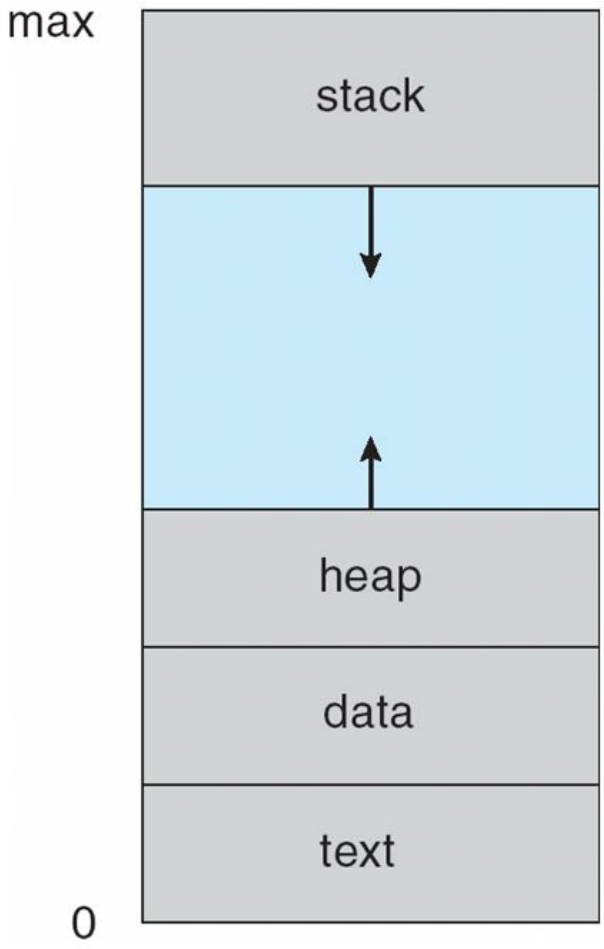
Chapter 3: Processes

- What is a process ?
- What is process scheduling ?
- What are the common operations on processes ?
- How to conduct process-level communication ?
- How to conduct client-server communication ?

Process Concept

- Process
  - is a program in execution
  - is an instance of a computer program being sequentially executed
  - process execution must progress in sequential fashion
  - process is also called a *job*
- Program Vs. process
  - program is a *passive* entity; process is an *active* entity
  - program only contains text; process is associated with code, data, PC, heap, stack, registers, and other information
  - program becomes a process when an executable file is loaded into memory
  - same program executed multiple times will correspond to different process each time

Process in Memory



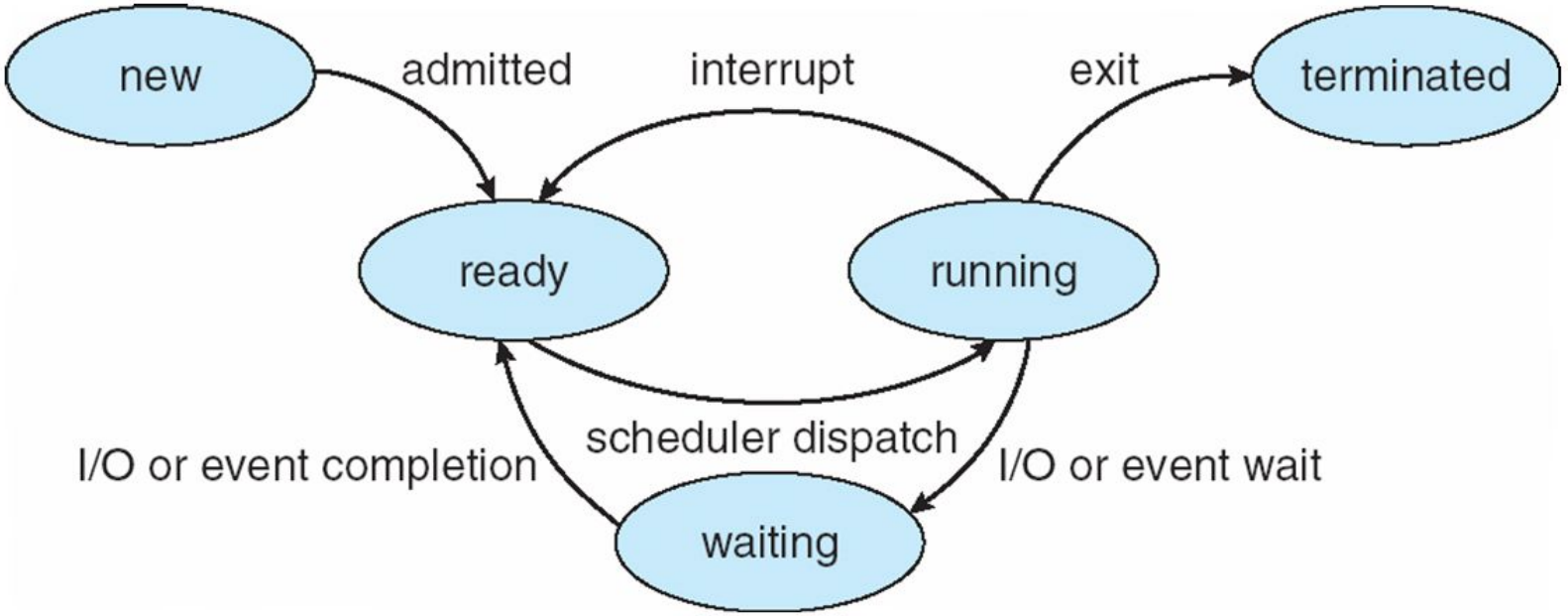
Regions in Process Memory

	Holds?	Allocation	Deallocation	Scope
Stack	Local variables (Function activation records)	Automatic (on function entry)	Automatic (on function exit)	Duration of function
Heap	Dynamically allocated data	Implicit or Explicit	Implicit or Explicit	Until deallocation
Data	Global and static data	On process creation	On process termination	During program execution
Text	Program binary instructions	N/A	N/A	N/A

Process State

- During execution, the process may be in one of the following *states*
  - new – process is being created
  - running – instructions are being executed
  - waiting – waiting for some event to occur
  - ready – waiting to be assigned a processor
  - terminated – process has finished execution
- Each processor can only run one process at any instant.

