10. Storage & File Management

9th ed: Ch. (10,) 11, 12

10th ed: Ch. (11,) 13, 14, 15

Objectives

- To understand the nature of mass storage
- To be aware of the challenges of (disk) storage management
- To understand concepts of files, directories and directory namespaces, directory structures, hard- and soft-links
- To know of basic file operations and access control mechanisms
- To be aware of the relationship between paging and block storage in the buffer cache

Outline

- Mass storage
- Disk scheduling
- Disk management
- Files
- Directories
- Other issues

Outline

- Mass storage
    - Hard disks
    - Solid state disks
- Disk scheduling
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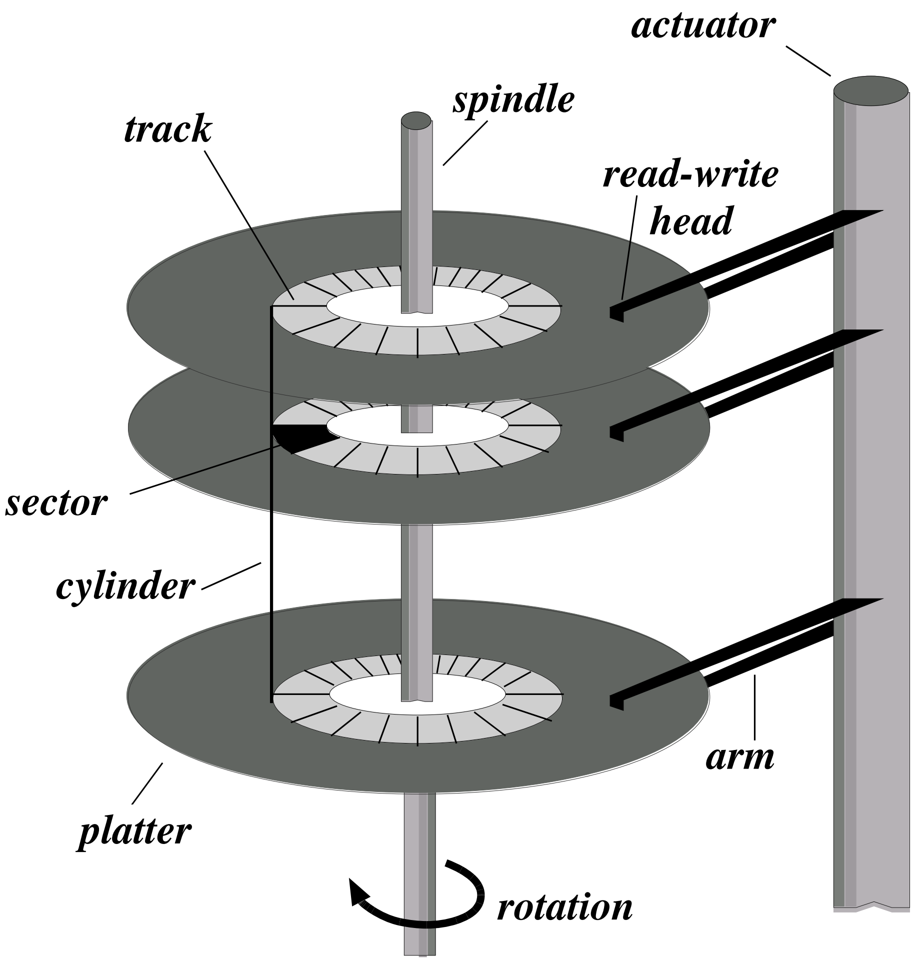
Mass storage: Hard Disks (HDs)

- Stack of platters
  - Historically 0.85” to 14”
  - Commonly 3.5”, 2.5”, 1.8”
  - Capacity continually increases but perhaps 30GB – 3TB
- Performance
  - Transfer Rate (theoretical) = 6 Gb/sec
  - Effective Transfer Rate (real) = 1Gb/sec
  - Seek time 3–12ms with around 9ms common
  - Rotation typically 7200 or 15,000 RPM



Hard disk performance

- **Average latency** [secs] = ½ latency = ½ × $^1/_{60}$ / ($^{\text{rotations}}/_{\text{minute}}$) = 30 / RPM
- **Access latency** [secs] = Average seek time + Average latency
- **Average I/O time** [secs]
  = Access latency + ($^{\text{transfer amount}}$ / $_{\text{transfer rate}}$) + controller overhead
- E.g., 4kB block, 7200 RPM, 5ms average seek time, 1Gb/sec transfer rate, 0.1ms controller overhead
  - Average latency = 30 / 7200 = 4.17ms
  - Transfer time = 4096 bytes × 8 $^{\text{bits}}/_{\text{byte}}$ / 1024^3 $^{\text{bits}}/_{\text{second}}$ = 0.031ms
  - Average I/O time = 5ms + 4.17ms + 0.031ms + 0.1ms = 9.301ms

Mass storage: Solid state disks (SSDs)

- Non-volatile memory used like a hard drive; many variations
- Pros
  - Can be more reliable than HDDs
  - No moving parts, so no seek time or rotational latency
  - Much faster
- Cons
  - Reads/writes wear out cells leading to unreliability and potentially shorter
  - More expensive per MB
  - Lower capacity

