CS162: Operating Systems and Systems Programming

Lecture 1: What is an Operating System?

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https://cs162.eecs.berkeley.edu/
Example: Search Query

Components to coordinate

Many shared resources
Why take CS162?

You will build (parts of) operating systems

You will build other software using OS concepts

You will build applications that use OSes
Topics for Today

What is (or is not) an operating system?

Some common operating system abstractions

... interrupted by Logistics
What is an operating system? (1)

Layer of software that provides applications access to hardware

- Abstraction of complex hardware
- Protected access to shared resources
- Security
- Communication
History: The Computer Operator
What is an operating system? (2)

Provide programs with a more convenient "abstract" machine instead of the existing machine.
The Abstract Virtual Machine (1)

```c
#include <stdlib.h>
int main(void) {
    printf("Hello!\n")
}
```

Applications

- Threads
- Address Spaces
- Processes
- Windows
- Sockets
- Files

Operating System

ISA/Hardware interface

- CPU
  - Screen
  - Keyboard
  - Storage
  - Network
  - Input/Output
  - Memory
Abstract VM: Application View

Applications

#include <stdlib.h>
int main(void) {
    printf("Hello!\n")
}

Application's "machine" is the OS

No hardware I/O details
- Future-proof

More featureful interfaces than HW
Abstract VM: OS View

Operating system *translates* from one interface to the other.
Abstraction: Program → Process

```c
#include <stdlib.h>
int main(void) {
    printf("Hello!\n")
}
```

Start program

Operating System

ISA/Hardware interface

CPU

Screen  Keyboard  Storage  Network

Input/Output

Process

Windows

Address Spaces

Files

Threads

Sockets
Multiple Processes: Context Switch

#include <stdlib.h>
int main(void) {
    printf("Hello!\n")
}

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int main(void) {
    printf("Hello!\n")
}
Security and Protection

```
#include <stdio.h>
int main(void) {
   FILE* fh = open("/etc/shadow");
}
```

Permission Denied

Threads Address Spaces Windows Sockets Files

OS's interface

Operating System

ISA/Hardware interface

CPU

Screen Keyboard Storage Network

Input/Output

Memory

ISA/Hardware interface

ISA/Hardware interface

Input/Output
Security and Protection

#include <stdlib.h>
int main(void) {
    ...
}

Segmentation Fault

OS's Interface

Processes
Address Spaces
Threads
Windows
Files
Sockets

Operating System

ISA/Hardware Interface

CPU

Screen
Keyboard
Storage
Network

Input/Output

Memory
Interlude: Logistics
Infrastructure

Website:
https://cs162.eecs.berkeley.edu/

Piazza:
https://piazza.com/berkeley/summer2015/cs162
Textbook

Anderson and Dahlin, *Operating Systems: Principles and Practice (2nd ed)*

Recommended Text: Silberchartz, Galvin, and Gagne *Operating Systems Concepts (9th ed)*

Online supplements
– Linked off "readings"
Syllabus Summary

**OS Interfaces**: processes, I/O, sockets, ...

**Concurrency**: threads, scheduling, locks, ...

**Address spaces**: virtual memory, protection, ...

**Distributed systems**: RPC, consistency, NFS, ...

**File systems**: I/O devices, naming, caching, ...

**Reliability & Security**: fault tolerance, security, ...
Syllabus Summary

OS Interfaces: processes, I/O, sockets, ...

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File systems: I/O devices, naming, caching, ...

Reliability & Security: fault tolerance, security, ...
Learn by Doing

Homeworks: **Individual** assignments
- HW0: Tools, Autograding, C, Executables
- HW1: Simple Shell
- HW2: Malloc
- HW3: Trivial Filesystem

Projects: **Group**
- 1: Threads & Scheduling
- 2: User programs
- 3: Key-value store
Start HW0 *Immediately*

**Due Friday at 11:59 PM**

- Gets your course account
- Gets you a class repo repository on github
- Setup VM for the course
Group Projects

4 person teams
  - Never 5

Find teams soon (or we will for you)

