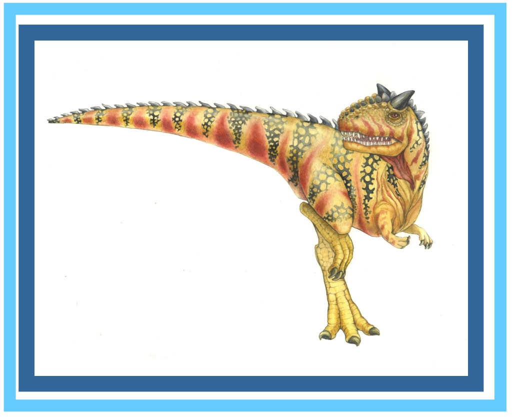
Chapter 3: Processes



Chapter 3: Processes

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

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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

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Process Concept

- An operating system executes programs:
  - Batch system – jobs are executed
  - 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
- ***Job – same definition as a process, but term is restricted to batch systems***
- A process includes:
  - program code (called the ***text***)
  - program counter
  - runtime stack
  - data section (for globals, both initialized and uninitialized)
  - heap (for dynamically allocated variables
  - other stuff that the operating system uses

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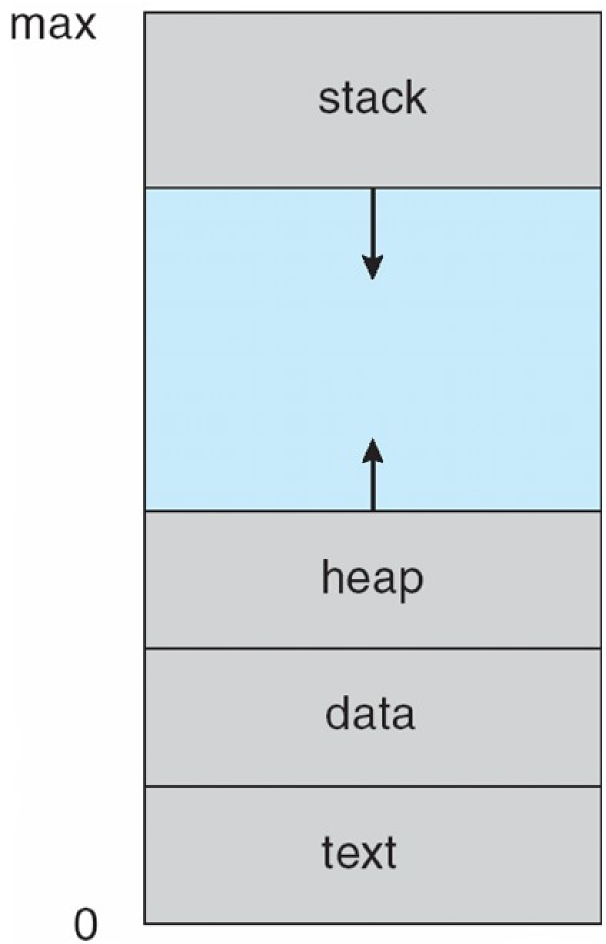
Typical Memory Layout of Process



Process State

- As a process executes, it changes *state*
  - **new**: The process is being created ***(This is not a real state!)***
  - **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
  - ***suspended sometimes***

