03. Processes

Ch. 1.6, 3

Objectives

- To understand the concept of a process vs a program, and the need for context switching
- To distinguish the states in a process' lifecycle
- To know some of the state required for process management

Outline

- What is a process?
- Process lifecycle
- Inter-Process Communication (IPC)

Outline

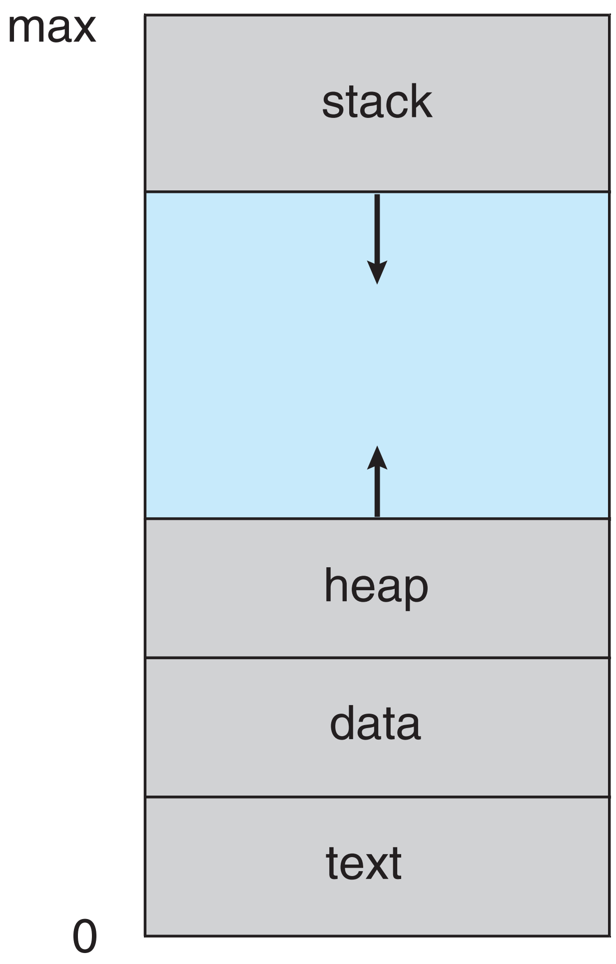
- What is a process?
  - Process Control Block (PCB)
  - Threads of execution
  - Context switching
- Process lifecycle
- Inter-Process Communication (IPC)

What is a process?

- The computer is there to execute programs, not the OS!
- Process ≠ Program
  - A **program** is static, on-disk
  - A **process** is dynamic, a program in execution
  - On a batch system, one might refer to jobs instead of processes – nowadays generally used interchangeably
- Process is the **unit of protection** and **resource allocation**
  - So you may have multiple running processes created from a single program

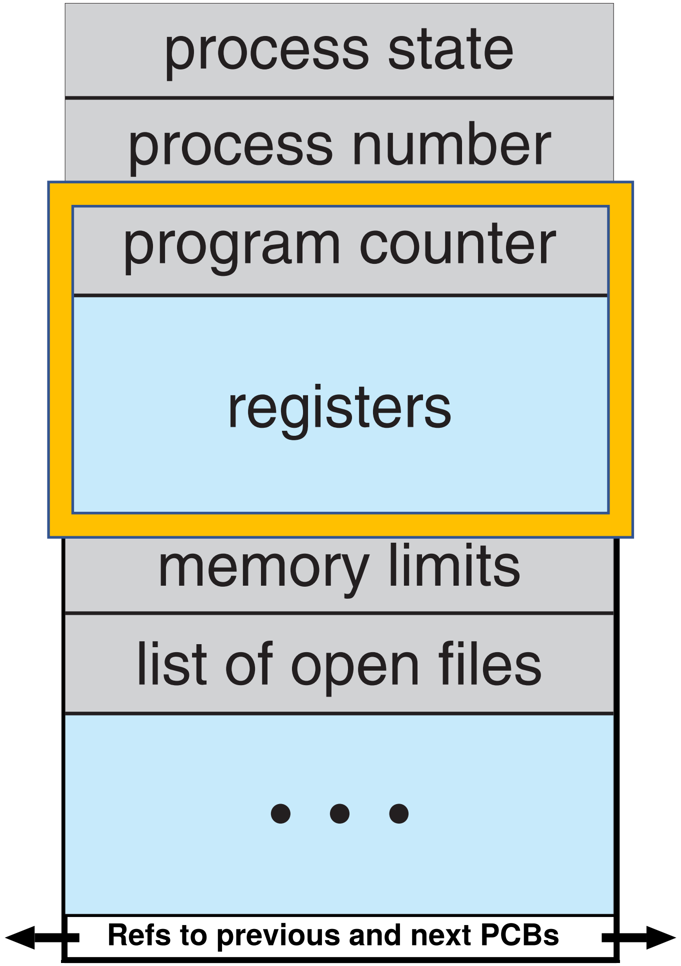
What is a process?

