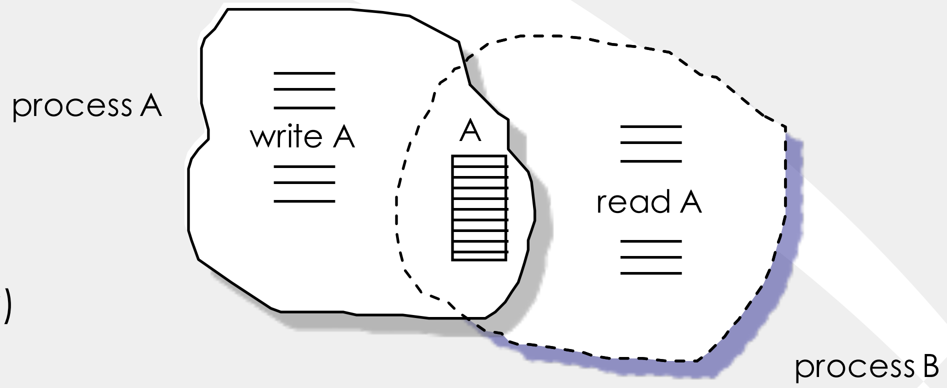
Introduction

- Cooperating processes need to exchange information
  - To synchronize with each other
  - To perform their collective task(s)
- Methods for exchanging information -- *inter-process communication (IPC) -- two* basic models are used:
  - *shared memory*—"shared data" are directly available to each process in their address spaces.
  - *message passing*—"shared data" are explicitly exchanged.

Shared Memory versus Message Passing

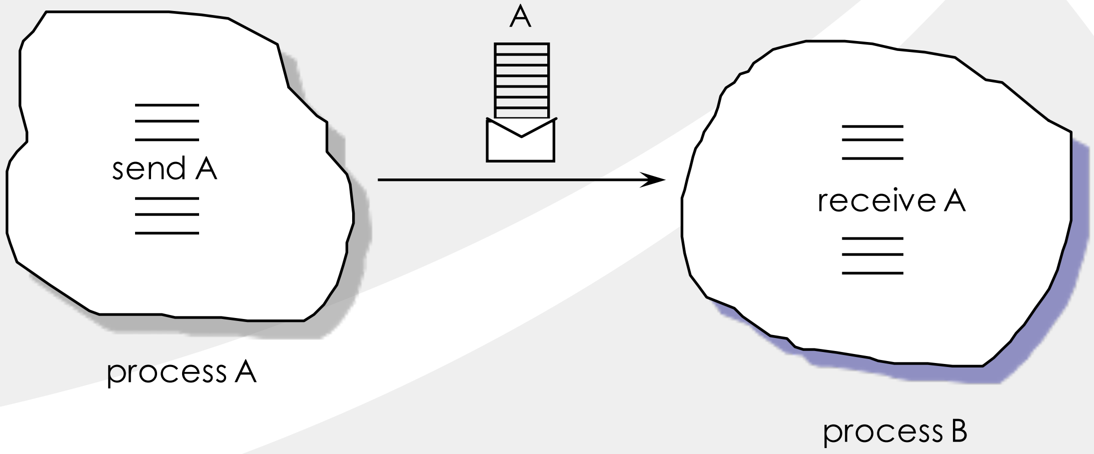
shared memory

(e.g., UNIX shared memory)



message passing

(e.g., UNIX sockets)



Terminology

- One process *sends* some information to another.
- Information exchanged among processes is called a *message*
  - message can be a structured (language) object, specified by its type, or var. length
- Two basic operations on messages:
  - **send()**—transmission of a message
  - **receive()**—receipt of a message

Fundamental questions

- Message passing protocols should answer questions such as:
  - What happens if a process executes a **receive()**, but no message has been sent?
  - Can a message be sent to <u>one</u> or to <u>many</u> processes?
  - Does a receiver identify the sender of the message or can it accept messages from <u>any</u> sender?
  - Where are messages kept while in transit? What is the capacity of such storage?

Design Issues

- Implementation affects the following functions of **send** and **receive**:
  - *Form of communication*—messages can be send directly to its recipient or indirectly through an intermediate named object.
  - *Buffering*—how and where the messages are stored.
  - *Error handling*—how to deal with exception conditions.

Direct communication

- The sender and receiver can communicate in either of the following forms:
  - *synchronous*—involved processes synchronize at every message. Both **send** and **receive** are *blocking* operations. This form is also known as a *rendezvous*.
  - *asynchronous*—the **send** operation is almost always non-blocking. The **receive** operation, however, can have blocking (waiting) or non-blocking (polling) variants.

Direct communication
cont.

- Symmetric addressing -- processes explicitly name the receiver or sender
    - **send** (*P, message*). Send *message* to process *P*.
    - **receive** (*Q, message*). Receive *message* from *Q*.
- Asymmetric addressing -- server does not know the name of client -- a variant of the **receive** operation can be used
    - **listen** (*ID*, *message*). Receive a pending (posted) *message* from any process; when a message arrives, *ID* is set to the name of the sender.

