CS310 Operating Systems

Lecture 15: Inter Process Communication – Message Passing

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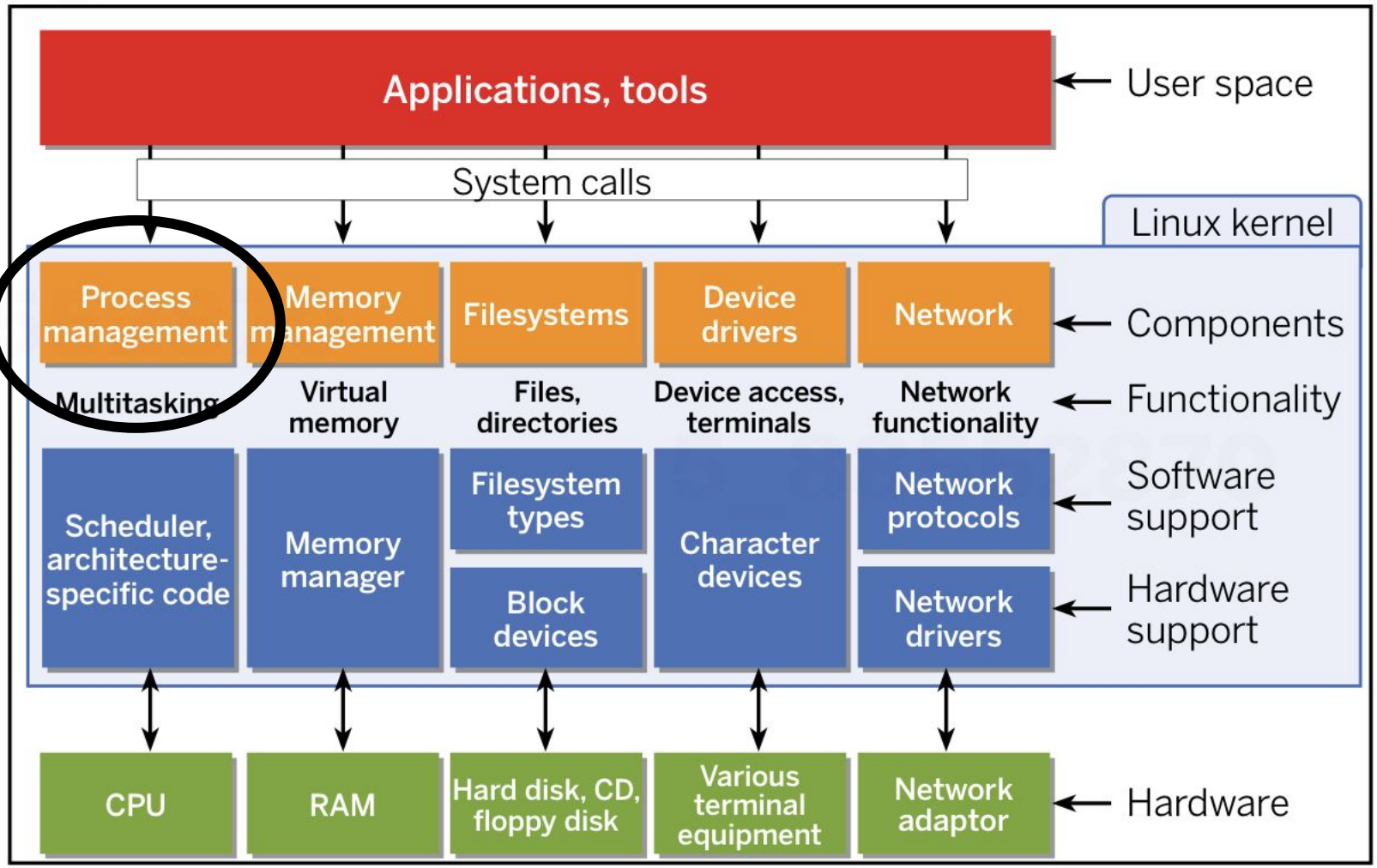
Reading

- Book: Operating Systems: Internals and Design Principles, William Stallings, Person Publishing
- Book: Operating System Concepts, 10th Edition, by Silberschatz, Galvin, and Gagne
  - Chapter 3.6
- Book: Book: Modern Operating Systems, Andrew Tenenbaum, and Herbert Bos, 4th Edition, Pearson
  - Chapter 5.6

In today's class, we will study

- Concurrent Execution of Processes – Issues
- Inter Process Communication (IPC) – Introduction
- Message Passing Concept
  - Synchronous Vs Asynchronous
  - Blocking Vs Non-blocking
  - Direct vs Indirect Communication
  - Mailboxes and Ports
  - Message Format

Were are we ?


Applications, tools
User space
System calls
Linux kernel
Process management
Memory management
Filesystems
Device drivers
Network
Components
Multitasking
Virtual memory
Files, directories
Device access, terminals
Network functionality
Functionality
Scheduler, architecture-specific code
Memory manager
Filesystem types
Block devices
Character devices
Network protocols
Network drivers
Software support
Hardware support
CPU
RAM
Hard disk, CD, floppy disk
Various terminal equipment
Network adaptor
Hardware

Concurrent Execution of Processes - Issues

Concurrent Execution of Processes / Threads

- Concurrency is inherent feature of multiprogramming, multiprocessing, distributed systems, and client-server model of computation
- Implementation of systems using concurrent Threads/Processes require
  - Communication between Processes/Threads
  - Synchronization among processes/Threads
  - Sharing of common resources

Interactions among processes

- Competing processes
  - Processes themselves do not share anything
  - However, OS has to share the system resources among these processes
    - Processes compete for system resources such as disk, file or printer.
- Cooperating processes
  - Results of one or more processes may be needed for another process, for
    - Information sharing
    - Computation Speedup
    - Modularity
    - Convenience

