Chapter 4: Processes

- Process Concept
- Process Scheduling
- Operations on Processes
- Cooperating Processes
- Interprocess Communication
- Communication in Client-Server Systems

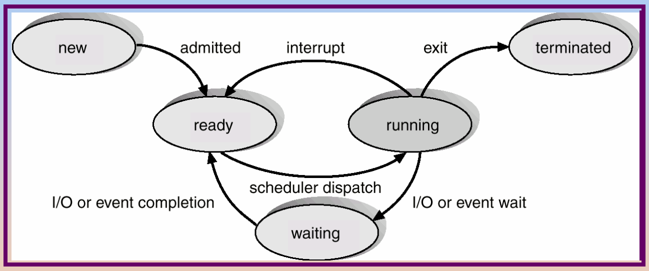
Process Concept

- An operating system executes a variety of programs:
  - Batch system – jobs
  - 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.
- A process includes:
  - program counter
  - stack
  - data section

Process State

- As a process executes, it changes *state*
  - **new**: The process is being created.
  - **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.

Diagram of Process State

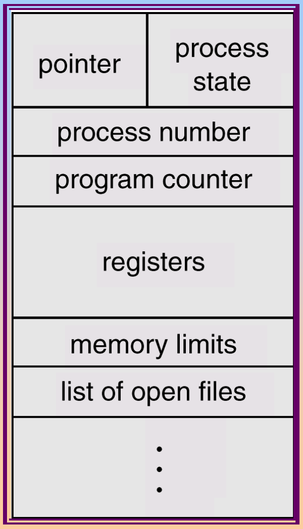


Process Control Block (PCB)

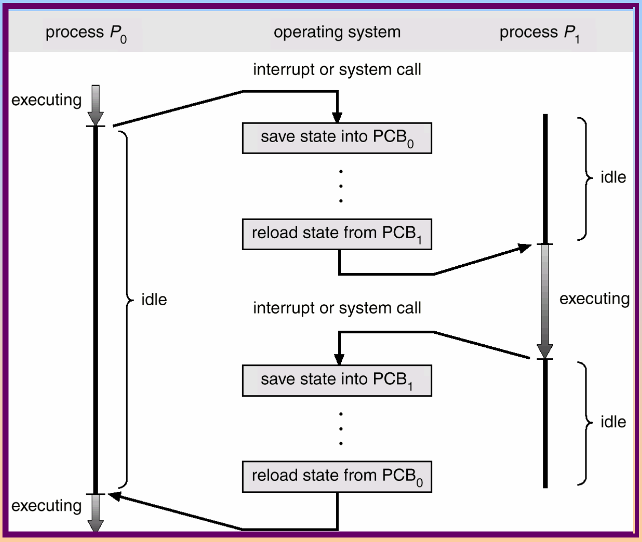
Information associated with each process.

- Process ID
- Process state
- Program counter
- CPU registers
- CPU scheduling information
- Memory-management information
- Accounting information
- I/O status information

Process Control Block (PCB)



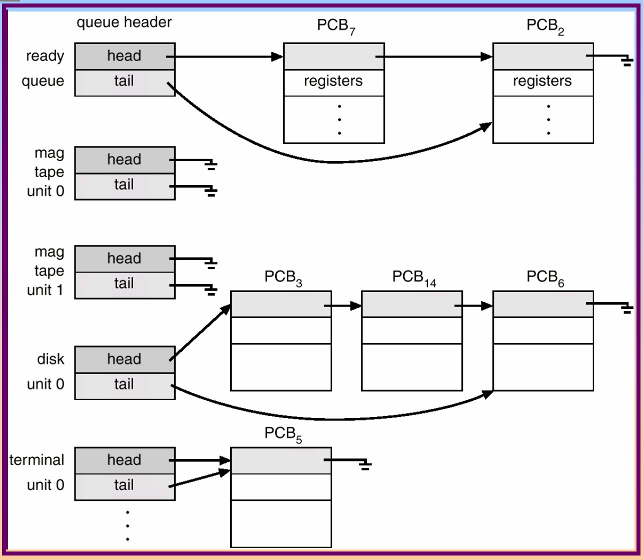
CPU Switch From Process to Process



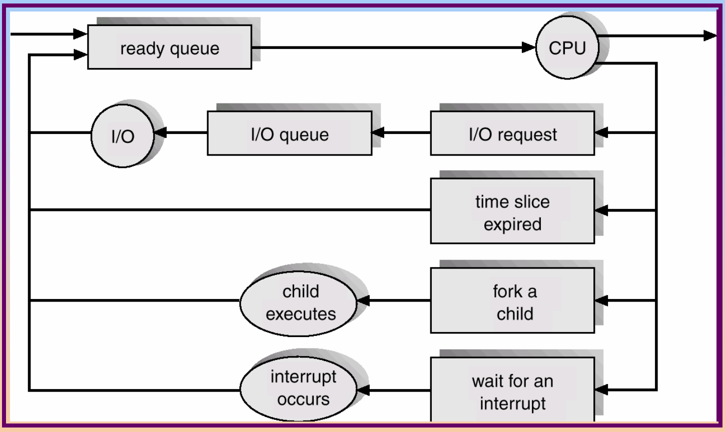
Process Scheduling Queues

- 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 between the various queues.

