# CSE 120: Principles of Operating Systems
# Lecture 11: File System

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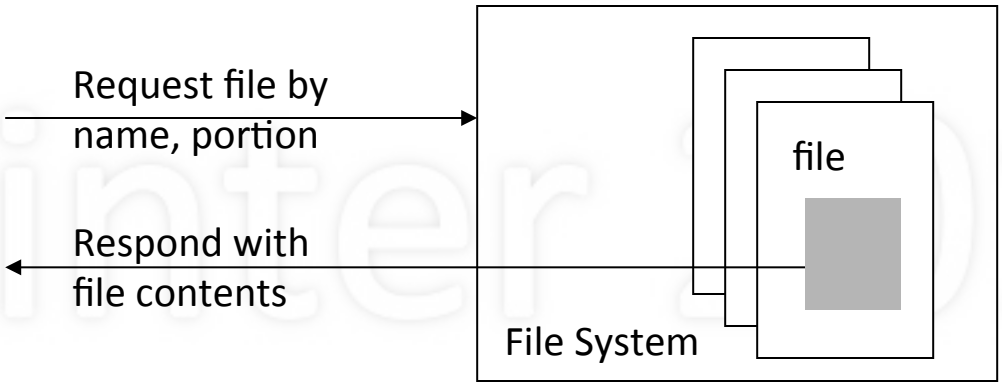
February 20, 2019

# What is a File? File System?




- File: logical unit of storage, container of data
  - Accessed by <name, region within file>
- File System: a structured collection of files
  - Access control, name space, persistent storage

# File System Abstraction

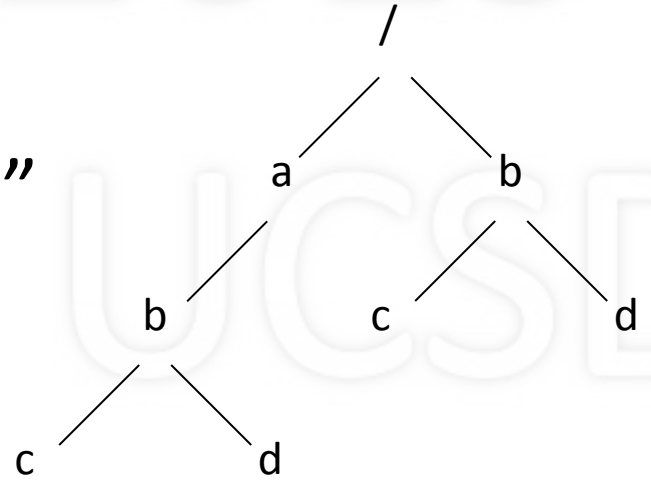
- Repository of objects
  - Objects are data, programs, for system, users
  - Objects referenced by name, to be read/written
- Persistent: remains "forever"
- Large: "unlimited" size
- Sharing: controlled access
- Security: protecting information

# More than a Repository

- Any/all objects where following make sense
  - Accessed by name
  - Can be read and/or written
  - Can be protected: read-only, read-write, …
  - Can be shared
  - Can be locked
- I/O devices: disk, keyboard, display, …
- Processes: memory

# Hierarchical File Name Space

- Name space is organized as a tree
  - Name has components, branches start from root
  - No size restrictions
  - Intuitive for users
- Example: UNIX “pathnames”
  - Absolute: /a/b/c
  - Relative: b/c relative to /a
  - Not strictly a tree: links



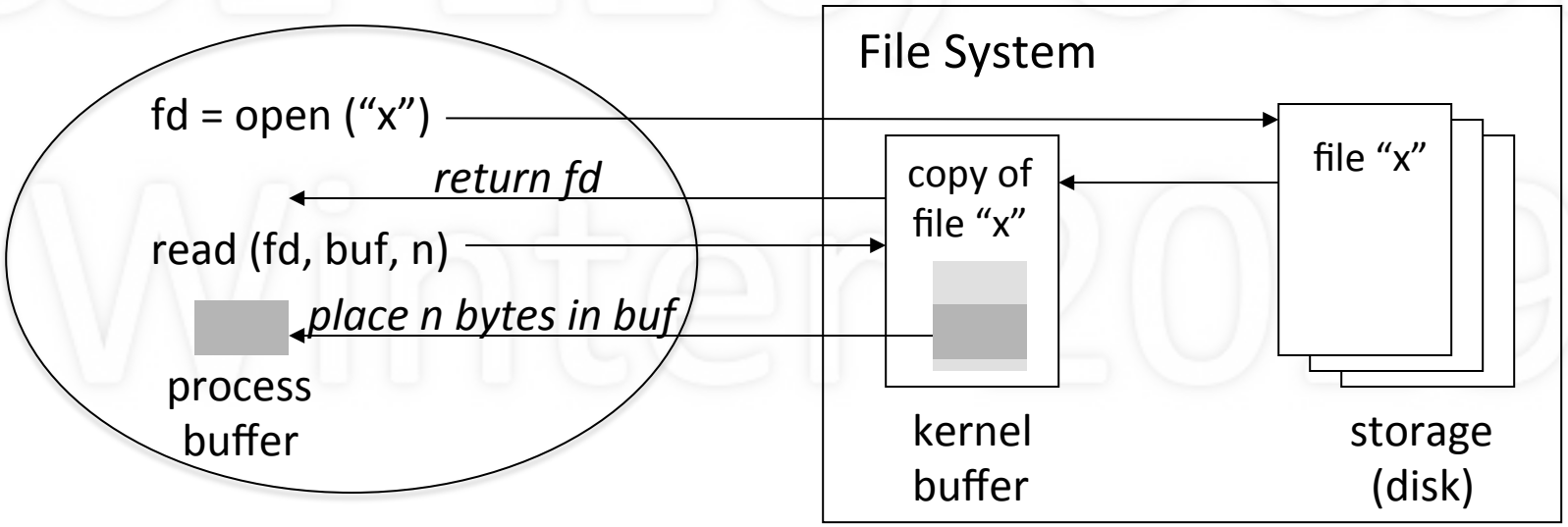
# A File Has Attributes

- Type (recognized by system or users)
- Times: creation, accessed, modified
- Sizes: current size, maximum size
- Access control (permissions)