- Each process executed on a virtual processor has
  - **Text** containing the program code
  - **Data** containing global variables
  - **Heap** containing memory allocating during runtime
  - …plus one or more **threads of execution**
- Each thread has
  - **Program counter** indicating current instruction
  - **Stack** for temporary variables, parameters, return addresses, etc.



Process Control Block (PCB)

- Data structure representing a process, containing
  - **Process ID** or **number** – uniquely identifies the process
  - **Current process state** – running, waiting, etc
  - **CPU scheduling information** – priorities, scheduling queue pointers
  - **Memory-management information** – memory allocated to the process
  - **Accounting information** – CPU used, clock time elapsed since start, time limits
  - **I/O status information** – I/O devices allocated to process, list of open files
- Highlighted **process context** is the machine environment while the process is running
  - **Program counter**, location of next instruction to execute
  - **CPU registers**, contents of all process-centric registers

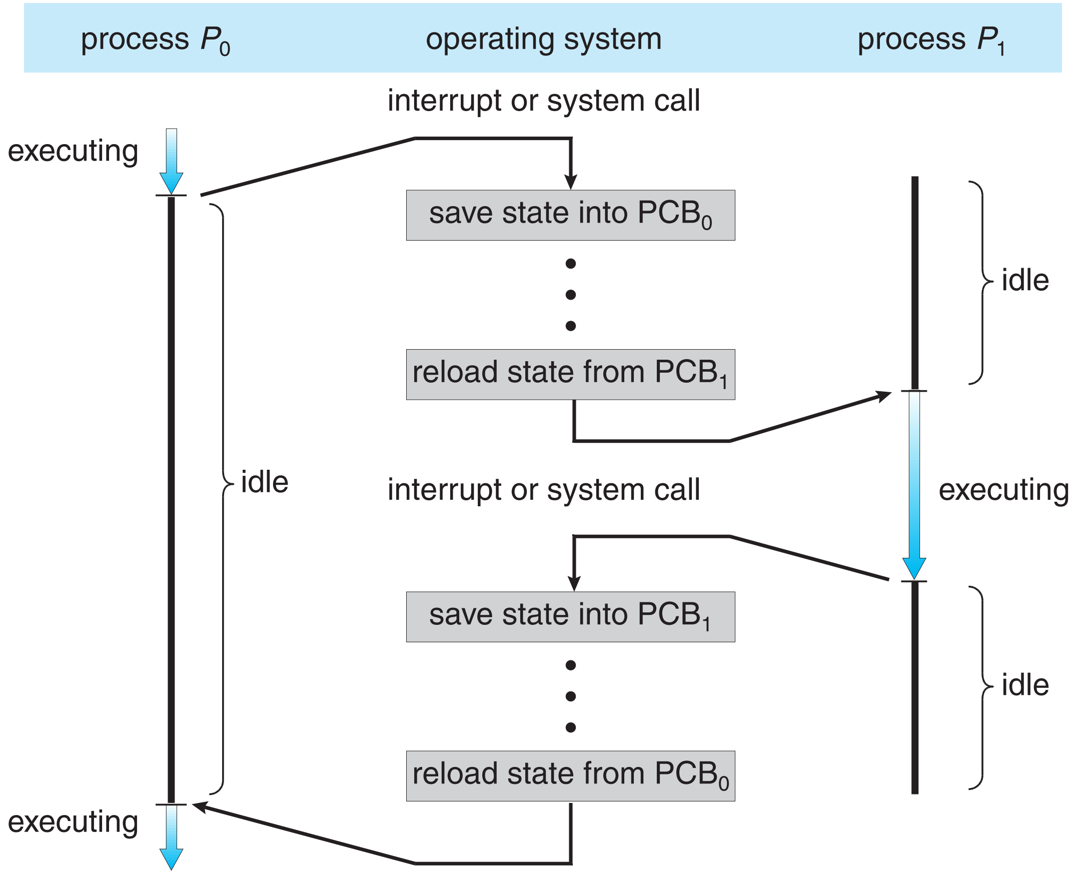


