CSCI 6730 / 4730
Operating Systems

Processes

Review

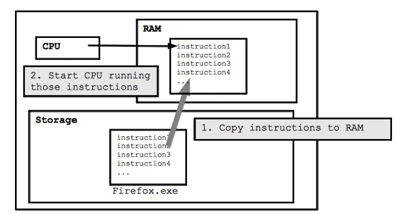
- Operating System Fundamentals
  - » What is an OS?
  - » What does it do?
  - » How and when is it invoked?
- Structures
  - » Monolithic
  - » Layered
  - » Microkernels
  - » Virtual Machines
  - » Modular

Chapter 3: Processes: Outline

- Process Concept: views of a process
- Process Basics Scheduling Principles
- Operations on Processes
  - » Life of a process: from birth to death …
- Cooperating Processes (Thursday)
  - » Inter process Communication
    - – Mailboxes
    - – Shared Memory
    - – Sockets

What is a Process?

- A program in execution
- An activity
- A *running* program.
  - » Basic unit of work on a computer, a job, or a task.
  - » A container of instructions with some resources:
    - – e.g. CPU time (CPU carries out the instructions), memory, files, I/O devices to accomplish its task

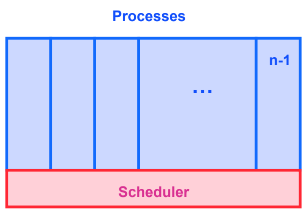


Examples: compilation process, word processing process, scheduler (sched, swapper) process or daemon processes: ftpd, http

What are Processes?

System View:

- Multiple processes:
  - » Several distinct processes can execute the SAME program
- Time sharing systems run several processes by multiplexing between them
- ALL “runnables” including the OS are organized into a number of “sequential processes”

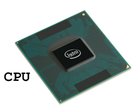


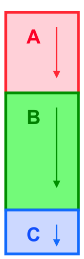
Process Definition

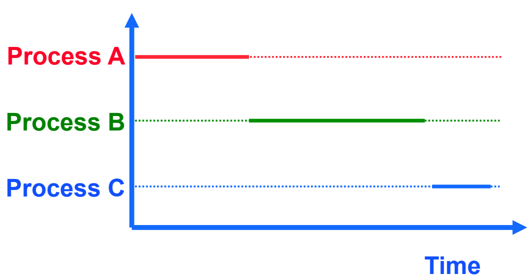
*A process is a ‘program in execution’, a sequential execution characterized by trace. It has a **context** (the information or data) and this ‘context’ is maintained as the process progresses through the system.*

Activity of a Process

1 CPU



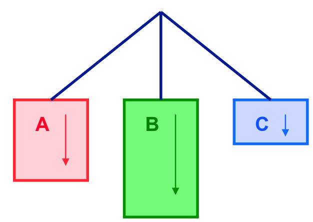


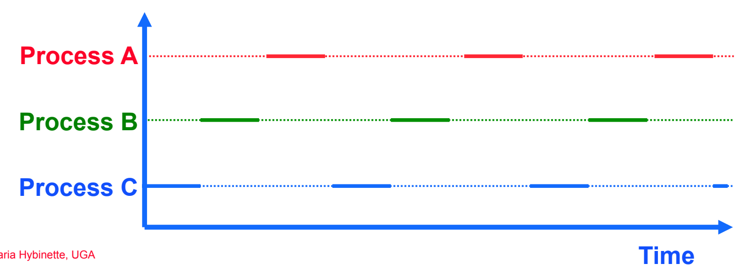


Multiprogramming:

- Solution: provide a programming counter.
- One processor (CPU).

Activity of a Process: Time Sharing



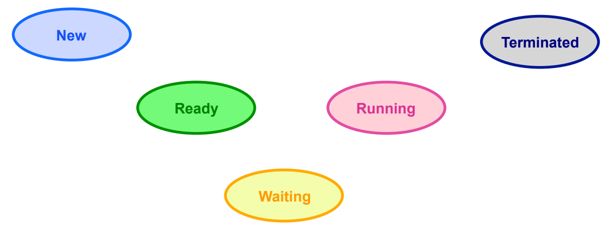


What Does the Process Do?

- Created
- Runs
- Does not run (but ready to run)
- Runs
- Does not run (but ready to run)
- ….
- Terminates

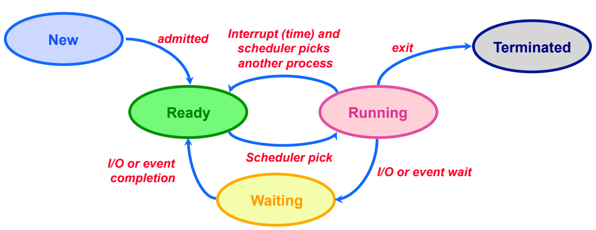
‘States’ of a Process

- As a process executes, it changes *state*
  - » New: The process is being created.
  - » Running: Instructions are being executed.
  - » Ready: The process is waiting to be assigned to a processor (CPU).
  - » Terminated: The process has finished execution.
  - » Waiting: The process is waiting for some event to occur.



