Chapter 3: Processes

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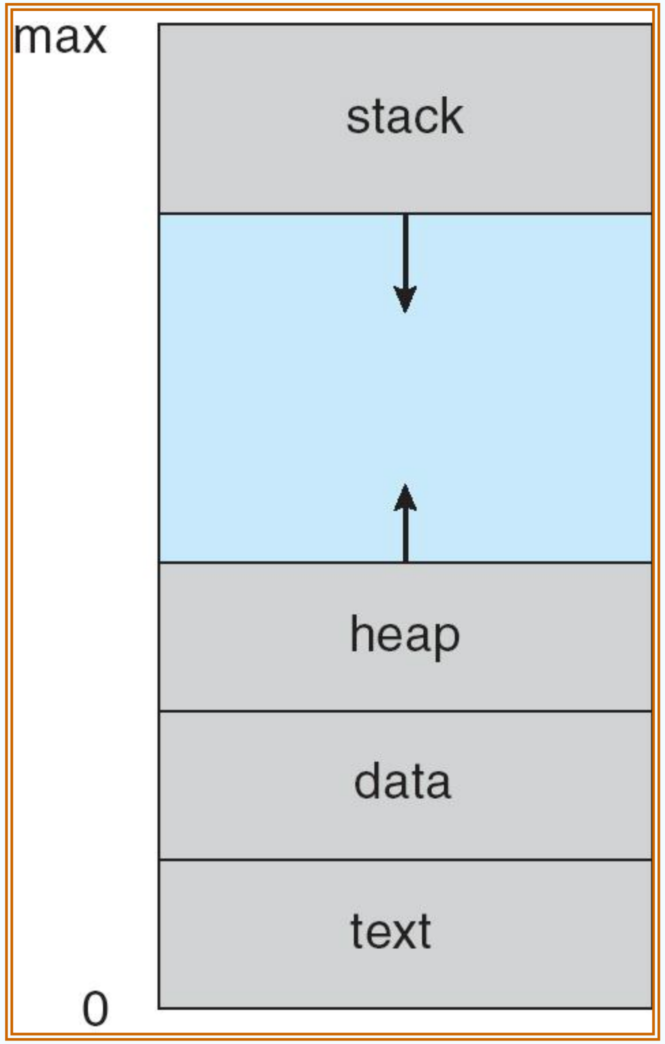
- Process Concept
- Process Scheduling
- Operations on Processes
- Cooperating Processes
- Interprocess Communication
- Communication in Client-Server Systems

Process Concept

- An operating system executes a variety of programs:
  - Batch system – jobs
  - Time-shared systems – user programs or tasks
- Textbook uses the terms *job* and *process* almost interchangeably
- Process – a program in execution; process execution must progress in sequential fashion
- A process includes:
  - text section (code)
  - program counter
  - stack (function parameters, local vars, return addresses)
  - data section (global vars)
  - heap (dynamically allocated memory)

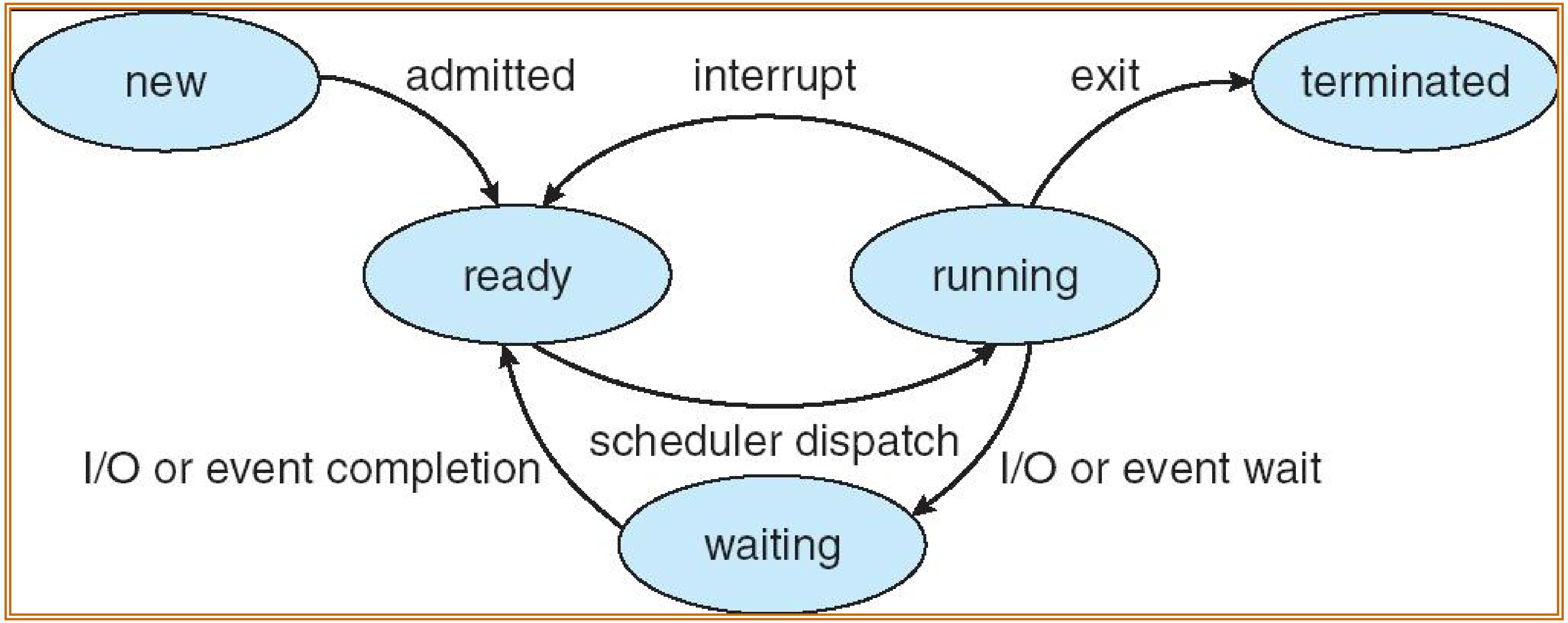
Process in Memory



Process State

- As a process executes, it changes *state*
  - **new**: The process is being created
  - **running**: Instructions are being executed
  - **waiting**: The process is waiting/blocked for some event to occur
  - **ready**: The process is waiting to be assigned to a processor
  - **terminated**: The process has finished execution

Diagram of Process State

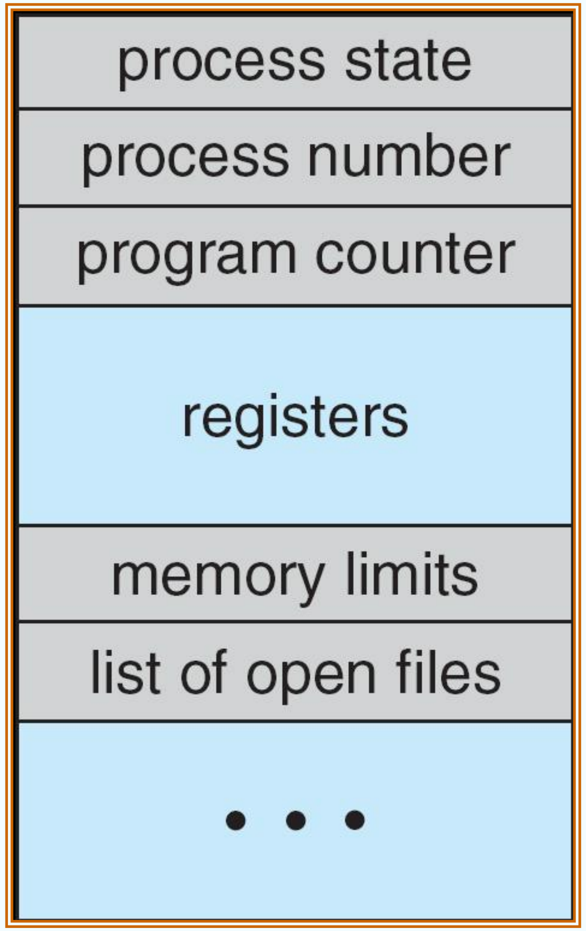


Process Control Block (PCB)