Diagram of Process State



Process Control Block (PCB)

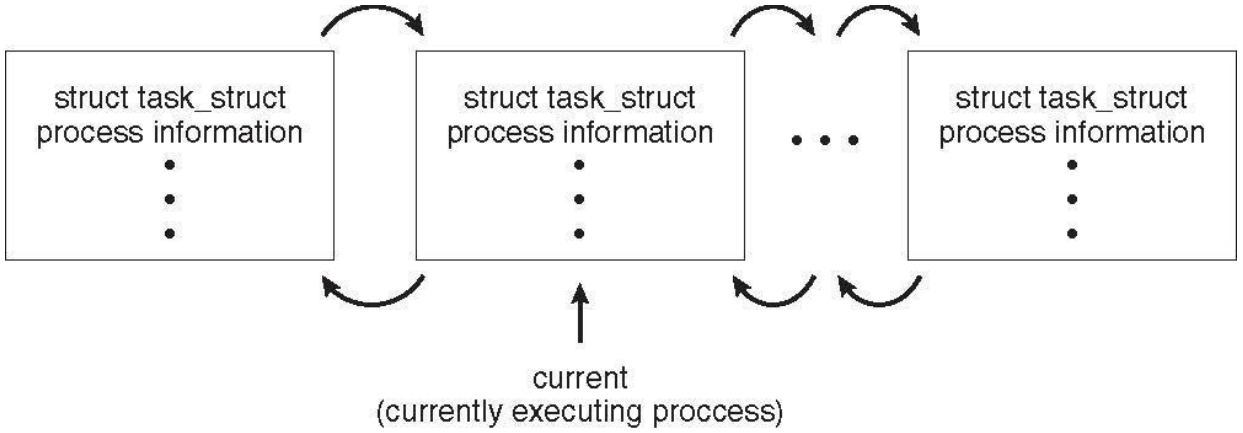
- PCB is representation of a process in an operating system.
  - maintains process-specific information
  - necessary for scheduling
- Information associated with each process
  - process state
  - program counter
  - CPU registers
  - CPU scheduling information
  - memory-management information
  - accounting information
  - I/O status information

Process Control Block (PCB) (2)

