Chapter 6
Concurrency: Deadlock and Starvation

Deadlock

- Permanent blocking of a set of processes that either compete for system resources or communicate with each other
- No efficient solution in the general case
  (distinguish between universal properties and application-specific properties)
- Involve conflicting needs for resources by two or more processes

Joint Progress Diagram

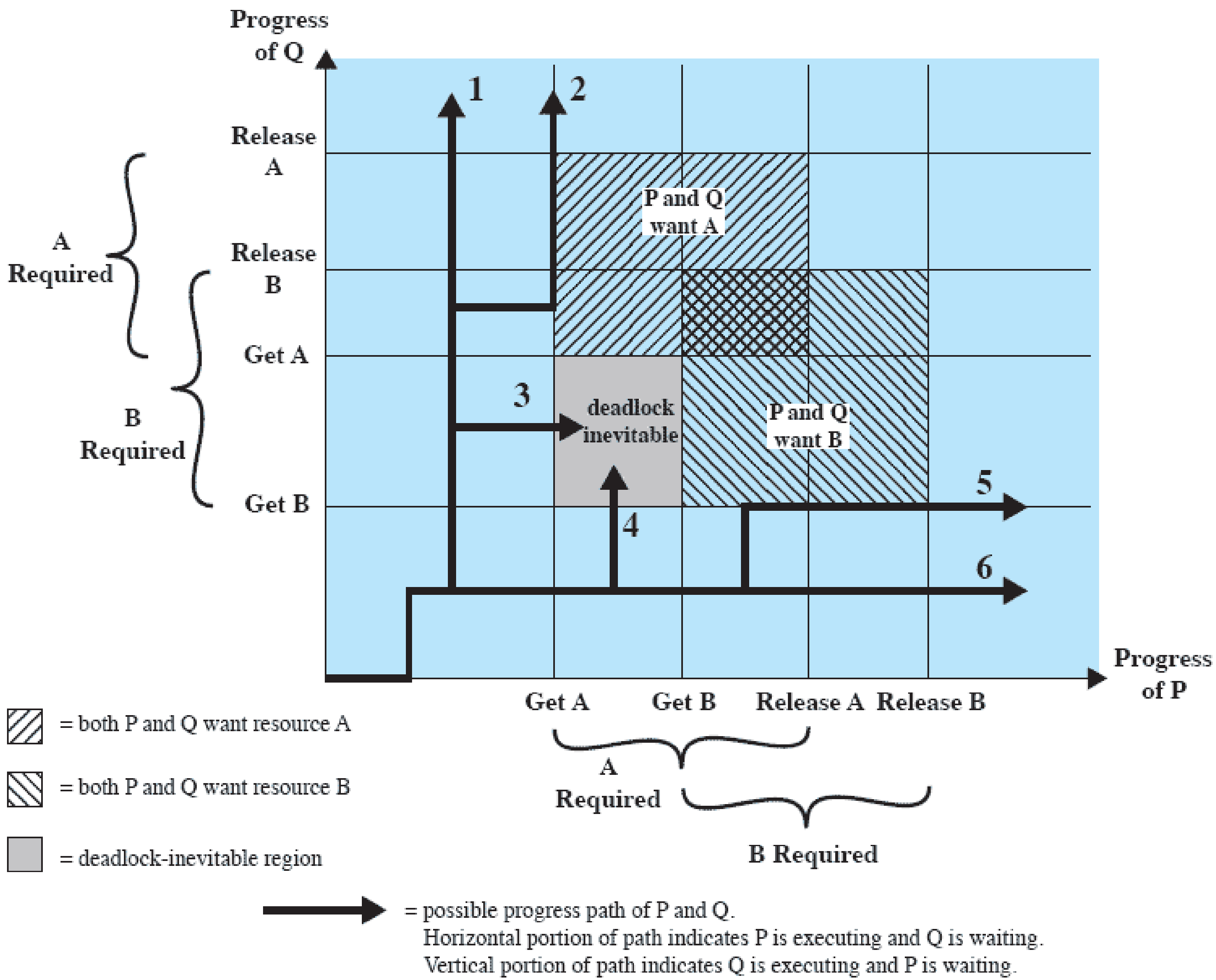


Figure 6.2 Example of Deadlock

Deadlock Avoidance

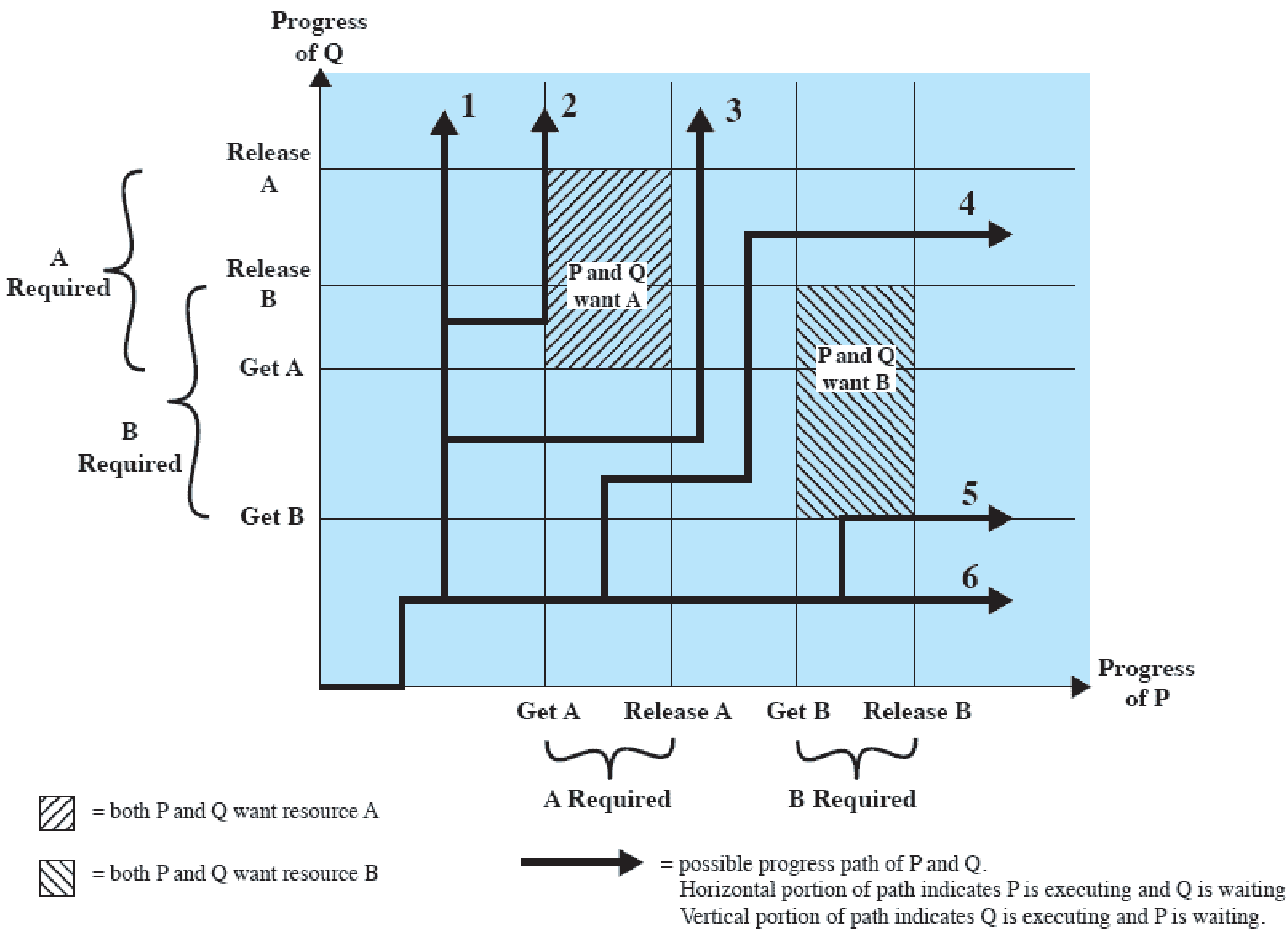


Figure 6.3 Example of No Deadlock [BACO03]

Reusable & Consumable Resources

Reusable:

- Processors, I/O channels, main and secondary memory, devices, and data structures such as files, databases, and semaphores
- Deadlock occurs if each process holds one resource and requests the other *(in case only one resource element exists)*
- … or a large amount in small chunks

Consumable:

- Created (produced) and destroyed (consumed)
- Interrupts, signals, messages, and information in I/O buffers
- Deadlock may occur if a Receive() message is blocking

Reusable Resources

Process P

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

Process Q

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

Figure 6.4 Example of Two Processes Competing for Reusable Resources

Deadlock occurs if: p0 p1 q0 q1 p2 q2

Reusable Resources

- Space is available for allocation of 200Kbytes, 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 occurs if receives blocking

