Today's class

- Deadlock

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Deadlock

- Permanent blocking of a set of processes that either compete for system resources or communicate with each other
- No efficient solution
- Involve conflicting needs for resources by two or more processes

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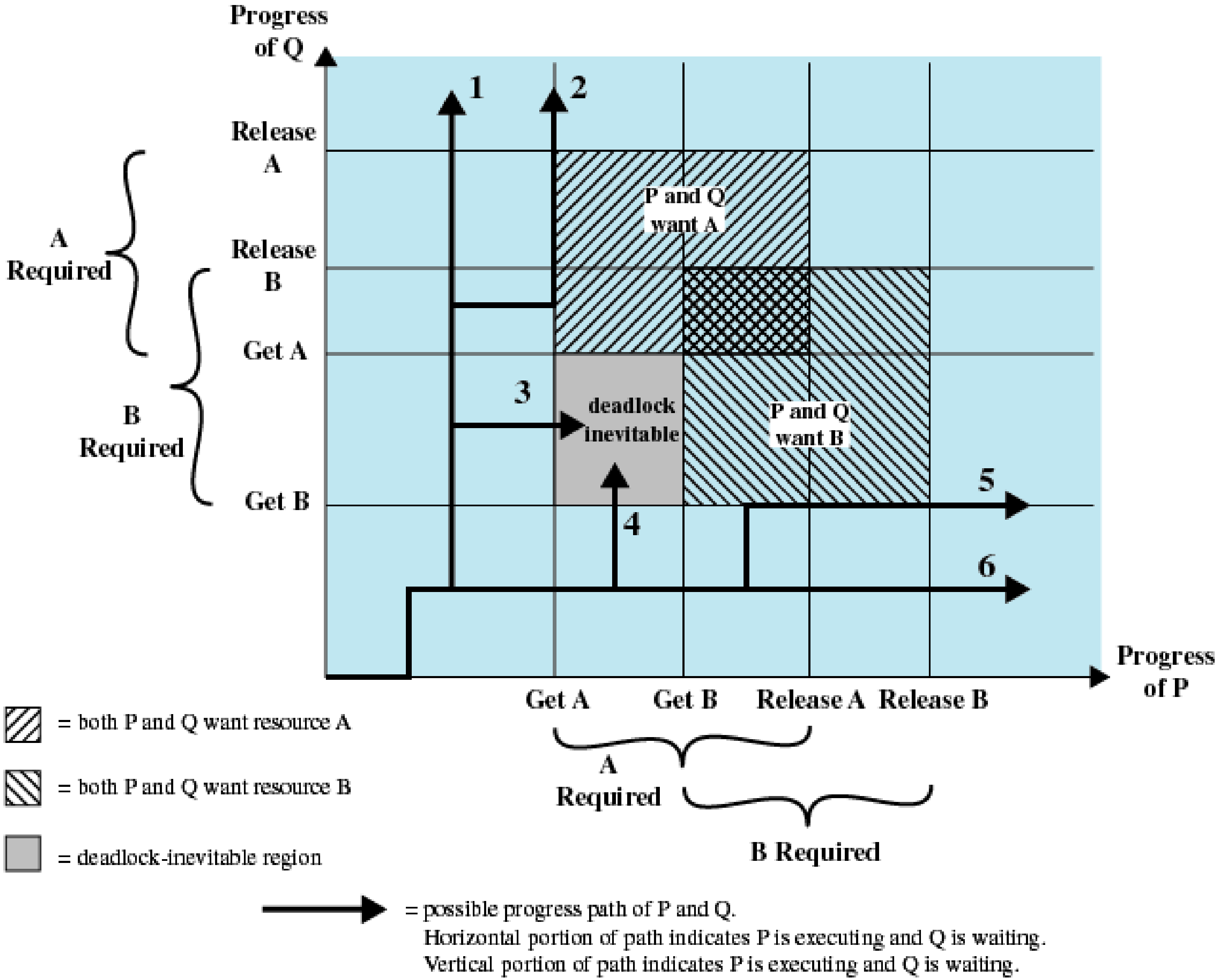