Process Representation in Linux

Represented by the C structure `task_struct`

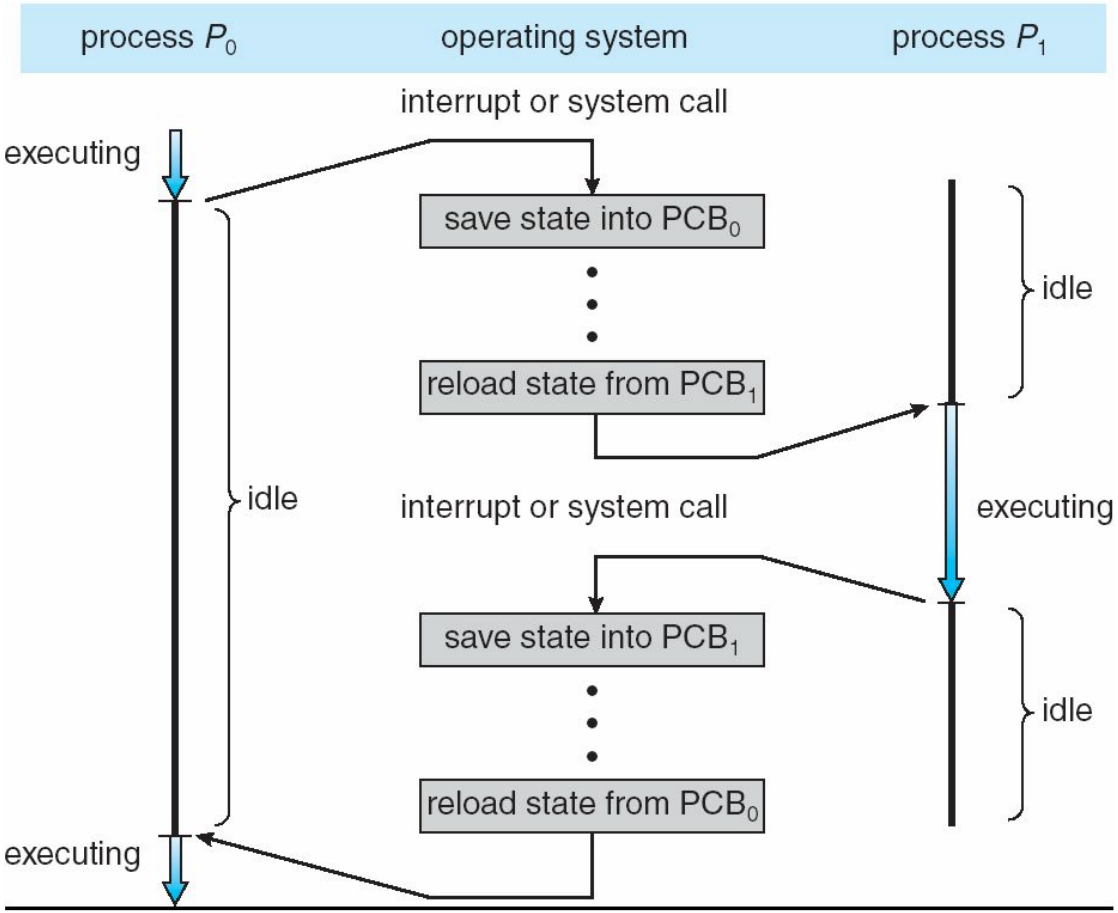
```
pid t_pid; /* process identifier */
long state; /* state of the process */
unsigned int time_slice /* scheduling information */
struct task_struct *parent; /* this process's parent */
struct list_head children; /* this process's children */
struct files_struct *files; /* list of open files */
struct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



Context Switch

- A *context switch* is the process of storing and restoring the state (context) of the CPU such that multiple processes can share a single CPU resource
  - for time-shared or multiprogramming environments
  - context of a process represented in the PCB
  - context switch involves a state *save* of the current process, and a state *restore* of the process being resumed next
  - switch from *user* to *kernel* mode or vice-versa is a mode switch
- Context-switch time is overhead
  - the system does no useful work while switching
  - overhead depends on hardware support
    - Sun UltraSPARC provides multiple banks of registers
    - Intel x86 processors also provide some support

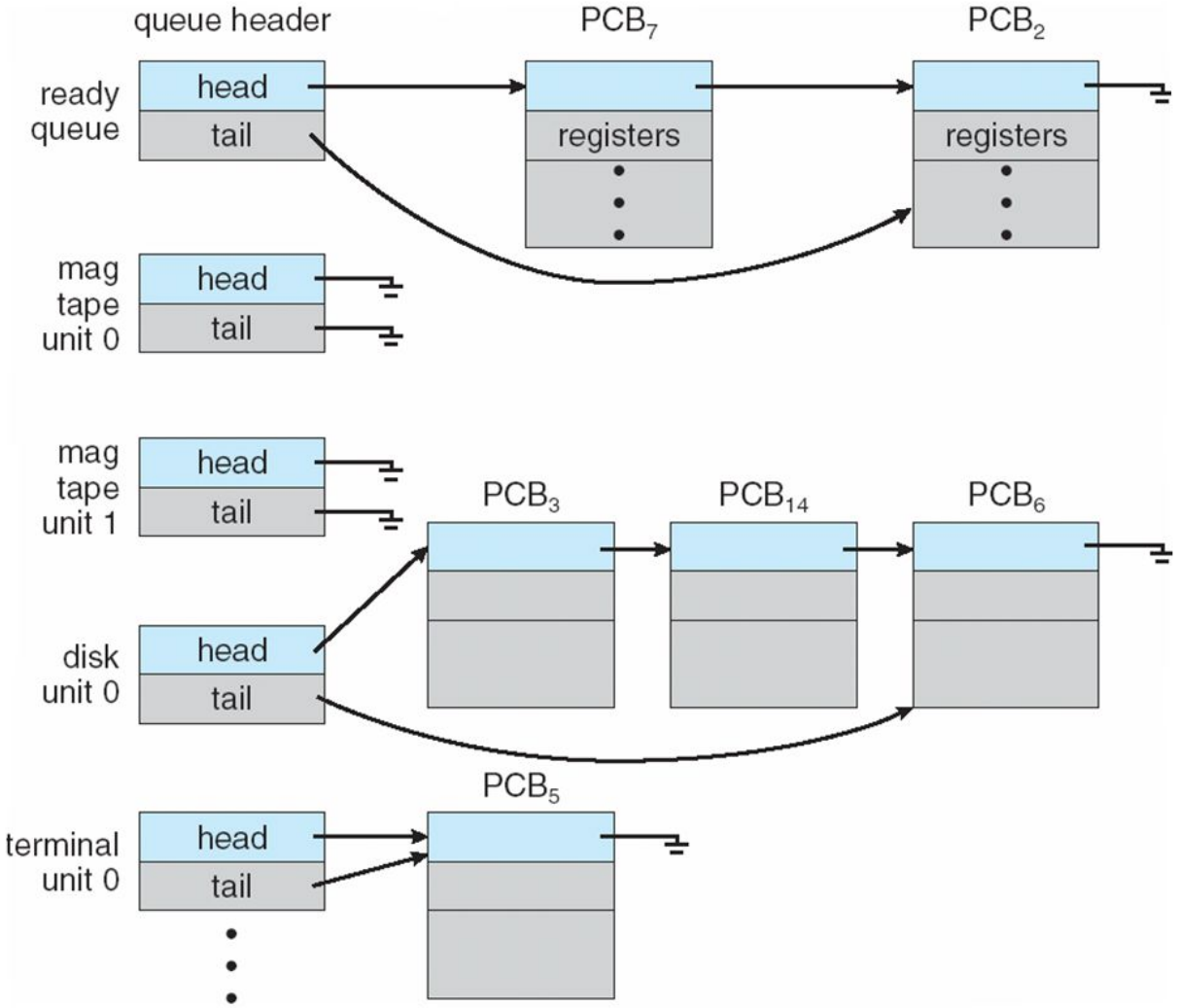
CPU Switch From Process to Process



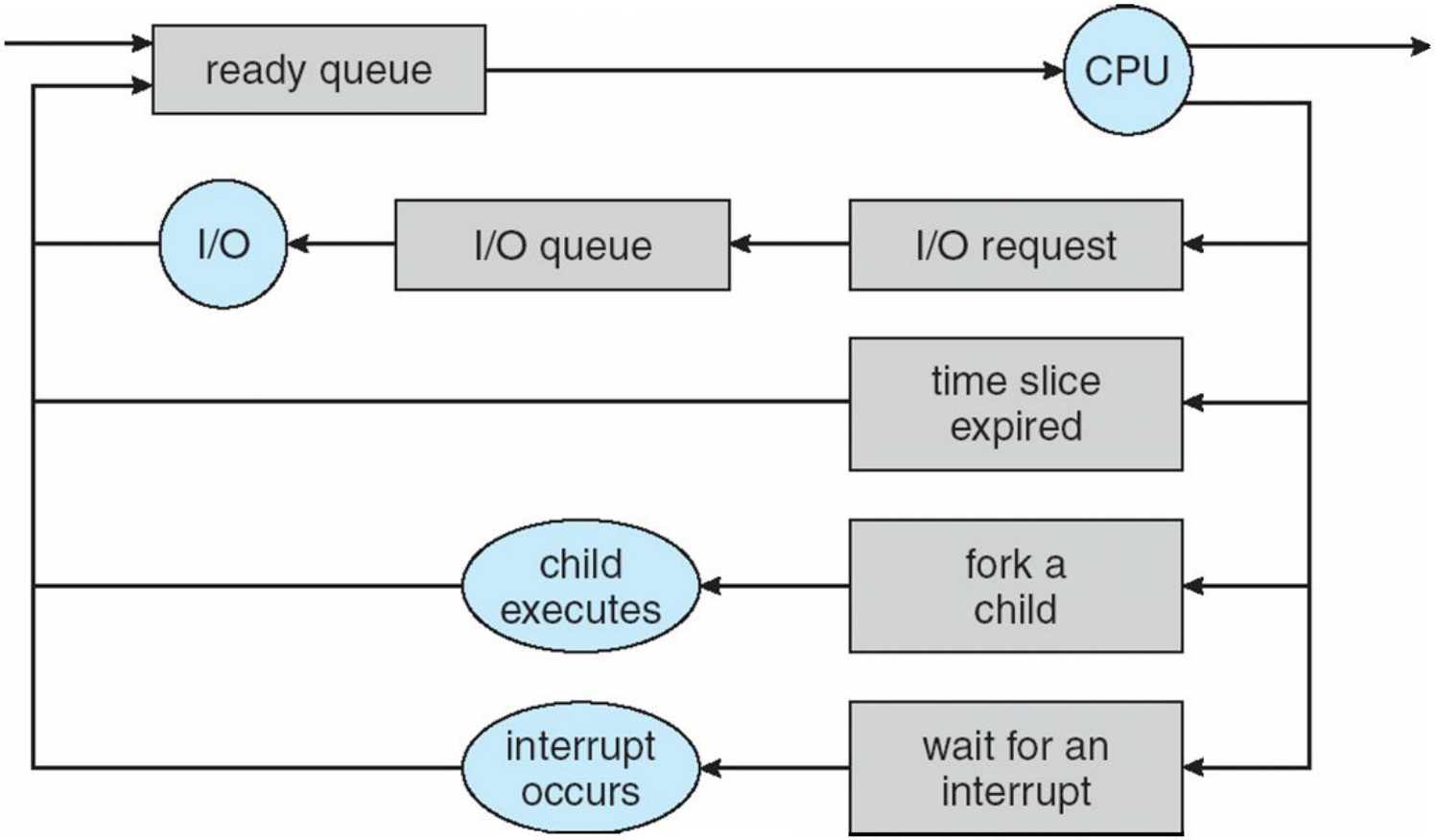
Process Scheduling

- Process scheduling selects the process to run on a CPU
  - maximizes CPU utilization in a multiprogramming OS
  - provides illusion of each process owning the system in a time-shared OS