Communicate!
  - Everyone should do work – clear responsibility!
  - Each group assigned a TA

Design documents
Project Grading

[20 pts] Initial Design + Design Review

[50 pts] Code (2 checkpoints)

[30 pts] Final Design

[0 pts] Peer Evaluation

Submission: `git push` to release branch
Grading

20% Midterm

20% Final
  - Both during class time, see schedule on web

45% Projects (15% each)

15% Homeworks (~4% each)
Collaboration Policy

OK:

- Explaining a concept to someone in another group
- Discussing algorithms/testing strategies with other groups
- Helping debug someone else’s code (in another group)
- Searching online for generic algorithms (e.g., hash table)

NOT OKAY:

- Sharing (pseudo-)code or test cases with another group
- Copying OR reading another group’s code or test cases
- Copying OR reading online code or test cases from prior years
- Sharing homework code with other members of your project group

Confused? Ask. We can't help you after you cheat.
Late Policy

Assignments are due 11:59PM Pacific Time (except initial design documents).
  - There is a "grace period"; please don't try to test it.

There are no slip days.

Submit up to 48 hours late: 20% deduction
  - Not for initial design documents for projects

Submit more than 48 hours late: no credit
  - We'll still tell you how you did, if you want...
Staff

Instructor Charles Reiss
- OH: MWF 1-2p 651 Soda

GSI Frank Nothaft
- Main discussion TA (both discussions)
- Starting Wednesday/Thursday
- Possible project TA
- OH: TuTh 1-2p 651 Soda

GSI Alex Yang
- Lead project/homework TA
- Possible project TA
- OH: MW 2-3p, Tu 5-6p 651 Soda

Readers: Nick Xu and Leon Wang
- Grade your final design docs; manual parts of homeworks; etc.
Topics for Today

What is (or is not) an operating system?

Some common operating system abstractions

... interrupted by Logistics
What is an operating system? (3)

Referee
- Resource sharing, protection, isolation

Illusionist
- Clean, easy abstractions

Glue: Common services
- Storage
- Window systems
- Authorization
- Networking
Unify theme: Complexity

All the definitions: operating systems are about hiding complexity
Challenge: Complexity

*Competing* applications with
- Unexpected *failures*
- Even *malicious* applications

*Varying* hardware with
- Diverse, evolving interfaces
- Unexpected failures

→ Not feasible to test all configurations!
Complexity Example: Mars Pathfinder

Lots of types of hardware:
- radios, scientific instruments, batteries, solar panels, and locomotion equipment

Reliability requirements:
- No reset button: must reboot self automatically
- Must always be able to receive commands from Earth

Remote debugging?
- Software will crash (e.g. instrument breaks – is that handled?)
- Need to debug from earth

Time critical functions
- Stop before hitting something
- Earth communication
Complexity: Variety

Different CPUs
  – Pentium, PowerPC, ColdFire, ARM, MIPS

Different amounts of memory, disk, …

Different types of devices
  – Mice, Keyboards, Sensors, Cameras, …

Different networking equipment
  – Cable, DSL, Wireless, Ethernet, …
Complexity: Modern Hardware

SandyBridge I/O Configuration

- Proc
- Caches
- Memory
- Busses
- Controllers
- I/O Devices:
  - Disks
  - Displays
  - Keyboards

Networks
Unifying theme: Helping the application programmer

Write once for lots of hardware

Without reimplementing common functionality

Run alongside other programs

One program crashing doesn't crash everything
Break
Abstract VM Goals

Application

Virtual Machine Interface

Operating System

Physical Machine Interface

Hardware

OS Goals:

- **Remove** hardware/software quirks *(fight complexity)*
- **Optimize** for convenience, utilization, reliability, ... *(help programmer)*

Big questions for any area of OS *(file systems, scheduling, ...)*:

- What hardware interface to handle? *(physical reality)*
- What software interface to provide? *(nicer abstraction)*
Side Note: Virtual Machines

Definition: Software emulation of *abstract machine*
- Programs believe *they own the machine*
- Simulated "hardware" has the *features we want*

Two types:
- *Process VM*: run a single program (typical OS)
- *System VM*: run entire OS + its applications
  (Virtualbox, VMWare, Parallels, Xen, ...)