P1

```
. . .
Receive(P2);
. . .
Send(P2, M1);
```

P2

```
. . .
Receive(P1);
. . .
Send(P1, M2);
```

Resource Allocation Graphs

- Directed graph that depicts a state of the system of resources and processes

(a) Resouce is requested

(b) Resource is held

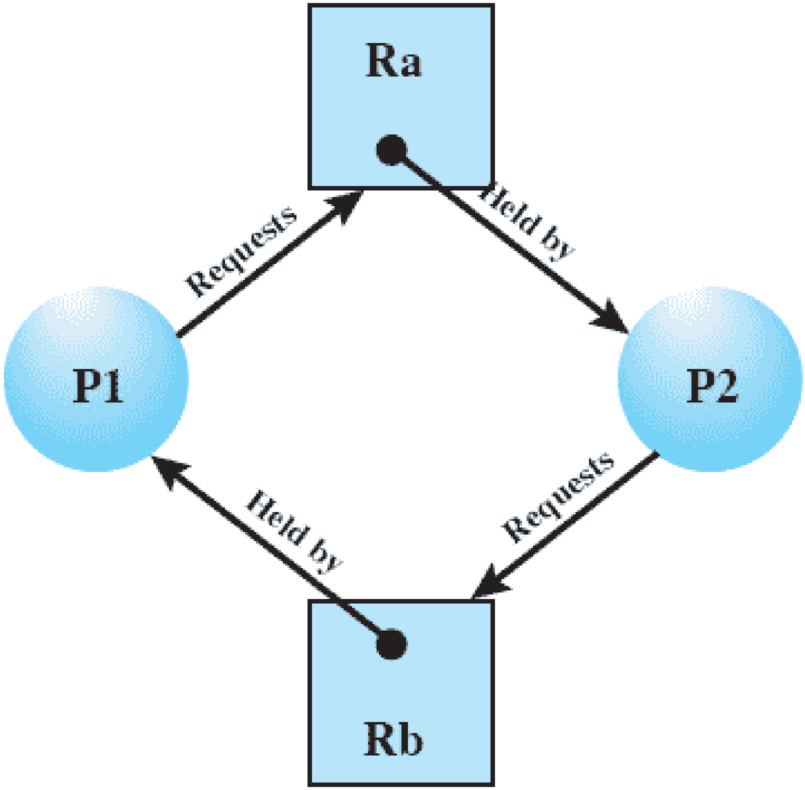
Conditions for Deadlock

- 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 (wrt. resources)
  - No resource can be forcibly removed form a process holding it
  - Requires rollback mechanism or saving state