# File Operations

- Creation: create, delete
- Prepare for access: open, close, mmap
- Access: read, write
- Search: move to location
- Attributes: get, set (e.g., permissions)
- Mutual exclusion: lock, unlock
- Name management: rename

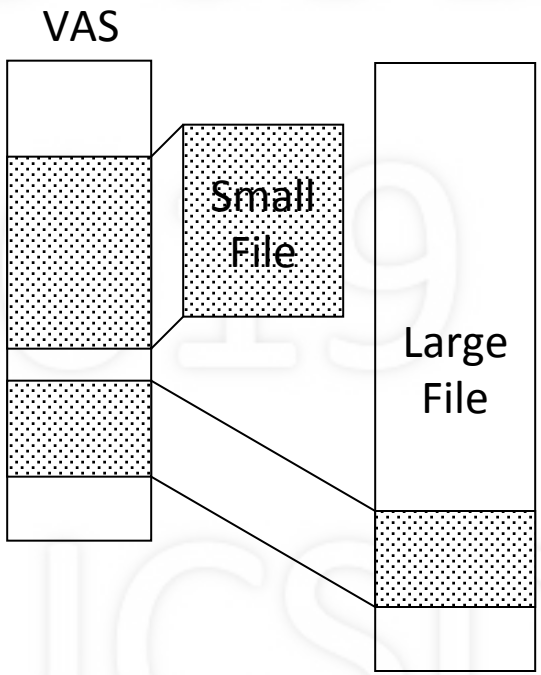
# Read/Write Model




- fd = open (fname, usage)
- nr = read (fd, buf, size)
- nw = write (fd, buf, size)
- close (fd)

# Memory-mapped Model

- Map file into address space
  - mmap (addr, n, ..., fd, …)
  - addr = mmap (NULL, n, …, fd, …)
- Can then use memory ops
  - x = addr[5]; strcpy (addr, “hello”);
- Issues
  - Efficient for multiple processes sharing memory
  - If memory is written, how is file actually updated?



# Access Control

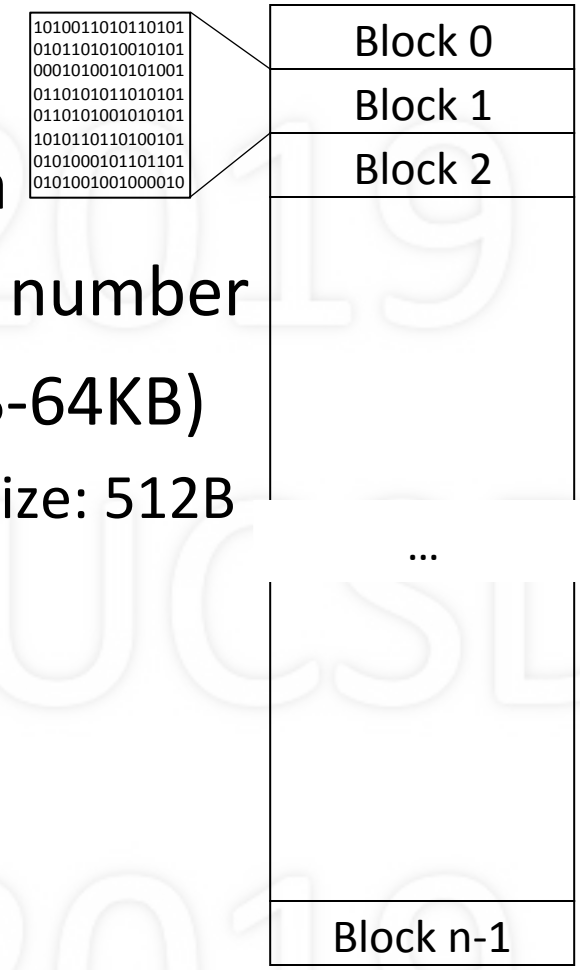
- How are files shared, to varying degrees?
- Access control
  - Who can access file
  - What operations are allowed
  - User interface must be simple and intuitive
- Example: UNIX
  - r/w/x permissions for owner, group, and everyone

# File System Implementation: Goals

- Archival storage
  - Keep forever, including previous versions
- Support various storage technologies
  - Disks (different types), remote disks, …
- How to best achieve and balance
  - Performance
  - Reliability
  - Security

