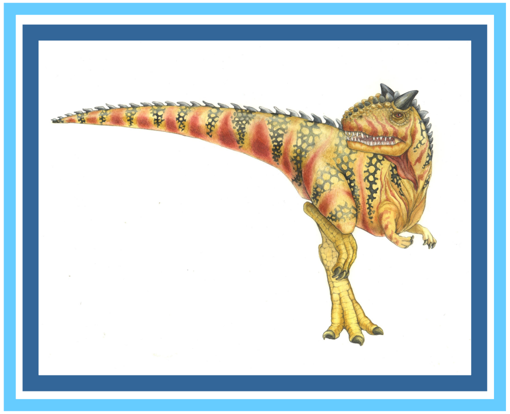
Chapter 3: Processes



Chapter 3: Processes

- 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 explore interprocess communication using shared memory and message passing
- To describe communication in client-server systems

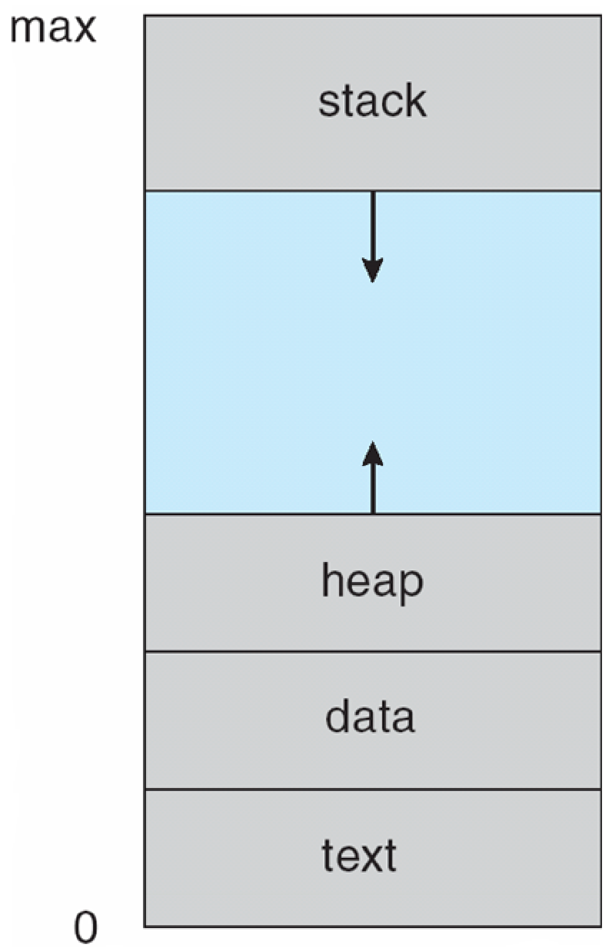
Process Concept

- An operating system executes a variety of programs:
  - Batch system (multiprogramming) – **jobs**
  - Time-shared (multitasking) systems – **processes** or **tasks**
- Textbook uses the terms ***job*** and ***process*** almost interchangeably
- **Process**: program in execution; unit of work in modern time-sharing systems
- System is a collection of OS processes and user processes
- Program is ***passive*** entity stored on disk (**executable file**), process is ***active***
  - Program becomes process when executable file gets loaded into memory
- Execution of program started via GUI mouse click or name entry on command line
- One program can be several processes
  - Consider multiple users executing the same program or one user executing multiple instances of the same program

Process in Memory

- The program code, also called **text section**
- **Data section** containing global variables
- **Stack** containing temporary data
  - Function parameters, local variables, return values, return addresses
- **Heap** containing memory dynamically allocated during run time

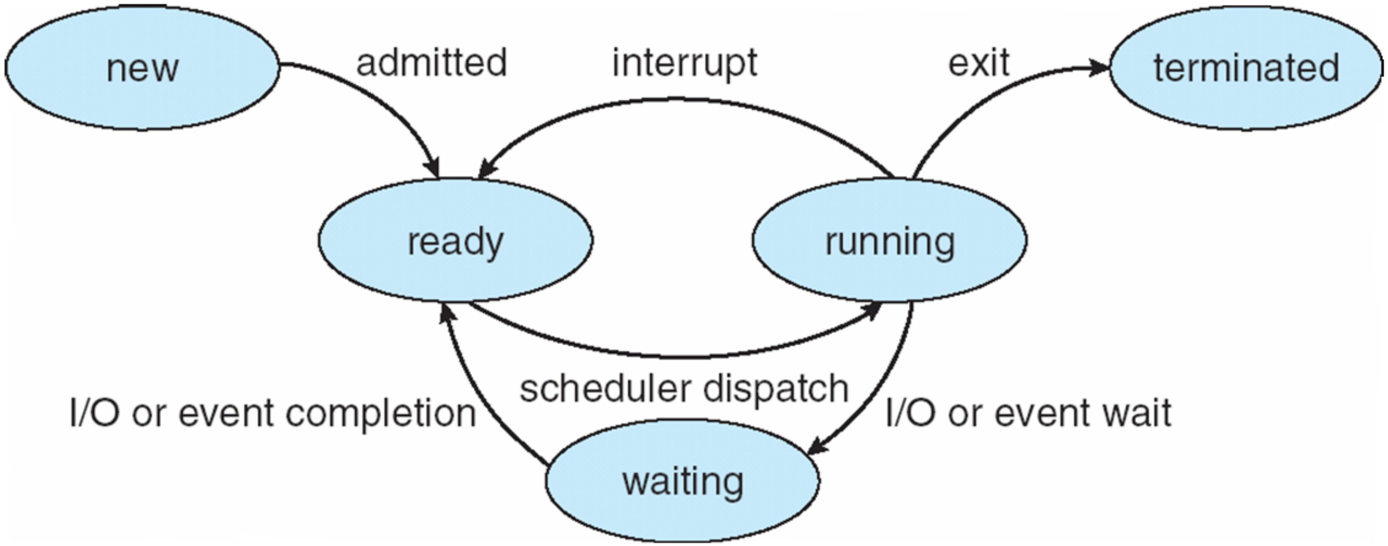
Process in Memory



Process State

- As a process executes, it changes **state**
  - **new**: The process is being created
  - **running**: Instructions are being executed on CPU
  - **waiting**: The process is waiting for some event to occur (such as I/O completion, semaphore, message, child termination)
  - **ready**: The process is waiting to be assigned to a processor
  - **terminated**: The process has finished execution
- Only one process can be running on any processor at any instant