Outline

- Mass storage
- Disk scheduling
  - First-Come First-Served (FCFS)
  - Shortest Seek Time First (SSTF)
  - SCAN, C-SCAN
- Disk management
- Files
- Directories
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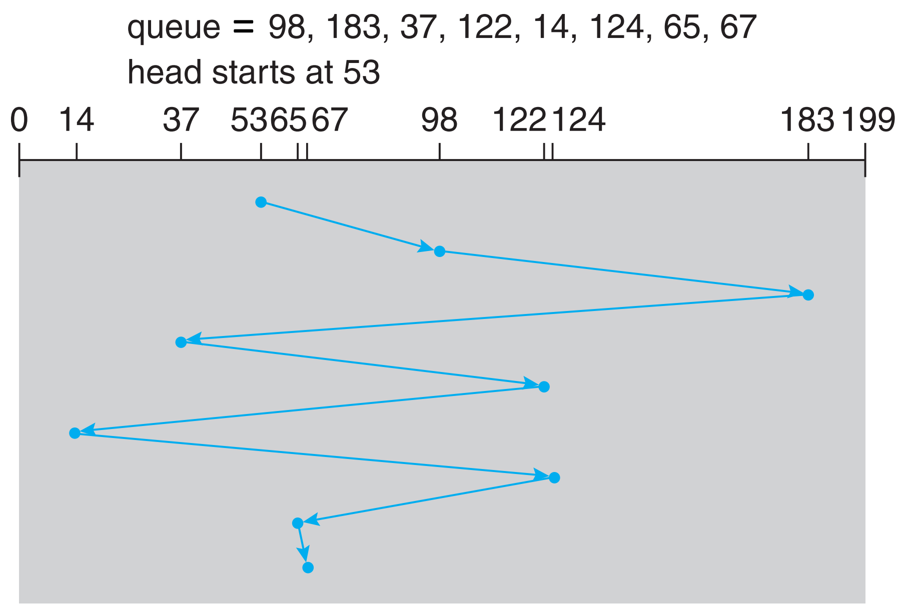
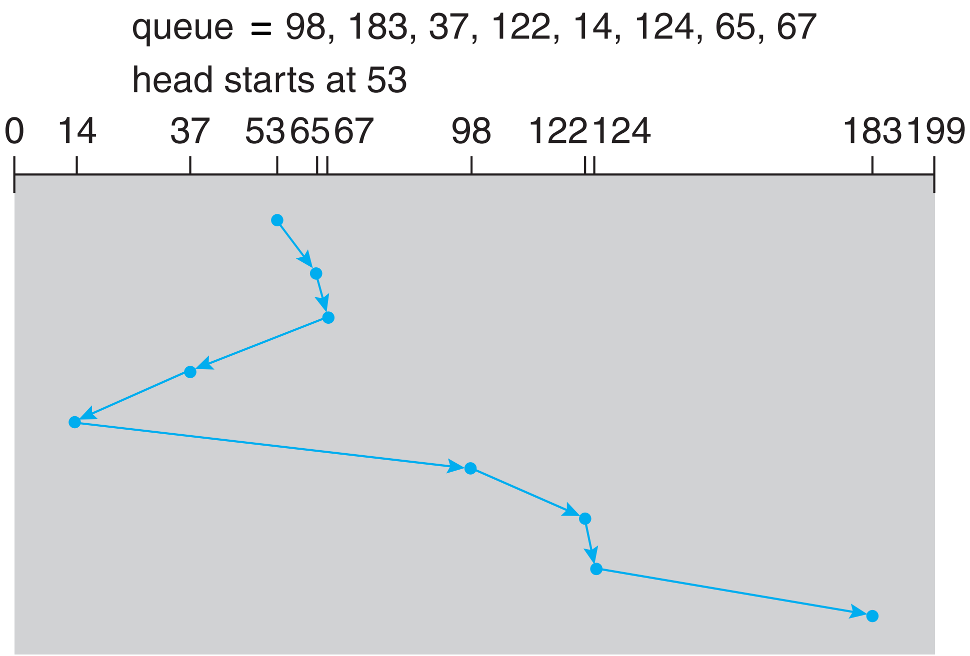
Disk scheduling

- The disk controller receives a sequence of read/write requests from the OS that it must schedule
  - How best to order reads and writes to achieve policy aim?
  - Analogous to CPU scheduling but with very different mechanisms, constraints, and policy aims
  - Many algorithms exist
- Simplest: First-come First-served (FCFS)
  - Intrinsically fair but inefficient
  - E.g., requests for blocks on cylinders are 98, 183, 37, 122, 14, 124, 65, 67



