CSC 4304 - Systems Programming
Fall 2010

Lecture - XVII
Interprocess Communication

Tevfik Koşar

Louisiana State University
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Interprocess Communication (IPC)

- Threads may want to communicate beyond the process boundaries for:
  - Data Transfer & Sharing
  - Event notification
  - Resource Sharing & Synchronization
  - Process Control
- If threads belong to the same process, they execute in the same address space, i.e. they can access global (static) data or heap directly, without the help of the operating system.
- However, if threads belong to different processes, they cannot access each others address spaces without the help of the operating system.

Interprocess Communication (IPC)

- There are two fundamentally different approaches in IPC:
  - processes are residing on the same computer
    - (i.e. a shared memory system)
  - processes are residing on different computers

- The first case is easier to implement because processes can share memory either in the user space or in the system space.

- In the second case the computers do not share physical memory, they are connected via I/O devices (for example serial communication or Ethernet). Therefore the processes residing in different computers can not use memory as a means for communication

IPC Approaches

- We have already learned:
  - Shared memory
  - Pipes
  - Sockets
  - Signals

- We will learn:
  - Message Passing
  - FIFO (Named Pipes)

IPC: Message Passing

Message Passing

- 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)
  - logical (e.g., logical properties)

Implementation Questions

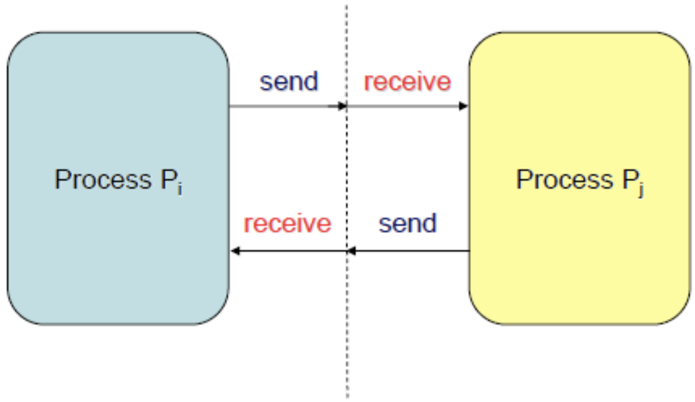
- How are links established?
- Can a link be associated with more than two processes?
- How many links can there be between every pair of communicating processes?
- What is the capacity of a link?
- Is the size of a message that the link can accommodate fixed or variable?
- Is a link unidirectional or 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.

Direct Communication - Naming



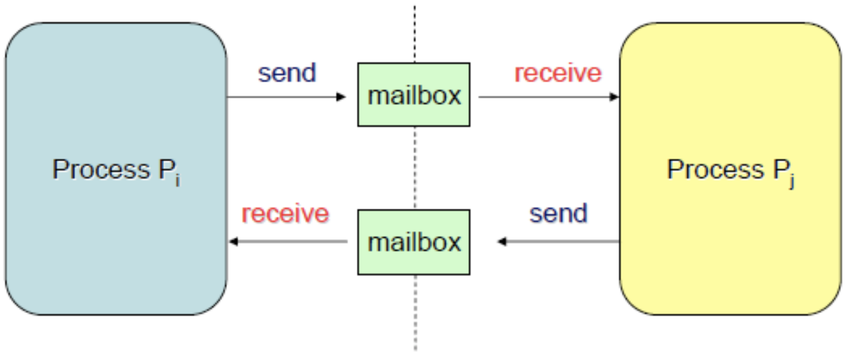
naming (direct)

- send(P_j, message): P_j identifies process j in the system
- receive(P_i, message): P_i identifies process i in the system

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 - Naming



naming (indirect)

- send(m_a, message): m_a identifies mailbox a in the system
- receive(m_b, message): m_b identifies mailbox b in the system

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

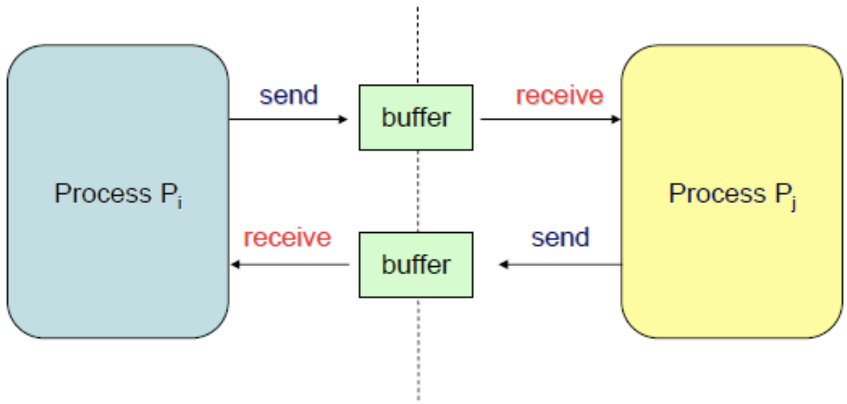
- Mailbox sharing:
  - P_1, P_2, and P_3 share mailbox A,
  - P_1, sends; P_2 and P_3 receive,
  - Who gets the message?
- Solutions
  - Allow a link to be associated with at most two processes.
  - Allow only one process at a time to execute a receive operation.
  - Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was.

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.