State Transitions

- A process may change state as a result:
  - » Program action (system call)
  - » OS action (scheduling decision)
  - » External action (interrupts)



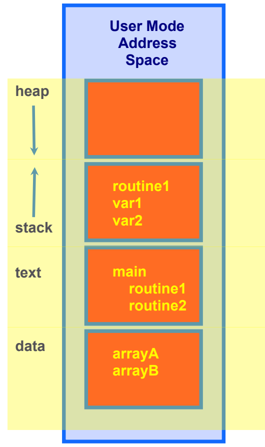
OS Designer’s Questions?

- How is process state represented?
  - » What information is needed to represent a process?
- How are processes selected to transition between states?
- What mechanism is needed for a process to run on the CPU?

What Makes up a Process?

User resources/OS Resources:

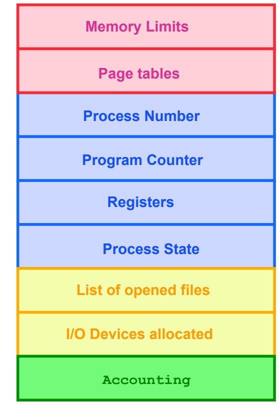
- Program code (text)
- Data
  - » global variables
  - » heap (dynamically allocated memory)
- Process stack
  - » function parameters
  - » return addresses
  - » local variables and functions
- OS Resources, environment
  - » open files, sockets
  - » Credential for security
- Registers
  - » program counter, stack pointer



address space are the shared resources of a(ll) thread(s) in a program

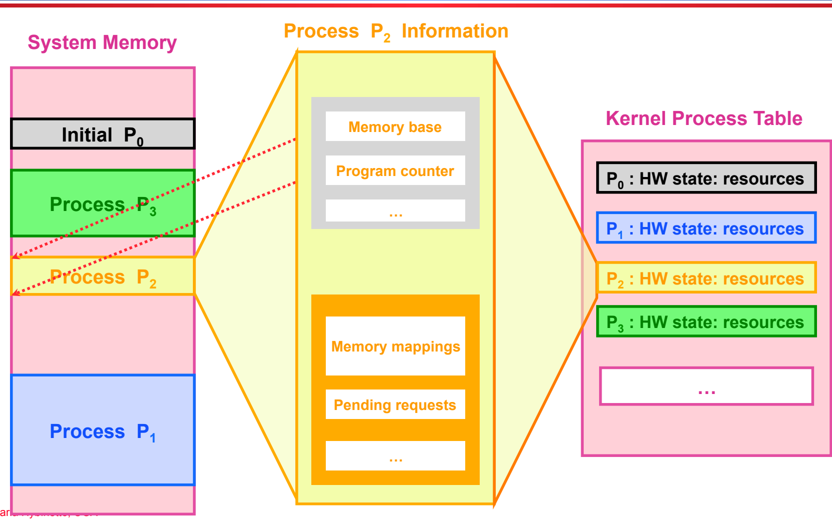
What is needed to keep track of a Process?

- **Memory information**:
  - » Pointer to memory segments needed to run a process, i.e., pointers to the address space -- text, data, stack segments.
- **Process management information**:
  - » Process state, ID
  - » Content of registers:
    - – Program counter, stack pointer, process state, priority, process ID, CPU time used
- **File management & I/O information**:
  - » Working directory, file descriptors open, I/O devices allocated
- **Accounting**: amount of CPU used.



Process control Block (PCB)

Process Representation



OS View: Process Control Block (PCB)

- How does an OS keep track of the state of a process?
  - » Keep track of 'some information' in a structure.
    - – Example: In Linux a process' information is kept in a structure called `struct task_struct` declared in `#include linux/sched.h`
    - – What is in the structure?

```
struct task_struct
   pid_t pid;                   /* process identifier */
   long state;                  /* state for the process */
   unsigned int time_slice      /* scheduling information */
   struct mm_struct *mm         /* address space of this process */
```

- – Where is it defined:
  - not in /usr/include/linux – only user level code
  - /usr/src/kernels/2.6.32-642.3.1.el6.x86_64/include/linux
    - » (on nike).

State in Linux

```
volatile long state;    /* -1 unrunnable, 0 runnable, >0 stopped */

#define TASK_RUNNING            0
#define TASK_INTERRUPTIBLE      1
#define TASK_UNINTERRUPTIBLE    2
#define TASK_ZOMBIE             4
#define TASK_STOPPED            8
#define TASK_EXCLUSIVE          32
```

• traditionally 'zombies' are child processes of parents that have not processed a wait() instruction.

• Note: processes that have been 'adopted' by init are not zombies (these are children of parents that terminates before the child). Init automatically calls wait() on these children when they terminate.

