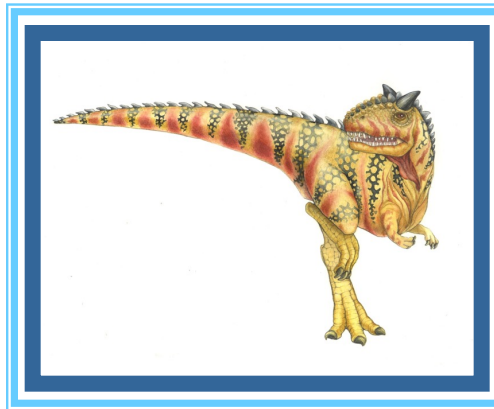


Chapter 3: Processes





Chapter 3: Processes

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





Objectives

- Identify the separate components of a process and illustrate how they are represented and scheduled in an operating system.
- Describe how processes are created and terminated in an operating system, including developing programs using the appropriate system calls that perform these operations.
- Describe and contrast interprocess communication using shared memory and message passing.
- Design programs that uses pipes and POSIX shared memory to perform interprocess communication.
- Describe client-server communication using sockets and remote procedure calls.
- Design kernel modules that interact with the Linux operating system.





Interprocess Communication

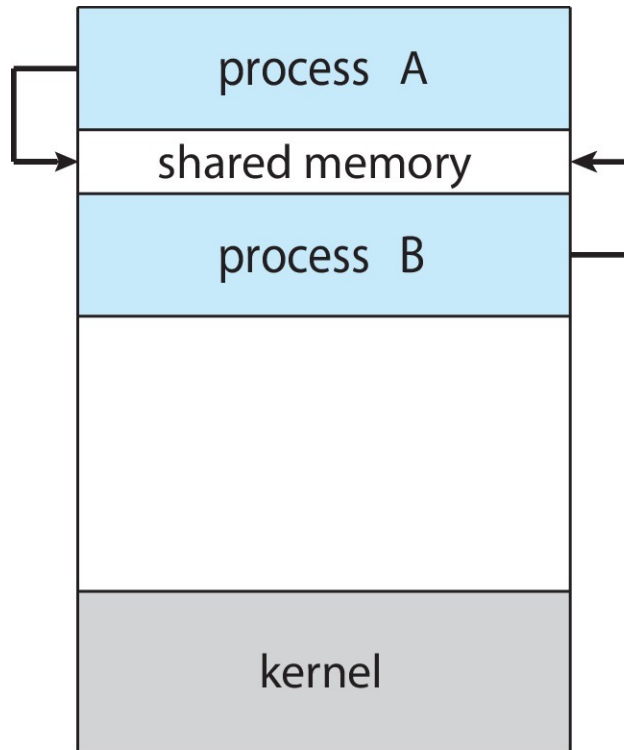
- Processes within a system may be *independent* or *cooperating*
- Cooperating process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
 - Information sharing
 - Computation speedup
 - Modularity
 - Convenience
- Cooperating processes need **interprocess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





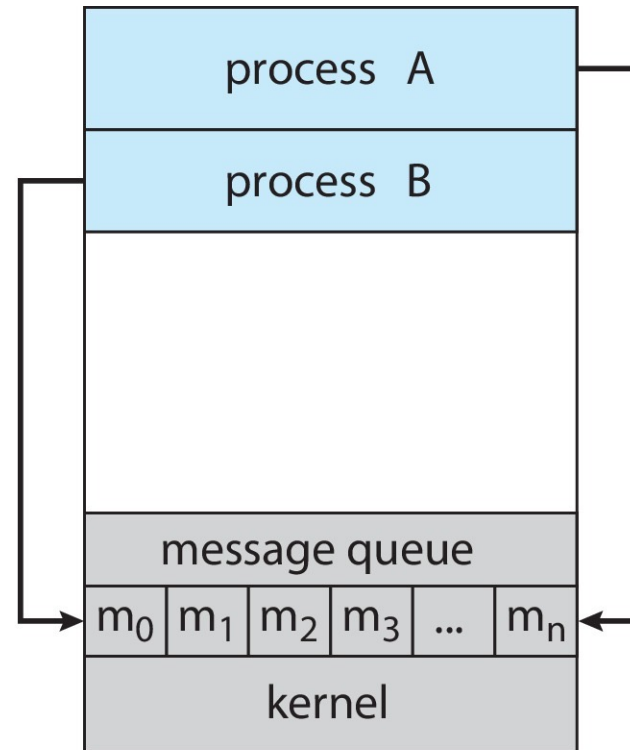
Communications Models

(a) Shared memory.



