Chapter 3: Processes

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- Process Concept
- Process Scheduling
- Operations on Processes
- Interprocess Communication
- Examples of IPC Systems
- Communication in Client-Server Systems

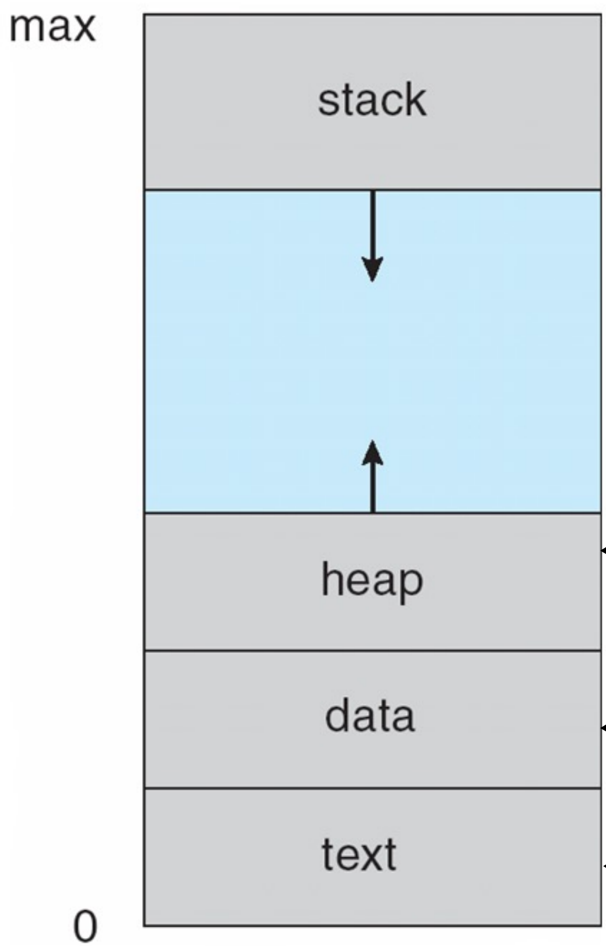
Objectives

- To introduce the notion of a process -- **a program in execution**, which forms the basis of all computation
- To describe the various features of processes, including scheduling, creation and termination, and communication
- To describe communication in client-server systems

3.1 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:
  - program counter – next instruction to execute
  - Stack – contains temporary data such as function parameter
  - data section – Function parameters, return address, local variable

Process in Memory



A program becomes a process when an executable file is loaded into memory.

Dynamically allocated memory during process run time

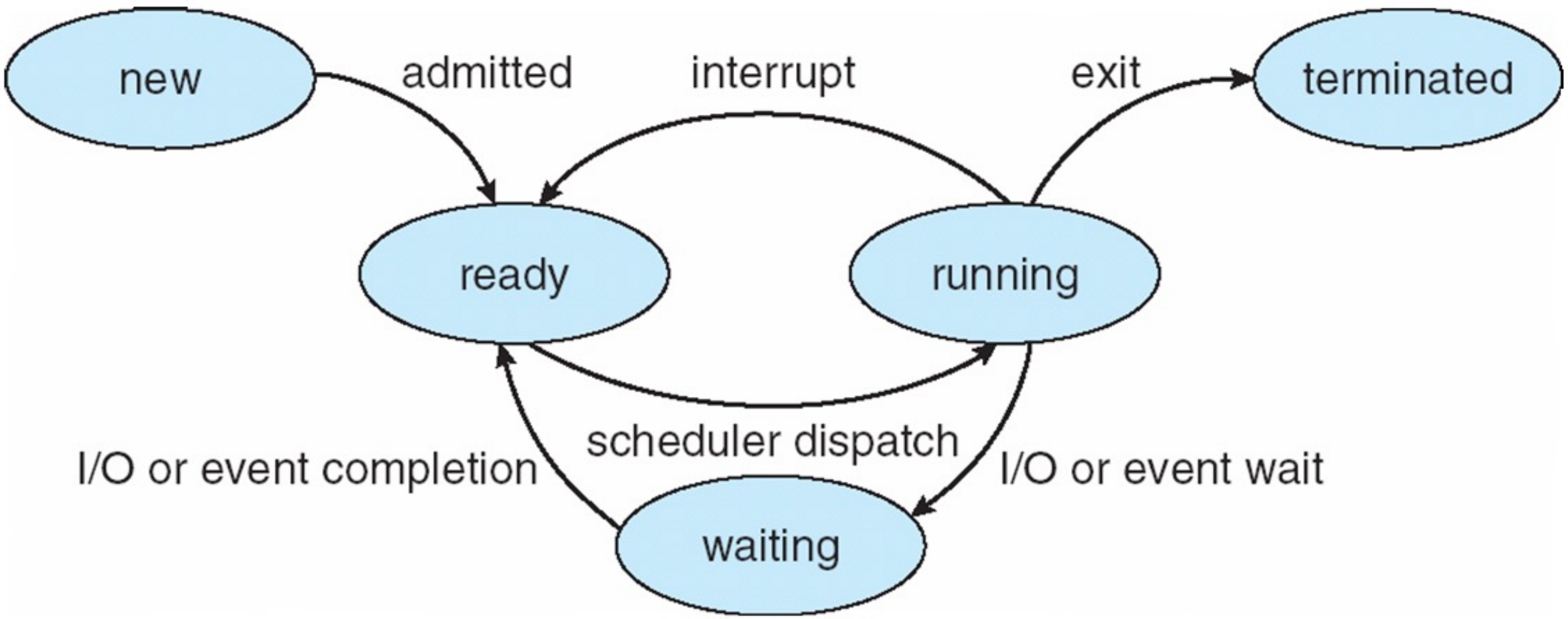
Function parameters, return address, local variable.