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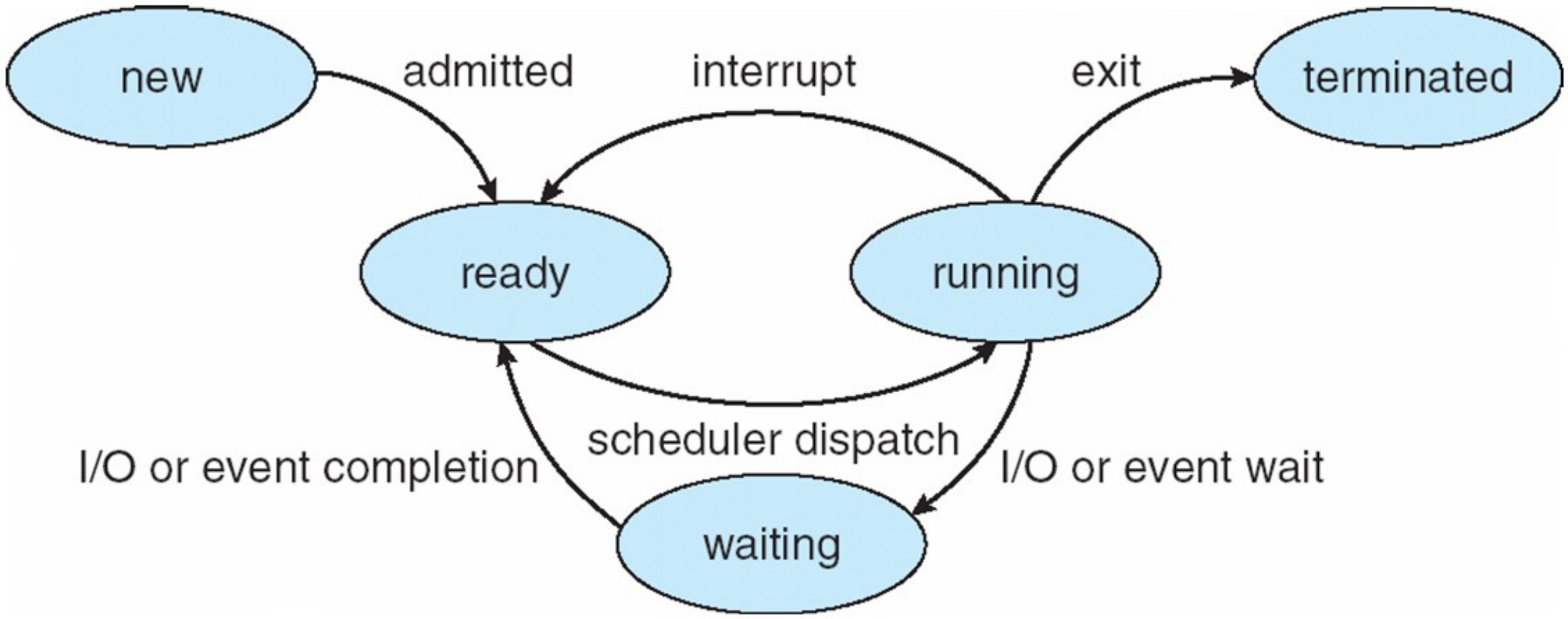
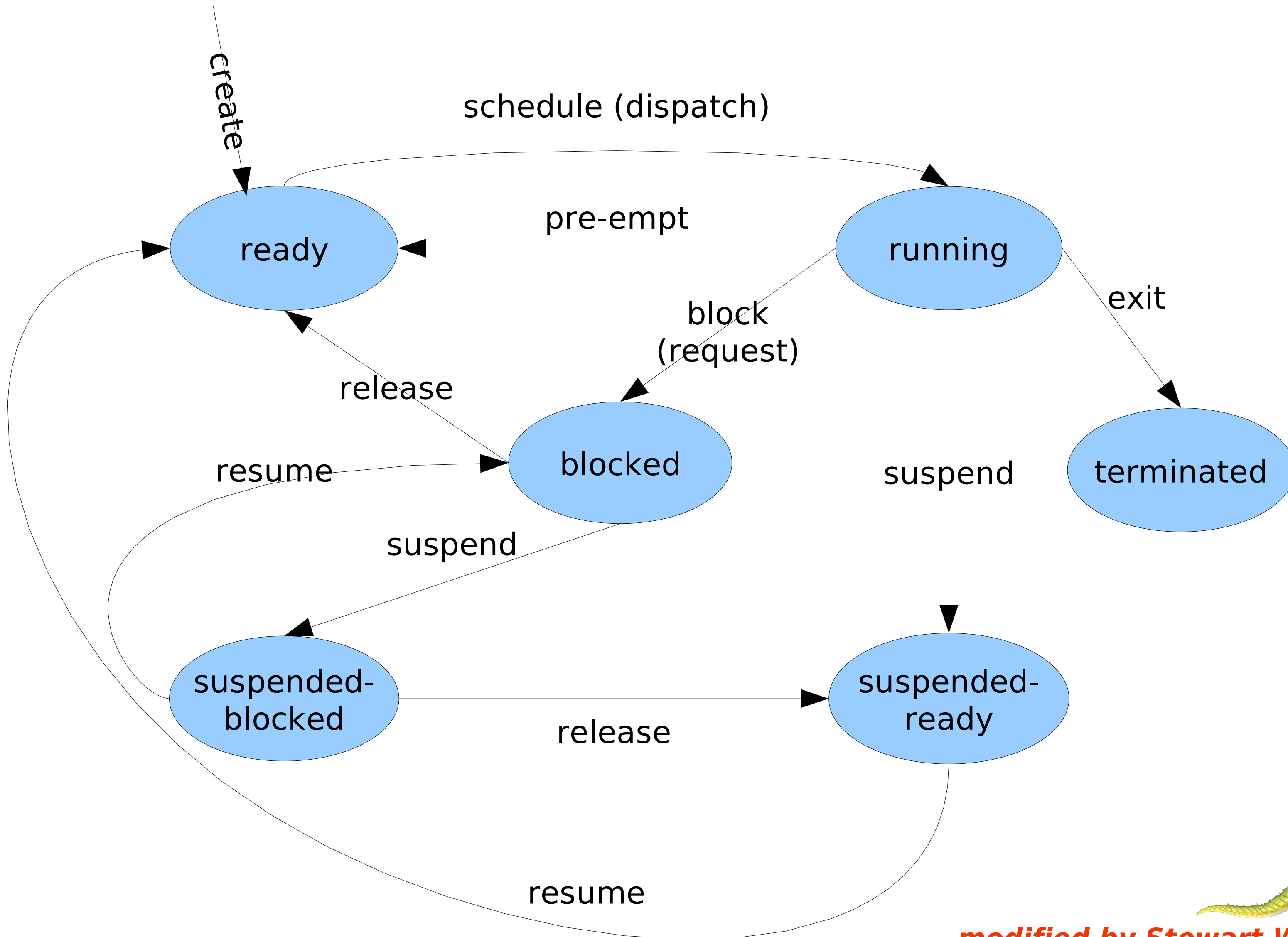
Book's Diagram of Process State



My Diagram of Process State



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Process Control Block (PCB)

PCB is the data structure containing information associated with each process, needed by OS, including:

- Process state
- Program counter (only when not running!)
- CPU registers (hardware state, only when not running!)
- CPU scheduling information (priority etc)
- Memory-management information (where stuff is)
- Accounting information (e.g. how much resources used so far)
- I/O status information (which files open, what it's waiting for)
- list of child processes, parent process
- owner, group, etc

