CSE 3221 Operating System Fundamentals

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General Info

- **Textbook:** *operating system concepts, 7th edition*
- **3 lecture hours each week**
- **2 assignments (2*5%=10%)**
- **1 project (10%)**
- **Mid-term (35%)**
- **Final Exam (45%)** (Final exam period)
- **In-class**
  - **Focus on basic concepts, principles and algorithms**
  - **Examples given in C**
  - **Brief case study on Unix series (Solaris, Linux)**
- **Assignments and tests**
  - **Use C language**
- **Policies: see course Web site**

Biobibliography

- **Required textbook**
  - **"*Operating System Concepts: 7th edition*"**
- **Other reference books (optional):**
  - "*Advanced Programming in the Unix Environment*" (for Unix programming, Unix API)
  - "*Programming with POSIX threads*" (Multithread programming in Unix, Pthread)

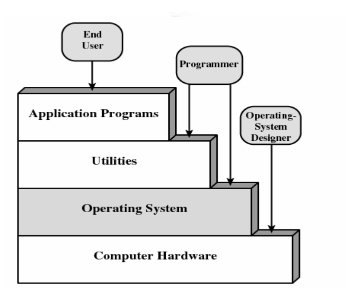
Why this course?

- OS is an essential part of any computer system
- To know
  - what's going on behind the computer screen
  - how to design a complex software system
- Commercial OS's:
  - Unix, BSD, Solaris, Linux
  - Microsoft DOS, Windows 95/98,NT,2000,XP,Vista

What is an Operating System?

- A program that acts as an intermediary between a user of a computer and the computer hardware.
- Manage computer hardware:
  - Use the computer hardware efficiently.
  - Make the computer hardware convenient to use.
  - Control resource allocation.
  - Protect resource from unauthorized access.

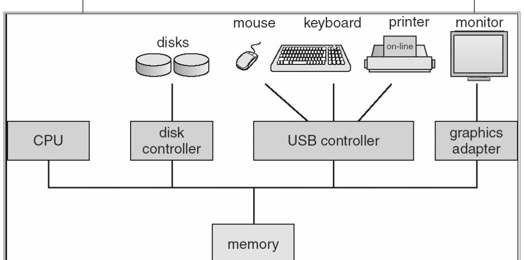
Computer Structure



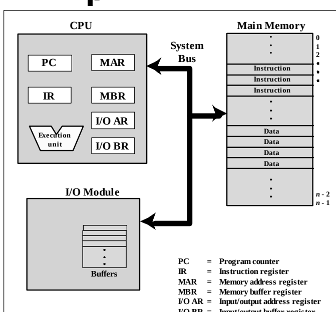
Hardware Review

- Instruction execution
- Interrupt
- Three basic I/O methods
- Storage hierarchy and caching

Computer Hardware

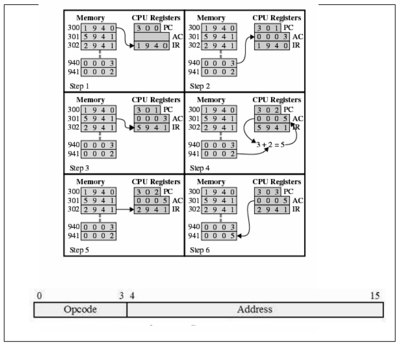


Computer Hardware



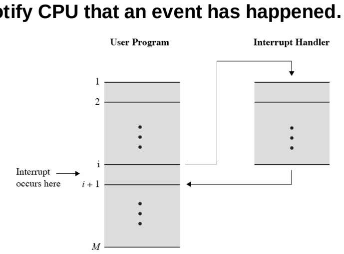
Computer Components: Top-Level View

Instruction Execution

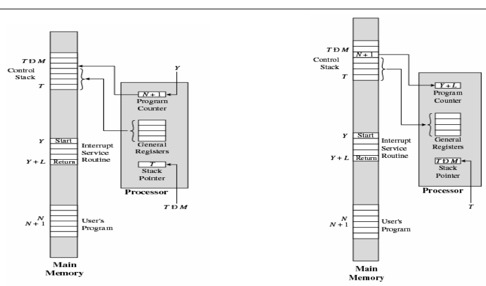


Interrupts

- A hardware signal to interrupt the normal execution sequence of CPU.
- To notify CPU that an event has happened.