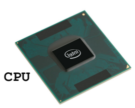
• this is true in LINUX.
• What to do: 1) Kill the parent 2) Fix the parent (make it issue a wait) 2) Don't care

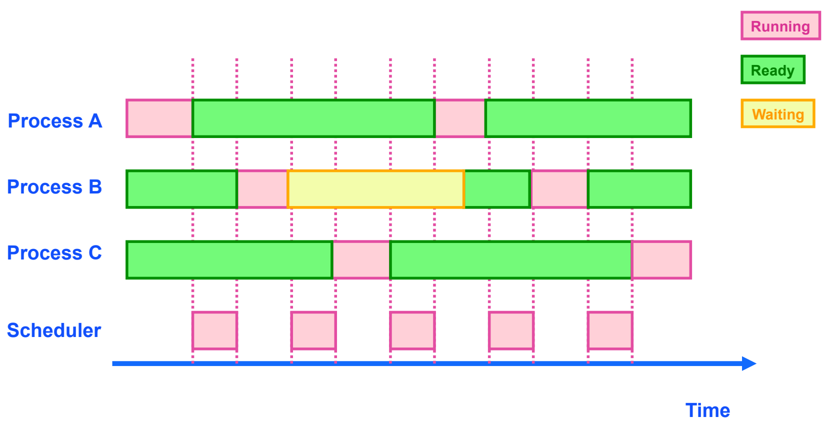
Process Table in Microkernel (e.g., MINIX)

- Microkernel design - process table functionality (monolithic) partitioned into four tables:
  - » Kernel management (kernel/proc.h)
  - » Memory management (VM server vm/vmproc.h)
    - – Memory part of fork, exit etc calls
    - – Used/unused part of memory
  - » File management (FS) (FS server fs/fproc.h
  - » Process management (PM server pm/mproc.h)

Running Processes

1 CPU





Why is Scheduling important?

- Goals:
  - » Maximize the 'usage' of the computer system
  - » Maximize CPU usage (utilization)
  - » Maximize I/O device usage
  - » Meet as many task deadlines as possible (maximize throughput).

HERE

Scheduling

- Approach: Divide up scheduling into task levels:
  - » Select process who gets the CPU (from main memory).
  - » Admit processes into memory
    - – Sub problem: How?
- Short-term scheduler (CPU scheduler):
  - » selects which process should be executed next and allocates CPU.
  - » invoked frequently (ms) ⇒ (must be fast).
- Long-term scheduler (look at first):
  - » selects which processes should be brought into the memory (and into the ready state)
  - » invoked infrequently (seconds, minutes)
  - » controls the *degree of multiprogramming.*

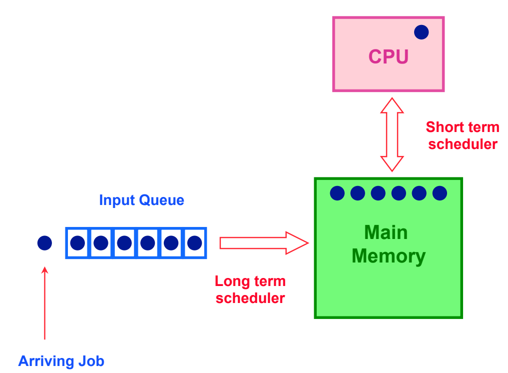
Process Characteristics

- **Processes can be described as either:**
  - » **I/O-bound process – spends more time doing I/O than computations, many short CPU bursts.**
  - » **CPU-bound process – spends more time doing computations; few very long CPU bursts.**

Observations

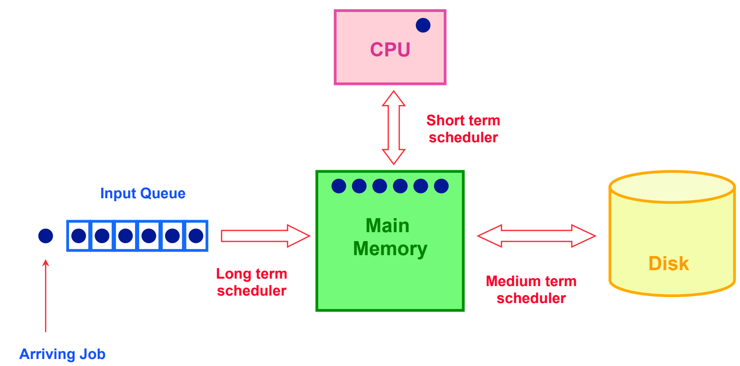
- If all processes are I/O bound, the ready queue will almost always be empty (little scheduling)
- If all processes are CPU bound the I/O devices are underutilized
- Approach (long term scheduler): 'Admit' a good mix of CPU bound and I/O bound processes.

Big Picture (so far)



Exhaust Memory?

- **Problem:** What happens when the number of processes is so large that there is not enough room for all of them in memory?
- **Solution:** Medium-level scheduler:
  - » Introduce another level of scheduling that removes processes from memory; at some later time, the process can be reintroduced into memory and its execution can be continued where it left off
  - » Also affect degree of multi-programming.