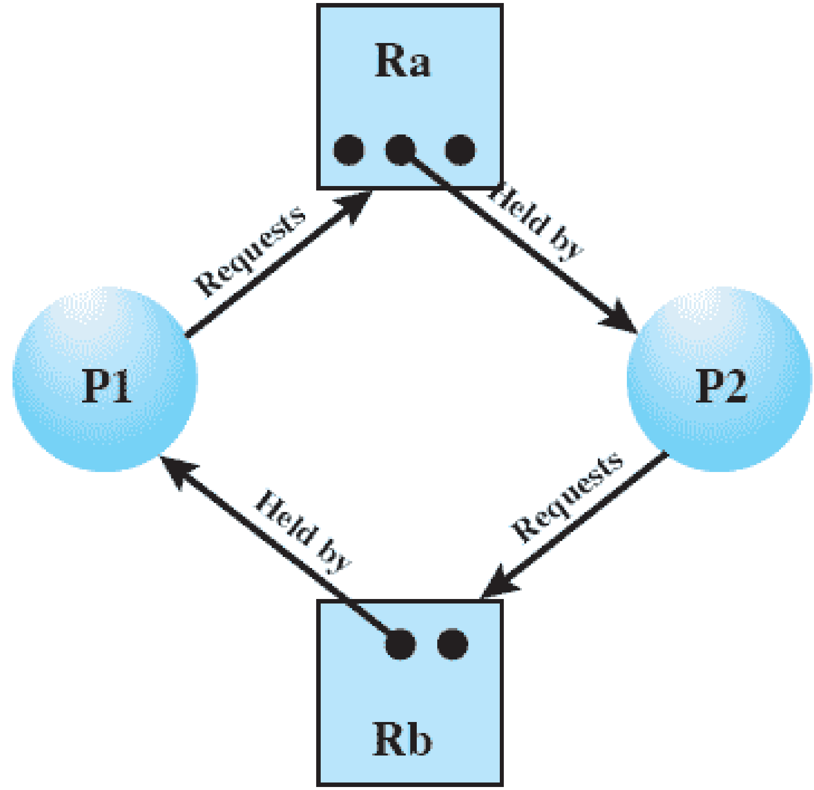
Conditions for Deadlock

- 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

Resource Allocation Graphs



(c) Circular wait



(d) No deadlock

Resource Allocation Graphs

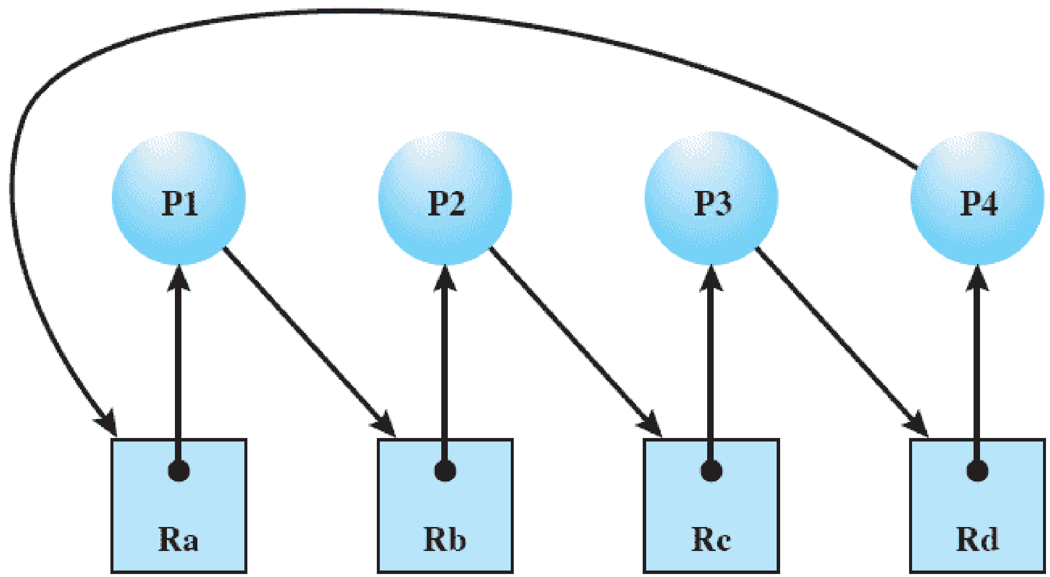


Figure 6.6 Resource Allocation Graph for Figure 6.1b

Possibility of Deadlock

- Mutual Exclusion
- No preemption
- Hold and wait

Necessary conditions

Existence of Deadlock

- Mutual Exclusion
- No preemption
- Hold and wait
- Circular wait

Sufficient conditions

Deadlock Prevention

... Design the system in such a way that no deadlock can occur. (remove one of the conditions)

- Mutual Exclusion
  - Must be supported by the OS
  - Can we remove this?
- Hold and Wait
  - Require a process request all of its required resources at one time (e.g, Ravenscar profile)

Deadlock Prevention

- No Preemption
  - Process must release resource and request again if it’s denied
  - OS may preempt a process to require it releases its resources (=> no two processes have same priority)
  - Requires saving and restoring state
- Circular Wait
  - Define a linear ordering of resource types
  - Lock resources following the ordering

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

Two Approaches to Deadlock Avoidance

1. Do not start a process if its demands might lead to deadlock
   - If the sum of all requested resources exceeds the resource budget, then don't admit the process.
   - Problems of this approach?

2. Do not grant an incremental resource request to a process if this allocation might lead to deadlock

Resource Allocation Denial

- Referred to as the banker’s algorithm
- State of the system is the current allocation of resources to process
- **Safe state** is where there is at least one sequence that does not result in deadlock
- **Unsafe state** is a state that is not safe
- <u>Goal: always have a safe state</u>

Are we in a safe 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	6	1	2
P3	2	1	1
P4	0	0	2

