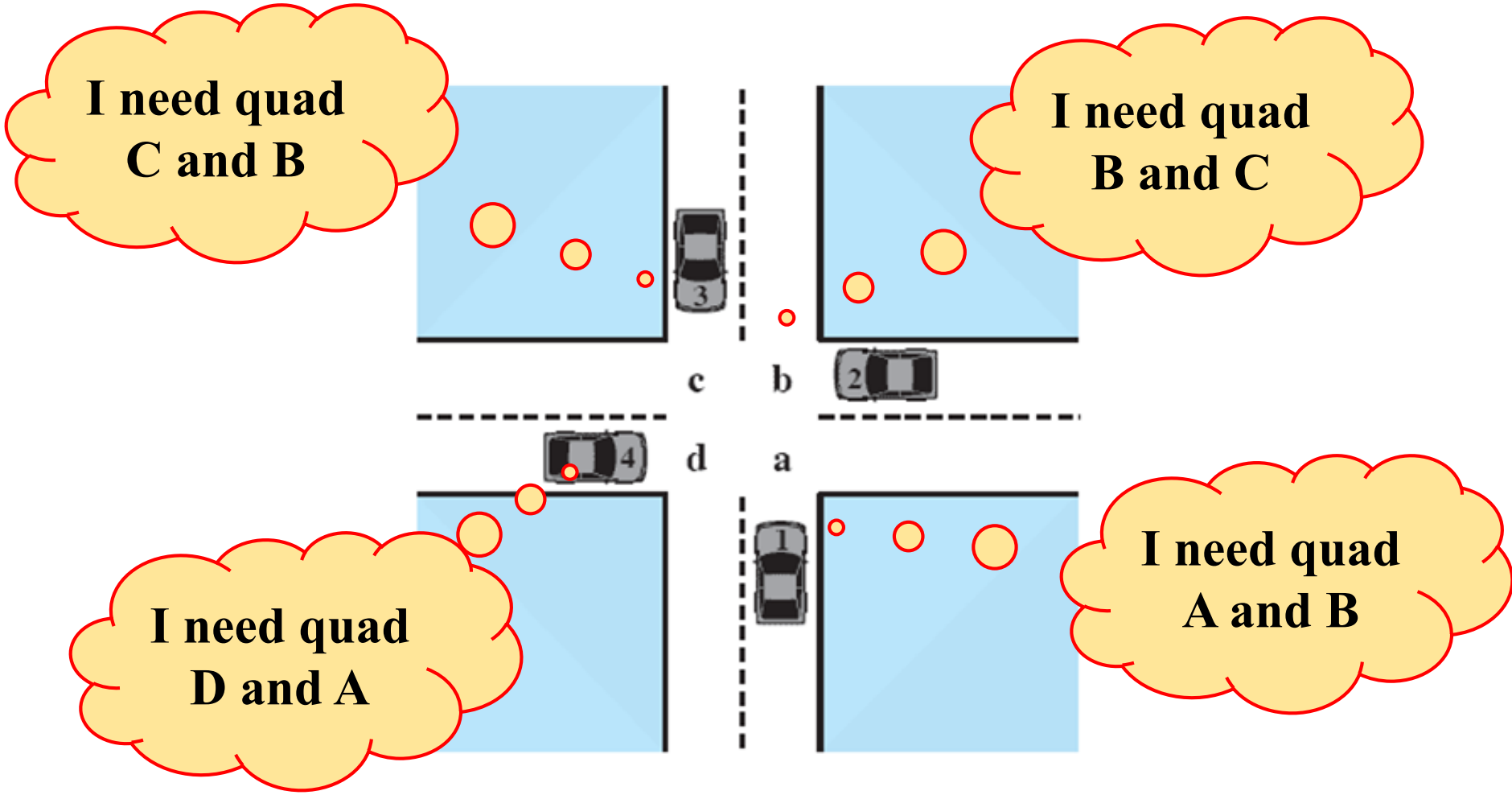
When two trains approach each other at a crossing, both shall come to a full stop and neither shall start up again until the other has gone. Statute passed by the Kansas State Legislature, early in the 20th century.