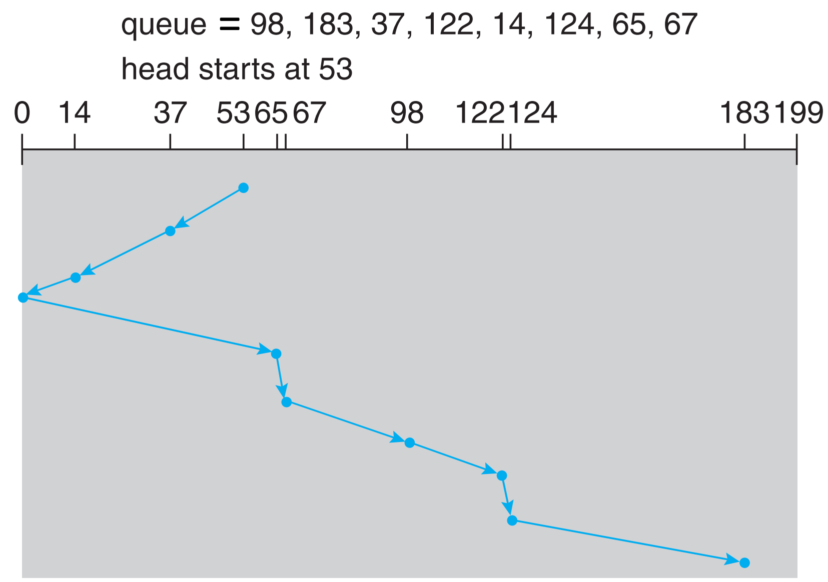
Shortest Seek-Time First (SSTF)

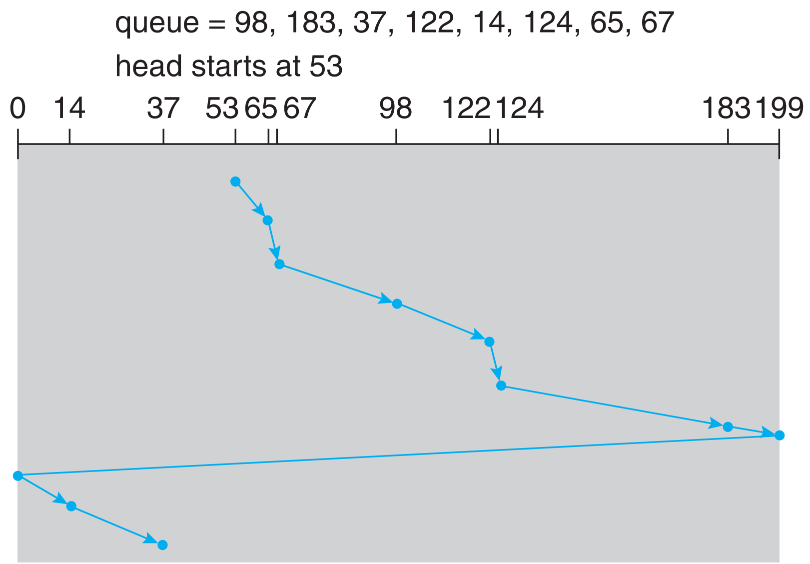
- Service requests based on distance to current head position
  - Next request in queue is that with the shortest seek time
- For this example, involves movement of just 236 cylinders
  - $^{1}/_{3}$ of that required by FCFS
- Somewhat analogous to SJF
  - A big improvement but allows starvation
  - Not optimal: from 53 move to 37 then 14 and then 65 etc – gives movement of 208 cylinders



SCAN and C-SCAN

- **SCAN** or **elevator** algorithm
  - Start at one end of the disk and move to the other end
  - Service everything on the way
- Consider density of requests when changing direction
  - Have just serviced (almost) everything in that vicinity
  - Those furthest away have waited longest so…
- **Circular-SCAN**
  - Return back to the start when reaching the end
  - Cylinders treated as a circular list, wrapping when reaching the end





Outline

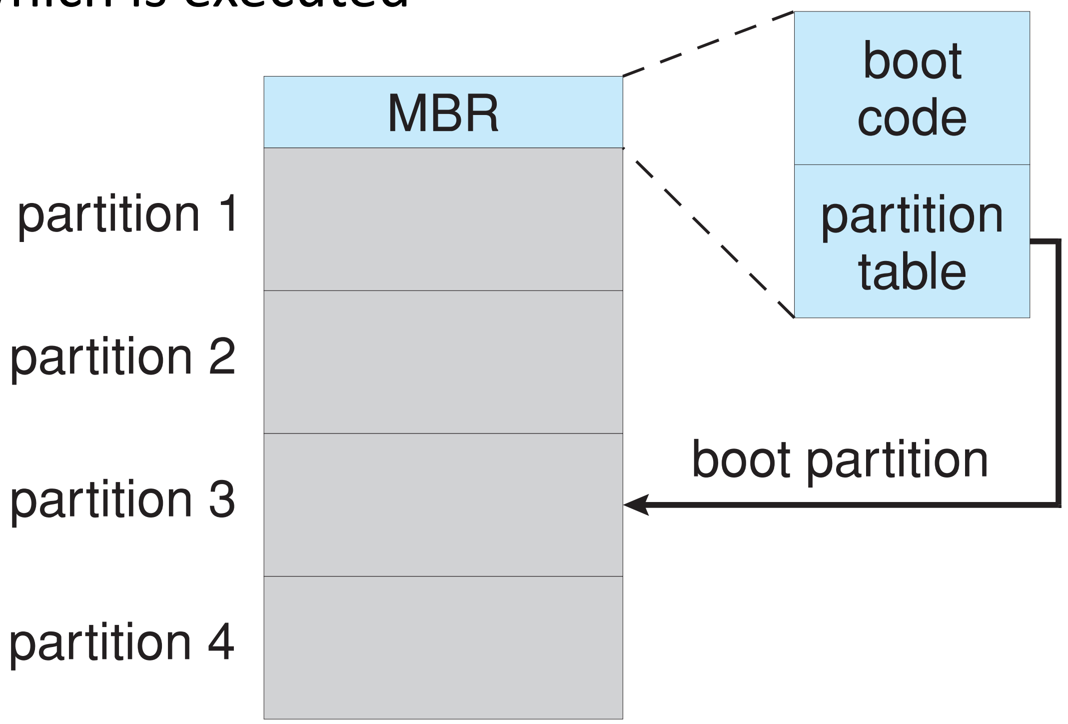
- Mass storage
- Disk scheduling
- Disk management
    - Booting from disk
- Files
- Directories
- Other issues

