Inter-Process 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:-**Since several users may be interested in the same piece of information ,we must provide an environment to allow concurrent access to such information.
- **Computation speedup:-** If we want a particular task to run faster, we must

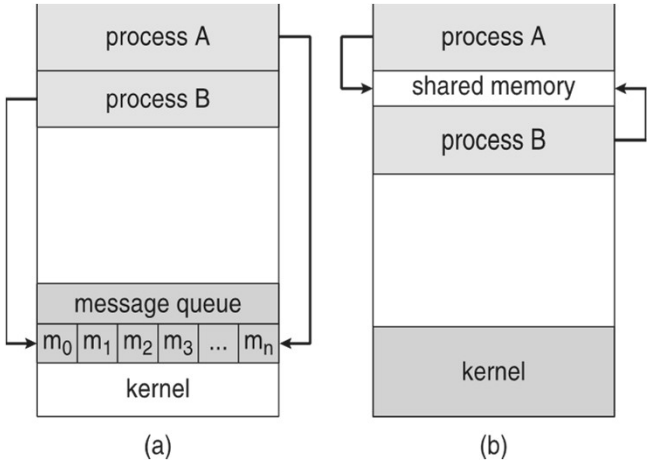
break it into subtasks, each of which will be executing in parallel with the other.

- **Modularity:-**We may want to construct the system in a modular fashion, dividing the system functions into separate processes or threads
- **Convenience**. Even an individual user may work on many tasks at the same time. For instance, a user may be editing, listening to music, and compiling in parallel.

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

Communications Models

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



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

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.

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

Producer-Consumer problem

- There are two processes: Producer and Consumer. Producer produces some item and Consumer consumes that item.
- The two processes shares a common space or memory location known as buffer where the item produced by Producer is stored and from where the Consumer consumes the item if needed.
- There are two version of this problem: first one is known as unbounded buffer problem in which Producer can keep on producing items and there is no limit on size of buffer, the second one is known as bounded buffer problem in which producer can produce up to a certain amount of item and after that it starts waiting for consumer to consume it.
- We will discuss the bounded buffer problem.
- First, the Producer and the Consumer will share some common memory, then producer will start producing items.
- If the total produced item is equal to the size of buffer, producer will wait to get it consumed by the Consumer.
- Similarly, the consumer first check for the availability of the item and if no item is available, Consumer will wait for producer to produce it.
- If there are items available, consumer will consume it.

Interprocess Communication – Message Passing

- Mechanism for processes to communicate and to synchronize their actions

- Message passing provides a mechanism to allow processes to communicate and to synchronize their actions without sharing the same address space.
- It is particularly useful in a distributed environment, where the communicating processes may reside on different computers connected by a network. For example, an Internet chat program could be designed so that chat participants communicate with one another by exchanging messages.

- IPC facility provides two operations:
  - **`send`**(*message*)
  - **`receive`**(*message*)
- The *message* size is either fixed or variable

Message Passing

- If processes *P* and *Q* want to communicate, they must send messages to and receive messages from each other: a ***communication link*** must exist between them.
- This link can be implemented in a variety of ways. We are concerned here not with the link's physical implementation but rather with its **logical implementation.**
- Here are several methods for logically implementing a link and the send()/receive() operations:
- Direct or indirect communication
- Synchronous or asynchronous communication
- Automatic or explicit buffering

Naming

- Processes that want to communicate must have a way to refer to each other.
- They can use either direct or indirect communication.
- Under **direct communication**, each process that wants to communicate must explicitly name the recipient or sender of the communication.
- In this scheme, the send() and receive() primitives are defined as:
  send(P, message)—Send a message to process P.
  receive(Q, message)—Receive a message from process Q.

A communication link- direct communication

- A communication link in this scheme has the following properties:
- A link is established automatically between every pair of processes that want to communicate. The processes need to know only each other's identity to communicate.
- A link is associated with exactly two processes.
- Between each pair of processes, there exists exactly one link.

Naming-Symmetry and asymmetry

- This scheme exhibits ***symmetry*** in addressing; that is, both the sender process and the receiver process must name the other to communicate.
- A variant of this scheme employs ***asymmetry*** in addressing.
- Here, only the sender names the recipient; the recipient is not required to name the sender.
- In this scheme, the send() and receive() primitives are defined as follows:
- send(P, message)—Send a message to process P.
- receive(id, message)—Receive a message from any process.

The variable id is set to the name of the process with which communication has taken place.

A communication link- Indirect communication

- With ***indirect communication***, the messages are sent to and received from
- ***mailboxes***, or ***ports***.
- A mailbox can be viewed abstractly as an object into which messages can be placed by processes and from which messages can be removed.
- Each mailbox has a unique identification. For example, POSIX message queues use an integer value to identify a mailbox.
- A process can communicate with another process via a number of different mailboxes, but two processes can communicate only if they have a shared mailbox.
- The send() and receive() primitives are defined as follows:
- send(A, message)—Send a message to mailbox A.
- receive(A, message)—Receive a message from mailbox A.

A communication link- Indirect communication contd…

- In this scheme, a communication link has the following properties:
- A link is established between a pair of processes only if both members of the pair have a shared mailbox.
- A link may be associated with more than two processes.
- Between each pair of communicating processes, a number of different links may exist, with each link corresponding to one mailbox.

