Operating Systems

- Most operating systems are large & complex systems
  - Most people don’t understand every aspect of them – including sysadmins and computer scientists!
  - Simple programs like “Hello, World” can be millions of lines of code
  - Many research projects study operating systems behavior

- Studying OS is learning how to deal with complexity
  - Abstractions (+interfaces)
  - Modularity (+structure)
  - Iteration (+learning from experience)
What does an OS do?

- Software layer that sits between applications and hardware
- Performs services
  - Abstrats hardware
  - Provides protection
  - Manages resources

OS vs Kernel

- Windows, Linux, Mac OS are operating systems
  - Includes system programs, system libraries, servers, shells, GUI, etc.
- Linux kernel, Windows executive, etc. – the special piece of software that runs with special privileges and actually controls the machine
- OS often equated with the kernel
Evolution of OS

• **OS as a library**
  – Abstracts away hardware, provides neat interfaces
    • Makes software portable; allows software evolution
  – Single user, single program computers
    • No need for protection: no malicious users, no interactions between programs
    • No resource sharing
  – Disadvantages of uniprogramming model
    • Expensive
    • Poor resource utilization
    • Doesn’t support complex/large applications

Evolution of OS

• **Invent multiprogramming**
  – First multi-programmed batch systems, then time-sharing systems

• Idea:
  – Load multiple programs in memory
  – Do something else while one program is waiting, don’t sit idle (see next slide)

• Complexity increases:
  – What if programs interfere with each other (wild writes)
  – What if programs don’t relinquish control (infinite loop)
Single Program vs Multiprogramming

Protection

• Multiprogramming requires isolation
• OS must protect/isolate applications from each other, but also OS from applications
  – Applications should not crash OS or other applications!

• Three techniques
  – Preemption
  – Interposition/mediation
  – Privileged mode
Protection #1: Preemption

- Resource can be given to program and access can be revoked
  - Example: CPU, Memory, Printer, “abstract” resources: files, sockets
- CPU preemption using **interrupts**
  - Hardware timer interrupt invokes OS, OS checks if current program should be preempted, done every few milliseconds in Linux
  - Solves infinite loop problem!
- Does it work with all resources equally?

Protection #2: Interposition

- OS hides the hardware
- Application have to go through OS to access resources (SYSTEM CALLS!)
- OS can interpose checks:
  - Validity (Address Translation)
  - Permission (Security Policy)
  - Resource Constraints (Quotas)
Protection #3: Privilege

- Two fundamental modes:
  - “kernel mode” – privileged
    - aka system, supervisor, or monitor mode
    - Intel calls its PL0, Privilege Level 0 on x86
  - “user mode” – non-privileged
    - PL3 on x86
- Bit in CPU – controls operation of CPU
  - Protection operations can only be performed in kernel mode.
    - Example: `hlt`
  - Carefully control transitions between user & kernel mode

OS as a Resource Manager

- OS provides “illusions”; examples:
  - Every program is run on its own CPU
  - Every program has all the memory of the machine (and more)
  - Every program has its own I/O terminal
- “Stretches” resources
  - Possible because resource usage is typically “bursty”
- Increases utilization
Resource Management

• Multiplexing increases complexity
• Car analogy:
  – Dedicated road inefficient, so sharing is needed
  – Abstraction: different lanes per direction
  – Synchronization: traffic lights
  – Capacity: build more roads/lanes
• More utilization creates contention
  – Decrease demand: slow down
  – Backoff/retry: use highway during off-peak hours
  – Refuse service, quotas: force people into public transportation
  – System collapse: traffic jam

Resource Management

• OS must decide who gets to use what resource
• Approach 1: have admin (boss) tell it
• Approach 2: have user tell it
  – What if user lies? What if user doesn’t know?
• Approach 3: figure it out through feedback
  – Problem: how to tell power users from resource hogs?
Goals for Resource Management

• Fairness
  – Assign resources equitably
• Differential Responsiveness
  – Cater to individual applications’ needs
• Efficiency
  – Maximize throughput, minimize response time, support as many apps as you can
• These goals are often conflicting
  – All about trade-offs

Summary: Core OS Functions

• Hardware abstraction through interfaces
• Protection:
  – Preemption
  – Interposition
  – Privilege (user/kernel mode)
• Resource Management
  – Virtualizing of resources
  – Scheduling of resources
“Entrance Exam”

• What is a multi-threaded process?
• What is the purpose of mutual exclusion?
• What does it mean to say an operation is atomic?
• Use a brief example to describe what a deadlock is or how it can be caused.
• What is the difference between deadlock and starvation?

“Entrance Exam”

• What is the purpose of an interrupt?
• What is priority inversion?
• What does a page table do?
• What does thrashing mean?
• What is a symbolic link?
• What is a parity bit?
• What is an i-node (or file control block)?
“Entrance Exam”

• What does it mean to **fork** a process?
• What is the danger of **caching a write**?
• What is a **page fault**?
• What is the difference between **kernel space** and **user space**?
• What is **disk fragmentation**?
• What is a **critical section**?

“Entrance Exam”

• What is a **runqueue** (or **ready queue**)?
• What is a **binary semaphore**?
• What is the difference between a **direct pointer** and an **indirect pointer** in a file system such as EXT?
• Can you name and very briefly describe a **scheduling algorithm** that would be **fair** to all tasks awaiting execution?
“Entrance Exam”

• Can you name and very briefly describe a scheduling algorithm that might be a good choice in a real-time system?
• What is a system call?
• What does it mean for a system call to block?

Next Week

• Next week:
  – OS History and Architecture