Threads of execution

- A **thread** represents an individual execution context
  - One process may have many threads
  - OS visible threads are **kernel threads**, whether executing in kernel or user space
- Each thread has an associated **Thread Control Block** (TCB)
  - Contains thread metadata: saved context (registers, including stack pointer), scheduler info, program counter, etc.
- A scheduler determines which thread to run
  - Changing the running thread involves a **context switch**
  - If between threads in different processes, the process state also switches

Context switching

- Switching between processes means
  - Saving the context of the currently executing process (if any), and
  - Restoring the context of the process being resumed
- Wasted time! No useful work is carried out while switching
- How much time depends on hardware support
  - From nothing, to
  - Save/load multiple registers to/from memory, to
  - Complete hardware “task switch”

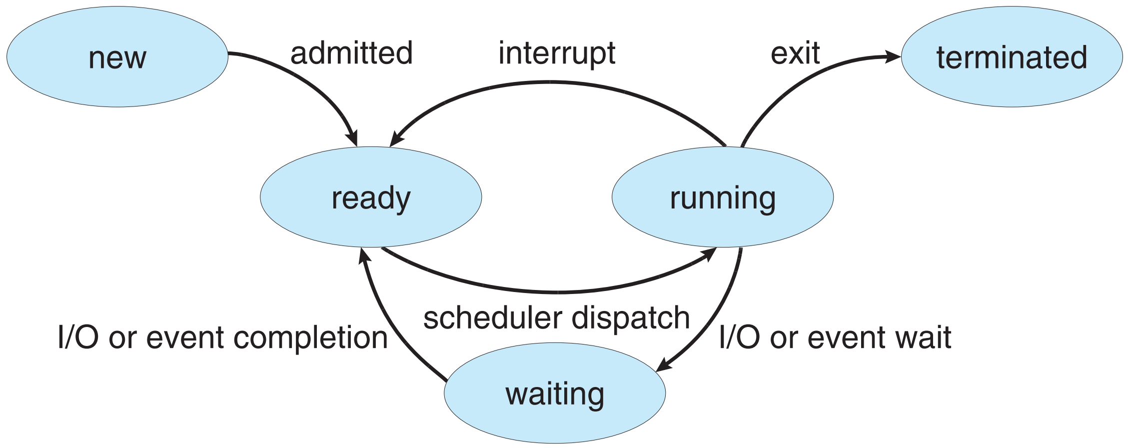


Outline

- What is a process?
- Process lifecycle
    - Process states
    - Process creation
    - Process termination
- Inter-Process Communication (IPC)