Buffering



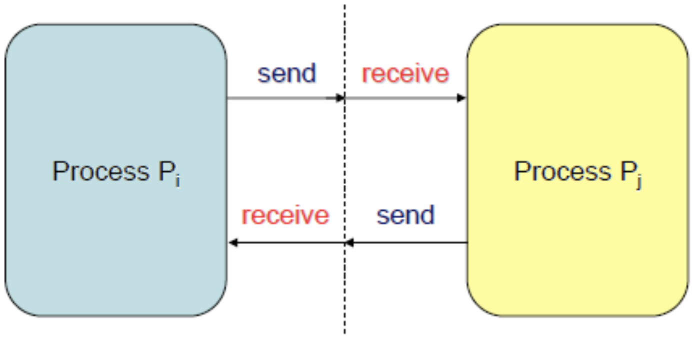
The **buffer** can have:

- zero-capacity
- bounded-capacity
- unbounded capacity

Synchronization

- *Message passing* may be either blocking or non-blocking.
- **Blocking** is considered **synchronous**:
  - **Blocking send** has the sender block until the message is received.
  - **Blocking receive** has the receiver block until a message is available.
- **Non-blocking** is considered **asynchronous**
  - **Non-blocking** send has the sender send the message and continue.
  - **Non-blocking** receive has the receiver receive a valid message or null.

Synchronization



Blocking send
Blocking receive

Non-blocking send
Non-blocking receive

Message Queues

- A Message Queue is a linked list of message structures stored inside the kernel's memory space and accessible by multiple processes
- Synchronization is provided automatically by the kernel
- New messages are added at the end of the queue
- Each message structure has a long *message type*
- Messages may be obtained from the queue either in a FIFO manner (default) or by requesting a specific *type* of message (based on *message type*)

Message Structure

- Each message structure must start with a long message type:

```
struct mymsg {
    long msg_type;
    char mytext[512]; /* rest of message */
    int somethingelse;
    ....
};
```


Message Queue Limits

- Each message queue is limited in terms of both the maximum number of messages it can contain and the maximum number of bytes it may contain
- New messages cannot be added if *either* limit is hit (new writes will normally block)
- On linux, these limits are defined as (in /usr/include/linux/msg.h):
  - MSGMAX 8192 /*total number of messages */
  - MSBMNB 16384 /* max bytes in a queue */

Creating a Message Queue

- #include <sys/types.h>
  #include <sys/ipc.h>
  #include <sys/msg.h>
  int msgget(key_t key, int msgflg);
- The key parameter is either a non-zero identifier for the queue to be created or the value IPC_PRIVATE, which guarantees that a new queue is created.
- The msgflg parameter is the read-write permissions for the queue OR'd with one of two flags:
  - IPC_CREAT will create a new queue or return an existing one
  - IPC_EXCL added will force the creation of a new queue, or return an error

Writing to a Message Queue

- int msgsnd (int msqid, const void * msg_ptr, size_t msg_size, int msgflags);

- msgqid is the id returned from the msgget call
- msg_ptr is a pointer to the message structure
- msg_size is the size of that structure
- msgflags defines what happens when no message of the appropriate type is waiting, and can be set to the following:
  - IPC_NOWAIT (non-blocking, return –1 immediately if queue is full)

Reading from a Message Queue

- int msgrcv(int msqid, const void * msg_ptr, size_t msg_size, long msgtype, int msgflags);

- msgqid is the id returned from the msgget call
- msg_ptr is a pointer to the message structure
- msg_size is the size of that structure
- msgtype is set to:

  = 0 first message available in FIFO stack

  > 0 first message on queue whose type equals type

  < 0 first message on queue whose type is the lowest value less than or equal to the absolute value of msgtype
- msgflags defines what happens when no message of the appropriate type is waiting, and can be set to the following:
  - IPC_NOWAIT (non-blocking, return –1 immediately if queue is empty)

IPC: FIFO (Names Pipes)

Pipes are limited

Pipes depend on *shared file descriptors*, shared from a parent processes forking a child process, which *inherits* the open file descriptors as part of the parent's environment for the pipe.

- Question: How do two entirely *unrelated* processes communicate via a pipe?

FIFOs: Named Pipes

- FIFOs are "named" in the sense that they have a name in the filesystem (like a file!)
- This common name is used by two separate processes to communicate over a pipe
- The command mknod can be used to create a FIFO:

```
mkfifo MYFIFO (or "mknod MYFIFO p")
ls –l
echo "hello world" >MYFIFO &
ls –l
cat <MYFIFO
```

Creating FIFOs in Code

```
#include <sys/stat.h>

int mkfifo(const char *path, mode_t mode);
```

Returns: 0 if OK, -1 otherwise

- **path** is the pathname to the FIFO to be created on the filesystem
- **mode** is a bitmask of permissions for the file, modified by the default umask
- **mkfifo** returns 0 on success, -1 on failure and sets errno (perror())
- e.g. mkfifo("MYFIFO", 0666);

Example

```
    int main(void)
{
    int      fdread, fdwrite;

    unlink(FIFO);
    if (mkfifo(FIFO, FILE_MODE) < 0)
        err_sys("mkfifo error");

    if ( (fdread = open(FIFO, O_RDONLY | O_NONBLOCK)) < 0)
        err_sys("open error for reading");
    if ( (fdwrite = open(FIFO, O_WRONLY)) < 0)
        err_sys("open error for writing");

    clr_fl(fdread, O_NONBLOCK);

    exit(0);
}
```

FIFO vs Pipe

- Pipes do not create files, FIFOs do.
- Unrelated processes can communicate through FIFOs but not through Pipes.

FIFO vs File

- A file will keep all the data until deleted/overwritten while FIFO will dump the data after it is read.

- A write to a FIFO will block if there is no corresponding process reading from the pipe, usually blocking the whole process until there's a reader.

- One can only read or write from and to the FIFO, the pointer of the current position can not be moved (lseek is unacceptable)

Summary

- Interprocess Communication
  - Message Passing
  - FIFOs

- Next Lecture: Final Review

- Read Ch.14 from Stevens
- Project-2 is due December 3rd

Acknowledgments

- Advanced Programming in the Unix Environment by R. Stevens
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