CAS CS 552
Intro to Operating Systems

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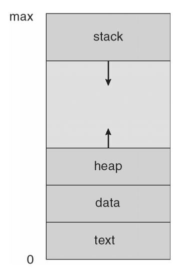
Processes

Process Concept

- Process – a program in a state of execution
  - A program is a passive entity. It may consist of code and data in files, which are stored on disk and brought to main memory when the program is executed
  - A process is an active entity and includes:
    - a program counter value
    - stack
    - data segment
    - text segment
    - heap

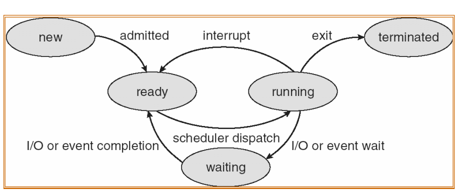
Process in Memory



Process State

- As a process executes, it changes *state*
- Possible states:
  - **new**: The process is being created
  - **running**: Instructions are being executed
  - **waiting/blocked**: The process is waiting for some event to occur (e.g., I/O completion, signal from OS)
  - **ready**: The process is runnable but waiting to be assigned to a CPU
  - **terminated**: The process has finished execution

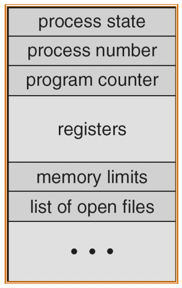
Diagram of Process State



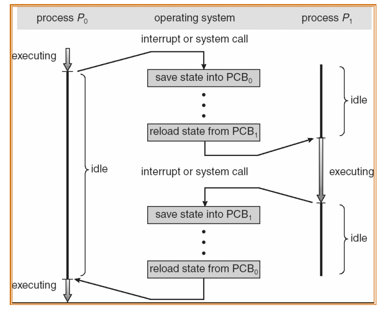
Process Control Block (PCB)

- OS maintains a process/task control block (PCB) for each process in system
- Information associated with each process includes:
  - Process (run) state
  - Program counter value
  - CPU registers
  - CPU scheduling information – priority, size of time-slice, pointers to scheduling queues etc…
  - Memory-management information – base/limit values for address space, page table info, list of virtual memory regions that make up address space…
  - Accounting information – how long process has been running, time spent at user/kernel level etc…
  - File management info – list of open files in use by process…
  - I/O status information – list of devices allocated to a process…

Process Control Block (PCB)



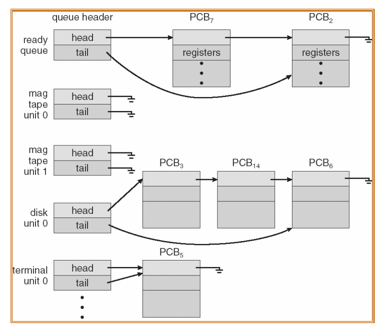
CPU Switch From Process to Process



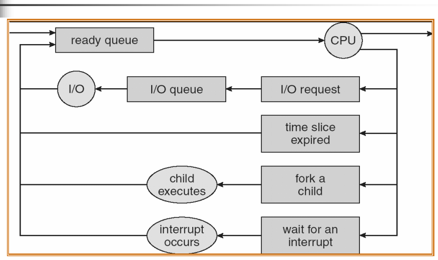
Process Scheduling Queues

- **Job queue** – set of all processes in the system
- **Ready queue** – set of all processes residing in main memory, ready and waiting to execute
  - Processes are dispatched from the ready queue and assigned to the CPU
- **Device queues** – set of processes waiting for an I/O device
  - Typically one device queue for each device
- Processes migrate among the various queues during their lifetimes

Ready Queue And Various I/O Device Queues



Representation of Process Scheduling



- During the execution of a process, **P**, several events may occur that cause **P** to be moved to a wait queue, or the "ready queue"

Schedulers

- **Long-term scheduler** – selects which processes should be brought into the ready queue
  - Controls degree of multiprogramming by selecting processes from disk to be loaded into main memory
- **Short-term scheduler** (or CPU scheduler) – selects a process for execution from the ready queue and allocates CPU

CPU- versus I/O-bound Processes

- Processes can be described as either:
  - **I/O-bound processes**
    - spend more time doing I/O than computations, many short CPU bursts
  - **CPU-bound processes**
    - spend more time using CPU cycles rather than waiting on I/O
- Long term scheduling can be used to ensure "good mix" of CPU- and I/O-bound processes are present in main memory

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:
  - Memory speed, machine state (#registers)…
  - Nowadays, in the nano-/microsecond range

Operations on Processes

- Process Creation
  - Parent processes may create/fork child processes
  - Children may inherit/share system resources from/with parent process (e.g., some memory, open files…)
- When a parent creates a child process:
  - Parent and child may execute concurrently
  - Parent can wait until some/all children have terminated
  - e.g., fork() versus vfork() on UNIX systems

UNIX Process Creation

- fork() creates "copy" of parent's address space for child…or does it?
  - What about "copy on write" (COW)?
  - When is COW most useful?
- An exec() call (typically execve()) replaces address space of caller with new program image
- Extra: vfork() suspends parent while child uses parent's page table mappings. Parent resumes either when child calls exec() or _exit()…child cannot call exit()!

