CSCI 6730 / 4730
Operating Systems

Processes

Maria Hybinette, UGA

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

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Chapter 3: Processes: Outline

- Process Concept: views of a process
- Process Basics Scheduling
- Operations on Processes
  - » Life of a process: from birth to death
- Cooperating Processes
  - » Interprocess Communication
    - – Mailboxes
    - – Shared Memory
    - – Sockets

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What is a Process?

- A process is a program in execution (an active entity, i.e. it is a *running* program)
  - » Basic unit of work on a computer, a job, 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`, `httpd`
- System view…

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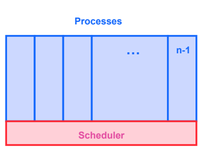
What are Processes?

- 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”



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Our 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.

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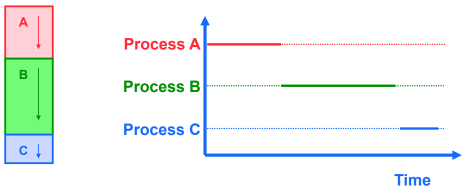
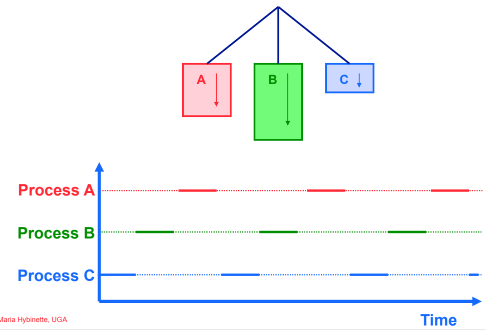
Activity of a Process



Multiprogramming:

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

Activity of a Process: Time Sharing

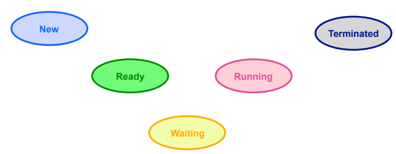


What Does the Process Do?

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

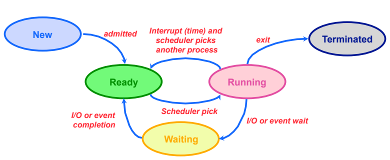
'States' of a Process

- 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)



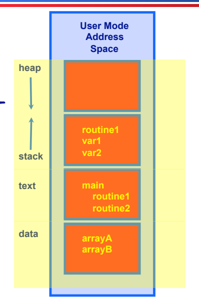
OS Designer's Questions?

- 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

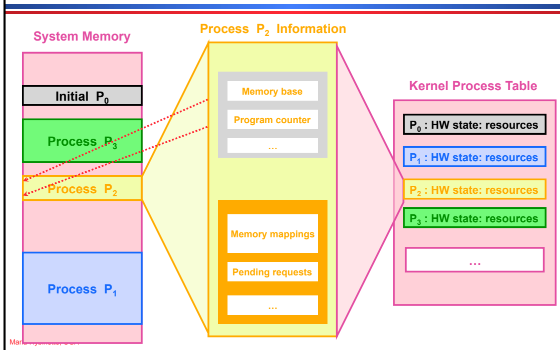


What is needed to keep track of a Process?

- 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 */
```


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
```

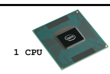
- traditionally 'zombies' are child processes of parents that have not processed a wait() instruction.
- Note: processes that have been 'adopted' by init are not zombies (these are children of parents that terminates before the child). Init automatically calls wait() on these children when they terminate.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

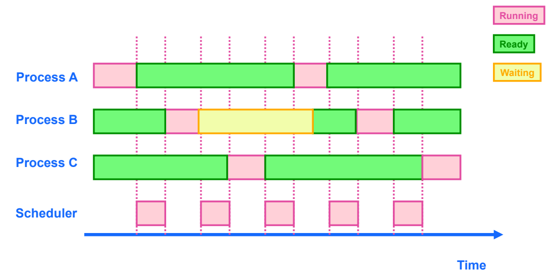
Process Table in MINIX

- 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)