(a)

(b) Message passing.



(b)





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





Interprocess Communication – Shared Memory

- An area of memory shared among the processes that wish to communicate
- The communication is under the control of the users processes not the operating system.
- Major issues 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 Chapters 6 & 7.





Bounded-Buffer – Shared-Memory Solution

- Shared data

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

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

- Solution is correct, but can only use `BUFFER_SIZE-1` elements



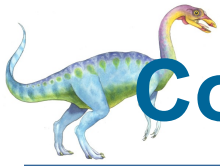


Producer Process – Shared Memory

```
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;
}
```





Consumer Process – Shared Memory

```
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 */
}
```





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





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 (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

■ 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** -- 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 continue
 - **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**





Producer – Shared Memory

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





Consumer– Shared Memory

```
message next_consumed;  
  
while (true) {  
    receive(next_consumed)  
  
    /* consume the item in next_consumed */  
}
```





Buffering

- 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 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

```
shm_fd = shm_open(name, O_CREAT | O_RDWR, 0666);
```

- Also used to open an existing segment
- Set the size of the object

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

- Use `mmap()` to memory-map a file pointer to the shared memory object
- Reading and writing to shared memory is done by using the pointer returned by `mmap()`.





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 object */
    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 object */
    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;
}
```





Examples of IPC Systems - Mach

- Mach communication is message based
 - Even system calls are messages
 - Each task gets two ports at creation- Kernel and Notify
 - Messages are sent and received using the `mach_msg()` function
 - Ports needed for communication, created via `mach_port_allocate()`
 - Send and receive are flexible, for example four options if mailbox full:
 - ▶ Wait indefinitely
 - ▶ Wait at most n milliseconds
 - ▶ Return immediately
 - ▶ Temporarily cache a message





Mach Messages

```
#include<mach/mach.h>

struct message {
    mach_msg_header_t header;
    int data;
};

mach port t client;
mach port t server;
```





Mach Message Passing - Client

```
/* Client Code */

struct message message;

// construct the header
message.header.msgh_size = sizeof(message);
message.header.msgh_remote_port = server;
message.header.msgh_local_port = client;

// send the message
mach_msg(&message.header, // message header
        MACH_SEND_MSG, // sending a message
        sizeof(message), // size of message sent
        0, // maximum size of received message - unnecessary
        MACH_PORT_NULL, // name of receive port - unnecessary
        MACH_MSG_TIMEOUT_NONE, // no time outs
        MACH_PORT_NULL // no notify port
);
```





Mach Message Passing - Server

```
/* Server Code */

struct message message;