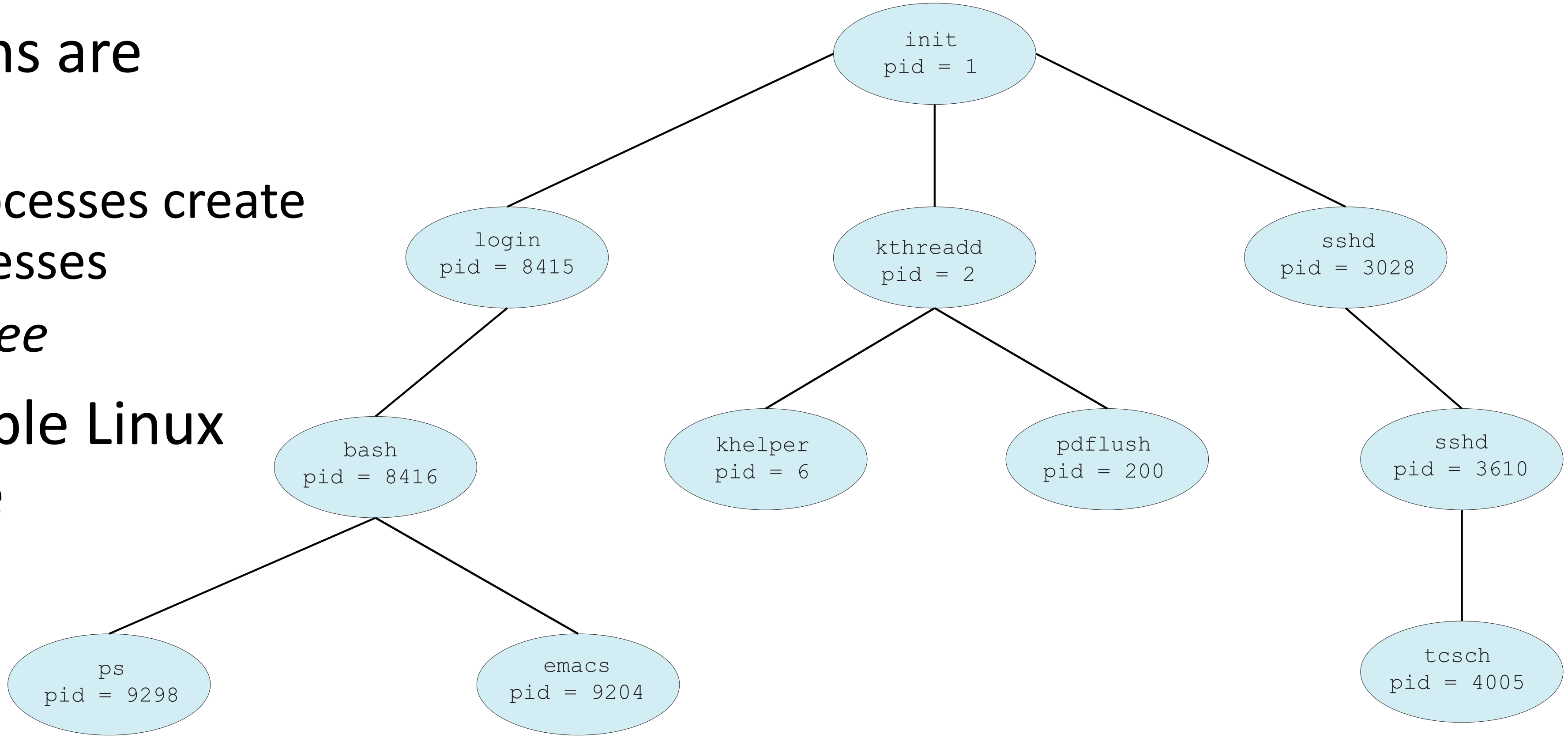
Process states

- **New**: process is being created
- **Ready**: process is ready to run, and is waiting for the CPU
- **Running**: process' instructions are being executed on the CPU
- **Waiting (Blocked)**: process has stopped executing, and is waiting for an event to occur
- **Terminated (Exit)**: process has finished executing



