Motivation

- Locks, semaphores, monitors are good but they only work under the shared-memory model

- How to synchronize / schedule / communicate between processes that reside in different address spaces / different machines?

- Can we have a single set of primitives that are transparently extensible to the distributed environment?
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 a message - message size fixed or variable
  - receive a 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)
  - logical (e.g., logical properties)

The big picture

![Diagram showing the relationship between a sender and a receiver, with processes connected by a line.]
Message passing API

- **Generic API**
  - `send(dest, msg)`, `receive(src, msg)`

- **What should the "dest" and "src" be?**
  - `pid`
  - `file`: e.g. a pipe
  - `port`: network address, pid, etc
  - `no src`: receive any message
  - `src` combines both specific and any

- **What should "msg" be?**
  - Need both buffer and size for a variable sized message

Implementation issues

- Asynchronous vs. synchronous
- Event handler vs. receive
- How to buffer messages?
- Direct vs. indirect
- 1-to-1 vs. 1-to-many vs. many-to-one vs. many-to-many
- Unidirectional vs. bidirectional
- What is the size of a message?
- How to handle exceptions (when bad things happen)?
Synchronous vs. asynchronous: send

- **Synchronous**
  - Will not return until data is out of its source memory
  - Block on full buffer

- **Asynchronous**
  - Return as soon as initiating its hardware
  - Completion
    - Require applications to check status
    - Notify or signal the application
  - Block on full buffer

```c
send( dest, msg );
```

```c
status = async_send( dest, msg );
...
if !send_complete( status )
  wait for completion;
...
use msg data structure;
...
```

Synchronous vs. asynchronous: receive

- **Synchronous**
  - Return data if there is a message
  - Block on empty buffer

- **Asynchronous**
  - Return data if there is a message
  - Return status if there is no message (probe)

```c
recv( src, msg );
```

```c
status = async_recv( src, msg );
if ( status == SUCCESS )
  consume msg;
while ( probe(src) != HaveMSG )
  wait for msg arrival
recv( src, msg );
consume msg;
```
Event handler vs. receive

- **hrecv(src, msg, func)**
  - **msg** is an arg of **func**
  - Execute “**func**” on a message arrival
- **Which one is more powerful?**
  - Recv with a thread can emulate a Handler
  - Handler can be used to emulate Recv by using Monitor
- **Pros and Cons**
  - Handler is better for event-based applications (no need to think about threads), but concurrent executions require more thoughts
  - Recv with a thread require thread context switches but can run concurrently

```c
void func( char * msg ) {
    ...
}
```

```c
while(1) {
    recv(src,msg);
    func(msg);
}
```

Buffering

- **No buffering**
  - Sender must wait until the receiver receives the message
  - Rendezvous on each message
- **Bounded buffer**
  - Finite size
  - Sender blocks on buffer full
  - Use mesa-monitor to solve the problem
- **Unbounded buffer**
  - “Infinite” size
  - Sender never blocks
Direct communication

- A single buffer at the receiver
  - More than one process may send messages to the receiver
  - To receive from a specific sender, it requires searching through the whole buffer

- A buffer at each sender
  - A sender may send messages to multiple receivers
  - To get a message, it also requires searching through the whole buffer

Indirect communication

- Use a “mailbox” to allow many-to-many communication
  - Requires open/close a mailbox before using it

- Where should the buffer be?
  - A buffer, its mutex and condition variables should be at the mailbox

- Fixed sized messages?
  - Not necessarily. One can break a large message into packets

- Are there any differences between a mailbox and a pipe?
  - A mailbox allows many to many communication
  - A pipe implies one sender and one receiver
Indirect communication (cont’d)

- 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.

Example: keyboard input

- How do you implement keyboard input?
  - Need an interrupt handler
  - Generate a mbox message from the interrupt handler

- Suppose a keyboard device thread converts input characters into an mbox message
  - How would you synchronize between the keyboard interrupt handler and device thread?
  - How can a device thread convert input into mbox messages?
**Example: Sockets API**

- **Abstraction for TCP and UDP**
  - Learn more about internetworking in the future
- **Addressing**
  - IP address and port number ($2^{16}$ ports available for users)
- **Create and close a socket**
  
  ```
  sockid = socket (af, type, protocol);
  sockerr = close(sockid);
  ```
- **Bind a socket to a local address**
  
  ```
  sockerr = bind(sockid, localaddr, addrlen);
  ```
- **Negotiate the connection**
  
  ```
  listen(sockid, length);
  accept(sockid, addr, length);
  ```
- **Connect a socket to destination**
  
  ```
  Connect(sockid, destaddr, addrlen);
  ```

**Unix pipes**

- An output stream connected to an input stream by a chunk of memory (a queue of bytes).
- **Send** (called write) is non-blocking
- **Receive** (called read) is blocking
- **Buffering** is provided by OS
- **Message boundaries** erased while reading
**Exception: losing messages**

- Use ack and timeout to detect and retransmit a lost message
  - Require the receiver to send an ack message for each message
  - Sender blocks until an ack message is back or timeout
    \[ \text{status} = \text{send} (\text{dest}, \text{msg}, \text{timeout}); \]
  - If timeout happens and no ack, then retransmit the message

- **Issues**
  - Duplicates
  - Losing ack messages

**Exception: losing messages (cont’d)**

- **Retransmission must handle**
  - Duplicate messages on receiver side
  - Out-of-sequence ack messages on sender side

- **Retransmission**
  - Use sequence number for each message to identify duplicates
  - Remove duplicates on receiver side
  - Sender retransmits on an out-of-sequence ack

- **Reduce ack messages**
  - Bundle ack messages
  - Receiver sends noack messages: can be complex
  - Piggy-back acks in send messages
Summary

- **Message passing**
  - Move data between processes
  - Implicit synchronization

- **Implementation issues**
  - Synchronous method is most common
  - Asynchronous method provides overlapping but requires careful design considerations
  - Indirection makes implementation flexible
  - Exception needs to be carefully handled