❖ Message Oriented Communication

Remote procedure calls and remote object invocations contribute to hiding communication in distributed systems, that is, they enhance access transparency. Unfortunately, neither mechanism is always appropriate. In particular, when it cannot be assumed that the receiving side is executing at the time a request is issued, alternative communication services are needed. Likewise, the inherent synchronous nature of RPCs, by which a client is blocked until its request has been processed, sometimes needs to be replaced by something else.

That something else is messaging. In this section we concentrate on message-oriented communication in distributed systems by first taking a closer look at what exactly synchronous behavior is and what its implications are. Then, we discuss messaging systems that assume that parties are executing at the time of communication. Finally, we will examine message-queuing systems that allow proc- esses to exchange information, even if the other party is not executing at the time communication is initiated.

Message-Oriented Transient Communication

Many distributed systems and applications are built directly on top of the simple message-oriented model offered by the transport layer. To better understand and appreciate the message-oriented systems as part of middleware solutions, we first discuss messaging through transport-level sockets.

Berkeley Sockets

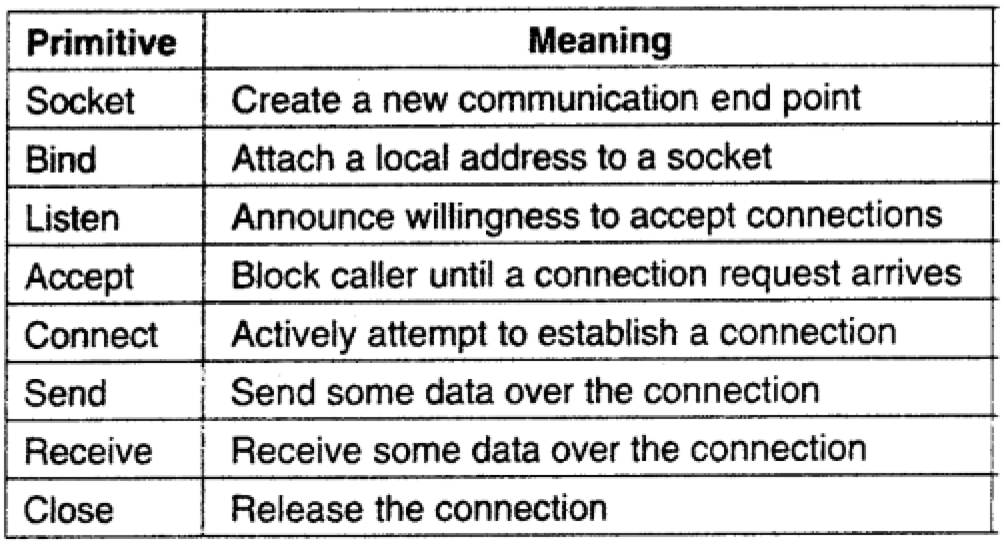
Special attention has been paid to standardizing the interface of the transport layer to allow programmers to make use of its entire suite of (messaging) protocols through a simple set of primitives. Also, standard interfaces make it easier to port an application to a different machine.

As an example, we briefly discuss the sockets interface as introduced in the 1970s in Berkeley UNIX. Another important interface is XTI, which stands for the X10pen Transport Interface, formerly called the Transport Layer Interface (TLI), and developed by AT&T. Sockets and XTI are very similar in their model of network programming, but differ in their set of primitives.

Conceptually, a socket is a communication end point to which an application can write data that are to be sent out over the underlying network, and from which incoming data can be read. A socket forms an abstraction over the actual communication end point that is used by the local operating system for a specific transport protocol. In the following text, we concentrate on the socket primitives for TCP, which are shown in Fig. 4-14.

Servers generally execute the first four primitives, normally in the order given. When calling the socket primitive, the caller creates a new communication endpoint for a specific transport protocol. Internally, creating a communication endpoint means that the local operating system reserves resources to accommodate sending and receiving messages for the specified protocol.

The bind primitive associates a local address with the newly-created socket. For example, a server should bind the IP address of its machine together with a (possibly well-known) port number to a socket. Binding tells the operating system that the server wants to receive messages only on the specified address and port.



Primitive	Meaning
Socket	Create a new communication end point
Bind	Attach a local address to a socket
Listen	Announce willingness to accept connections
Accept	Block caller until a connection request arrives
Connect	Actively attempt to establish a connection
Send	Send some data over the connection
Receive	Receive some data over the connection
Close	Release the connection

Figure 4-14. The socket primitives for TCPIIP.