Process creation

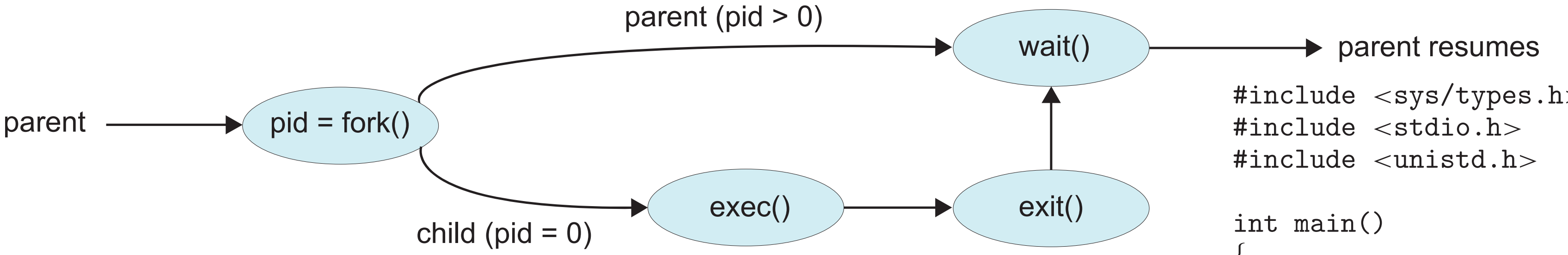
- Most systems are hierarchical
  - Parent processes create child processes
  - Forms a *tree*
- E.g., a possible Linux process tree



Process creation

- How are resources shared?
    1. Parent and children share all resources
    2. Children share subset of parent's resources
    3. Parent and child share no resources
- How is the child's memory initialised?
    1. Child starts with a duplicate of the parent and then modifies it
    2. Child explicitly has a program loaded into it
- How is execution of parent and children handled?
    1. Parent and children execute concurrently
    2. Parent waits until children terminate

Process creation



- E.g., on Unix
  - *fork* clones a child process from parent,
  - then *execve* replaces child's memory space with a new program,
  - meanwhile parent *waits* until child *exits*
- Alternative approach in NT/2K/XP
  - *CreateProcess* explicitly includes name of program to be executed

```
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

int main()
{
pid_t pid;

   /* fork a child process */
   pid = fork();

   if (pid < 0) { /* error occurred */
     fprintf(stderr, "Fork Failed");
     return 1;
   }
   else if (pid == 0) { /* child process */
     execlp("/bin/ls","ls",NULL);
   }
   else { /* parent process */
     /* parent will wait for the child to complete */
     wait(NULL);
     printf("Child Complete");
   }

   return 0;
}
```

Process termination

1. Process performs an illegal operation, e.g.,
   - Makes an attempt to access memory without authorisation
   - Attempts to execute a privileged instruction
2. Parent terminates child (*abort*, *kill*), e.g. because
   - Child has exceeded allocated resources
   - Task assigned to child is no longer required
   - **Cascading termination** – parent is exiting and OS requires children must also exit
3. Process executes last statement and asks the OS to delete it (*exit*)
   - Parent *waits* and obtains status data from child
   - If parent didn't wait, process is a **zombie**
   - If parent terminated without waiting, process is an **orphan**

Outline

- What is a process?
- Process lifecycle
- Inter-Process Communication (IPC)
  - Message passing vs Shared memory
  - Signals
  - Pipes
  - Shared memory segments