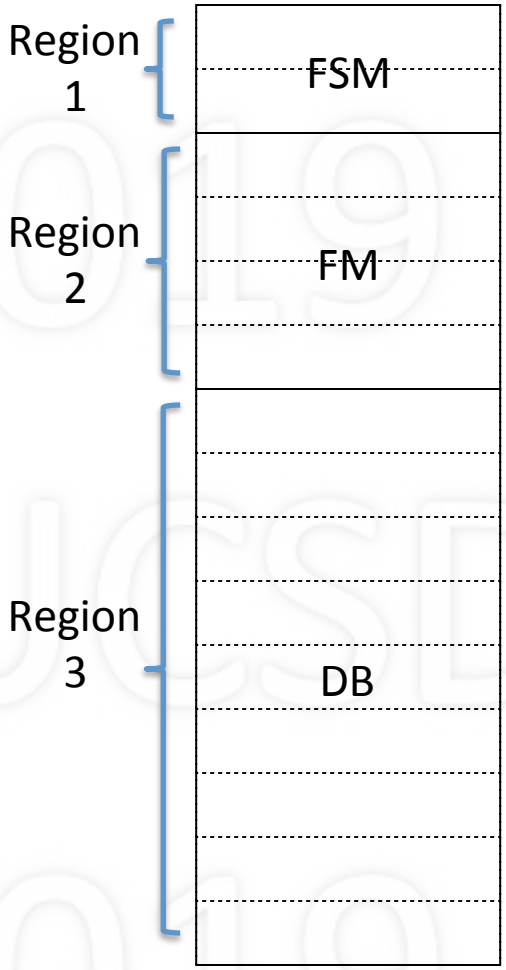
# Storage Abstraction

- Hide complexity of device
  - Model as array of blocks of data
  - Randomly addressable by block number
  - Typical block size: 1KB (also 4KB-64KB)
    - Generally multiple of disk sector size: 512B
- Simple interface
  - read (block_num, mem_addr)
  - write (block_num, mem_addr)



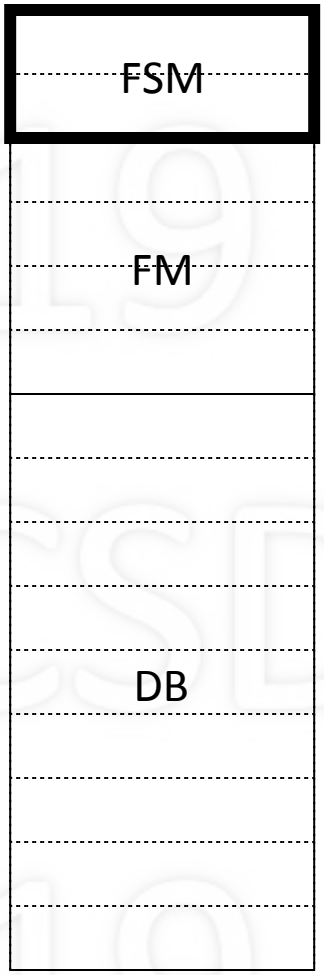
# Typical Implementation Structure

- Three major regions
  - Sequence of blocks for each one
- Region 1: File System Metadata
  - Information about file system
- Region 2: File Metadata
  - File control blocks
- Region 3: Data Blocks
  - File contents



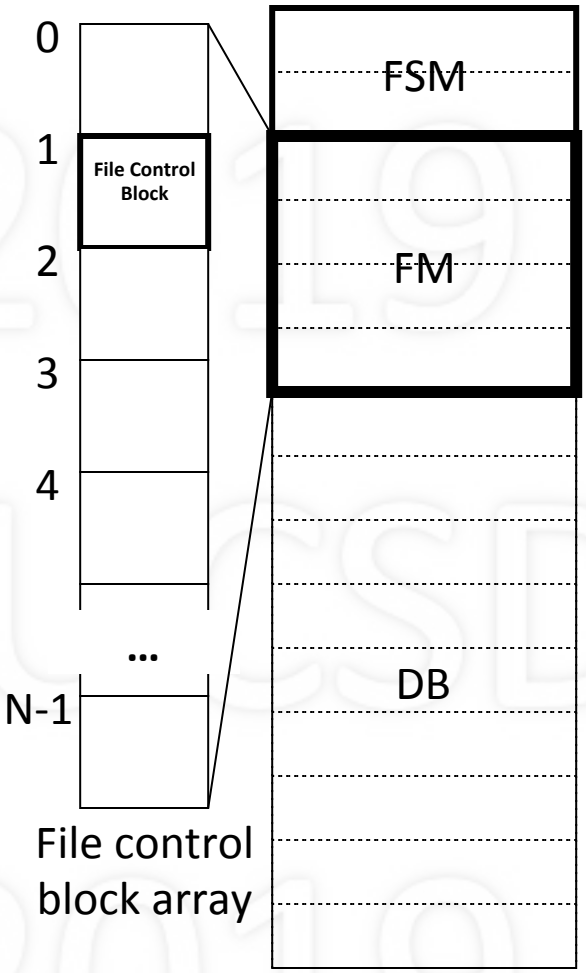
# File System Metadata

- Information about the file system
- Sizes
  - Files in use, free entries
  - Data blocks in use, free entries
- Free lists (or bitmaps)
  - File control blocks
  - Data blocks



# File Metadata: File Control Blocks

- Information about a file
- Referenced by number/index
- Contains
  - Attributes
    - type of file, size, permissions, …
  - References to data blocks
    - disk block map
- Note: many file control blocks may fit in single storage block

