# Operating Systems

## INF-333

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Lecture I

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# Course website

burakarslan.com/inf333

# Based On

cs111.stanford.edu

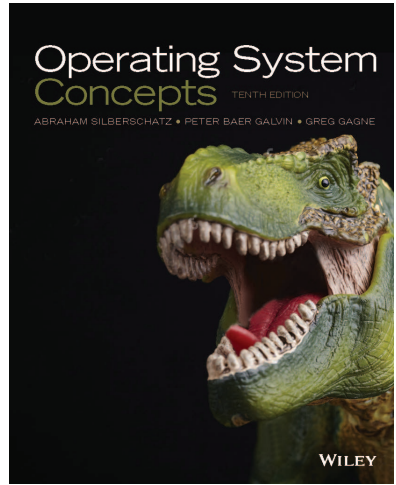
cs212.stanford.edu

OSC-10 Slides

# Book

Operating System Concepts

Silberschatz, Galvin, Gagne



# Course Structure

This is a project-driven course – you will have to do a lot of hands-on coding work!

- %70 attendance is **required**
- **%60 of grade**: 3 or 4 homeworks + 1 homework = All of the *travaux pratiques*
- **%40 of grade**: Final exam
- No midterm

# Two Courses in One

- This course: Operating Systems
- TP course: Linux Fundamentals

# Which type of OS?

- Preemtpive vs Cooperative Multitasking
- Single-user vs multi-user
- Kernel vs unikernel
- Local vs distributed
- Single Process vs Multi process

# Course Highlights

- Threads & Processes
- Concurrency & Synchronization
- Scheduling
- Virtual Memory
- I/O
  - File systems
  - Networking[1]

[1] We will have some very rudimentary coverage since we have dedicated networking courses

# Course Goals

By the end of the semester, we hope to have taught you about:

- Caching, concurrency, memory management, I/O
- Dealing with complexity, big codebases

And improved on your skills about:

- Being better team players
- Email manners 😆
- LaTeX

# Course Goals

Fact:

Knowing about OS internals will make you a more effective software engineer

# Homeworks

What kind of Code?

- We will write lots of C
- Mostly kernelspace but userspace as well

# Homeworks

You will work in groups of 2:

- Same team until the end of semester
- Course discussion between groups is encouraged
- However you are supposed to do your work in isolation
- Duplicate homeworks get **0** with no questions asked!
- Non-compiling projects get **0** with no questions asked!
- Don't miss the deadlines!

# Homeworks

You will hand in reports where you detail your solution:

- We will verify that you actually implemented your design
- Happy path coders will lose points – do proper error handling!
- Messy code will also cost you points – we need to understand your code!

# Operating Systems

A Gentle Introduction

# Intro to OS

A fundamental goal of the OS is to elevate the hardware at hand to a **well-defined abstraction level**

# Intro to OS

Some examples:

| | |
|---|---|
| **NIC** | Ethernet, WiFi, Infiniband, VPN, ... |
| **Connectivity** | USB, Bluetooth, PCI, Thunderbolt, Serial, ... |
| **Display** | HDMI, USB-C, VGA, DVI, DisplayPort, ... |
| **Input** | Keyboard, Mouse, Gamepad, Touchpad, ... |
| **FS** | xfs, zfs, ext4, ntfs, apfs, ufs, ... |

# Intro to OS

In the dark ages of consumer operating systems, ...

# Intro to OS

In the dark ages of consumer operating systems, ...

... we used DOS!

- DOS apps like video games came with drivers for:
  - Different graphics standards (EGA, VGA, Tandy, etc.)
  - Different sound cards (SoundBlaster, AdLib, etc.)
  - Memory manager (DOS/4GW)

# Intro to OS

Modern operating systems have come a long way!

A modern OS provides:

- A proper layer between applications and hardware
- (Almost) Universal interfaces to the outside world
- Some level of protection against threats from local / external malfunctioning / malicious software.