C – A

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

Resource vector **R**

R1	R2	R3
9	3	6

Available vector **V**

R1	R2	R3
0	1	1

(a) Initial state

Determination of a Safe State

Claim matrix C

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

Allocation matrix A

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

C – A

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

Resource vector **R**

R1	R2	R3
9	3	6

Available vector **V**

R1	R2	R3
6	2	3

(b) **P2 runs to completion**

Determination of a Safe State

Claim matrix **C**

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

Allocation matrix **A**

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

C – A

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

Resource vector **R**

R1	R2	R3
9	3	6

Available vector **V**

R1	R2	R3
7	2	3

(c) P1 runs to completion

Determination of a Safe State

Claim matrix C

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

Allocation matrix A

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

C – A

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

Resource vector R

R1	R2	R3
9	3	6

Available vector V

R1	R2	R3
9	3	4

(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**

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

C – A

	R1	R2	R3
P1	1	2	1
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
0	1	1

(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)

Figure 6.9 Deadlock Avoidance Logic

Deadlock Avoidance

- 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

	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**

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

Strategies Once Deadlock Detected

- Successively abort deadlocked processes until deadlock no longer exists
- Successively preempt resources until deadlock no longer exists

Advantages and Disadvantages

Table 6.1 Summary of Deadlock Detection, Prevention, and Avoidance Approaches for Operating Systems [ISLO80]

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

Dining Philosophers Problem

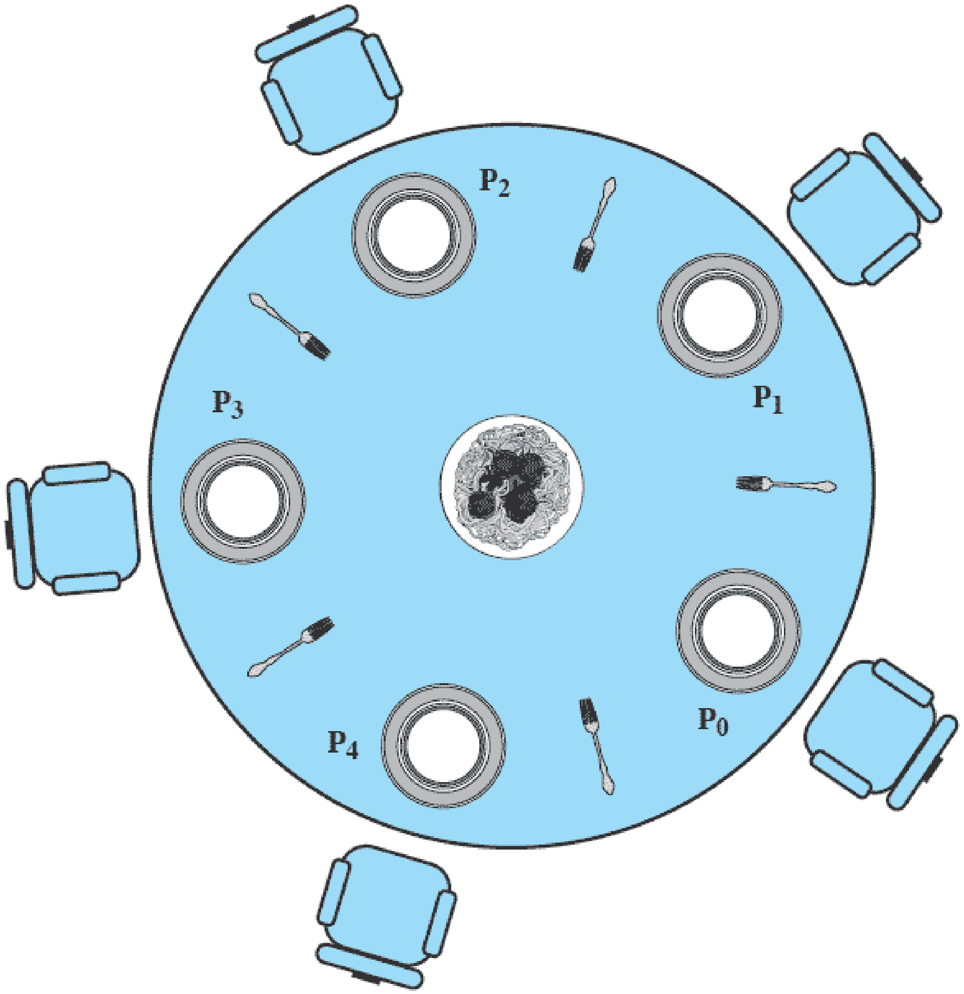


Figure 6.11 Dining Arrangement for Philosophers

Dining Philosophers Problem

```
/* 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));
     }
```