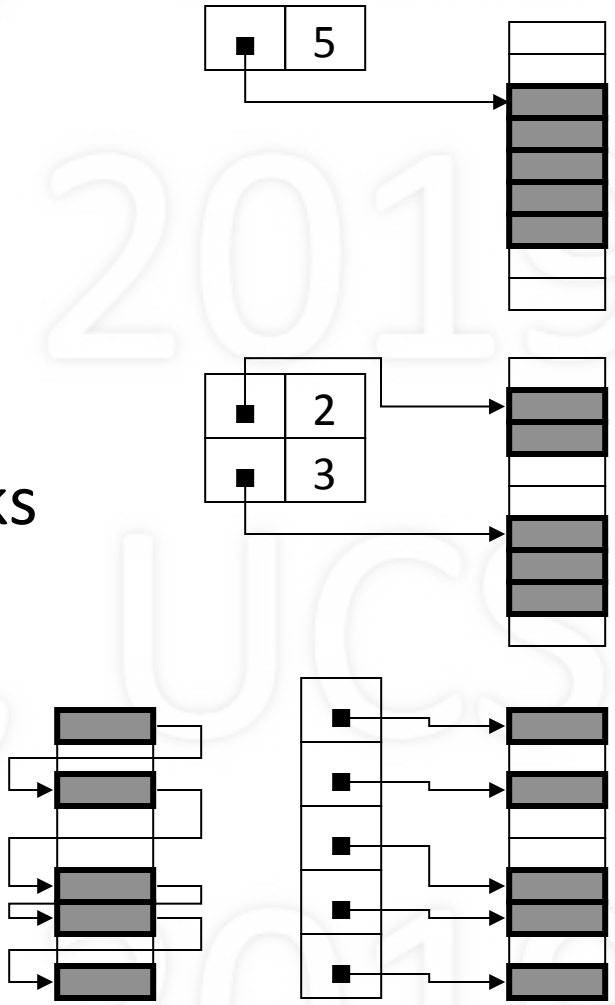


# Example of File Control Block

- Number: 88 (index in file control block array)
- Size: 4096 bytes
- Permissions: rw-r--r--
- Data blocks: set of indexes into storage array
  - E.g., 567, 7076, 9201, 9248 (assuming 1KB blocks)
  - This is an example of list of non-contiguous blocks
- What about file name?

# Keeping Track of Allocated Blocks

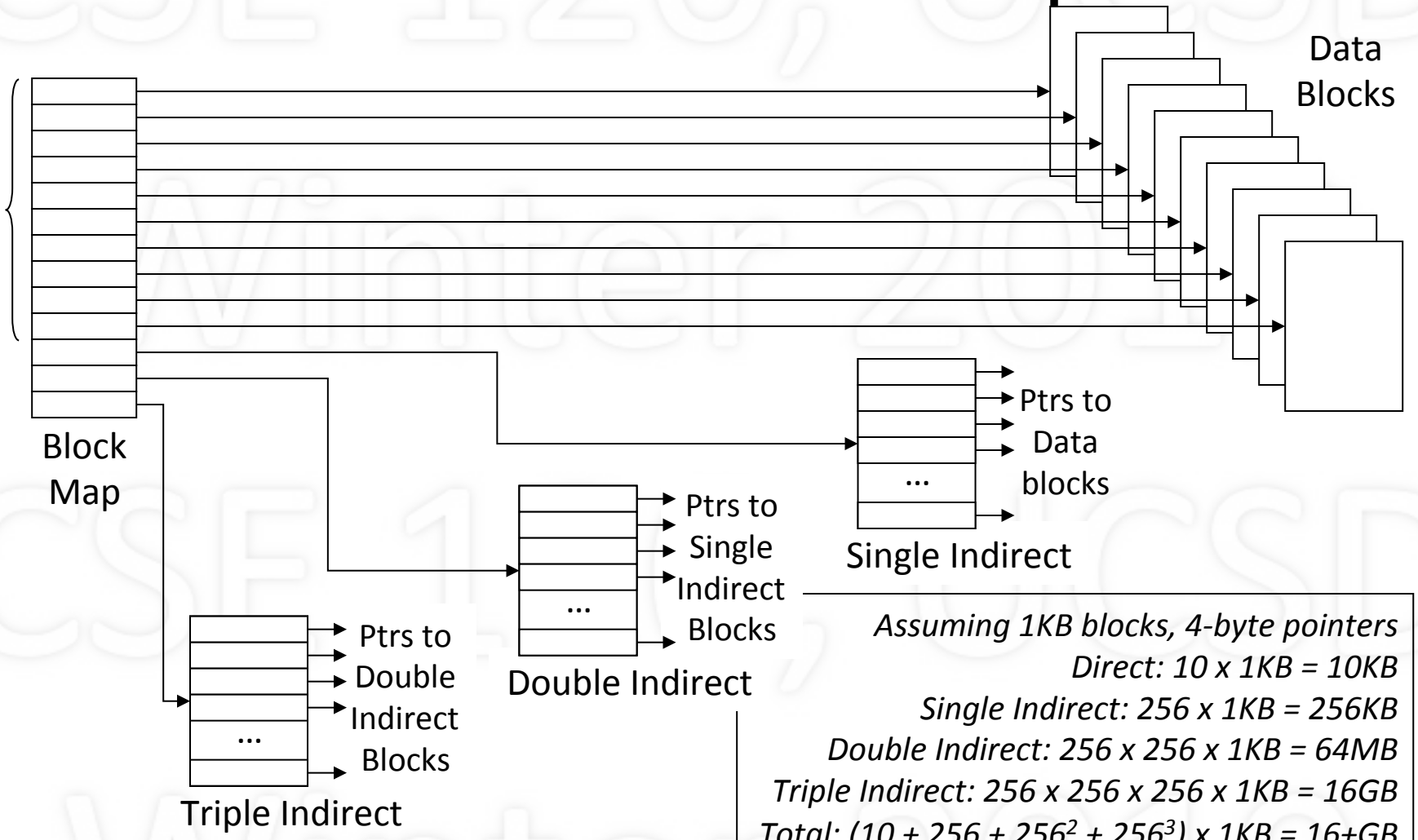
- Contiguous blocks
  - Single sequence of blocks
- Extents
  - Groups of contiguous blocks
- Non-contiguous blocks
  - Blocks individually named



