# CSE 451: Operating Systems

Section 9

Project 3 wrap-up, final exam review

# Project 3 wrap-up

- Make sure you're using the latest ext2fs.h from the starter code
  - It *should* work now, but bug me if it doesn't
  - You should be able to compile a file that includes ext2fs.h without errors on Linux and OS X
- Use a hex editor and dumpe2fs to compare with the filesystem attributes you see
  - Create/delete a file and see what changes

# Project 3 wrap-up

- Test a variety of filesystems
  - Large files with multiple levels of indirection
  - Filesystems with multiple block groups
  - Filesystems with different block sizes
- You *must* submit a peer evaluation to Pete to receive credit for project 3 by June 4
  - Don’t submit them to me (i.e. not Elliott)
- Any project 3 questions?

# Final exam review

- Goal of this section: key concepts you should understand
  - Not just a summary of lectures
  - Slides may not cover all topics that will be on exam

# Thread management

- Queues
  - Why do thread libraries make use of queues?
- Synchronization
  - What are the mechanisms for protecting critical sections, how do they work, and when should one be used over another?
- Preemption
  - What is preemption and how does the process of one thread preempting another work?

# Memory management

- Purposes:
  - Resource partitioning / sharing
  - Isolation
  - Usability
- Paging
- Segmentation