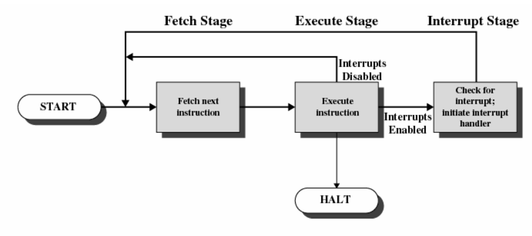
Interrupts



(a) Interrupt occurs after instruction at location N

(b) Return from interrupt

Instruction Cycle with interrupts



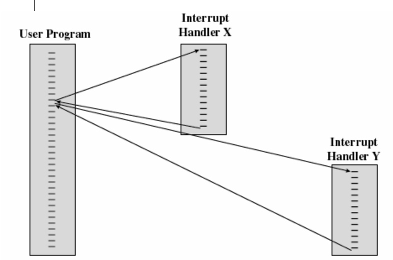
Instruction Cycle with Interrupts

Interrupt Handler

- Program or subroutine to service a particular interrupt.
- Generally part of the operating system since modern OS design is always *interrupt-driven.*
- Determines which type of interrupt has occurred:
  - *polling*
  - vectored interrupt system
- Interrupt Vectors: saved in low-end memory space

Multiple Interrupts

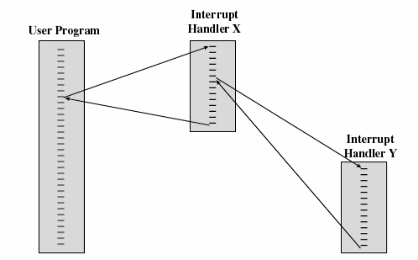
- Sequential interrupt processing: Disable interrupts while an interrupt is being processed



(a) Sequential interrupt processing

Multiple Interrupts

- Nested interrupt processing: define priority for interrupts.
- A high-priority interrupt preempts a low-priority one.

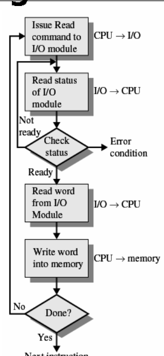


(b) Nested interrupt processing

I/O Communication Techniques

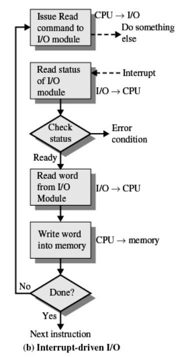
- Programmed I/O
- Interrupt-driven I/O
- Direct memory access (DMA)