Figure 6.12 A First Solution to the Dining Philosophers Problem

Dining Philosophers Problem

```
/* 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));
}
```

Figure 6.13 A Second Solution to the Dining Philosophers Problem

Dining Philosophers Problem

```
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]);
}
```

Dining Philosophers Problem

```
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 */
   }
}
```

Figure 6.14 A Solution to the Dining Philosophers Problem Using a Monitor

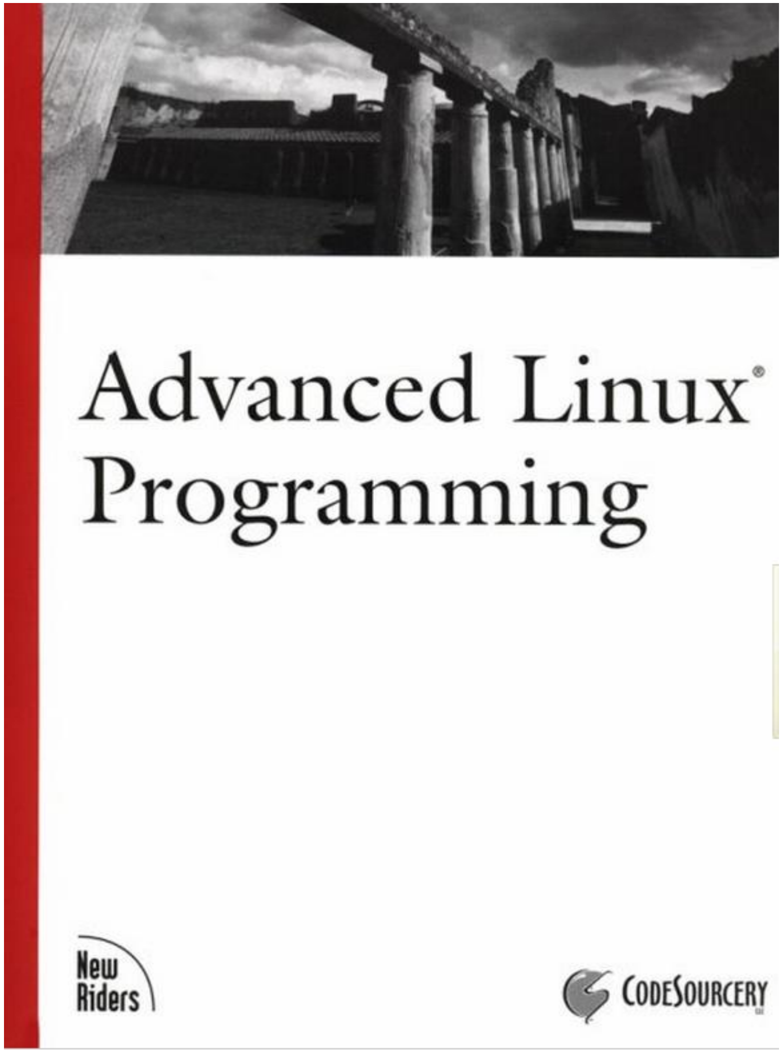
UNIX Concurrency Mechanisms

- Pipes: Producer/consumer data passing between two programs
- Messages
- Shared memory
- Semaphores
- Signals: implement asynchronous events

UNIX Signals

Value	Name	Description
01	SIGHUP	Hang up; sent to process when kernel assumes that the user of that process is doing no useful work
02	SIGINT	Interrupt
03	SIGQUIT	Quit; sent by user to induce halting of process and production of core dump
04	SIGILL	Illegal instruction
05	SIGTRAP	Trace trap; triggers the execution of code for process tracing
06	SIGIOT	IOT instruction
07	SIGEMT	EMT instruction
08	SIGFPE	Floating-point exception
09	SIGKILL	Kill; terminate process
10	SIGBUS	Bus error
11	SIGSEGV	Segmentation violation; process attempts to access location outside its virtual address space
12	SIGSYS	Bad argument to system call
13	SIGPIPE	Write on a pipe that has no readers attached to it
14	SIGALRM	Alarm clock; issued when a process wishes to receive a signal after a period of time
15	SIGTERM	Software termination
16	SIGUSR1	User-defined signal 1
17	SIGUSR2	User-defined signal 2
18	SIGCHLD	Death of a child
19	SIGPWR	Power failure

Try it out yourself…



http://www.advancedlinuxprogramming.com/