Disk management

- **Low-level** or **physical formatting**
  - Divides a disk into sectors that the disk controller can read and write
  - Each sector can hold header information, plus data, plus error correction code (ECC)
  - Usually 512 bytes of data but can be selectable
- **Logical formatting** to make a file system required before disk can hold files
  - OS needs to record its own data structures on the disk so it can find files
  - Partition the disk into one or more groups of cylinders, each treated as a logical disk
  - To increase efficiency most file systems group blocks into clusters
- **Disk** I/O done in **blocks**
- **File** I/O done in **clusters**
  - Some applications, e.g., databases, will prefer “raw” block access

Booting from disk

- OS needs to know where to start looking
  - BIOS (or similar) is “firm-coded” to e.g., read first block of first disk
- First block contains bootloader program, which is executed
- Bootloader knows enough to start reading in the right blocks to read the filesystem starting with the **partition table**
  - Sometimes need to **chain-load** to get enough code to parse more complex filesystems
- Allows for handling of bad blocks
  - E.g., by **sector sparing** where spare good blocks logically substitute for bad ones



Outline

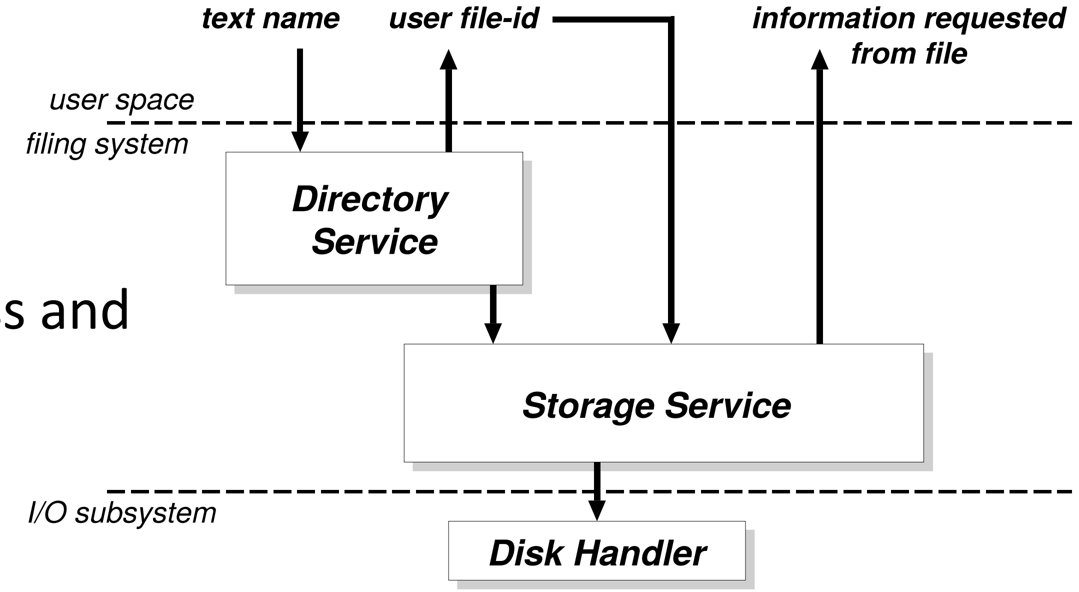
- Mass storage
- Disk scheduling
- Disk management
- Files
  - File systems
  - File metadata
  - File and directory operations
- Directories
- Other issues

Files

- The basic abstraction for non-volatile storage:
  - Can be a user or an OS abstraction (convenience vs flexibility)
  - Typically comprises a single contiguous logical address space
- Many different types
  - Data: numeric, character, binary (text vs binary split quite common)
  - Program: source, object, executable
  - “Documents”
- Can have varied internal structure:
  - None: a simple sequence of words or bytes
  - Simple record structures: lines, fixed length, variable length
  - Complex internal structure: formatted document, relocatable object file