Ready Queue And Various I/O Device Queues



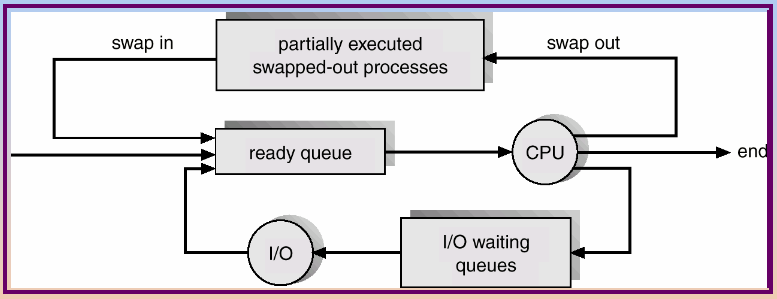
Representation of Process Scheduling



Schedulers

- Long-term scheduler (or job scheduler) – selects which processes should be brought into the ready queue.
- Short-term scheduler (or CPU scheduler) – selects which process should be executed next and allocates CPU.

Addition of Medium Term Scheduling

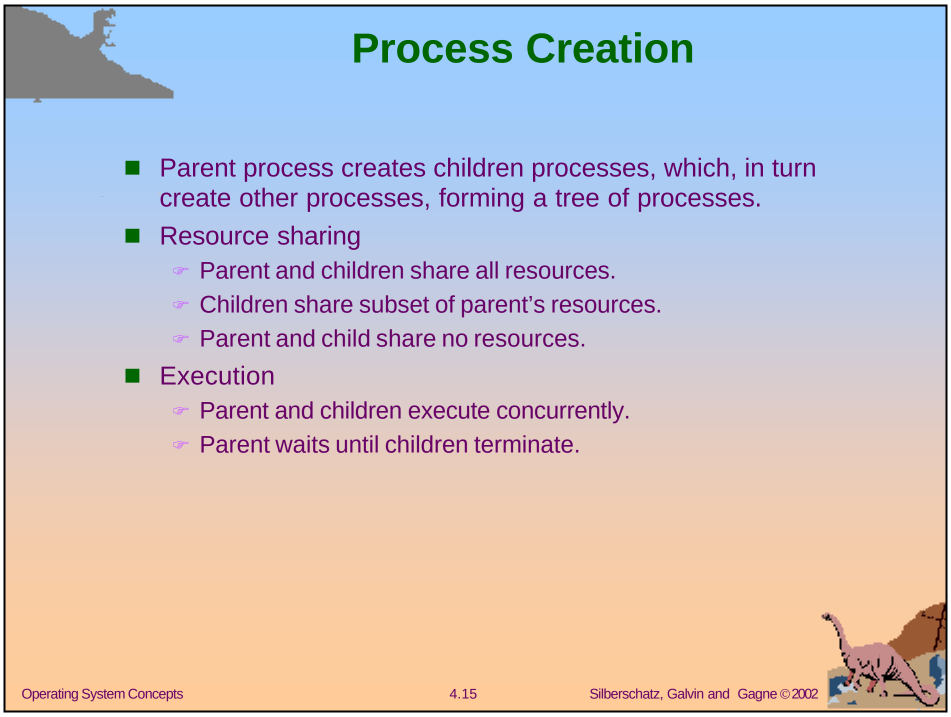


Schedulers (Cont.)

- Short-term scheduler is invoked very frequently (milliseconds) $\Rightarrow$ (must be fast).
- Long-term scheduler is invoked very infrequently (seconds, minutes) $\Rightarrow$ (may be slow).
- The long-term scheduler controls the *degree of multiprogramming.*
- 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.