Diagram of Process State

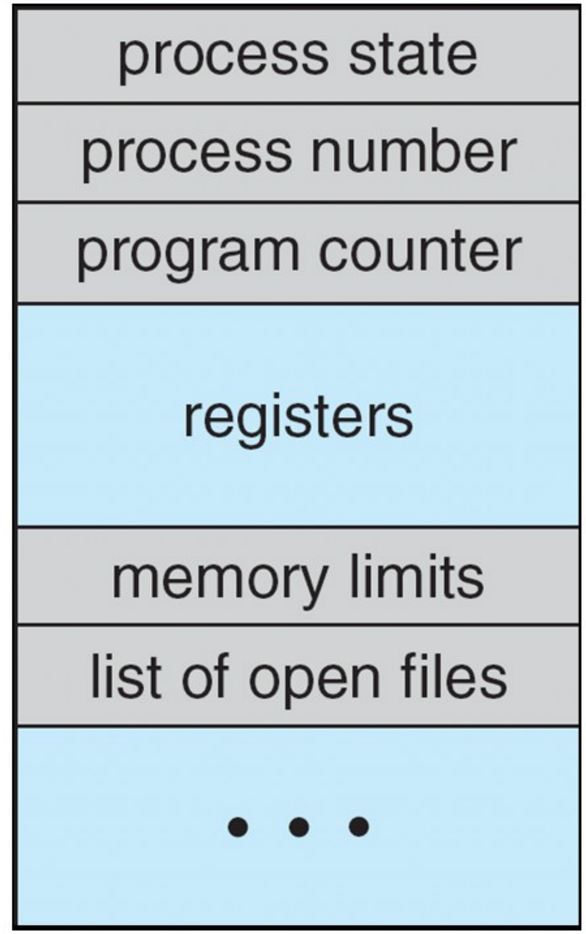


Process Control Block (PCB)

Information associated with each process

(also called **task control block**)

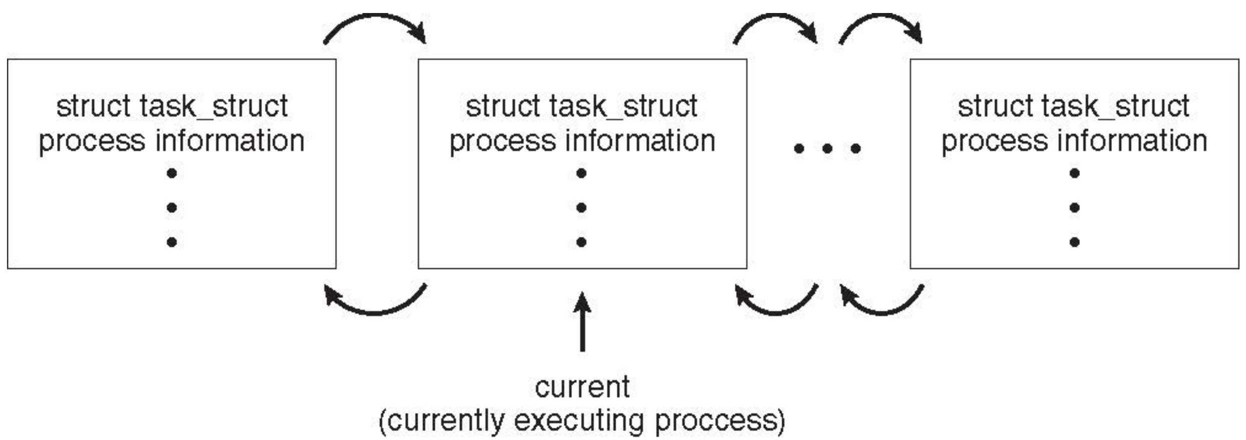
- Process state – running, waiting, etc
- Program counter – address of next instruction to execute
- CPU registers – contents of all CPU registers: general purpose, stack reg, ...
- CPU scheduling information- priority, scheduling queue pointers
- Memory-management information – memory allocated to the process
- Accounting information – CPU time used, clock time elapsed since start, time limits
- I/O status information – I/O devices allocated to process, list of open files