Process Interaction - Issues

1. What way one process can pass information to another process ?

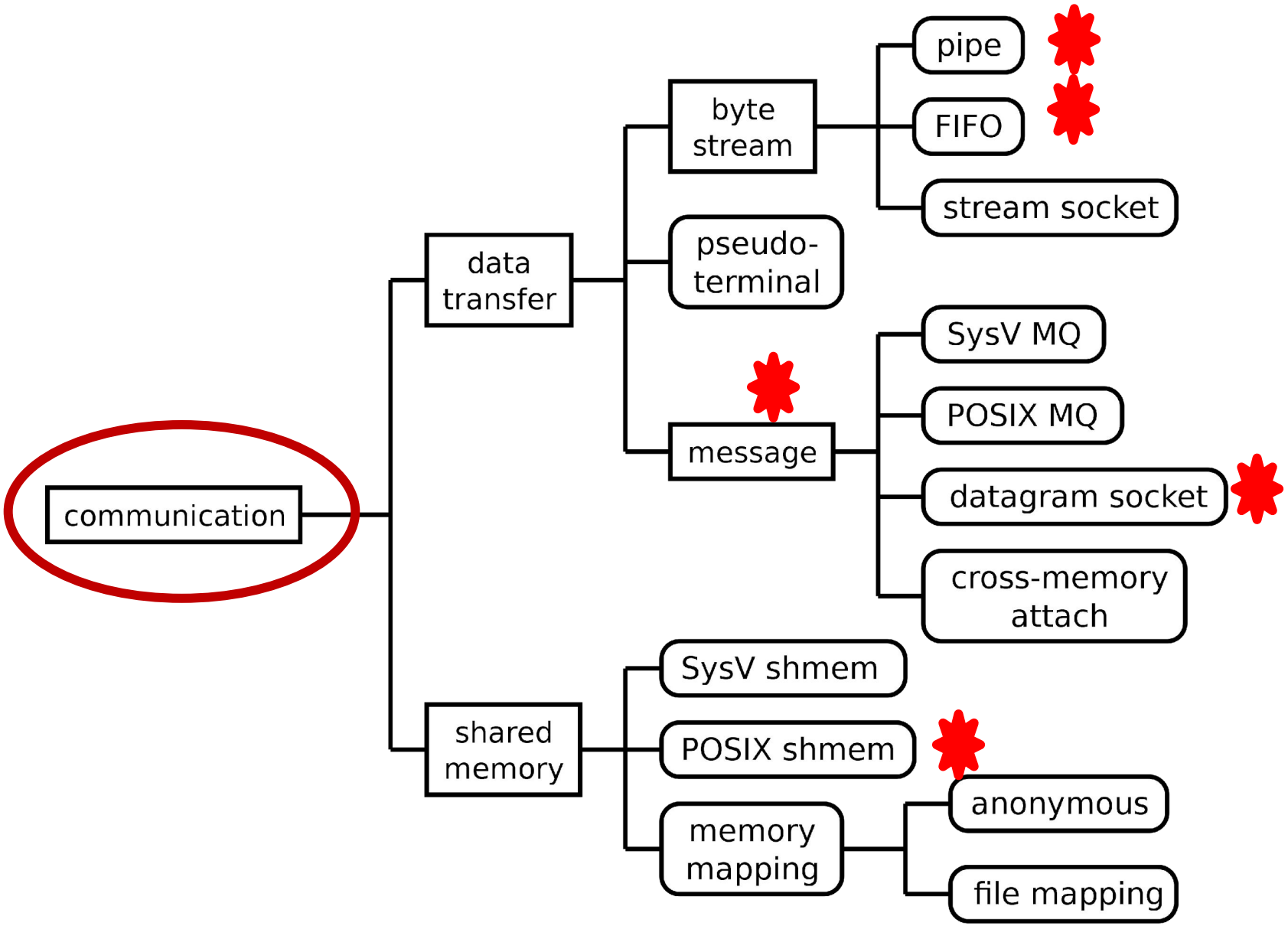
2. Two processes don't get into each other's way
   - Two competing processes in airways reservation system trying to grab the last seat
3. Need for proper sequencing when there is a dependency
   - If process A produces data that B prints, process B must wait until A has produced data

- All of the above issues are also applicable to threads
  - Though information passing is easy as threads share the same address space

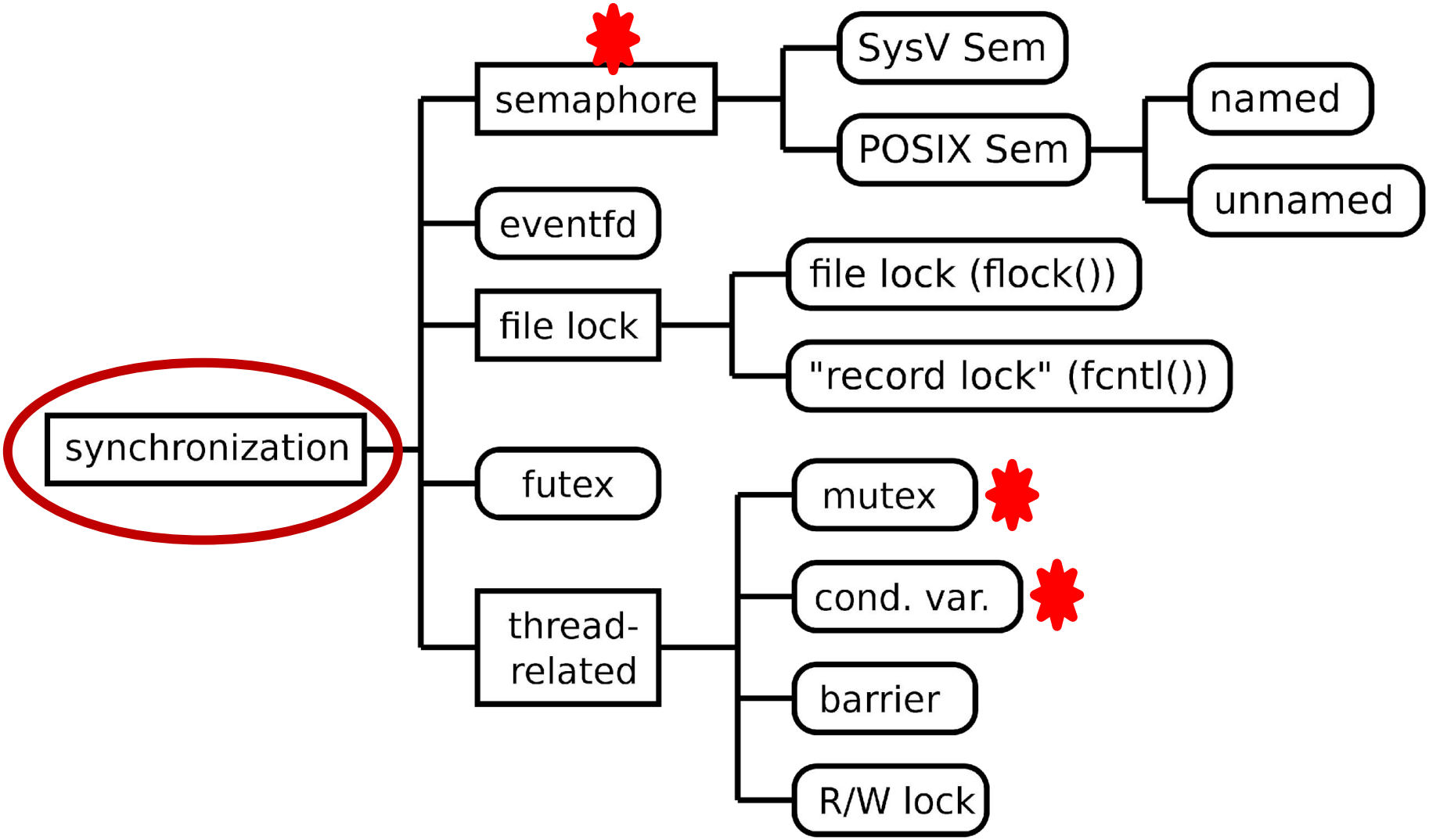
Requirements of Processes/Threads - Interaction