- Terminology used in OS schedulers
  - **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



Schedulers

- Systems with a possibility of huge deluge of job requests may use multiple schedulers.
- **Long-term scheduler** (or job scheduler)
  - selects processes to be brought into the ready queue
  - controls the *degree of multiprogramming*
  - controls the mix of active CPU-bound and I/O-bound processes
  - invoked infrequently
  - can afford more time to make selection decision
- **Short-term scheduler** (or CPU scheduler)
  - selects the process to be executed next and allocates CPU
  - invoked frequently
  - necessary to limit scheduling overhead

Process Creation

- Any process can create other processes during its execution
  - operating systems have a *primordial* process
  - creating process called parent process
  - new process called child process
  - processes 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 (Unix)
- Execution options
  - parent and children execute concurrently (Unix)
  - parent waits until children terminate
    - on Unix, parent can *explicitly* call the wait() system call to wait for the child process to finish

Process Creation (Cont)

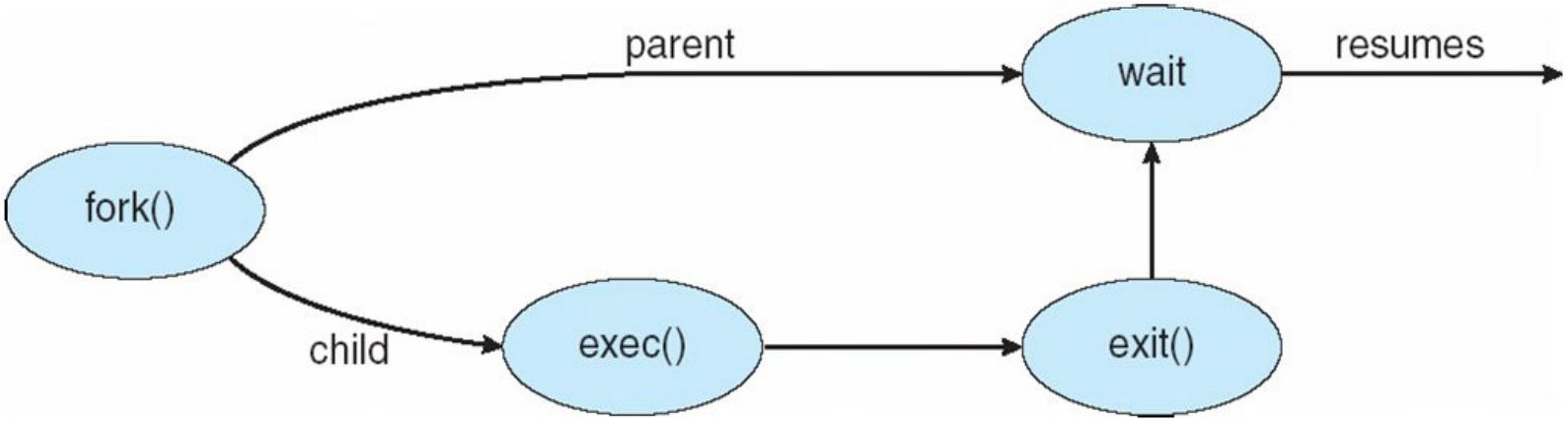
- Address space options
  - child duplicate of parent
  - child has a program loaded into it (by using exec)
- UNIX examples
  - **fork** system call creates new process
  - **exec** system call replaces the process' memory space with a new program

Process Creation Example on Unix