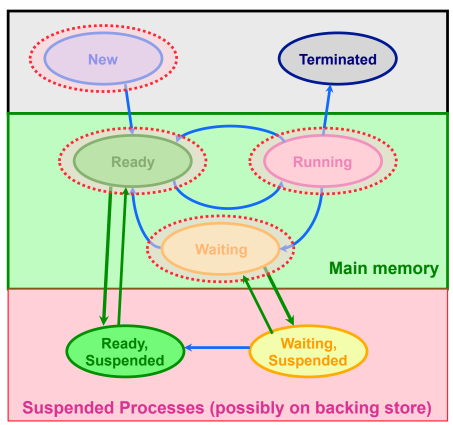


Which processes should be selected?

- Processor (CPU) is faster than I/O so all processes could be waiting for I/O
  - » Swap these processes to disk to free up more memory
- Blocked state becomes suspend state when swapped to disk
  - » Two new states
    - – waiting, suspend
    - – Ready, suspend

Suspending a Process

- Which to suspend?
- Others?



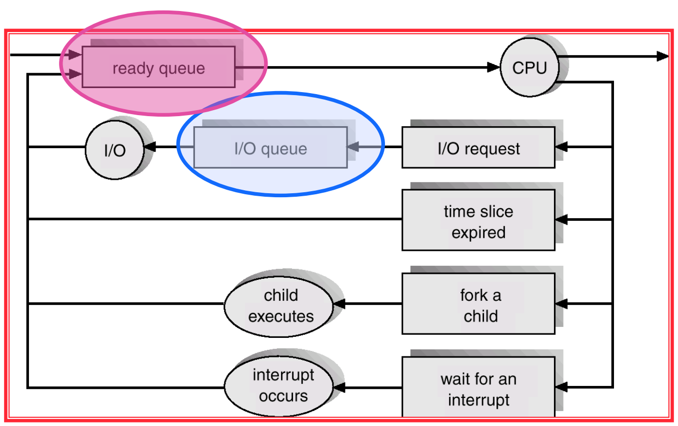
Possible Scheduling Criteria

- How long since process was swapped in our out?
- How much CPU time has the process had recently?
- How big is the process (small ones do not get in the way)?
- How important is the process (high priority)?

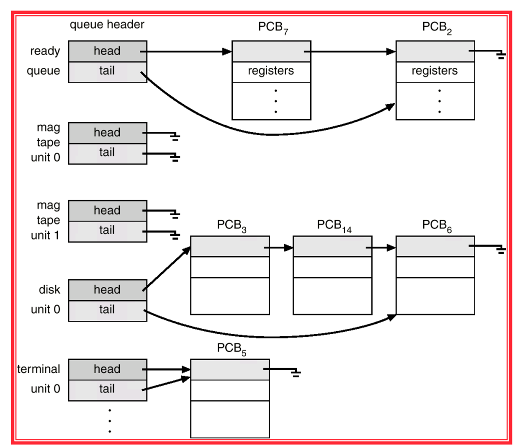
OS Implementation: Process Scheduling Queues

- **Job queue** – set of all processes in the system.
- **Ready queue** – set of all processes residing in main memory, ready and waiting to execute on CPU
- **Device queues** – set of processes waiting for an I/O device.
- Process migration between the various queues.

Representation of Process Scheduling



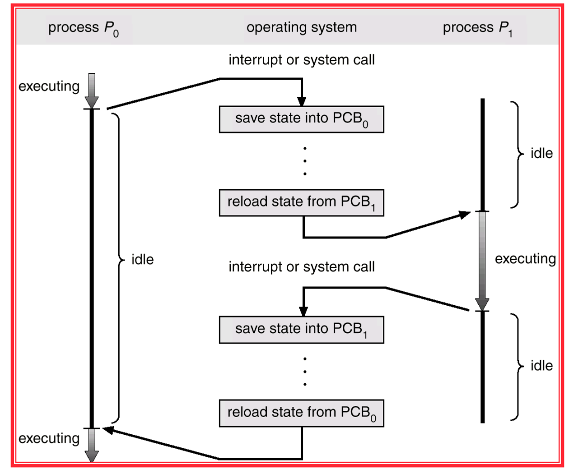
Ready Queue, I/O Device Queues



Context Switch

- When CPU switches to another process, the system must save the state of the old process and load the saved state for the new process.
- Context-switch time is overhead; the system does no useful work while switching.
- Time dependent on hardware support.

