# CE 440 Introduction to Operating System

## Lecture 22: Midterm 2 Review
## Fall 2025

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Slides courtesy of Manuel Egele, Ryan Huang and Baris Kasikci

# Administrivia

**Date：Dec. 10th (Wednesday), 4:30-6:20 pm**

**Covers material in the second half of the class**

- Most questions about lecture 10 to lecture 16
- A few basic questions for lecture 17 to lecture 20

**Closed book, two double-sided 8.5”x11” pages of notes**

**Can use a calculator but no other electronic devices**

**Based upon lectures, homework, and project**

- Do the homework to practice for the exam

# Overview

**Memory management**

**Paging**

**Page replacement Disk**

**I/O**

**File systems**

# Memory Management

## Why is memory management useful?

- Why do we have virtual memory if it is so complex?

## What are the mechanisms for implementing MM?

- Physical and virtual addressing
- Partitioning, paging, and segmentation
- Page tables, TLB

## What are the policies related to MM?

- Page replacement

## What are the overheads related to providing memory management?

# Virtualizing Memory (1)

**What are the issues with physical addressing?**

- Protection, transparency, resource exhaustion

**What are the goals of virtual memory?**

**What are the advantages of virtual memory?**

**What is the difference between a physical and virtual address?**

**Which component does the translation and management?**

# Virtualizing Memory (2)

## How does load-time linking work?

- What are its advantages and disadvantages?

## How does partitioning work?

- Fixed-sized partitioning (base)
- Variable-sized partitioning (base + bound registers)
- What are its advantages and disadvantages?

## What is internal fragmentation?

## What is external fragmentation?

# Segmentation

**What is segmentation?**

**What is a segment table?**

**How is virtual address translated with segmentation?**

**What are its advantages and disadvantages?**

**How does it compare/contrast with paging?**

**How can paging and segmentation be combined?**

# Paging

**How is paging different from partitioning?**

**What are the advantages/disadvantages of paging?**

**What are page tables?**

**What are page table entries (PTE)?**

**Know these terms**

- Virtual page number (VPN), physical page number (PPN)/page frame number (PFN), offset

**Know how to break down virtual addresses into page numbers, offset**

**How have you implemented paging in Pintos?**

# Page Table Entries

**What is a page table entry? (In Pintos?)**

**What are all of the PTE bits used for?**

- Modify
- Reference
- Valid
- Protection

# Page Tables

**Page tables introduce overhead**

- Space for storing them
- Time to use them for translation

**What techniques can be used to reduce their overhead?**

**How do two-level (multi-level) page tables work?**

**Know how to break down virtual addresses into page directory, page numbers, offset**

# TLBs

**What problem does the TLB solve?**

**How do TLBs work?**

**Why are TLBs effective?**

**How are TLBs managed?**

- What happens on a TLB miss fault?

**What is the difference between a hardware and software managed TLB?**

# Page Faults

**What is a page fault?**

**How is it used to implement demand paged virtual memory?**

**What is the complete sequence of steps, from a TLB miss to paging in from disk, for translating a virtual address to a physical address?**

- What is done in hardware, what is done in software?

# Advanced Memory Management

## What is shared memory?

## What is copy on write?

- Why is CoW useful?

## When is copy on write used?

## What are memory mapped files?

- What is the benefit of memory mapped file?
- What is its drawback?

# Page Replacement

**What is the purpose of the page replacement algorithm?**

**What application behavior does page replacement try to exploit?**

**When is the page replacement algorithm used?**

**Understand**

- Belady's (optimal), FIFO, LRU, Approximate LRU, LRU Clock, Working Set, Page Fault Frequency

**What is thrashing?**

# Dynamic Memory Allocation

**What does dynamic memory allocator do and what it cannot do?**

**What are the decisions to make?**

**What is the strategy of a best-fit and first-fit allocator, respectively?**

- What the potential problems for them

**Why is buddy allocator proposed?**

**Why is slab allocator proposed?**

# Disk

**Understand the memory hierarchy concept, locality**

**Physical disk structure**

- Platters, surfaces, tracks, sectors, cylinders, arms, heads

**Disk interface**

- How does the OS make requests to the disk?

**Disk performance**

- What steps determine disk request performance?
- What are seek, rotation, transfer?

**Disk scheduling: FCFS, SSTF, SCAN, C-SCAN**

# File Systems

**Topics**

- Files
- Directories
- Sharing
- Protection
- Layouts
- Buffer Cache

**What is a file system?**

**Why are file systems useful (why do we have them)?**

# Files and Directories

## What is a file?

- What operations are supported?
- What characteristics do they have?
- What are file access methods?

## What is a directory?

- What are they used for?
- How are the implemented?
- What is a directory entry?

# File System Layouts

**What are file system layouts used for?**

**What are the general strategies?**

- Contiguous, linked, indexed?