-- *A TREASURY OF RAILROAD FOLKLORE,*
B. A. Botkin and Alvin F. Harlow

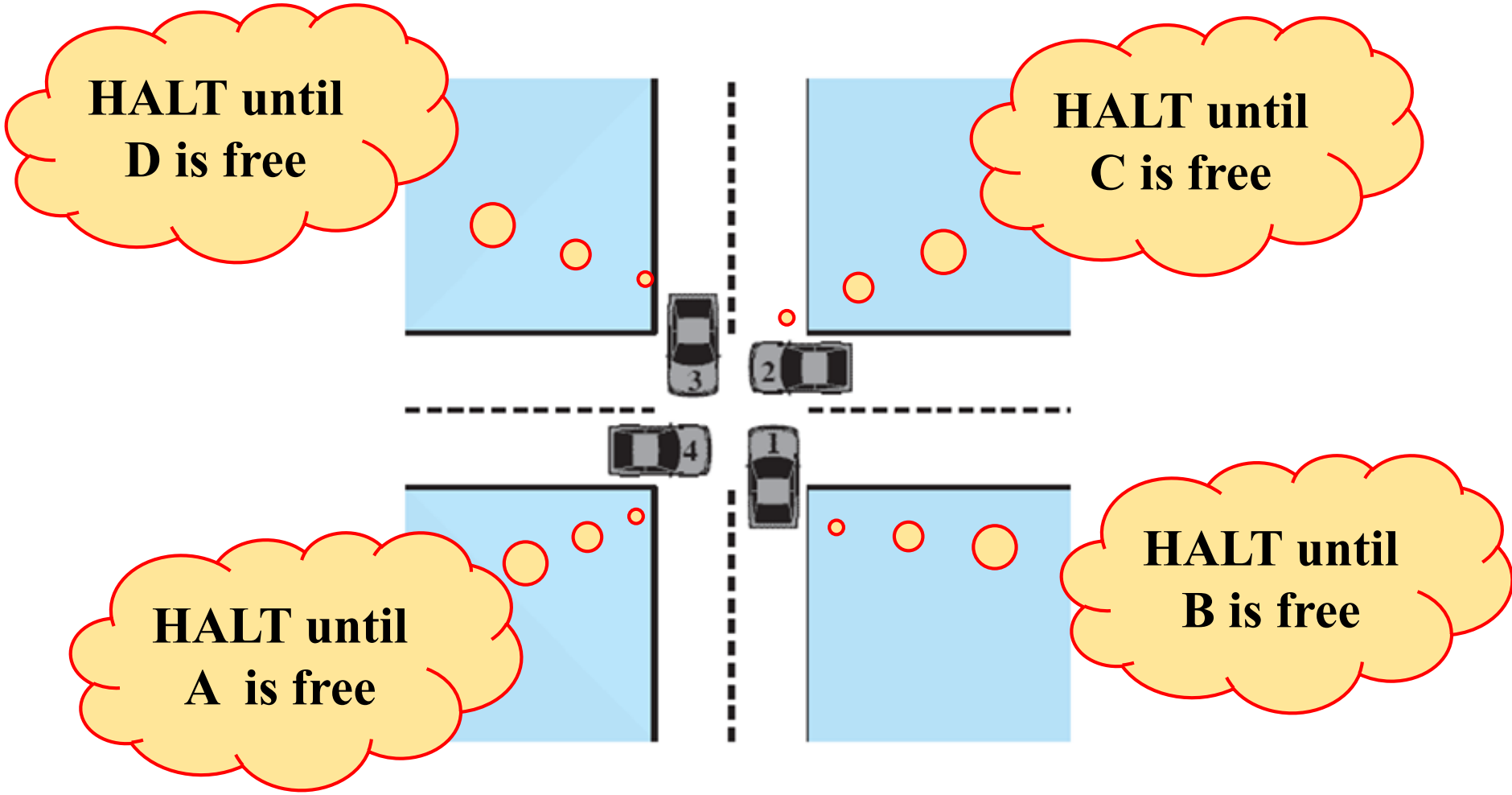
Deadlock

- The permanent blocking of a set of processes that either compete for system resources or communicate with each other
- A set of processes is deadlocked when each process in the set is blocked awaiting an event that can only be triggered by another blocked process in the set
- Permanent
- No efficient solution