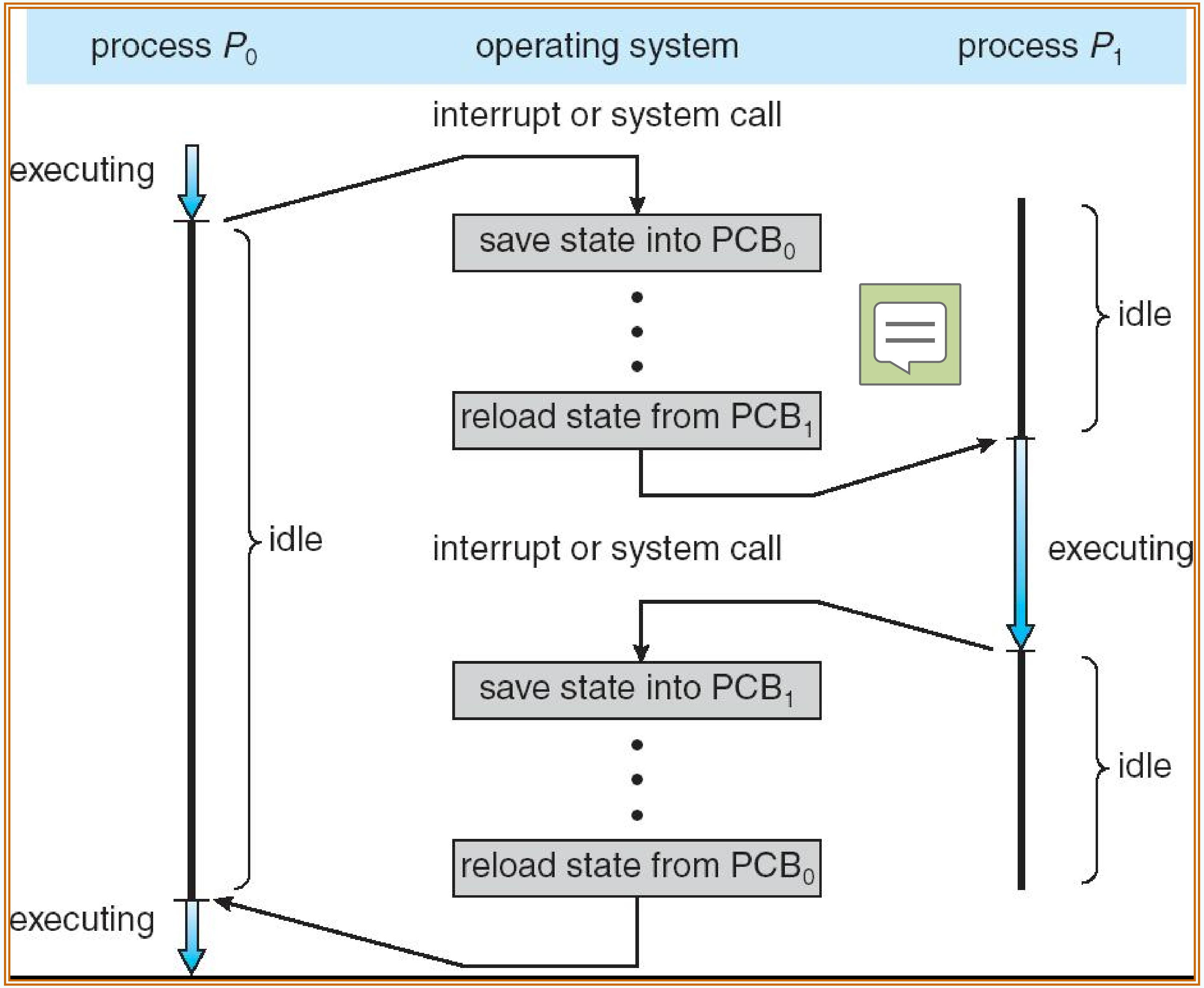
Information associated with each process

- Process state
- Program counter
- Contents of CPU registers
- CPU scheduling information
- Memory-management information
- Accounting information
- I/O status information

Process Control Block (PCB)



CPU Switch From Process to Process



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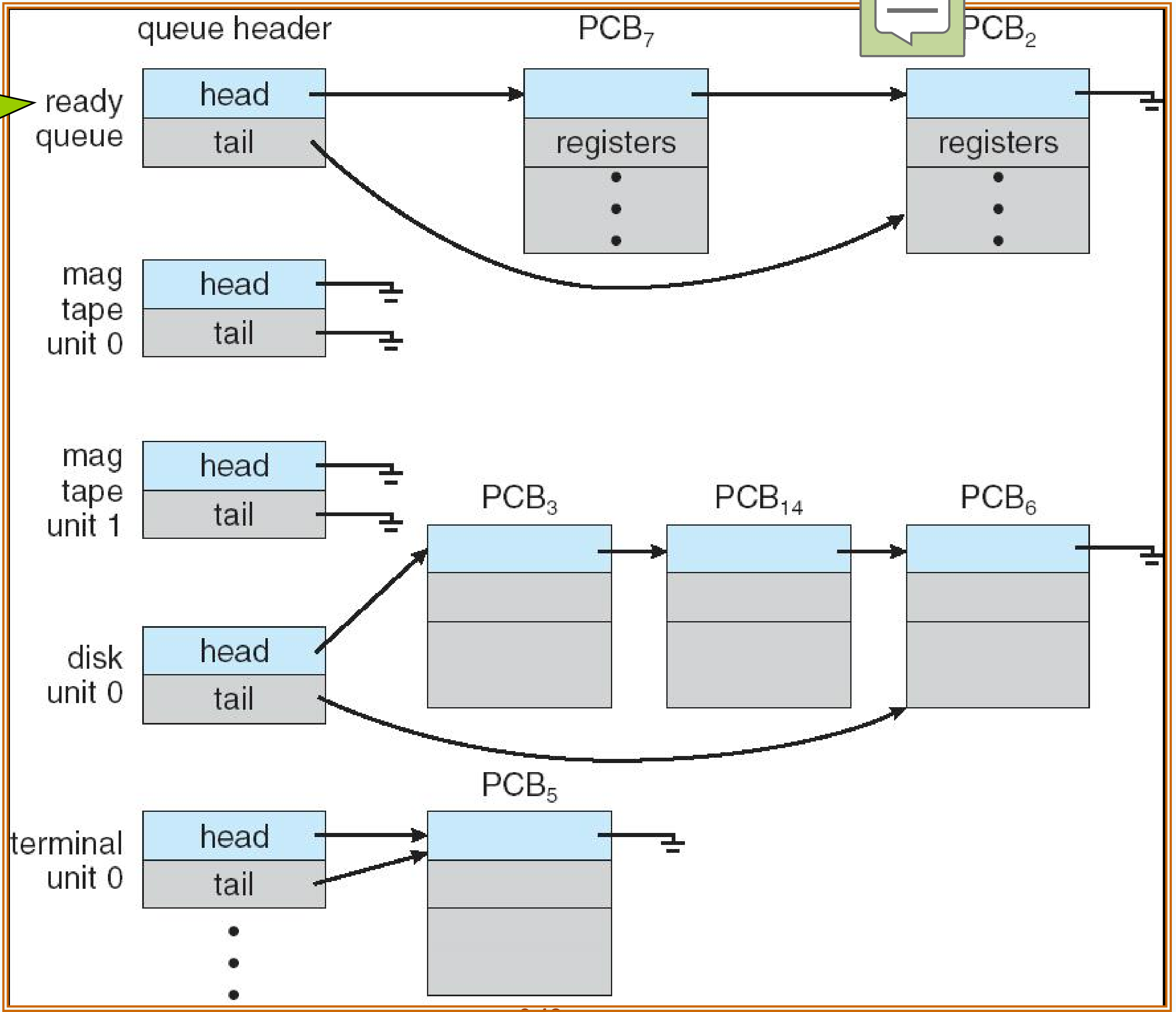
Process Scheduling Queues