Program code

3.1.2 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 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

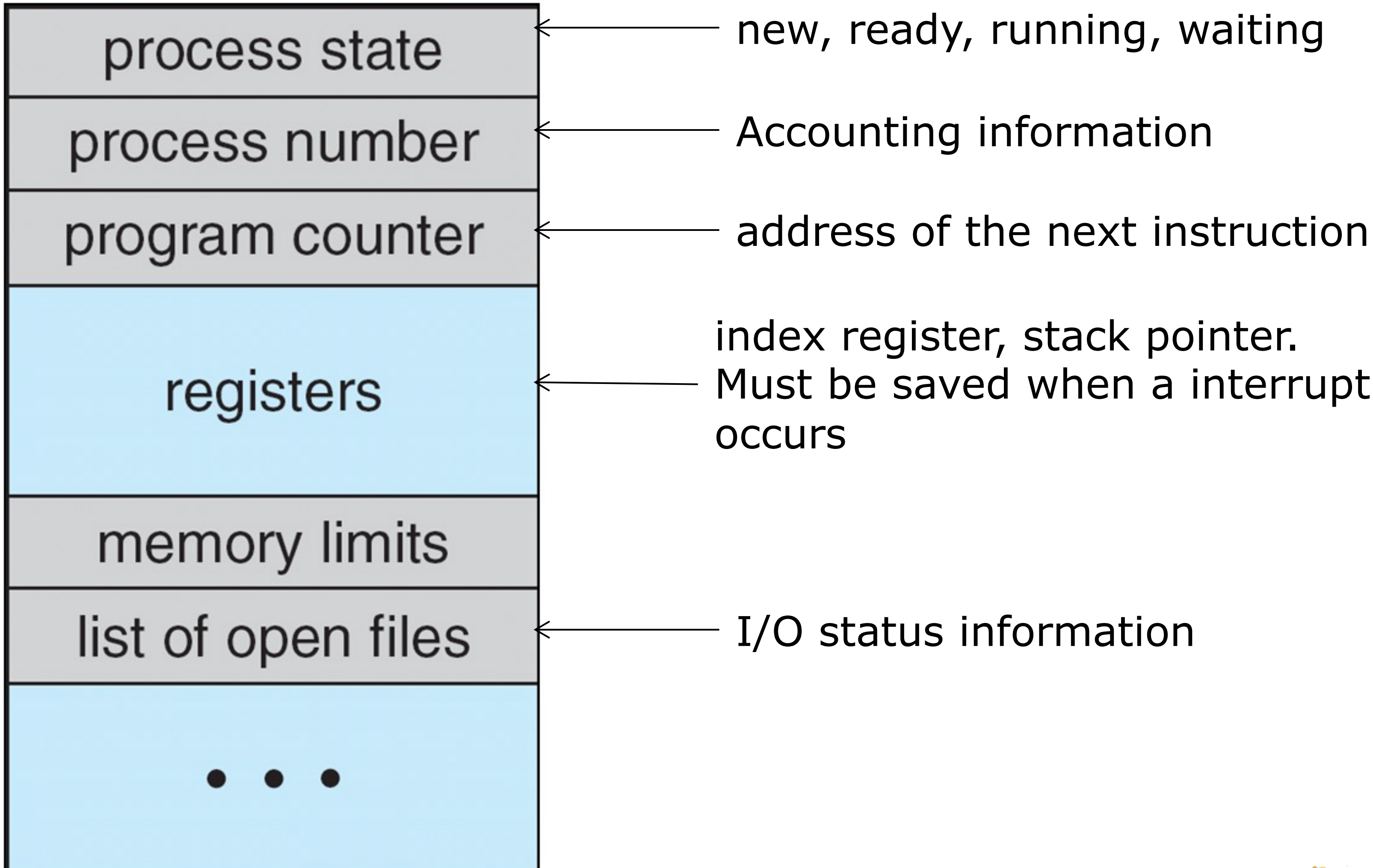


3.1.3 Process Control Block (PCB)

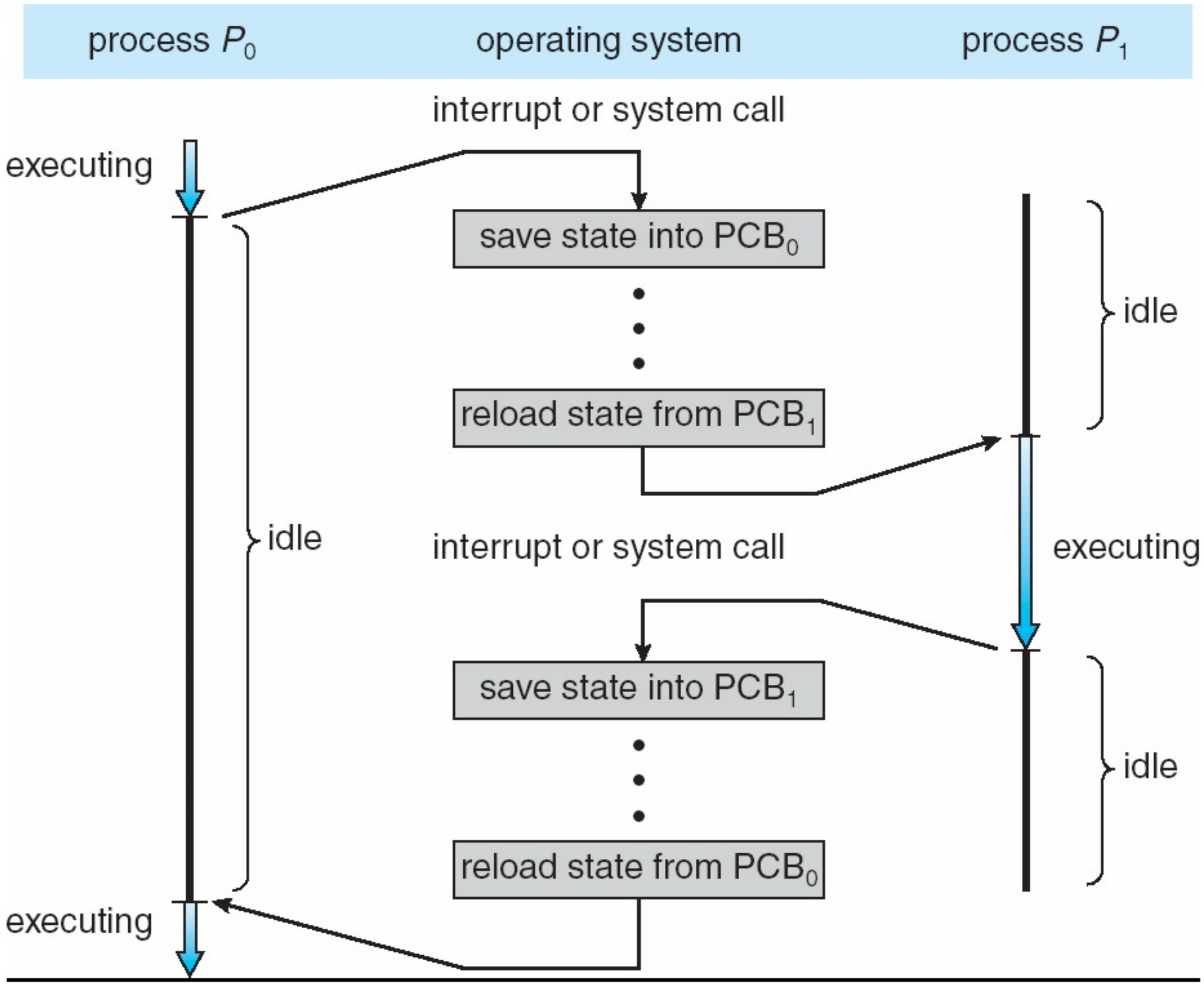
Information associated with each process

- Process state – new, ready, running, waiting, …
- Accounting information – account #, process #
- Program counter – address of the next instruction
- CPU registers – index register, stack pointer. Must be saved when a interrupt occurs.
- CPU scheduling information – process priority
- Memory-management information – base and limit
- I/O status information – list of devices, open files

Process Control Block (PCB)