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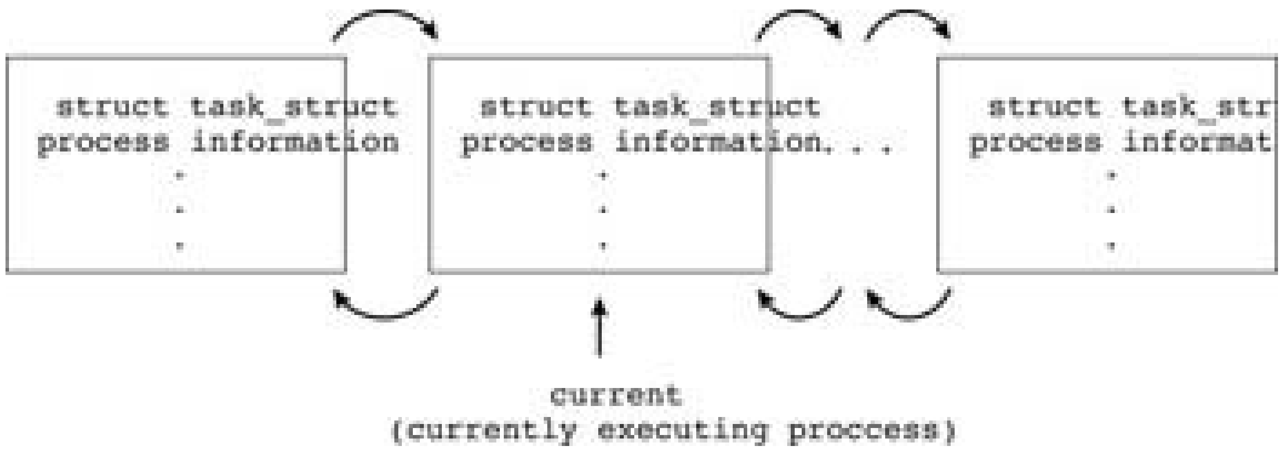
Process Table

- OS can keep PCBs in an array, or in linked lists, or in a mixed method like an array with embedded free list and active list (as was done in BSD UNIX).
- Linux uses linked lists of task_structs:



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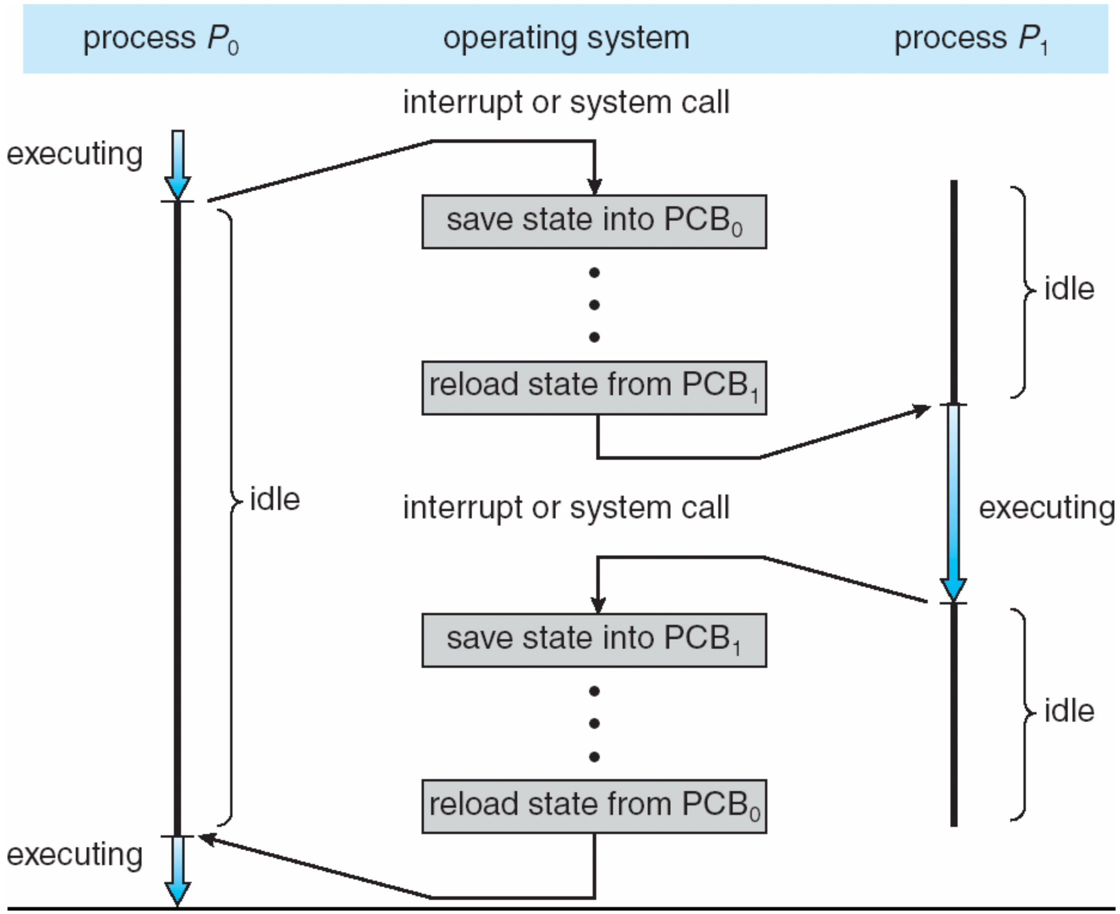
CPU Switch From Process to Process



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Process Scheduling Queues

- **Job queue** – set of all processes in the system ***(only in batch mode)***
- **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