- **Job queue** – set of all processes in the system
- **Ready queue** – set of all processes residing in main memory, ready and waiting to execute
- **Device queues** – set of processes waiting for an I/O device
- Processes migrate among the various queues

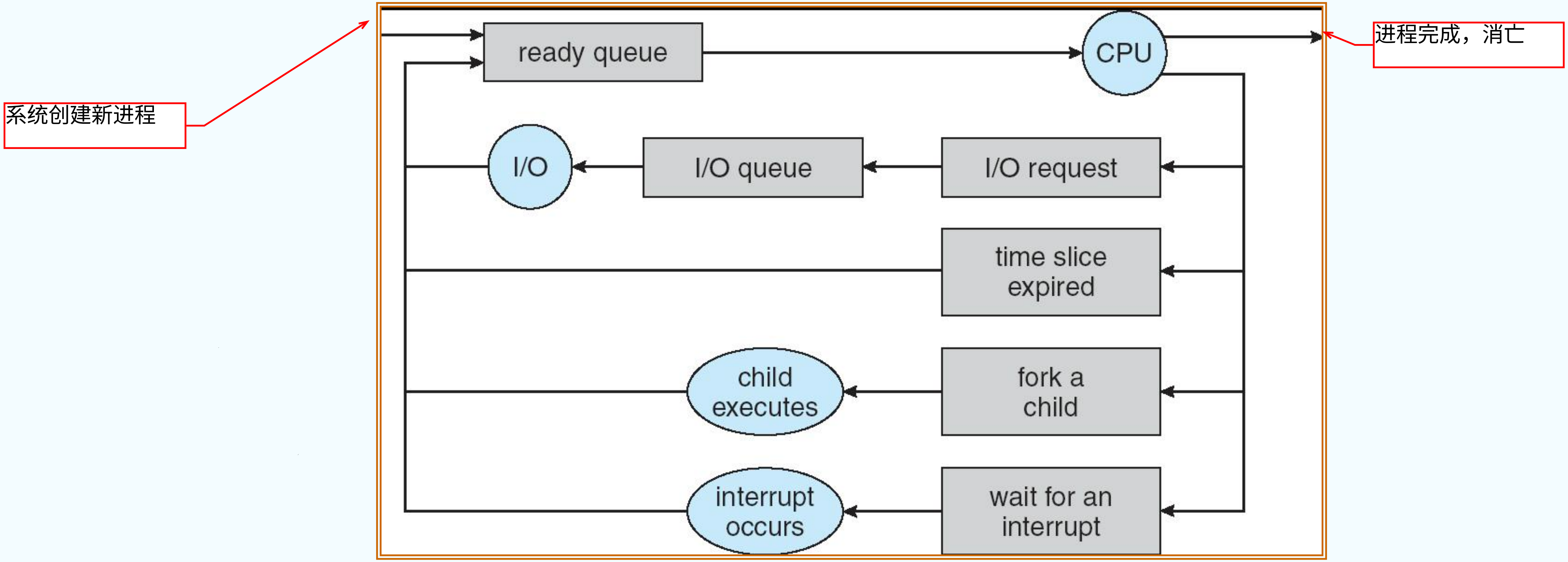
Ready Queue And Various I/O Device Queues