- Communication
  - Cooperating processes may need to exchange information
- Synchronization
  - Processes may need to be synchronized to enforce mutual exclusion

Communication (in Linux)



Synchronization (in Linux)



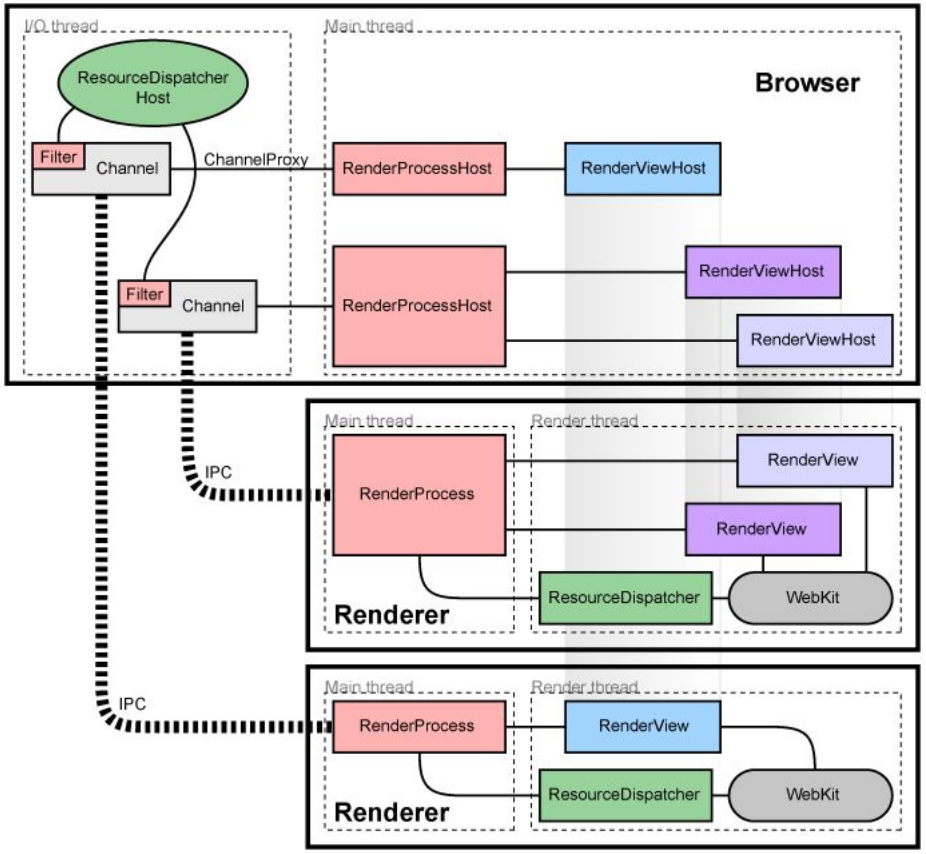
Inter-Process Communication (IPC) - Introduction

IPC Requirement

- Any use case of IPC that comes to your mind?

- Any big application?

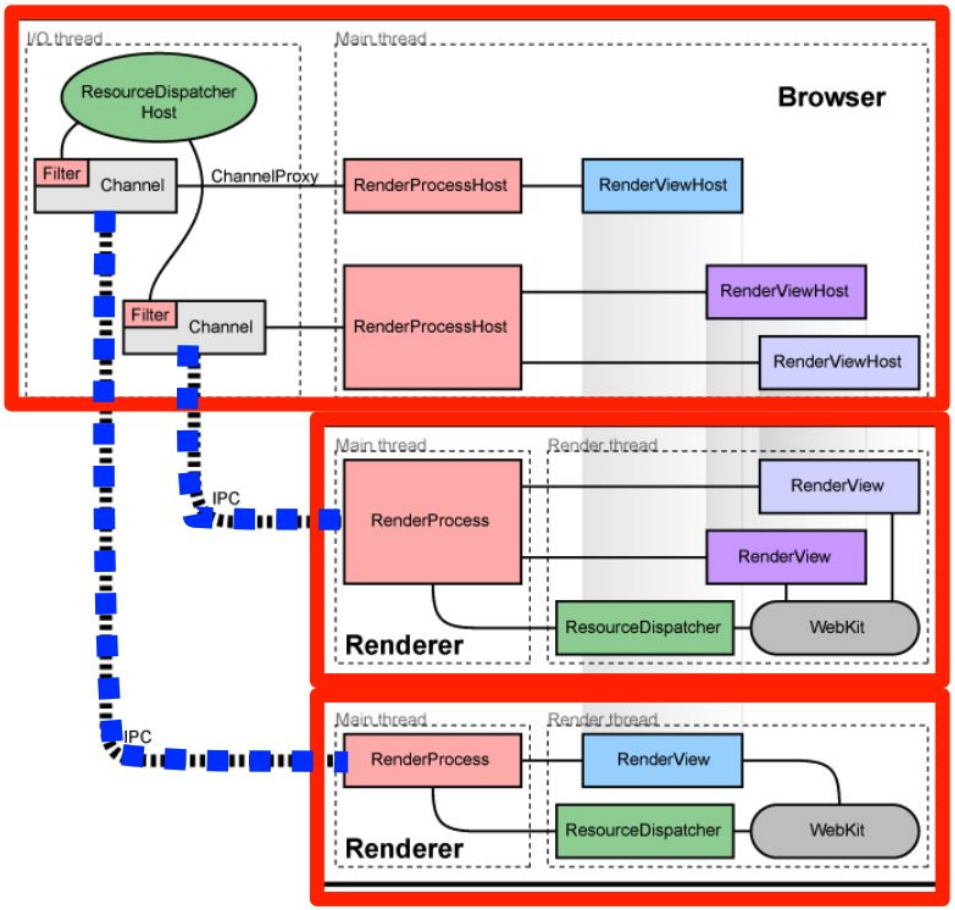
Google Chrome Architecture



- Separate processes for browser tabs to protect the overall application from bugs and glitches in the rendering engine
- Restricted access from each rendering engine process to others and to the rest of the system