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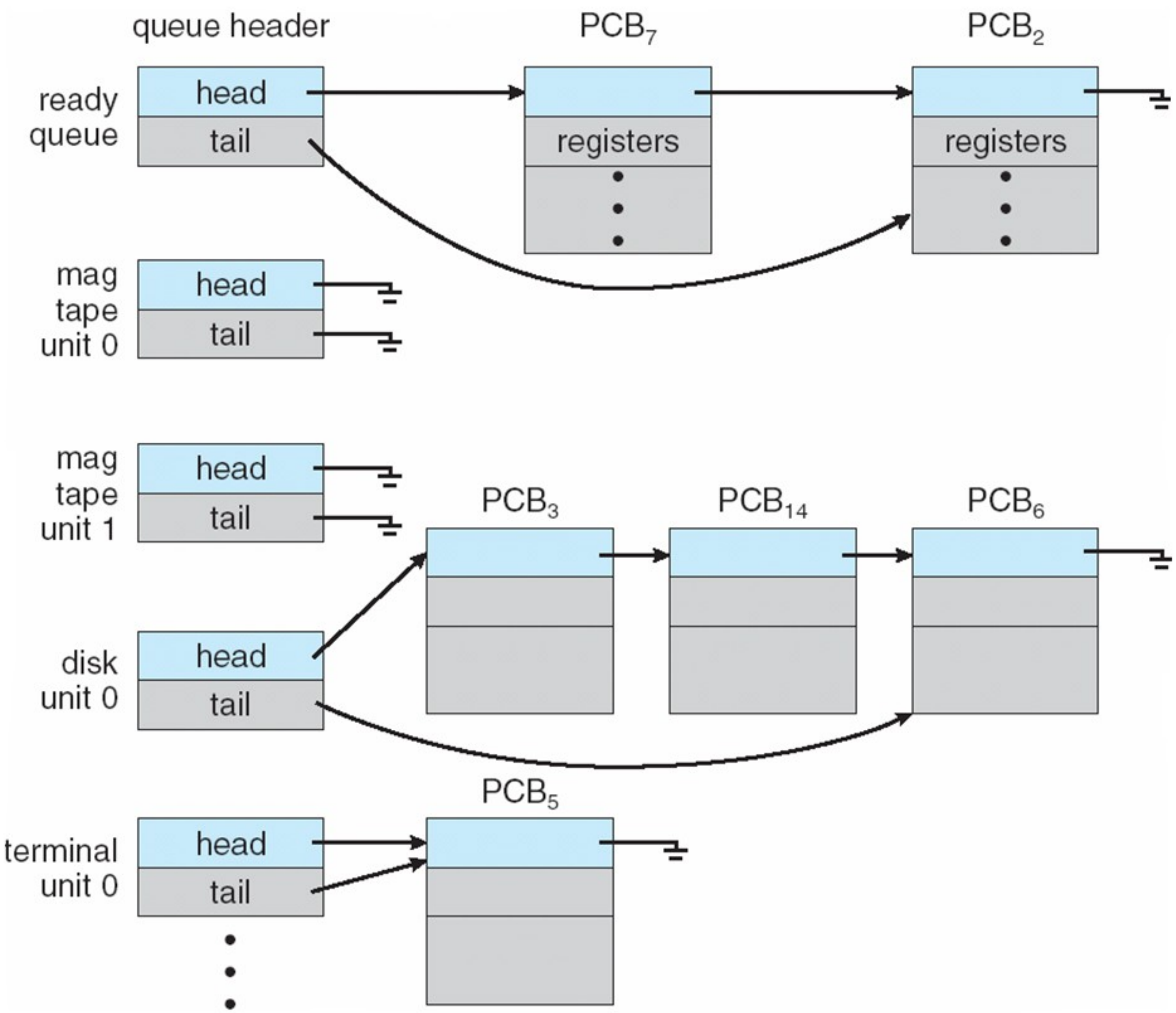
Ready Queue And Various I/O Device Queues



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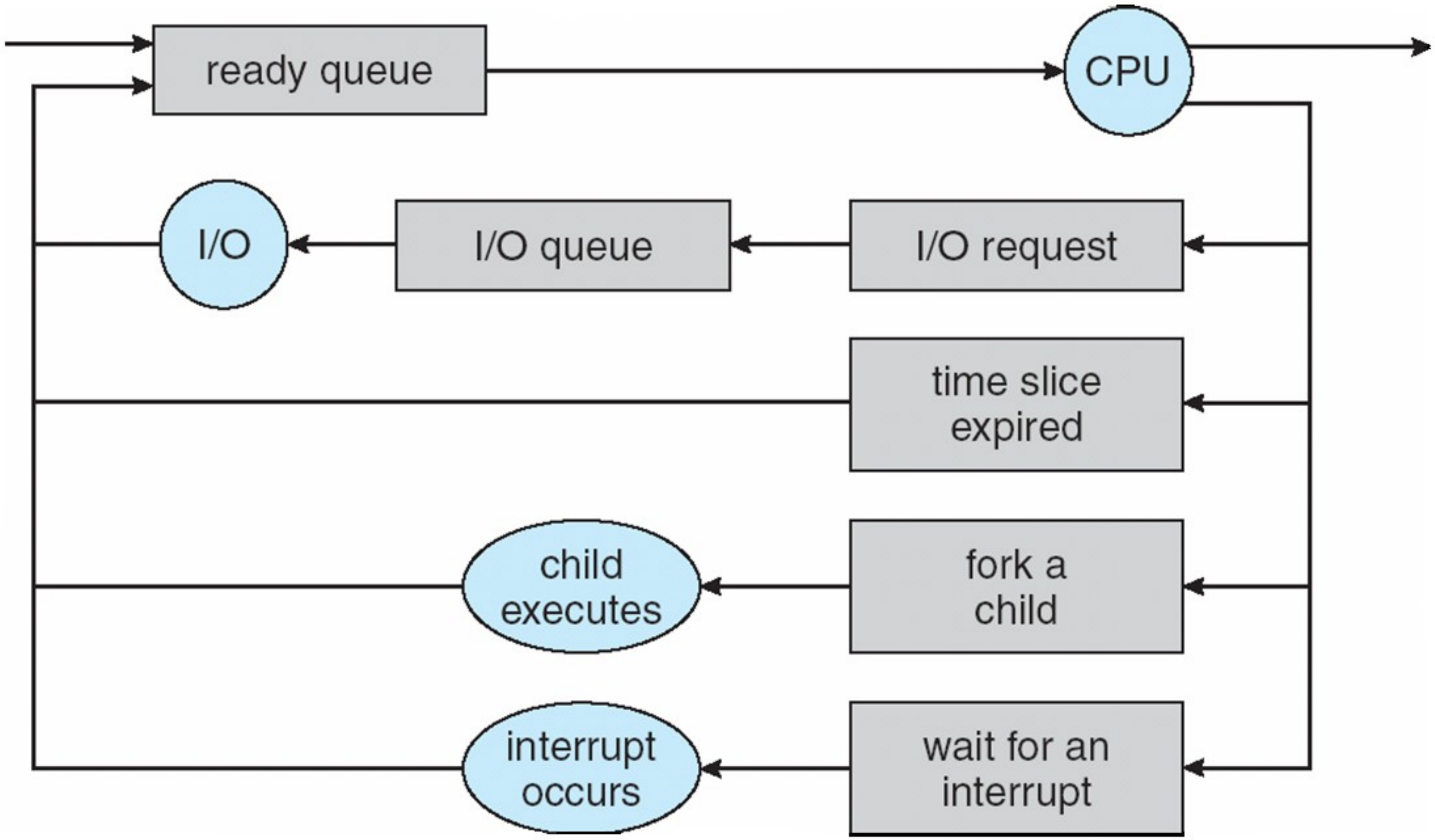
Representation of Process Scheduling