The CPU queue



Representation of Process Scheduling

A queueing-diagram



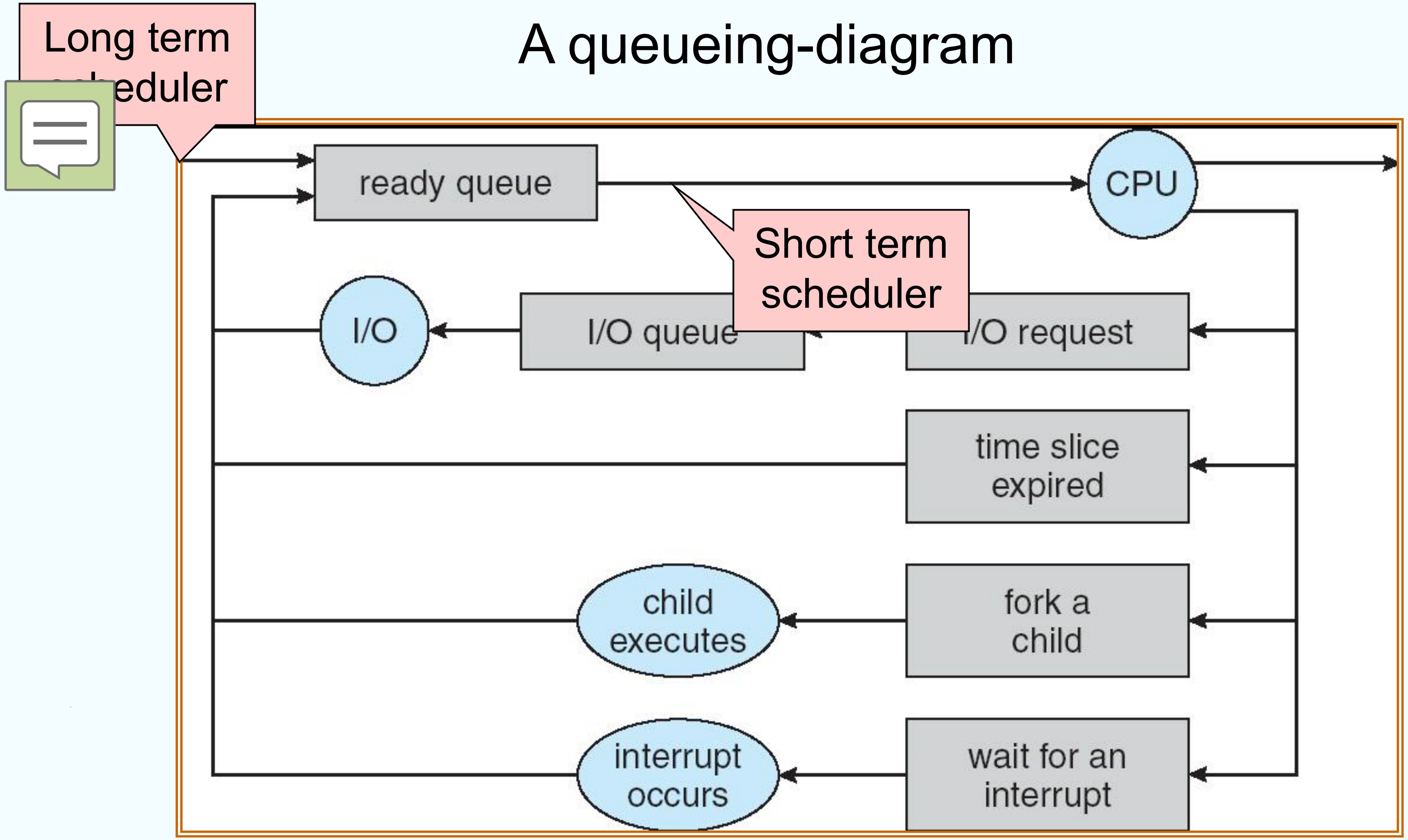
Schedulers

- What is a scheduler? A piece of program
- **Long-term scheduler** (or job scheduler) – selects which processes should be brought into memory (the ready queue)
- **Short-term scheduler** (or CPU scheduler) – selects which process should be executed next and allocates CPU

UNIX and Windows do not use long-term scheduling

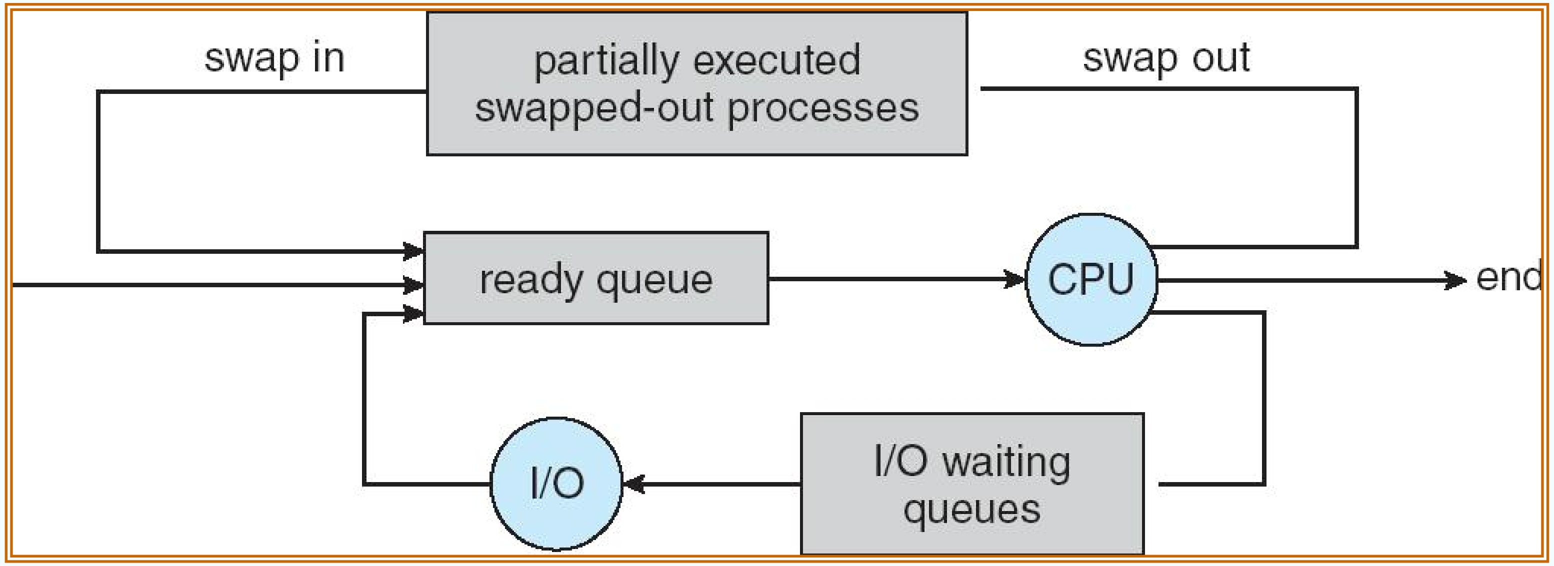
Representation of Process Scheduling

A queueing-diagram



Addition of Medium Term Scheduling

Sometimes, it can be good to swap processes out.



Schedulers (Cont.)

- Short-term scheduler is invoked very frequently (milliseconds) $\Rightarrow$ (must be fast)
- Long-term scheduler is invoked very infrequently (seconds, minutes) $\Rightarrow$ (may be slow)
- The long-term scheduler controls the *degree of multiprogramming*
- Processes can be described as either:
  - **I/O-bound process** – spends more time doing I/O than computations, many short CPU bursts
  - **CPU-bound process** – spends more time doing computations; few very long CPU bursts

Need to select good combination of CPU bound and I/O bound processes.

Context Switch

- When CPU switches to another process, the system must save the state of the old process and load the saved state for the new process
- Context-switch time is overhead; the system does no useful work while switching - typically takes milliseconds
- Time dependent on hardware support. In the SPARC architecture, groups of registers are provided.

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Process Creation

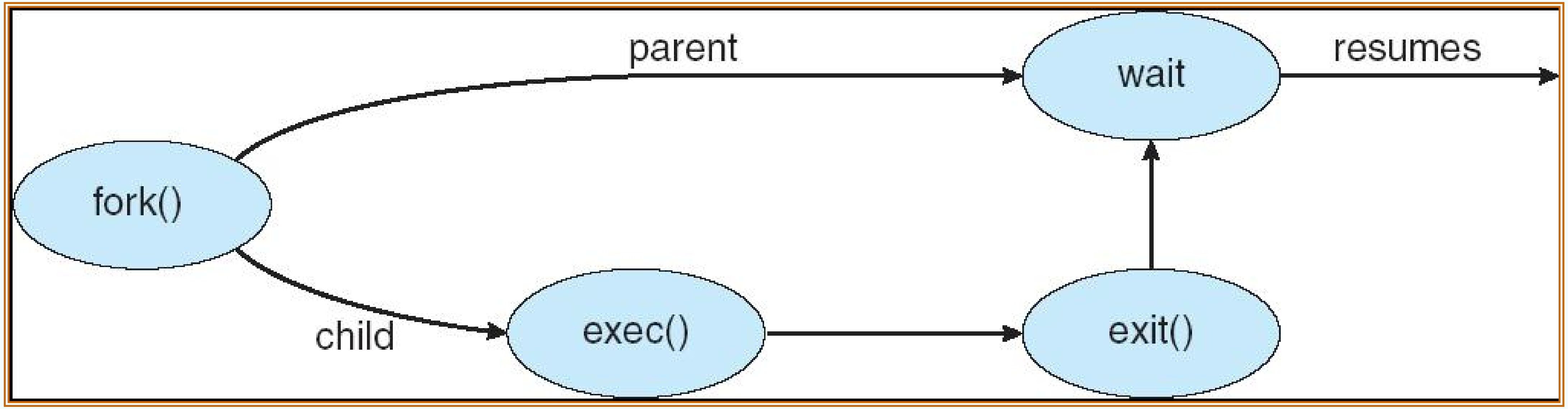
- Parent process creates children processes, which, in turn create other processes, forming a tree of processes
- Resource sharing
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution
  - Parent and children execute concurrently
  - Parent waits until children terminate

Process Creation (Cont.)