CPU Context Switches



Process Creation

- **Process Cycle**: Parents create children; results in a (inverse) tree of processes.
  - » Forms an ancestral hierarchy
- Address space models:
  - » Child duplicate of parent.
  - » Child has a program loaded into it.
- Execution models:
  - » Parent and children execute concurrently.
  - » Parent waits until children terminate.
- Examples

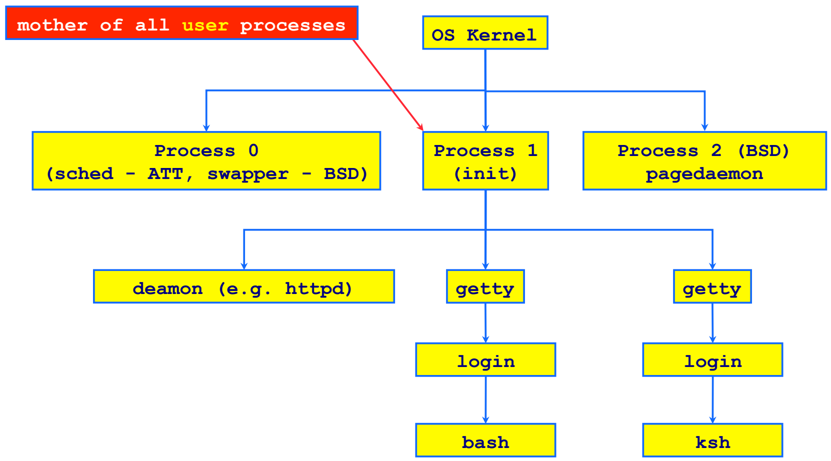
Continuing the Boot Sequence…

- After loading in the Kernel and it does a number of system checks it creates a number of 'dummy processes' -- processes that cannot be killed -- to handle system tasks.
- A common approach (UNIX) is to create processes in a tree process structure ….

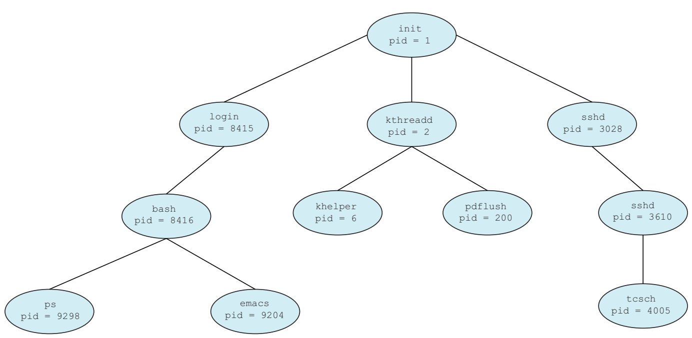
Process Life Cycle: UNIX (cont)

- PID 0 is *usually* the `sched` process (often called `swapper` – which handles memory/page mapping of processes).
  - » is a system process -- **** it is part of the kernel *****
  - » the grandmother of all processes).
- `init` - Mother of all user processes, init is started at boot time (at end of the boot strap procedure) and is responsible for starting other processes
  - » It is a user process (not a system process that runs within the kernel like `swapper`) with PID 1 (but runs with root privileges)
  - » `init` uses file `inittab` and directory `/etc/rc?.d`
  - » brings the user to a certain specified state (e.g., multiuser mode)
  - » Daemons (background process):
    - – http://en.wikipedia.org/wiki/Daemon_(computing)
- `getty` - login process that manages login sessions

Processes Tree on a typical UNIX System



Linux Specific Process Tree



Other Systems

HP-UX 10.20

UID	PID	PPID	C	STIME	TTY	TIME	COMMAND
root	0	0	0	Apr 20	?	0:17	swapper
root	1	0	0	Apr 20	?	0:00	init
root	2	0	0	Apr 20	?	1:02	vhand

Page handler
Process spawner
Sched
Buffering/Flushing I/O

Linux RedHat 6.0:

UID	PID	PPID	C	STIME	TTY	TIME	CMD
root	1	0	0	09:59	?	00:00:07	init
root	2	1	0	09:59	?	00:00:00	[kflushd]
root	3	1	0	09:59	?	00:00:00	[kpiod]
root	4	1	0	09:59	?	00:00:00	[kswapd]
root	5	1	0	10:00	?	00:00:00	[mdrecoveryd]

Solaris:

UID	PID	PPID	C	STIME	TTY	TIME	CMD
root	0	0	0	Apr 19	?	0:00	sched
root	1	0	0	Apr 19	?	0:22	/etc/init –
root	2	0	0	Apr 19	?	0:00	pageout

* sched – dummy process which provides swapping services
* pageout – dummy process which provides virtual memory (paging) services