- A queuing theory model can be used to analyze and optimize operating system design.



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Process Characterization

- Processes can be described as either:
  - **I/O-bound process** – spends more time doing I/O than computations, many short CPU bursts – runs on CPU and quickly asks for I/O
  - **CPU-bound process** – spends more time doing computations; few very long CPU bursts, so it will not remove itself from CPU very often.

Schedulers

- **Long-term scheduler** (or job scheduler) – in batch systems only; controls process mix (I/O-bound versus CPU-bound) to maximize resource utilization.
- Medium-term scheduler - selects which processes should be brought into the ready queue ***(in UNIX this was the swapper – chose which processes to swap in and out of memory) ; controls degree of multi-programming***
- **Short-term scheduler** (or CPU scheduler) – selects which process should be executed next and allocates CPU; must be very fast because it may run 10 or more times per second

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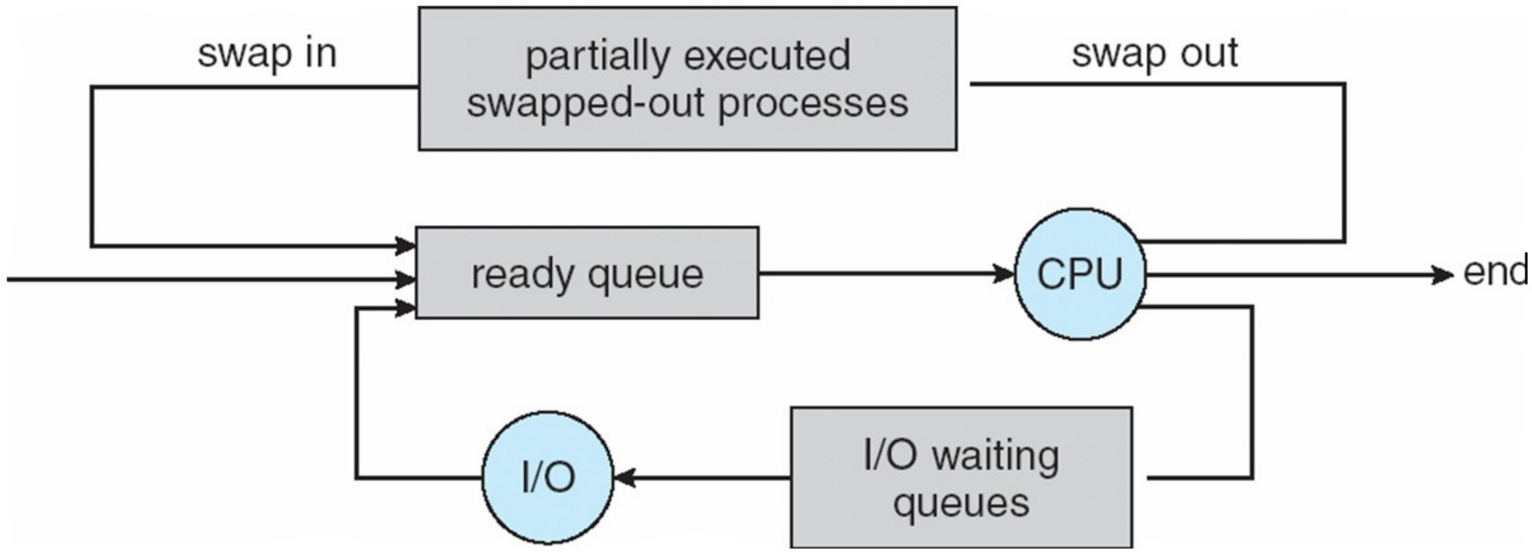
Medium Term Scheduling



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 **child** processes, which, in turn create other processes, forming a tree of processes
- Generally, process identified and managed via **a process identifier** (**pid**)
- New process needs resources. Where do they come from?
- Resource sharing choices:
  - Parent shares all of its resources with child
  - Children share subset of parent's resources (UNIX)
  - Parent and child share no resources (Windows)
- Execution choices: after child is created:
  - Parent and children execute concurrently (UNIX)
  - Parent waits until children terminate

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Process Creation (Cont)

