CS 153
Design of Operating Systems

Fall 20

Midterm Review

Midterm

- in class on Monday (Nov 9)
- Covers material from arch support to deadlock
- Based upon lecture material and modules of the book indicated on the class schedule
  - Semaphore book: chapter 1-4
  - Closed book. No additional sheets of notes

Overview

- Architectural Support
- Processes
- Scheduling
- Threads
- Synchronization

Roles an OS

- **Abstraction**: defines a set of logical resources (objects) and well-defined operations on them (interfaces)
  - **Why?** Easier app programming
  - Humans are good at abstraction instead of details
- **Virtualization**: Isolates and multiplexes physical resources via spatial and temporal sharing
  - **Why?** Better hardware utilization, easier programming (don't need to consider co-existing programs)
- **Access Control**: who, when, how
  - **Why?** Fairness, performance, security, privacy, etc.

Arch Support

- Purpose of architecture support
  - Why we need them? Easier OS implementation

- Types of architecture support
  - Manipulating privileged machine state
  - Generating and handling events
  - Synchronization

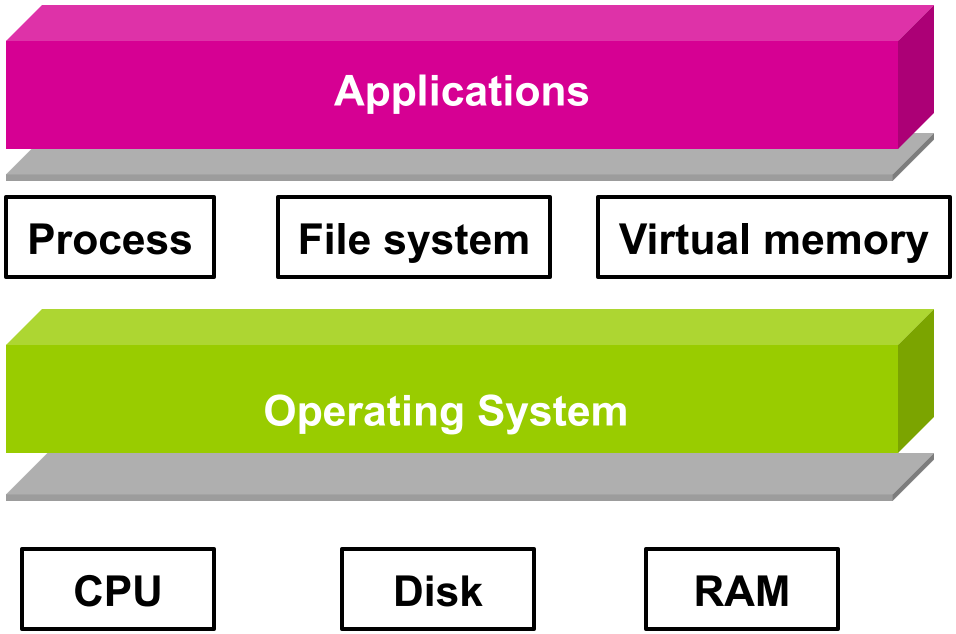
Privileged Instructions

- What are privileged instructions?
  - Who gets to execute them?
  - How does the CPU know whether they can be executed?
  - Difference between user and kernel mode
- Why do they need to be privileged?
- What do they manipulate?
  - Protected control registers
  - Memory management
  - I/O devices

Events

- Events
  - Synchronous: faults (exceptions), system calls
  - Asynchronous: interrupts, signals
- What are faults, and how are they handled?
- What are system calls, and how are they handled?
- What are interrupts, and how are they handled?
  - How do I/O devices use interrupts?
- What is the difference between exceptions and interrupts?

OS Abstractions



Processes

- What is a process?
- How do we use process to **virtualize CPU**?
- What is the difference between a process and a program?
- What is contained in a process?

Process Data Structures

- Process Control Blocks (PCBs)
  - What information does it contain?
  - How is it used in a context switch?
- State queues
  - What are process states?
  - What is the process state graph?
  - When does a process change state?
  - How does the OS use queues to keep track of processes?

Process Interface

- What **operations** can be performed on processes?
  - What does CreateProcess on Windows do?
  - What does fork() on Unix do?
    - What does it mean for it to "return twice"?
  - What does exec() on Unix do?
    - How is it different from fork?
- How are fork and exec used to implement shells?

Threads

- What is a thread?
  - What is the difference between a thread and a process?
  - How are they related?
- **Why** are threads useful?
  - Concurrency → utilizing more CPU powers
    - The thermal wall of single thread performance
  - Lightweight, fast communication
- What is the difference between user-level and kernel-level threads?
  - What are the advantages/disadvantages of one over another?