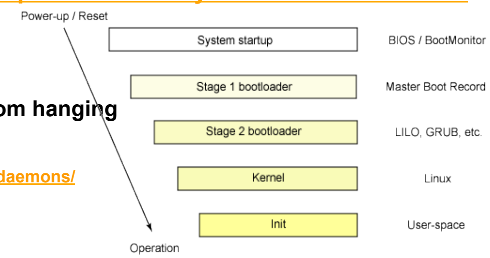
Running Processes

- Print out status information of various processes in the system: `ps -axj` (BSD) , `ps -efjc` (SVR4)
- Daemons (background processes) with root privileges, no controlling terminal, parent process is `init`

```
{atlas:maria} ps -efjc | sort -k 2 -n | less
{nike:maria} ps -ajx | sort -n -k 2 | less
    UID   PID PPID  PGID  SID  CLS PRI    STIME TTY   TIME CMD
   root     0    0     0    0  SYS  96   Mar 03 ?    0:01 sched
   root     1    0     0    0   TS  59   Mar 03 ?    1:13 /etc/init -r
   root     2    0     0    0  SYS  98   Mar 03 ?    0:00 pageout
   root     3    0     0    0  SYS  60   Mar 03 ? 4786:00 fsflush
   root    61    1    61   61   TS  59   Mar 03 ?    0:00 /usr/lib/sysevent/syseventd
   root    64    1    64   64   TS  59   Mar 03 ?    0:08 devfsadmd
   root    73    1    73   73   TS  59   Mar 03 ?   30:29 /usr/lib/picl/picld
   root   256    1   256  256   TS  59   Mar 03 ?    2:56 /usr/sbin/rpcbind
   root   259    1   259  259   TS  59   Mar 03 ?    2:05 /usr/sbin/keyserv
   root   284    1   284  284   TS  59   Mar 03 ?    0:38 /usr/sbin/inetd -s
 daemon   300    1   300  300   TS  59   Mar 03 ?    0:02 /usr/lib/nfs/statd
   root   302    1   302  302   TS  59   Mar 03 ?    0:05 /usr/lib/nfs/lockd
   root   308    1   308  308   TS  59   Mar 03 ?  377:42 /usr/lib/autofs/automountd
   root   319    1   319  319   TS  59   Mar 03 ?    6:33 /usr/sbin/syslogd
```


Linux Processes/Daemons

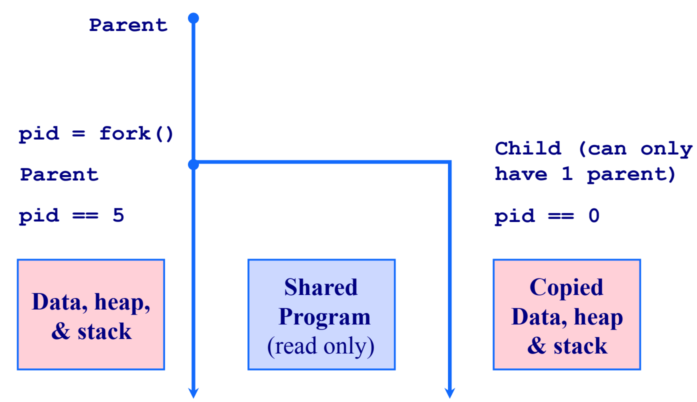
- Linux processes (ps –ef)
  - » pstree –a 1 (see the hierarchy of processes starting at pid 1).
  - » lsof (list of open files)
  - » htop, atop, top (process viewer, interactive version of ps)
- Read:
  - » http://www.ibm.com/developerworks/library/l-linuxboot/index.html
- Linux Daemons:
  - » watchdog
    - – Timer prevent system from hanging
  - » ksoftirqd
  - » http://www.sorgonet.com/linux/linuxdaemons/



Process Creation: Execution & Address Space in UNIX

- In UNIX process `fork()-exec()` mechanisms handles process creation and its behavior:
  - » `fork()` creates an exact copy of itself (the parent) and the new process is called the child process
  - » `exec()` system call places the image of a new program over the newly copied program of the parent

`fork()` a child



Example: `parent-child.c`

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

int main()
  {
   int i;
   pid_t pid;
   pid = fork();
   if( pid > 0 )
          {                   /* parent */
          for( i = 0; i < 1000; i++ )
                   printf( "\tPARENT %d\n", i );
          }
   else
          {                   /* child */
          for( i = 0; i < 1000; i++ )
                   printf( "\t\tCHILD %d\n", i );
          }
   }
```