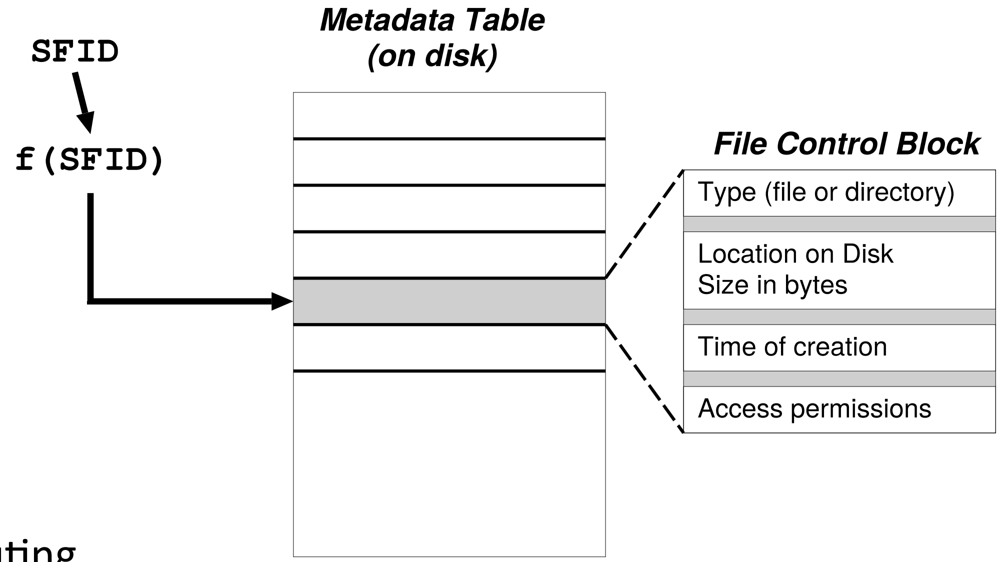
File system

- Consider only simple file systems
  - **Directory service** maps names to file identifiers and metadata, handles access and existence control
  - **Storage service** stores data on disk, including storing directories
- Each partition formatted with a filesystem
  - Logically, a **directory** and some **files**
  - Directory maps human name (*hello.java*) to **System File ID** (typically an integer)
  - Different filesystems implement using different structures



Name	SFID
hello.java	12353
Makefile	23812
README	9742

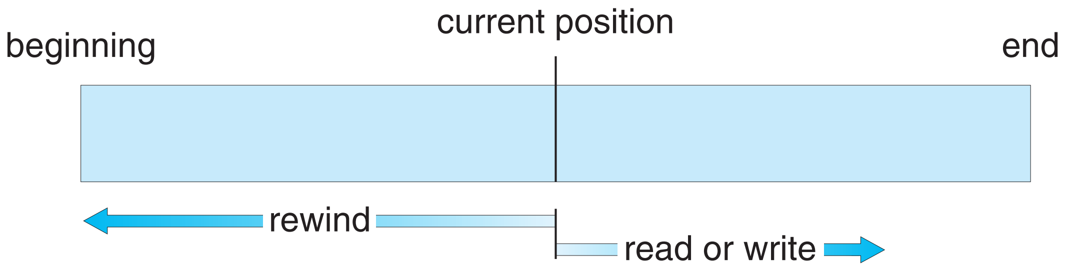
File metadata



- The mapping from SFID to File Control Block (FCB) is filesystem specific
- Files typically have a number of other attributes or metadata stored in directory
  - **Type** – file or directory
  - **Location** – pointer to file location on device
  - **Size** – current file size
  - **Protection** – controls who can do reading, writing, executing
  - **Time**, **date**, and **user identification** – data for protection, security, and usage monitoring
- OS must also track open files in an **open-file table** containing
  - **File pointer** or **cursor**: last read/written location per process with the file open
  - **File-open count**: how often is each file open, so as to remove it from open-file table when last process closes it
  - **On-disk location**: a cache of data access information
  - **Access rights**: per-process access mode information

File and directory operations

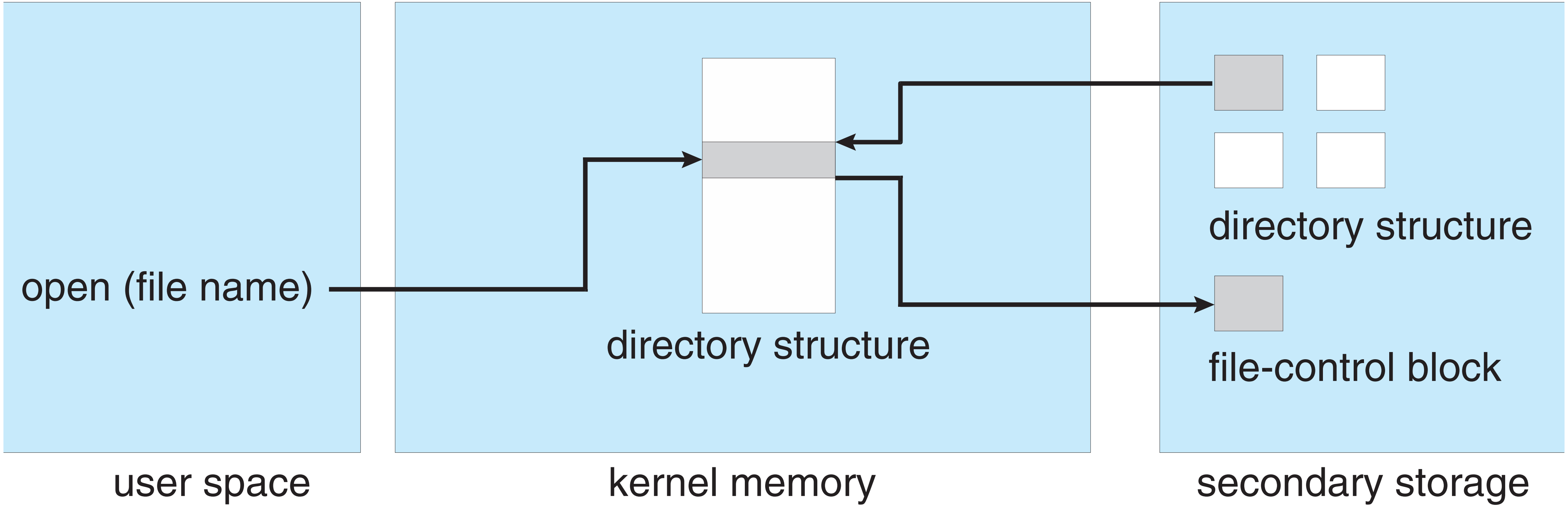
- A file as an **abstract data type** (**ADT**) over some (possibly structured) bytes
- **Directory operations** to manage lifetime of a file
  - **Create** allocates blocks to back the file
  - **Open/Close** handle to the file, typically including OS maintained current position (**cursor**)
  - **Delete** returns allocated blocks to the free list
  - **Stat** retrieves file status including existence reads and returns file metadata
- **File operations** to interact with file
  - **Write** provided data at cursor location
  - **Read** data at cursor location into provided memory
  - **Truncate** clips length of file to end at current cursor value



