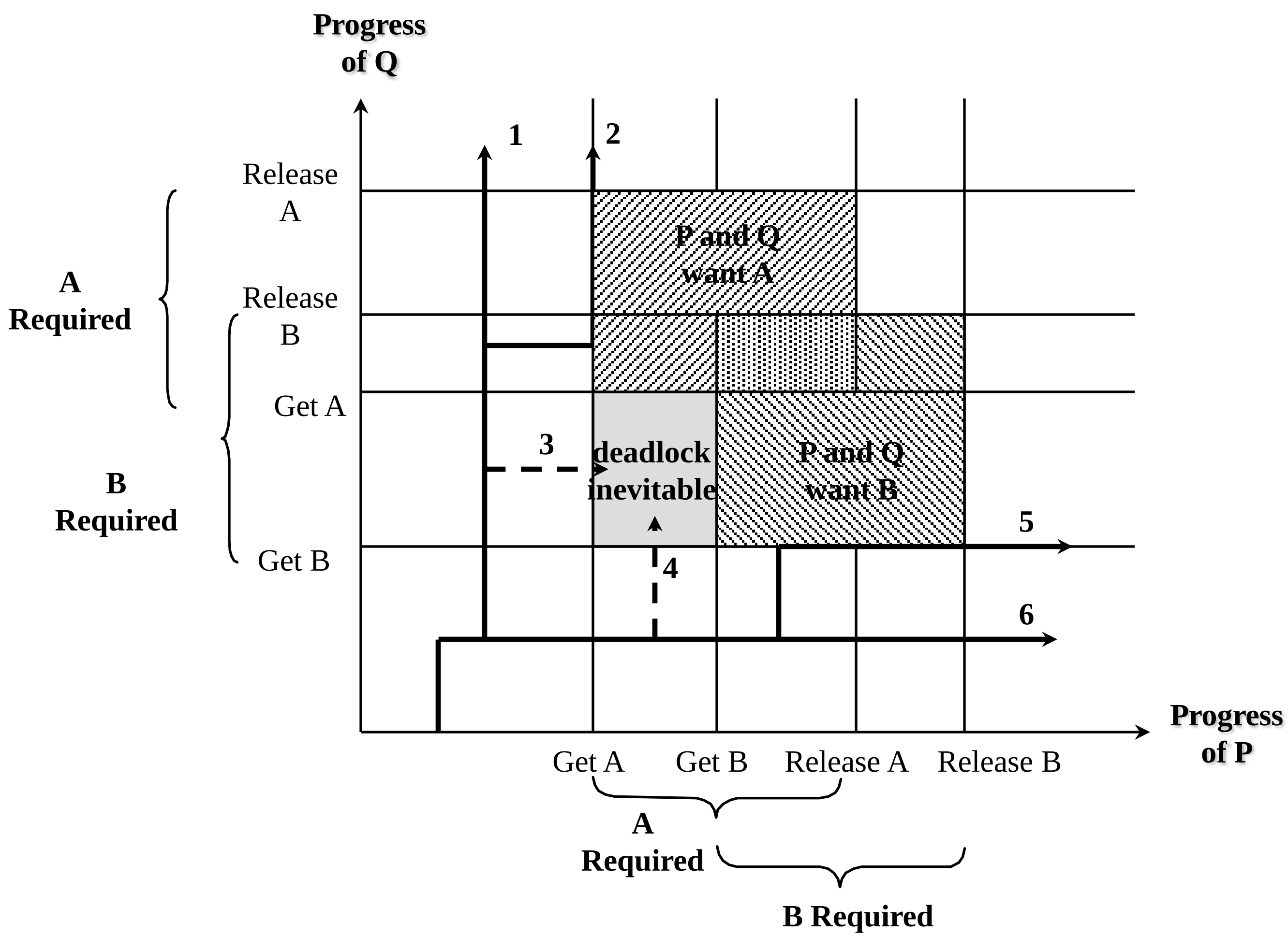
Concurrency: Deadlock and Starvation

Chapter 6

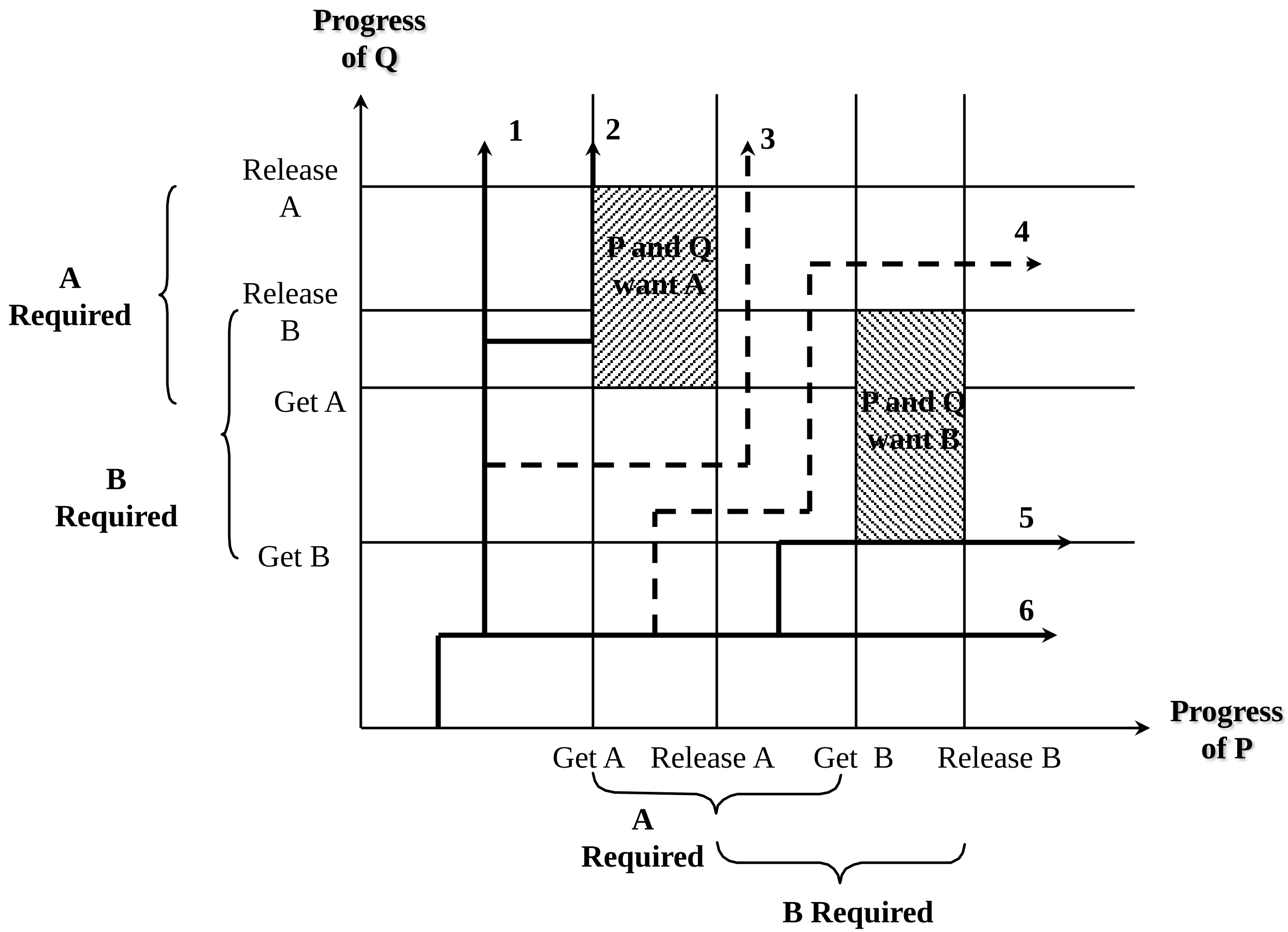
Deadlock

- ✓ Permanent blocking of a set of processes that either compete for system resources or communicate with each other
- ✓ Involve conflicting needs for resources by two or more processes

Example of Deadlock



Example of No Deadlock



Reusable, Nonsharable Resources

- ✓ Used by <u>one process at a time</u> and not depleted by that use
- ✓ Processes obtain resources that they later release for reuse by other processes
- ✓ Processor time, I/O channels, main and secondary memory, files, databases, and semaphores
- ✓ Deadlock occurs if each process holds one resource and requests the other

Example of Deadlock

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

P1	P2
. . .	. . .
Request 80K bytes;	**Request 70K bytes;**
. . .	. . .
Request 60K bytes;	**Request 80K bytes;**