https://www.chromium.org/developers/design-documents/multi-process-architecture

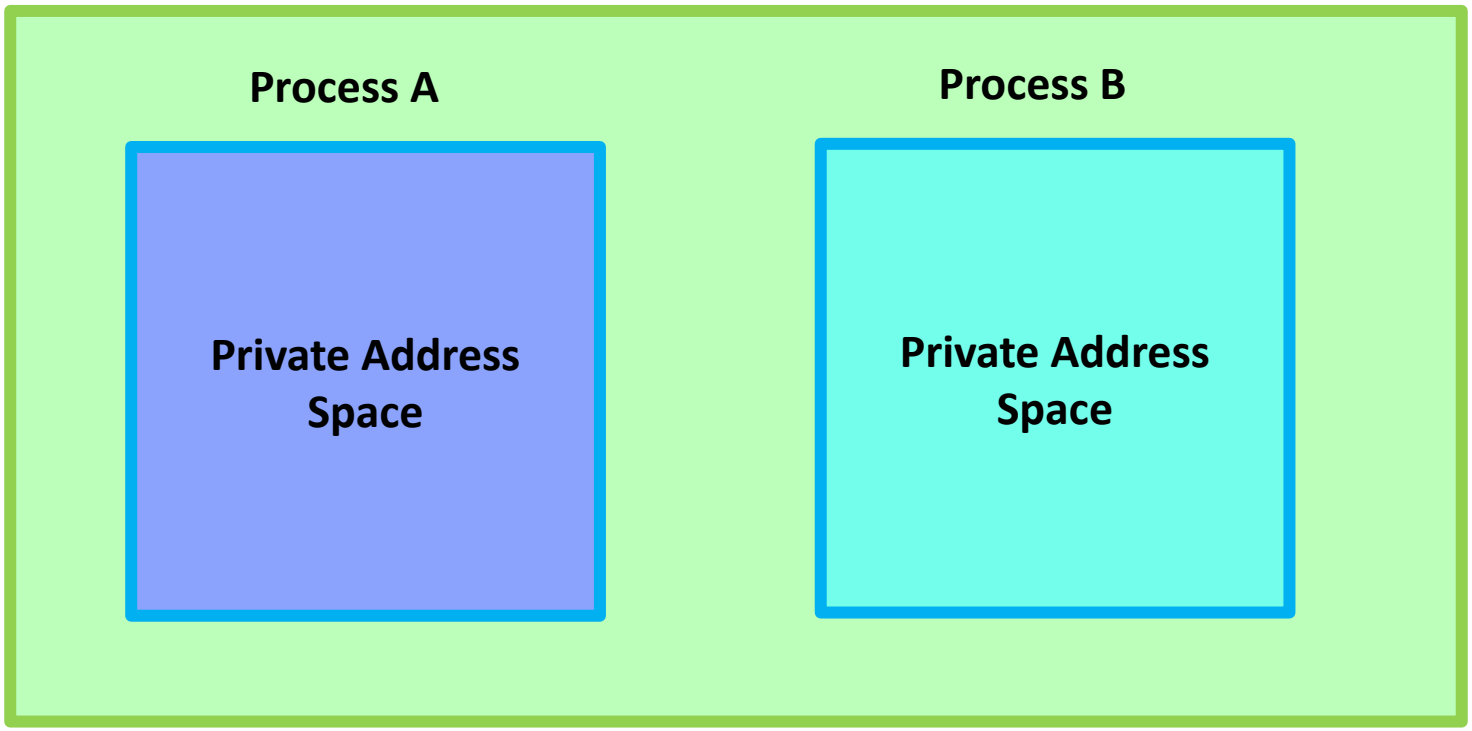
Google Chrome Architecture



- A named pipe is allocated for each renderer process for communication with the browser process
- Pipes are used in asynchronous mode to ensure that neither end is blocked waiting for the other

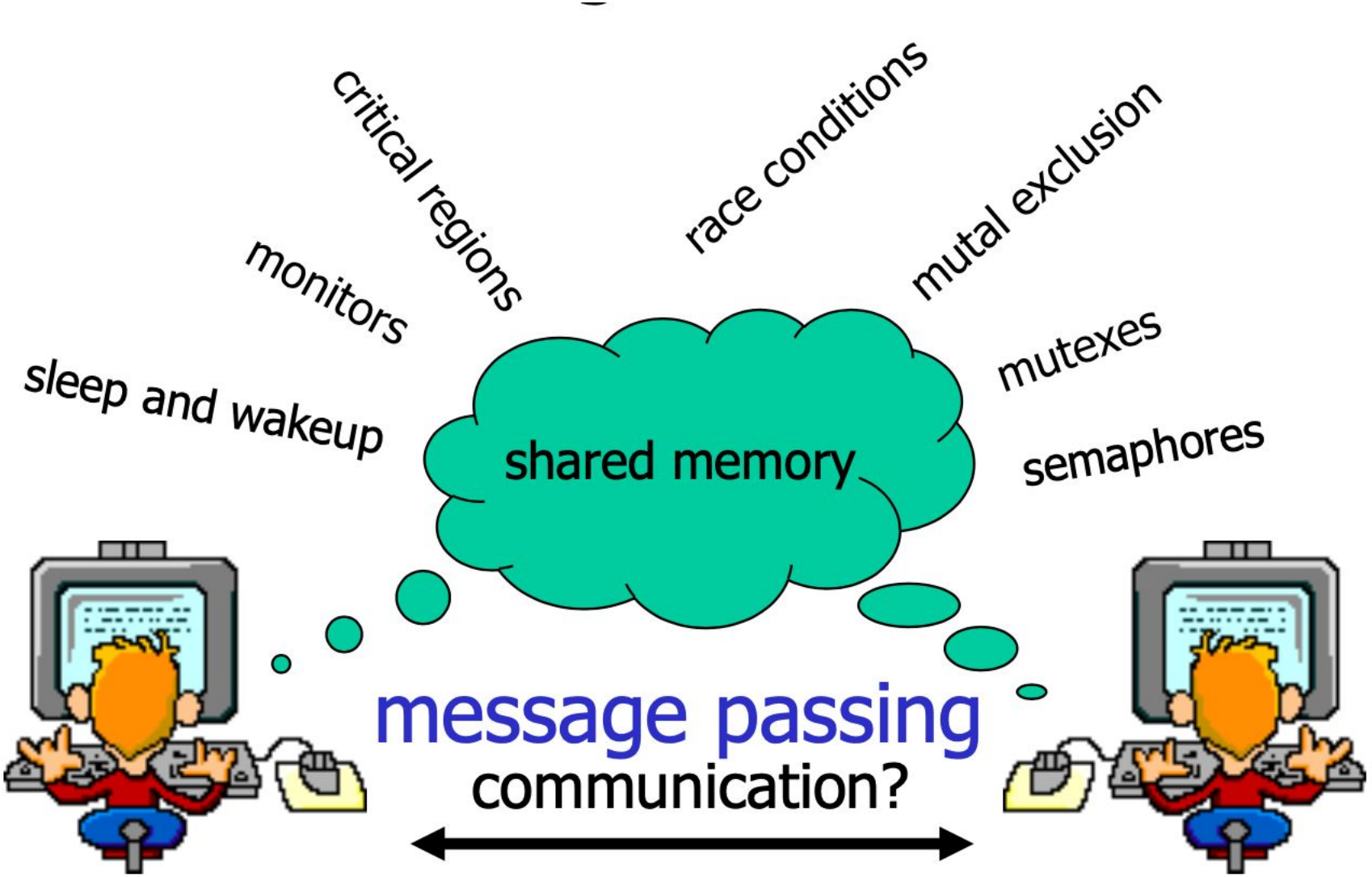
https://www.chromium.org/developers/design-documents/multi-process-architecture