```
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);
        }
}
```

Process Creation

- Parent waiting for child process to finish



Process Termination

- Process terminates after executing last statement
  - can explicitly invoke the **exit** system call to terminate
  - OS implicitly calls exit, if it is not explicitly invoked
  - child can pass return status to parent (via **wait**)
  - process resources are deallocated by operating system
- Parent may *explicitly* terminate execution of child processes (**abort**)
  - for example, if child has exceeded allocated resources
  - or, task assigned to child is no longer required
- If parent is exiting
  - on Unix-like OS, child runs independently and is unaffected; OS assigns it a *new* parent
  - some other OS may not allow child to continue if its parent terminates

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

Interprocess Communication

- Communication within the same system.
- Processes may need to *co-operate* for several reasons
  - information sharing
  - computation speedup
  - modularity
  - convenience
- Cooperating process can affect or be affected by other processes
  - typically, by sharing data
- Cooperating processes need **interprocess communication** (**IPC**)

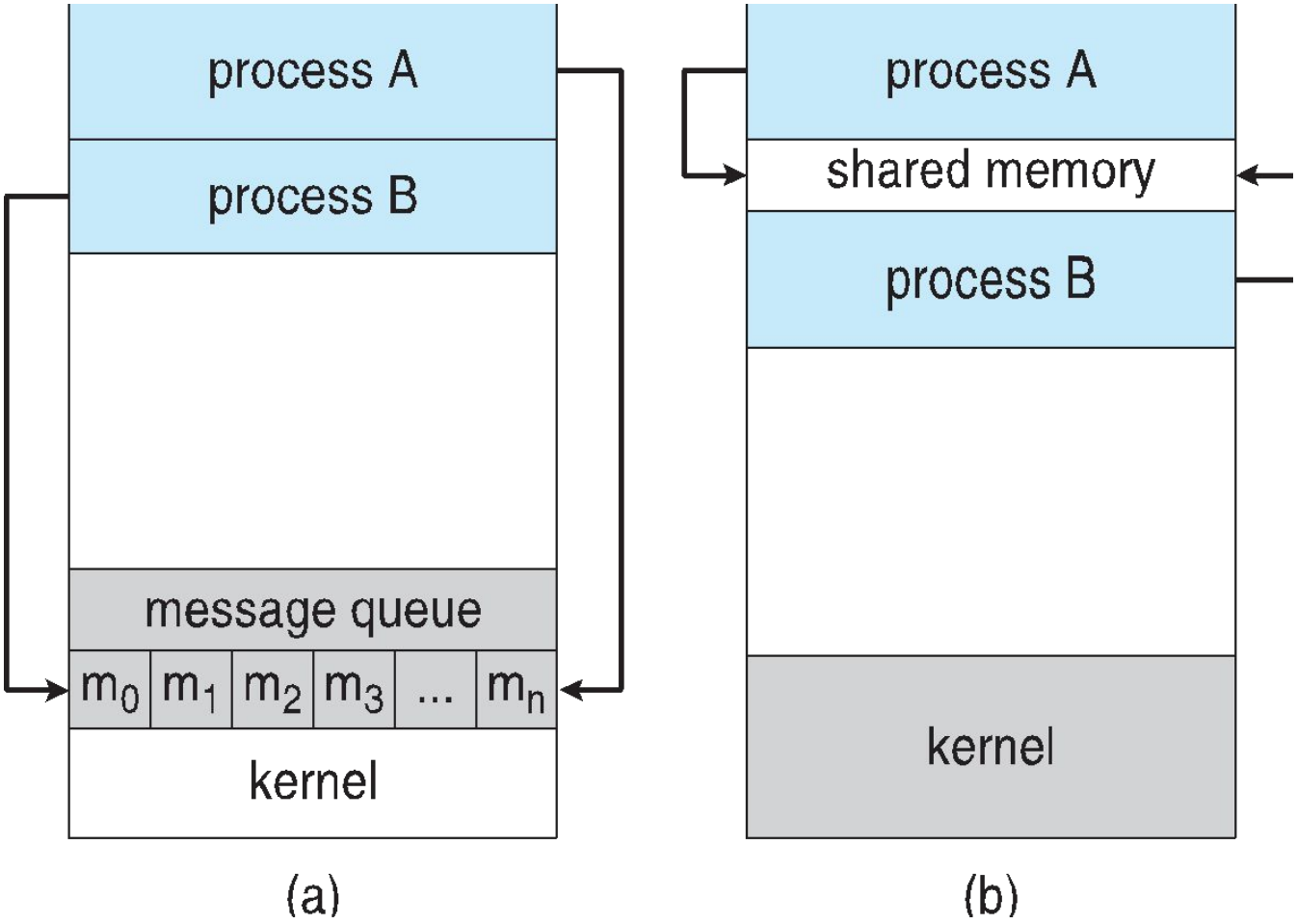
Producer-Consumer Problem

- Common paradigm for co-operating processes
  - *producer* process produces information
  - *consumer* process consumes the produced information
- Processes need synchronization
  - *consumer* cannot use information before it is produced by the *producer*
- Abstraction models
  - *unbounded-buffer* places no practical limit on the size of the buffer
  - *bounded-buffer* assumes that there is a fixed buffer size

Models of IPC

- Shared memory
  - share a region of memory between co-operating processes
  - read or write to the shared memory region
  - fast communication
  - convenient communication
- Message passing
  - exchange messages (*send* and *receive*)
  - typically, messages do not overwrite each other
    - no need for conflict resolution
  - typically, used for sending smaller amounts of data
  - slower communication
  - easy to implement (even for inter-computer communication)

Models of IPC (2)



Message Passing

- Another mechanism for interprocess communication
  - can be employed for client-server communication
- Message passing facility provides at least two operations:
  - **send** (*message*) and **receive** (*message*)
- If *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 between every pair of communicating processes?
  - what is the capacity of a link?
  - fixed or variable sized message ?
  - is the link unidirectional or bi-directional?

Message Passing – Naming

- 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
  - disadvantage
    - process identifiers are hard-coded

Message Passing – Naming (2)

- Indirect communication
  - messages are directed and received from mailboxes (also referred to as ports)
    - **send** (A, message) – send a message to mailbox A
    - **receive** (A, message) – receive a message from mailbox A
  - each mailbox has a unique id
  - processes can communicate only if they share a mailbox
  - properties of communication link
    - link may be associated with many processes
    - each pair of processes may share several communication links
    - link may be unidirectional or bi-directional
    - multiple receivers may need synchronization
  - mailbox can be held in the process address space or in the kernel

Message Passing (3)

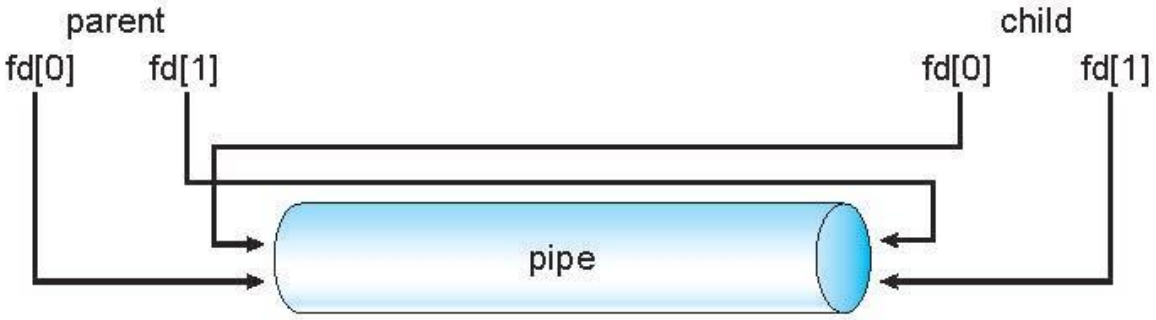
- Synchronization
  - message passing may be either blocking (synchronous) or
  - non-blocking (asynchronous)
  - **blocking send** has the sender block until the message is received
  - **blocking receive** has the receiver block until a message is available
  - **non-blocking** send has the sender 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
  - zero capacity – 0 messages
    - Sender must wait for receiver
  - bounded capacity – finite length of *n* messages
    - Sender must wait if link full
  - unbounded capacity – infinite length
    - Sender never waits

Interprocess Communication in Unix

- Provides multiple modes of IPC
  - pipes
  - FIFOs (names pipes)
  - message queues
  - shared memory
  - sockets

Pipes

- Most basic form of IPC on all Unix systems
  - also provides a useful command-line interface
- Conduit for two processes to communicate
  - ordinary pipes require parent-child relationship between communicating processes



Pipes

- Issues to be addressed
  - is communication unidirectional or bidirectional ?
    - Unix pipes only allow unidirectional communication
  - should communication processes be related ?
    - *anonymous* pipes can only be constructed between parent-child
  - can pipes communicate over a network
    - processes must be controlled by the same OS
- Pipes exist only until the processes exist
  - pre-mature process exit may cause data loss
- Data can only be collected in FIFO order

Simple Example Using Pipes