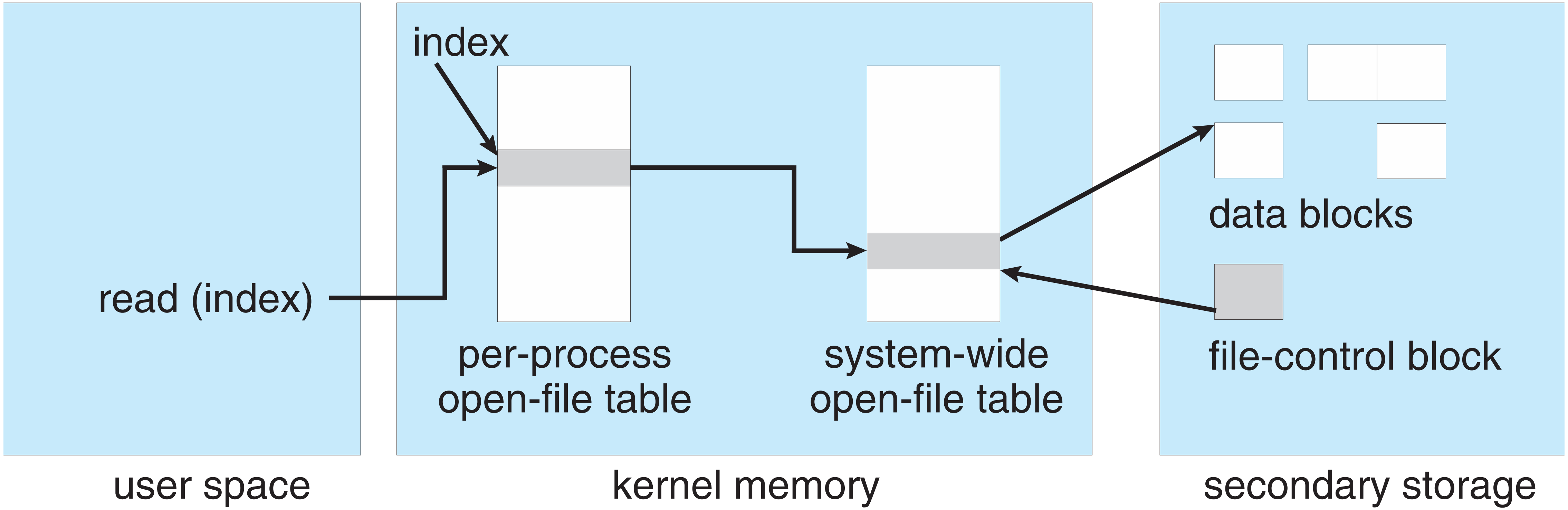
- Access pattern:
  - **Random access** permits **seek** to move cursor without reading or writing
  - **Sequential access** permits only **rewind** to move cursor back to beginning

Opening a file

- In-memory directory structure previously read from disk resolves file name to a file control block



Reading a file



- Using per-process open-file table, index (file handle or file descriptor) resolves to system-wide open-file table containing file-control block which resolves to actual data blocks on disk