IPC Communication Model

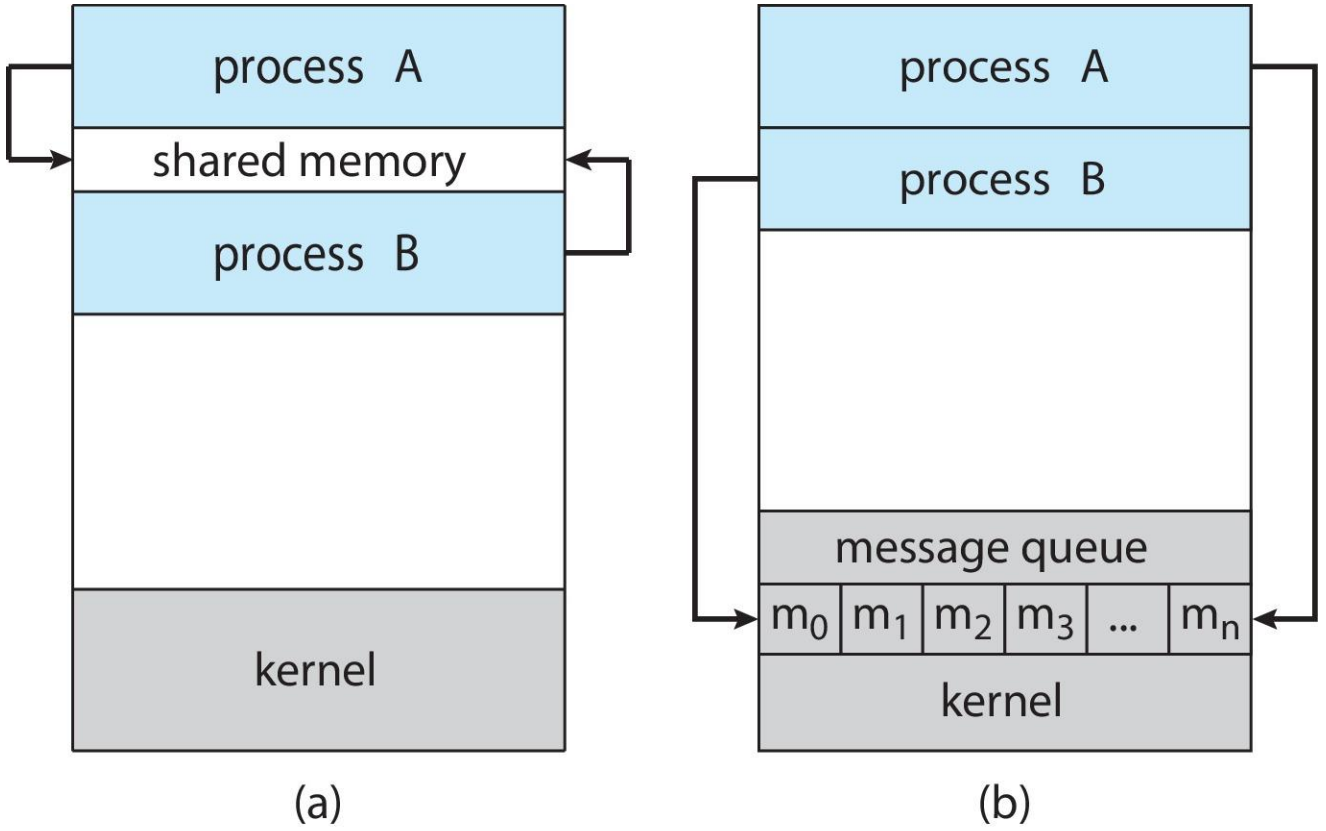


- Each process has it’s own address space
- No process can write/read from other process’s address space