```
#include <unistd.h>
#include <stdio.h>
#include <string.h>

main()
{
  char *s, buf[1024];
  int fds[2];
  s  = "EECS 678\n";

  /* open a pipe. fd[0] is opened for reading,
     and fd[1] for writing.*/
  pipe(fds);

  /* write to the write-end of the pipe */
  write(fds[1], s, strlen(s));

  /* This can be read from the other end of the pipe */
  read(fds[0], buf, strlen(s));

  printf("fds[0]=%d, fds[1]=%d\n", fds[0], fds[1]);
  write(1, buf, strlen(s));
}
```

IPC Example Using Pipes

```
main()
{
  char *s, buf[1024];
  int fds[2];
  s  = "EECS 678. Pipe program 2\n";

  /* create a pipe */
  pipe(fds);

  /* create a new process using fork */
  if (fork() == 0) {

    /* child process. All file descriptors, including
       pipe are inherited, and copied.*/
    write(fds[1], s, strlen(s));
    exit(0);
  }

  /* parent process */
  read(fds[0], buf, strlen(s));
  write(1, buf, strlen(s));
}
```

Pipes Used for Process Synchronization

```
main()
{
  char *s, buf[1024];
  int fds[2];
  s  = "EECS 678. Pipe program 3\n";

  /* create a pipe */
  pipe(fds);

  if (fork() == 0) {

    /* child process. */
    printf("Child line 1\n");
    read(fds[0], s, strlen(s));
    printf("Child line 2\n");
  } else {

    /* parent process */
    printf("Parent line 1\n");
     write(fds[1], buf, strlen(s));
    printf("Parent line 2\n");
  }
}
```

Pipes Used in Unix Shells

- Pipes commonly used in most Unix shells
  - output of one command is input to the next command
  - example: `/bin/ps -ef | /bin/more`
- How does the shell realize this command?
  - create a process to run `ps -ef`
  - create a process to run `more`
  - create a pipe from `ps -ef` to `more`
  - the standard output of the process to run `ps -ef` is redirected to a pipe streaming to the process to run `more`
  - the standard input of the process to run `more` is redirected to be the pipe from the process running `ps -ef`

FIFO (Named Pipes)

- Pipe with a name !
- More powerful than *anonymous* pipes
  - no parent-sibling relationship required
  - allow bidirectional communication
  - FIFOs exists even after creating process is terminated
- Characteristics of FIFOs
  - appear as typical files
  - only allow half-duplex communication
  - communicating process must reside on the same machine

Producer Consumer Example with FIFO

- Producer Code:

```
main()
{
  char str[MAX_LENGTH];
  int num, fd;

  mkfifo(FIFO_NAME, 0666); // create FIFO file

  printf("waiting for readers...");
  fd = open(FIFO_NAME, O_WRONLY); // open FIFO for writing
  printf("got a reader !\n");

  printf("Enter text to write in the FIFO file: ");
  fgets(str, MAX_LENGTH, stdin);
  while(!(feof(stdin))){
    if ((num = write(fd, str, strlen(str))) == -1)
      perror("write");
    else
      printf("producer: wrote %d bytes\n", num);
    fgets(str, MAX_LENGTH, stdin);
  }
}
```

Producer Consumer Example with FIFO (2)

- Consumer code:

```
main()
{
  char str[MAX_LENGTH];
  int num, fd;

  mkfifo(FIFO_NAME, 0666); // make fifo, if not already present

  printf("waiting for writers...");
  fd = open(FIFO_NAME, O_RDONLY); // open fifo for reading
  printf("got a writer !\n");

  do{
    if((num = read(fd, str, MAX_LENGTH)) == -1)
      perror("read");
    else{
      str[num] = '\0';
      printf("consumer: read %d bytes\n", num);
      printf("%s", str);
    }
  }while(num > 0);
}
```

Message Passing in Unix

- Linux uses indirect communication or mailboxes.
- Queues can be associated with multiple processes
  - synchronization may be required
- Communicating processes can use any number of queues
  - each queue is identified by a unique identifier
- Capacity of the link is system initialized
  - can be overridden by the user
- Messages are of a fixed size
  - specified by the buffer length
- Each communicating process can send and receive from the same queue.

Message Queue Example

```
int main()
{
  /* identifier for the message queue */
  int queue_id;
  /* send and receive message buffers */
  struct msg_buf send_buf, recv_buf;