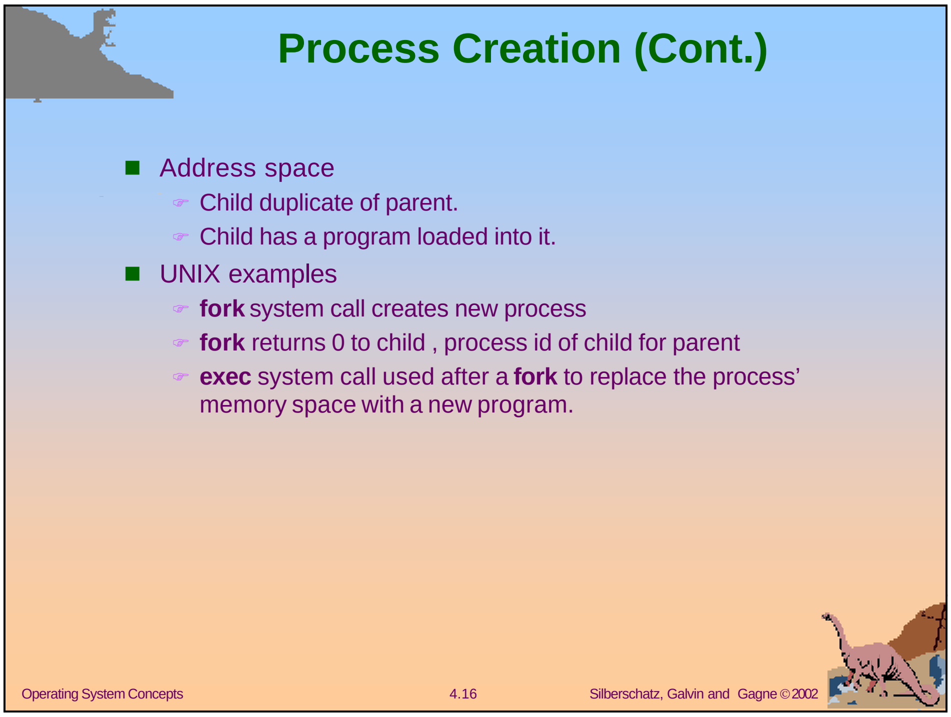
Context Switch

- 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.
- Context-switch time is overhead; the system does no useful work while switching.
- Time dependent on hardware support.



Process Creation

- Parent process creates children processes, which, in turn create other processes, forming a tree of processes.
- Resource sharing
  - Parent and children share all resources.
  - Children share subset of parent’s resources.
  - Parent and child share no resources.
- Execution
  - Parent and children execute concurrently.
  - Parent waits until children terminate.



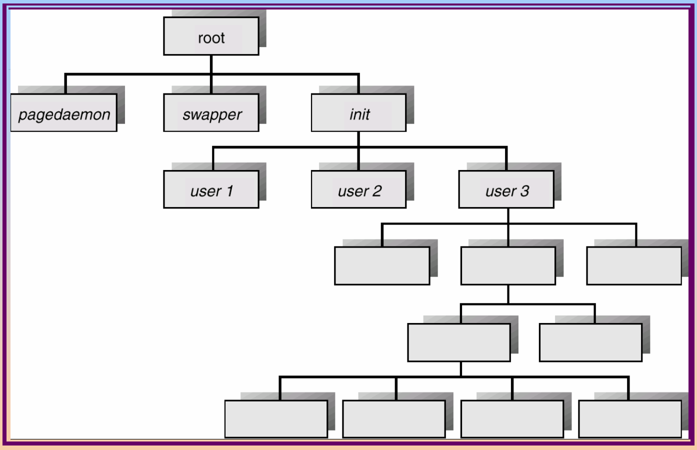
Process Creation (Cont.)

- Address space
  - Child duplicate of parent.
  - Child has a program loaded into it.
- UNIX examples
  - **fork** system call creates new process
  - **fork** returns 0 to child , process id of child for parent
  - **exec** system call used after a **fork** to replace the process’ memory space with a new program.

Unix Program

```
#include <stdio.h >
main(int argc, char *argv[])
{  int pid;
        pid=fork();    /* fork another process */
        if (pid == 0) { /* child */
                exclp("/bin/ls","ls",NULL);
        }
        else { /* parent */
                wait(NULL);  /* parent waits for child */
                printf("Child complete\n");
                exit(0);
        }
}
```

Processes Tree on a UNIX System



Process Termination

- Process executes last statement and asks the operating system to delete it (**exit**).
  - Output data from child to parent (via **wait**).
  - Process' resources are deallocated by operating system.
- Parent may terminate execution of children processes (**abort**).
  - Child has exceeded allocated resources.
  - Task assigned to child is no longer required.
  - Parent is exiting.
    - Operating system does not allow child to continue if its parent terminates.
    - Cascading termination.
  - In Unix, if parent exits children are assigned **init** as parent

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.

Bounded-Buffer – Shared-Memory Solution

- **Shared data**

```
#define BUFFER_SIZE 10
Typedef struct {
   . . .
} item;
item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```

- **Circular array**
- **Empty: in == out**
- **Full: ((in+1)%BUFFER_SIZE) == out**
- **Solution is correct, but can only use BUFFER_SIZE-1 elements**

Bounded-Buffer – Producer Process

```
item nextProduced;