- Address space
  - Child duplicate of parent
  - Child has a program loaded into it
- UNIX examples
  - **fork** system call creates new process
  - **exec** system call used after a **fork** to replace the process' memory space with a new program

There are a lot "exec" APIs. For example: *execve() execv() execle() execvp() execlp()* etc.

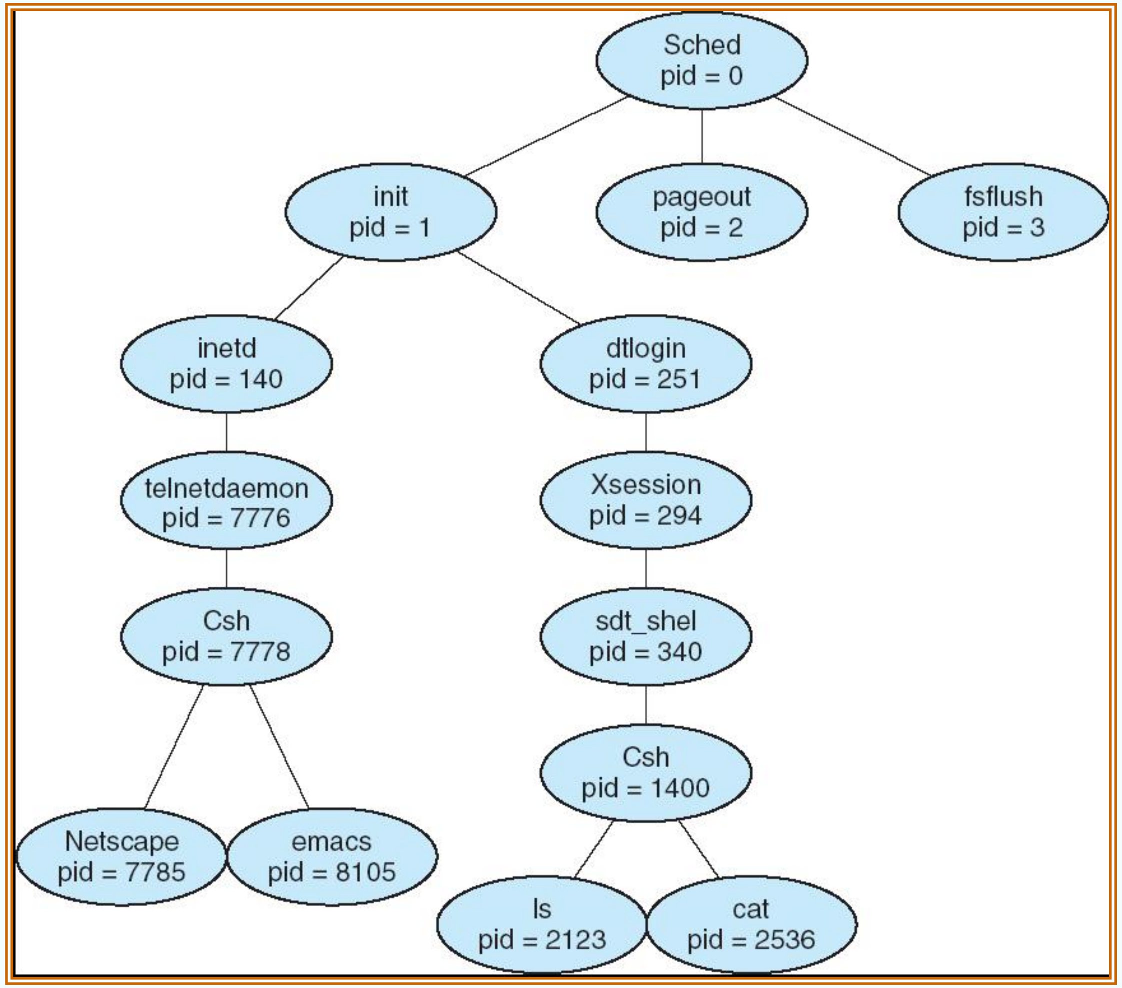
Process Creation



C Program Forking Separate Process

```
int main()
{
    pid_t  pid;
    /* fork another process */
    pid = fork();
    if (pid < 0) { /* error occurred */
        fprintf(stderr, "Fork Failed");
        exit(-1);
    }
    else if (pid == 0) { /* child process */
        execlp("/bin/ls", "ls", NULL);
    }
    else { /* parent process */
        /* parent will wait for the child to complete */
        wait (NULL);
        printf ("Child Complete");
        exit(0);
    }
}
```

A tree of processes on a typical Solaris



Process Termination

- Process executes last statement and asks the operating system to delete it (**exit**)
  - Output data from child to parent (via **wait**)
  - Process' resources are deallocated by operating system
- Parent may terminate execution of children processes (**abort**)
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - If parent is exiting
    - Some operating system do not allow child to continue if its parent terminates
      - All children terminated - *cascading termination*
    - In some other operating systems, the child gets *orphaned – and its parent becomes the "init" process (PID=1).*

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Cooperating Processes

- **Independent** process cannot affect or be affected by the execution of another process
- **Cooperating** process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - Information sharing
  - Computation speed-up (Multiple CPUs)
  - Modularity
  - Convenience

Producer-Consumer Problem

- Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process
  - *unbounded-buffer* places no practical limit on the size of the buffer. Consumer has to wait if no new item.
  - *bounded-buffer* assumes that there is a fixed buffer size. Producer must wait if buffer full.

Bounded-Buffer – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 10
typedef struct {
   . . .
} item;

item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```

Bounded-Buffer – Insert() Method

Producer pseudo-code:

```
while (true) {
        Produce an item;

      while (((in + 1) % BUFFER_SIZE    == out)
         ; /* do nothing -- no free buffers */
        buffer[in] = item;
        in = (in + 1) % BUFFER_SIZE;
  }
```

Bounded Buffer – Remove() Method

Consumer pseudo-code:

```
while (true) {
      while (in == out)
         ; //do nothing, nothing to consume

       Remove an item from the buffer;
       item = buffer[out];
       out = (out + 1) % BUFFER SIZE;
       return item;
   }
```