  /* create a message queue */
  queue_id = msgget(0, S_IRUSR|S_IWUSR|IPC_CREAT);

  /* send a message to the queue */
  send_buf.mtype = 1;
  strcpy(send_buf.buffer, "EECS 678 Class");
  msgsnd(queue_id, (struct msg_buf *)&send_buf, sizeof(send_buf));

  /* get the message from the queue */
  msgrcv(queue_id, (struct msg_buf *)&recv_buf, sizeof(recv_buf), 0,
0);
  printf("%s\n", recv_buf.buffer);

  /* delete the message queue, and deallocate resources */
  msgctl(queue_id, IPC_RMID, NULL);
  return 0;
}
```

```
struct msg_buf{
   long mtype;
   char buffer[1000];
}
```

Message Queues Example (2)

- Message passing in Linux is done via message queues.
- msgget – create a new message queue
  - return existing queue identifier if it exists
- msgsnd – send a message to the queue
  - each message should be in a buffer like,
  - `struct msg_buf {`
  - `    long mtype;`
  - `    char mtext[1]; }`
  - nonblocking, unless no space in the queue
- msgrcv – receive message from the queue
  - `mtype` can be used to get specific messages
- msgctl – perform control operations specified by *cmd*
  - second argument, we use it to terminate queue

Memory Sharing in Unix

- Multiple processes share single chunk of memory.
- Implementation principles
  - uniquely naming the shared segment
    - system-wide or anonymous name
  - specifying access permissions
    - read, write, execute
  - dealing with race conditions
    - atomic, synchronized access
- Most *thread*-level communication is via shared memory.

Shared Memory Example

```
int main()
{
  int segment_id;
  char *shared_memory;
  const int size = 4096;

  /* allocate and attach a shared memory segment */
  segment_id = shmget(IPC_PRIVATE, size, S_IRUSR|S_IWUSR);
  shared_memory = (char *) shmat(segment_id, NULL, 0);

  /* write and print a message to the shared memory segment */
  sprintf(shared_memory, "EECS 678 Class");
  printf("%s\n", shared_memory);

  /* detach and remove the shared memory segment */
  shmdt(shared_memory);
  shmctl(segment_id, IPC_RMID, NULL);

