CSC 2/456: Operating Systems

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General Course Information

- Course Web page:
  - www.cs.rochester.edu/~sandhya/csc256
- Course-related announcement/correspondence:
  - Blackboard Discussion Board
- Texts
  - Tanenbaum, "Modern Operating Systems"
  - Silberschatz et al, "Operating System Concepts"

General Course Information (cont.)

- Assignments and grading
  - six programming assignments (total 50%)
  - midterm and final (40%)
  - homework/other (10%)
  - Other: participation in class discussions, presentations
- "CSC456 Part" in assignments
- C programming
- Class presentation and end-of-term survey paper for CSC456 students

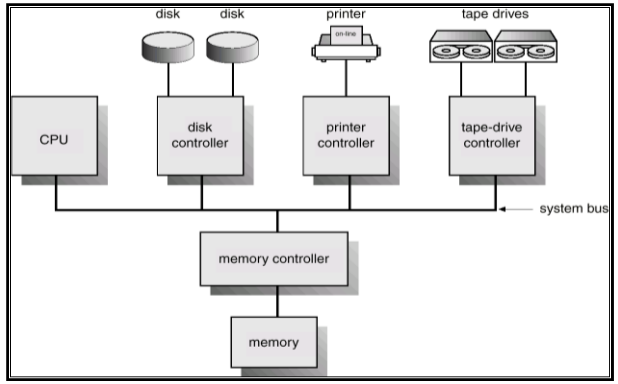
What is an Operating System?

- Software that abstracts the computer hardware
  - Hides the messy details of the underlying hardware
  - Presents users with a resource abstraction that is easy to use
  - Extends or virtualizes the underlying machine
- Manages the resources
  - Processors, memory, timers, disks, mice, network interfaces, printers, displays, …
  - Allows multiple users and programs to share the resources and coordinates the sharing

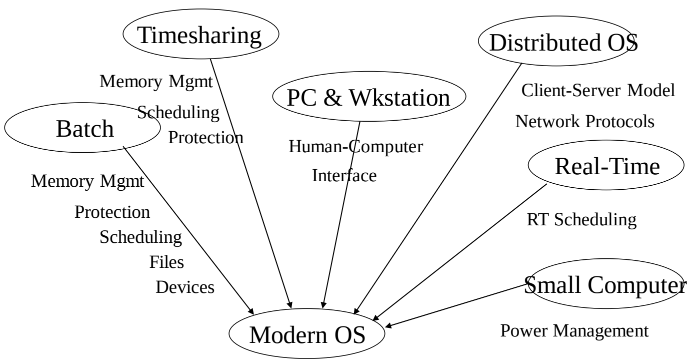
Why Study Operating Systems?

- Learn to design an OS or other computer systems
- Understand an OS
  - Understand the inner workings of an OS
  - Enable you to write <u>efficient/correct</u> application code

Computer-System Architecture



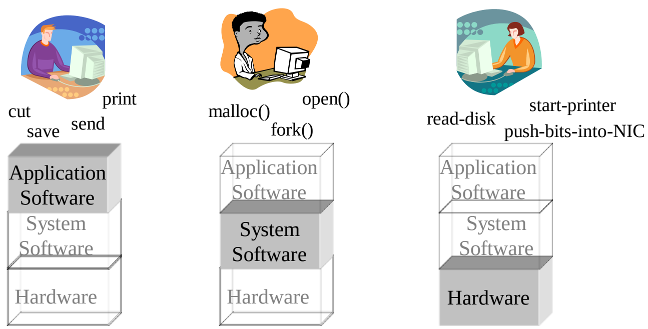
Evolution of Modern OS



Examples of Modern OSes

- UNIX variants (e.g., Solaris, Linux) -- have evolved since 1970
- Windows 7/NT/2K -- has evolved since 1989
- Smartphone Oses: Android, iOS, …
- Other OSes –
  - microkernel
  - extensible OS
  - virtual machines
  - sensor OS
  - Software isolated processes
  - special-purpose OS – for highly concurrent Internet servers
  - still evolving …