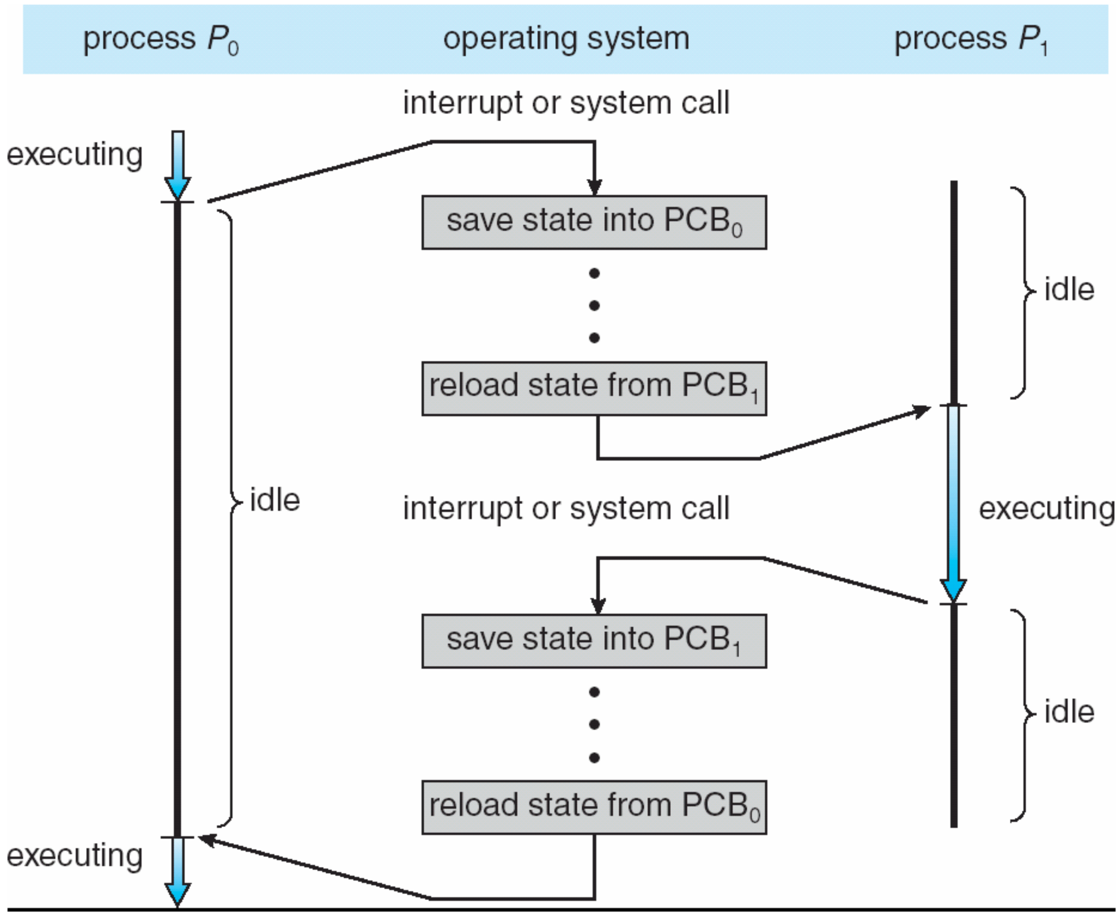
Process Representation in Linux

Represented by the C structure `task_struct`

```
pid t_pid; /* process identifier */
long state; /* state of the process */
unsigned int time_slice /* scheduling information */
struct task_struct *parent; /* this process's parent */
struct list_head children; /* this process's children */
struct files_struct *files; /* list of open files */
struct mm_struct *mm; /* address space of this process */
```



CPU Switch From Process to Process



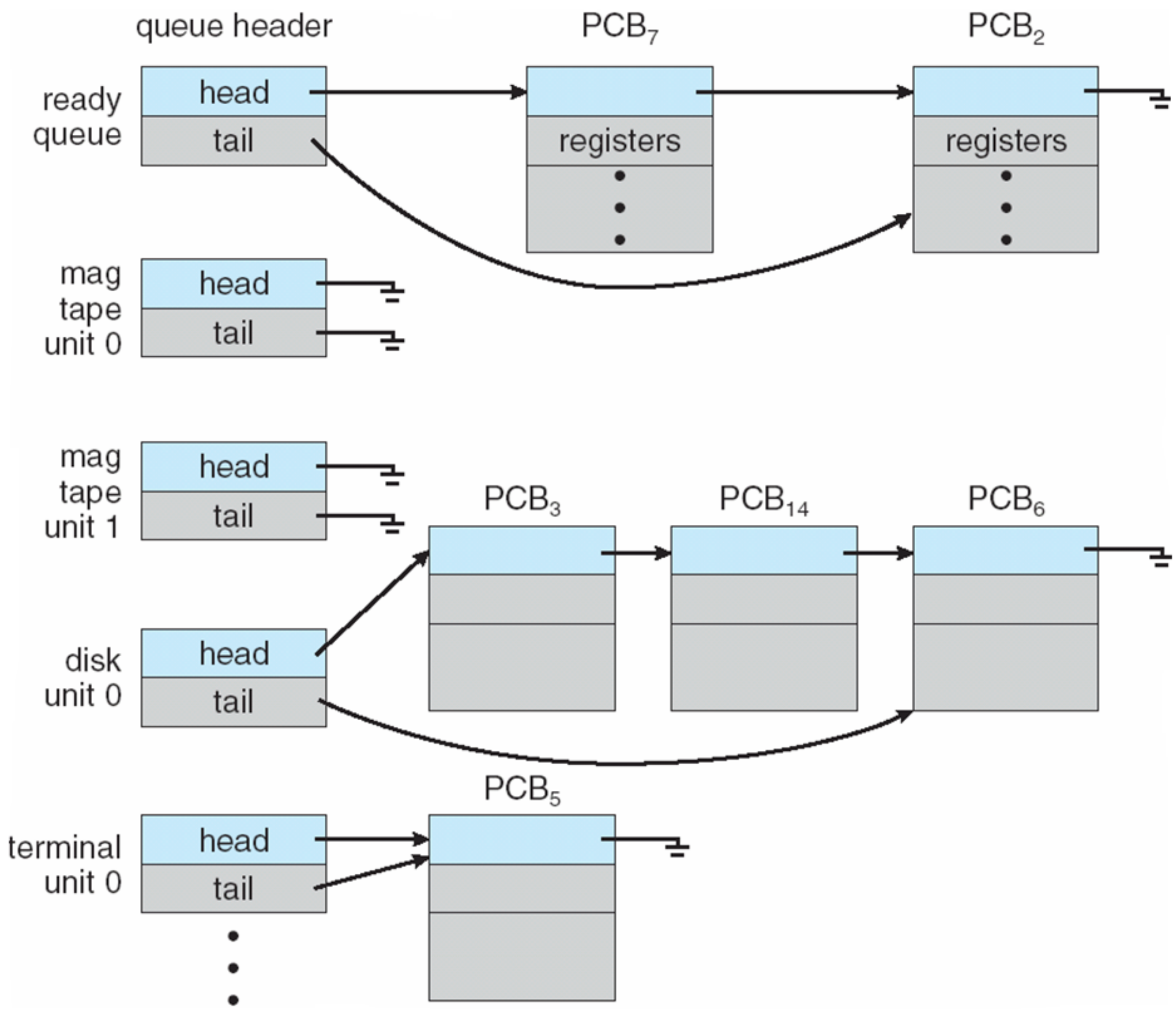
Threads

- So far, process has a single thread of execution
- A Thread is a lightweight process
- Consider having multiple program counters per process
  - Multiple locations can execute at once
    - Multiple threads of control -> **threads**
- Must then have storage for thread details, multiple program counters in PCB
- Details in next chapter