```
{saffron} parent-child
          PARENT 0
          PARENT 1
          PARENT 2
                    CHILD 0
                    CHILD 1
          PARENT 3
          PARENT 4
                    CHILD 2
          .
          .
```


Things to Note

- **`i` is copied between parent and child**
- **The switching between parent and child depends on many factors:**
  - » **Machine load, system process scheduling, …**
- **I/O buffering effects the output shown**
  - » **Output interleaving is *non-deterministic***
    - – **Cannot determine output by looking at code**

Process Creation: Windows

- **Processes created via 10 params `CreateProcess()`**
- **Child process *requires* loading a specific program into the address space.**

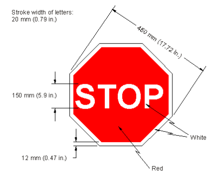
```c
BOOL WINAPI CreateProcess(
  LPCTSTR lpApplicationName,
  LPTSTR lpCommandLine,
  LPSECURITY_ATTRIBUTES lpProcessAttributes,
  LPSECURITY_ATTRIBUTES lpThreadAttributes,
  BOOL bInheritHandles,
  DWORD dwCreationFlags,
  LPVOID lpEnvironment,
  LPCTSTR lpCurrentDirectory,
  LPSTARTUPINFO lpStartupInfo,
  LPPROCESS_INFORMATION lpProcessInformation );
```


Process Termination

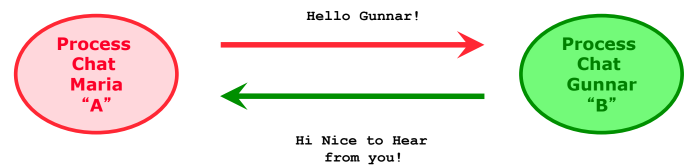
- **Process executes last statement and asks the operating system to delete it by using the `exit()` system call.**
  - » **Output data from child to parent (via wait).**
  - » **Process' resources are deallocated by operating system.**
- **Parent may terminate execution of children processes (abort).**
  - » **Child has exceeded allocated resources.**
  - » **Task assigned to child is no longer required.**
  - » **Parent is exiting.**
    - – **Some Operating system does not allow child to continue if its parent terminates.**
      - **Cascading termination (initiated by system to kill of children of parents that exited).**
    - – **If a parents terminates children are adopted by init() - so they still have a parent to collect their status and statistics**

Cooperating Processes

- *Independent* process cannot affect or be affected by the execution of another process.
- *Cooperating* process can affect or be affected by the execution of another process
  - » **Advantages** of process cooperation
    - Information sharing
    - Computation speed-up
    - Modularity
    - Convenience
  - » **Requirement:** Inter-process communication (IPC) mechanism.



Two Communicating Processes



- Concept that we want to implement

On the path to communication…

- **Want**: A communicating processes
- Have so far: Forking – to create processes
- Problem:
  - » After fork() is called we end up with two **independent** processes.
  - » Separate Address Spaces
- Solution? How do we communicate?

How do we communicate?

Local Machines:

- Files (done)
- Pipes (done)
- Signals (we talked about this)
- …

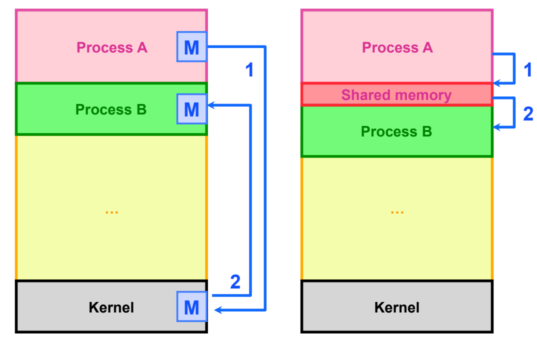
Remote Machines: 2 Primary Paradigms:

- Shared Memory
- Messages (this paradigm also extends to Remote Machines) [Same machine, Remote Machines, RPC].

Communication Models

- Shared memory model
  - » Share memory region for communication
  - » Read and write data to shared region
  - » Typically Requires synchronization (e.g., locks)
  - » Faster than message passing
  - » Setup time
- Message Passing model
  - » Communication via exchanging messages

Communication Models

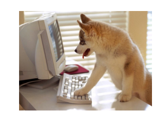


Message Passing   Shared Memory

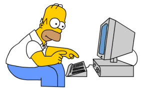
Communication Implementations

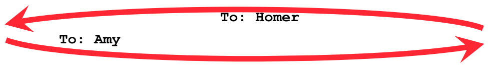
- Within a single computer
  - » Pipes (done)
    - – Unamed: only persist as long as process lives
    - – Named Pipes (FIFO)- looks like a file (`mkfifo filename, attach, open, close, read, write)`
      - http://developers.sun.com/solaris/articles/named_pipes.html
  - » Message Passing (message Queues, next HW)
  - » Shared Memory (next HW)
- Distributed System (remote computers, connected via cable, air e.g., WiFi) - Later
  - » TCP/IP sockets
  - » Remote Procedure Calls (next, to next project)
  - » Remote Method Invocations (RMI, maybe project)
  - » Message passing libraries: MPI, PVM

Message Passing Systems



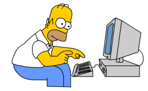
- NO shared state
  - » Communicate across address spaces and protection
  - » Agreed protocol
- Generic API
  - » `send( dest, &msg )`
  - » `recv( src, &msg )`
- What is the dest and src?
  - » pid
  - » File: e.g., pipe
  - » Port, network address, queue
  - » Unspecified source (any source, any message)



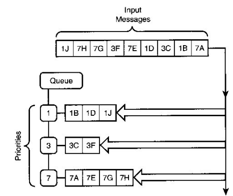


Direct Communication

- Explicitly specify dest and src process by an identifier
- Multiple buffers:
  - » Receiver
    - – If it has multiple senders (then need to search through a 'buffer(s)' to get a specific sender)
  - » Sender
- What is the dest and src?
  - » pid
  - » File: e.g., pipe
  - » Port, network address,
  - » Unspecified source (any source, any message)



Indirect Communication



- dest and src are (unique) queues
- Uses a unique shared queue, allows many to many communication :
  - » messages sorted FIFO
  - » messages are stored as a sequence of bytes
  - » get a message queue identifier (can create queue)