Figure 6.2 Example of Deadlock

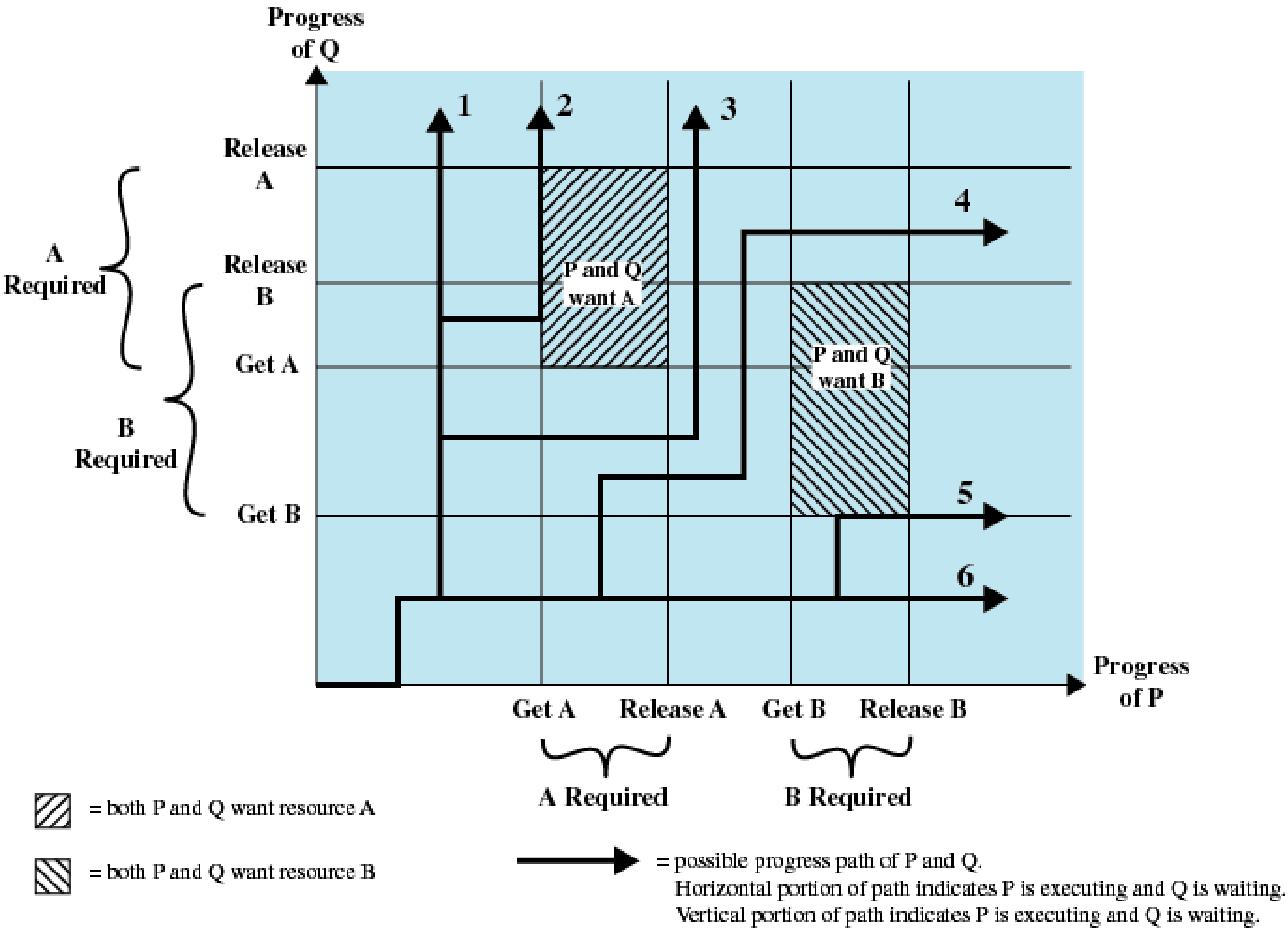

Figure 6.3 Example of No Deadlock [BACO03]