Process Scheduling

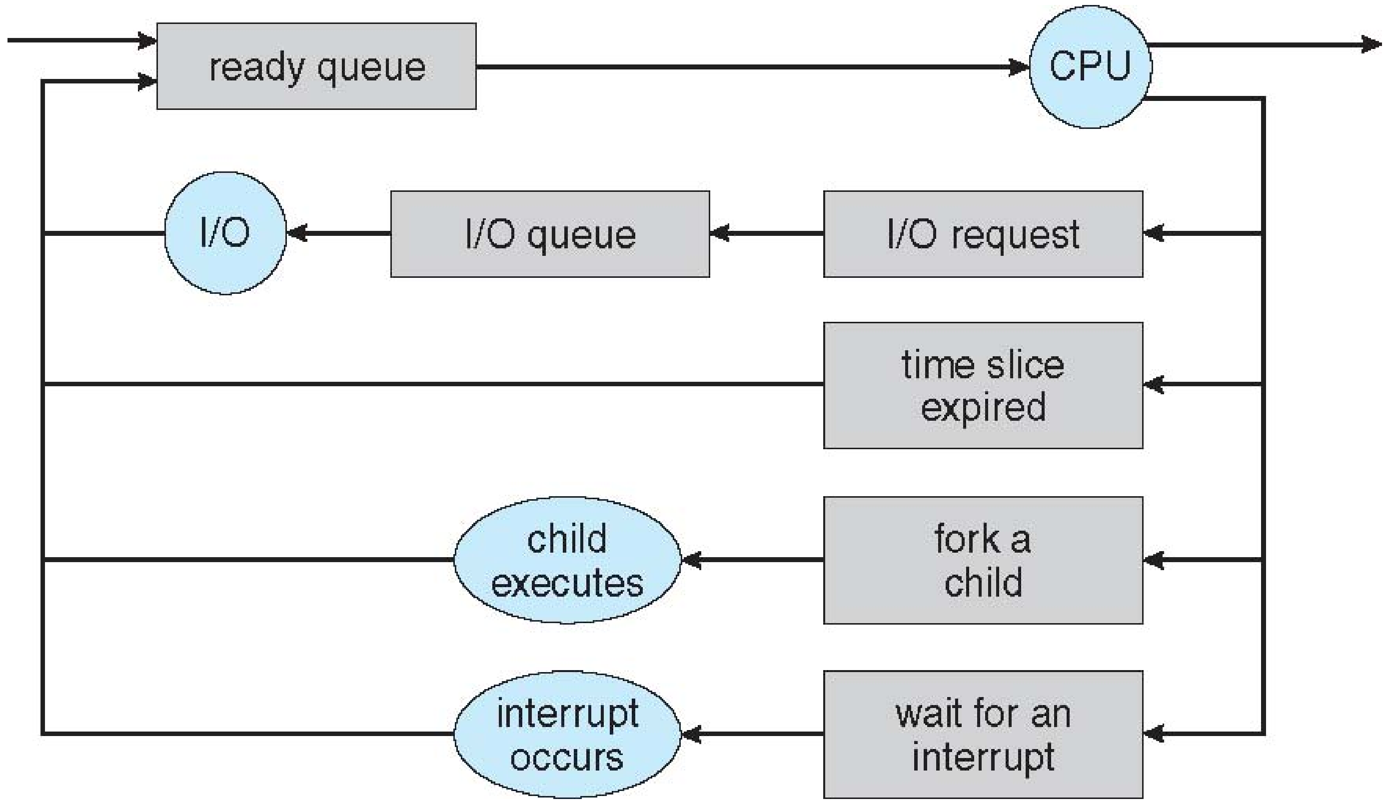
- Maximize CPU use, quickly switch processes onto CPU for time sharing
- **Process scheduler** selects among available processes for next execution on CPU
- Maintains **scheduling queues** of processes
  - **Job queue** – list of all processes in the system
  - **Ready queue** – processes residing in main memory, ready to execute.
    - Data structure depends on the scheduling algorithm
  - **Device queues** – processes waiting for an I/O device
    - Each device has its own queue
  - Processes migrate among the various queues

Ready Queue And Various I/O Device Queues



Representation of Process Scheduling

- **Queueing diagram** represents queues, resources, flows

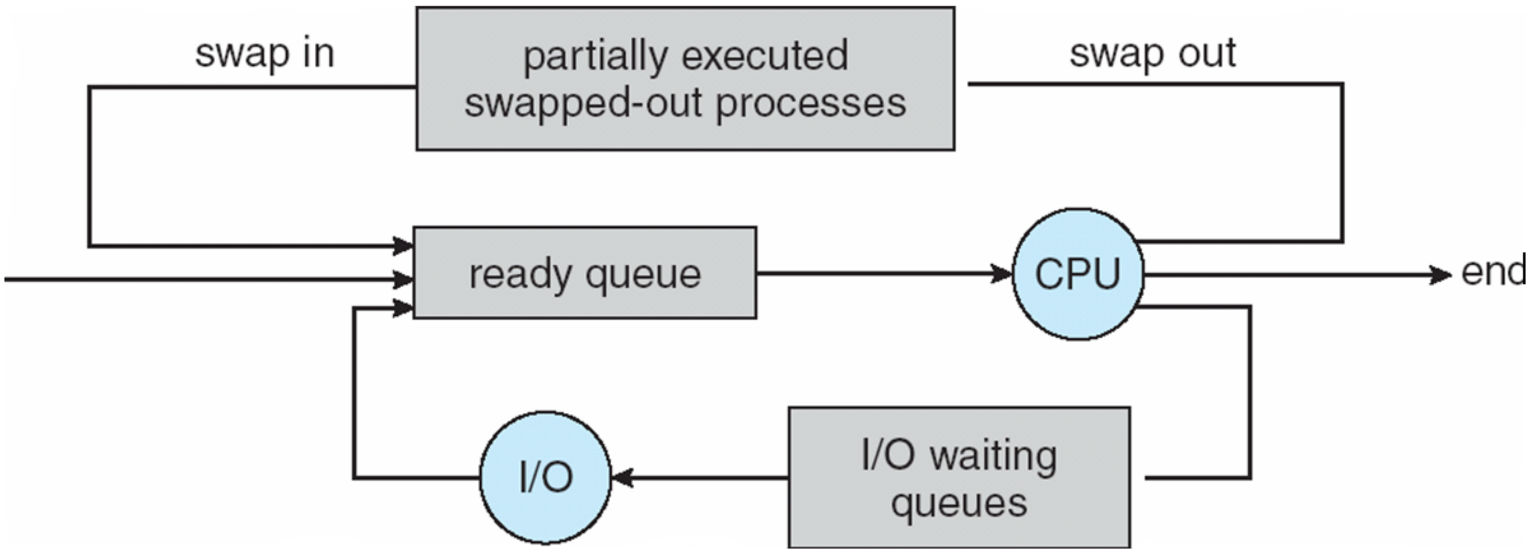


Schedulers

- **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
  - Sometimes the only scheduler in a system (Unix and Windows)
  - Short-term scheduler is invoked frequently (milliseconds) ⇒ (must be fast)
- **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue (loaded into memory)
  - Long-term scheduler is invoked infrequently (seconds, minutes) ⇒ (may be slow)
  - The long-term scheduler controls the **degree of multiprogramming** (number of processes in memory)
- 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
- Long-term scheduler strives for a good ***process mix*** to achieve balance

Addition of Medium-Term Scheduling

- **Medium-term scheduler** can be added if degree of multiprogramming needs to be decreased
  - Remove process from memory, store on disk, bring back in from disk to continue execution: **swapping**
  - Reasons: improving the mix or freeing memory



Context Switch

- When CPU switches to another process, the system must **save the state** of the current 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 depends on OS complexity and design (e.g. memory management techniques)
- Time depends on hardware support
  - Memory speed, number of registers, existence of special instructions, such as a single instruction to load and store all registers
  - Some hardware provides multiple sets of registers per CPU
- Typical switching speed is a few milliseconds