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

Bounded-Buffer – Consumer Process

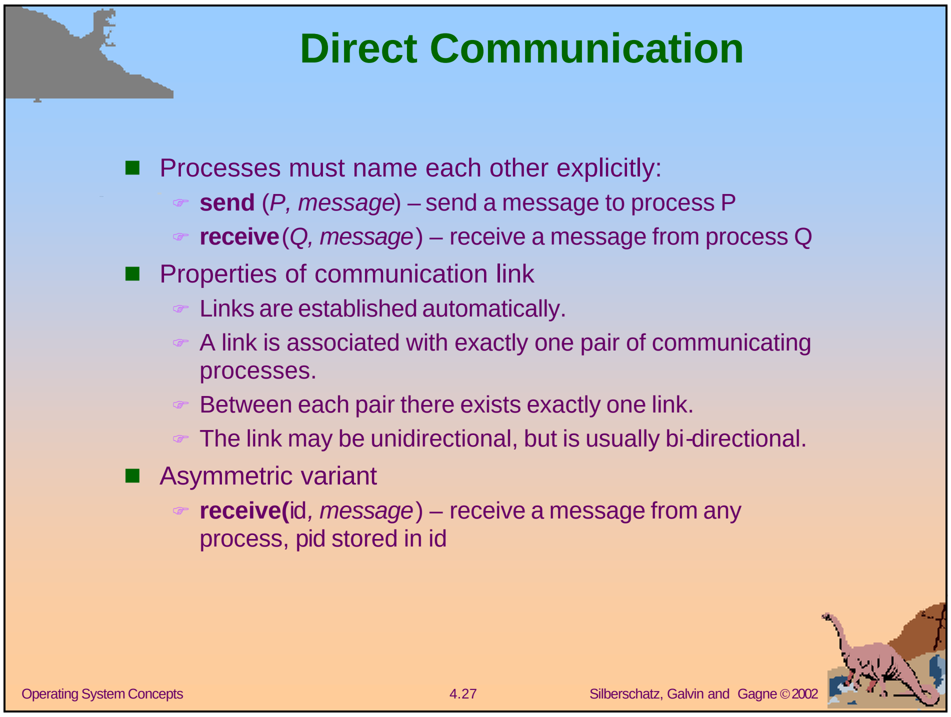
```
item nextConsumed;

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

Interprocess Communication (IPC)

- 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*) – message size 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) considered later
  - logical (e.g., logical properties) now

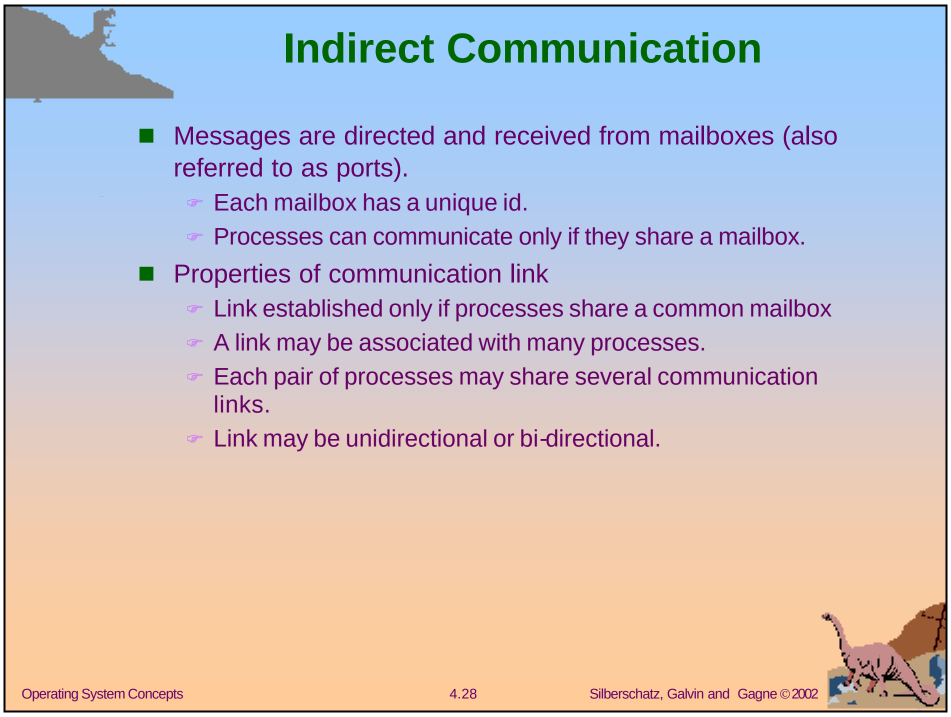
Implementation Questions

- 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?
- Is the size of a message that the link can accommodate fixed or variable?
- Is a link unidirectional or bi-directional?



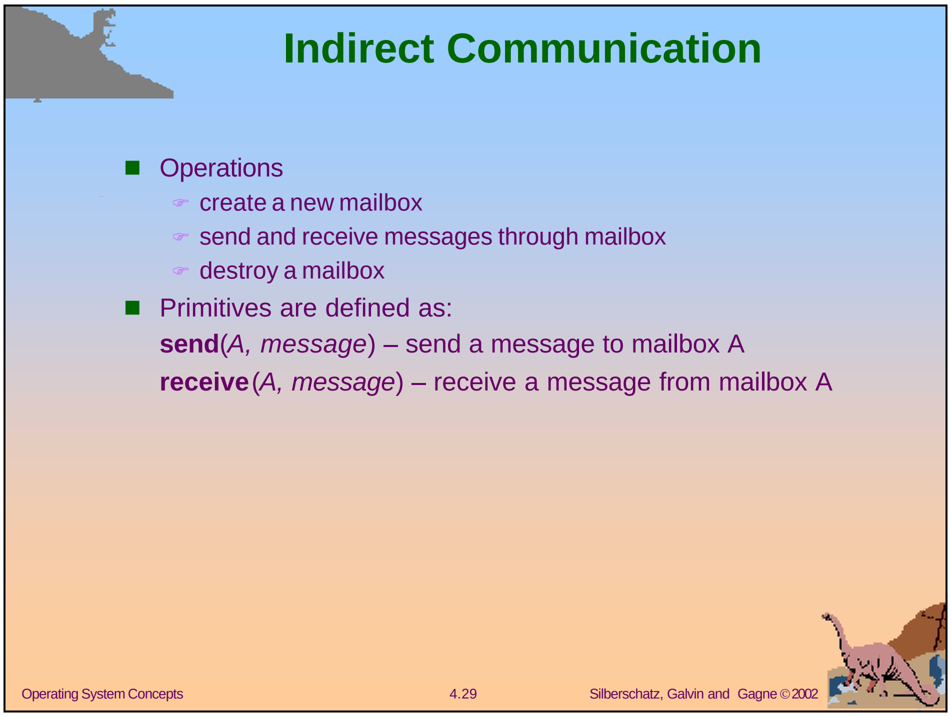
Direct Communication

- 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.
- Asymmetric variant
  - **receive(**id, *message*) – receive a message from any process, pid stored in id



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.

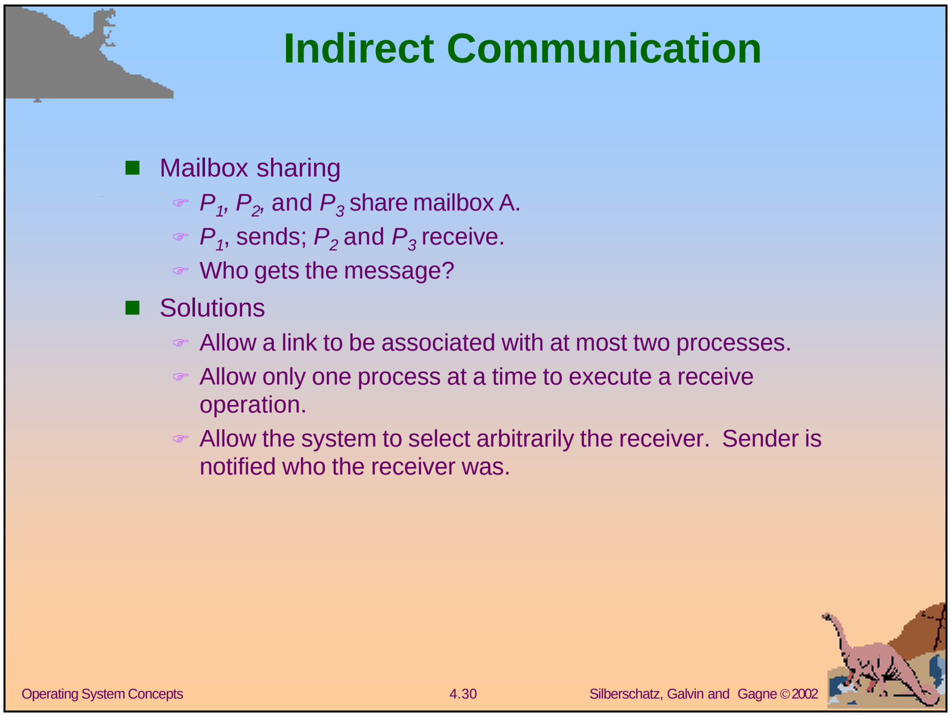


Indirect Communication

- Operations
  - create a new mailbox
  - 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.

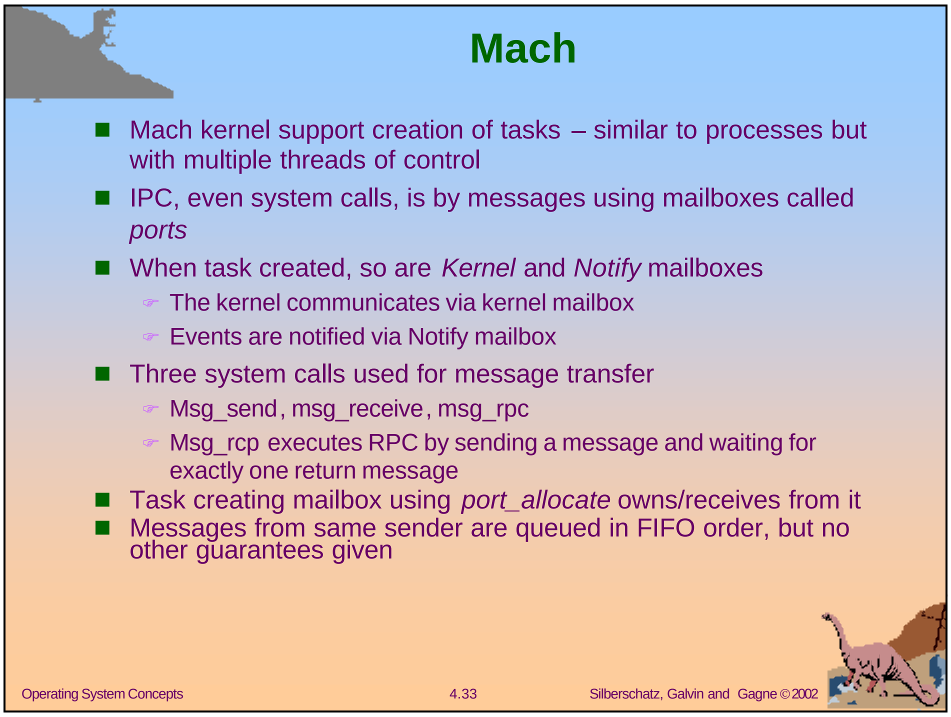
Synchronization

- Message passing may be either blocking or non-blocking.
- **Blocking** is considered **synchronous**
- **Non-blocking** is considered **asynchronous**
- **send** and **receive** primitives may be either blocking or non-blocking.

Buffering

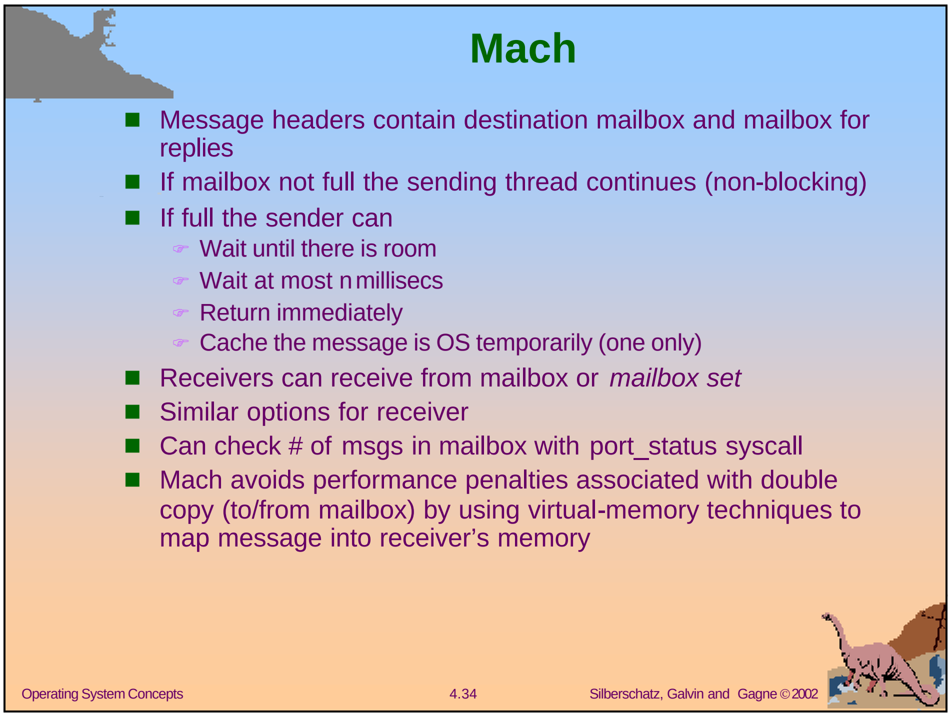
- Queue of messages attached to the link; implemented in one of three ways.
  1. Zero capacity – 0 messages