Solution is correct, but can only use BUFFER_SIZE – 1 elements

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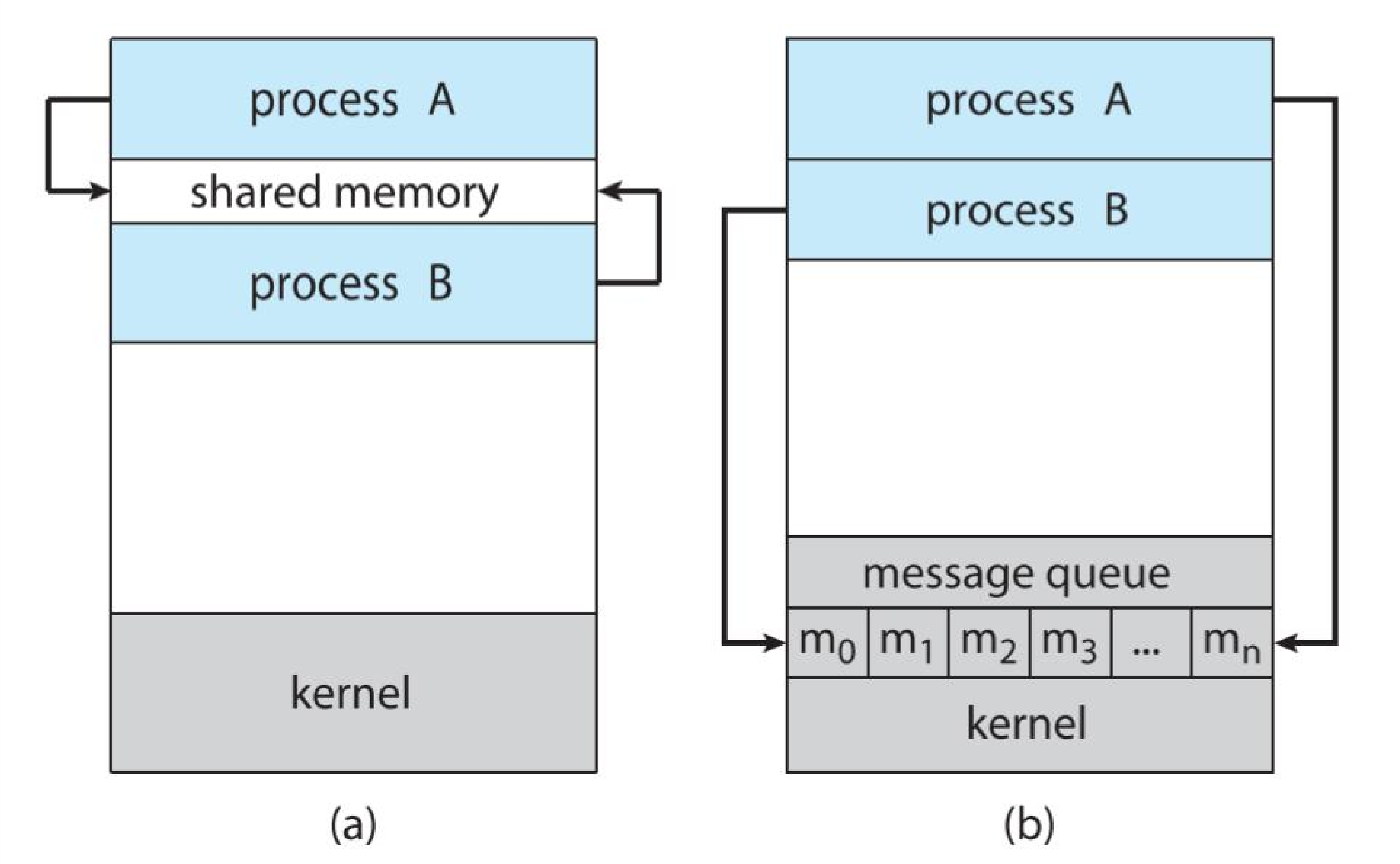
Interprocess Communication (IPC)

- Mechanism for processes to communicate and to synchronize their actions
- Two models for IPC: *message passing* and *shared memory*
- Message passing – processes communicate with each other without resorting to shared variables
- Message-passing facility provides two operations:
  - **send**(*message*) – message size fixed or variable
  - **receive**(*message*)
- If *P* and *Q* wish to communicate, they need to:
  - establish a *communication link* between them
  - exchange messages via send/receive
- Implementation of communication link
  - physical (e.g., shared memory, hardware bus)
  - logical (e.g., logical properties)

Communication Models



Shared memory

Message passing

Implementation Questions

- How are links established?
- Can a link be associated with more than two processes?
- How many links can there be between every pair of communicating processes?
- What is the capacity of a link?
- Is the size of a message that the link can accommodate fixed or variable?
- Is a link unidirectional or bi-directional?

Direct Communication

- Processes must name each other explicitly:
  - **send** (*P, message*) – send a message to process P
  - **receive**(*Q, message*) – receive a message from process Q
- Properties of communication link
  - Links are established automatically
  - A link is associated with exactly one pair of communicating processes
  - Between each pair there exists exactly one link
  - The link may be unidirectional, but is usually bi-directional

Indirect Communication

- Messages are directed and received from mailboxes (also referred to as ports)
  - Each mailbox has a unique id
  - Processes can communicate only if they share a mailbox
- Properties of communication link
  - Link established only if processes share a common mailbox
  - A link may be associated with many processes
  - Each pair of processes may share several communication links
  - Link may be unidirectional or bi-directional

Indirect Communication

- Operations
  - create a new mailbox
  - send and receive messages through mailbox
  - destroy a mailbox
- Primitives are defined as:

  send(*A, message*) – send a message to mailbox A

  receive(*A, message*) – receive a message from mailbox A

Indirect Communication

- Mailbox sharing
  - P_1, P_2, and P_3 share mailbox A
  - P_1, sends; P_2 and P_3 receive
  - Who gets the message?
- Solutions
  - Allow a link to be associated with at most two processes
  - Allow only one process at a time to execute a receive operation
  - Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was.

Synchronization

- Message passing may be either blocking or non-blocking
- **Blocking** is considered **synchronous**
  - **Blocking send** has the sender blocked until the message is received
  - **Blocking receive** has the receiver block until a message is available
- **Non-blocking** is considered **asynchronous**
  - **Non-blocking** send has the sender send the message and continue
  - **Non-blocking** receive has the receiver receive a valid message or null

Buffering

- Queue of messages attached to the link; implemented in one of three ways
  1. Zero capacity – 0 messages
     Sender must wait for receiver
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if link full
  3. Unbounded capacity – infinite length
     Sender never waits
- Control of Buffering