- Deadlock occurs if both processes progress to their second request

Consumable Resources

- Created (produced) and destroyed (consumed) by a process
- 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

Example of Deadlock

- ✓ Deadlock occurs if receive is blocking

```
P1
. . .
Receive(P2);
. . .
Send(P2);
```

```
P2
. . .
Receive(P1);
. . .
Send(P1);
```

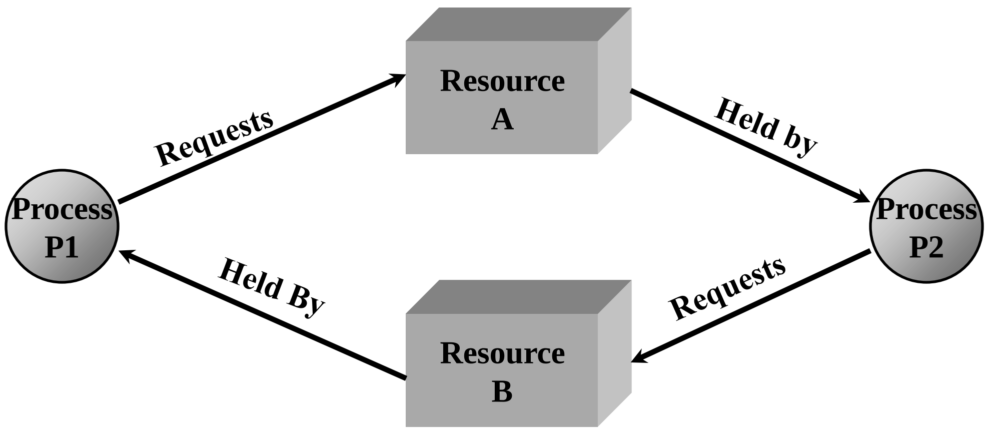
Conditions for Deadlock

- ✓ Mutual exclusion
  - only one process may use a resource at a time
- ✓ Hold-and-wait
  - a process is allowed to hold allocated resources while awaiting assignment of others
- ✓ No preemption
  - no resource can be forcibly removed from 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
  - Necessary for deadlock to happen
  - Sufficient under certain circumstances
- Other conditions are necessary but not sufficient for deadlock

Circular Wait



Deadlock Prevention

- Disallowing "Mutual Exclusion"
  - cannot be achieved, due to the nature of non-sharable resources
- Disallowing "Hold-and-Wait"
- Require that a process request all its required resources ***at once***

  Block the process until all requests can be granted simultaneously
- Problem:
  - process can be held up for a long time waiting for all its requests
  - starvation is possible

Deadlock Prevention

- Disallowing "No Preemption"
  - If a process is denied a further request, the process must release the original resources
  - If a process cannot obtain a resource, the process may have to release the resources it already holds. Process must have capability to restore these resources to current state.
  - Practical only only when the state can be easily saved and restored later, *such as the CPU or main memory.*

Deadlock Prevention

✓ Disallowing "Circular Wait"

- define a linear ordering for resources
- once a resource is obtained, only those resources that have id number higher can be obtained (if a process requests a resource with lower id number than what it has obtained so far, that request is denied)
- Problem: may deny resources for no reason other than the "wrong" id number. Low resource utilization.

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
- ✓ Not necessary to preempt and rollback processes

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 Avoidance: The Banker's Algorithm

- Assume: M resources $R_1, \ldots, R_M$
  - system has several identical copies of each resource: $Q_1, \ldots, Q_M$ (maximums/resource)
  - a process can ask for several copies of each resource type; doesn't care which specific copies are given as long as they are of the requested type
- State: a particular allocation of resources to processes:

	P1	P2	P3	P4
R1 Q1=9	3	0	1	2
R2 Q2=7	2	4	0	1
R3 Q3=4	0	0	1	2

processes (columns)

resources (rows)

Deadlock Avoidance: Banker's Algorithm

- Safe state:
  - state where we can order the remaining processes so they can run to completion without a deadlock.