# Example: UNIX v.7 Block Map

- Array of pointers to data blocks
- 13 pointers
  - 10 direct: references 10 data blocks
  - 1 singly-indirect: references *n* data blocks
  - 1 doubly-indirect: references $n^2$ data blocks
  - 1 triply-indirect: references $n^3$ data blocks
- *n* depends on how many pointers fit in a block
  - Example: 256 4-byte pointers will fit in 1KB block

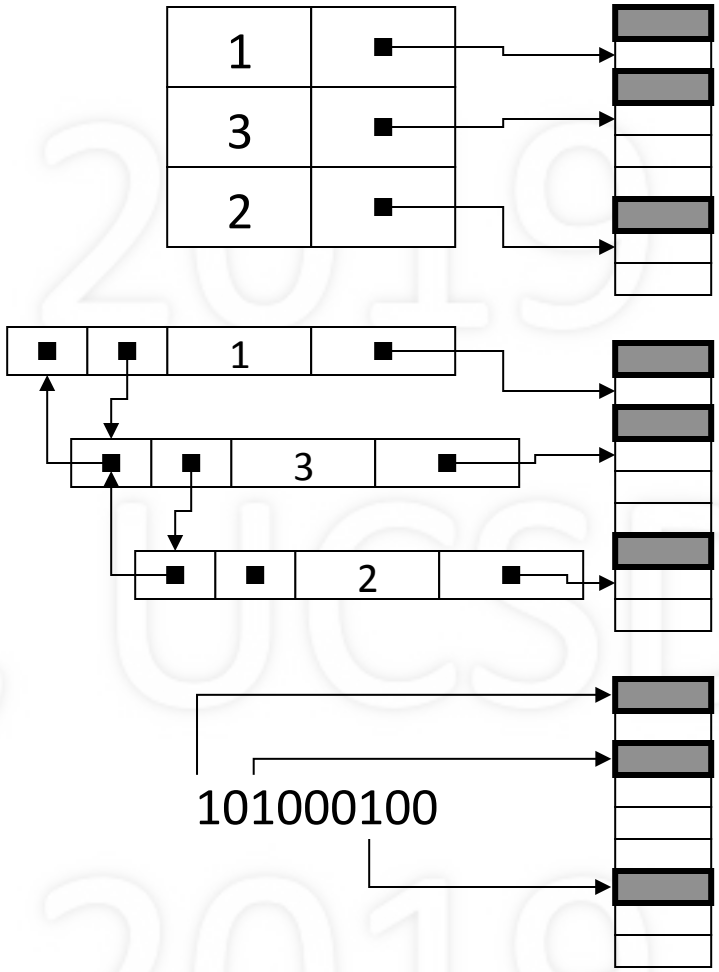
# UNIX v.7 Block Map




*Assuming 1KB blocks, 4-byte pointers*
*Direct: 10 x 1KB = 10KB*
*Single Indirect: 256 x 1KB = 256KB*
*Double Indirect: 256 x 256 x 1KB = 64MB*
*Triple Indirect: 256 x 256 x 256 x 1KB = 16GB*
*Total: $(10 + 256 + 256^2 + 256^3)$ x 1KB = 16+GB*

# Keeping Track of Free Blocks

- Free Block Map
  - Compact if lots of free regions of space
- Doubly Linked List
  - Easy to keep ordered due to fast inserts and deletes
- Bit Map
  - Fixed size regardless of fragmentation



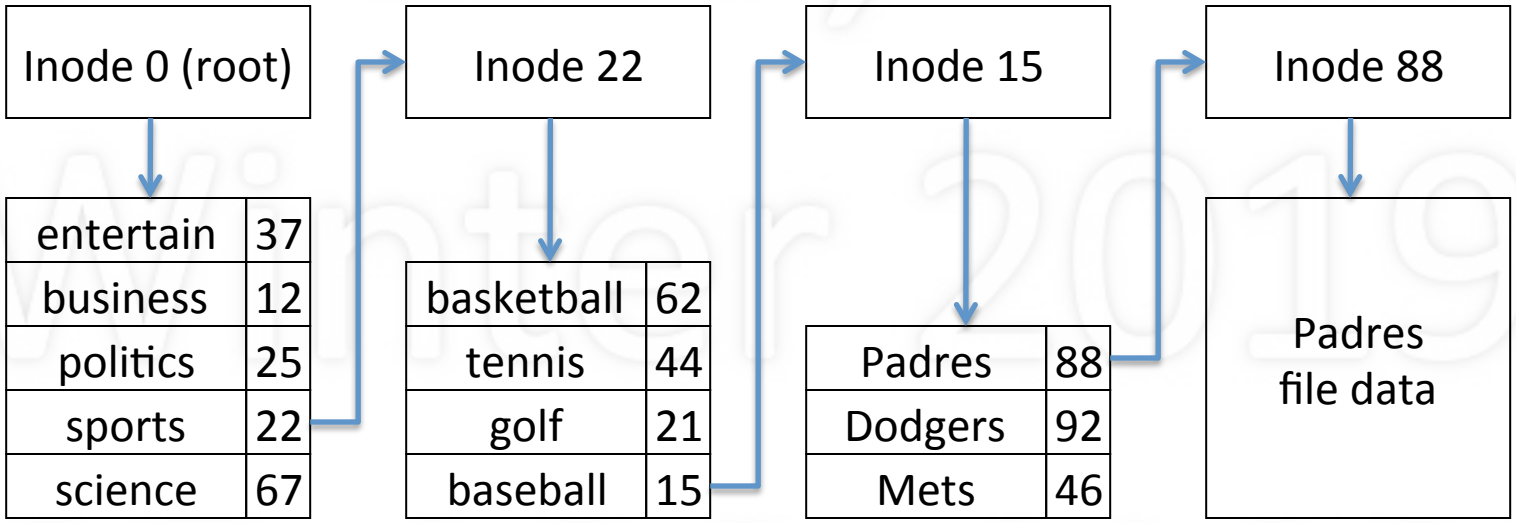
# File Name to File Control Block

- Users access files using file names
- Problem: how to translate
  - from file name: "/sports/baseball/Padres"
  - to file control block number: 88
- Must parse file name
- Each branch corresponds to a directory/folder
- Each directory/folder may itself be a file