Process Termination

- exit() routine terminates process, releasing its resources back to system
  - On UNIX systems, _exit() is syscall that releases memory allocated to process
  - May need to keep enough state for a "dead" process in case parent wishes to find exit status via a wait/waitpid() call
    - Can lead to "zombie" processes

Additional Information

- The following slides are taken, for the most part, from Silberschatz et al…

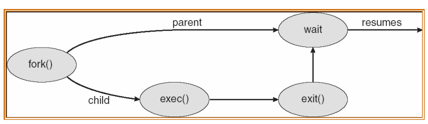
Process Creation

- Parent process create children processes, which, in turn create other processes, forming a tree of processes
- Resource sharing
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution
  - Parent and children execute concurrently
  - Parent waits until children terminate

Process Creation (Cont.)

- Address space
  - Child duplicate of parent
  - Child has a program loaded into it
- UNIX examples
  - **fork** system call creates new process
  - **exec** system call used after a **fork** to replace the process' memory space with a new program

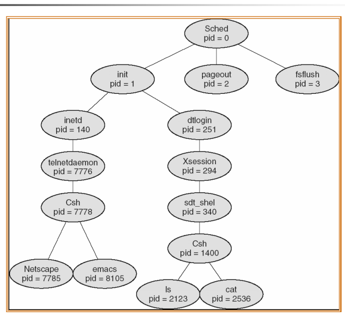
Process Creation



C Program Forking Separate Process

```
int main()
{
Pid_t  pid;
    /* fork another process */
    pid = fork();
    if (pid < 0) { /* error occurred */
            fprintf(stderr, "Fork Failed");
            exit(-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");
            exit(0);
    }
}
```

A tree of processes on a typical Solaris



Process Termination

- Process executes last statement and asks the operating system to delete it (**exit**)
  - Termination status of child sent 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
  - If parent is exiting
    - Some operating systems do not allow child to continue if its parent terminates
      - All children terminated - *cascading termination*

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

Producer-Consumer Problem

- Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process
  - *unbounded-buffer* places no practical limit on the size of the buffer
  - *bounded-buffer* assumes that there is a fixed buffer size

Bounded-Buffer – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 10
Typedef struct {
  . . .
} item;

item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```

- Solution is correct, but can only use BUFFER_SIZE-1 elements

Bounded-Buffer – Insert() Method

```
while (true) {
  /* Produce an item */
   while (((in = (in + 1) % BUFFER SIZE
count)  == out)
     ;   /* do nothing -- no free buffers */
     buffer[in] = item;
     in = (in + 1) % BUFFER SIZE;
  }
```

Bounded Buffer – Remove() Method

```
while (true) {
     while (in == out)
          ; // do nothing -- nothing to
consume

     // remove an item from the buffer
     item = buffer[out];
     out = (out + 1) % BUFFER SIZE;
return item;
 }
```

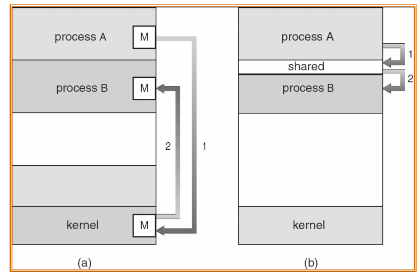
Interprocess Communication (IPC)

- Mechanism for processes to communicate and to synchronize their actions
- 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?

Communications Models



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

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

- 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.

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

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

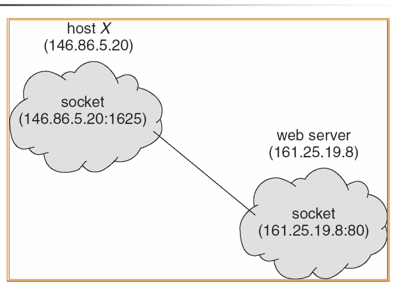
Client-Server Communication

- Sockets
- Remote Procedure Calls
- Remote Method Invocation (Java)

Sockets

- A socket is defined as an *endpoint for communication*
- Concatenation of IP address and port
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- Communication consists between a pair of sockets

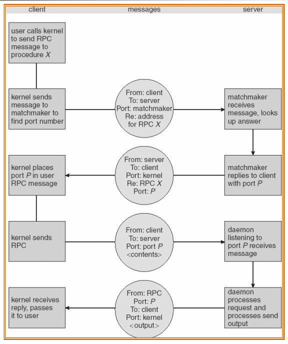
Socket Communication



Remote Procedure Calls

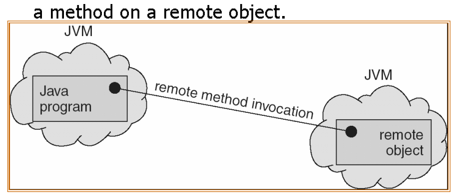
- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
- **Stubs** – client-side proxy for the actual procedure on the server
- The client-side stub locates the server and *marshalls* the parameters
- The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server

Execution of RPC



Remote Method Invocation

- Remote Method Invocation (RMI) is a Java mechanism similar to RPCs.
- RMI allows a Java program on one machine to invoke a method on a remote object.



Marshalling Parameters