IPC – Big Picture



Models of IPC: Shared Memory, Message Passing



Shared memory **Message passing.**

Message Passing - Concepts

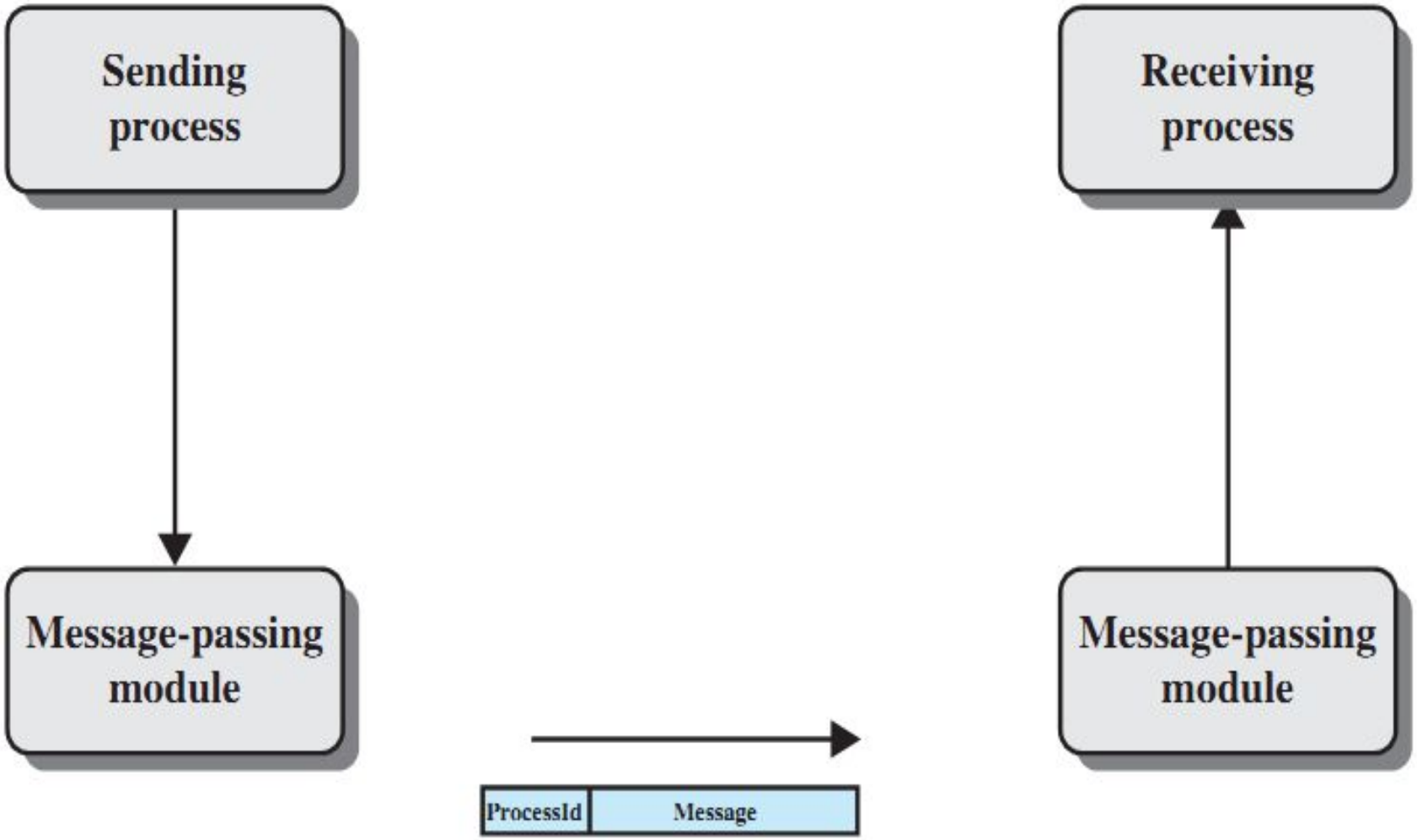
IPC: Message-Passing Systems

- No sharing of address space
- Very useful in distributed systems where the communicating processes reside on different computers connected by a network
- There are many forms of message Passing systems
  - Our focus is only in general concepts
- IPC facility provides two operations:
  - **`send`**(destination, *message*)
  - **`receive`**(source, *message*)
- A process sends information to another process (destination) in the form of message – by executing send primitive
- A process receives information by executing the receive primitive, indicating the source and the message

IPC: Message-Passing Systems: Issues

- Synchronous vs Asynchronous
- Direct vs Indirect
- 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 b-directional?

Basic Message Passing Primitives



Message Passing – Local or distributed

- In a Message passing system
  - Processes may inside the same computer
  - Processes may reside in a networked/distributed system

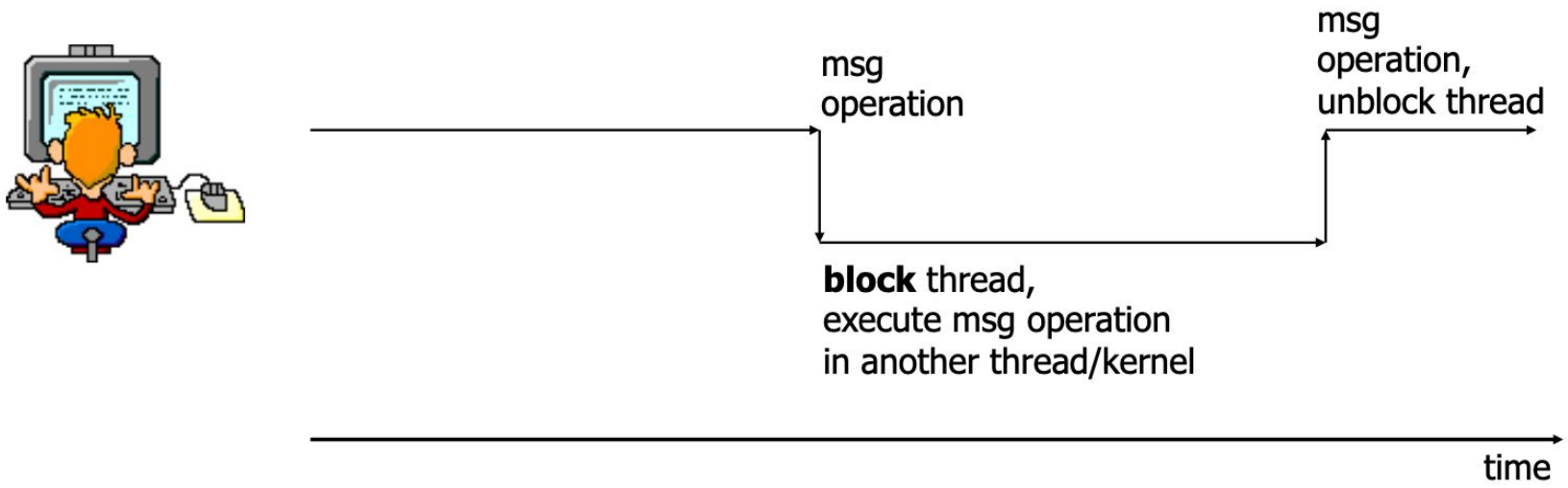
- We will later study a popular method of distributed communication
  - Remote Procedure Call (RPC)

