CS 370: OPERATING SYSTEMS

[FILE SYSTEMS]

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CS370: Operating Systems [Fall 2018]
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Frequently asked questions from the previous class survey

- Type-1 or Type-2? Which is better?
- Binary translation: How do you emulate an instruction?
- VMs inside VMs?
- Is the shadow table a copy of the real page table?
- Why not allocate memory to VMs contiguously?
- Does the ring in you are in dictate *which* instructions you can run?
- How risky is it for a new company to say they only want and no data centers of their own?

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Topics covered in this lecture

- □ File System Structure
- □ File System Implementation
- □ Allocations
  - □ Contiguous allocation

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Memory is the treasury and guardian of all things.

— Marcus Tullius Cicero

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Rationale: Applications need to store and retrieve information

- □ A program can store a **limited** amount of information in its own address space

- □ Storage capacity is **restricted** to the size of virtual memory
  - □ Far too small for several applications
    - ■ Airline reservations, banking, directory services etc

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Rationale: Information in the address space of a process is not persistent

- □ When process terminates, information is lost

- □ For many applications information must be **retained** for a much longer time
  - □ Weeks, Years, Forever

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Rationale: Multiple processes often need to access (parts of) information at the same time

- Storing an online telephone directory in the address space of one process?
  - Only that process can access the info
  - Only one telephone number can be looked up at a time

Essential requirements for long-term storage

1. **Store** a very large amount of information
2. Information must **survive** process termination
3. Multiple processes must be able to **concurrently access** the information

- Store information on disk or external media
  - In units called **files**
    * If you printed 1 TB of data as text on paper, you would produce a stack about 20 miles high.

Files are an abstraction mechanism

- Provide a way to store information and read it back later
- Do this is an way that **shields** the user from
  - <u>How</u> and <u>where</u> information is stored on disk
  - How disks really work

Naming files

- Important characteristic of the abstraction mechanism
- Data must be shared across programs
  - Storage systems must provide ways to easily identify data of interest
- Strings 8-255 characters long
- Most OS support two-part file names separated by a period
  - Last part referred to as the **file extension**
    - Conventions: Easy to remember
    - Enforced in some cases e.g. the compiler

Files can be structured in many ways:
Unstructured sequence of bytes

- The OS does not know or care what is in the file
  - Maximum **flexibility**
- OS does not help, but does not get in the way either
- Meaning is imposed by programs
- Most OS support this

File Structure: A sequence of records

- A file is a sequence of **fixed-length** records
- Read operation returns one record
  - Write operation overwrites/appends one record
- 80-column punch card used to be dominant
  - Files consisted of 80 character records

Directory and disk structure

- Typically, there are millions of files within a computer
- Storage device can be used in its entirety for a file system
- It could also be **partitioned**
  - Limit size of individual file systems
  - Put multiple file system types
  - Set aside for **swap space**

Directories are used to organize files

- Can be viewed as a **symbol table**
- In many systems directories themselves are files
- Supported operations
  1. Insert, delete, search, list and rename entries
  2. Traversal

Organization of directories

- Single level directory
- Two-level directory
- Tree-structured directories
- Acyclic graph directories
  - Shared sub-directory

Mounting file systems

- Many systems have more than one disk
  - How do you handle them?

- **S1**:Keep self contained file system on each disk
  - And keep them separate

- **S2**: Allow one disk to be **mounted** in another disk's file tree

Mounting file systems

cp D:/x /a/d/x
H is default

cp /b/x /a/d/x

Checks performed during mounting

- OS **verifies** that the device contains a valid file system
- Read device directory
  - Make sure that the format is an expected one
- Windows mounting
  - Each device in a separate name space
  - {Letter followed by a colon e.g. **G:**}

FILE SYSTEM STRUCTURE

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Nonvolatile storage and file systems

- Technologies such as magnetic disks and high-density flash **do not allow** random access to individual words of storage
  - Instead, access must be done in coarser-grained units — 512, 2048, or more bytes at a time
- Furthermore, these accesses can be much slower than access to DRAM (5-6 orders of magnitude)
- This large difference drives the OS to organize and use persistent storage devices differently than main memory

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Disks provide the bulk of secondary storage

- A disk can be **rewritten** in place
  - Read, modify, and then write-back to same place
- Disks can **directly access** any block of information
- I/O transfers between memory and disk are performed in units of **blocks**

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There are two core design problems in file systems

- Defining how the file system should **look** to the user
- Creating algorithms and data structures to **map** logical file system onto physical storage

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There are many levels that comprise a file system