Perspectives of the Computer



(a) End User View

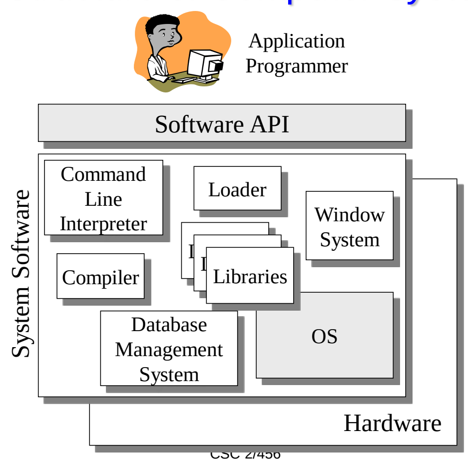
(b) Application Programmer View

(c) System Programmer View

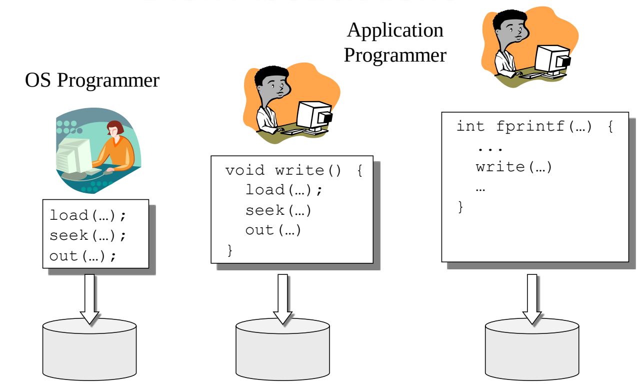
System Software

- A general piece of software with common functionalities that support many applications
- Examples
  - C compiler and library functions
  - Shell – command line interpreter
  - A window system
  - A database management system
  - The operating system
    - A thin layer of software that operates directly on the raw hardware

The Structure of Computer Systems



Disk Abstractions



(a) Direct Control

(b) `write()` abstraction

(c) `fprintf()` abstraction

System Calls and Interfaces/Abstractions

- Examples: Win32, POSIX, or Java APIs
- Process management
  - fork, waitpid, execve, exit, kill
- Exceptions, interrupts (events)
  - signals
- File management
  - open, close, read, write, lseek
- Directory and file system management
  - mkdir, rmdir, link, unlink, mount, umount
- Inter-process communication
  - sockets, ipc (msg, shm, sem)

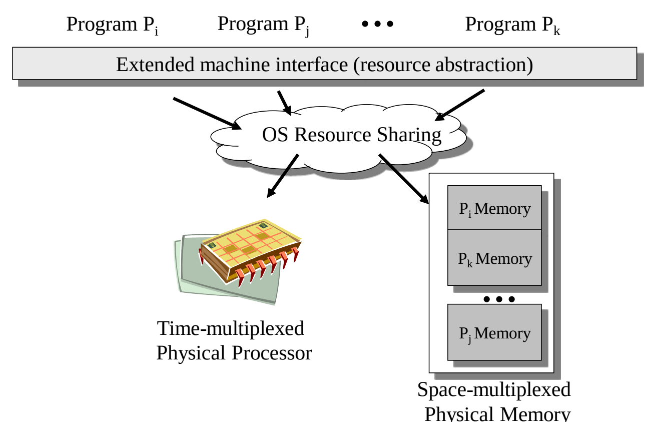
Procfs: The /proc filesystem [Killian'84]

- Processes as files: a pseudo-file system
  - a file system interface to kernel in-memory data structures
- Linux implementation originated with Bell Labs' Plan 9
- Hierarchical file system
  - Each live process has its own directory (numbered with pid)
  - Non-process-related system information in named files: e.g., cpuinfo, meminfo

Under the Abstraction

- *functional complexity*
- *a single abstraction over multiple devices*
- *replication → reliability*
- *resouce sharing*

Resource Sharing



Objectives of Resource Sharing

- Efficiency
- Fairness
- Security/protection

History

- Machine language
- Batch systems (mainframes)
- Multiprogramming and time sharing
- Graphical user interfaces, virtual memory, protection, network/distributed operating systems

Operating Systems Concepts

- Processes
- Memory management
- File systems
- Device management
- Security/protection

