The Big Picture So Far

From the Architecture to the OS to the User: Architectural resources, OS management, and User Abstractions.

Hardware Abstraction	**Example OS Services**	**User Abstraction**
Processor	Process management, Scheduling, Traps Protection, Billing, Synchronization	Process
Memory	Management, Protection, Virtual memory	Address space
I/O devices	Concurrency with CPU, Interrupt handling	Terminal, Mouse, Printer, System Calls
File system	Management, Persistence	Files
Distributed systems	Network security, Distributed file system	RPC system calls, file sharing

Today: Process Management

- A process as the unit of execution.
- How are processes represented in the OS?
- What are possible execution states and how does the system move from one state to another?
- How do processes communicate? Is this efficient?

What's in a Process?

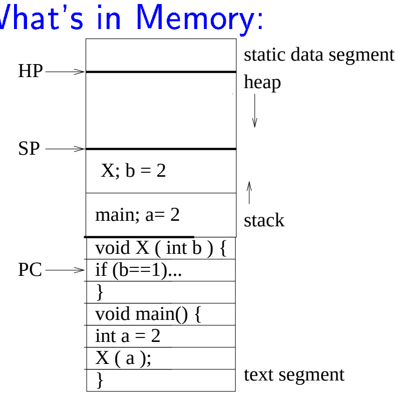
- **Process:** dynamic execution context of an executing program
- Several processes may run the same program, but each is a distinct process with its own state (e.g., MS Word).
- A process executes sequentially, one instruction at a time
- Process state consists of at least:
  - the code for the running program,
  - the static data for the running program,
  - space for dynamic data (the heap), the heap pointer (HP),
  - the Program Counter (PC), indicating the next instruction,
  - an execution stack with the program's call chain (the stack), the stack pointer (SP)
  - values of CPU registers
  - a set of OS resources in use (e.g., open files)
  - process execution state (ready, running, etc.).

Example Process State in Memory

What you wrote:

```
      void X ( int b ) {
PC→       if (b == 1) ...
      }
      main() {
          int a = 2;
          X ( a );
      }
```

What's in Memory:



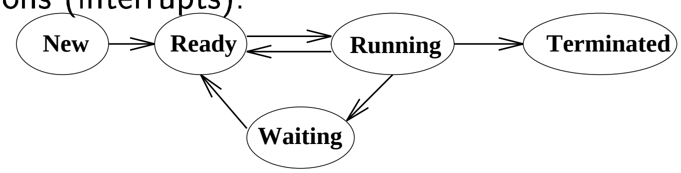
Process State

Process Execution State

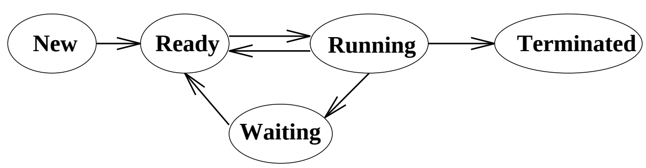
- Execution state of a process indicates what it is doing

new:	the OS is setting up the process state
running:	executing instructions on the CPU
ready:	ready to run, but waiting for the CPU
waiting:	waiting for an event to complete (e.g., I/O)
terminated:	the OS is destroying this process

- As the program executes, it moves from state to state, as a result of the program actions (e.g., system calls), OS actions (scheduling), and external actions (interrupts).



Process Execution State



Example:

```
  void main() {
    printf('Hello World\n');
}
```

state sequence
new
ready
running
waiting for I/O
ready
running
terminated

- The OS manages multiple active process using *state queues* (More on this in a minute . . .)

Process Data Structures

- Process Control Block (PCB): OS data structure to keep track of all processes
  - The PCB tracks the execution state and location of each process
  - The OS allocates a new PCB on the creation of each process and places it on a state queue
  - The OS deallocates the PCB when the process terminates

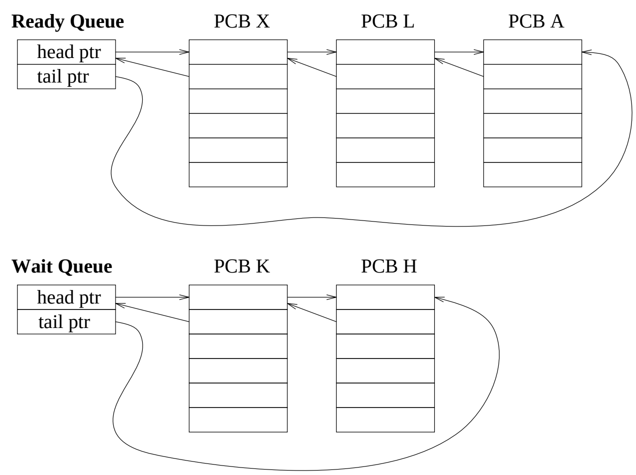
- The PCB contains:

- Process state (running, waiting, etc.)
- Process number
- Program Counter
- Stack Pointer
- General Purpose Registers
- Memory Management Information
- Username of owner
- List of open files
- Queue pointers for state queues
- Scheduling information (e.g., priority)
- I/O status
- ...

Process State Queues

- The OS maintains the PCBs of all the processes in *state queues*.
- The OS places the PCBs of all the processes in the same *execution state* in the same queue.
- When the OS changes the state of a process, the PCB is unlinked from its current queue and moved to its new state queue.
- The OS can use different policies to manage each queue.
- Each I/O device has its own wait queue.

State Queues: Example



PCBs and Hardware State

- Starting and stopping processes is called a **context switch**, and is a relatively expensive operation.
- The OS starts executing a ready process by loading hardware registers (PC, SP, etc) from its PCB
- While a process is running, the CPU modifies the Program Counter (PC), Stack Pointer (SP), registers, etc.
- When the OS stops a process, it saves the current values of the registers, (PC, SP, etc.) into its PCB
- This process of switching the CPU from one process to another (stopping one and starting the next) is the context switch.
  - Time sharing systems may do 100 to 1000 context switches a second.
  - The cost of a context switch and the time between switches are closely related

Creating a Process

- One process can create other processes to do work.
  - The creator is called the *parent* and the new process is the *child*
  - The parent defines (or donates) resources and privileges to its children
  - A parent can either wait for the child to complete, or continue in parallel
- In Unix, the *fork* system call called is used to create child processes
  - Fork copies variables and registers from the parent to the child
  - The *only difference* between the child and the parent is the value returned by fork
    - In the parent process, fork returns the process id of the child
    - In the child process, the return value is 0
  - The parent can wait for the child to terminate by executing the *wait* system call or continue execution
  - The child often starts a new and different program within itself, via a call to *exec* system call.

Creating a Process: Example

- When you log in to a machine running Unix, you create a shell process.
- Every command you type into the shell is a child of your shell process and is an implicit *fork* and *exec* pair.
- For example, you type emacs, the OS *"forks"* a new process and then *"exec"* (executes) emacs.
- If you type an & after the command, Unix will run the process in parallel with your shell, otherwise, your next shell command must wait until the first one completes.

Example Unix Program: Fork

```
#include <unistd.h>
#include <sys/wait.h>
#include <stdio.h>
main() {
  int parentID = getpid();    /* ID of this process */
  char  prgname[1024];
  gets(prgname); /* read the name of program we want to start */
  int cid = fork();
  if(cid == 0) {  /* I'm the child process */
    execlp( prgname, prgname, 0);  /* Load the program */
    /* If the program named prgname can be started, we never get
   to this line,  because the child program is replaced by prgname */
    printf("I didn't find program %s\n", prgname);
  } else { /* I'm the parent process */
    sleep (1);  /*  Give my child time to start. */
    waitpid(cid, 0, 0);  /*  Wait for my child to terminate. */
    printf("Program %s finished\n", prgname);
} }
```


Example Unix Program: Explanation

fork() forks a new child process that is a copy of the parent.

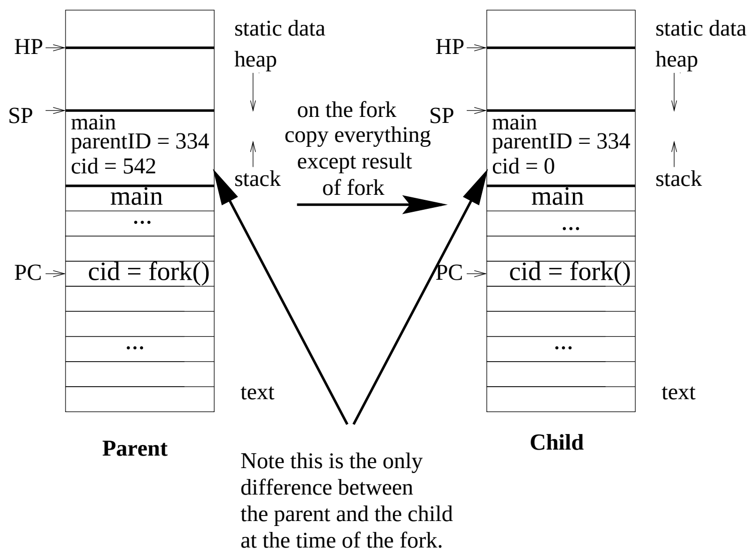
execlp() replaces the program of the current process with the named program.

sleep() suspends execution for at least the specified time.

waitpid() waits for the named process to finish execution.

gets() reads a line from a file.