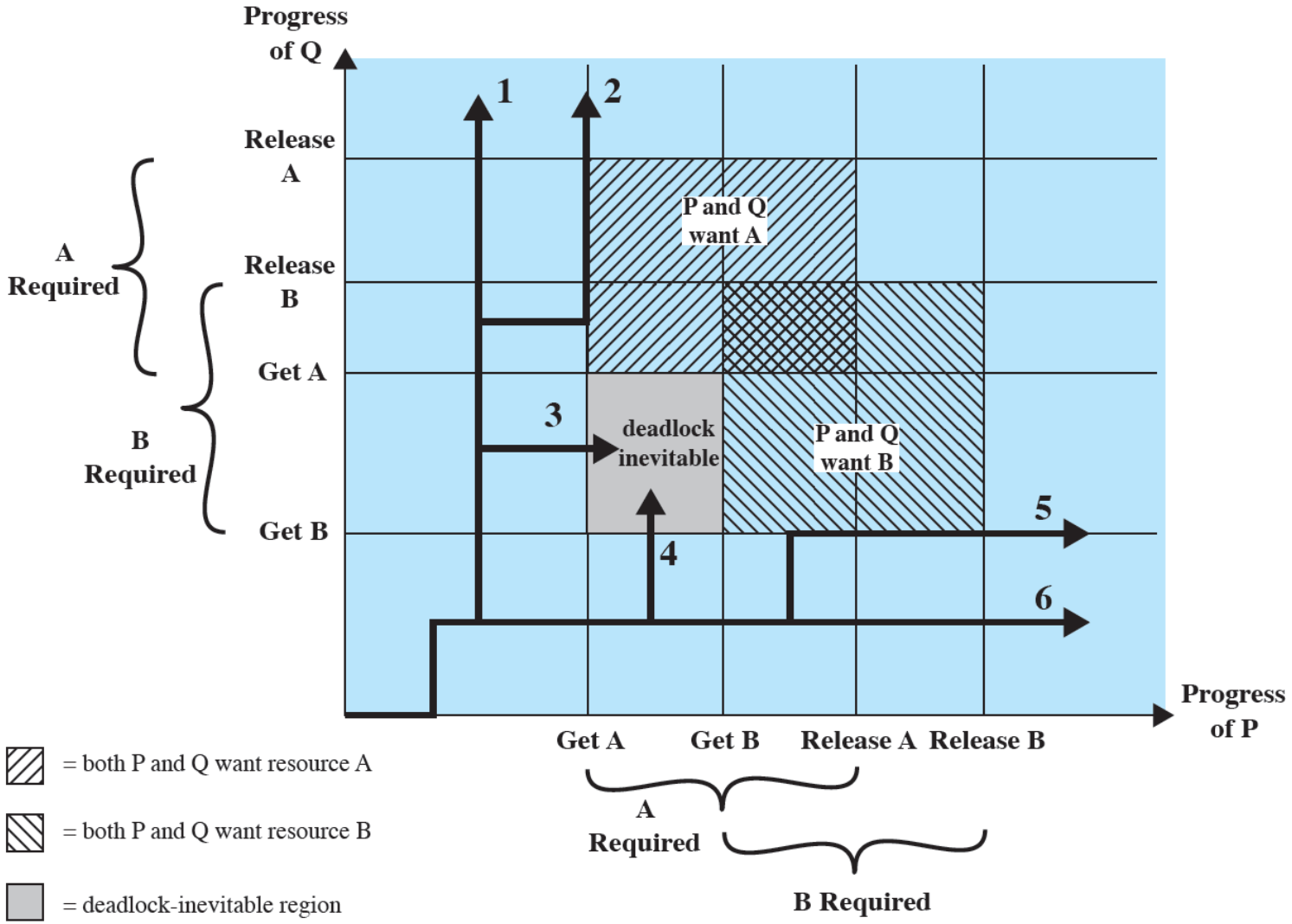
Potential Deadlock



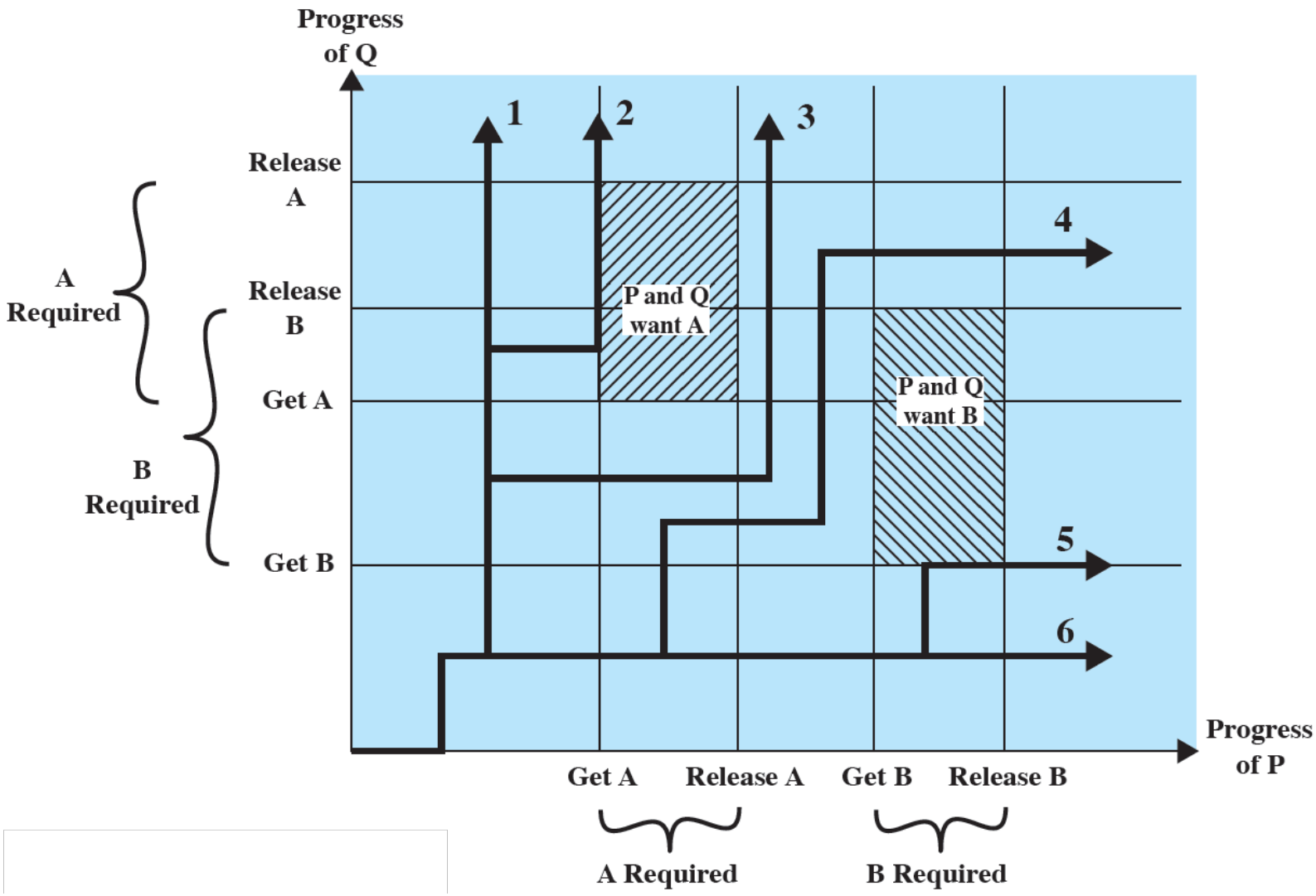
Actual Deadlock



Deadlock Example



No Deadlock Example



Resource Categories

- **Reusable**
  - can be safely used by **only one process at a time** and is **not depleted** by that use
    - processors
    - I/O channels
    - main and secondary memory
    - devices
    - data structures such as files, databases, and semaphores
- **Consumable**
  - one that can be **created** (produced) and **destroyed** (consumed)
    - interrupts
    - signals
    - messages
    - information in I/O buffers

Reusable Resources: Example 1

Process P

Step	Action
p_0 1	Request (D)
p_1 2	Lock (D)
p_2 5	Request (T)
p_3	Lock (T)
p_4	Perform function
p_5	Unlock (D)
p_6	Unlock (T)

Process Q

Step	Action
q_0 3	Request (T)
q_1 4	Lock (T)
q_2 6	Request (D)
q_3	Lock (D)
q_4	Perform function
q_5	Unlock (T)
q_6	Unlock (D)

Example of Two Processes Competing for Reusable Resources

Example 2: Memory Request

- Space is available for allocation of 200 Kbytes, and the following sequence of events occur

P1	P2
…	…
Request 80 Kbytes;	Request 70 Kbytes;
…	…
Request 60 Kbytes;	Request 80 Kbytes;