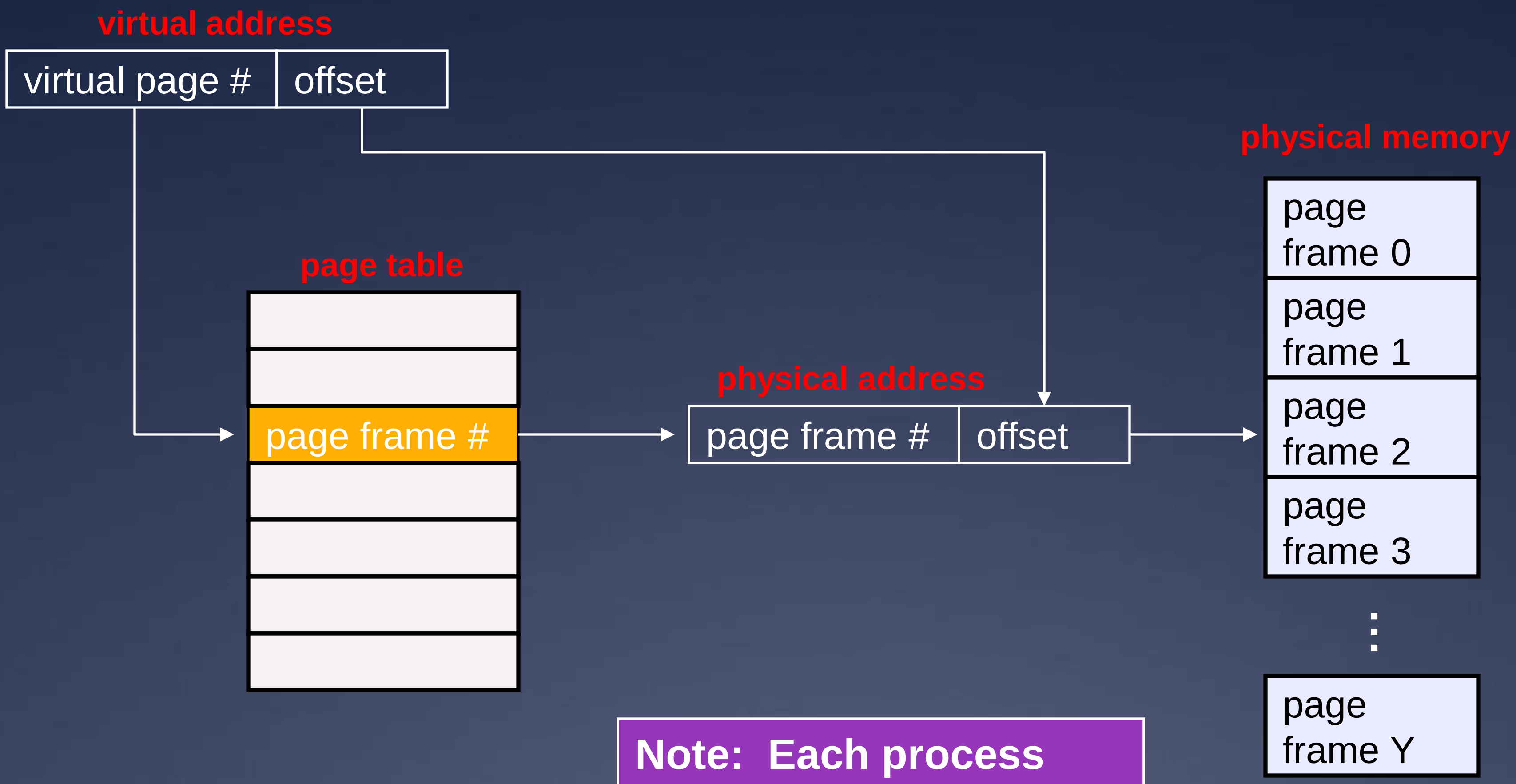
# Virtual memory

- What happens on a virtual memory access?

# Virtual memory

- What happens on a virtual memory access?
  - Address translation: who performs it?
    - Page table lookup
    - Translation Lookaside Buffer (TLB)
  - Page fault?
    - Page replacement
    - Process/queue management
- How does all of this overhead pay off?
  - Locality! Both temporal (in time) and spatial (nearby).

# Virtual memory



virtual address

virtual page # | offset

page table

page frame #

physical address

page frame # | offset

physical memory

page frame 0

page frame 1

page frame 2

page frame 3

⋮

page frame Y

**Note: Each process has its own page table!**

# Page replacement

- Algorithms:
  - Belady, FIFO, LRU, LRU clock / NRU, random, working set…
  - Local vs. global
- How/why are any of these better or worse than the others?
- What happens when paging goes wrong?
  - Thrashing, 10-year old computers running XP

# Advanced virtual memory

- What problem does a TLB address?
- What problem do two-level page tables address?
  - What's the key concept?

# Advanced virtual memory

- What problem does a TLB address?
  - Increases speed of virtual address translation
- What problem do two-level page tables address?
  - What's the key concept?
    - Indirection