Synchronization

- The communication of a message between two processes implies some level of synchronization between the two
- What happens to a process after it issues a send or receive primitive?
- When a send primitive is executed in a process: two possibilities
  - Sending process is blocked until the message is received
  - Sending process is Not blocked until the message is received

Blocking send and receive

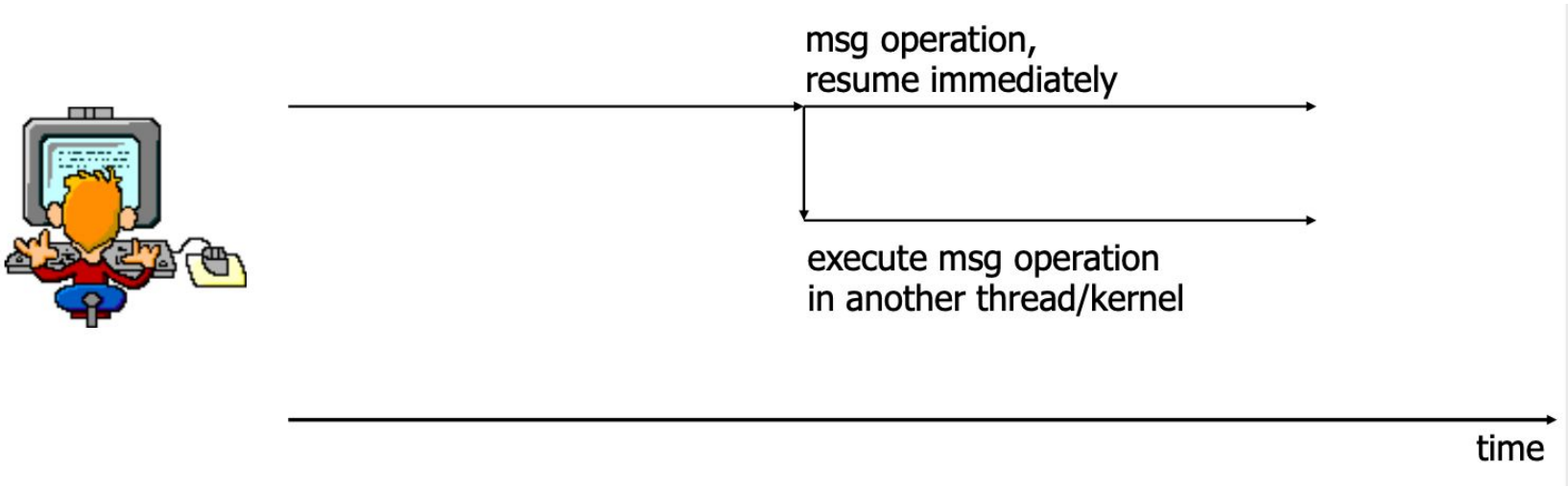
- **Blocking send** has the sender block until the message is received
- **Blocking receive** has the receiver block until a message is available



- Process/Thread is blocked until message primitive has been performed
- May be blocked for a very long time

Non-blocking send and receive

- **Non-blocking send** has the sender send the message and continue
- **Non-blocking receive** has the receiver retrieves a valid message or null



- Process /Thread gets control back immediately
- Process/Thread cannot reuse buffer for message before message is received

Blocking Vs Non-blocking Message Passing

- For the sender: it is more natural not to be blocked after issuing send:
  - can send several messages to multiple destinations
  - but sender usually expect acknowledgment of message receipt (in case receiver fails)
- For the receiver: it is more natural to be blocked after issuing receive:
  - the receiver usually needs the information before proceeding
  - but could be blocked indefinitely if sender process fails before send.

Blocking Vs Non-blocking Message Passing

There are really 3 combinations here that make sense:

1. Blocking send, Blocking receive
2. Nonblocking send, Nonblocking receive
3. Nonblocking send, Blocking receive
   - Most popular
   - Example: Server process that provides services/resources to other processes. It will need the expected information before proceeding.

Link Capacity – Buffering

- Links are associated with queues at both ends of the communication link.
- Queues are implemented with
  - Zero capacity – 0 messages
    - Sender must wait for receiver
  - Bounded capacity – finite length of n messages. At most n messages can reside in it
    - Sender must wait if link full
  - Unbounded capacity – infinite length (very large capacity)
    - Sender never waits

IPC Requirements

- If P and Q wish to communicate, they need to:
  - Establish communication link between them
  - Exchange messages via send/receive

Direct and Indirect Communication

- Direct communication (Direct Addressing):
  - When a specific process identifier is used in send primitive for source/destination i.e. the names of both the sender and the receiver are known
  - In many scenarios it is not possible to know source ahead of time. For example: connection to a print server

Indirect communication (Indirect Addressing):

- Messages are sent to or received from a shared mailbox or ports
  - Shared data structure - queues
- A mailbox can be viewed as an object into which messages can be placed by processes and from which messages can be removed
- Two processes can communicate only if they have a shared mailbox

Direct Communication

- The process that wants to communicate must explicitly name the recipient or sender of the communication
- The send() and receive() primitives are defined as:
  - `send(P, message)` : send a message to process P
  - `receive(Q, message)` : receive a message from Q
- Properties of communication link:
  - The processes need to know only each other's identity to communicate
  - A link is established automatically between every pair of processes that want to communicate
  - A link is associated with exactly one pair of communicating processes
  - Between each pair there exists exactly one link

Indirect Communication

- Messages are directed to and received from mailboxes (also referred to as ports)
  - Each mailbox has a unique id
    - Example: POSIX message queues use an integer value to identify a mailbox
  - Processes can communicate only if they share a mailbox
- A process can communicate with another process via a number of different mailboxes
- Two processes can communicate only through a shared mailbox

Indirect Communication

- Primitives:

  `send(A, message)` : send a message to mailbox A

  `receive(A, message)` : receive a message from mailbox A

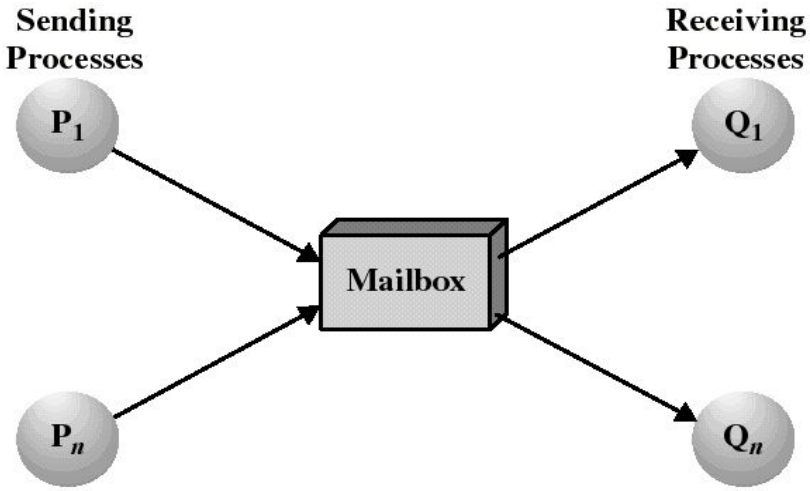
- Link established only if both processes share a common mailbox
- Each pair of processes may share several communication links
- Link may be unidirectional or bi-directional
- Operations
  - Create a new mailbox (port)
  - Send and receive messages through mailbox
  - Destroy a mailbox