- Deadlock occurs if both processes progress to their second request

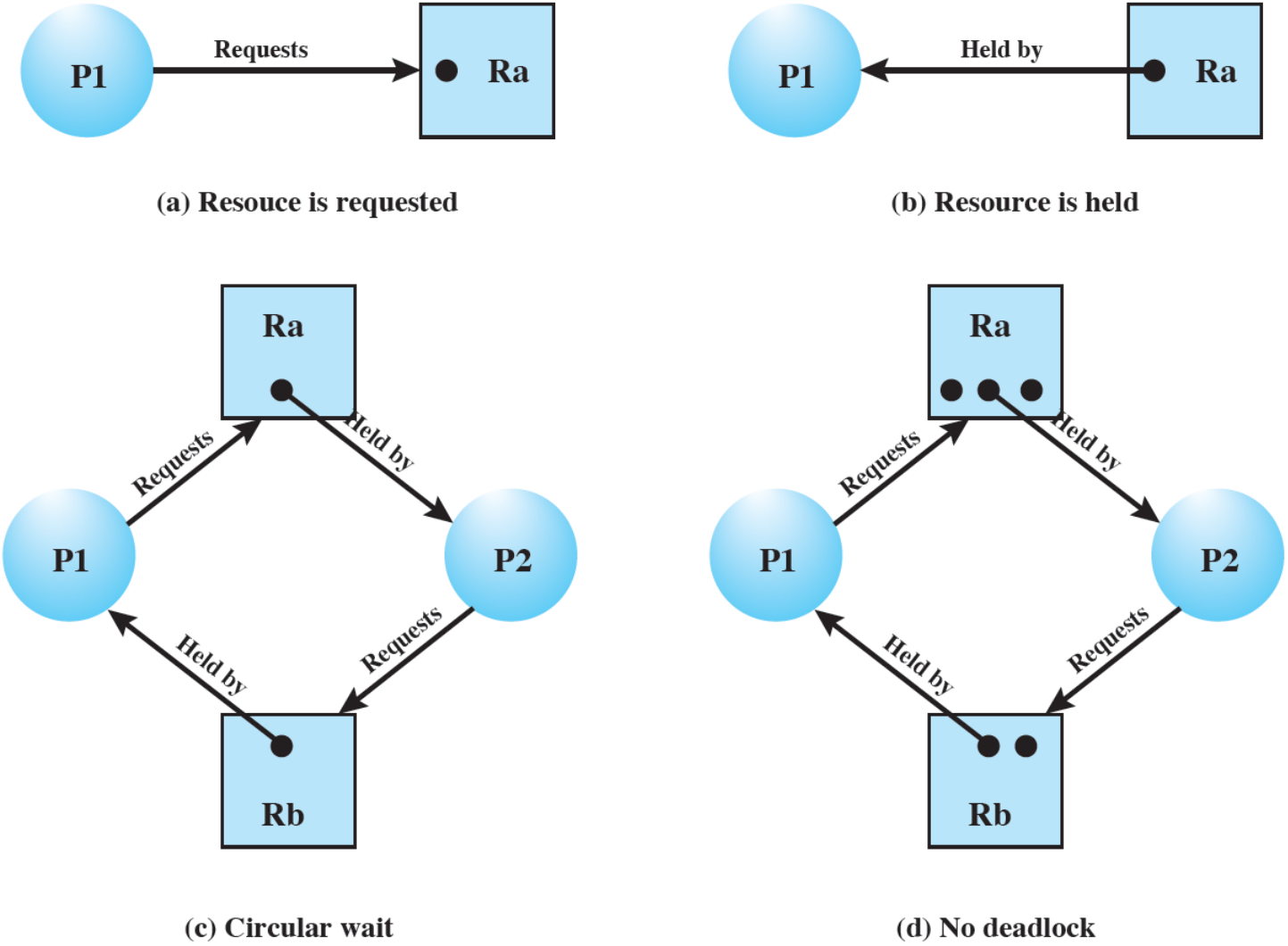
Consumable Resources Deadlock

- Consider a pair of processes, in which each process attempts to receive a message from the other process and then send a message to the other process:

P_1	P_2
…	…
Receive(P_2);	Receive(P_1);
…	…
Send(P_2,M_1);	Send(P_1,M_2);

- Deadlock occurs if the Receive is blocking

Resource Allocation Graphs



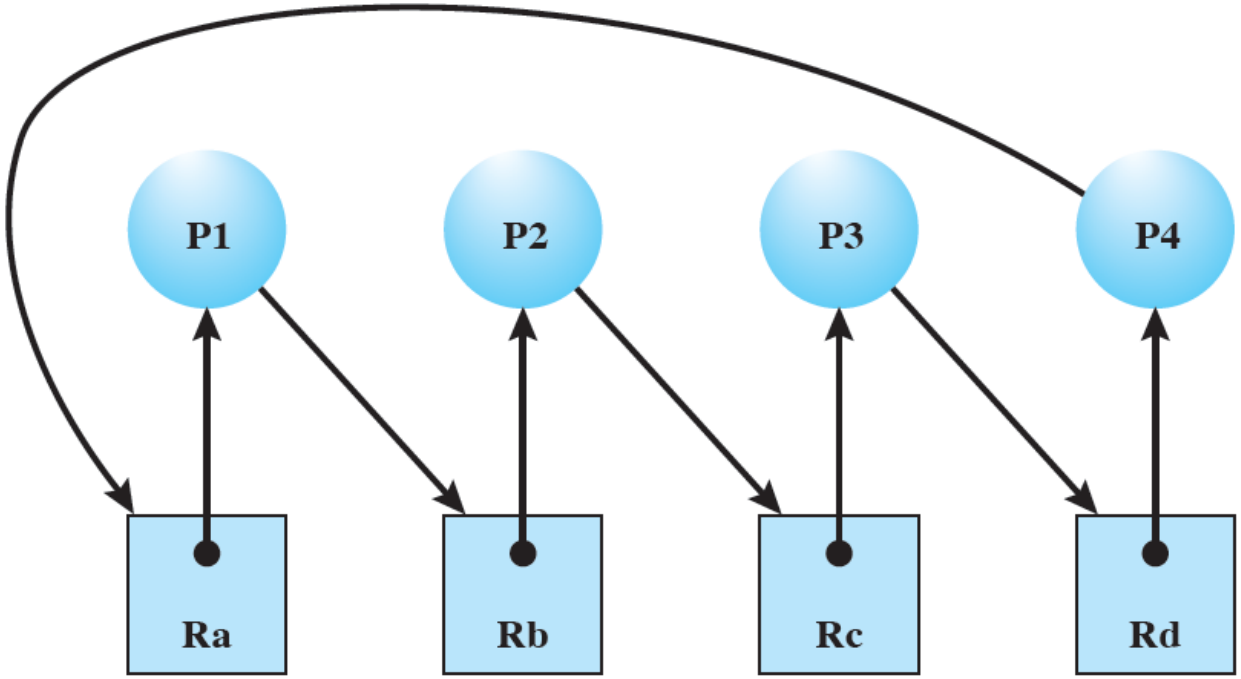
(a) Resouce is requested

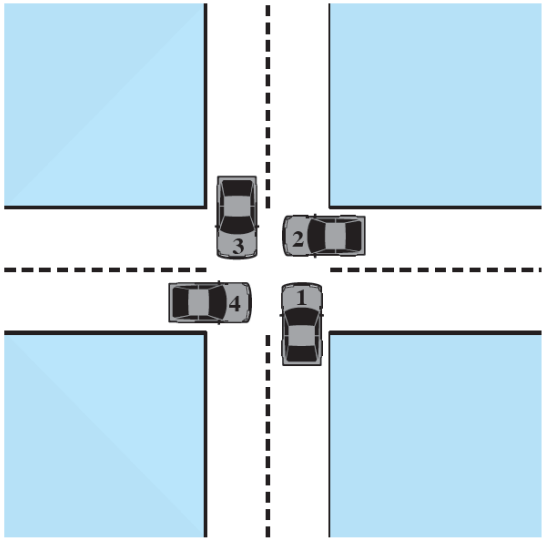
(b) Resource is held

(c) Circular wait

(d) No deadlock

Resource Allocation Graphs





(b) Deadlock

Conditions for Deadlock

policy decisions

Mutual Exclusion

- only one process may use a resource at a time

Hold and Wait

- a process may hold allocated resources while awaiting assignment of others

No Preemption

- no resource can be forcibly removed from a process holding it

Circular Wait

- a closed chain of processes exists, such that each process holds at least one resource needed by the next process in the chain

might occur

To summarize

- **Possibility of Deadlock**
  - Mutual exclusion
  - No preemption
  - Hold and wait
- **Existence of Deadlock**
  - Mutual exclusion
  - No preemption
  - Hold and wait
  - **Circular wait**