```
int queue_id = msgget ( key, flags )
```

- sending messages:
  - » `msgsnd( queue_id, &buffer, size, flags )`
- receiving messages (type is priority):
  - » `msgrcv( queue_id, &buffer, size, type, flags )`

Demo

- kirk.c
- spock.c
- ipcs
- ipcrm

Mailboxes vs Pipes

- Same machine: Are there any differences between a mailbox and a pipe?
  - » Message types
    - – mailboxes may have messages of different types
    - – pipes do not have different types
- Buffer
  - » Pipes: Messages stored in contiguous bytes
  - » Mailbox – linked list of messages of different types
- Number of processes
  - » Typically 2 for pipes (one sender & one receiver)
  - » Many processes typically use a mailbox (understood paradigm)

Shared Memory

- Efficient and fast way for processes to communicate
  - » After setting up a shared memory segment
- Process: Create, Attach, Populate, Detach
  - » create a shared memory segment
    - – `shmid = shmget( key, size, flags )`
  - » attach a sms to a data space:
    - – `shmat( shmid, *shmaddr, flags )`
  - » Populate or Read/Write `(with regular instructions)`
  - » detach (close) a shared segment:
    - – `shmdt( *shmaddr )- synchronized.`

if more than one process can access segment, an outside protocol or mechanism (like semaphores) should enforce consistency and avoid collisions

Simple Example: shm_server.c and shm_client.c

shm_server.c

```
#include <sys/types.h>
#include <sys/ipc.h>
#include <sys/shm.h>
#include <stdio.h>

#define SHMSZ     27

main()
{
    int shmid;
    key_t key;
    char c, *shm, *s;

    key = 5678; /* selected key */

    /* Create the segment.*/
    if ((shmid = shmget(key,SHMSZ,IPC_CREAT | 0666)) <
     0)
    {
        perror("shmget"); exit(1);
    }

    /* Attach the segment to our data space.*/
    if ((shm = shmat(shmid, NULL, 0)) == (char *) -1)
    {
        perror("shmat"); exit(1);
    }

    /* Populate/Write: put some things into memory */
    for (s = shm, c = 'a'; c <= 'z'; c++) *s++ = c;
    *s = NULL;

    /* Read: wait until first character changes to '*'
     */
    while (*shm != '*') sleep(1);

    exit(0);
}
```

shm_client

```
#include <sys/types.h>
#include <sys/ipc.h>
#include <sys/shm.h>
#include <stdio.h>

#define SHMSZ     27

main()
{
    int shmid;
    key_t key;
    char *shm, *s;

    key = 5678; /* selected key by server */

    /* Locate the segment. */
    if ((shmid = shmget(key,SHMSZ,0666)) < 0)
    {
        perror("shmget"); exit(1);
    }

    /* Attach the segment to our data space. */
    if ((shm = shmat(shmid, NULL, 0)) == (char *) -1) \
    {
        perror("shmat"); exit(1);
    }

    /* Read what the server put in the memory. */
    for (s = shm; *s != NULL; s++) putchar(*s);
    putchar('\n');

    /* Write/Synchronize change the first character in
     segment to '*' */
    *shm = '*';

    exit(0);
}
```

Synchronous/Asynchronous Commands

- Synchronous – e.g., blocking (wait until command is complete, e.g., block read or receive).
  - » Synchronous Receive:
    - – receiver process waits until message is copied into user level buffer
- Asynchronous – e.g., non-blocking (don't wait)
  - » Asynchronous Receive
    - – Receiver process issues a receive operation and then carries on with task
      - Polling – comes back to see if receive as completed
      - Interrupt – OS issues interrupt when receive has completed

Synchronous: OS view vs Programming Languages

- OS View:
  - » synchronous send ⇒ sender blocks until message has been copied from application buffers to the kernel
  - » Asynchronous send ⇒ sender continues processing after notifying OS of the buffer in which the message is stored; have to be careful to not overwrite buffer until it is safe to do so
- PL view:
  - » synchronous send ⇒ sender blocks until message has been received by the receiver
  - » asynchronous send ⇒ sender carries on with other tasks after sending message

Buffering

- Queue of messages attached to link:
  - » Zero capacity
    - – 0 message - link cannot have any messages waiting
    - – Sender must wait for receiver (rendezvous)
  - » Bounded capacity
    - – n messages - finite capacity of n messages
    - – Sender must wait if link is full
  - » Unbounded capacity
    - – infinite messages -
    - – Sender never waits

Remote Machine Communication

- Socket communication (do on your own, bonus available, with tutorial and code snippets): Interested?
- Remote Procedure Calls RPC (right now)
- Remote Method Invocation (next week)

HW 3 – later will be a one week HW RPC & RMI