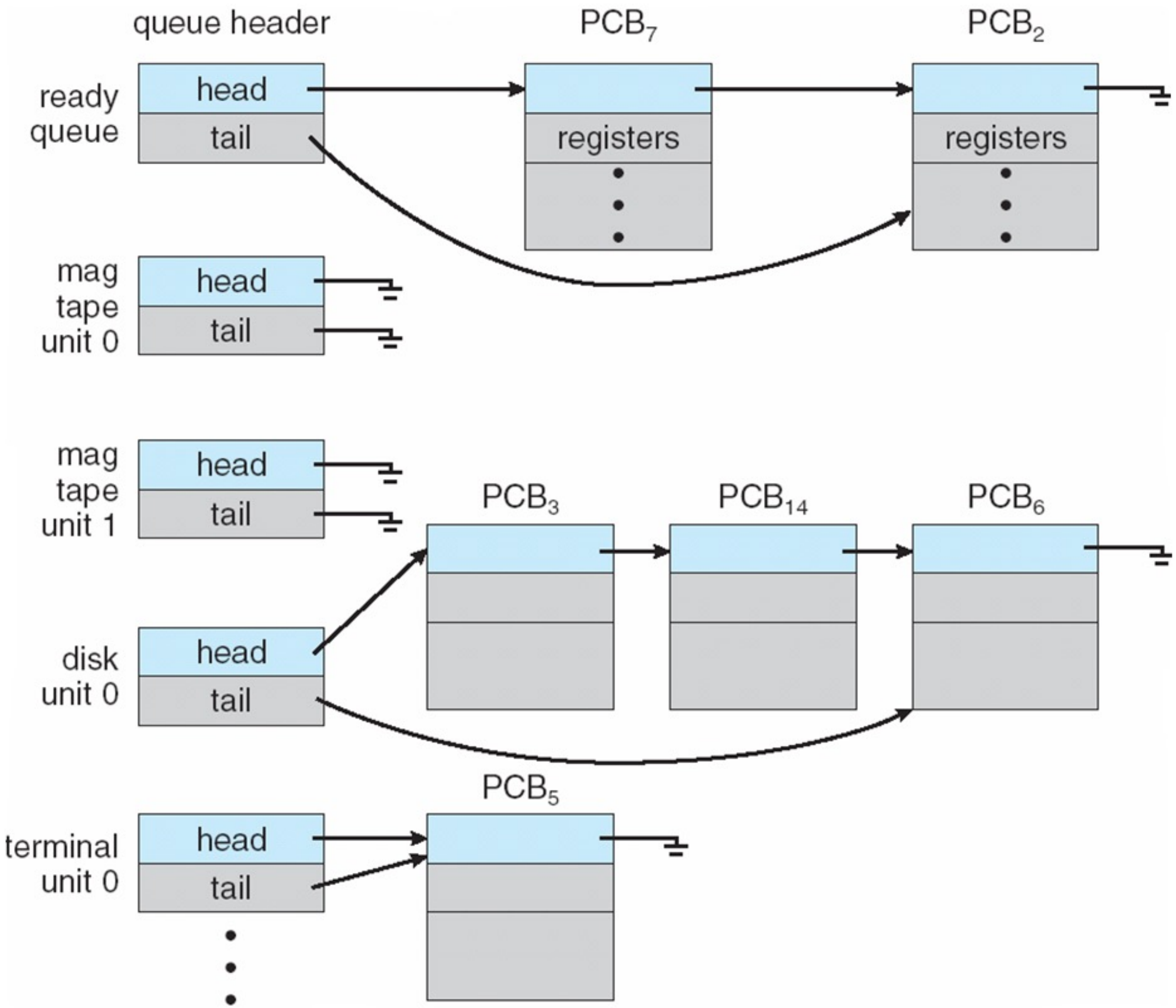
CPU Switch From Process to Process



3.2 Process Scheduling Queues

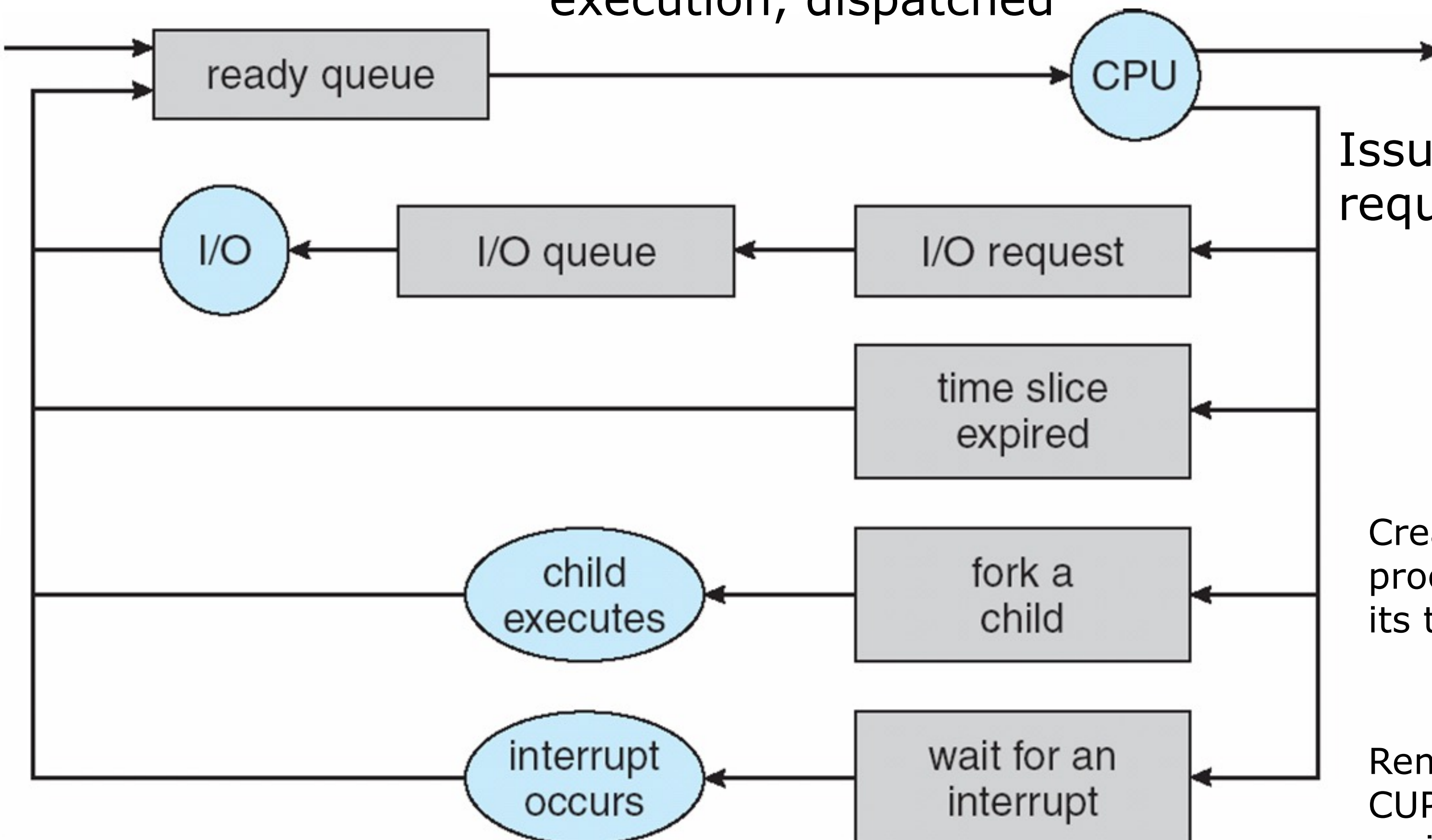
- **Job queue** – set of **all processes** in the system
- **Ready queue** – set of all processes residing in **main memory**, **ready and waiting** to execute
- **Device queues** – set of processes **waiting for an I/O device**
- Processes migrate among the various queues