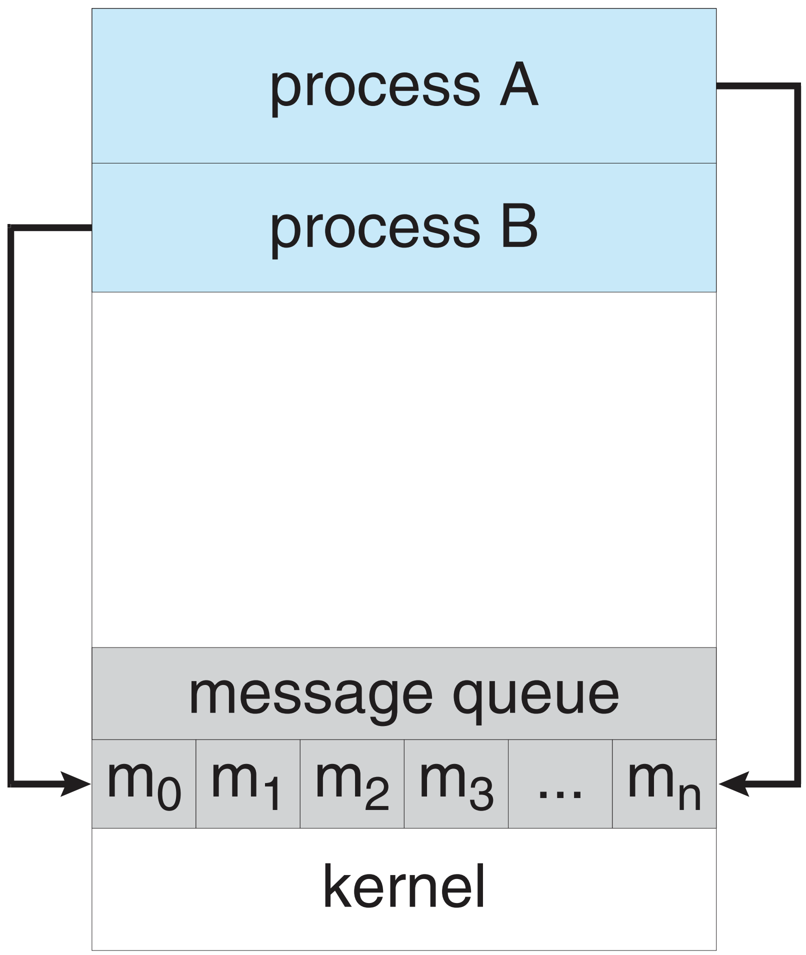
Inter-Process Communication (IPC)

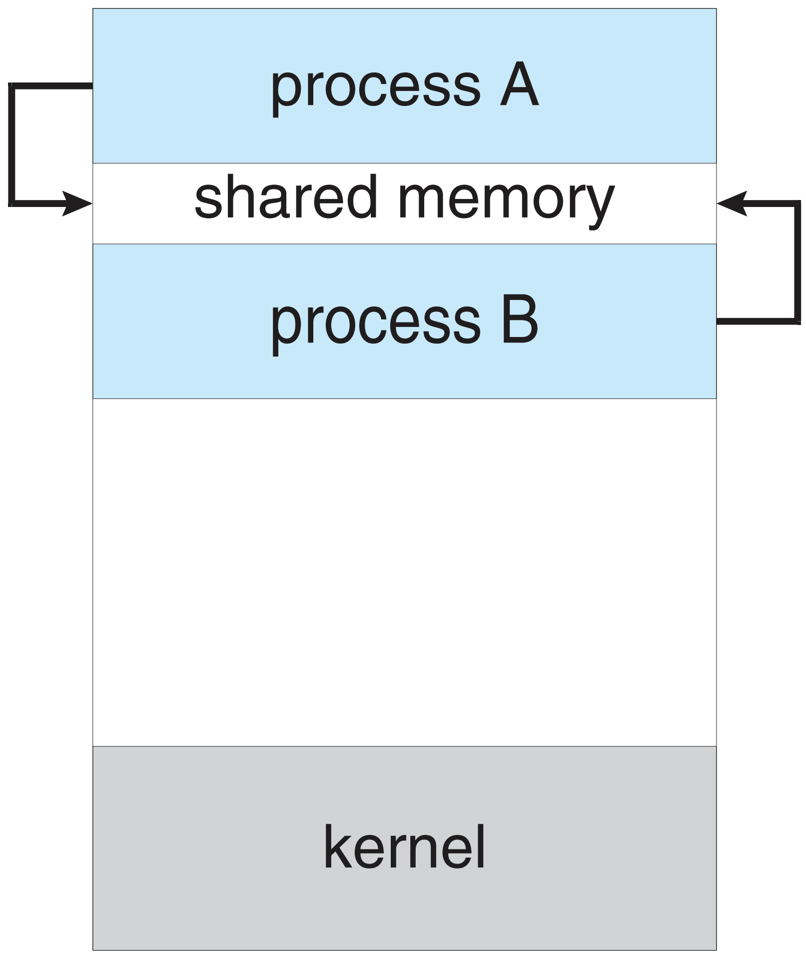
- All communications require some protocol, with data transfer
  - …in a commonly-understood format (**syntax**)
  - …having mutually-agreed meaning (**semantics**)
  - …taking place according to agree rules (**synchronisation**)
  - (Ignore problems of discovery, identification, errors, etc. for now)
- Communication between hosts is IB Computer Networking
  - Separate hosts means handling reliability and asynchrony
- Communication between threads is IB Concurrent & Distributed Systems
  - Shared data structures can suffer corruption, deadlock, etc.
- IPC basic requirement: access to shared memory on same host