     Sender must wait for receiver (rendezvous).
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if link full.
  3. Unbounded capacity – infinite length
     Sender never waits.

Exercise: Read about Mach and Windows 2000



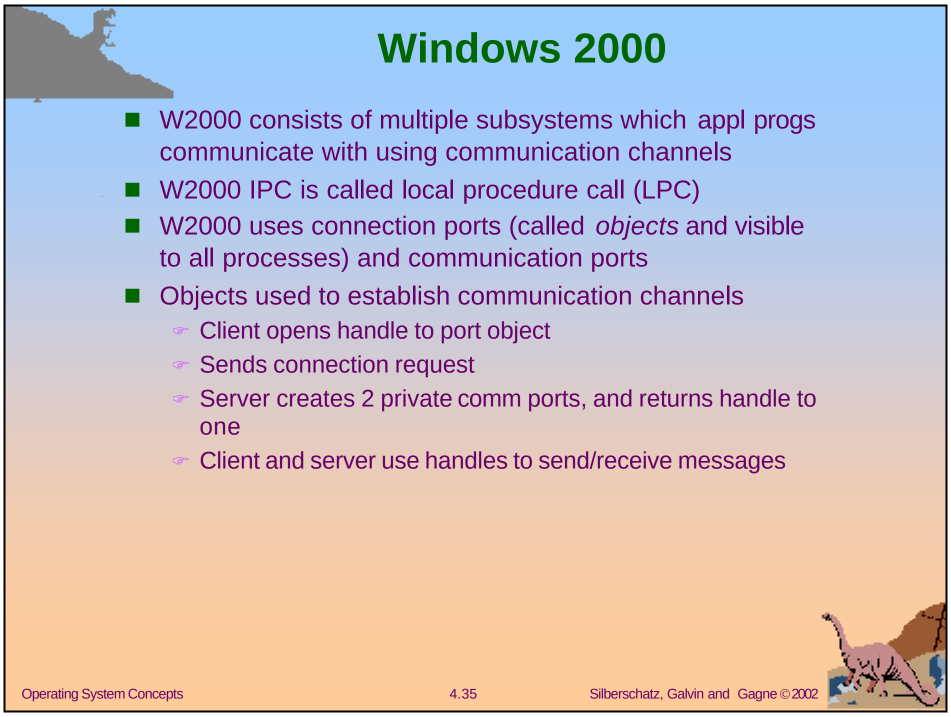
Mach

- Mach kernel support creation of tasks – similar to processes but with multiple threads of control
- IPC, even system calls, is by messages using mailboxes called *ports*
- When task created, so are *Kernel* and *Notify* mailboxes
  - The kernel communicates via kernel mailbox
  - Events are notified via Notify mailbox
- Three system calls used for message transfer
  - Msg_send, msg_receive, msg_rpc
  - Msg_rcp executes RPC by sending a message and waiting for exactly one return message
- Task creating mailbox using *port_allocate* owns/receives from it
- Messages from same sender are queued in FIFO order, but no other guarantees given



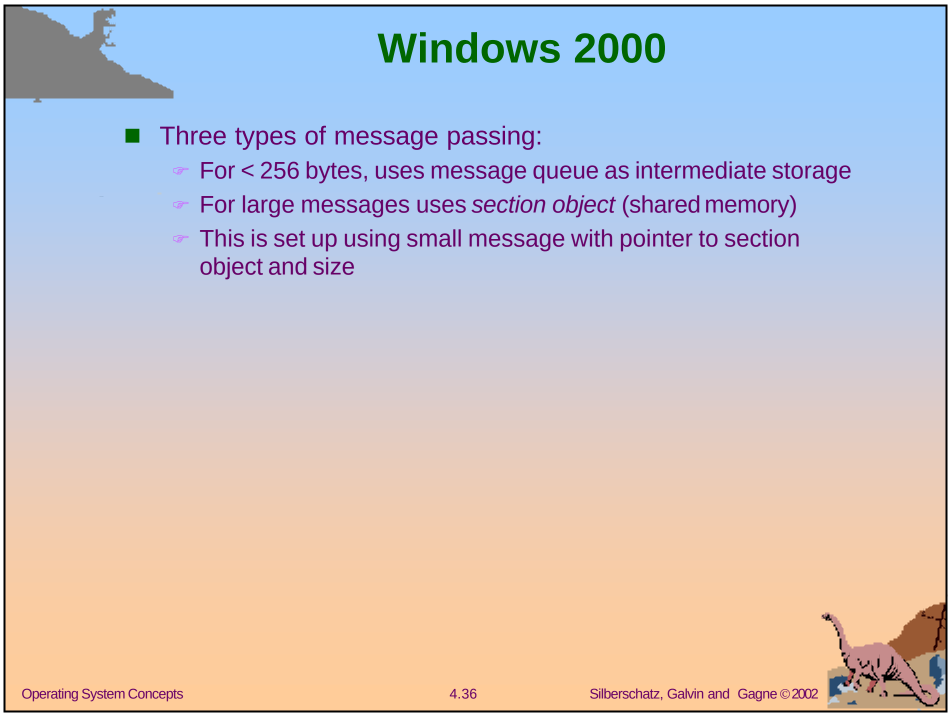
Mach

- Message headers contain destination mailbox and mailbox for replies
- If mailbox not full the sending thread continues (non-blocking)
- If full the sender can
  - Wait until there is room
  - Wait at most n millisecs
  - Return immediately
  - Cache the message is OS temporarily (one only)
- Receivers can receive from mailbox or *mailbox set*
- Similar options for receiver
- Can check # of msgs in mailbox with port_status syscall
- Mach avoids performance penalties associated with double copy (to/from mailbox) by using virtual-memory techniques to map message into receiver's memory



Windows 2000