// receive the message
mach_msg(&message.header, // message header
        MACH_RCV_MSG, // sending a message
        0, // size of message sent
        sizeof(message), // maximum size of received message
        server, // name of receive port
        MACH_MSG_TIMEOUT_NONE, // no time outs
        MACH_PORT_NULL // no notify port
    );
```





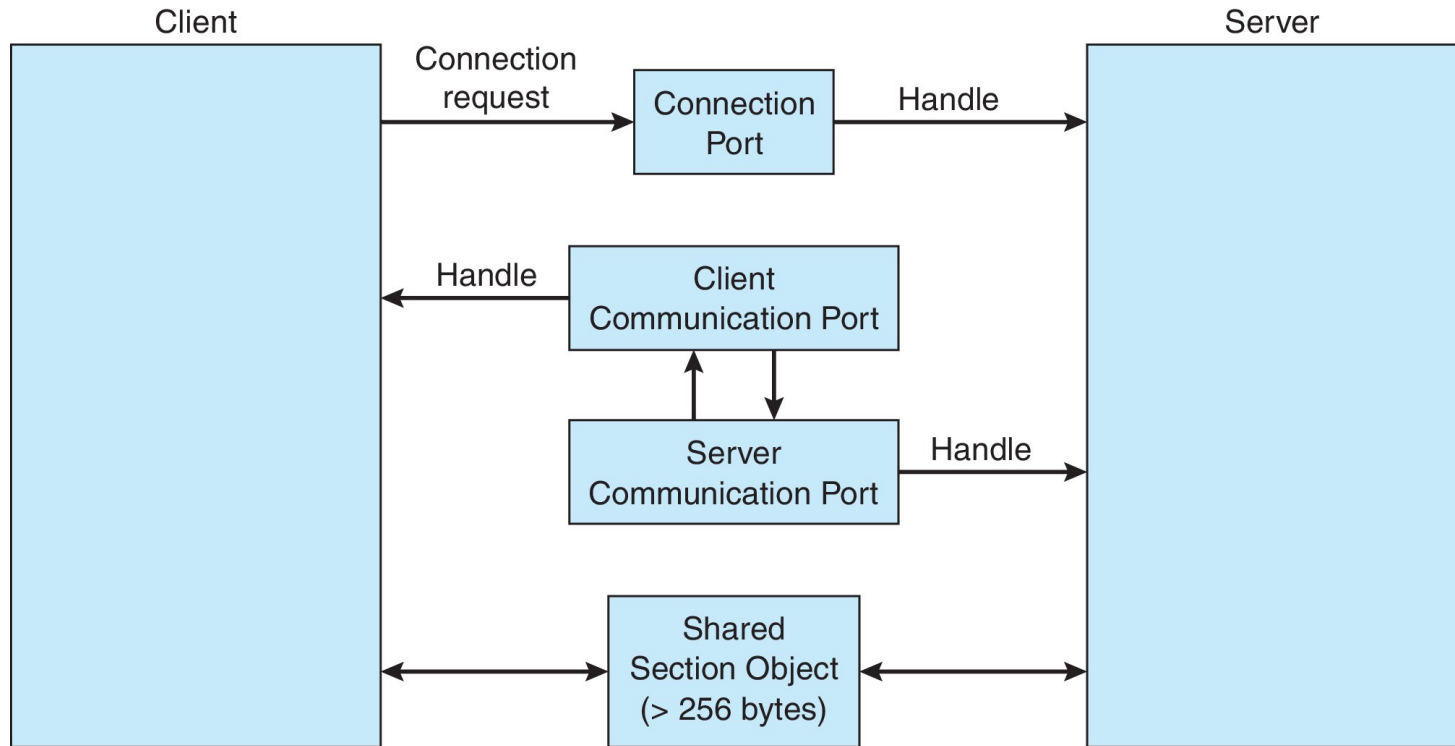
Examples of IPC Systems – Windows

- Message-passing centric via **advanced 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





Pipes

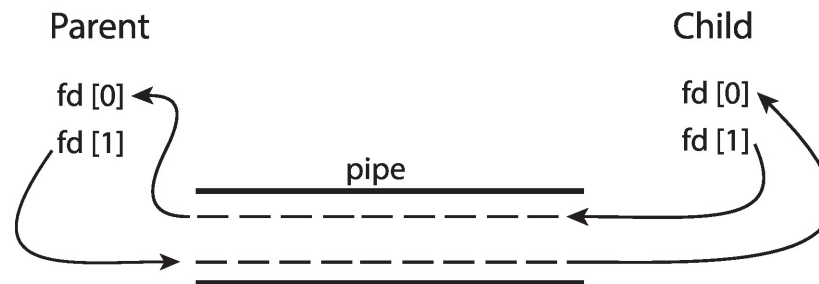
- Acts as a conduit allowing two processes to communicate
- Issues:
 - Is communication unidirectional or bidirectional?
 - In the case of two-way communication, is it half or full-duplex?
 - Must there exist a relationship (i.e., ***parent-child***) between the communicating processes?