Direct communication *cont.*

- Direct comm. – connection between sender and receiver:
  - A link is established automatically, but the processes need to know each other's identity
  - A unique link is associated with the two processes
  - Each pair of processes has only one link between them
  - The link is usually bi-directional, but it can be uni-directional

Indirect communication

- Indirect communication uses *mailboxes*, which are special repositories – sent and retrieved from these repositories
  - **send** (*A, message*). Send a *message* to mailbox *A*.
  - **receive** (*A, message*). Receive a *message* from mailbox *A.*
- decouples the sender and receiver and allows greater flexibility.

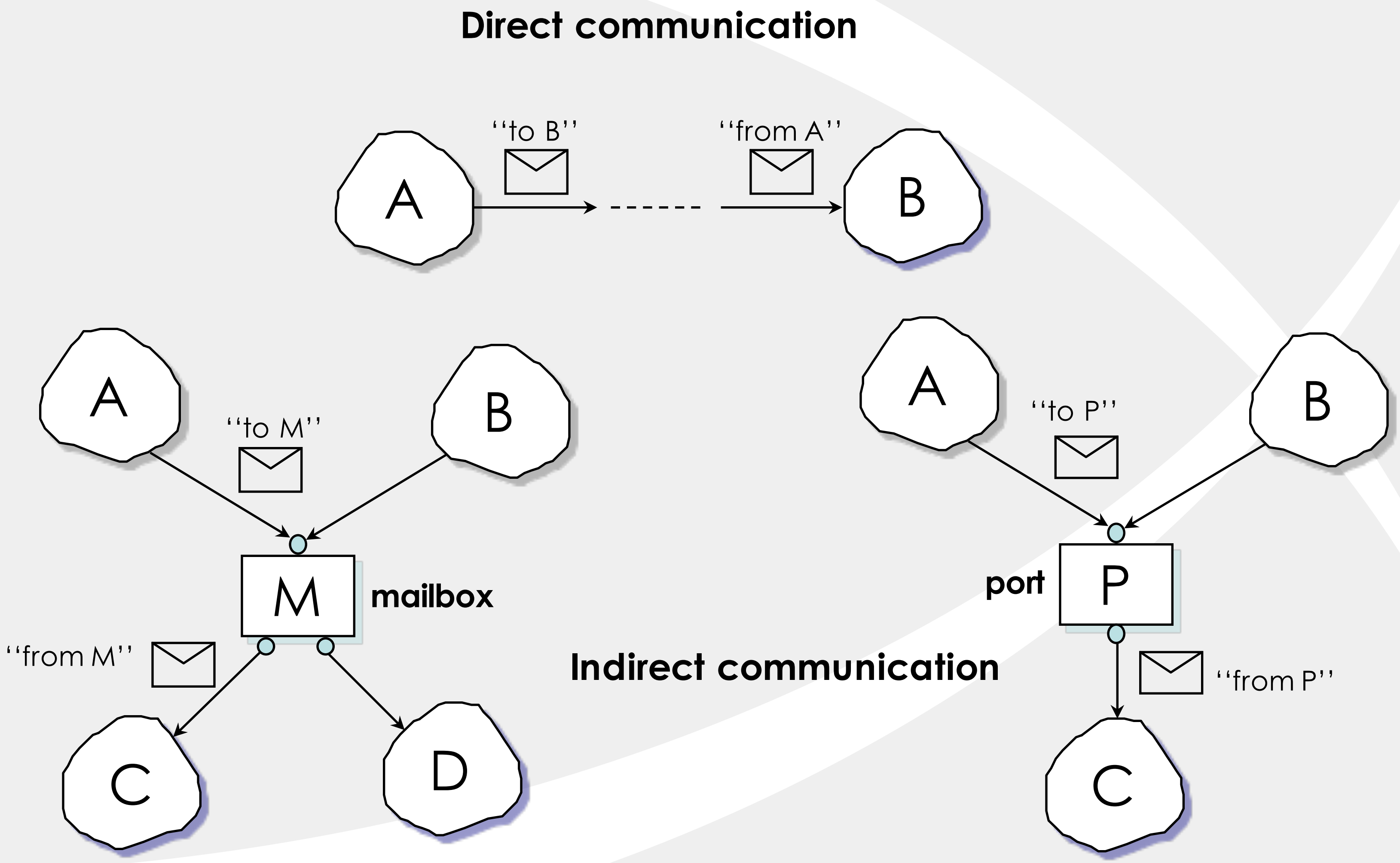
Indirect communication *cont.*

- Mailbox can be associated with many senders and receivers
- Special case – mailbox statically bound to a receiver – called *port*
- Process creating a mailbox is the owner (sender). Mailboxes are usually managed by the system.

Indirect communication *cont.*

- The interconnection between the sender and receiver has the following characteristics:
  - A link is established between two processes only if they “share” a mailbox.
  - A link may be associated with more than two processes.
  - Communicating processes may have different links between them, each corresponding to one mailbox.
  - The link is usually bi-directional, but it can be uni-directional.