Multitasking in Mobile Systems

- Some mobile systems (e.g., early version of iOS) allow only one user process to run, others suspended
- iOS 4 allows:
  - Single **foreground** process- controlled via user interface
  - Multiple **background** processes– in memory, running, but not on the display, and with limits
    - Limits include short task, receiving notification of events, specific long-running tasks like audio playback
    - Limitation due to battery life and memory use concerns
- Android runs foreground and background with fewer limits
  - Background process uses a **service** to perform tasks
  - Service can keep running even if background process is suspended
  - Service has no user interface, small memory use

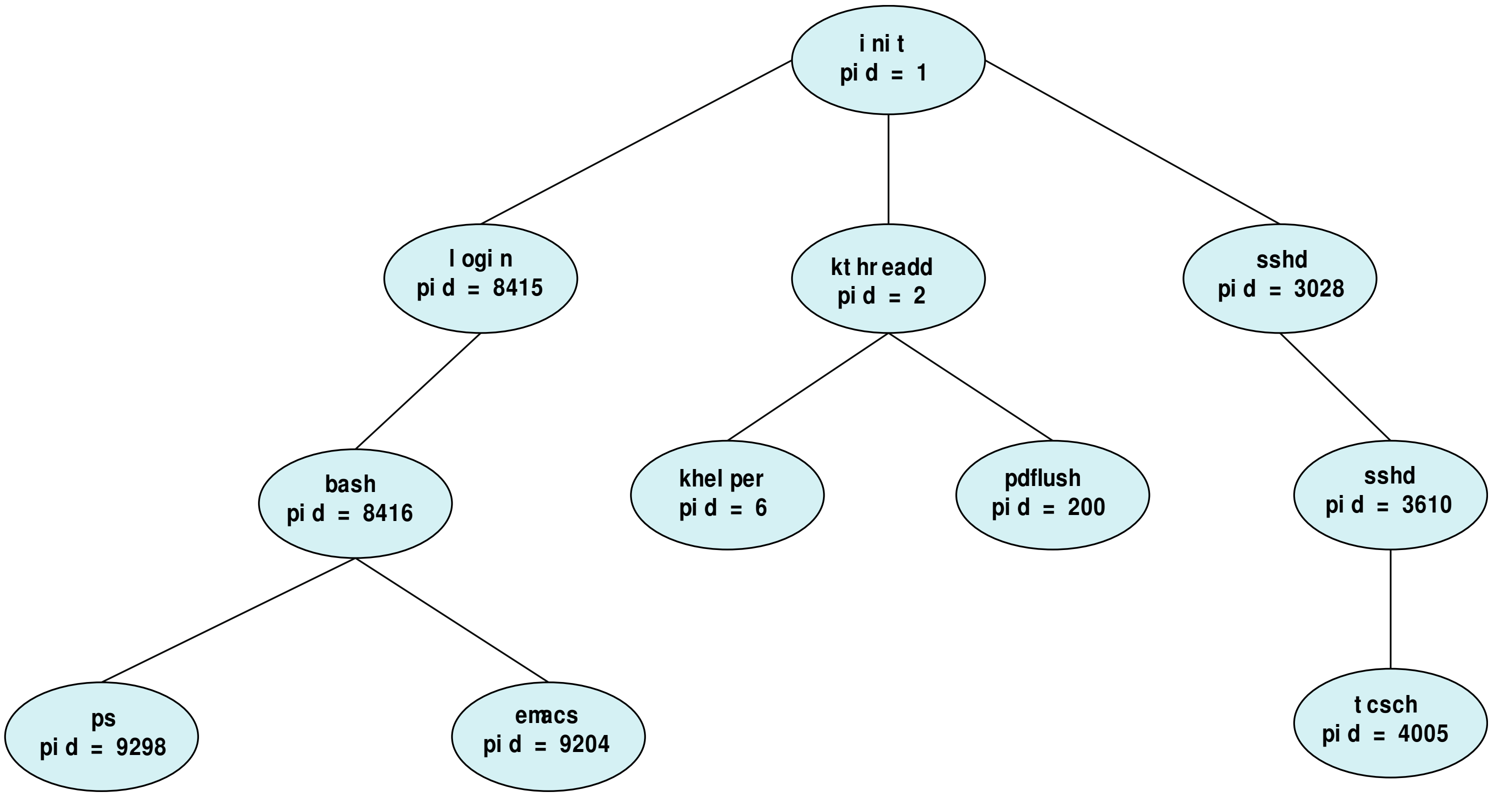
Operations on Processes

- System must provide mechanisms for:
  - process creation,
  - process termination,
  - other operations, as detailed next

Process Creation

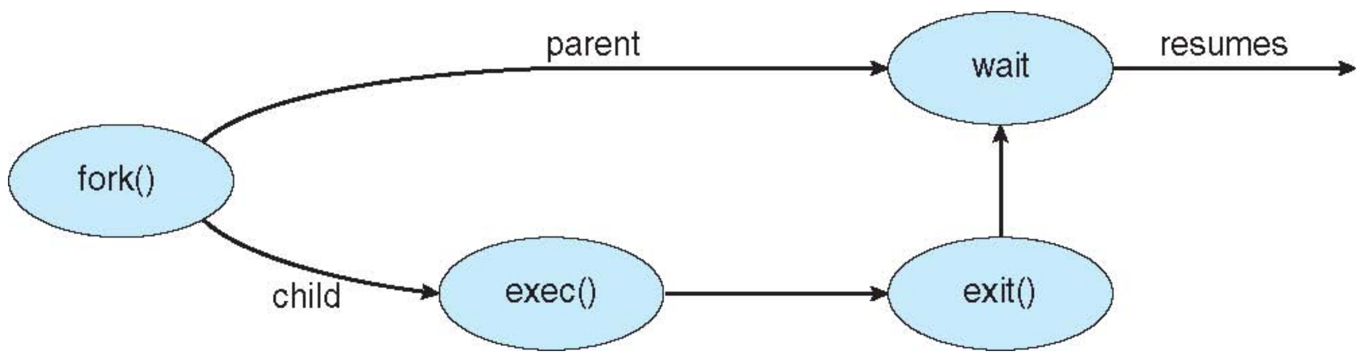
- **Parent** process creates **child** processes, which, in turn create other processes, forming a **tree** of processes
- Generally, process identified and managed via a **process identifier** (**pid**)
- Resource sharing options
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution options
  - Parent and children execute concurrently
  - Parent waits until some or all children terminate

A Tree of Processes in Linux



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's memory space with a new program
  - Child inherits privileges, scheduling attributes and other resources (open files) from parent