Indirect Communication

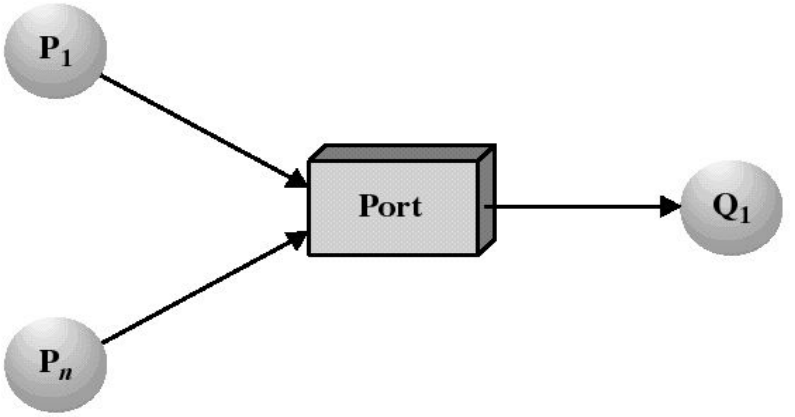
- Consider that processes P1, P2, and P3 share mailbox A
- Process P1 sends a message to A, while both P2 and P3 execute a `receive()` from A
- Who gets the message? The answer depends on which of the following methods are used?
  - Allow a link to be associated with at most two processes
  - Allow only one process at a time to execute a `receive()` operation
  - Allow the system to select arbitrarily which process will receive the message
    - Example: round robin – where processes take turns to receive messages
    - The system must notify to the sender about the receiver

Mailboxes and Ports

- A mailbox can be private to one sender/receiver pair
- A mailbox can also be shared among several senders and receivers (many – to – many)



- Port: is a mailbox associated with one receiver and multiple senders
  - used for client/server applications: the receiver is the server
  - A port is usually own and created by the receiving process
  - The port is destroyed when the receiver terminates

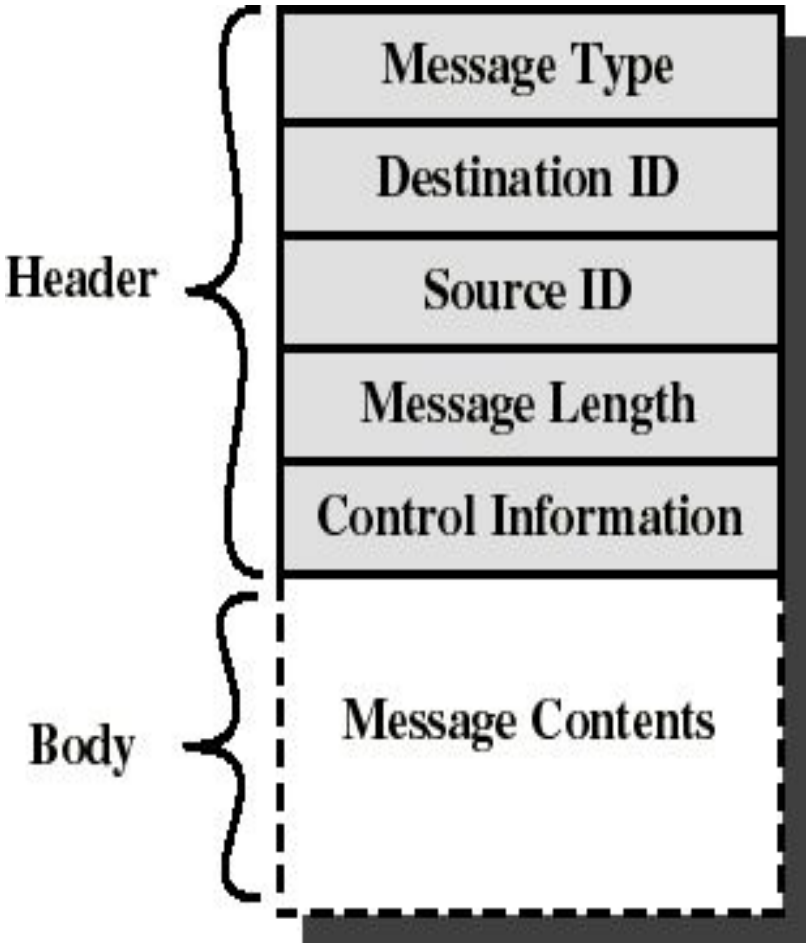


Mailboxes

- Who owns and creates mailbox ?
- Ex: If you have a mailbox in front gate of your home, it is surely owned and managed by you
- Mostly mailboxes are owned and created by the receiving process
  - Generally with the help of the OS
- Alternatively, mailboxes can be created and owned by the OS
- When a process is destroyed, the associated port is also destroyed

Message format

- Consists of header and body of message
- In Unix: no ID, only message type
- Control info:
  - what to do if run out of buffer space
  - sequence numbers
  - priority
- Queuing discipline: usually FIFO but can also include priorities.



Lecture Summary

- Two processes may communicate by exchanging messages with one another using message passing
- In the lecture we have looked in to various aspects of message passing mechanism
  - Synchronous and Asynchronous sending and receiving
  - Buffering – Zero capacity, Bounded Capacity, Unbounded Capacity
  - Direct and Indirect Communication
  - Mail boxes and Ports

Models of IPC: Shared Memory, Message Passing

Both models are commonly used in operating systems

- Shared Memory
  - Faster than message passing as message passing is implemented using system calls (generally slow)
  - System Calls are needed only to establish shared memory regions
    - Once shared memory is created, access is the same as routine memory access – thus no help from OS is required
- Message passing
  - Useful for exchanging small amount of data
  - Easier to implement in distributed systems
  - Usually implemented using system calls