  return 0;
}
```

Shared Memory Example (2)

- shmget – create shared memory segment
  - IPC_PRIVATE specifies creation of new memory segment of size rounded to the system page size
  - access permissions as for normal file access
  - returns identifier of shared memory segment
- shmat – attach shared memory segment
  - must for every process wanting access to the region
  - segment identified by segment_id
  - system chooses a suitable attach address
- shmctl – performs the control operation specified by *cmd*
  - command is IPC_RMID to remove shared segment
- see program shared_memory2.c
- Read man pages!

Unix Domain Sockets

- Sockets
  - can be defined as an end-point for communications
  - two-way communication pipe
  - can be used in a variety of domains, including *Internet*
- Unix Domain Sockets
  - communication between processes on the same Unix system
  - special file in the file system
- Mostly used for client-server programming
  - client sending requests for information, processing
  - server waiting for user requests
  - server performing the requested activity and sending updates to client
- Socket communication modes
  - connection-based, TCP
  - connection-less, UDP

Unix Domain Sockets – System Calls

- socket ( ) - create the Unix socket
  - `int socket(int domain, int type, int protocol);`
  - domain is `AF_UNIX`
- bind ( ) - assign a name to a socket
  - `int bind(int sockfd, const struct sockaddr *my_addr, socklen_t addrlen);`
  - `my_addr` is `addrlen` bytes long
- listen ( ) - listen to incoming client requests
  - `int listen(int sockfd, int backlog);`
  - `backlog` specifies the queue limit for incoming connctions

Unix Domain Sockets – System Calls (2)

- accept ( ) - create a new connected socket
  - `int accept(int sockfd, struct sockaddr *addr, socklen_t *addrlen);`
  - only for connection-based protocols
- recv ( ) - receive messages from socket
  - `ssize_t recv(int s, void *buf, size_t len, int flags);`
  - message placed in `buf`
- close ( ) - close the socket connection

Socket Example – Echo Server

- see socket_server.c
- see socket_client.c

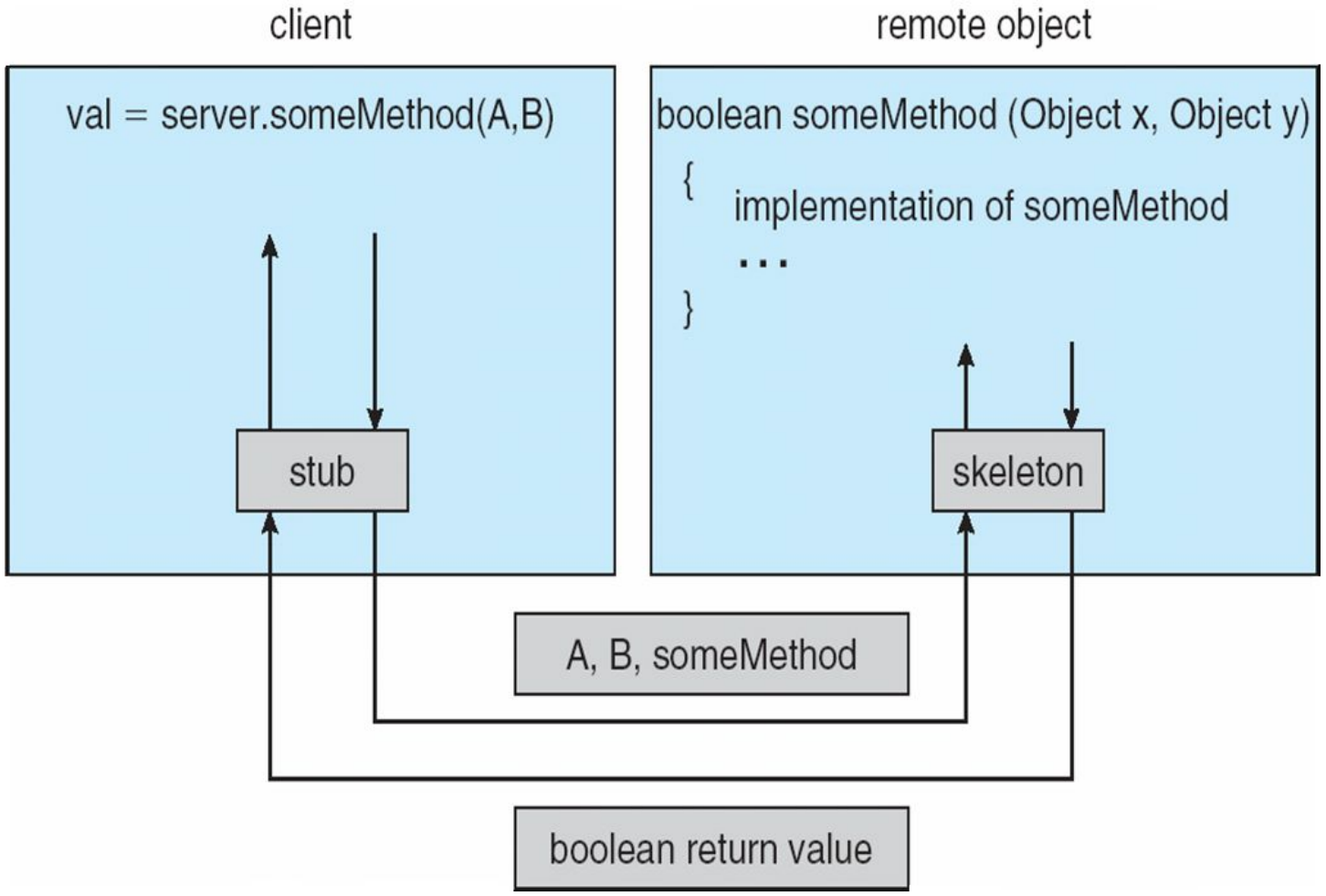
Communications in Client-Server Systems

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

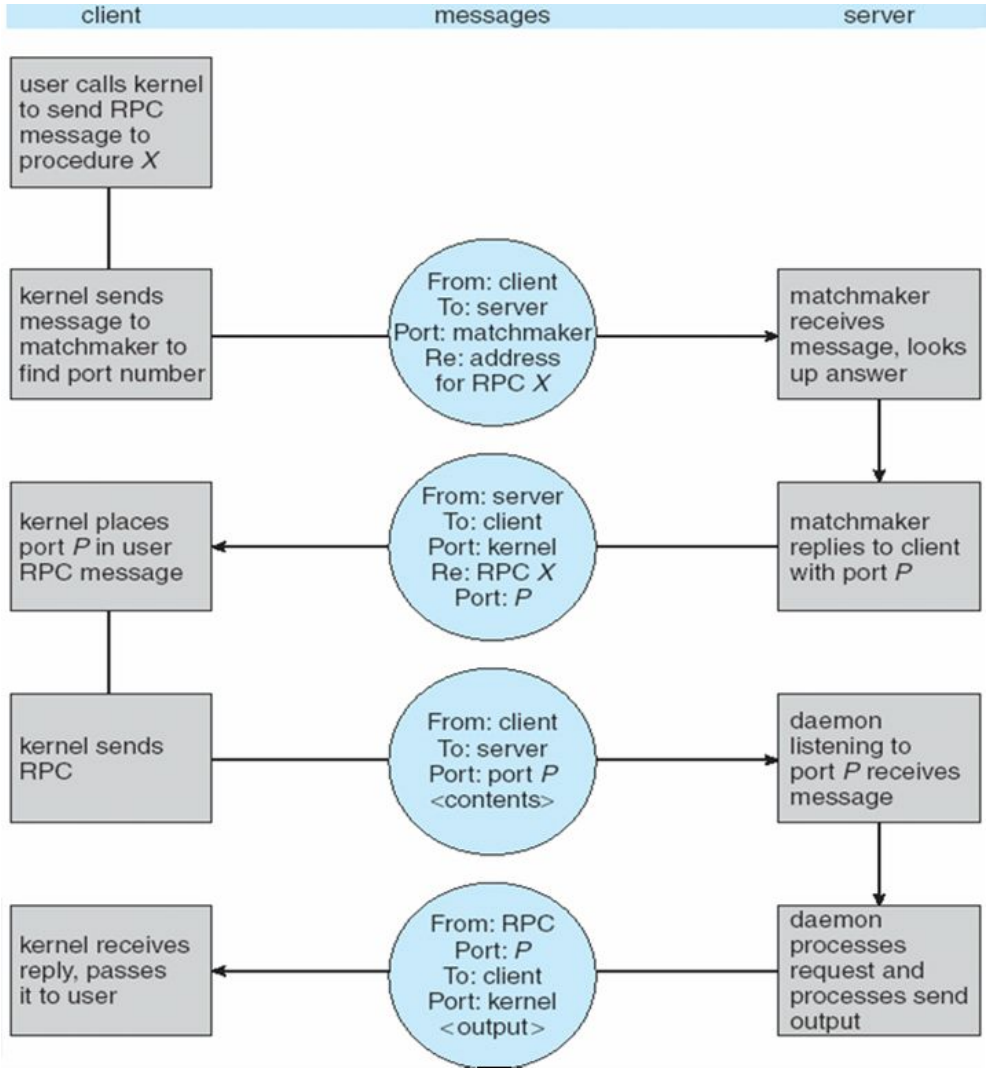
Remote Procedure Calls

- Remote procedure call (RPC) abstracts subroutine calls between processes on networked systems
  - subroutine executes in another address space
  - uses message passing communication model
  - messages are well-structured
  - RPC daemon on the server handles the remote calls
- Client-side *stub*
  - proxy for the actual procedure on the server
  - responsible for locating correct port on the server
  - responsible for *marshalling* the procedure parameters
- Server-side stub
  - receives the message; unpacks the marshalled parameters
  - performs the procedure on the server, returns result

Marshalling Parameters



Execution of RPC



Remote Method Invocation

- Remote Method Invocation (RMI)
  - Java mechanism (API) to perform RPCs
  - Java remote method protocol (JRMP) only allows calls from one JVM to another JVM
  - CORBA is used to support communication with non-JVM code
  - client obtains reference to remote object, and invokes methods on them