**What are the tradeoffs for those strategies?**

**How do those strategies reflect file access methods?**

# Unix inodes

## What is an inode?

- How are inodes different from directories?
- How to use inodes and directories used to do path resolution and find files?
  - Like in homework 3 exercise

## How Unix inodes enable both efficient access of small files and growth of large files

- Direct blocks, in-direct blocks
- How to calculate file and disk access info given some inode info?
  - Like in homework 3 exercise

## Where are inodes stored?

- What about data blocks?

# File Buffer Cache

**What is the file buffer cache, and why do operating systems use one?**

**What is the difference between caching reads and caching writes?**

# Protection

**What is file protection used for?**

**How is it implemented?**

**What are access control lists (ACLs)?**

**What are capabilities?**

**What are the advantages/disadvantages of each?**

# Advanced File Systems

**What is FFS, and how is it an improvement over the original Unix file system?**

**What is LFS, and how is it an improvement over FFS?**

**What is the file system consistent update problem?**

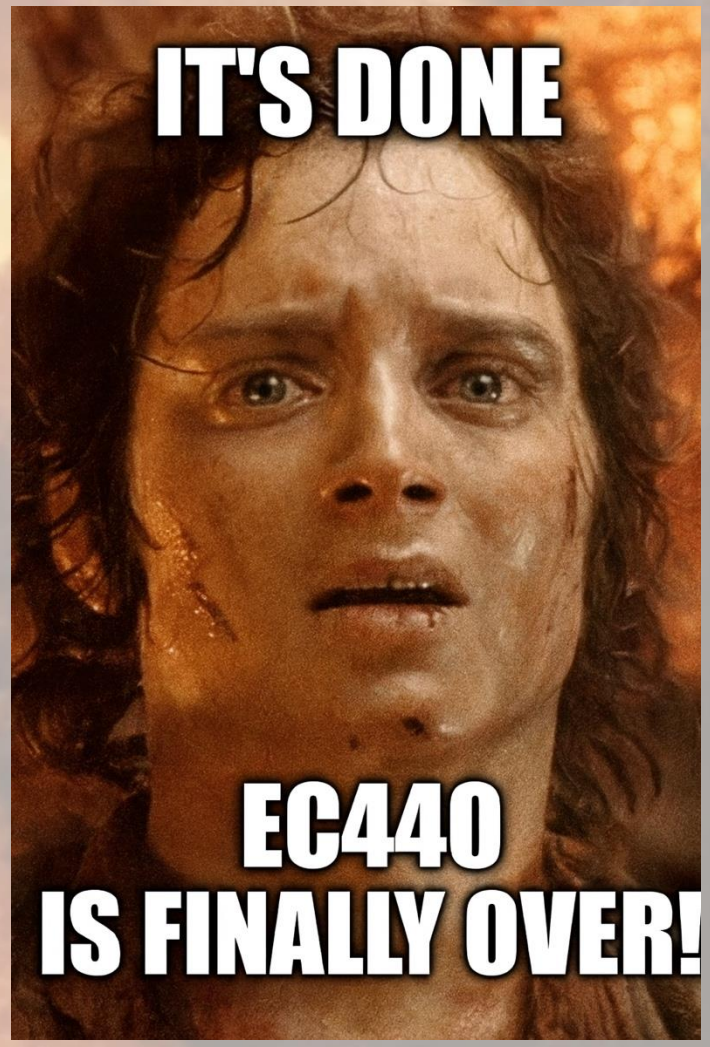
- What are the possible crash scenarios and consequences?
- What are the different strategies to do the updates?
- What problems can the file system checkers (FSCK) fix?
- What is journaling and its steps?

# Summary

**Any remaining questions?**

# Concluding Remarks

**Congratulations on (almost) surviving EC 440!**



# Concluding Remarks

**It's a challenging course**

- It takes grit to take the course and stick to the end

**But I hope you found it worthwhile**

- that it helps improve your system programming skills

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**But I hope you found it worthwhile**

- that it helps improve your system programming skills
- … and that you look at (& appreciate) OSes in a new way

# Acknowledgement

**Special thanks to students who regularly attend the class**

- It made a big difference

**Thanks to William, Matthew, and Amado**

- This is a challenging course for both students and the TA/CAs
- They spread the much of the load to make the course possible

# Four Take-Away Messages

1. **The devil is in the detail**
   - building systems needs elegant ideas, but just having ideas is far from enough

2. **Never underestimate the power of abstraction & indirection**
   - “All problems in computer science can be solved by another level of indirection” -- Butler Lampson

3. **Dare to inspect, modify and rewrite any “mysterious” software**
   - You’ve gone through the dark side, and few software is as complex as the OS

4. **System thinking**
   - Even if you forget how OS works, I hope you develop the habit of system thinking


Good luck and take care!