- Now suppose that processes *P*1, *P*2, and *P*3 all share mailbox *A*. Process*P*1 sends a message to *A*, while both *P*2 and *P*3 execute a receive() from *A*.

Synchronization

- Communication between processes takes place through calls to send() and receive() primitives.
- There are different design options for implementing each primitive. Message passing may be either **blocking** or **non-blocking**— also known as **synchronous** and **asynchronous**.
- **Blocking send**. The sending process is blocked until the message is received by the receiving process or by the mailbox.
- **Non-blocking send**. The sending process sends the message and resumes operation.
- **Blocking receive**. The receiver blocks until a message is available.
- **Non-blocking receive**. The receiver retrieves either a valid message or a null.

Synchronization

- Different combinations of send() and receive() are possible.
- When both send() and receive() are blocking, we have a **rendezvous** between the sender and the receiver.
- The solution to the producer–consumer problem becomes trivial when we use blocking send() and receive() statements.
- The producer merely invokes the blocking send() call and waits until the message is delivered to either the receiver or the mailbox.

Buffering

- Whether communication is direct or indirect, messages exchanged by communicating processes reside in a temporary queue.
- Basically, such queues can be implemented in three ways:
- **Zero capacity**. The queue has a maximum length of zero; thus, the link cannot have any messages waiting in it. In this case, the sender must block until the recipient receives the message.
- **Bounded capacity**. The queue has finite length *n;* thus, at most *n* messages can reside in it.
- If the queue is not full when a new message is sent, the message is placed in the queue (either the message is copied or a pointer to the message is kept), and the sender can continue execution without waiting.
- The link's capacity is finite, however. If the link is full, the sender must block until space is available in the queue.
- **Unbounded capacity**. The queue's length is potentially infinite; thus, any number of messages can wait in it. The sender never blocks.

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**

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

- 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 to share it
  - Set the size of the object
    ```
    ftruncate(shm fd, 4096);
    ```
  - Now the process could write to the shared memory
    ```
    sprintf(shared memory, "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;
}
```

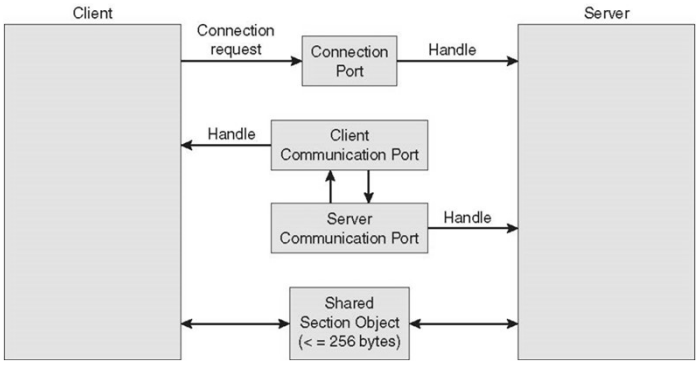
Examples of IPC Systems - Mach

- 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()`
  - 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

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



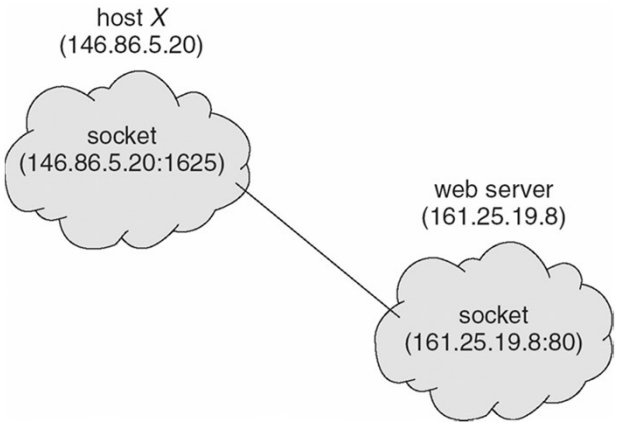
Communications in Client-Server Systems

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

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:

```
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);
    }
  }
}
```

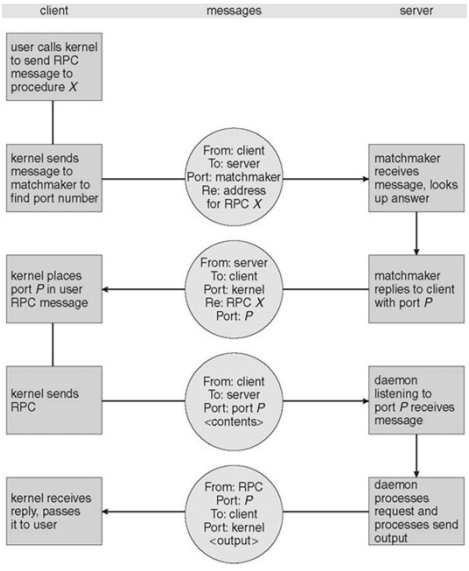
Remote Procedure Calls

- 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

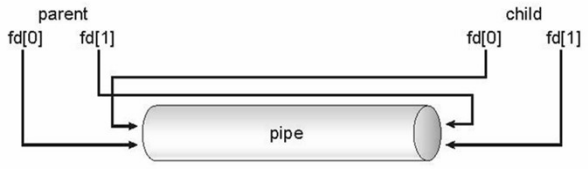


Pipes

- 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**
- 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