# Implementing UNIX Directories

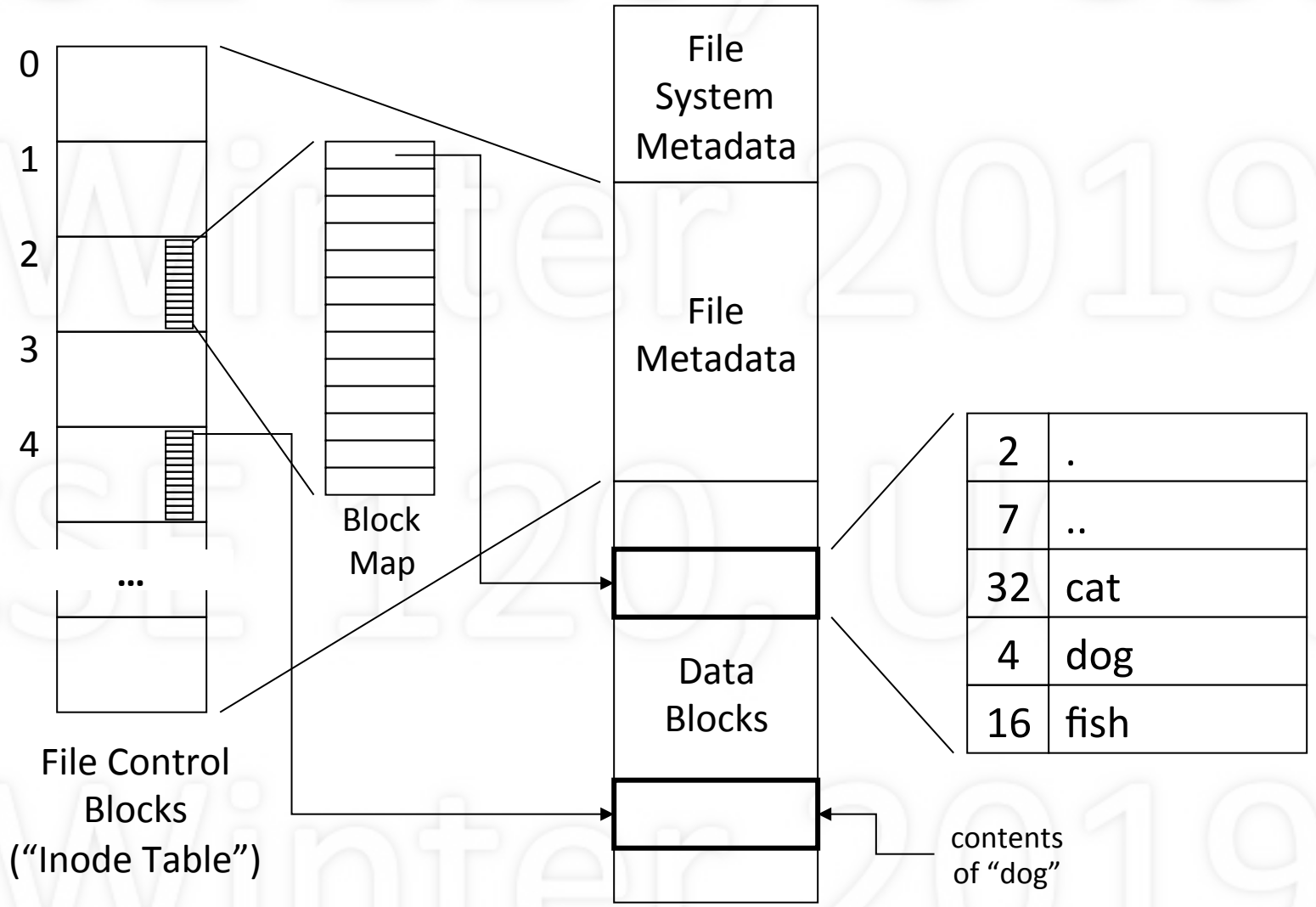
- Table where each entry contains
  - name and attributes
  - name and pointer to file control structure
- Unix (name and pointer) – pre-BSD
  - Each entry: branch name (14), i-node number (2)
  - Berkeley Unix uses a more complex scheme to support long names