The listen primitive is called only in the case of connection-oriented communication. It is a nonblocking call that allows the local operating system to reserve enough buffers for a specified maximum number of connections that the caller is willing to accept. A call to accept blocks the caller until a connection request arrives. When a request arrives, the local operating system creates a new socket with the same properties as the original one, and returns it to the caller. This approach will allow the server to, for example, fork off a process that will subsequently handle the actual communication through the new connection. The server, in the meantime, can go back and wait for another connection request on the original socket.

Let us now take a look at the client side. Here, too, a socket must first be created using the socket primitive, but explicitly binding the socket to a local address is not necessary, since the operating system can dynamically allocate a port when the connection is set up. The connect primitive requires that the caller specifies the transport-level address to which a connection request is to be sent. The client is blocked until a connection has been set up successfully, after which both sides can start exchanging information through the send and receive primitives.

Finally, closing a connection is symmetric when using sockets, and is established by having both the client and server call the close primitive. The general pattern followed by a client and server for connection-oriented communication using sockets is shown in Fig. 4-15. Details about network programming using sockets and other interfaces in a UNIX environment can be found in Stevens (1998).

<u>The Message-Passing Interface (MPI)</u>

With the advent of high-performance multicomputers, developers have been looking for message-oriented primitives that would allow them to easily write highly efficient applications. This means that the primitives should be at a convenient level of abstraction (to ease application development), and that their implementation incurs only minimal overhead. Sockets were deemed insufficient for two reasons. First, they were at the wrong level of abstraction by supporting only simple send and receive primitives. Second, sockets had been designed to communicate across networks using general-purpose protocol stacks such as TCPIIP. They were not considered suitable for the proprietary protocols developed for high-speed interconnection networks, such as those used in high-performance server clusters. Those protocols required an 'interface that could handle more advanced features, such as different forms of buffering and synchronization.

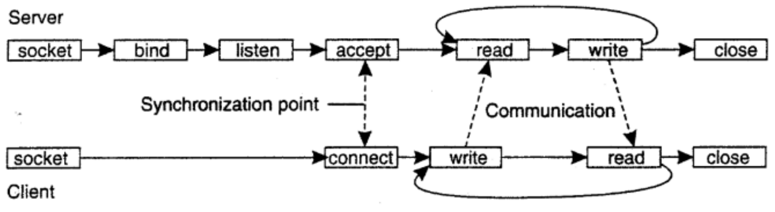


Figure 4-15. Connection-oriented communication pattern using sockets.

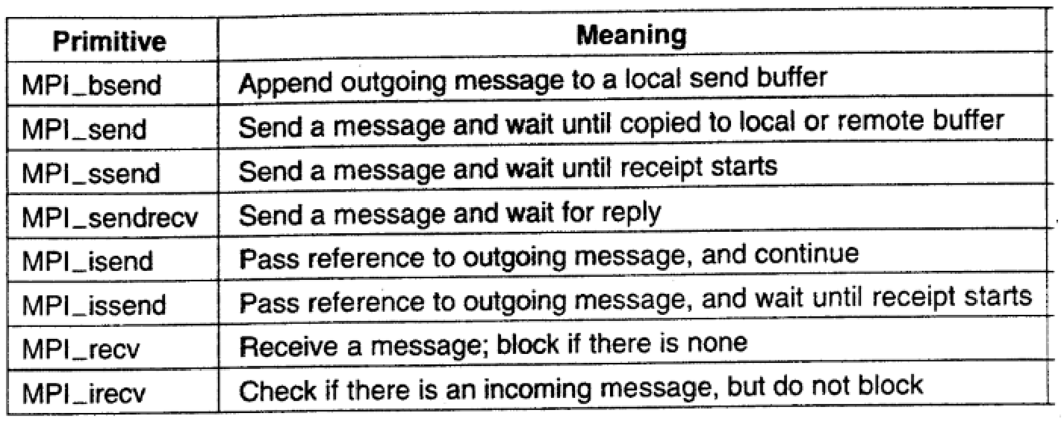
The result was that most interconnection networks and high-performance multicomputers were shipped with proprietary communication libraries. These libraries offered a wealth of high-level and generally efficient communication primitives. Of course, all libraries were mutually incompatible, so that application developers now had a portability problem.

The need to be hardware and platform independent eventually led to the definition of a standard for message passing, simply called the Message-Passing Interface or MPI. MPI is designed for parallel applications and as such is tailored to transient communication. It makes direct use of the underlying network..Also, it assumes that serious failures such as process crashes or network partitions are fatal and do not require automatic recovery.