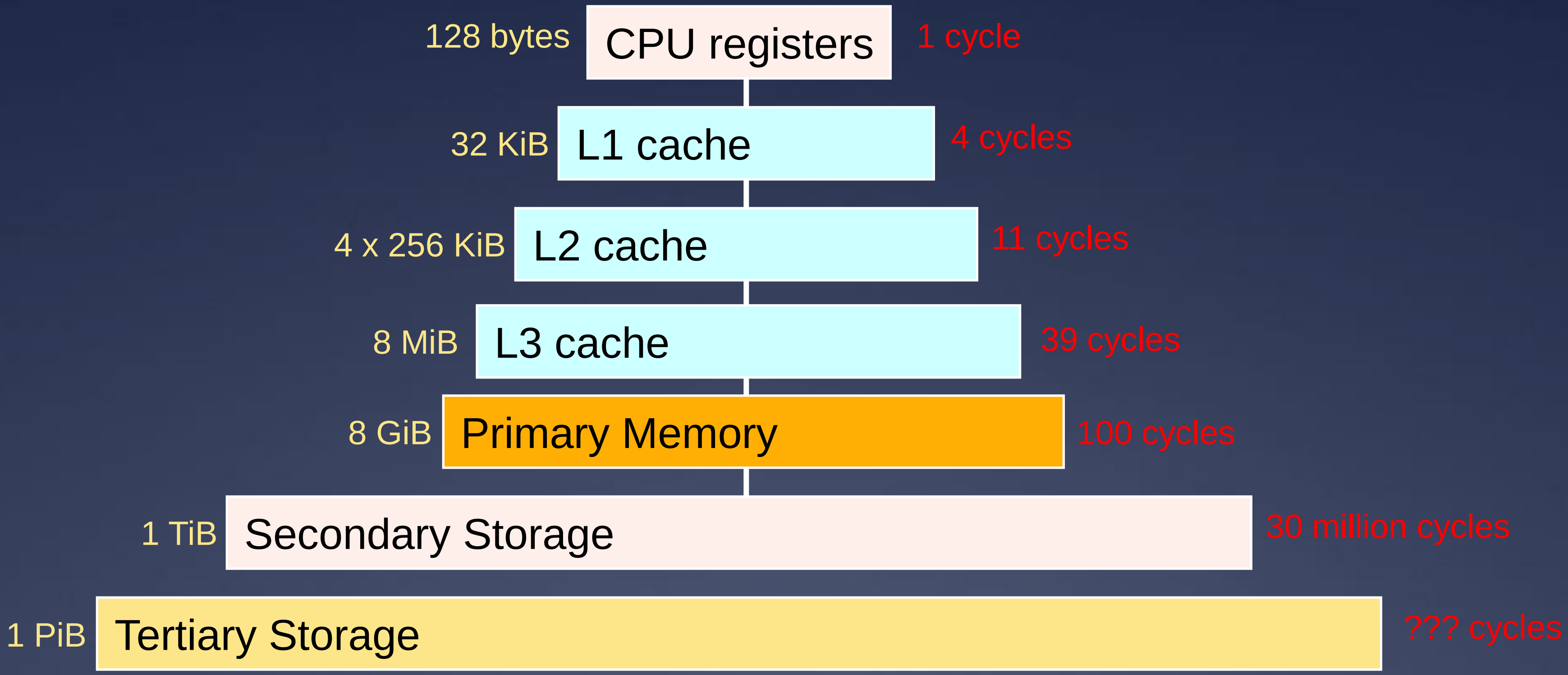
# Secondary storage

- Memory forms a hierarchy
- Different levels of disk abstraction:
  - Sectors
  - Blocks
  - Files
- What factor most influences the ways that we interact with disks?

# Secondary storage

- Memory forms a hierarchy
- Different levels of disk abstraction:
  - Sectors
  - Blocks
  - Files
- What factor most influences the ways that we interact with disks?
  - Latency

# Memory hierarchy



| | | |
|---|---|---|
| 128 bytes | CPU registers | 1 cycle |
| 32 KiB | L1 cache | 4 cycles |
| 4 x 256 KiB | L2 cache | 11 cycles |
| 8 MiB | L3 cache | 39 cycles |
| 8 GiB | Primary Memory | 100 cycles |
| 1 TiB | Secondary Storage | 30 million cycles |
| 1 PiB | Tertiary Storage | ??? cycles |

- Each level acts as a cache of lower levels
  - (Stats more or less for Core i7 3770)

# File systems

- What does a file system give you?
  - Useful abstraction for secondary storage
  - Organization of data
    - Hierarchy of directories and files
  - Sharing of data

# File system internals

- Directories
- Directory entries
- Inodes
- Files:
  - One inode per file
  - Multiple directory entries (links) per file

# Inode-based file system

- Sequence of steps when I run *echo “some text” > /homes/pjh/file.txt* ?
  - Open file:
    - Get inode for / -> get data block for /
    - Read directory entry for / -> get inode for /homes
    - Repeat… -> get data block for file.txt, check permissions
  - Write to file:
    - Modify data block(s) for file.txt in buffer cache
  - Close file:
    - Mark buffer as dirty, release to buffer cache
    - Kernel flushes dirty blocks back to disk at a later time

# Other file systems

- What problem does each of these address?
  - BSD Unix fast file system (FFS):
    - Performance: smarter physical disk layout
  - Journaling file systems (JFS):
    - Reliability: transactions prevent inconsistencies after crash
  - Berkeley log-structured file system (LFS):
    - Performance: even smarter physical disk layout?

# RAID

- Striping: read/write from multiple disks simultaneously
  - Improves performance
  - Hurts reliability
- Parity: store redundant information to allow data recovery after disk failures
  - Improves reliability
  - Hurts performance

# Networking

- Layering
- Encapsulation

# RPC

- Benefits:
  - Low-level details taken care of for you
  - Natural interface
- Implementation issues:
  - Network failures / retries
  - Architecture differences
  - Performance

# Distributed file systems

- Why do we want them?
  - Location independence
  - Large-scale data sharing
- Why are they hard?
  - Consistency
  - Replication
  - Performance
- Understand the target workloads

# Distributed systems

- Scalability
  - Limited by sharing
    - How does this relate to multi-core CPUs?
  - Does more nodes equal more performance?
  - How do companies like Amazon, Facebook, Google, Microsoft, etc. parallelize workloads?

# Virtual machine monitors

- VMM is an additional layer between OS and hardware
  - Can interpose on instruction execution, memory accesses, I/O requests, and network communication

# Security

- Symmetric (secret key) vs. asymmetric (public key) encryption
- Privacy/confidentiality vs. integrity

# Course evaluations!