Message passing vs Shared memory

- Two fundamental models for IPC
- **Shared memory**
  - Communicating processes establish some part of memory both can access
  - Requires removing usual restriction that processes have memory protection
- **Message passing**
  - Processes send messages to each other mediated by the kernel
  - Requires support for processes to
    - name each other or a shared mailbox (direct vs indirect communication)
    - send and receive synchronously or asynchronously (blocking vs non-blocking)
    - buffer messages to match rates if non-blocking (zero, finite, unbounded buffers)

Message passing vs Shared memory



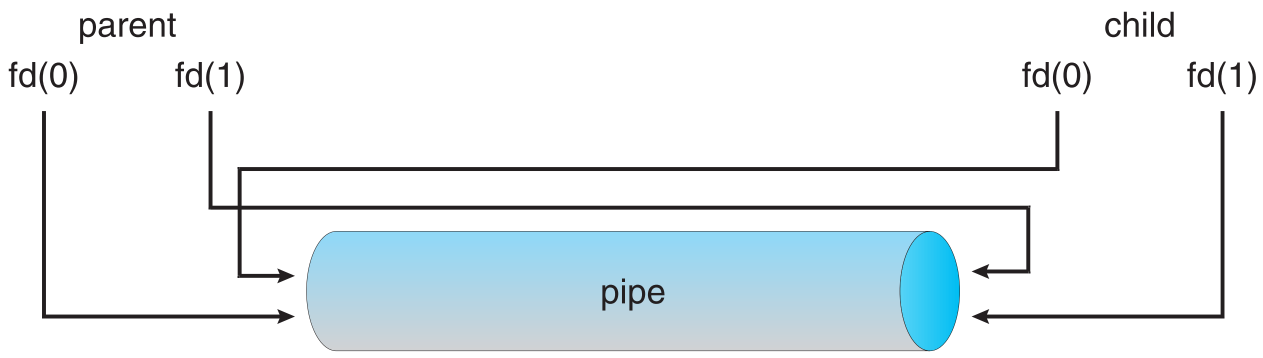


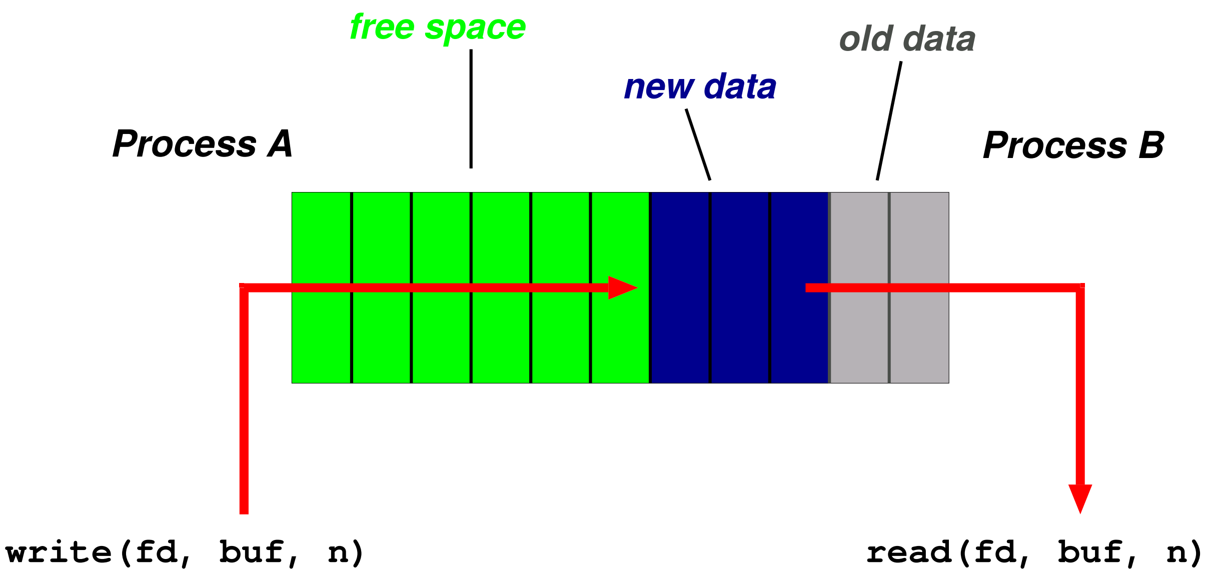
Signals

- Simple message passing: asynchronous notifications on another process
  - *kill* system call sends a signal to a specified process/es
  - *sigaction* examines or changes a **signal handler** disposition (terminate, ignore, etc)
  - *pause* suspends process until signal is caught
- Each signal mapped to an integer, different between architectures
  - https://www.man7.org/linux/man-pages/man7/signal.7.html
- Among the more commonly encountered:
  - SIGHUP: hangup detected on terminal / death of controlling process (1)
  - SIGINT: terminal interrupt (2)
  - SIGILL: illegal instruction (4)