Scheduling

- **Why** we need scheduling?
  - Long-term scheduling / Goals
  - Short-term scheduling / Goals
- Components
  - Scheduler (dispatcher)
- When does scheduling happen?
  - Job changes state (e.g., running to waiting, waiting to ready)
  - Interrupt, exception
  - Job creation, termination

Scheduling Goals

- Goals
  - Maximize CPU utilization
  - Maximize job throughput
  - Minimize turnaround time
  - Minimize waiting time
  - Minimize response time
- What is the goal of a batch system?
- What is the goal of an interactive system?

Starvation

- Starvation
  - Indefinite denial of a resource (CPU, lock)
- Causes
  - Side effect of scheduling
  - Side effect of synchronization
- Operating systems try to prevent starvation

Scheduling Algorithms

- What are the properties, advantages and disadvantages of the following scheduling algorithms?
  - First Come First Serve (FCFS)/First In First Out (FIFO)
  - Shortest Job First (SJF)
  - Priority
  - Round Robin
  - Multilevel feedback queues
- What scheduling algorithm does Unix use? Why?

Synchronization

- **Why** do we need synchronization?
  - Coordinate access to shared data structures
  - Coordinate thread/process execution (active scheduling)
- What can happen to shared data structures if synchronization is not used?
  - Race condition
  - Corruption
  - Bank account example
- When are resources shared?
  - Global variables, static objects
  - Heap objects

Mutual Exclusion

- What is mutual exclusion?
- What is a critical section?
    - What guarantees do critical sections provide?
    - What are the requirements of critical sections?
        - Mutual exclusion (safety)
        - Progress (liveness)
        - Bounded waiting (no starvation: liveness)
        - Performance
- How does mutual exclusion relate to critical sections?
- What are the mechanisms for building critical sections?
    - Locks, semaphores, monitors, condition variables

Locks

- What does Acquire do?
- What does Release do?
- How can locks be implemented?
  - Test-and-set spinlocks
  - Disable/enable interrupts
- What are the limitations of using spinlocks, interrupts?
  - Inefficient, interrupts turned off too long

Semaphores

- What is a semaphore?
  - What does Wait/P/Decrement do?
  - What does Signal/V/Increment do?
  - How does a semaphore differ from a lock?
  - What is the difference between a binary semaphore and a counting semaphore?
- When do threads block on semaphores?
- When are they woken up again?
- Using semaphores to solve synchronization problems
  - Readers/Writers problem
  - Bounded Buffer problem

Deadlock

- Deadlock happens when processes are waiting on each other and cannot make progress
- What are the conditions for deadlock?
  - Mutual exclusion
  - Hold and wait
  - No preemption
  - Circular wait
- How to visualize, represent abstractly?
  - Resource allocation graph (RAG)
  - Waits for graph (WFG)

Deadlock Approaches

- Dealing with deadlock
  - Ignore it
  - Prevent it (prevent one of the four conditions)
    - Acquire recourses in the same order
  - Avoid it (have tight control over resource allocation)
  - Detect and recover from it

Let’s do some problems

- Check iLearn for keys to homework and previous exams

fork() and isolation

```
int main() {
  int count = 1;
  int pid = 0, pid2 = 0;
  if ( (pid = fork()) ) {
    count = count + 2;
    printf("%d ", count);
  }
  if (count == 1) {
    count++;
    pid2 = fork();
    printf("%d ", count);
  }
  if (pid2) {
    waitpid(pid2, NULL, 0);
    count = count * 2;
  printf("%d ", count);
  }
}
```

```
P
|
|
+----------------C1
|                |
print "3"        |
|                +------------C2
|                |            |
|           print "2"    print "2"
|                |            |
exit           wait         exit
                 |
            print "4"
                 |
               exit
```

Thread and data races

```
int count = 0; // shared variable since its global
void twiddledee() {
  int i = 0;
  for (i = 0; i < 2; i++) {
    count = count * count; // assume count read from memory once
  }
}
void twiddledum() {
  int i = 0;
  for (i = 0; i < 2; i++) {
    count = count - 1;
  }
}
void main() {
  thread_fork(twiddledee);
  thread_fork(twiddledum);
  print count;
}
```

```
dum: c2 = count // read count, c2 = 0
dum: c2 = c2 - 1 // c2 = -1
dee: c1 = count // read count, c1 = 0
dum: count = c2 // write count, count = -1
dee: c1 = c1 * c1 // c1 = 0
dee: count = c1 // write count, count = 0
main: print count // read count, count = 0
...
```

Barrier

- A group of us go to a restaurant; we wait until the last person arrives before we go in.
- This pattern is similar to the last reader thread exiting in the readers-writers pattern.

Bounded Buffer

- A cake baking thread needs three ingredients: cake mix, filling, and ice to make a cake. Each ingredient is made by a dedicated thread. Whenever we have one of each, we make a cake. The bakery can store a maximum of three portions of each ingredient.

Voting Machine

- You are writing code for the voting machines for an election. A central display shows the counter of each candidate as results come from different voting machines. You can consider each machine as a thread and counters are shared between different threads.