MPI assumes communication takes place within a known group of processes. Each group is assigned an identifier. Each process within a group is also assigned a (local) identifier. A (group/D, process/D) pair therefore uniquely identifies the source or destination of a message, and is used instead of a transport-level address. There may be several, possibly overlapping groups of processes involved in a computation and that are all executing at the same time.

At the core of MPI are messaging primitives to support transient communica- tion, of which the most intuitive ones are summarized in Fig. 4-16.

Transient asynchronous communication is supported by means of the MPI_bsend primitive. The sender submits a message for transmission, which is generally first copied to a local buffer in the MPI runtime system. When the message has been copied. the sender continues. The local MPI runtime system will remove the message from its local buffer and take care of transmission as soon as a receiver has called a receive primitive.



Primitive	Meaning
MPI_bsend	Append outgoing message to a local send buffer
MPI_send	Send a message and wait until copied to local or remote buffer
MPI_ssend	Send a message and wait until receipt starts
MPI_sendrecv	Send a message and wait for reply
MPI_isend	Pass reference to outgoing message, and continue
MPI_issend	Pass reference to outgoing message, and wait until receipt starts
MPI_recv	Receive a message; block if there is none
MPI_irecv	Check if there is an incoming message, but do not block

Figure 4-16. Some of the most intuitive message-passing primitives of MPI.

There is also a blocking send operation, called MPLsend, of which the sem- antics are implementation dependent. The primitive MPLsend may either block the caller until the specified message has been copied to the MPI runtime system at the sender's side, or until the receiver has initiated a receive operation. Synchronous communication by which the sender blocks until its request is accepted for further processing is available through the MPI~ssend primitive. Finally, the strongest form of synchronous communication is also supported: when a sender calls MPLsendrecv, it sends a request to the receiver and blocks until the latter returns a reply. Basically, this primitive corresponds to a normal RPC. Both MPLsend and MPLssend have variants that avoid copying messages from user buffers to buffers internal to the local MPI runtime system. These variants correspond to a form of asynchronous communication. With MPI_isend, a sender passes a pointer to the message after which the MPI runtime system takes care of communication. The sender immediately continues. To prevent overwriting the message before communication completes, MPI offers primitives to check for completion, or even to block if required. As with MPLsend, whether the message has actually been transferred to the receiver or that it has merely been copied by the local MPI runtime system to an internal buffer is left unspecified.

Likewise, with MPLissend, a sender also passes only a pointer to the :MPI runtime system. When the runtime system indicates it has processed the message, the sender is then guaranteed that the receiver has accepted the message and is now working on it.

The operation MPLrecv is called to receive a message; it blocks the caller until a message arrives. There is also an asynchronous variant, called MPLirecv, by which a receiver indicates that is prepared to accept a message. The receiver can check whether or not a message has indeed arrived, or block until one does.

The semantics of MPI communication primitives are not always straightforward, and different primitives can sometimes be interchanged without affecting the correctness of a program. The official reason why so many different forms of communication are supported is that it gives implementers of MPI systems enough possibilities for optimizing performance. Cynics might say the committee could not make up its collective mind, so it threw in everything. MPI has been designed for high-performance parallel applications, which makes it easier to understand its diversity in different communication primitives.

Message-Oriented Persistent Communication

We now come to an important class of message-oriented middle ware services, generally known as message-queuing systems, or just Message-Oriented Middleware (MOM). Message-queuing systems provide extensive support for persistent asynchronous communication. The essence of these systems is that they offer intermediate-term storage capacity for messages, without requiring either the sender or receiver to be active during message transmission. An important difference with Berkeley sockets and MPI is that message-queuing systems are typically targeted to support message transfers that are allowed to take minutes instead of seconds or milliseconds. We first explain a general approach to message queuing systems, and conclude this section by comparing them to more traditional systems, notably the Internet e-mail systems.

Message-Queuing Model

The basic idea behind a message-queuing system is that applications communicate by inserting messages in specific queues. These messages are forwarded over a series of communication servers and are eventually delivered to the destination, even if it was down when the message was sent. In practice, most communication servers are directly connected to each other. In other words, a message is generally transferred directly to a destination server. In principle, each application has its own private queue to which other applications can send messages. A queue can be read only by its associated application, but it is also possible for multiple applications to share a single queue.