Dealing with Deadlock

Prevent Deadlock

- adopt a policy that **eliminates one of the conditions**

Avoid Deadlock

- make the **appropriate dynamic choices** based on the current state of resource allocation

Detect Deadlock

- attempt to **detect** the presence of deadlock and take action to recover

Deadlock Prevention Strategy

- **Design a system in such a way that the possibility of deadlock is excluded**
- **Two main methods**
  - Indirect
    - prevent the occurrence of **one of the three** necessary conditions
  - Direct
    - prevent the occurrence of a **circular wait**

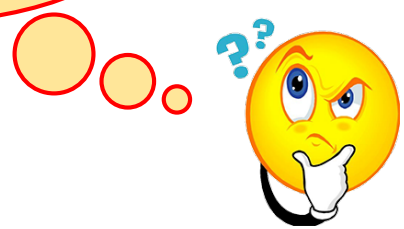
Deadlock Condition Prevention

- **Mutual Exclusion**
  - if access to a resource requires mutual exclusion then it must be supported by the OS
- **Hold and Wait**
  - require that a process request all of its required resources **at one time** and blocking the process until all requests can be **granted simultaneously**
- **No Preemption**
  - if a process holding certain resources is denied a further request, that process must **release** its original resources and request them again
  - OS may preempt the second process and require it to release its resources
    - **different priority**
- **Circular Wait**
  - define a **linear ordering** of resource types

Deadlock Avoidance

- **A decision is made dynamically**
  - whether the current resource allocation request will, if granted, potentially lead to a deadlock
- **Requires knowledge of future process requests**

Different from deadlock prevention
allows the three necessary conditions but makes judicious choices to assure that the **deadlock point is never reached**



Two Approaches to Deadlock Avoidance

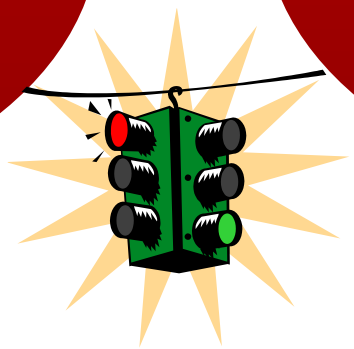
Deadlock Avoidance

Resource Allocation Denial

- do not grant an incremental resource request to a process if this allocation might lead to deadlock

Process Initiation Denial

- do not start a process if its demands might lead to deadlock



Resource Allocation Denial

- **Referred to as the banker's algorithm**
- **State of the system**
  - reflects the current allocation of resources to processes
- **Safe state**
  - is one in which there is **at least one sequence** of resource allocations to processes that **does not result in a deadlock**
- **Unsafe state**
  - is a state that is not safe

A system of n processes and m resources

Resource $= \mathbf{R} = (R_1, R_2, \ldots, R_m)$	Total amount of each resource in the system
Available $= \mathbf{V} = (V_1, V_2, \ldots, V_m)$	Total amount of each resource not allocated to any process
Claim $= \mathbf{C} = \begin{pmatrix} C_{11} & C_{12} & \ldots & C_{1m} \\ C_{21} & C_{22} & \ldots & C_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ C_{n1} & C_{n2} & \ldots & C_{nm} \end{pmatrix}$	C_{ij} = requirement of process i for resource j
Allocation $= \mathbf{A} = \begin{pmatrix} A_{11} & A_{12} & \ldots & A_{1m} \\ A_{21} & A_{22} & \ldots & A_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ A_{n1} & A_{n2} & \ldots & A_{nm} \end{pmatrix}$	A_{ij} = current allocation to process i of resource j

1. $R_j = V_j + \sum_{i=1}^{n} A_{ij}$, for all j — All resources are either available or allocated.

2. $C_{ij} \leq R_j$, for all i,j — No process can claim more than the total amount of resources in the system.

3. $A_{ij} \leq C_{ij}$, for all i,j — No process is allocated more resources of any type than the process originally claimed to need.