Ready Queue And Various I/O Device Queues



Representation of Process Scheduling

Selected for execution, dispatched



Issue I/O request

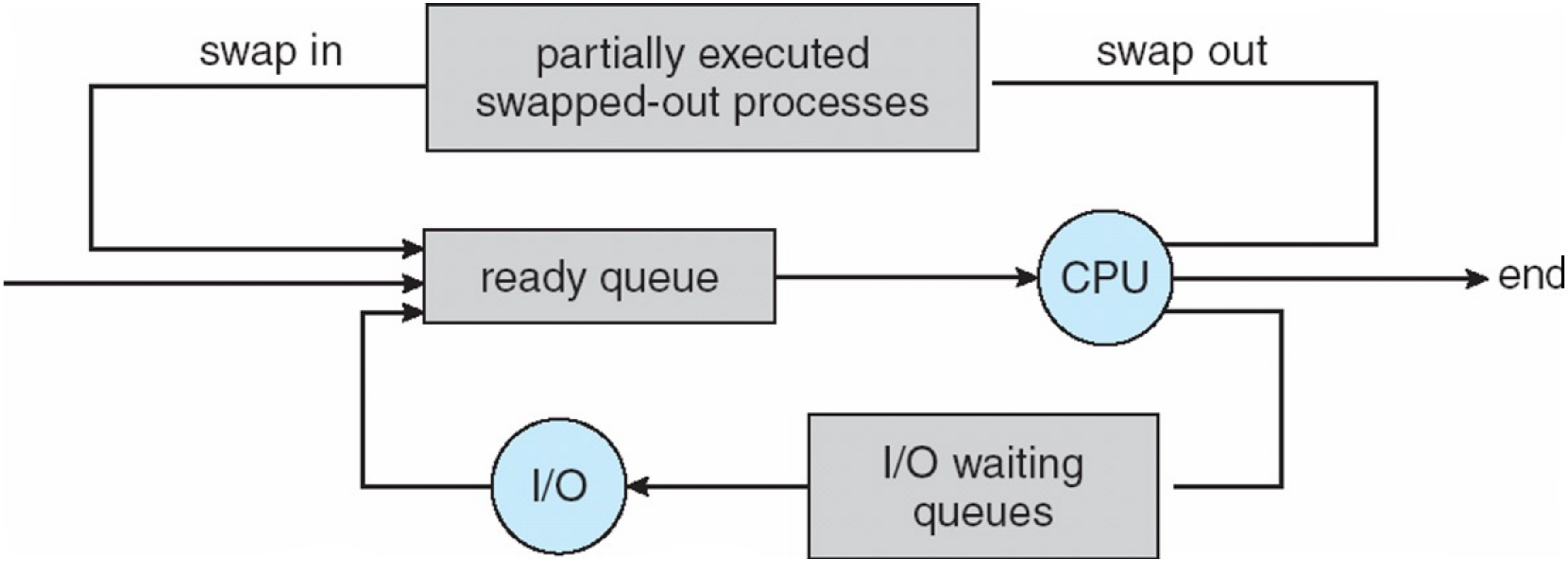
Create sub-process, wait for its termination

Removed from CUP because of an interrupt

3.2.2 Schedulers

- **Long-term scheduler** (or job scheduler) – selects which processes should be brought into the ready queue
- **Short-term scheduler** (or CPU scheduler) – selects which process should be executed next and allocates CPU

Addition of Medium Term Scheduling



- Sometimes it can be advantageous to **remove** process from memory to reduce the degree of multiprograming.
- Later, the process can **be reintroduced** into memory to continue execution.