 - Can the pipes 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
- Require parent-child relationship between communicating processes



- Windows calls these **anonymous pipes**





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





Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls





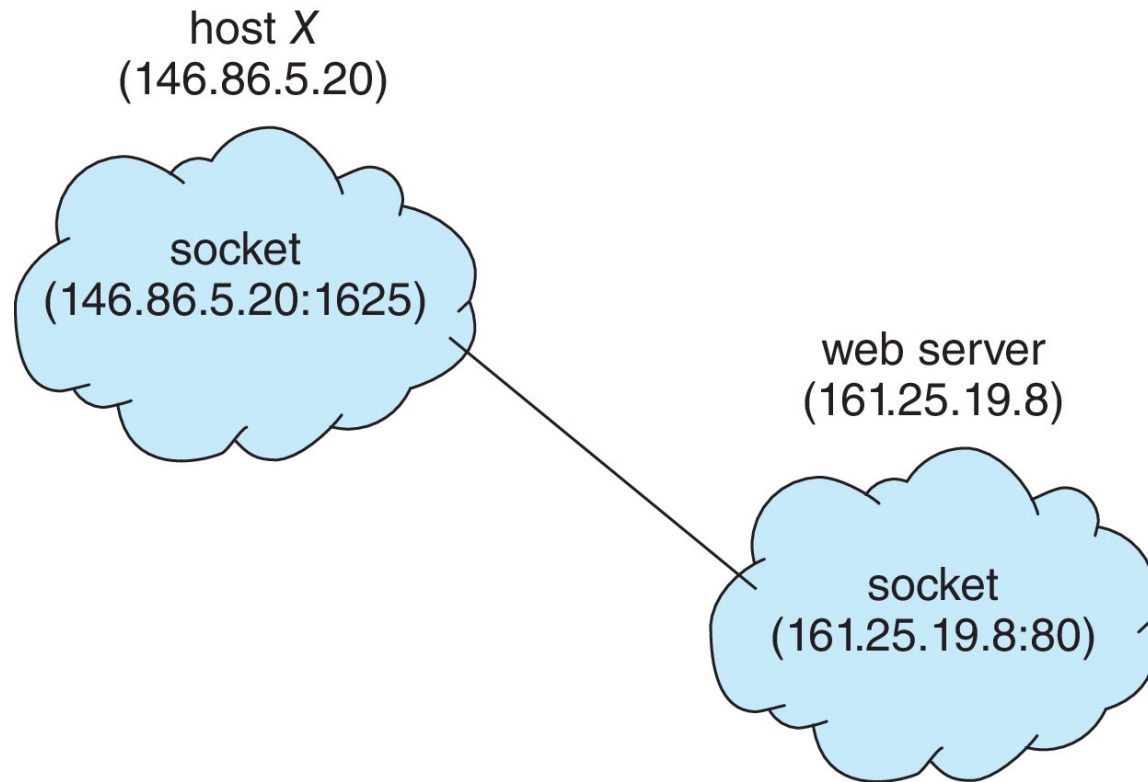
Sockets

- A **socket** is defined as an endpoint for 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 consists between a pair of sockets
- All ports below 1024 are **well known**, used for standard services
- Special IP address 127.0.0.1 (**loopback**) to refer to system on which process is running





Socket Communication





Sockets in Java

- Three types of sockets
 - **Connection-oriented (TCP)**
 - **Connectionless (UDP)**
 - **MulticastSocket** class— data can be sent to multiple recipients
- Consider this “Date” server in Java:

```
import java.net.*;
import java.io.*;

public class DateServer
{
    public static void main(String[] args) {
        try {
            ServerSocket sock = new ServerSocket(6013);

            /* now listen for connections */
            while (true) {
                Socket client = sock.accept();

                PrintWriter pout = new
                    PrintWriter(client.getOutputStream(), true);

                /* write the Date to the socket */
                pout.println(new java.util.Date().toString());

                /* close the socket and resume */
                /* listening for connections */
                client.close();
            }
        }
        catch (IOException ioe) {
            System.err.println(ioe);
        }
    }
}
```





Sockets in Java

The equivalent Date client

```
import java.net.*;
import java.io.*;

public class DateClient
{
    public static void main(String[] args) {
        try {
            /* make connection to server socket */
            Socket sock = new Socket("127.0.0.1",6013);

            InputStream in = sock.getInputStream();
            BufferedReader bin = new
                BufferedReader(new InputStreamReader(in));

            /* read the date from the socket */
            String line;
            while ( (line = bin.readLine()) != null)
                System.out.println(line);

            /* close the socket connection*/
            sock.close();
        }
        catch (IOException ioe) {
            System.err.println(ioe);
        }
    }
}
```





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
- The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server
- On Windows, stub code compile from specification written in **Microsoft Interface Definition Language (MIDL)**





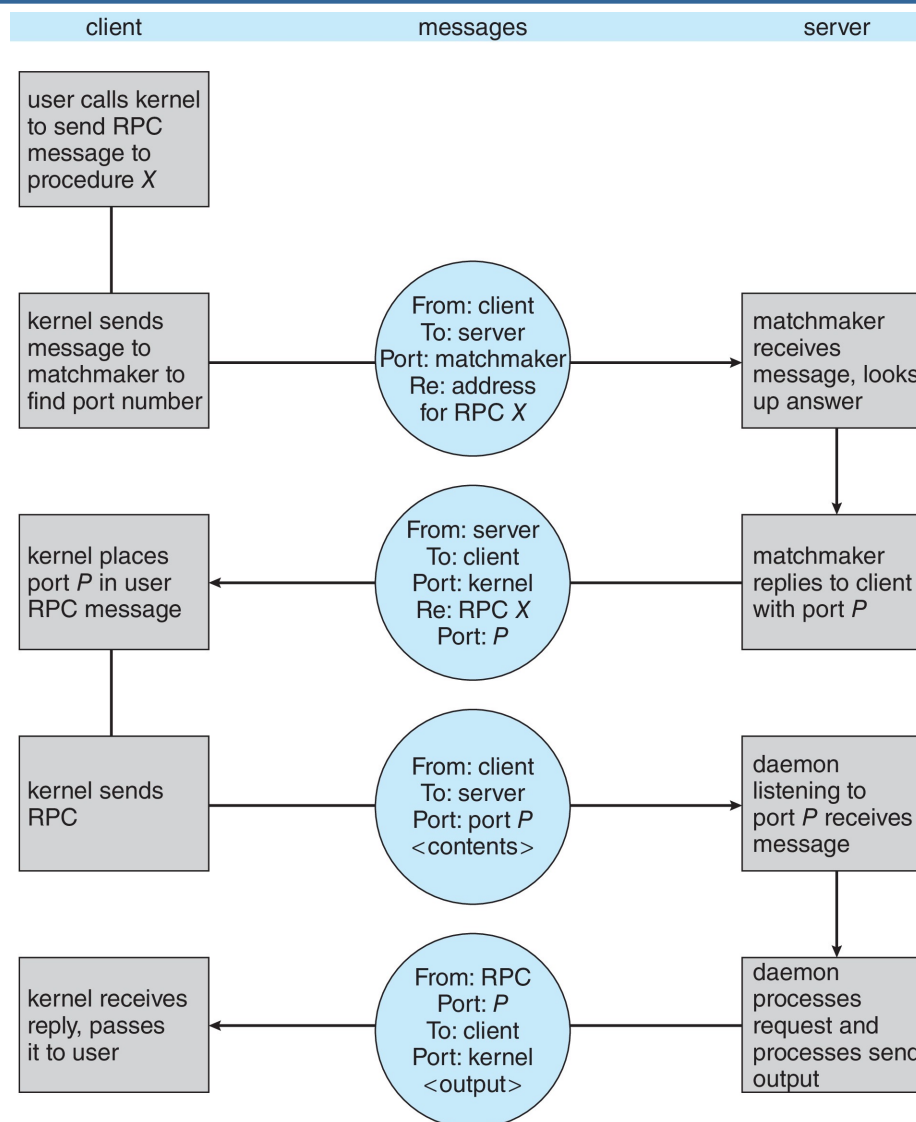
Remote Procedure Calls (Cont.)

- Data representation handled via **External Data Representation (XDL)** format to account for different architectures
 - **Big-endian** and **little-endian**
- Remote communication has more failure scenarios than local
 - Messages can be delivered ***exactly once*** rather than ***at most once***
- OS typically provides a rendezvous (or **matchmaker**) service to connect client and server





Execution of RPC



End of Chapter 3