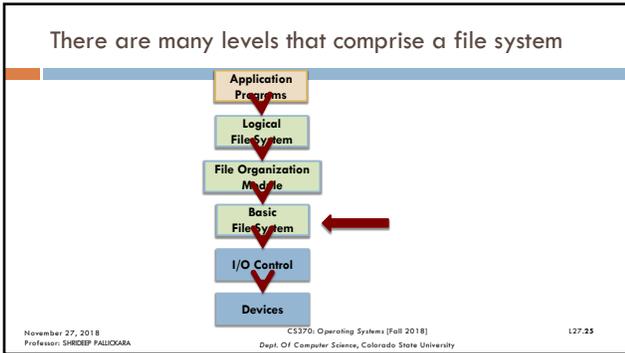Application Programs
↓
Logical File System
↓
File Organization Module
↓
Basic File System
↓
I/O Control
↓
Devices

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I/O Control consists of device drivers

- Transfers information *between main memory and disk*
- Receives **high-level** commands
  - Retrieve block 123, etc
- Outputs low-level, hardware-specific instructions
  - Used by the hardware controller
  - Writes bit patterns into specific locations of the I/O controller

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There are many levels that comprise a file system

Application Programs
Logical File System
File Organization Module
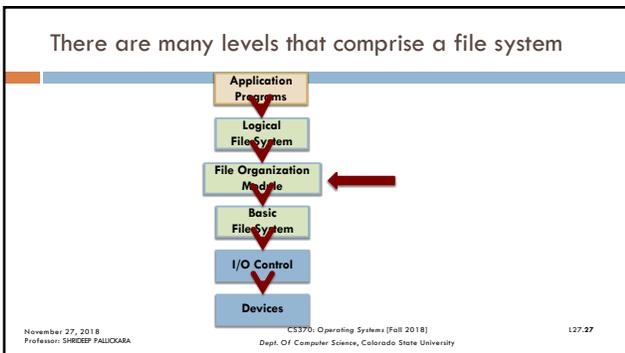Basic File System ←
I/O Control
Devices

Basic file system issues commands to the device driver

☐ Read and write physical blocks on disk
- E.g. Drive 1, cylinder 73, sector 10

☐ Manages **buffers and caches**
① To hold file system, directory and data blocks
② Improves performance

There are many levels that comprise a file system

Application Programs
Logical File System
File Organization Module ←
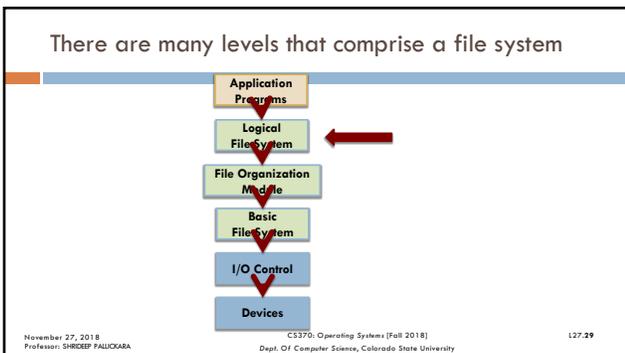Basic File System
I/O Control
Devices

File organization module

☐ Knows about files
- Logical and physical blocks

☐ **Translate** logical addresses to physical ones
- Needed for every block

☐ Includes a **free space manager**
- Tracks unallocated blocks and allocates as needed

There are many levels that comprise a file system

Application Programs
Logical File System ←
File Organization Module
Basic File System
I/O Control
Devices

The logical file system

☐ Manages **metadata** information
- Metadata is *data describing the data*

☐ Maintains file structure via **file control blocks**
- Info about the file
  - Ownership and permissions
  - Location of file contents
- **inode** in UNIX file systems

Several file systems are in use

- CD-ROMs written in ISO 9660 format
  - Designed by CD manufacturers
- UNIX
  - Unix file system (**UFS**)
  - Berkley Fast File System (**FFS**)
- Windows: **FAT, FAT32** and **NTFS**
- Linux
  - Supports 40 different file systems
  - Extended file system: **ext2, ext3** and **ext4**

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THE ANATOMY OF A DISK

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Using a magnet and a nail for instant messaging?   [1/2]

- **Message**: See you later; or not

- Drop a nail in your friend's mailbox
  - If nail is magnetized?   You'll see the friend
  - If nail is not magnetized?   You won't

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Using a magnet and a nail for instant messaging?   [2/2]

- Your friend comes home and picks up the nail
  - Uses the nail to pick up a paper-clip
    - If it sticks? Friend will expect to see you

- Magnetism can be used to store information!

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Using magnetism to store information

- Store information even when you turn power off!