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

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 via a context switch
- Context of a process represented in the PCB
- Context-switch time is **overhead**; the system does no useful work while switching
- Time dependent on hardware support

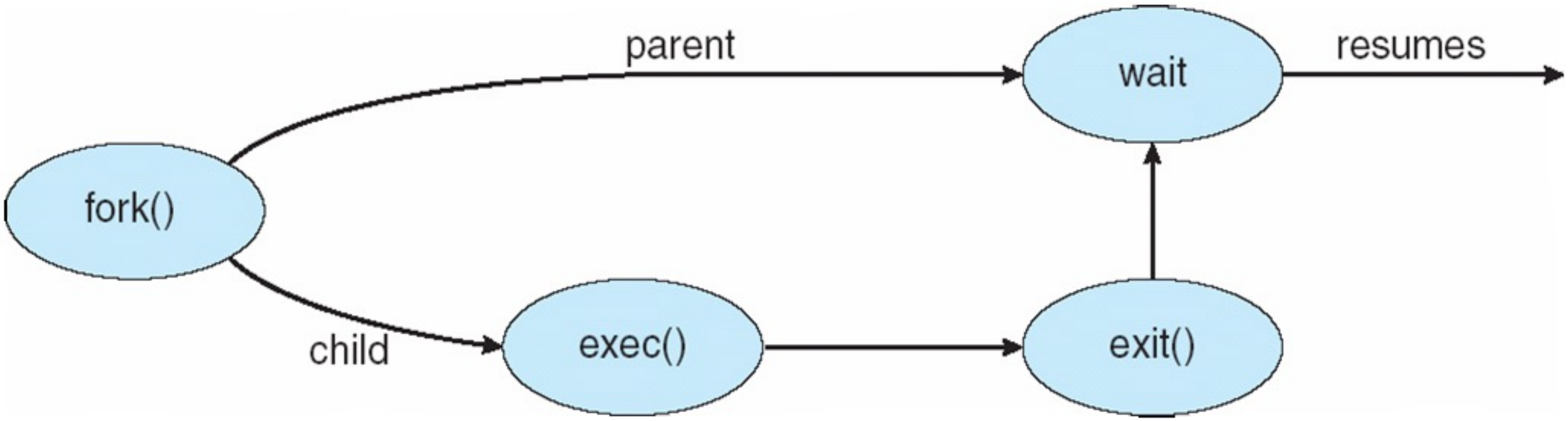
Process Creation

- **Parent** process create **children** processes, which, in turn create other processes, forming <u>a tree of processes</u>
- Generally, process identified and managed via **a process identifier** (**pid**)
- 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

Process Creation



C Program Forking Separate Process

```
int main()
{
pid_t  pid;
   /* fork a child 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);
   }
}
```

- child pid = 0
- parent pid > 0
- execlp replaces the process memory with a new program
- the child process inherits privilege, scheduling attributes, and resources from the parent.

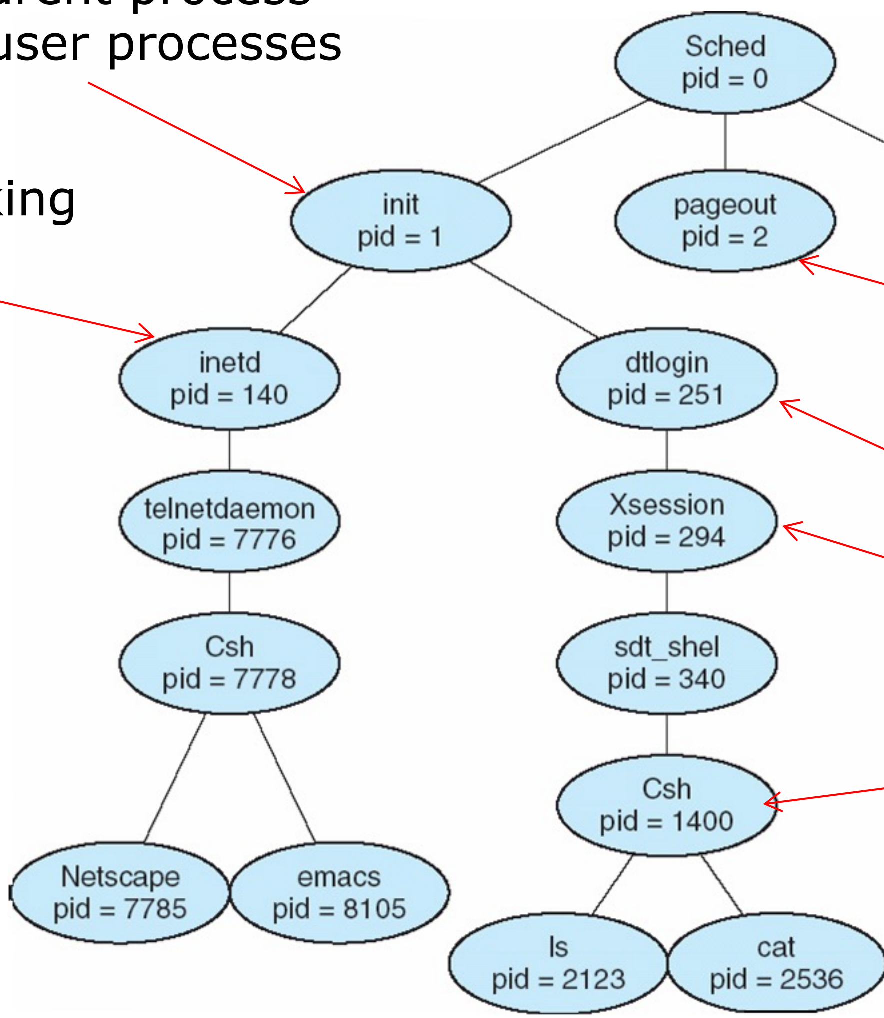
Process Creation in Java

```
import java.io.*;

public class OSProcess
{
  public static void main(String[] args) throws IOException {
    if (args.length != 1) {
      System.err.println("Usage: java OSProcess <command>");
      System.exit(0);
    }

    // args[0] is the command
    ProcessBuilder pb = new ProcessBuilder(args[0]);
    Process proc = pb.start();

    // obtain the input stream
    InputStream is = proc.getInputStream();
    InputStreamReader isr = new InputStreamReader(is);
    BufferedReader br = new BufferedReader(isr);

    // read what is returned by the command
    String line;
    while ( (line = br.readLine()) != null)
      System.out.println(line);

    br.close();
  }
}
```