# Intro to OS

It's a mature field:

- We all use a small number of well-known operating systems
- Greenfield OS projects are a rare occurence, hardly have any impact

# Intro to OS

However the so-called mature OS are dealing with huge problems;

- Security (hacking is still a thing!)
- Scalability (making use of growing hardware capacity)
- Efficiency (performance per watt)
- Difficulty to retrofit to new types of devices that would require new approaches

# Back to basics

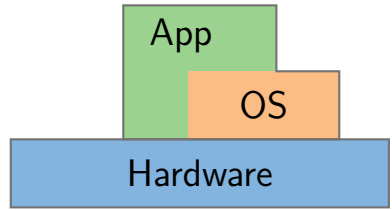
Let's go back to basics and retrace the steps of the modern operating system

# Back to basics

## Unikernel

A unikernel is a *statically linked* operating system:

- The system runs one program at a time
- No need for memory protection
- No precautions against malicious users or programs

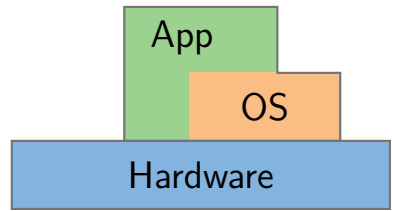


# Back to basics

## Unikernel

In the general case, this is furthest from optimal as possible:

- HUGE amount of code since it needs to have drivers, scheduler, memory manager, etc. etc.
- Can not run other tasks when idle or eg. CPU is waiting for IO
- Bad use of its users time: It's now up to the user to switch between tasks manually

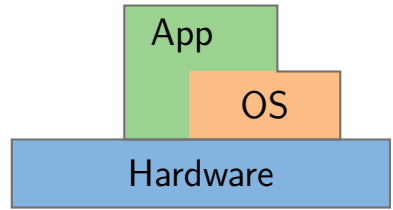


# Back to basics

## Unikernel

Not safe at all:

- It's up to the app to let other apps run (cooperative multitasking)
- The app can damage other users' data (single-user)
- The app has full access to the hardware (imagine dragons!)

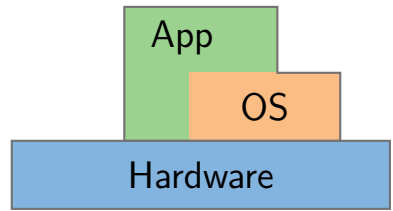


# Back to basics

## Unikernel

No program needs to be compatible with another:

- May use own file system
- May require specific hardware configuration
- That's why most of the code in early consumer operating systems consisted of the file system

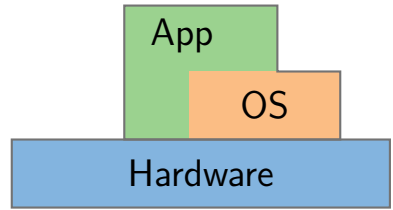


# Back to basics

## Unikernel

Also not an interesting topic of discussion:

- Today, any of you could write one given all the hardware manuals and enough time
- It's like writing games for very old game consoles!

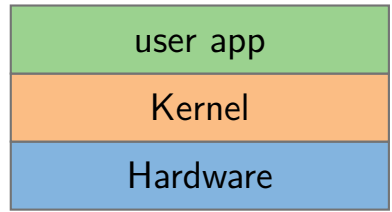


# Back to basics

## OS comes with Hardware

What if OS was “part of” the hardware instead of the application?

- User programs are now more loosely coupled with the OS
- Talks to the OS instead of the hardware
  - Of course, there may be exceptions...

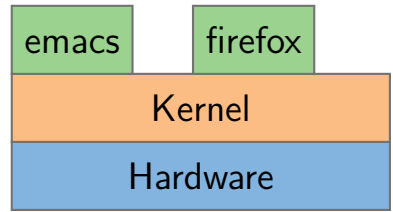


# Back to basics

## Multitasking

Maybe we could try to run other tasks when possible?

- Now we need a mechanism to protect tasks from each other
- What if a process wants to manipulate other users' data?
- What if a process wants to use all the storage capacity?

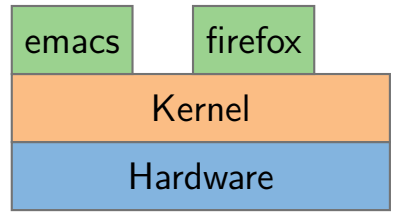


# Back to basics

## Multitasking

Solutions:

- **Preemptive scheduling**: Stop assuming well-mannered processes
- **Memory protection**: Stop processes from reading other processes' memory

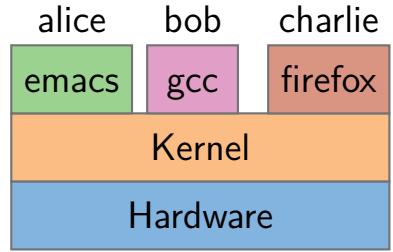


# Back to basics

## Multiple Users

Maybe we let more than one person use the computer as well?