C Program Forking Separate Process

```
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

int main()
{
pid_t pid;

   /* fork a child process */
   pid = fork();

   if (pid < 0) { /* error occurred */
      fprintf(stderr, "Fork Failed");
      return 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");
   }

   return 0;
}
```

Creating a Separate Process via Windows API

```
#include <stdio.h>
#include <windows.h>

int main(VOID)
{
STARTUPINFO si;
PROCESS_INFORMATION pi;

   /* allocate memory */
   ZeroMemory(&si, sizeof(si));
   si.cb = sizeof(si);
   ZeroMemory(&pi, sizeof(pi));

   /* create child process */
   if (!CreateProcess(NULL, /* use command line */
    "C:\\WINDOWS\\system32\\mspaint.exe", /* command */
    NULL, /* don't inherit process handle */
    NULL, /* don't inherit thread handle */
    FALSE, /* disable handle inheritance */
    0, /* no creation flags */
    NULL, /* use parent's environment block */
    NULL, /* use parent's existing directory */
    &si,
    &pi))
   {
     fprintf(stderr, "Create Process Failed");
     return -1;
   }
   /* parent will wait for the child to complete */
   WaitForSingleObject(pi.hProcess, INFINITE);
   printf("Child Complete");

   /* close handles */
   CloseHandle(pi.hProcess);
   CloseHandle(pi.hThread);
}
```

Process Termination

- Process executes last statement and then asks the operating system to delete it using the **`exit()`** system call.
  - Returns status data from child to parent (via **`wait()`**)
  - Process's resources (memory, files, I/O) are deallocated by operating system
  - Process entry in the process table remains until parent calls wait
- Parent may terminate the execution of children processes using a system call like **`TerminateProcess()`** on Windows. Some reasons for doing so:
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - The parent is exiting and the operating system does not allow a child to continue if its parent terminates

Process Termination

- Some operating systems do not allow child to exist if its parent has terminated. If a process terminates, then all its children must also be terminated.
  - **cascading termination.** All children, grandchildren, etc. are terminated.
  - Termination is initiated by the operating system.
- The parent process may wait for termination of a child process by using the **`wait()`** system call**.** The call returns status information and the pid of the terminated process

```
pid = wait(&status);
```

- If process terminates but no parent waiting (has not invoked **`wait()`**) process is a **zombie**
- If process terminates but parent terminated without invoking **`wait()`**, process is an **orphan**

Multiprocess Architecture – Chrome Browser

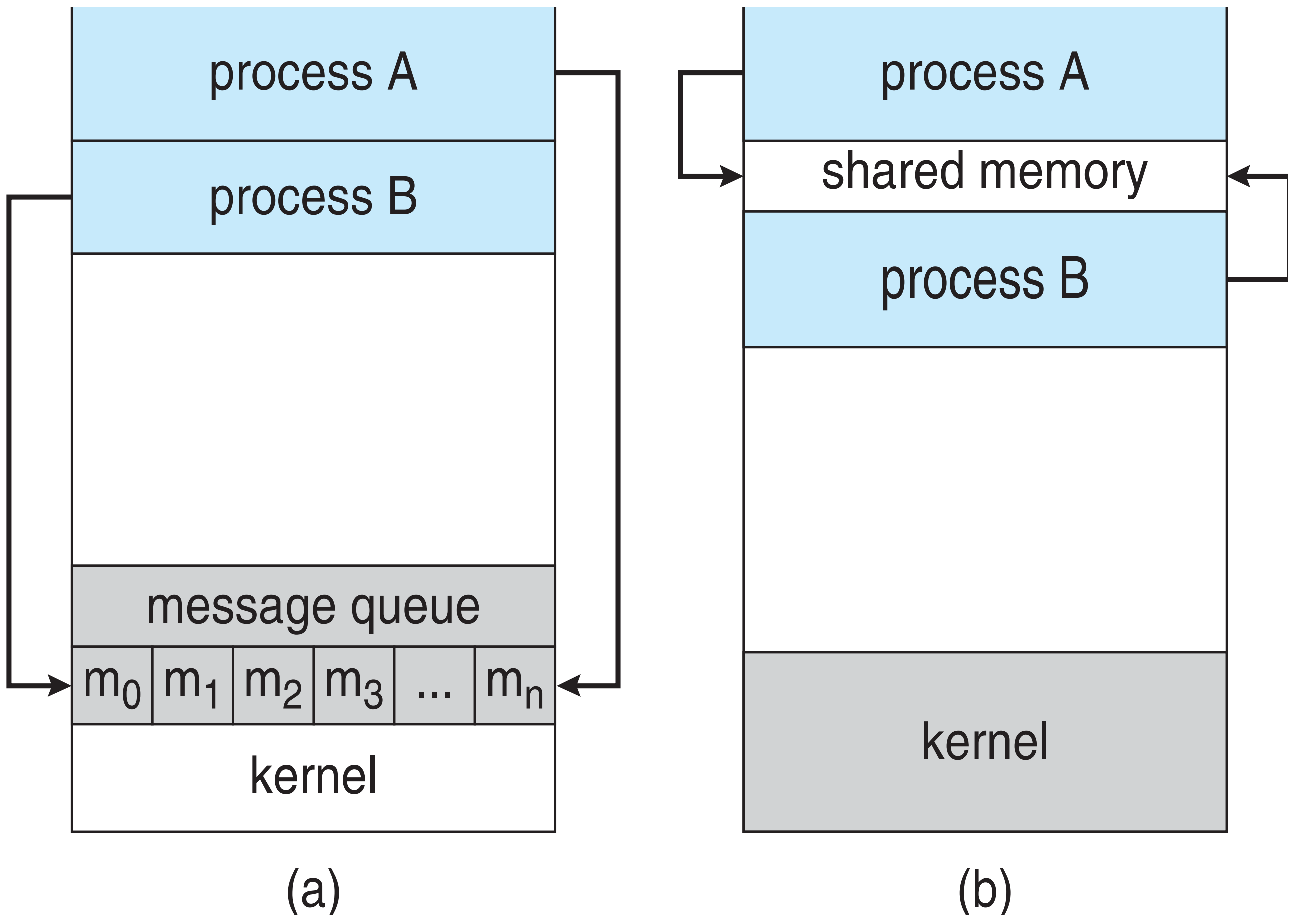
- Many web browsers ran as single process (some still do)
  - If one web site causes trouble, entire browser can hang or crash
- Google Chrome Browser is multiprocess with 3 different types of processes:
  - **Browser** process manages user interface, disk and network I/O
  - **Renderer** process renders web pages, deals with HTML, Javascript. A new renderer created for each website opened
    - Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits
  - **Plug-in** process for each type of plug-in (e.g. Flash, QuickTime)

Interprocess Communication

- Processes within a system may be ***independent*** or ***cooperating***
- Cooperating process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
  - Information sharing
  - Computation speedup
  - Modularity
  - Convenience
- Cooperating processes need **interprocess communication** (**IPC**)
- Two models of IPC
  - **Shared memory**
  - **Message passing**

Communications Models

(a) Message passing. (b) shared memory.