Message passing by "picture"



Buffering

- Three types of messaging based on the capacity of the link
  - *Zero capacity*—used by synchronous communication.
  - *Bounded capacity*—when the buffer is full, the sender must wait.
  - *Indefinite capacity*—the sender never waits.
- In non-zero capacity cases (asynchronous), the sender is unaware of the status of the message

Error handling

- In distributed systems, message passing mechanisms extend interprocess communication beyond the machine boundaries. Consequently, messages are occasionally lost, duplicated, delayed, or delivered out of order. The following are the most common "error" conditions which requires proper handling:
  - *Process terminates*—either a sender or a receiver may terminate <u>before</u> a message is processed.
  - *Lost or delayed messages*—a message may be lost (or delayed) in the communications network.
  - *Scrambled messages*—a message arrives in an unprocessible state.

Synchronization with messages

- The primitives discussed earlier are not suitable for synchronization in distributed systems. For example, semaphores require global memory, whereas monitors require centralized control. Application of such *centralized* mechanisms to distributed environments is not possible.
- However, message passing is a mechanism suitable not only for interprocess communication, but also for synchronization, in both centralized and distributed environments.

An example

```
typedef message {
   ...
}
const capacity = ... ;
message dummy = {};

int main()
{
   int i;

   create_mailbox( mayconsume );
   create_mailbox( mayproduce );
   for ( i = 0; i < capacity; i++ )
     send( mayproduce, dummy );
   producer();
   consumer();
}
```

```
producer()
{
   message pmsg;

   while ( true ) {
     receive( mayproduce, pmsg );

     < produce >

     send( mayconsume, pmsg );
   }
}
```

```
consumer()
{
   message cmsg;

   while ( true ) {
     receive( mayconsume, cmsg );

     < consume >

     send( mayproduce, cmsg );
   }
}
```

Note: In this example, both send() and receive() are blocking operations.

Other IPC mechanisms

- The following are IPC mechanisms found in various flavors of UNIX:
  - Pipes
  - FIFOs (named pipes)
  - Streams and Messages
  - System V IPC
    - Message Queues
    - Semaphores
    - Shared Memory
  - Sockets (BSD)
  - Transport Level Interface (System V)

A case study—UNIX signals

- A UNIX *signal*, a rudimentary form of IPC, is used to notify a process of an event. A signal is <u>generated</u> when the event first occurs and <u>delivered</u> when the process takes an action on that signal. A signal is <u>pending</u> when it is generated but not yet delivered. Signals, also called *software interrupts*, generally occur asynchronously.
- A signal can be sent:
  - by one process to another, including itself (in the latter case it is synchronous)
  - by the kernel to a process

Sending a *signal*

```
    kill(int pid, int sig);
```

sends a signal **`sig`** to the process **`pid`**. A process sends a signal to itself with

```
    raise(int sig);
```

There is no operation to receive a signal. However, a process may declare a function to service a particular signal as:

```
    signal(int sig, SIGARG func);
```

Whenever the specified signal **`sig`** is received, the process is interrupted and **`func`** is called immediately. In other words, the process catches the signal when it is delivered. On return from **`func`**, the process resumes its execution from where it was interrupted.

What to do with a *signal?*

- Using the **`signal()`** system call, a process can:
  - *Ignore the signal*—all except for two signals (**`SIGKILL`** and **`SIGSTOP`**) can be ignored.
  - *Catch the signal*—tell the kernel to call a function whenever the signal occurs.
  - *Let the default action apply*—depending on the signal, the default action can be:
    - **exit**—perform all activities as if the exit system call is requested.
    - **core**—first produce a core image on disk and then perform the exit activities.
    - **stop**—suspend the process.
    - **ignore**—disregard the signal.

UNIX signals—an example

```
#include < stdio.h >
#include < signal.h >
#include < unistd.h >
#include < stdlib.h >

int main ( void )
{
  int     i ;
  void    catch_signal( int ) ;

    if ( signal( SIGINT, catch_signal  ) == SIG_ERR ) {
         perror( "SIGINT failed" ) ;
         exit  ( 1 );
    }
    if ( signal( SIGQUIT, catch_signal ) == SIG_ERR ) {
         perror( "SIGQUIT failed" ) ;
         exit( 1 ) ;
    }
    for ( i = 0; ; i++ ) {      /* loop forever */
         printf( "%d\n", i ) ;
         sleep( 1 ) ;
    }
}

void catch_signal( int the_signal ) {
    signal( the_signal, catch_signal ) ;   /* catch again */
    printf( "\nSignal %d received.\n", the_signal ) ;
    if ( the_signal  == SIGQUIT ) {
       printf( "Exiting...\n" ) ;
       exit( 3 );
    }
}
```

output

```
% a.out
0
1
2
^C
Signal 2 received.
3
^C
Signal 2 received.
4
5
6
^\
Signal 3 received.
Exiting...
%
```