Process VM

Each process thinks ...
- It has all the memory, CPU time, devices, ...
- All devices have the same interface
- Device interfaces more powerful than raw hardware:
  - Reliable TCP/IP instead of Ethernet card
  - Windowing system instead of bitmapped display

Fault isolation:
- Can't directly impact other processes
- Bugs won't crash everything

Portability: Write application for OS, not hardware
System VMs: Layers of OSs

Run entire OSs
- Good for OS development, portability

Interface closer to raw HW
- to aid porting/running OSs built to use raw HW
- different kind of "application programmer" to design for
What is an operating system? (4)

Always:
- Memory management
- I/O management
- CPU scheduling
- Communication?

Sometimes:
- Filesystems
- ? Multimedia support
- ? User interface
- ? Internet browser
What is an operating system? (5)

No universal definition

One approximation: "Everything a vendor ships when you order an OS"
  - But varies a lot!

"The one program running at all times" is the **kernel**. The rest are
  - **System programs** (ship with operating system) and
  - **Application programs**
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OS Goal: Protecting Processes

Most important task of OSs?
Run multiple applications, and...
Keep them from crashing the OS
Keep them from crashing each other
[Keep parts of OS from crashing other parts?]
Protecting Processes

Available mechanisms (hardware interfaces):
- Address translation
- Dual mode operation

Simple policy: Programs are not allowed to read or write memory of other programs or OS
Address Translation

**Abstraction**: Address space
- Group of memory addresses usable by something
- Each process, kernel have *different address spaces*
- Illusion of owning all memory

**Mechanism**: Address Translation
- Translate virtual addresses (emitted by CPU) to physical addresses
- Usually performed in HW by Memory Management Unit (MMU)
Example of Address Translation

Translation Map 1

Translation Map 2

Physical Address Space
Address Translation Details

(Covered in 61C?)

![Diagram of address translation]

Implements policy? Can't read/write if no translation

Problem:
- Can user change page table pointer?
Dual Mode Operation

**Hardware** provides at least two modes:
- "Kernel" (or "supervisor" or "protected")
- "User" mode

Some operations **prohibited** in user mode
- e.g. changing the page table pointer

**Controlled** transitions from user to kernel mode
- Systems calls, interrupts, exceptions, ...

![Diagram showing dual mode operation](image)
**UNIX System Structure**

<table>
<thead>
<tr>
<th>User Mode</th>
<th>Kernel Mode</th>
<th>Hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applications</strong></td>
<td>(the users)</td>
<td></td>
</tr>
<tr>
<td><strong>Standard Libs</strong></td>
<td>shells and commands compilers and interpreters system libraries</td>
<td></td>
</tr>
<tr>
<td><strong>Kernel</strong></td>
<td>system-call interface to the kernel</td>
<td></td>
</tr>
<tr>
<td>signals terminal handling character I/O system terminal drivers</td>
<td>file system swapping block I/O system disk and tape drivers</td>
<td>CPU scheduling page replacement demand paging virtual memory</td>
</tr>
<tr>
<td><strong>Kernel interface to the hardware</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>terminal controllers terminals</td>
<td>device controllers disks and tapes</td>
<td>memory controllers physical memory</td>
</tr>
</tbody>
</table>

- **User Mode**
  - Applications: User programs that interact with the user
  - Standard Libs: Libraries for common tasks
  - Kernel: System processes that interact with hardware
  - Hardware: Physical components of the system

- **Kernel Mode**
  - Kernel: System processes that control the system
  - Standard Libs: Libraries for common tasks
  - Hardware: Physical components of the system

- **Hardware**
  - Terminal Controllers
  - Device Controllers
  - Memory Controllers
Conclusion

Operating systems

- provide a virtual machine abstraction to handle diverse hardware
- coordinate resources and protect users from each other
- simplify application development by providing standard services
- can provide an array of fault containment, fault tolerance, and fault recovery