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Reusable Resources

- Used by only one process at a time and not depleted by that use
- Processes obtain resources that they later release for reuse by other processes
- 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

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Example of Deadlock

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

Another Example of Deadlock

- 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

- Created (produced) and destroyed (consumed)
- Interrupts, signals, messages, and information in I/O buffers
- Deadlock may occur if a Receive message is blocking
- May take a rare combination of events to cause deadlock

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Example of Deadlock

- Deadlock occurs if Receive is blocking

P1

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

P2

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

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Resource Allocation Graphs

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

(a) Resouce is requested

(b) Resource is held

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Resource Allocation Graphs

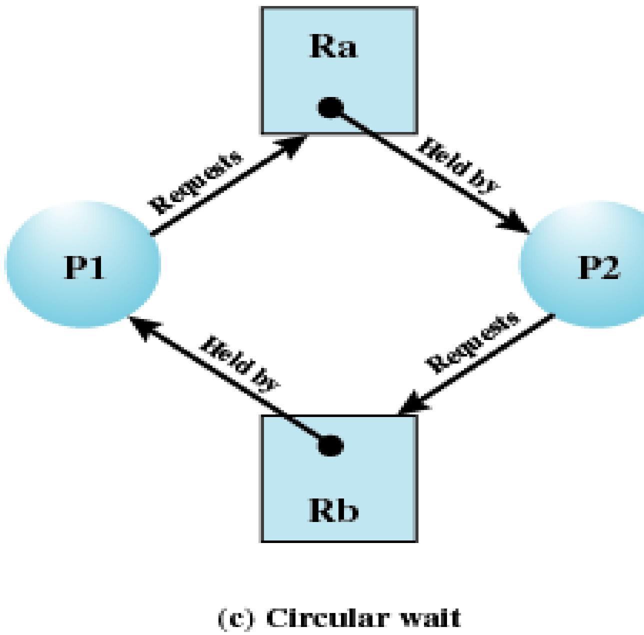

Figure 6.5 Examples of Resource Allocation Graphs

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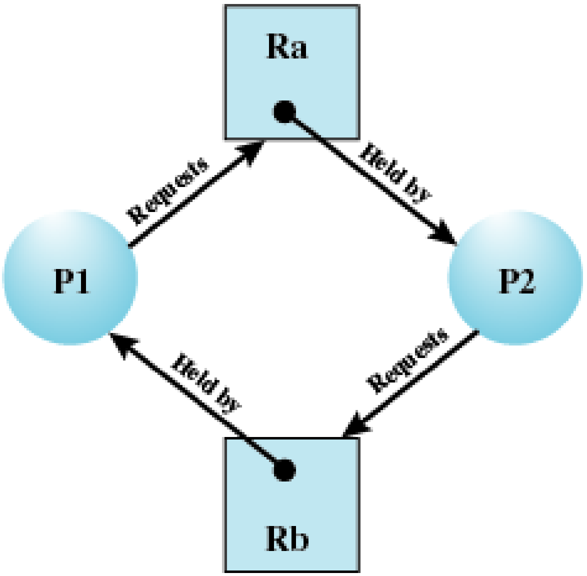
Conditions for Deadlock

- 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
  - No resource can be forcibly removed form a process holding it

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



(c) Circular wait

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Possibility of Deadlock

- Mutual Exclusion
- No preemption
- Hold and wait

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Existence of Deadlock

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

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Deadlock Prevention

- Strategy of deadlock prevention is to design a system in such a way that the possibility of deadlock is excluded
- Indirect method – prevent the occurrence of one of the three necessary conditions mentioned earlier
- Direct method – prevent the occurrence of a circular wait