Programmed I/O



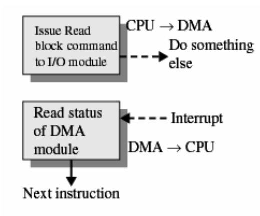
(a) Programmed I/O

Interrupt-driven I/O



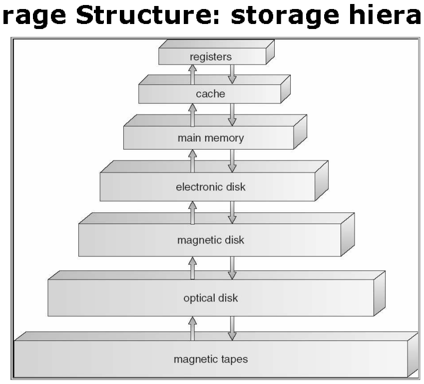
(b) Interrupt-driven I/O

DMA



(c) Direct memory access

Storage Structure: storage hierarchy



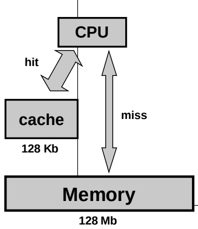
storage hierarchy

Level	1	2	3	4
Name	registers	cache	main memory	disk storage
Typical size	< 1 KB	> 16 MB	> 1 GB	> 100 GB
Implementation technology	custom memory with multiple ports, CMOS	on-chip or off-chip CMOS SRAM	CMOS DRAM	magnetic disk
Access time (ns)	0.25 – 0.5	0.5 – 25	80 – 250	5,000.000
Bandwidth (MB/sec)	20,000 – 100,000	5000 – 10,000	1000 – 5000	20 – 150
Managed by	compiler	hardware	operating system	operating system
Backed by	cache	main memory	disk	CD or tape

Volatile vs. Persistent

Caching

- **Caching is an important principle in computer system.**
- **Improve access speed with minimum cost.**
- **Caching: copy information to a faster storage system on a temporary basis.**

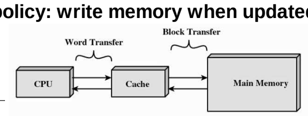


Example:

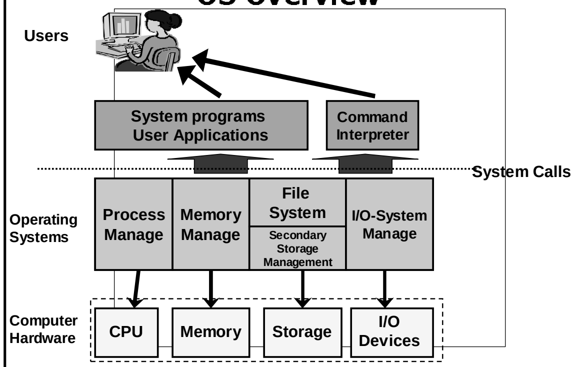
One memory access 100 nanoseconds
One cache access 20 nanoseconds
If hit rate is 99%, then
(1) 128M memory without cache: 100 nano
(2) 128M cache: 20 nano (too expensive)
(3) 128M memory + 128K cache:
0.99*20+0.01*120 = 21 nano

Caching

- **Why high hit rate?**
  - **Memory access is highly correlated**
  - **Locality of reference**
- **Normally implemented by hardware.**
- **Cache Design:**
  - **Case size**
  - **Replacement algorithm: Least-Recently-Used (LRU) algorithm**
  - **Write policy: write memory when updated or replaced.**



OS Overview



Process Management

- A *process* is a program in execution.
- A process needs certain resources, including CPU time, memory, files, and I/O devices, to accomplish its task.
- The operating system is responsible for the following activities in connection with process management.
  - Process creation and deletion.
  - process suspension and resumption.
  - Provision of mechanisms for:
    - process synchronization
    - Inter-process communication
    - handling dead-lock among processes

Main-Memory Management

- Memory is a large array of words or bytes, each with its own address. It is a repository of quickly accessible data shared by the CPU and I/O devices.
- Main memory is a volatile storage device. It loses its contents in the case of system failure.
- For a program to be executed, it must be mapped to absolute addresses and loaded into memory.
- We keep several programs in memory to improve CPU utilization
- The operating system is responsible for the following activities in connections with memory management:
  - Keep track of memory usage.
  - Manage memory space of all processes.
  - Allocate and de-allocate memory space as needed.