  - SIGKILL: terminate the process [cannot be caught or ignored] (9)
  - SIGTERM: politely terminate process (15)
  - SIGSEGV: segmentation fault (11) — process made an invalid memory reference
  - SIGUSR1/2: two user defined signals [system defined numbers]

Pipes

- Simple form of shared memory IPC
  - *pipe* returns a pair of file descriptors, (fd[0], fd[1])
  - *fork* creates child process
- Parent and child can now communicate
  - *read*/*write* on the pair of (read, write) fds
- **Named pipes** (**FIFOs**) extend beyond parent/child relation
  - Appear as files in the filesystem





Shared memory segments

- Obtain a segment of memory shared between two (or more) processes
  - *shmget* to get a segment
  - *shmat* to attach to it
- Simply read and write via pointers into the shared memory segment
  - Need to impose controls to avoid collisions when simultaneously reading and writing
- When finished,
  - *shmdt* to detach, and
  - *shmctl* to destroy once you know no-one still using it

Summary

- What is a process?
  - Process Control Block (PCB)
  - Threads of execution
  - Context switching
- Process lifecycle
  - Process states
  - Process creation
  - Process termination
- Inter-Process Communication (IPC)
  - Message passing vs Shared memory
  - Signals
  - Pipes
  - Shared memory segments