Determination of a Safe 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**

Initial state

	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**

P2 runs to completion

Determination of a Safe State

	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**

P1 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**

P3 runs to completion

Determination of an Unsafe 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	5	1	1
P3	2	1	1
P4	0	0	2

Allocation matrix **A**

	R1	R2	R3
P1	2	2	2
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
1	1	2

Available vector **V**

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	2	0	1
P2	5	1	1
P3	2	1	1
P4	0	0	2

Allocation matrix **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**

P_1 requests one unit each of R_1 and R_3

Deadlock Avoidance Logic

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

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 >;
}
```

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);
}
```

test for safety algorithm (banker's algorithm)

Advantages and Restrictions

- **Advantages**
  - It is **not necessary** to preempt and rollback processes, as in deadlock detection
  - It is **less restrictive** than **deadlock prevention**
- **Restrictions**
  - **Maximum resource requirement** for each process must be stated in advance
  - Processes under consideration must be **independent** and **with no synchronization requirements**
  - There must be a **fixed number** of resources to allocate
  - **No process may exit** while holding resources

Deadlock Strategies

- **Deadlock prevention**
  - very **conservative**
  - **limit access** to resources by imposing restrictions on processes
- **Deadlock detection**
  - do the opposite
  - resource requests are granted **whenever possible**

Deadline Detection Algorithms

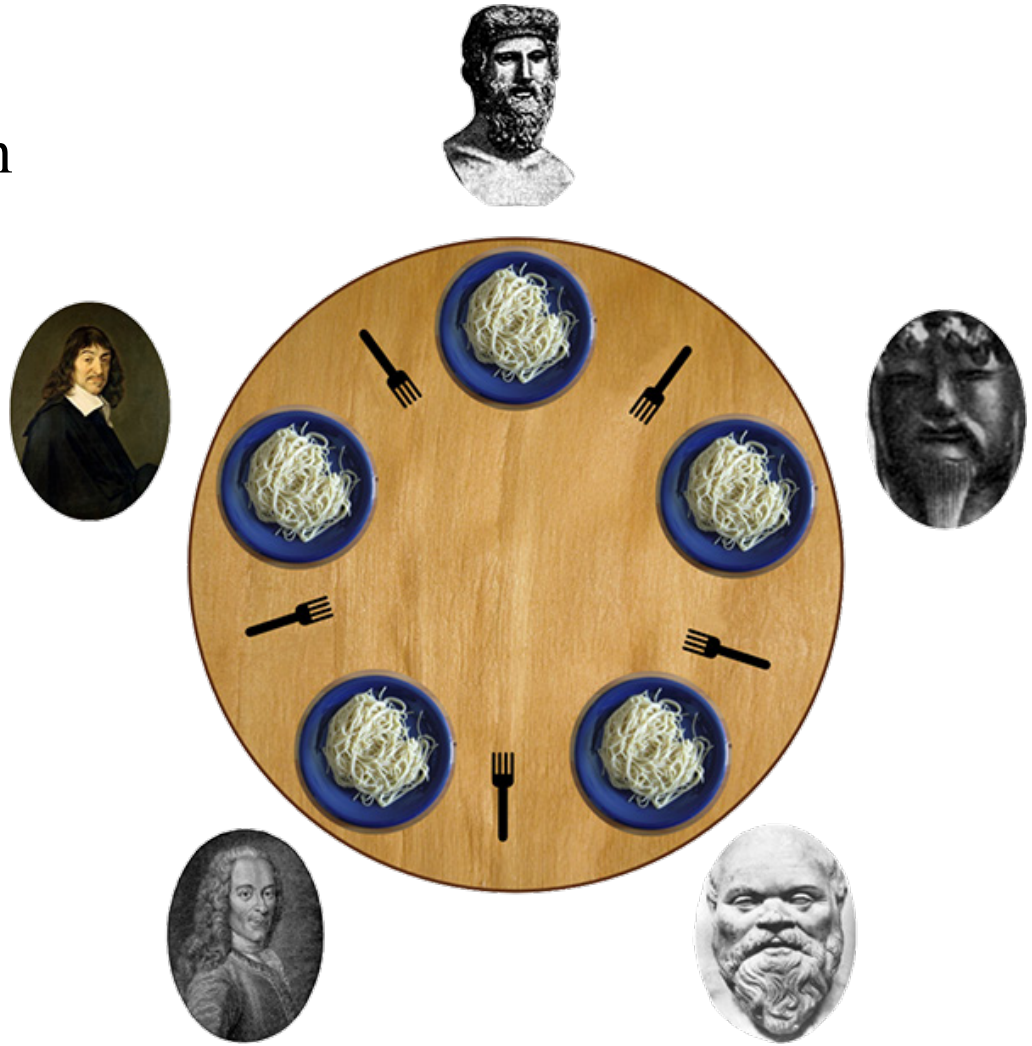
- **A check for deadlock can be made as frequently as each resource request or, less frequently, depending on how likely it is for a deadlock to occur**
- **Advantages:**
  - it leads to **early detection**
  - the algorithm is **relatively simple**
- **Disadvantage**
  - **frequent** checks
  - **consume** considerable processor time

Approach	Resource Allocation Policy	Different Schemes	Major Advantages	Major Disadvantages
Prevention	Conservative; undercommits resources	Requesting all resources at once	• Works well for processes that perform a single burst of activity • No preemption necessary	• Inefficient • Delays process initiation • Future resource requirements must be known by processes
		Preemption	• Convenient when applied to resources whose state can be saved and restored easily	• Preempts more often than necessary
		Resource ordering	• Feasible to enforce via compile-time checks • Needs no run-time computation since problem is solved in system design	• Disallows incremental resource requests
Avoidance	Midway between that of detection and prevention	Manipulate to find at least one safe path	• No preemption necessary	• Future resource requirements must be known by OS • Processes can be blocked for long periods
Detection	Very liberal; requested resources are granted where possible	Invoke periodically to test for deadlock	• Never delays process initiation • Facilitates online handling	• Inherent preemption losses