- Storing …**10001**…?
  - Magnetize first bit
  - Demagnetize next 3
  - Magnetize the next bit

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The anatomy of a disk

- A disk comprises a set of **platter**s
  - These have a flat, circular shape
  - Usually made of glass or aluminum
- Both surfaces of a platter covered with **magnetic material**
  - Store information by recording it magnetically
- A platter is logically divided into circular **tracks**
  - These are subdivided into **sectors**

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Rates and times associated with disks

- Rate of data movement between the disk and the memory
  - **Transfer rate**

- Positioning time
  - **Seek time**
    - Move disk arm to the necessary cylinder
  - **Rotational latency**
    - Time for the desired sector to rotate to the disk head

How about CD-ROMs, DVDs, and Blu-Rays? [1/2]

- Data written with the help of *high intensity* laser that makes "**pits**" on the reflecting surface
- During reads:
  - Use a lower intensity laser
  - Mirrors and a focusing lens are used to shine light on a specific portion of the disk
  - The amount of light that is *reflected back* depends on the presence or absence of a pit
    - Use this to interpret a 1 or 0

How about CD-ROMs, DVDs, and Blu-Rays? [2/2]

- The *shorter* the wavelength, the *smaller* the pit
  - And greater the density of what can be stored
- DVD uses a 650 nm wavelength laser diode
  - 780 nm for CD
  - Pit sizes: DVD = 0.74 μm and CD = 1.6 μm
- What about Blu-Ray?
  - 405 nm wavelength, 0.13 μm pit size
  - 50 GB storage possible on one disk
- What's next?
  - Archival Disc (Sony/Panasonic) 79.5 nm with 300 GB of data storage

FILE SYSTEM IMPLEMENTATION

On-disk structures used to implement a file system [1/2]

- **Boot control block**
  - Information needed to boot an OS from that volume

- **Volume control block**: Volume information
  - Number of blocks in the partition
  - Size of the blocks
  - Free-block count/pointers
  - Free file-control-block count/pointers
  - UFS: **super-block**   Windows: **Master file table**

On-disk structures used to implement a file system [2/2]

- Directory structure to organize files
  - One per file system

- Per file file-control-block
  - Contains details about individual files

In memory structures used to improve performance via caching

- **Mount** table
  - Information about each mounted volume
- Directory structure **cache**
  - Holds information about recently accessed directories
- System-wide **open file** table
  - File control block of each open file
- **Buffers** to hold file-system blocks
  - To read and write to storage

Creation of a new file

- **Allocate** a file-control block (FCB)
- Read appropriate directory into memory
  - Directory is just a file in UNIX
    - Special **type** field
- **Update** directory with new file name and FCB
- Write directory back to disk

Partitions: A disk can be sliced into multiple partitions

- **Cooked**
  - Has a file system

- **Raw**
  - No file system
  - UNIX swap space uses this
  - Hold information needed by disk RAID (*R*edundant *A*rray of *I*ndependent *D*isks) systems

Boot information can be stored in a separate partition

- Usually a **sequential** series of blocks
  - Loaded as an image into memory
- Image execution starts at a predefined location

DIRECTORY IMPLEMENTATION

Directory Implementation

- Linear List
- Hash Table

Directory Implementation
Linear List

- File names with pointers to data blocks
- Simple to program
  - Inefficient and slow execution
- Finding a file requires a **linear search**
- Sorted list
  - Complicates creation and deletion
- Tree data structures might help here
  - B-Tree

Directory implementation:
Hash table

- Linear list **and** a hash table is maintained
- Key computed from file name
  - Hash table value returns pointer to entry in linear list
- Things to consider
  1. Account for **collisions** in the hash space
  2. Need to **rehash** the hash table when the number of entries exceed the limit

Allocation methods:
Objective and approaches

- How to allocate space for files such that:
  - Disk space is utilized effectively
  - File is accessed **quickly**

- Major Methods
  - Contiguous
  - Linked
  - Indexed

CONTIGUOUS ALLOCATIONS

Contiguous Allocation

- Each file occupies a set of contiguous blocks on the disk
  - If file is of size **n** blocks and starts at location **b**
    - Occupies blocks **b, b+1, ..., b+n−1**

- Disk head movements
  - None for moving from block **b** to (**b+1**)
  - Only when moving to a different track

Sequential and direct access in contiguous allocations

- Sequential accesses
  - Remember *disk address* of the last referenced block
  - When needed, read the next block

- **Direct access** to block **i** of file that starts at block **b**
  - **b + i**

Contiguous allocations suffer from external fragmentation

☐ **Free space is broken up into chunks**
    ▪ Space is **fragmented**

☐ Largest continuous chunk may be insufficient for meeting request

☐ **Compaction** is very slow on large disks
    ▪ Needs several hours

Determining how much space is needed for a file is another problem

☐ **Preallocate** if eventual size of file is known?
    ▫ Inefficient if file grows very slowly
        ▪ Much of the allocated space is unused for a long time

☐ Modified contiguous allocation scheme
    ▫ Allocate space in a continuous chunk initially
    ▫ When space runs out allocate another set of chunks (**extent**)

The contents of this slide-set are based on the following references

☐ *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330. [Chapter 4]*

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