- Now we need a mechanism to protect users from each other
- What if a process doesn't want to let others do some work?
- What if a process wants to manipulate other processes' memory?

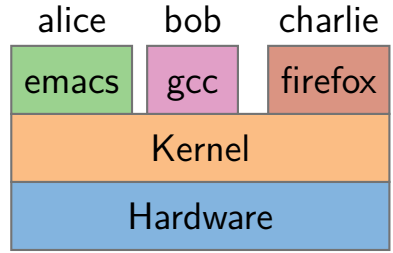


# Back to basics

## Multiple Users

Solutions:

- User authentication, permissions
- Virtual memory:
  - Allocate memory when actually used
  - Each process gets own address space
  - Swapping other processes' memory when required



# A Modern OS

Made of two essential components:

**Kernel** For privileged operations

**Userland** For everything else

$\Rightarrow$ Userland is actually optional.

# A Modern OS

The part of userland that interacts with its user(s) is called a **shell**.

## Examples

- Ba**sh** is a command line shell.
- KDE is a graphical shell (among other subsystems)
- SSH is the **S**ecure **SH**ell
- etc.

# A Modern OS

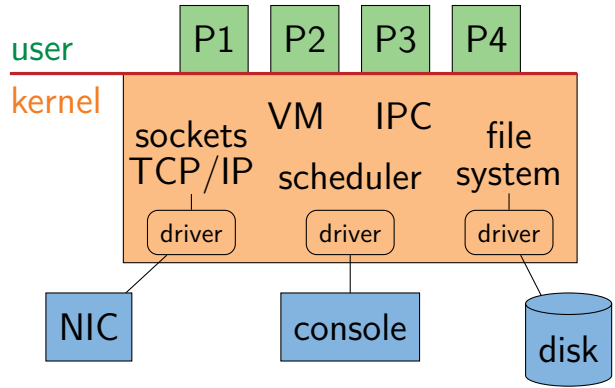
The user processes run in *user mode* where:

- The need for direct access to hardware is obviated by abstractions
- Every resource use attempt is verified

In this design, only the OS components are trusted to do the right thing.

# A Modern OS

- Most code runs as user-level processes (P[1-4])
- The kernel runs in *privileged* mode
  - Manages processes
  - Mediates access to hardware



# A Modern OS

This course will focus on the following operating systems that are:

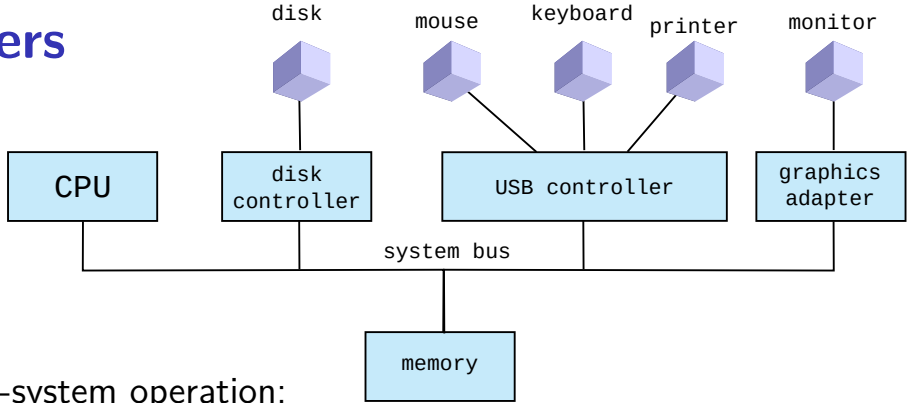
- Preemptive (not cooperative)
- Multi-user (not single user)
- Local (not distributed)
- Multi-address space / distinct kernel (not unikernel)
- Multi-process, with hardware support for memory protection

We will use Linux or similar OS to illustrate these and other concepts.

# Computers

What exactly are they?