HERE

Running Processes





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).**

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.***

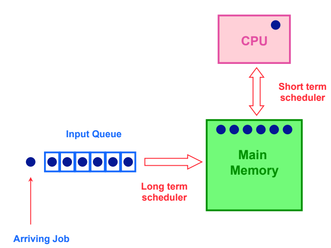
Process Characteristics

- **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

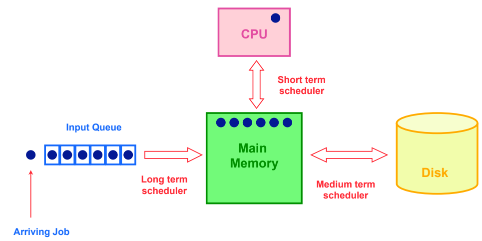
- **If all processes are I/O bound, the ready queue will almost always be empty (little scheduling)**
- **If all processes are CPU bound the I/O devices are underutilized**
- **Approach (long term scheduler): 'Admit' a good mix of CPU bound and I/O bound processes.**

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.

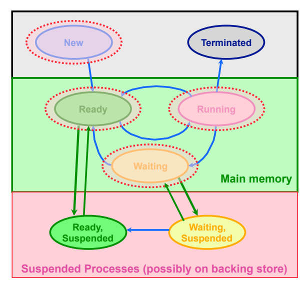


Which processes should be selected?

- 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?



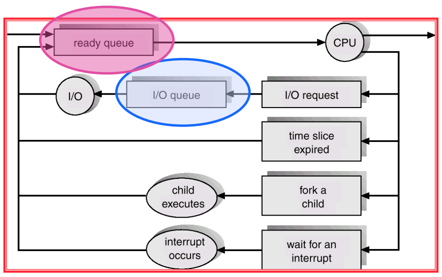
Possible Scheduling Criteria

- 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)?

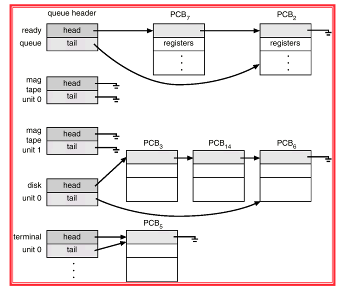
OS Implementation: Process Scheduling Queues

- **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



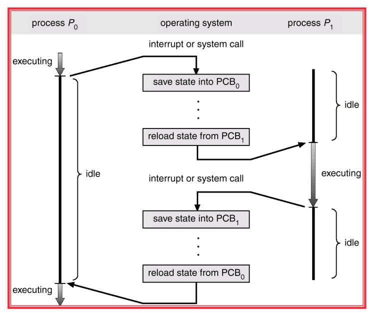
Ready Queue, I/O Device Queues



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

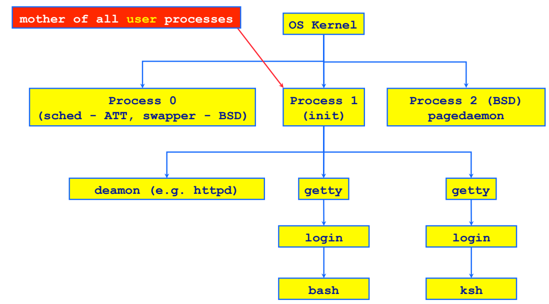
Continuing the Boot Sequence…

- 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.
- Usually ….

Process Life Cycle: UNIX (cont)

- PID 0 is *usually* the `scheduler` process (often called `swapper`)
  - » 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)
- `getty` - login process that manages login sessions

Processes Tree on a typical UNIX System



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
Scheduler
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

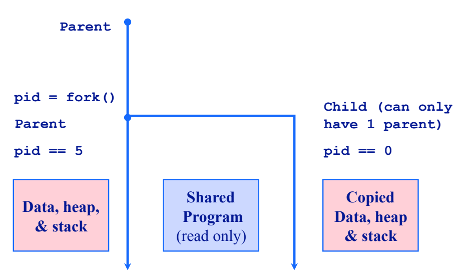
- Print out status information of various processes in the system: `ps -axj` (BSD) , `ps -efjc` (SVR4)
- Daemons (background processes) with root privileges, no controlling terminal, parent process is `init`

```
{atlas:maria} ps -efjc | sort -k 2 -n | more
    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
```