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

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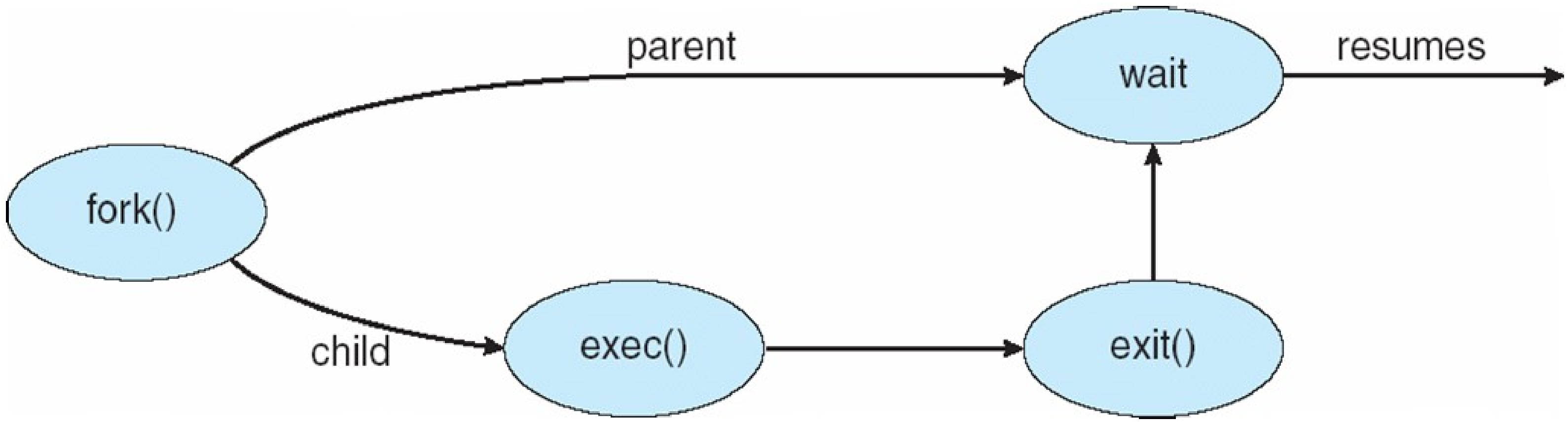
Process Creation in UNIX

- Typical parent-child execution (like shell in UNIX – parent creates child then blocks itself until child calls exit(). Child replces its program with a new one, runs and then calls exit().



C Program Forking Separate Process

- Code that does what previous slide depicted:

```
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);
     }
}
```

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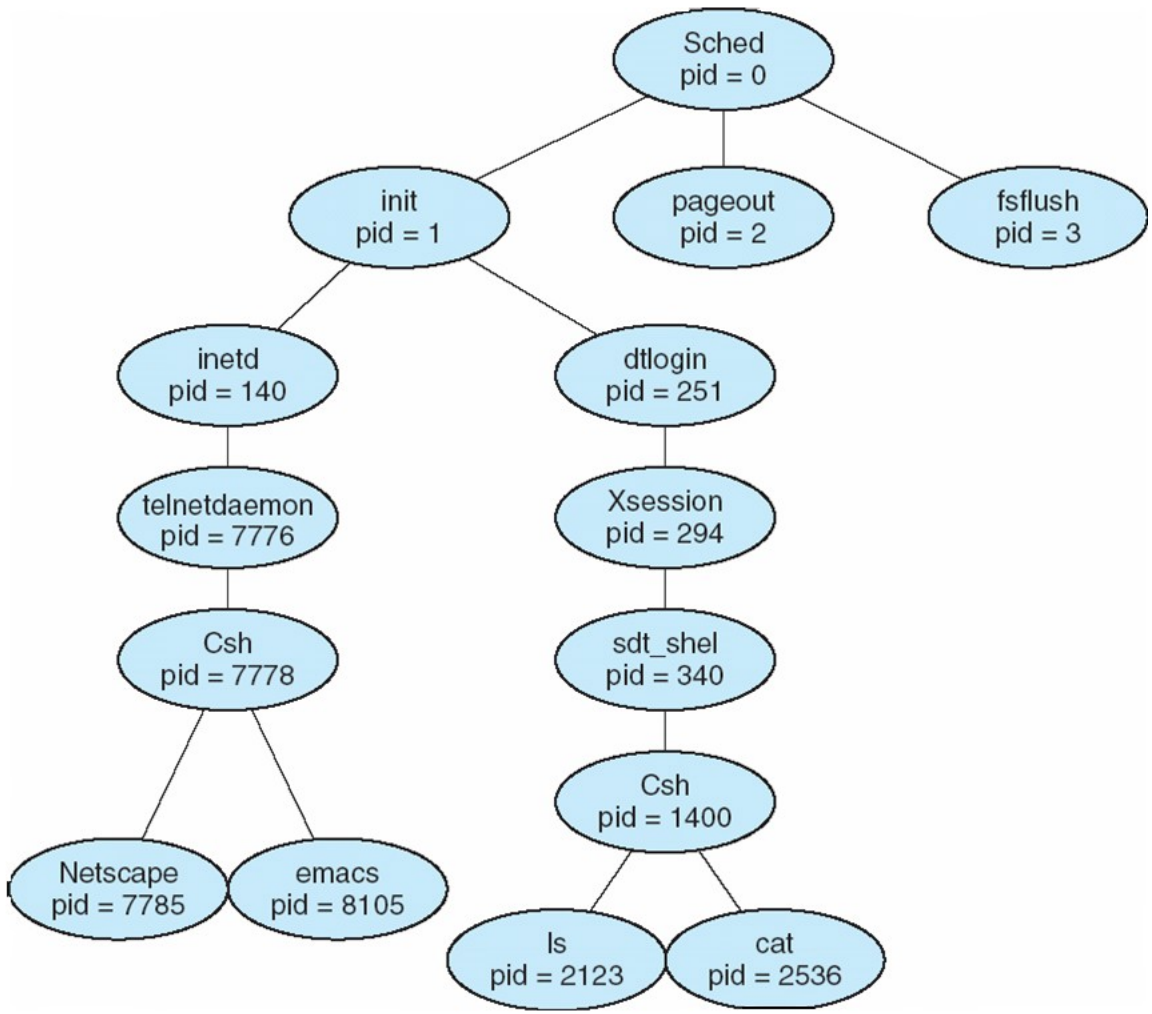
A tree of processes on a typical Solaris