# Example of Parsing Names in UNIX

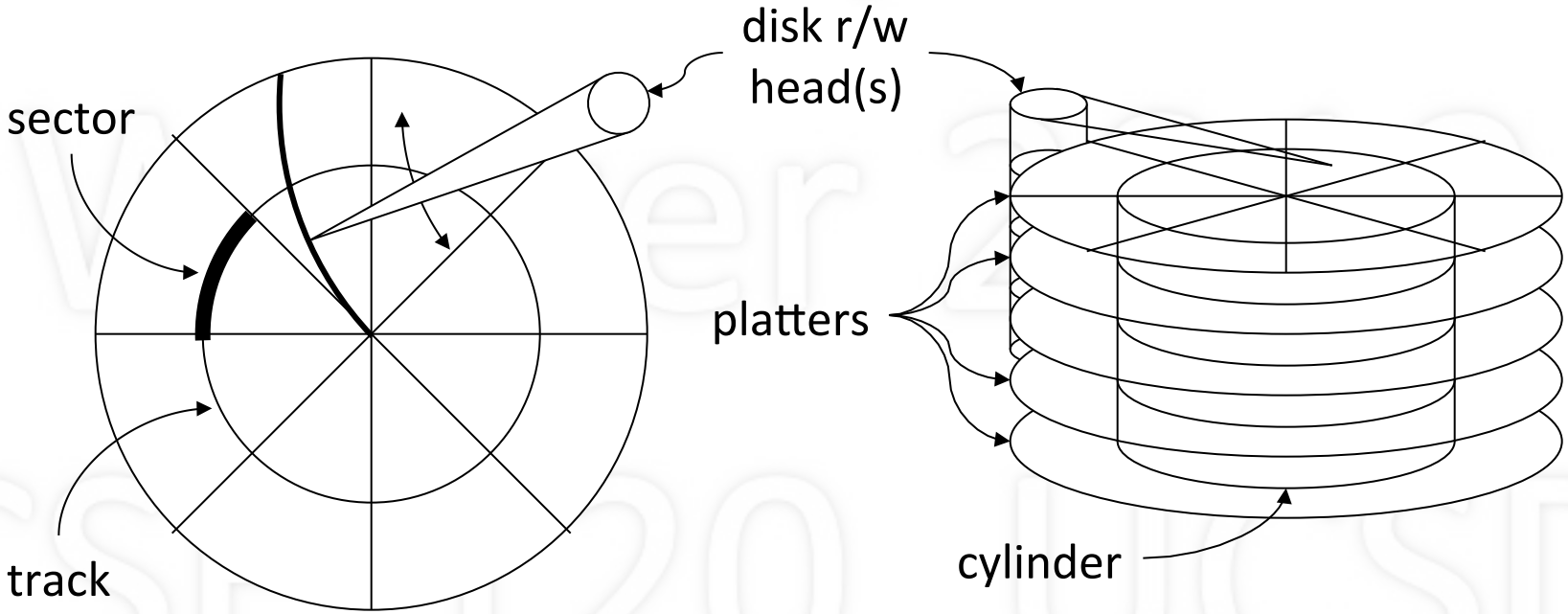



- Given pathname: /sports/baseball/Padres
  - Inode 0 block map points to data block(s) of root directory
  - Look up "sports" in root directory to get inode 22
  - Inode 22 block map points to data block(s) of sports directory
  - Look up "baseball" in sports directory to get inode 15
  - …

# The Big Picture



# File Systems Use Disks for Storage




- Why disks: persistent, random access, cheap
- But, disks are slow, because they are mechanical

# File System Performance

- Disk accesses are time expensive: 5-20 msec!
  - Rotational latency: 2-6 msec (5400-15000 RPM)
  - Seek time: 3-13 msec
  - Transfer rate: 100+ MB/sec
- Reduce accesses by
  - reading multiple blocks in one access (read ahead)
  - maintaining a block cache
- Cluster related blocks to reduce seek time

# Solid State Drives (SSD)

- NAND-based flash memory, non-volatile
- Unaffected by shock, magnetic fields; no noise
- Limited number of writes, wears out with age

| Attribute | Solid State Drive | Hard Disk Drive | SDD vs HDD |
|---|---|---|---|
| Access time | 0.1 msec | 10 msec | ** 100x ** |
| Throughput | 500 MB/sec | 100 MB/sec | 5x |
| Power | < 2 watts | 5-6 watts | 1/2x |
| Capacity | 64 GB – 1 TB | 500 GB – 8 TB | 1/10x |
| Cost | $50-100 for 100 GB | $5-10 for 100 GB | 10x |

# Performance: Caching

- Data blocks of files
- File system metadata (keep in memory)
- File metadata
  - Currently active files
  - Recently used
- Block maps
- File names
  - Name to file metadata translations

# Performance: Clustering

- Blocks that exhibit locality of reference
  - Directory, and files within that directory
  - The inodes of the directory and files
- Strategy
  - Place related blocks close to each other: clustering
  - Reduces disk head movement, and thus seek time

# Performance: Block Size

- What should the block size be?
  - The larger the block, the better the throughput
  - The smaller the block, the less wasted space
- Technology trends
  - Disk density is increasing faster than disk speed
  - Make disk blocks larger: 1 KB → 8 KB, 64 KB, 1 MB

# Reliability: Consistency

- Buffer cache reduces disk accesses
- But if system crashes, block modifications lost
- To improve file system consistency
  - Write out modified blocks (how often?)
  - Write out critical blocks (write-through)
- Critical blocks: file system meta-data
  - Directories, i-nodes, free block lists

# Reliability: Journaling

- Journal: log of file (or file system) updates
- For every update, create log entry
- Write log entry out to disk (part of journal)
- If there is a crash
  - Look at journal entries
  - Check if mods properly reflected in file system
  - Update appropriately

# Summary

- File system: abstraction for object repository
- Includes both static and dynamic objects
- Name space organized hierarchically
- Access models: read/write, memory-mapped
- Supports access control: read, write, sharing
- Implementation structure: FSM, FM, Data
- Performance (caching, clustering), reliability

# Textbook

- Read Chapters 13, 14
  - Lecture-related: 13.1-13.6, 14.1-14.6, 14.9
  - Recommended: 14.7-14.8, 15.1-15.9


CSE 120, UCSD Winter 2019

# Review & Research

- What is a file?
- What is a file system?
- Why is the word “system” used in “file system”; why not simply call it a “file collection”?***
- By “repository of objects”, what is meant by “repository” and what is meant by “object”; why not say a “repository of files”?**