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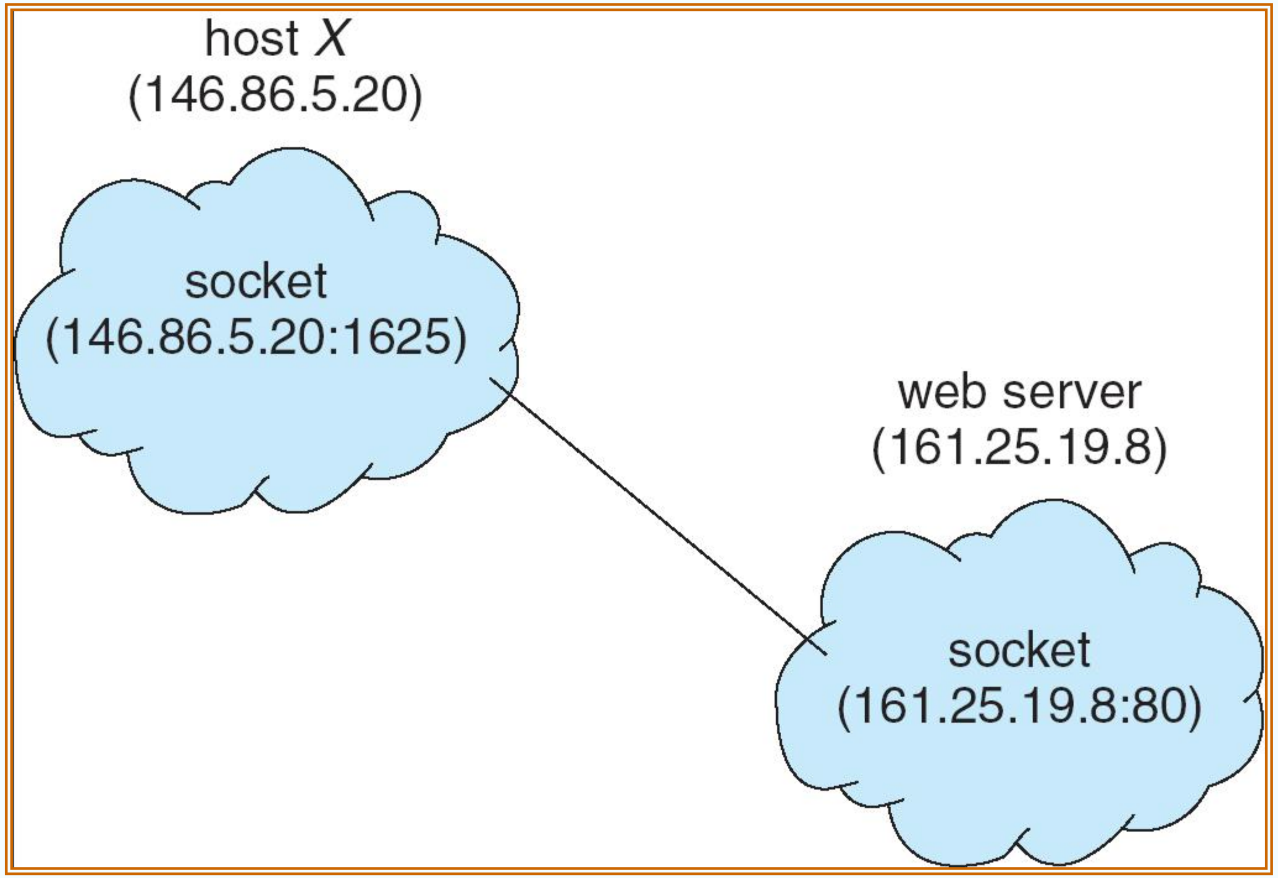
Client-Server Communication

- Sockets
- Remote Procedure Calls
- Remote Method Invocation (Java)

Sockets

- A socket is defined as an *endpoint for communication*
- Concatenation of IP address and port
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- Communication consists between a pair of sockets