- W2000 consists of multiple subsystems which appl progs communicate with using communication channels
- W2000 IPC is called local procedure call (LPC)
- W2000 uses connection ports (called *objects* and visible to all processes) and communication ports
- Objects used to establish communication channels
  - Client opens handle to port object
  - Sends connection request
  - Server creates 2 private comm ports, and returns handle to one
  - Client and server use handles to send/receive messages



Windows 2000

- Three types of message passing:
  - For < 256 bytes, uses message queue as intermediate storage
  - For large messages uses *section object* (shared memory)
  - This is set up using small message with pointer to section object and size

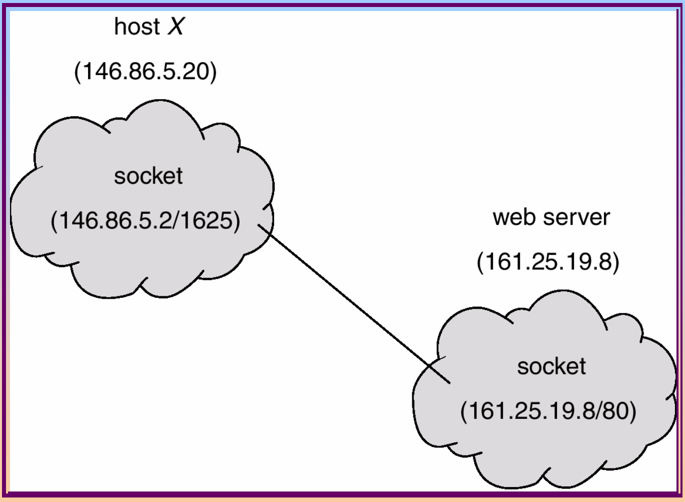
Client-Server Communication

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

Sockets

- A socket is defined as an *endpoint for communication*.
- Concatenation of IP address and port
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- Communication is between a pair of sockets.

Socket Communication



Java Sockets

- Java provides 3 types of socket
  - Connection-oriented (TCP) – Socket class
  - Connectionless (UDP) – DatagramSocket class
  - Multicast – MulticastSocket used to send to multiple clients
- Example: Time of day server
  - Clients request time of day from *localhost (127.0.0.1)*
  - Server listens on port 5155 with *accept* call
  - Blocks on accept until client request arrives
  - Creates new socket to communicate with client

Time of Day Server