# Computers




Computer-system operation:

- One or more CPUs, device controllers connect through common bus providing access to shared memory
- Concurrent execution of CPUs and devices competing for memory or cycles

# Computers

- I/O devices and the CPU can execute concurrently
- Each device controller is in charge of a particular device type
- Each device controller has a local buffer
- Each device controller type has an operating system device driver to manage it
- CPU moves data from/to main memory to/from local buffers
- I/O is from the device to local buffer of controller
- Device controller informs CPU that it has finished its operation by causing an interrupt

# Interrupts

- An interrupt transfers control to the interrupt service routine generally, through the **interrupt vector**, which contains the addresses of all the service routines
- Interrupt architecture must save the address of the interrupted instruction
- A trap or exception is a software-generated interrupt caused either by an error or a user request
- Operating systems are interrupt driven

# Interrupts

When an interrupt is triggered:

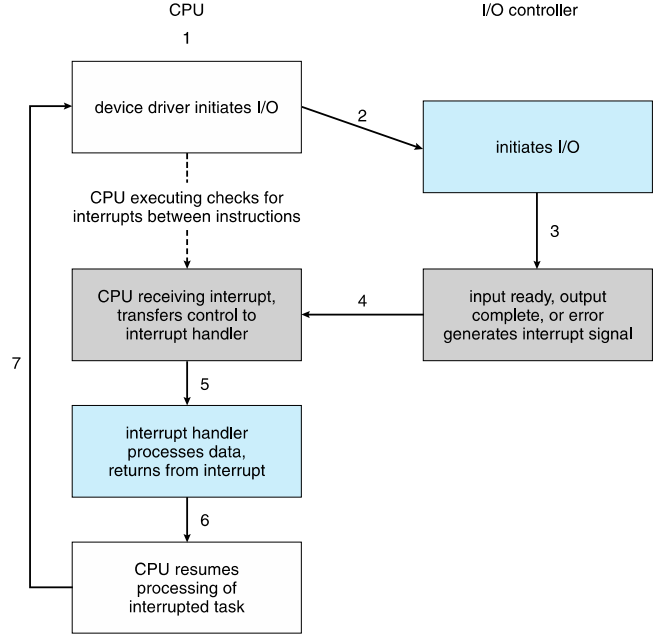
- The operating system preserves the state of the CPU by storing the registers and the program counter
- Handles the interrupt
- Restores CPU state and continues whet it left off.

# Input/Output

Two methods for handling I/O:

**Async** After I/O starts, control returns to user program without waiting for I/O completion

**Sync** After I/O starts, control returns to user program only upon I/O completion



# Input/Output

## Sync Case

The synchronous case:

- Wait instruction idles the CPU until the next interrupt
- Wait loop (contention for memory access)
- At most one I/O request is outstanding at a time, no simultaneous I/O processing

# Input/Output

## Async Case

The asynchronous case:

- System call – request to the OS to allow user to wait for I/O completion
- Device-status table contains entry for each I/O device indicating its type, address, and state
- OS indexes into I/O device table to determine device status and to modify table entry to include interrupt

# Storage Hierarchy

Storage systems are organized in a hierarchy

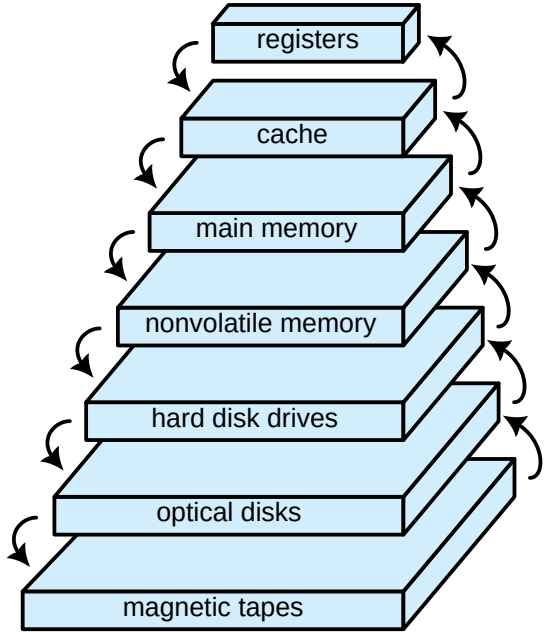
- Speed
- Latency
- Volatility

# Storage Hierarchy

**Caching** – copying information into faster storage system

## Example

- Main memory can be viewed as a cache for secondary storage



# Computer Architecture

This is the infamous **von Neumann** computer