Interprocess Communication – Shared Memory

- An area of memory shared among the processes that wish to communicate
- Typically shared memory resides in the address space of the process creating the shared memory segment
- The communication is under the control of the user processes not the operating system.
- Major issue is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.
- Synchronization is discussed in great details in Chapter 5.
- Shared memory can be faster than message passing, because the latter is implemented by system calls (there is more kernel intervention with message passing).
- Shared memory is not necessarily faster than message passing on systems with several processing cores, due to cache coherency issues.

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 must wait if buffer is empty, but producer never has to wait
  - **bounded-buffer** assumes that there is a fixed buffer size
    - Consumer must wait if buffer is empty
    - Producer must wait if buffer is full

Bounded-Buffer – Shared-Memory Solution

- Shared data

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

item buffer[BUFFER_SIZE];
int in = 0; // first free position
int out = 0; // first full position
```

Bounded-Buffer – Producer

```
item next_produced;
while (true) {
      /* produce an item in next produced */
      while (((in + 1) % BUFFER_SIZE) == out)
            ; /* do nothing */
      buffer[in] = next_produced;
      in = (in + 1) % BUFFER_SIZE;
}
```

Bounded Buffer – Consumer

```
item next_consumed;
while (true) {
        while (in == out)
                ; /* do nothing */
        next_consumed = buffer[out];
        out = (out + 1) % BUFFER_SIZE;

        /* consume the item in next consumed */
}
```

Examples of IPC Systems - POSIX

- POSIX Shared Memory
  - Process first creates shared memory segment
    ```
    shm_fd = shm_open(name, O_CREAT | O_RDWR, 0666);
    ```
  - Also used to open an existing segment to share it
  - Set the size of the object

```
ftruncate(shm_fd, 4096);
```

  - Map file to memory
    ```
    ptr = mmap(0, 4096, PORT_WRITE, MAP_SHARED, shm_fd,0);
    ```
  - Now the process could write to the shared memory
    ```
    sprintf(ptr, "Writing to shared memory");
    ```

IPC POSIX Producer

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main()
{
/* the size (in bytes) of shared memory object */
const int SIZE = 4096;
/* name of the shared memory object */
const char *name = "OS";
/* strings written to shared memory */
const char *message_0 = "Hello";
const char *message_1 = "World!";

/* shared memory file descriptor */
int shm_fd;
/* pointer to shared memory obect */
void *ptr;

   /* create the shared memory object */
   shm_fd = shm_open(name, O_CREAT | O_RDWR, 0666);

   /* configure the size of the shared memory object */
   ftruncate(shm_fd, SIZE);

   /* memory map the shared memory object */
   ptr = mmap(0, SIZE, PROT_WRITE, MAP_SHARED, shm_fd, 0);

   /* write to the shared memory object */
   sprintf(ptr,"%s",message_0);
   ptr += strlen(message_0);
   sprintf(ptr,"%s",message_1);
   ptr += strlen(message_1);

   return 0;
}
```

IPC POSIX Consumer

```
#include <stdio.h>
#include <stdlib.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main()
{
/* the size (in bytes) of shared memory object */
const int SIZE = 4096;
/* name of the shared memory object */
const char *name = "OS";
/* shared memory file descriptor */
int shm_fd;
/* pointer to shared memory obect */
void *ptr;

   /* open the shared memory object */
   shm_fd = shm_open(name, O_RDONLY, 0666);

   /* memory map the shared memory object */
   ptr = mmap(0, SIZE, PROT_READ, MAP_SHARED, shm_fd, 0);

   /* read from the shared memory object */
   printf("%s",(char *)ptr);

   /* remove the shared memory object */
   shm_unlink(name);

   return 0;
}
```

Interprocess Communication – Message Passing

- Mechanism for processes to communicate and to synchronize their actions
- Message system – processes communicate with each other without resorting to shared variables
- IPC facility provides two operations:
  - **`send`**(*message*)
  - **`receive`**(*message*)
- The *message* size is either fixed or variable

Message Passing (Cont.)

- If processes *P* and *Q* wish to communicate, they need to:
  - Establish a ***communication link*** between them
  - Exchange messages via send/receive
- Implementation issues:
  - 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?

Message Passing (Cont.)

- Implementation of communication link
  - Physical
    - Shared memory
    - Hardware bus
    - Network
  - Logical
    - Direct or indirect
    - Synchronous or asynchronous
    - Automatic or explicit buffering
- Our focus here is on the logical implementation

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
- Operations
  - create a new mailbox (port)
  - 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

- 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

- Mailbox sharing
  - P_1, P_2, and P_3 share mailbox A
  - P_1, sends; P_2 and P_3 receive
  - Which process 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 the receiver using a certain algorithm (e.g. round robin). Sender is notified who the receiver was.

Synchronization

- Message passing may be either blocking or non-blocking
- **Blocking** is considered **synchronous**
  - **Blocking send** -- the sender is blocked until the message is received
  - **Blocking receive** -- the receiver is blocked until a message is available
- **Non-blocking** is considered **asynchronous**
  - **Non-blocking send** -- the sender sends the message and continues
  - **Non-blocking receive** -- the receiver receives:
    - A valid message, or
    - Null message
- Different combinations possible
  - If both send and receive are blocking, we have a **rendezvous,** and the solution to the producer-consumer problem becomes trivial

Synchronization (Cont.)