```
import java.net.*;  import java.io.*;
public class Server
{  public static void main(String[] args ) throws IOException {
      Socket client = null ; PrintWriter pout = null; ServerSocket sock=null;
      try{
            sock = new ServerSocket(5155); //now listen for connections
            while(true){
              client = sock.accept();
              pout = new printWriter(client.getOutputStream (), true);
              pout.println(new java.util.Date().toString());
              pout.close();
              client.close();
            }
      }
      catch (IOException ioe) { System.err.println(ioe); }
      finally { if  (client != null)  client.close();
                  if (sock != null) sock.close();
      }
   }
}
```

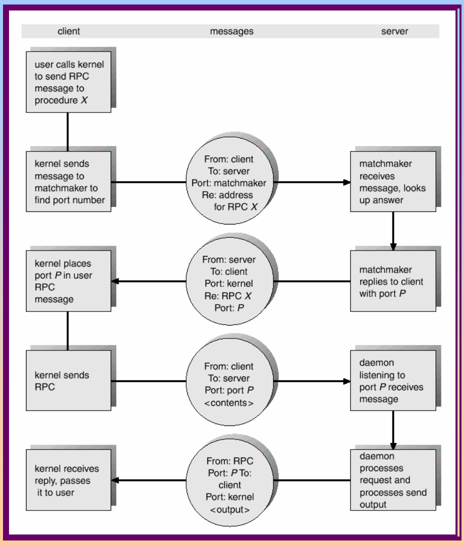
Client