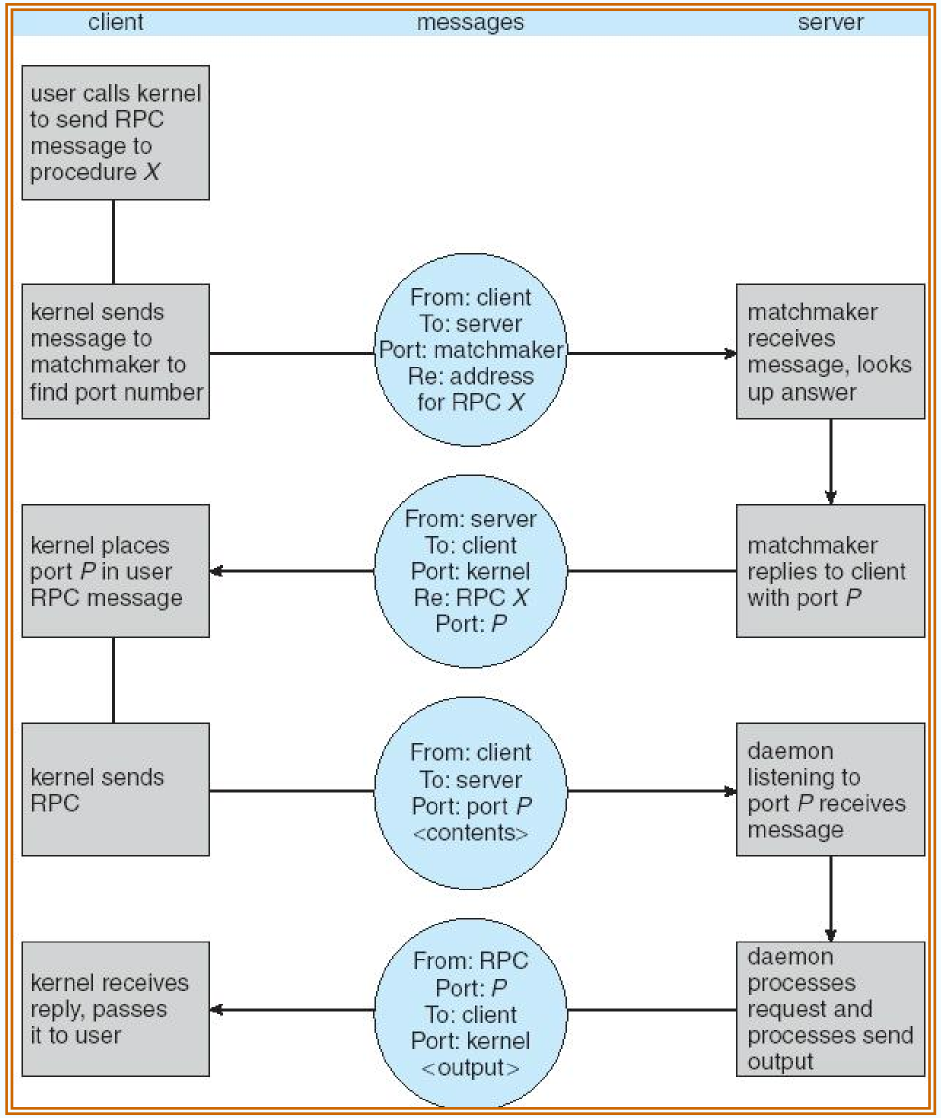
Socket Communication



Remote Procedure Calls

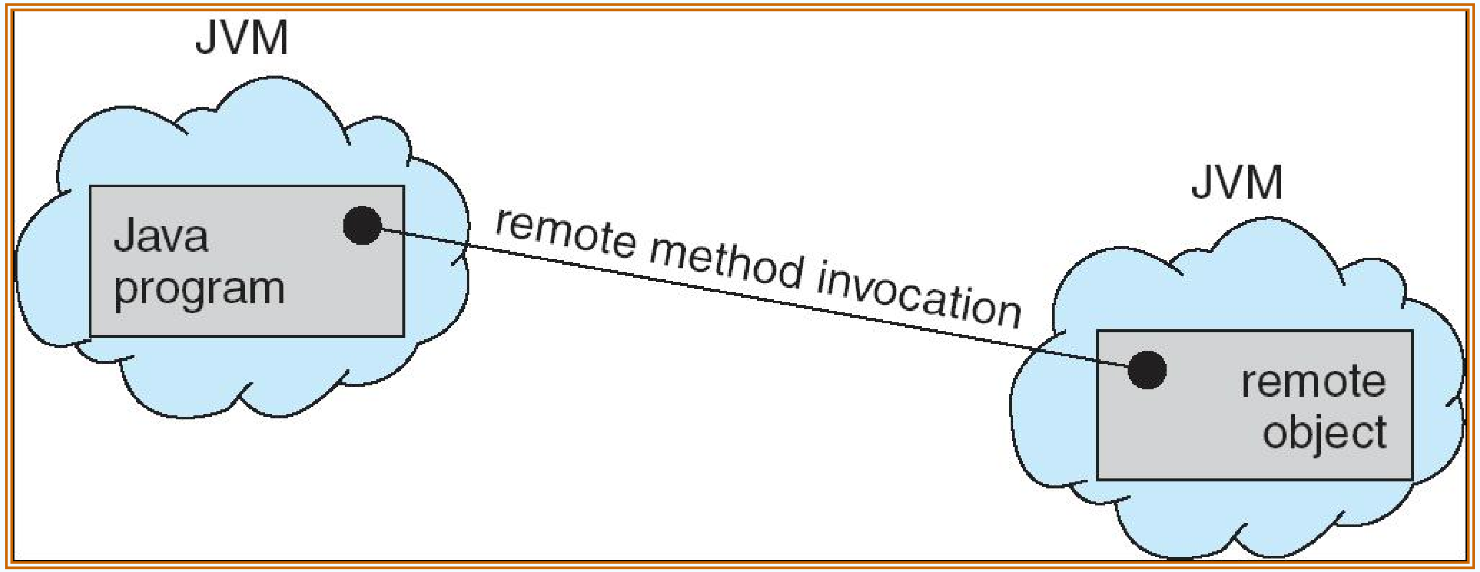
- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems.
- **Stubs** – client-side proxy for the actual procedure on the server.
- The client-side stub locates the server and *marshals* the parameters.
- The server-side stub receives this message, unpacks the marshaled parameters, and performs the procedure on the server.

Execution of RPC

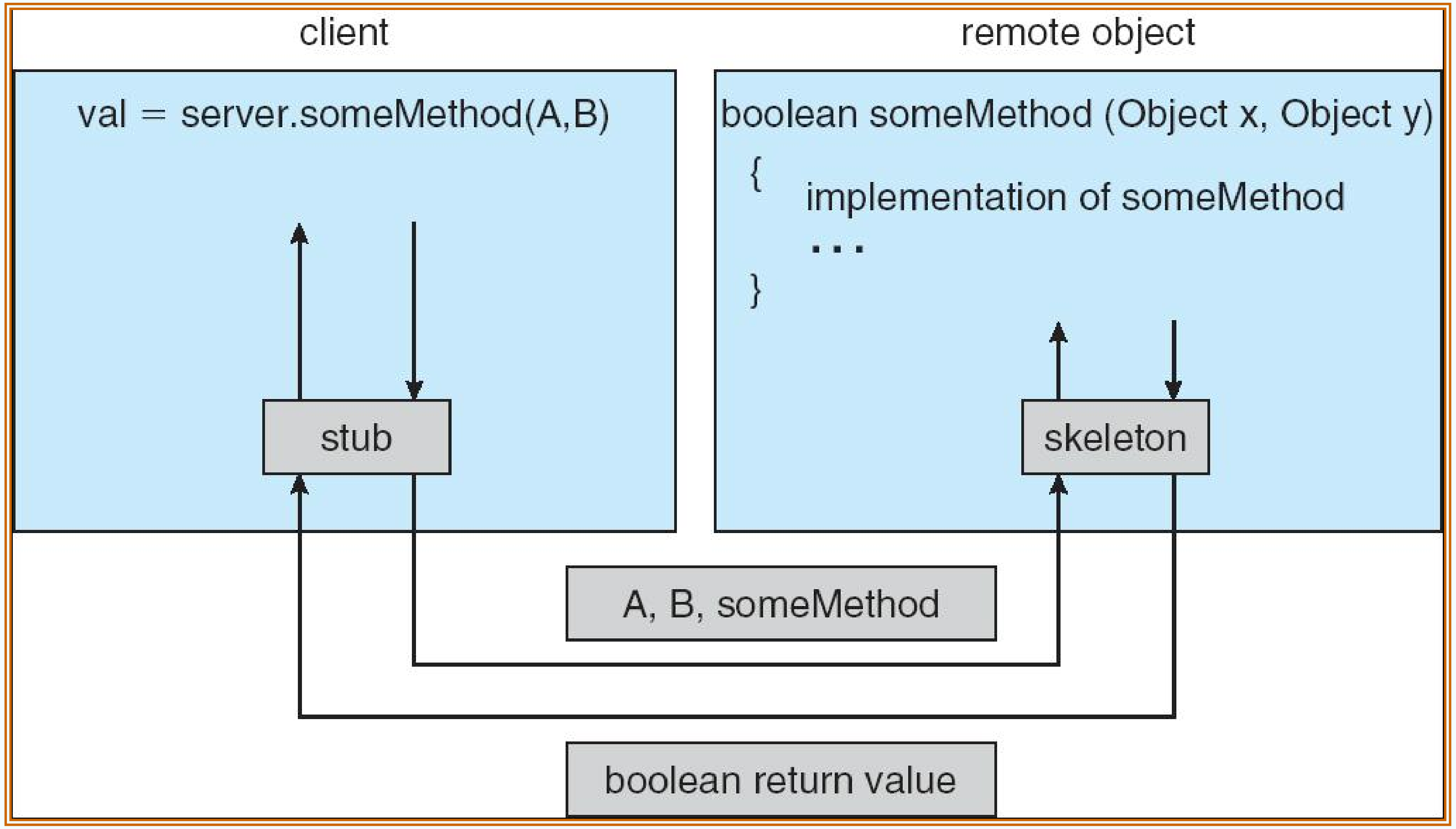


Remote Method Invocation

- Remote Method Invocation (RMI) is a Java mechanism similar to RPCs.
- RMI allows a Java program on one machine to invoke a method on a remote object.
- RMI is object-based



Marshalling Parameters



Since Java 2 v1.2, skeleton is not needed any more.

The “init” process in MacOS

- On MacOS, you should be able to see the "init" process named "launchd".

```
$ ps -eaf | grep launchd
  0  1  0   0  3 919  ??   33:55.81 /sbin/launchd
```

End of Chapter 3

Bounded-Buffer – Insert() Method

Producer pseudo-code:

```
while (true) {
   Produce an item;
   buffer[in] = item;
      while (((in + 1) % BUFFER_SIZE    == out)
         ; /* do nothing -- no free buffers */
   //buffer[in] = item;    /* move the line before while
  */
   in = (in + 1) % BUFFER_SIZE;
 }
```

Bounded Buffer – Remove() Method

Consumer pseudo-code:

```
while (true) {
        while (in == out)
           ; //do nothing, nothing to consume

        Remove an item from the buffer;
        item = buffer[out];
        out = (out + 1) % BUFFER SIZE;
        return item;
}
```

Count number of items, int count=0

Producer pseudo-code:

```
while (true) {
    Produce an item;
    buffer[in] = item;
      while (((in + 1) % BUFFER_SIZE   == out)
          ; /* do nothing -- no free buffers */
     //buffer[in] = item;    /*   move the line before
    while  */
    count++;
    in = (in + 1) % BUFFER_SIZE;
  }
```

Count number of items

Consumer pseudo-code:

```
while (true) {
        while (in == out)
            ; //do nothing, nothing to consume

        Remove an item from the buffer;
        item = buffer[out];
        count--;
        out = (out + 1) % BUFFER SIZE;
        return item;
}
```