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Process Termination

- Process executes last statement and asks the operating system to delete it (**exit**)
  - Deliver some data from child to parent (via **wait**)
  - Process' resources are deallocated by operating system
- Parent may terminate execution of children processes if (**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 ***(UNIX does – children continue to run, are adopted by init)***
      - All children terminated - **cascading termination**

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Interprocess Communication

- Processes within a system may be **independent** or **cooperating**
- **Definition:** A process is **Independent** if it cannot affect or be affected by the execution of another process
- **Definition.** A process is **Cooperating** if it can affect or be affected by the execution of another process
- Reasons for cooperating processes:
  - Information sharing
  - Computation speedup
  - Modularity
  - Convenience

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Interprocess Communication

- If processes cooperate they need a method of **interprocess communication** (**IPC**) and the ability to **synchronize** (chapter 6)
- Two models of IPC
  - Shared memory – e.g., common variables or files (think buffer)
  - Message passing – messages sent between processes

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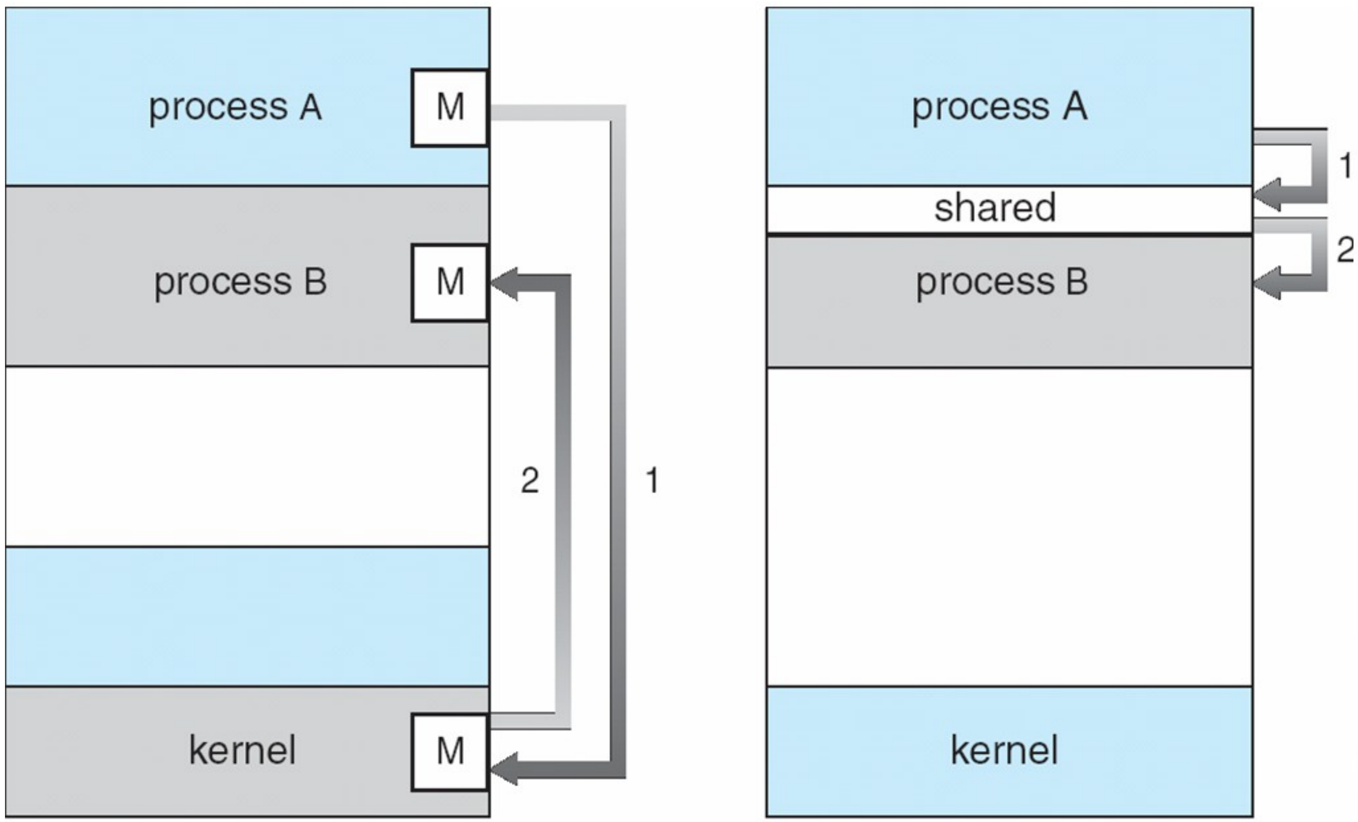
Communications Models



(a)
Message Passing

(b)
Shared Memory

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Producer-Consumer Problem

- A classical example of a cooperating process problem
- Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process – use a **buffer** for transfer of data
- Producer puts item into buffer; consumer removes item when it is ready.
  - what if no buffer?
  - what if small buffer?
  - what if unbounded buffer?