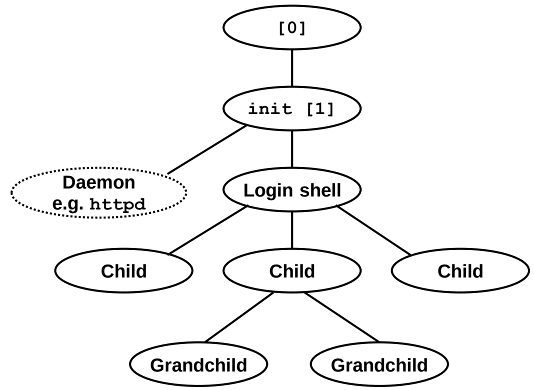
System Boot

- How does the hardware know where the kernel is or how to load that kernel?
  - Use a *bootstrap* program or loader
  - Execution starts at a predefined memory location in ROM (read-only memory)
  - Read a single block at a fixed location on disk and execute the code from that boot block
  - Easily change operating system image by writing new versions to disk

Processes

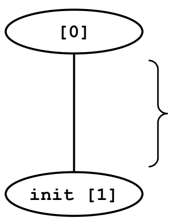
- Def: A *process* is an instance of a running program.
  - One of the most profound ideas in computer science.
  - Not the same as “program” or “processor”
- Process provides each program with two key abstractions:
  - Logical control flow
    - Each program seems to have exclusive use of the CPU.
  - Private address space
    - Each program seems to have exclusive use of main memory.
- How are these Illusions maintained?
  - Process executions interleaved (multitasking)
  - Address spaces managed by virtual memory system

Unix Process Hierarchy



Unix Startup: Step 1

1. **Pushing reset button loads the `PC` with the address of a small bootstrap program.**
2. **Bootstrap program loads the boot block (disk block 0).**
3. **Boot block program loads kernel binary (e.g., `/boot/vmlinux`)**
4. **Boot block program passes control to kernel.**
5. **Kernel handcrafts the data structures for process 0.**

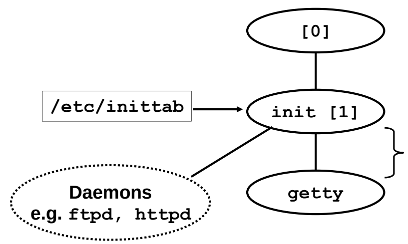


Process 0: handcrafted kernel process

Process 0 forks child process 1

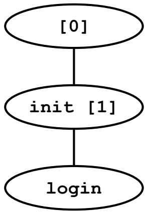
Child process 1 execs `/sbin/init`

Unix Startup: Step 2



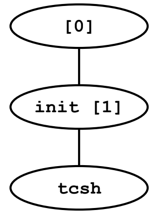
`init` forks and execs daemons per `/etc/inittab`, and forks and execs a `getty` program for the console

Unix Startup: Step 3



The `getty` process execs a `login` program

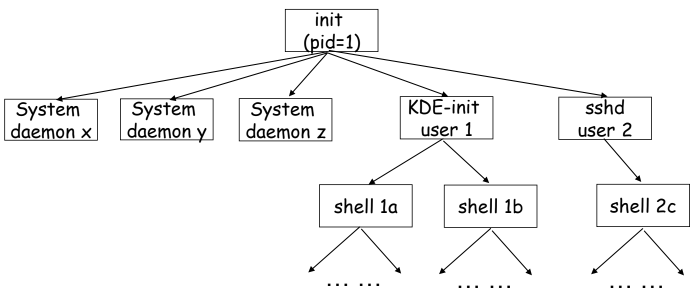
Unix Startup: Step 4



`login` reads login and passwd.
if OK, it execs a *shell.*
if not OK, it execs another `getty`

Process Tree on a Linux System

- Parent process creates children processes, which, in turn create other processes, forming a tree of processes.