# R&R

- What are the features of an object as it applies to files?*
- For each of the following I/O devices, how can it be viewed as a file object: disk, keyboard, display, mouse, printer?**
- How can the memory of a process be viewed as a file?**

# R&R

- What is a name space?*
- What makes a name space hierarchical?**
- What is the value of a hierarchical name space?*
- Why are UNIX files names called "pathnames"?*
- What's the difference between absolute and relative path names?*

# R&R

- What is meant by the word “attribute”?*
- What criteria would be used to determine that an attribute qualifies as a “system attribute”?***
- For each of the following, justify why they are system attributes: type (system or user), creation time, access time, modified time, current size, maximum size, permissions?***

# R&R

- What are the operations allowable on files?
- Some operations are issued via system calls, and some are not: for each of the operations in the previous question, argue why it should or should not be issued via a system call?***
- If an operation is deemed not to require a system call, then how would the operation be issued?**

# R&R

- What is the buffered Read/Write Model for file access?*
- What are the system calls for this model?*
- For each of the system calls, why are they necessary, or why are they not necessary?***
- For each of the system calls, why are each of the parameters and return value needed: justify each one?**

# R&R

- More generally, what criteria would determine whether a procedure call needs to be a system call?***
- The Standard I/O Library has a file interface that includes fopen, fread, fwrite, and fclose: how are these different from open, read, write, and close, and why are they not system calls?**

# R&R

- What is the Memory-Mapped Model for files?
- What parameters are needed for the mmap system call, and in what way are they used?**
- What are the pros/cons of mmap?**
- How can mmap be used for processes that share memory?**
- What complication arises if an mmapped file is modified?** What are solutions for this?***

# R&R

- What is access control?
- In what way does access control support the sharing of files?*
- What is the access control interface for UNIX? **
- How is access control in UNIX different from that of MULTICS?*** (research question, for which you are not responsible on an exam)

# R&R

- What are the goals for a file system implementation?
- Why must the following be “balanced”, as opposed to “maximized”: performance, reliability, security?**

# R&R

- What is the storage abstraction, and what is its value?*
- How is the storage abstraction interface used (explain the functions and parameters)?**
- In the typical implementation structure, what are the three regions, justify why each is necessary and sufficient?***

# R&R

- What is file system metadata?
- What kind of information comprises file system metadata, and what are examples?*
- For each of the examples you present, can you justify why they are file system metadata (as opposed to the other categories of file system information)?**

# R&R

- What is a free list?*
- What is a bit map?*
- For each, when is it better to use one vs. the other?**

# R&R

- What is file metadata?
- What kind of information comprises file metadata, and what are examples?*
- For each of the examples you present, can you justify why they are file metadata (as opposed to the other categories of file system information)?**
- What is a file control block?*

# R&R

- For the example of a file control block on slide 16, what is each one and why is it necessary?*
- What are the pros and cons of having the file's name be located in the file control block?**

# R&R

- What are the 3 basic ways for keeping track of allocated blocks; explain how each works?**
- On slide 17, two methods are shown for the non-contiguous block method: how does each work, and when would one be used vs. the other?**

# R&R

- What is the UNIX Version 7 Block Map, and how does it work?**
- What are indirect pointers, and what is the purpose of having them?**
- Can you explain the diagram on slide 19, and how the maximum file size is calculated?**
- If the block size is doubled, how does this affect the maximum block size?***

# R&R

- What are the three methods of keeping track of free blocks; how does each work?*
- What criteria would you use for deciding which method to use?**

# R&R

- Why is it necessary to convert file names to file control blocks?**
- How is this conversion done in pre-BSD UNIX (and by example, can you explain the diagram on slide 23 that shows how the UNIX file name "/sports/baseball/Padres" is converted)?**

# R&R

- In “The Big Picture” diagram on slide 24, how many blocks need to be accessed to get the data contents of the file “dog”, assuming the first required access is to the File System Metadata (and explain each of the accesses)? ***

# R&R

- How does a mechanical magnetic disk work, based on the diagram on slide 25?*
- Why are mechanical magnetic disks used for file system storage?*
- What is the biggest negative in using a magnetic disk, as it relates to system performance?**

# R&R

- What is the average time for a disk access?*
- What are the components of this time?
- For each component, can you think of a way of reducing its time, and if so, by how much do you think it can be reduced?***
- What is the main idea (can be stated in 3 words) for dealing with the time expense of using mechanical disks?**

# R&R

- What is a Solid State Drive (SSD)?
- In what ways are SSDs different from mechanical hard disk drives (HDD)?*
- Why does an SSD wear out with age?**
- What is the biggest advantage SSDs have over HDDs?*
- What is the biggest disadvantage SSDs have over HDDs?*

# R&R

- How can caches be used to improve file system performance?*
- What kinds of information can be cached?**
- For each kind of information, are there any special concerns as to caching that kind relative to the others?**

# R&R

- What is clustering, and how can it be used to improve file system performance?*
- Why does clustering improve performance?*

# R&R

- How is block size related to performance?
- Explain the effect on performance by making the block larger? Why this effect?*
- Explain the effect on performance by making the block smaller? Why this effect?*
- Given these effects, should the block size be made smaller or larger?* What goes into making this decision?**

# R&R

- What is meant by file system reliability?*
- What is meant by consistency?*
- How does consistency affect reliability?**
- How can consistency be increased?*
- Are there drawbacks to increasing consistency, and if so, what are they?*

# R&R

- What is meant by journaling?*
- How does journaling affect reliability?**
- What are the basic steps to journaling?*
- How is a journal used after a crash?**