- A safe state test:

```
// Let L be the list of unfinished processes
while L is non-empty do
   if can find process P in L whose
     outstanding requests can be satisfied
     using available resources then {
        delete P from L
        add all resources held by P
              to the pool of available
              resources
   } else return(unsafe)
return (safe)
```

- **This is only a *sufficient* - <u>not a necessary</u>, condition for safety!**

Deadlock Avoidance: Banker’s Algorithm

- ✓ **Request granting algorithm** `req(P,Qty,Rsrc):`

```
if Qty+allocated(P,Rsrc) > limit(Rsrc) then
     abort P;
 tentatively allocate request;
 if safe(resulting state) then
     grant request;
 else
     suspend P on Rsrc;
```

Deadlock Detection

- Operating system checks for deadlock
- When:
  - Check at resource request time
    - early detection of deadlock
    - frequent checks consume processor time
  - Check periodically
    - deadlocks stay undetected between checks

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 once again
- ✓ Successively abort deadlocked processes until deadlock no longer exists
- ✓ Successively preempt resources until deadlock no longer exists (if resource preemption is feasible and cost-effective)

Selection Criteria Deadlocked Processes

- ✓ Least amount of processor time consumed so far (so the least amount of work will be wasted)
- ✓ Least number of lines of output produced so far (so cheaper to preempt file resources)
- ✓ Most estimated time remaining (presumably, this process is most deadlock-prone)
- ✓ Least total resources allocated so far
- ✓ Lowest priority

Deadlock Detection Algorithms

- *Single instance* of each resource
  - draw a ***resource request graph*** as follows:
    - arc Proc --> Res exists if Proc requested Res
    - arc Proc <-- Res exists if Proc holds Res
  - The system has a deadlock **iff** the resource request graph has a cycle
    - Why?
    - Multiple resource instances:
      - is the cycle condition necessary for the existence of a deadlock?
      - Is it sufficient?