A tree of processes on a typical Solaris

Root parent process
for all user processes

Networking
service



Manage memory
and file system

User login

X-windows session

C-shell

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**

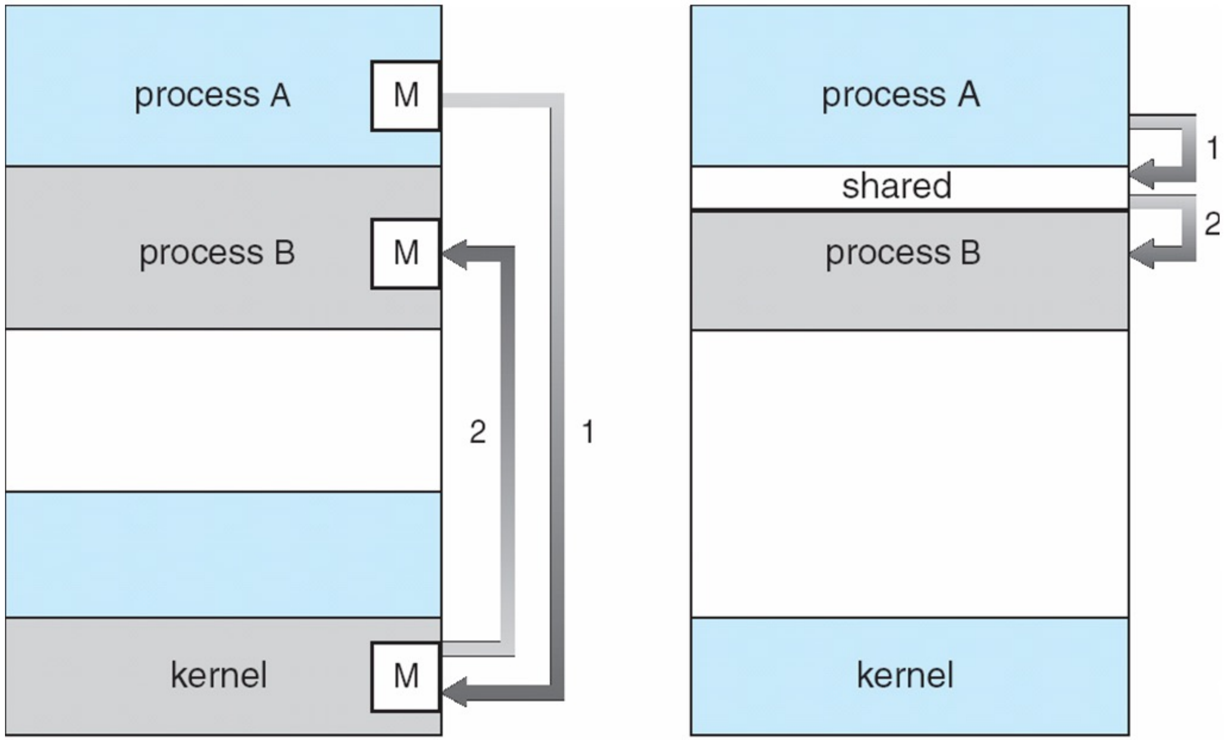
Interprocess Communication

- **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
  - Modularity
  - Convenience

Interprocess Communication

- Cooperating processes need **interprocess communication (IPC)**
- Two models of IPC
  - Shared memory
  - Message passing