Unix: fork, exec; Win32API: CreateProcess

System Protection

- User programs (programs not belonging to the OS) are generally not trusted
  - A user program may use an unfair amount of a resource
  - A user program may maliciously cause other programs or the OS to fail
- Need protection against untrusted user programs; the system must differentiate between at least two modes of operations
  1. *User mode* – execution of user programs
     - o untrusted
     - o not allowed to have complete/direct access to hardware resources
  2. *Kernel mode* (also *system mode* or *monitor mode*) – execution of the operating system
     - o trusted
     - o allowed to have complete/direct access to hardware resources

o Hardware support is needed for such protection

`fork`: Creating new processes

- `int fork(void)`
  - creates a new process (child process) that is identical to the calling process (parent process)
  - returns 0 to the child process
  - returns child's `pid` to the parent process

```
if (fork() == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

Fork is interesting (and often confusing) because it is called *once* but returns *twice*

`exit`: Destroying Process

- `void exit(int status)`
  - exits a process
    - Normally return with status 0
  - `atexit()` registers functions to be executed upon exit

```
void cleanup(void) {
   printf("cleaning up\n");
}

void fork6() {
   atexit(cleanup);
   fork();
   exit(0);
}
```

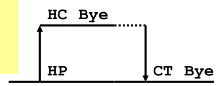

`wait`: Synchronizing with children

- `int wait(int *child_status)`
  - suspends current process until one of its children terminates
  - return value is the `pid` of the child process that terminated
  - if `child_status != NULL`, then the object it points to will be set to a status indicating why the child process terminated

`wait`: Synchronizing with children

```
void fork9() {
   int child_status;

   if (fork() == 0) {
      printf("HC: hello from child\n");
   }
   else {
      printf("HP: hello from parent\n");
      wait(&child_status);
      printf("CT: child has terminated\n");
   }
   printf("Bye\n");
   exit();
}
```



Waitpid

- `waitpid(pid, &status, options)`
  - Can wait for specific process
  - Various options

```
void fork11()
{
    pid_t pid[N];
    int i;
    int child_status;
    for (i = 0; i < N; i++)
       if ((pid[i] = fork()) == 0)
           exit(100+i); /* Child */
    for (i = 0; i < N; i++) {
       pid_t wpid = waitpid(pid[i], &child_status, 0);
       if (WIFEXITED(child_status))
           printf("Child %d terminated with exit status %d\n",
                  wpid, WEXITSTATUS(child_status));
       else
           printf("Child %d terminated abnormally\n", wpid);
    }
```

`exec`: Running new programs

- `int execl(char *path, char *arg0, char *arg1, …, 0)`
  - loads and runs executable at `path` with args `arg0`, `arg1`, …
    - `path` is the complete path of an executable
    - `arg0` becomes the name of the process
      - typically `arg0` is either identical to `path`, or else it contains only the executable filename from `path`
    - "real" arguments to the executable start with `arg1`, etc.
    - list of args is terminated by a `(char *)0` argument
  - returns `-1` if error, otherwise doesn't return!

```
main() {
   if (fork() == 0) {
      execl("/usr/bin/cp", "cp", "foo", "bar", 0);
   }
   wait(NULL);
   printf("copy completed\n");
   exit();
}
```

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User Operating-System Interface

- Command interpreter – special program initiated when a user first logs on
- Graphical user interface
  - Common desktop environment (CDE)
  - K desktop environment (KDE)
  - GNOME desktop (GNOME)
  - Aqua (MacOS X)

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Assignment #1

- Exclusively outside of the OS
- Part I: observing the OS through the /proc virtual file system
- Part II: building a shell (command-line interpreter)
  - Support foreground/background executions
  - Support pipes

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Simple Shell `eval` Function

```
void eval(char *cmdline)
{
    char *argv[MAXARGS]; /* argv for execve() */
    int bg;              /* should the job run in bg or fg? */
    pid_t pid;           /* process id */

    bg = parseline(cmdline, argv);
    if (!builtin_command(argv)) {
        if ((pid = Fork()) == 0) {   /* child runs user job */
            if (execve(argv[0], argv, environ) < 0) {
                printf("%s: Command not found.\n", argv[0]);
                exit(0);
            }
        }

        if (!bg) {   /* parent waits for fg job to terminate */
           int status;
            if (waitpid(pid, &status, 0) < 0)
                unix_error("waitfg: waitpid error");
        }
        else         /* otherwise, don't wait for bg job */
            printf("%d %s", pid, cmdline);
    }
}
```

Disclaimer

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