Secondary-Storage Management

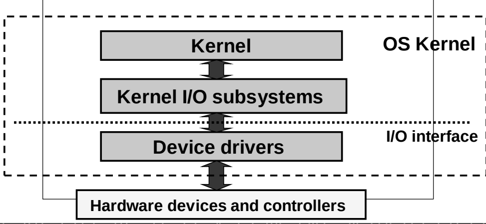
- Since main memory (*primary storage*) is volatile and too small to accommodate all data and programs permanently, the computer system must provide *secondary storage* to back up main memory.
- Most modern computer systems use disks as the principal on-line storage medium, for both programs and data.
- The operating system is responsible for the following activities in connection with disk management:
  - Free space management
  - Storage allocation
  - Disk scheduling

File Management

- File system: a uniform logical view of information storage
- A File:
  - logical storage unit
  - a collection of related information defined by its creator. Commonly, files represent programs (both source and object forms) and data.
- Files are organized into directories to ease their use.
- The operating system is responsible for the following activities in connections with file management:
  - File Name-space management
  - File creation and deletion.
  - Directory creation and deletion.
  - Support of primitives for manipulating files and directories.
  - Mapping files onto secondary storage.
  - File backup on stable (nonvolatile) storage media.

I/O System Management

- The I/O system consists of:
  - A memory-management component that includes *buffering*, *caching*, and *spooling*.
  - A general device-driver interface.
  - Drivers for specific hardware devices.



Protection System

- *Protection* refers to a mechanism for controlling access by programs, processes, or users to both system and user resources.
- The protection mechanism must:
  - distinguish between authorized and unauthorized usage.
  - specify the controls to be imposed.
  - provide a means of enforcement.

Content in this course

- Managing CPU usage
  - Process and thread concepts
  - Multi-process programming and multithread programming
  - CPU scheduling
  - Process Synchronization
  - Deadlock
- Managing memory usage
  - Memory management and virtual memory
- Managing secondary storage
  - File system and its implementation
  - Mass-storage structure
- Managing I/O devices:
  - I/O systems
- Case study on Unix series (scattered in all individual topics)

Tentative schedule (subject to change)

Totally 12 weeks:

- Background (1 week)
- Process and Thread (2 weeks)
- CPU scheduling (1 week)
- Process Synchronization (2 weeks)
- Deadlock (1 week)
- Memory Management (2 weeks)
- Virtual Memory (1 week)
- File-system and mass-storage structure (1 week)
- I/O systems (1 week)

Several must-know OS concepts

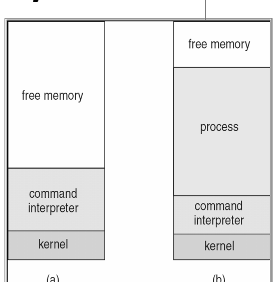
- System Boot
- Multiprogramming
- Hardware Protection
  - OS Kernel
- System Calls

System Boot

- Firmware: bootstrap program in ROM
  - Diagnose, test, initialize system
- Boot block in disc
- Entire OS loading

Simple Batch Systems

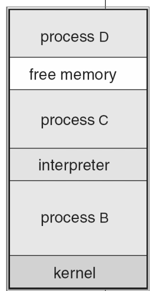
- Automatic job sequencing – automatically transfers control from one job to another.
- OS Kernel:
  - initial control in OS
  - control transfers to job
  - when job completes control transfers back to monitor
- But the CPU is often idle



Memory Layout for a Simple Batch System

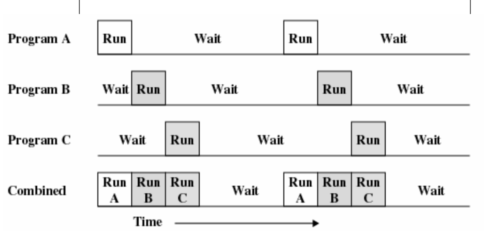
Multiprogramming System

- **Several jobs are kept in main memory at the same time, and the CPU is multiplexed among them.**
- **How to implement multiprogramming is the center of modern OS**
- **OS Features Needed for Multiprogramming**
  - Some scheduling mechanism – the system must choose among several jobs ready to run
  - Memory management – the system must allocate the memory to several jobs.
  - Allocation of devices to solve conflicts.
  - I/O routine supplied by the system.