An important aspect of message-queuing systems is that a sender is generally given only the guarantees that its message will eventually be inserted in the recipient's queue. No guarantees are given about when, or even if the message will actually be read, which is completely determined by the behavior of the recipient.

These semantics permit communication loosely-coupled in time. There is thus no need for the receiver to be executing when a message is being sent to its queue.

Likewise, there is no need for the sender to be executing at the moment its message is picked up by the receiver. The sender and receiver can execute completely independently of each other. In fact, once a message has been deposited in a queue, it will remain there until it is removed, irrespective of whether its sender or receiver is executing. This gives us four combinations with respect to the execution mode of the sender and receiver, as shown in Fig. 4-17.

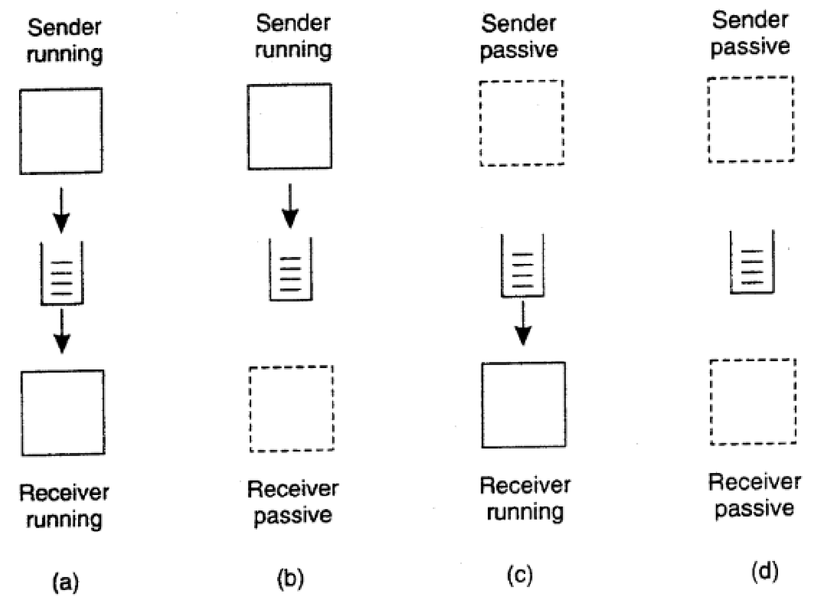


Figure 4-17. Four combinations for loosely-coupled communications using queues.

In Fig.4-17(a), both the sender and receiver execute during the entire transmission of a message. In.Fig. 4-17(b), only the sender is executing, while the receiver is passive, that is, in a state in which message delivery is not possible. Nevertheless, the sender can still send messages. The combination of a passive sender and an executing receiver is shown in Fig. 4-17(c). In this case, the receiver can read messages that were sent to it, but it is not necessary 'that their respective senders are executing as well. Finally, in Fig. 4-17(d), we see the situation that the system is storing (and possibly transmitting) messages even while sender and receiver are passive.

Messages can, in principle, contain any data. The only important aspect from the perspective of middleware is that messages are properly addressed. In practice, addressing is done by providing a systemwide unique name of the destination queue. In some cases, message size may be limited, although it is also possible that the underlying system takes care of fragmenting and assembling large messages in a way that is completely transparent to applications. An effect of this approach is that the basic interface offered to applications can be extremely simple,as shown in Fig. 4-18.

Primitive	Meaning
Put	Append a message to a specified queue
Get	Block until the specified queue is nonempty, and remove the first message
Poll	Check a specified queue for messages, and remove the first. Never block
Notify	Install a handler to be called when a message is put into the specified queue

Figure 4-18. Basic interface to a queue in a message-queuing system.

The put primitive is called by a sender to pass a message to the underlying system that is to be appended to the specified queue. As we explained. this is a nonblocking call. The get primitive is a blocking call by which an authorized process can remove the longest pending message in the specified queue. The process is blocked only if the queue is empty. Variations on this call allow searching for a specific message in the queue, for example, using a priority, or a matching pattern. The nonblocking variant is given by the pollprimitive. If the queue is empty, or if a specific message could not be found, the calling process simply continues.

Finally, most queuing systems also allow a process to install a handler as a callback function, which is automatically invoked whenever a message is put into the queue. Callbacks can also be used to automatically start a process that will fetch messages from the queue if no process is currently executing. This approach is often implemented by means of a daemon on the receiver's side that continuously monitors the queue for incoming messages and handles accordingly.