What is happening on the Fork



Process Termination

- On process termination, the OS reclaims all resources assigned to the process.
- In Unix
  - a process can terminate itself using the *exit* system call.
  - a process can terminate a child using the *kill* system call.

Example Unix Program: Process Termination

```
#include <signal.h>
#include <unistd.h>
#include <stdio.h>
main() {
  int parentID = getpid();    /* ID of this process */
  int cid = fork();
  if(cid == 0) {  /*  I'm the child process  */
    sleep (5);     /* I'll exit myself after 5 seconds. */
    printf ( "Quitting child\n" );
    exit (0);
    printf ( "Error!  After exit call.!"); /* should never get here */
  } else {  /*  I'm the parent process  */
    printf ( "Type any character to kill the child.\n" );
    char answer[10];
    gets (answer);
    if ( !kill(cid, SIGKILL) ) {
      printf("Killed the child.\n");
} } }
```


Cooperating Processes

- Any two process are either independent or cooperating
- Cooperating processes work with each other to accomplish a single task.
- Cooperating processes can
  - improve performance by overlapping activities or performing work in parallel,
  - enable an application to achieve a better program structure as a set of cooperating processes, where each is smaller than a single monolithic program, and
  - easily share information between tasks.

⇒ Distributed and parallel processing is the wave of the future. To program these machines, we must cooperate and coordinate between separate processes.

Cooperating Processes: Producers and Consumers

```
n = 100;    // max outstanding items
in = 0;
out = 0;
producer
    repeat  forever {
        ...
        nextp = produced item
        ...
        // Make sure buffer not full
        while in+1 mod n = out do
            no-op
        buffer[in] = nextp
        in = in+1 mod n
    }

consumer
    repeat  forever {
        // Make sure buffer not empty
        while in = out do no-op
        nextc = buffer[out]
        out = out+1 mod n
        ...
        consume nextc
        ...
    }
```

- Producers and consumers can communicate using *message passing* or *shared memory*

Communication using Message Passing

```
main()
    ...
    if (fork() != 0) producerSR();
    else consumerSR();
end

producerSR
    repeat
        ...
        produce item nextp
        ...
        send (nextp, consumer)

consumerSR
    repeat
        receive (nextc, producer)
        ...
        consume item nextc
        ...
```

Message Passing

- Distributed systems typically communicate using message passing
- Each process needs to be able to name the other process.
- The consumer is assumed to have an infinite buffer size.
- A bounded buffer would require the tests in the previous slide, and communication of the `in` and `out` variables (`in` from producer to consumer, `out` from consumer to producer).
- OS keeps track of messages (copies them, notifies receiving process, etc.).

⇒ How would you use message passing to implement a single producer and multiple consumers?

Communication using Shared Memory

- Establish a mapping between the process's address space to a named memory object that may be shared across processes
- The mmap(...) systems call performs this function.
- Fork processes that need to share the data structure.

Shared Memory Example

```
main()
    ...
    mmap(..., in, out, PROT_WRITE, MAP_SHARED, ...);
    in = 0;
    out = 0;
    if (fork() != 0) producer();
    else consumer();
end
```

```
producer                              consumer
repeat                                     repeat
     ...                                   while in = out do no-op
     produce item nextp                    nextc = buffer[out]
     ...                                   out = out+1 mod n
     while in+1 mod n = out do no-op       ...
     buffer[in] = nextp                    consume item nextc
     in = in+1 mod n                       ...
```


Process Management: Summary

- A process is the unit of execution.
- Processes are represented as Process Control Blocks in the OS
  - PCBs contain process state, scheduling and memory management information, etc
- A process is either New, Ready, Waiting, Running, or Terminated.
- On a uniprocessor, there is at most one running process at a time.
- The program currently executing on the CPU is changed by performing a context switch
- Processes communicate either with message passing or shared memory