Memory Layout for Multiprogramming System

Multiprogramming



(c) Multiprogramming with three programs

Multiprogramming: example

	JOB1	JOB2	JOB3
Type of job	Heavy compute	Heavy I/O	Heavy I/O
Duration	5 min	15 min	10 min
Memory required	50 M	100 M	75 M
Need disk?	No	No	Yes
Need terminal?	No	Yes	No
Need printer?	No	No	Yes

	Uniprogramming	Multiprogramming
Processor use	20%	40%
Memory use	33%	67%
Disk use	33%	67%
Printer use	33%	67%
Elapsed time	30 min	15 min
Throughput	6 jobs/hr	12 jobs/hr
Mean response time	18 min	10 min

Time-Sharing Systems (multitasking) –Interactive Computing

- Multitasking also allows time sharing among jobs: Job switch is so frequent that the user can interact with each program while it is running.
- Allow many users share a single computer
- To achieve a reasonable response time, a job is swapped into and out of the disk from memory.
- The CPU is multiplexed among several jobs that are kept in memory and on disk (CPU is allocated to a job only if the job is in memory).

Hardware Protection

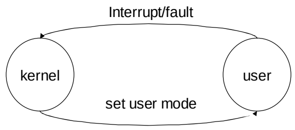
- Dual-mode Protection Strategy
  - OS Kernel
- Memory protection
- CPU protection
- I/O protection

Dual-Mode Operation

- Provide hardware support to differentiate between at least two modes of CPU execution.
  1. ***User mode*** **–** execution done on behalf of user processes.
  2. ***Kernel mode*** **(also monitor *mode* or *system mode*) –** execution done on behalf of operating system.
- A mode bit in CPU to indicate current mode
- Machine instructions:
  - Normal instructions: can be run in either mode
  - Privileged instructions: can be run only in kernel mode
- Carefully define which instruction should be privileged:
  - Change from user to kernel mode
  - Turn off interrupts
  - Set value of timer
  - etc.

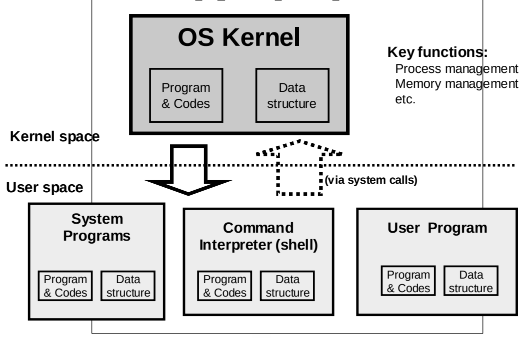
Dual-Mode Operation (Cont.)

- OS always in kernel mode; user program in user mode
- At boot time, CPU starts at kernel mode
- OS always switches to user mode before passing control to user program



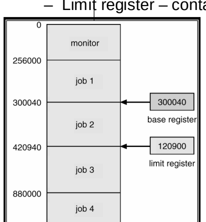
- When an interrupt or fault occurs hardware switches to monitor mode.

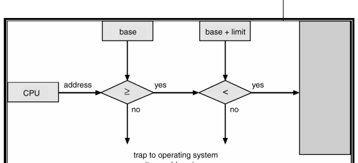
OS Kernel



Memory Protection

- Each running program has its own memory space
- Add two registers that determine the range of legal addresses:
  - base register – holds the smallest legal physical memory address.
  - Limit register – contains the size of the range





- Loading these registers are privileged instructions
- OS, running in kernel mode, can access all memory unrestrictedly

CPU Protection

- *Timer* – interrupts computer after specified period to ensure operating system maintains control.
  - Timer is decremented every clock tick.
  - When timer reaches the value 0, an interrupt occurs.
- OS must set timer before turning over control to the user.
- Load-timer is a privileged instruction.
- Timer commonly used to implement time sharing.
- Timer is also used to compute the current time.