- Producer-consumer becomes trivial

```
message next_produced;
while (true) {
      /* produce an item in next produced */
send(next_produced);
}
```

```
message next_consumed;
while (true) {
   receive(next_consumed);

   /* consume the item in next consumed */
}
```

Buffering

- Temporary queue of messages attached to the link.
- implemented in one of three ways
  1. Zero capacity – no messages are queued on a link.
     Sender must block until the recipient receives the message (rendezvous)
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if and only if link is full
  3. Unbounded capacity – infinite length
     Sender never waits

Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls
- Pipes

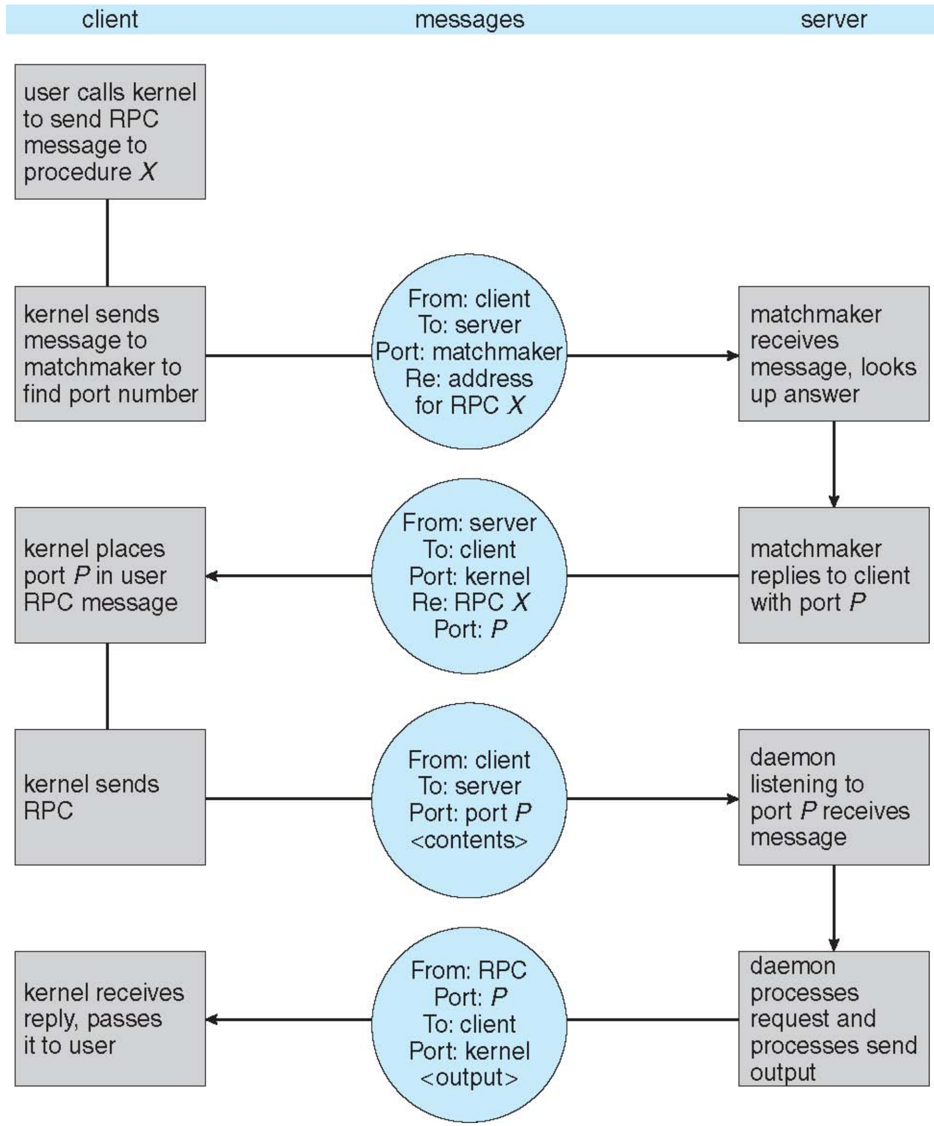
Sockets

- A **socket** is defined as an endpoint for communication
- Sockets allow low-level unstructured communication
- Concatenation of IP address and **port** – a number included at start of message packet to differentiate network services on a host
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- Communication takes place between a pair of sockets
- All ports below 1024 are ***well known***, used for standard services (telnet: 23, FTP: 21, HTTP: 80).
- Special IP address 127.0.0.1 (**loopback**) to refer to system on which process is running

Remote Procedure Calls

- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
  - Again uses ports for service differentiation
- **Stubs** – client-side proxy for the actual procedure on the server
- The client-side stub locates the server and **marshalls** the parameters (packages the parameters into a form that can be transmitted over a network).
- The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server
- OS typically provides a **matchmaker** service to connect client and server
- Data representation handled via **External Data Representation** (**XDL**) format to account for different architectures
  - **Big-endian** vs **little-endian**

Execution of RPC

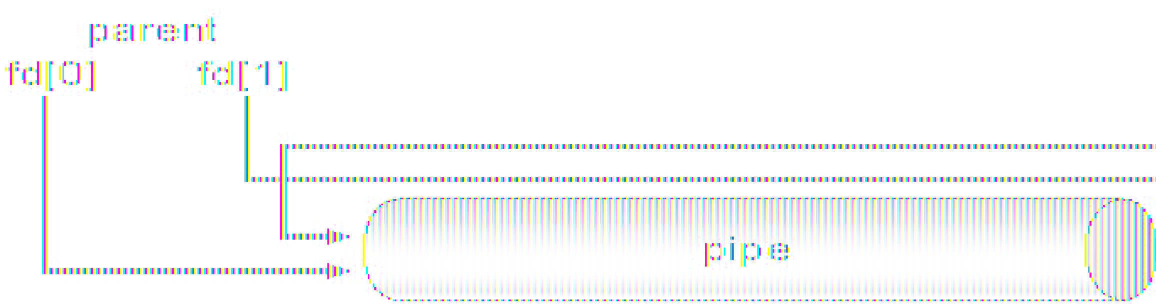


Pipes

- Acts as a conduit allowing two processes to communicate
- Issues:
  - Is communication unidirectional or bidirectional?
  - In the case of two-way communication, is it half or full-duplex?
  - Must there exist a relationship (i.e., ***parent-child***) between the communicating processes?
  - Can the pipes be used over a network?
- Ordinary pipes – cannot be accessed from outside the process that created it. Typically, a parent process creates a pipe and uses it to communicate with a child process that it created.
- Named pipes – can be accessed without a parent-child relationship.

Ordinary Pipes

- Ordinary Pipes allow communication in standard producer-consumer style
- Producer writes to one end (the **write-end** of the pipe)
- Consumer reads from the other end (the **read-end** of the pipe)
- Ordinary pipes are therefore unidirectional
- Constructed using pipe(int fd[]);
  - fd[0] is the read end and fd[1] is the write end
- Communicating processes use ordinary read() and write() system calls
- Require parent-child relationship between communicating processes



- Window
- See Unix and Windows code samples in textbook

Named Pipes

- Named Pipes are more powerful than ordinary pipes
- Communication is bidirectional
- No parent-child relationship is necessary between the communicating processes
- Several processes can use the named pipe for communication
- Provided on both UNIX and Windows systems

End of Chapter 3