Outline

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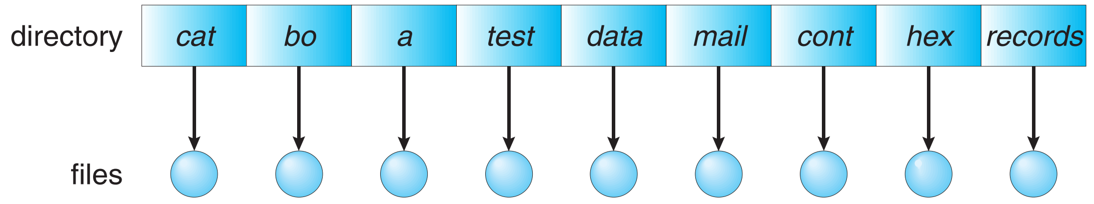
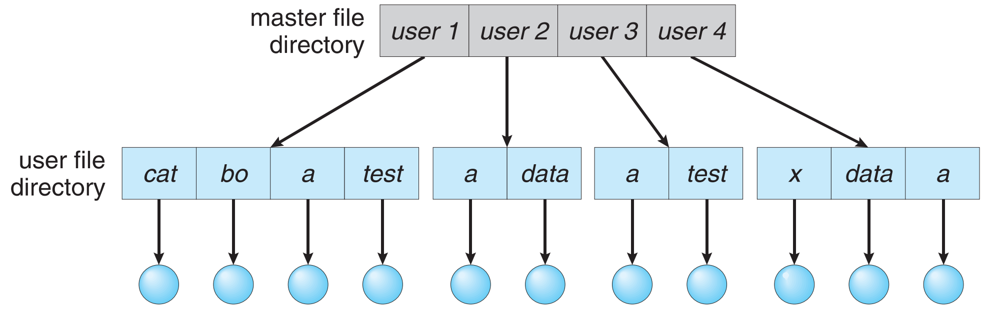
- Files
- Directories
  - Tree-structured
  - Acyclic-graph structured
  - File system mounting
- Other issues

Directories

- Implementations must provide
  - **Grouping**, to enable related files to be kept together
  - **Naming**, for user convenience so different files can have the same name and one file can have many names
  - **Efficiency**, to find files quickly
- **Single-level directory** is simplest
  - Naming and grouping problems though
- **Two-level directory** is next (FAT)
  - Same names for different users via paths
  - Efficient searching but no grouping





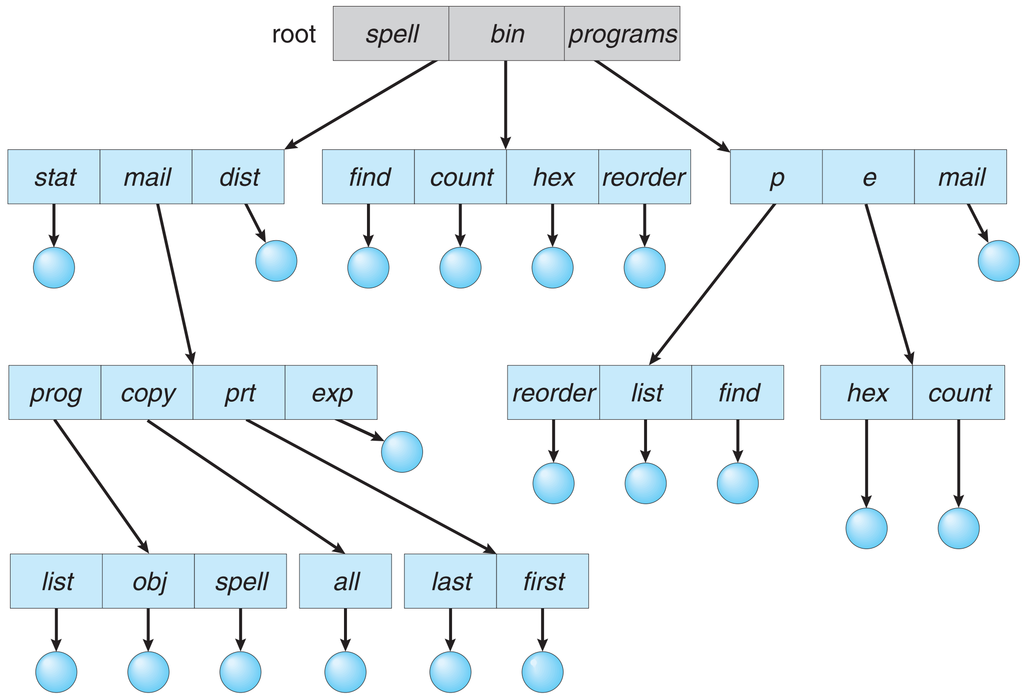
Tree-structured directories

- Provide naming convenience, efficient search, and grouping
- Introduce notion of **current working directory** (**CWD**)