Communications Models



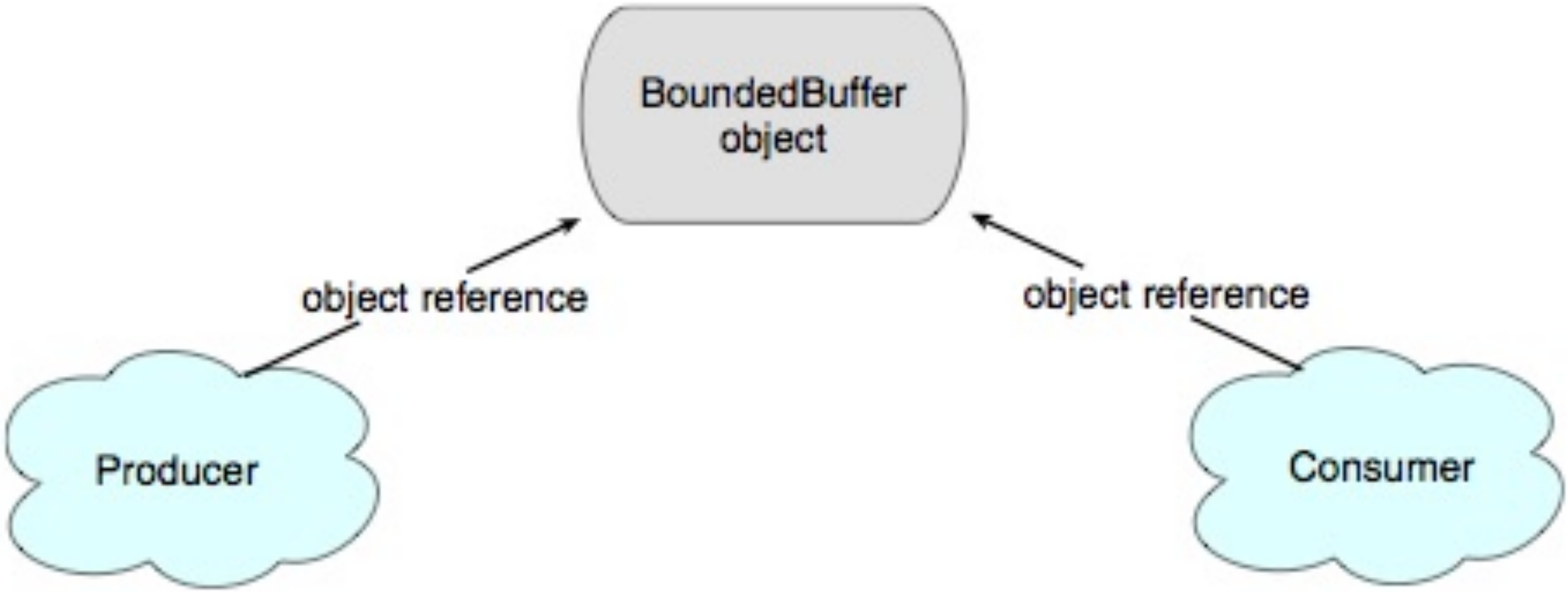
(a) (b)

a. Message passing: small amount of data, easier to implement
b. Shared memory: allow maximum speed, convenience of communication.

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
  - *bounded-buffer* assumes that there is **a fixed buffer size**

Simulating Shared Memory in Java



Bounded-Buffer – Shared-Memory Solution

- Shared data

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


item buffer[BUFFER_SIZE];  // a circular array
int in = 0;  // the next free position in the buffer
int out = 0;          //the first full position
```

- Solution is correct, but can only use BUFFER_SIZE-1 elements, how to have BUFFER_SIZE items in the buffer?

Bounded-Buffer – Producer

```
item nextProduced;
while (true) {
   /* Produce an item in nextProduced */
        while (((in = (in + 1) % BUFFER
SIZE count)   == out)
      ;   /* do nothing -- no free buffers
*/
    buffer[in] = nextProduced;
    in = (in + 1) % BUFFER SIZE;
   }
```

Bounded Buffer – Consumer

```
item nextConsumed;
while (true) {
          while (in == out)
                 ; // do nothing --
  nothing to consume


          /*consume the item in
  nextConsumed */
      nextConsumed = buffer[out];
          out = (out + 1) % BUFFER SIZE;


}
```

Interprocess Communication – Message Passing

- Message system – processes communicate with each other without resorting to shared variables
- IPC 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)

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 block 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 (rendezvous)
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if link full
  3. Unbounded capacity – infinite length
     Sender never waits

Examples of IPC Systems - POSIX

- POSIX Shared Memory
  - Process first **creates shared memory segment**

```
Segment_id = shmget(IPC_PRIVATE, size,
  S_IRUSR|S_IWUSR);
```

  - Process wanting access to that shared memory must **attach** to it

```
shared _memory = (char *) shmat(id, NULL, 0);
```

  - Now the process could **write** to the shared memory

```
sprintf(shared_memory, "Writing to shared
  memory");
```

  - When done a process can **detach the shared memory** from its address space

```
shmdt(shared_memory);
```

Examples of IPC Systems - Mach

- Mach communication is message based
  - Even system calls are messages
  - Each task gets two mailboxes at creation- Kernel and Notify
  - Only three system calls needed for message transfer

`msg_send(), msg_receive(), msg_rpc()`

  - Mailboxes needed for commuication, created via

`port_allocate()`

Examples of IPC Systems – Windows XP

- Message-passing centric via local procedure call (LPC) facility
  - Only works between processes on the same system
  - Uses ports (like mailboxes) to establish and maintain communication channels
  - Communication works as follows:
    - The client opens a handle to the subsystem's connection port object
    - The client sends a connection request
    - The server creates two private communication ports and returns the handle to one of them to the client
    - The client and server use the corresponding port handle to send messages or callbacks and to listen for replies

Local Procedure Calls in Windows XP