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Producer-Consumer Problem

- Examples
  - producer -- printing program, consumer – print driver
  - producer – compiler, consumer – assembler
  - UNIX pipe : last | sort
- Two versions:
  - *unbounded-buffer* places no practical limit on the size of the buffer
  - *bounded-buffer* assumes that there is a fixed buffer size

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Bounded-Buffer – Shared-Memory Solution

- Shared data, initialized as follows

```
#define BUFFER_SIZE 10
typedef struct {
   . . .
} item;
item buffer[BUFFER_SIZE];
int in = 0;      // index to put next item
int out = 0;     // index from which to get next item
```

- empty when in ==out, full when out == (in+1)% BUFFER_SIZE
  - can only use BUFFER_SIZE-1 elements

Bounded-Buffer – Producer

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

Bounded Buffer – Consumer

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

      // remove an item from the buffer
      itemToConsume = buffer[out];
      out = (out + 1) % BUFFER SIZE;
 process itemToConsume;
 }
```

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Producer Consumer -- Comments

- The buffer is a circular queue; in and out both wrap around,
- One cell is always empty
- Only producer changes in
- Only consumer changes out
- Is it correct? Can producer and consumer ever try to work on same cell – i.e. as producer is filling cell, consumer is trying to empty it?
- What if there are multiple consumers?

Interprocess Communication – Message Passing

- Mechanism for processes to communicate and to synchronize their actions without resorting to shared variables
- Necessary when processes cannot access the same memory – e.g. distributed environments
- Message passing facility provides two primitives:
  - **send**(*message*) – message size can be 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? I.e., how big a buffer?
- Is the size of a message that the link can accommodate fixed or variable?
- Is a link unidirectional or bi-directional?
- Direct or indirect naming?
- Symmetric or asymmetric communication?
- Automatic or explicit buffering?

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Direct Communication

- Processes name each other explicitly; names are bound at compile time
  - **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
- Because process must be identified at compile time , not very useful

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

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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.
- Linux implements with **`msgsnd()`** and **`msgrcv()`**, which are part of System V

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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

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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 queue is full; receiver waits if queue is empty
  3. Unbounded capacity – infinite length
     Sender never waits; receiver still waits if queue is empty

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);
```

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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()`

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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

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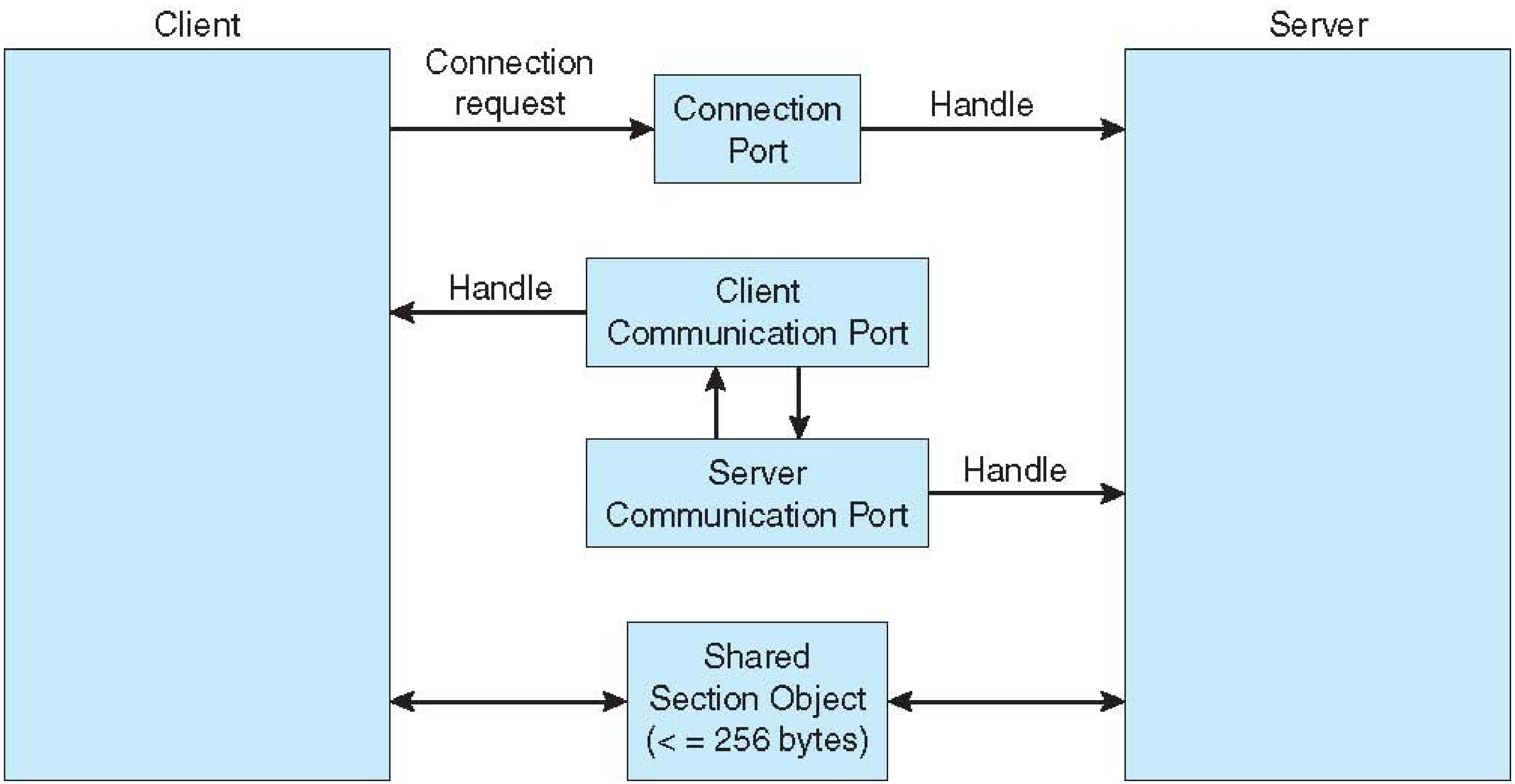
Local Procedure Calls in Windows XP



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