Deadlock Detection Algorithms

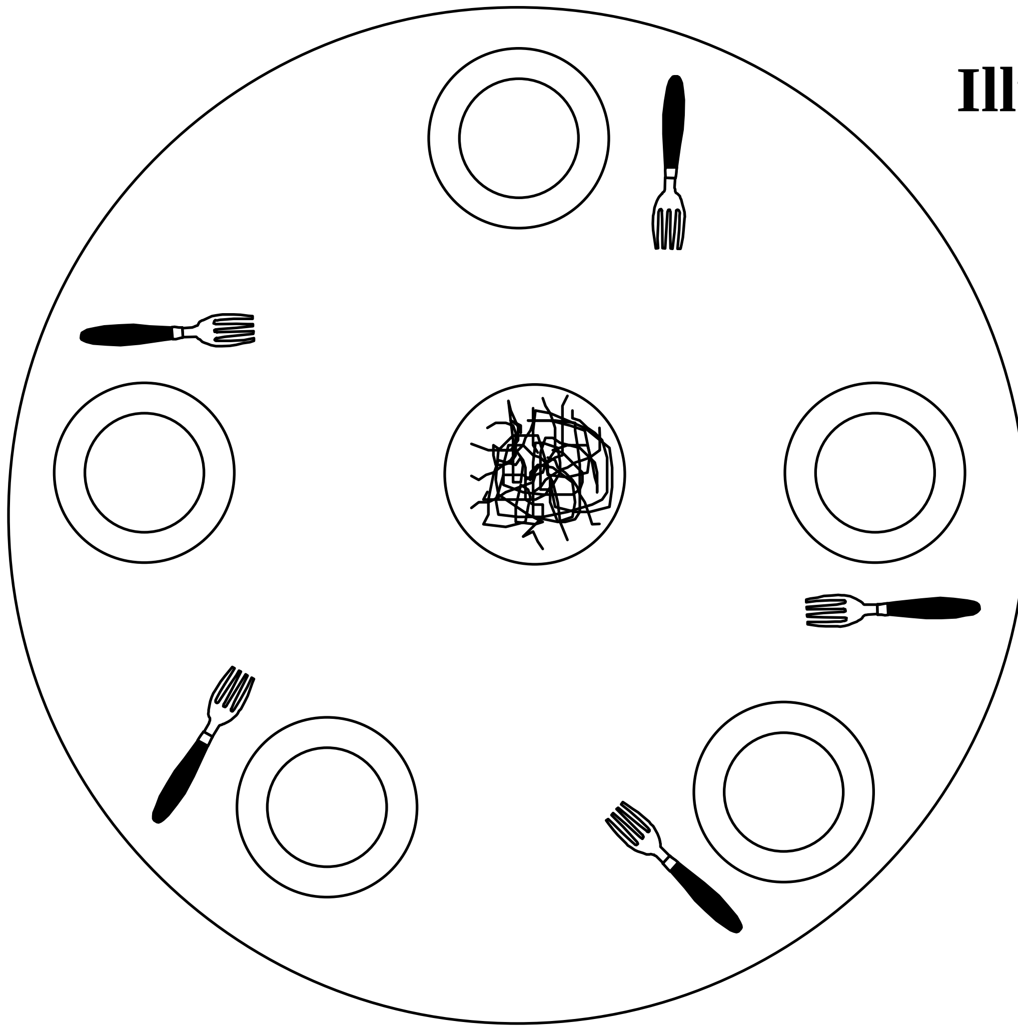
- Multiple resource instances

  similar to the safety test:

```
// Let L be the list of all unfinished processes
while nonempty(L) do{
   if found a process P in L all of whose requests
        can be satisfied with available resources do {
        delete P from L;
        add all resources held by P to the pool
              of available resources;
   } else return(deadlock);
}
return(nodedlock);
```

- The algorithm ensures that if *none of the processes issues additional resource requests*, then *there is no deadlock*.

Dining Philosophers Problem



Illustrates:

-deadlocks

-starvation

Dining Philosophers Solutions

```
// 5 philosophers
// & forks
semaphore  fork[4];
```

With starvation & deadlock:

```
repeat
  <think>
 wait(fork[I]);
 wait(fork[(I+1)mod 5]);
  <eat>
 signal(fork[I]);
 signal(fork[(I+1)mod 5]);
forever
```

- ✓ Give a scenario for deadlock.
- ✓ Give a scenario for starvation.

```
// at most 4 out of 5
//  philosophers eat simultaneously
semaphore  room = 4;
```

No starvation or deadlock:

```
repeat
  <think>
 wait(room);
 wait(fork[I]);
 wait(fork[(I+1)mod 5]);
  <eat>
 signal(fork[(I+1)mod 5]);
 signal(fork[I]);
 signal(room);
forever
```

Interprocess Concurrency Mechanisms

- *Pipes*
  - buffer allowing two processes to communicate
  - queue written by one process and read by another
  - operating system enforces mutual exclusion for writing and reading the pipe
  - write requests are immediately executed if there is room in the pipe, otherwise the process is blocked
  - read request is blocked if attempts to read more bytes than currently available in the pipe

Inter-process Concurrency Mechanisms

- *Messages*
  - block of text with accompanying type
  - receiver can either retrieve messages in FIFO order or by type
  - process suspends when trying to send a message to a queue that is full
  - process suspends when reading from an empty queue
  - process trying to read a certain type of messages *fails*, not *suspended*

Inter-process **Concurrency Mechanisms**

✓ *Shared memory*

- common block of virtual memory shared by multiple processes
- fast form of interprocess communication
- mutual exclusion must be provided by the processes, not the operating system

Inter-process Concurrency Mechanisms

- ***Semaphores***
  - `wait` and `signal` and **much** more
  - operating system handles all these requests
- ***Signals (UNIX-derived OS only)***
  - software mechanism that informs a process of the occurrence of asynchronous events
  - e.g. *interrupt process*, *quit process*, *kill process*, *floating point exception*, ...

Solaris *Thread* Synchronization Primitives

- Mutual exclusion lock
  - prevents more than one thread from proceeding when the lock is acquired
- Semaphores
  - used for incrementing and decrementing

- *Unlike the general synchronization primitives (which operate on resources shared by all threads of a process), these synchronization resources aren't shared by threads in the same process!*

Solaris Thread Synchronization Primitives

- Multiple readers, single writer locks
  - multiple threads have simultaneous read-only access
  - only one thread has access for writing
- Condition variables
  - used to wait until a particular condition is true

Windows NT Concurrency Mechanisms

- Synchronization Objects
  - process
  - thread
  - file
  - console input
  - file change notification
  - mutex
  - semaphore (counting)
  - event
  - waitable timer

- Each synchronization object can be in either *signaled* or *un-signaled* state
- Un-signaled state:
  - thread can be suspended on synchronization objects that are un-signaled
- Signaled state:
  - when object is in signaled state, all threads waiting on this object wake up