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Deadlock Prevention

- Mutual Exclusion
  - Must be supported by the operating system, so it's hard to not allow this
- Hold and Wait
  - Require a process request all of its required resources at one time
  - Block the process until all requests can be granted simultaneously
  - Inefficient
    - May wait a long time for all resources to become available
    - Resources allocated to a process may be unused for a long period of time

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Deadlock Prevention

- No Preemption
  - Process must release resource and request again
  - Operating system may preempt a process to require it releases its resources
- Circular Wait
  - Define a linear ordering of resource types

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Deadlock avoidance

- In deadlock prevention, resource requests are restrained to prevent one of the four conditions of deadlock
- This leads to inefficient use of resources and inefficient execution of processes
- Deadlock avoidance allows the three necessary conditions for deadlock but makes judicious choices to assure that the deadlock point is never reached

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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 request

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Two Approaches to Deadlock Avoidance

- Do not start a process if its demands might lead to deadlock
- Do not grant an incremental resource request to a process if this allocation might lead to deadlock

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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 of resource allocation to processes that does not result in deadlock
- Unsafe state is a state that is not safe

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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

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

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Determination of a Safe State P1 Runs to Completion

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

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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

	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**

(a) Initial state

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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	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**

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

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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

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Deadlock Detection

- Deadlock prevention strategies solve the problem of deadlock by limiting access to resources and imposing restrictions on processes. They are conservative in nature.
- Deadlock detection approaches grant resource requests whenever possible. Periodically, an algorithm that detects the circular wait condition is performed and recovery is attempted.

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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

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Strategies once Deadlock Detected

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

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Selection Criteria Deadlocked Processes

- Least amount of processor time consumed so far
- Least number of lines of output produced so far
- Most estimated time remaining
- Least total resources allocated so far
- Lowest priority

Dining Philosophers Problem

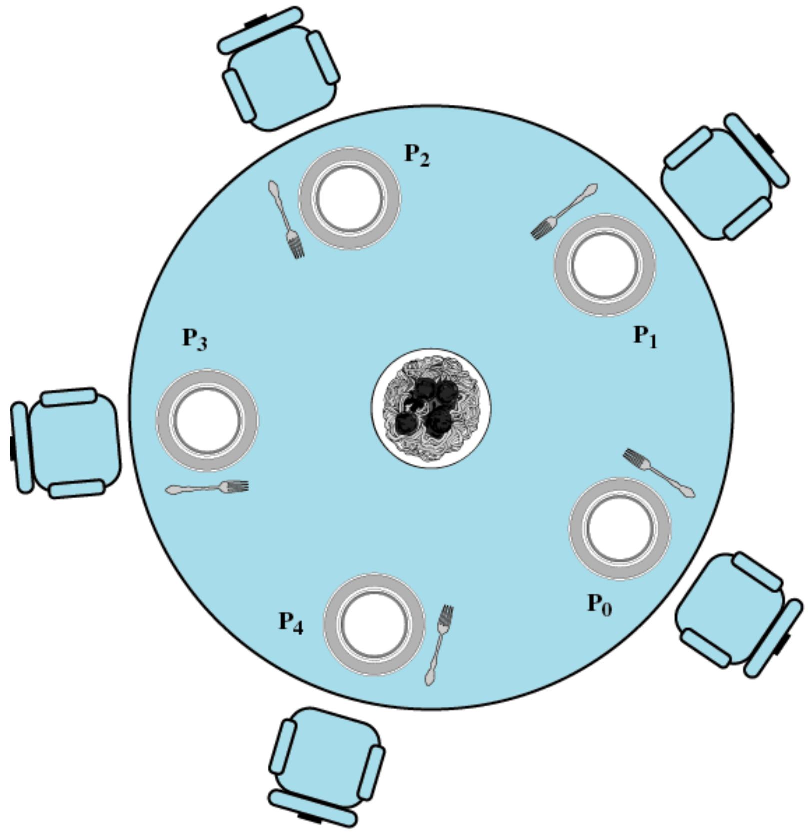

Figure 6.11 Dining Arrangement for Philosophers

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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

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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