```
import java.net.*;  import java.io.*;
public class Client
{  public static void main(String[] args ) throws IOException {
      InputStream  in = null; BufferedReader bin = null; Socket sock = null ;
      try{
            sock = new Socket("127.0.0.1", 5155);
            in = sock.getInputStream ();
            bin = new BufferedReader( new InputStreamReader(in));
            String line;
            while( (line = bin.readLine()) != null)
                System.out.println(line);
      }

      catch (IOException ioe) { System.err.println(ioe); }
      finally { if (sock != null) sock.close(); }
   }
}
```

Remote Procedure Calls

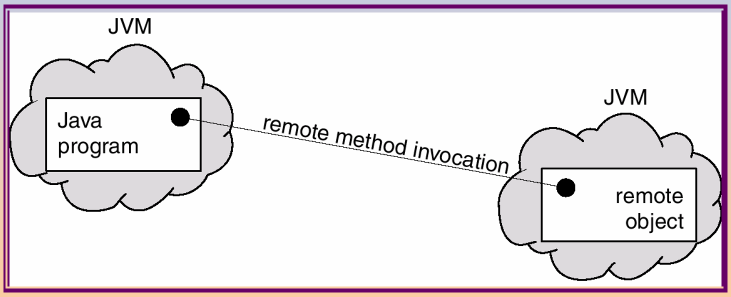
- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems.
- Messages in RPC are addressed to daemons listening on ports on a remote system
- **Stubs** – client-side proxy for the actual procedure on the server.
- The client-side stub locates the server and *marshalls* the parameters.
- The server-side stub receives this message, unpacks the marshalled parameters, and peforms the procedure on the server.
- To avoid data representation problems (bigendian/littleendian) many systems use XDR (external data representation)
- RPC can be used to implement a distributed file system (DFS)

Execution of RPC

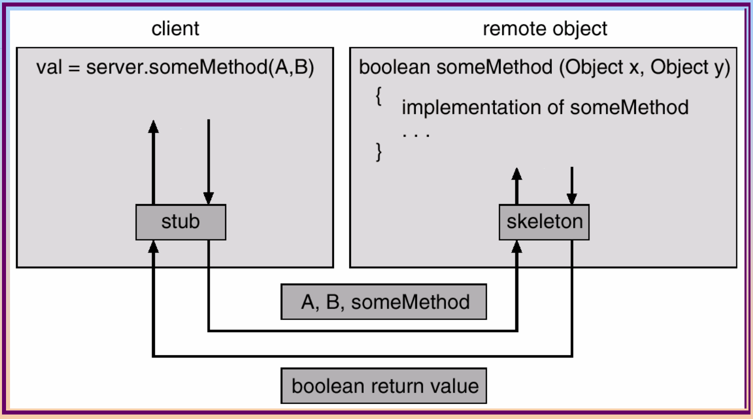

client
messages
server
user calls kernel to send RPC message to procedure X
kernel sends message to matchmaker to find port number
From: client To: server Port: matchmaker Re: address for RPC X
matchmaker receives message, looks up answer
kernel places port P in user RPC message
From: server To: client Port: kernel Re: RPC X Port: P
matchmaker replies to client with port P
kernel sends RPC
From: client To: server Port: port P <contents>
daemon listening to port P receives message
kernel receives reply, passes it to user
From: RPC Port: P To: client Port: kernel <output>
daemon processes request and processes send output

Remote Method Invocation

- Remote Method Invocation (RMI) is a Java mechanism similar to RPCs.
- RMI allows a Java program on one machine to invoke a method on a remote object.



Marshalling Parameters


client
val = server.someMethod(A,B)
stub
remote object
boolean someMethod (Object x, Object y)
{ implementation of someMethod . . . }
skeleton
A, B, someMethod
boolean return value