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

```
#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.

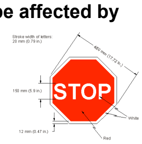
```
BOOL WINAPI CreateProcess(
  LPCTSTR lpApplicationName,
  LPTSTR lpCommandLine,
  LPSECURITY_ATTRIBUTES lpProcessAttributes,
  LPSECURITY_ATTRIBUTES lpThreadAttributes,
  BOOL bInheritHandles,
  DWORD dwCreationFlags,
  LPVOID lpEnvironment,
  LPCTSTR lpCurrentDirectory,
  LPSTARTUPINFO lpStartupInfo,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


Process Termination

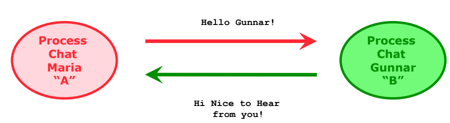
- Process executes last statement and asks the operating system to delete it by using the `exit()` system call.
  - » Output data from child to parent (via wait).
  - » Process' resources are deallocated by operating system.
- Parent may terminate execution of children processes (abort).
  - » Child 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

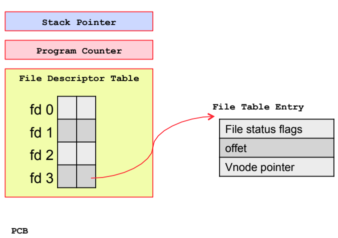
On the path to communication…

- 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?

File: The Unix Way

- One easy way to communicate is to use files.
  - » Process A writes to a file and process B reads from it
- File descriptors
  - » Mechanism to work with files
  - » Used by low level I/O
    - – Open(), close(), read(), write()
  - » file descriptors generalize to other communication devices such as pipes and sockets

Big Picture



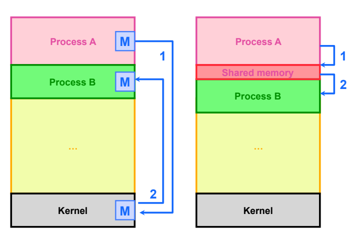
Other Methods (Right now assume we are on a 'local' computer)

- Pipes
- Sockets (starting thursday)
- Signal
- Shared Memory
- Messages (this paradigm also extends to Remote Machines)

Communication Models

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

Communication Models

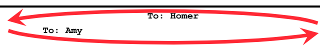


Communication Examples

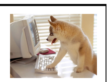
- Within a single computer
  - » Pipes,
    - – Unamed: only persist as long as process lives
    - – Named Pipes (FIFO)- looks like a file (`mkfifo filename, attach, open, close, read, write)`
      - http://developers.sun.com/solaris/articles/named_pipes.html
  - » Message Passing (Queues)
  - » Shared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

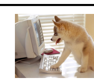


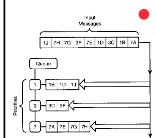
Direct Communication



- 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:
    `int queue_id = msgget ( key, flags )`
- sending messages:
  - » `msgsnd( queue_id, buffer, size, flags )`
- receiving messages (type is priority):
  - » `msgsnd( queue_id, buffer, size, type, flags )`

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
- Multiple processes can attach a segment of physical memory to their virtual address space
  - » Process: Create, Attach an Populate
- create a shared segment `shmid = shmget( key, size, flags )`
- attach a sm to a data space: `shmat( shmid, *shmaddr, flags )`
- detach (close) a shared segment: shmdt(*shmaddr)

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

Simple Example

```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);
    }

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

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

    /* wait until first character is changed to '*' */
    while (*shm != '*') sleep(1);

    exit(0);
}
```

```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 *shm, *s;

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

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

    /* Now we 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');

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

    exit(0);
}
```

Synchronization

- **Synchronous – e.g., blocking (wait until command is complete)**
  - » E.g.: Synchronous Receive:
    - – receiver process waits until message is copied into user level buffer
- **Asynchronous – e.g., non-blocking (don't wait)**
  - » E.g.,: Asynchronous Receive
    - – Receiver process issues a receive operation and then carries on with task
      - Polling – comes back tosee if receive as completed
      - Interrupt – OS issues an 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 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
- Remote Procedure Calls (next week)
- Remote Method Invocation (Java)