Summary of Deadlock Detection, Prevention, and Avoidance Approaches for Operating Systems

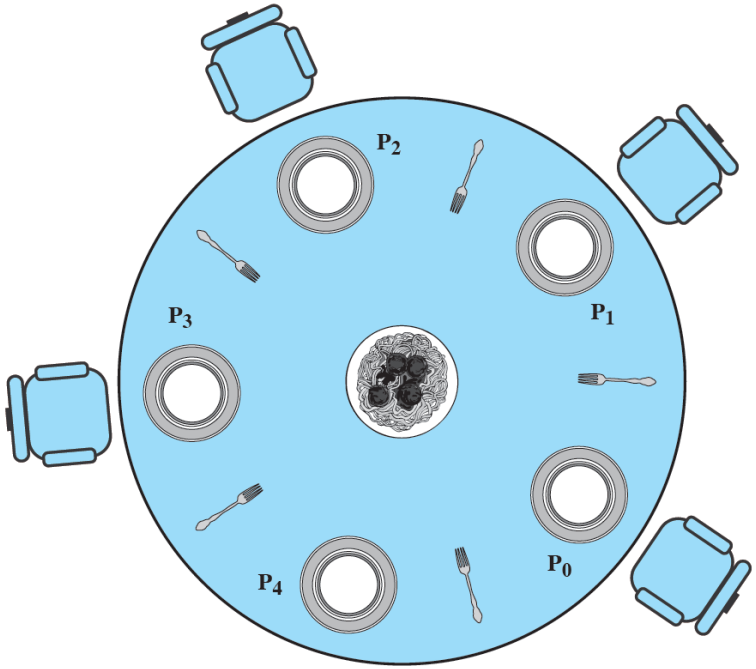
Dining Philosophers Problem

- **Mutual exclusion**
  - **No two philosophers** can use **the same fork** at the **same time**
- **Avoid deadlock and starvation**
  - No philosopher must starve to death



Using Semaphores

```
/* program     diningphilosophers */
semaphore fork [5] = {1};
int i;
void philosopher (int i)
{
     while (true) {
          think();
          wait (fork[i]);
          wait (fork [(i+1) mod 5]);
          eat();
          signal(fork [(i+1) mod 5]);
          signal(fork[i]);
     }
}
void main()
{
     parbegin (philosopher (0), philosopher (1), philosopher
(2),
          philosopher (3), philosopher (4));
     }
```


P2
P1
P3
P0
P4

Hello Kitty

OK ?

A Second Solution

```
/* program diningphilosophers */
semaphore fork[5] = {1};
semaphore room = {4};
int i;
void philosopher (int i)
{
    while (true) {
     think();
     wait (room);
     wait (fork[i]);
     wait (fork [(i+1) mod 5]);
     eat();
     signal (fork [(i+1) mod 5]);
     signal (fork[i]);
     signal (room);
    }

}
void main()
{
    parbegin (philosopher (0), philosopher (1), philosopher (2),
          philosopher (3), philosopher (4));
}
```

Using A Monitor

```
void philosopher[k=0 to 4]          /* the five philosopher clients */
{
   while (true) {
      <think>;
      get_forks(k);          /* client requests two forks via monitor */
      <eat spaghetti>;
      release_forks(k);      /* client releases forks via the monitor */
   }
}
```

```
void main()
{
    parbegin (philosopher (0), philosopher (1), philosopher (2),
          philosopher (3), philosopher (4));
}
```

```
monitor dining_controller;
cond ForkReady[5];          /* condition variable for synchronization */
boolean fork[5] = {true};        /* availability status of each fork */

void get_forks(int pid)          /* pid is the philosopher id number */
{
   int left = pid;
   int right = (++pid) % 5;
   /*grant the left fork*/
   if (!fork(left)
      cwait(ForkReady[left]);          /* queue on condition variable */
   fork(left) = false;
   /*grant the right fork*/
   if (!fork(right)
      cwait(ForkReady(right);          /* queue on condition variable */
   fork(right) = false:
}
void release_forks(int pid)
{
   int left = pid;
   int right = (++pid) % 5;
   /*release the left fork*/
   if (empty(ForkReady[left])      /*no one is waiting for this fork */
      fork(left) = true;
   else                      /* awaken a process waiting on this fork */
      csignal(ForkReady[left]);
   /*release the right fork*/
   if (empty(ForkReady[right])     /*no one is waiting for this fork */
      fork(right) = true;
   else                      /* awaken a process waiting on this fork */
      csignal(ForkReady[right]);
}
```

Summary

- **Deadlock:**
  - the blocking of a set of processes that either compete for system resources or communicate with each other
  - blockage is **permanent** unless OS takes action
  - may involve reusable or consumable resources
    - Consumable = destroyed
    - Reusable = not depleted or destroyed by use
- **Dealing with deadlock:**
  - **prevention**
    - guarantees that deadlock will not occur
  - **avoidance**
    - analyzes each new resource request
  - **detection**
    - OS checks for deadlock and takes action