I/O protection

- To prevent users from performing illegal I/O, define all I/O instructions to be privileged instructions.
- User programs can not do any I/O operations directly.
- User program must require OS to do I/O on its behalf:
  - OS runs in monitor mode
  - OS first checks if the I/O is valid
  - If valid, OS does the requested operation. Otherwise, do nothing
  - Then OS return to user program with status info.
- How a user program asks OS to do I/O
  - Through *SYSTEM CALL* (software interrupt)

System Calls

- System calls provide the interface between a running user program and the operating system.
- Process Control:
  - Create, terminate, abort a process.
  - Load, execute a program.
  - Get/Set process attribute.
  - Wait for time (sleep), wait event, signal event.
  - Allocate and free memory.
  - Debugging facilities: trace, dump, time profiling.
- File Management:
  - create, delete, read, write, reposition, open, close, etc.
- Device Management: request, release, open, close, etc.
- Information Maintain: time, date, etc.
- Communication.

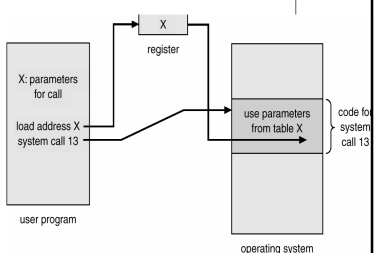
System Call Implementation

- Typically, a number is associated with each system call:
  - System-call interface maintains a table indexed according to these numbers.
- Roughly, system calls make a software interrupt (TRAP).
- The system call interface invokes intended system call in OS kernel and returns status of the system call and any return values
- Three general methods are used to pass parameters between a running program and the operating system.
  - Pass parameters in *registers*.
  - Store the parameters in a table in memory, and the table address is passed as a parameter in a register.

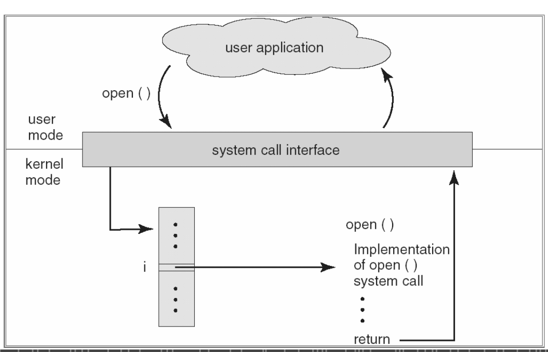
    (This approach taken by Linux and Solaris.)
  - *Push* (store) the parameters onto the *stack* by the program, and *pop* off the stack by operating system.

Parameters Passing Via Table

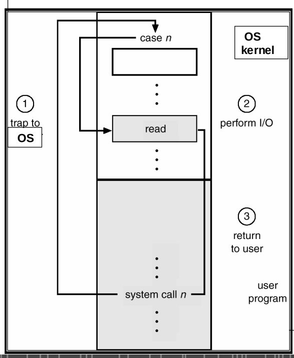
```
main()
{
   _strut_PARA  sp;

…

_set_para_(&sp) ;

_system_call_(13,&sp);

…

}
```



System Call – OS Relationship



Use of A System Call to Perform I/O



Some I/O system calls

- open(), read(), write(), close(), lseek():

```
#include <sys/stat.h>
#include <fcntl.h>
 int open(const char *path, int oflag)  ;

#include <unistd.h>
  ssize_t read(int fd, void *buf, size_t count);

#include <unistd.h>
 ssize_t write(int fd, const void *buf, size_t count);

#include <unistd.h>
 int close(int fd);

#include <unistd.h>
  off_t lseek(int fildes, off_t offset, int whence);
```

System Call vs. API

- System calls are generally available as assembly-language instructions:
  - Some languages support direct system calls, C/C++/Perl.
- Mostly accessed by programs via a higher-level Application Program Interface (API) rather than direct system call use.
- Why use APIs rather than system calls?
  - Improve portability
  - API's are easier to use than actual system calls since they hide lots of details

Standard C Library Example

- C program invoking *`printf()`* library call, which calls *`write()`* system call