  cd /spell/mail/prog

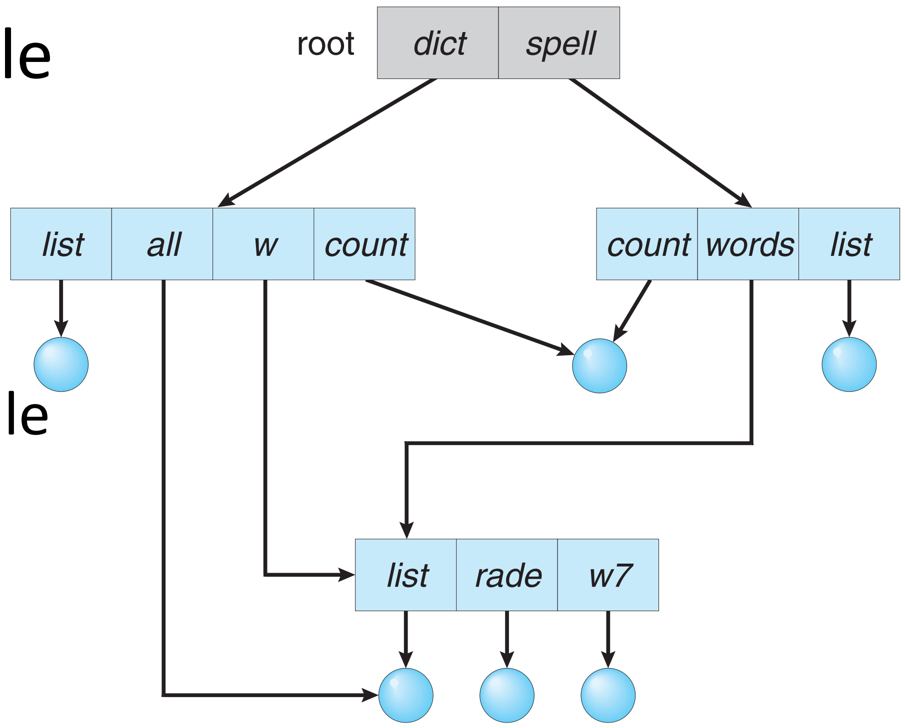
  type list

- Gives rise to **absolute** or **relative** path names
  - Name is resolved with respect to the CWD
- Other operations also typically carried out relative to CWD



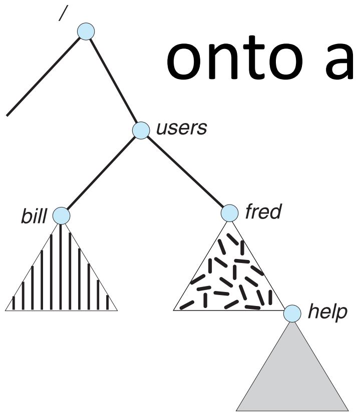
Acyclic-graph structured directories

- Generalise to a DAG so can share subdirectories and files
  - Allows files to have two different absolute names (**aliasing**)
- Need to know when to actually delete a file
  - Use back-references or reference counting
  - Compare soft- and hard-links in Unix
- Need to know how to account storage
  - Which user "owns" the storage backing the file
  - For deletion and generally for permissions
- Need to avoid creating cycles
  - Forbid links to subdirectories

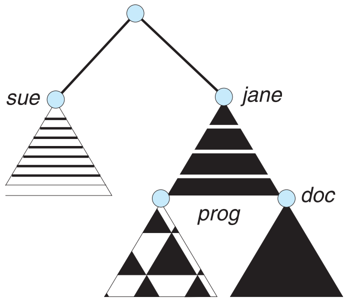


File-system mounting

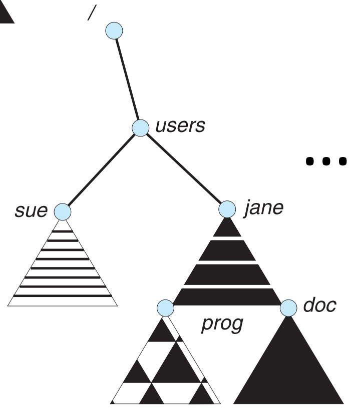
- Filesystems must be **mounted** at a **mount-point** before access, e.g.,



onto a pre-existing file-system...



...an unmounted filesystem in another partition



...is mounted, overlaying the *users* subdirectory

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  - Consistency
  - Efficiency
  - Buffer cache

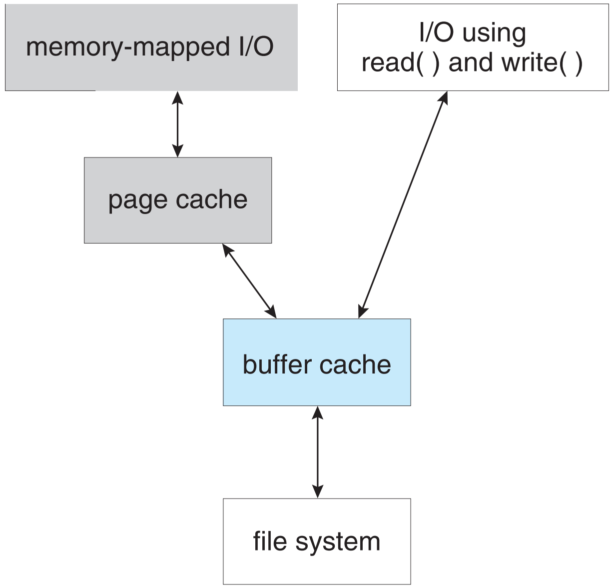
Consistency issues

- Arise without multiple threads!
- E.g., Deleting a file uses the *unlink* system call
  - Invoked from the shell as *rm <filename>*
- Implementation must
  - Check if user has sufficient permissions on the file (write access)
  - Check if user has sufficient permissions on the directory (write access)
  - If ok, remove entry from directory
  - Decrement reference count on inode
  - If reference count is now zero, free data blocks and inode
- If the system crashes, must check the entire filesystem (*fsck*)
  - Check if any block is unreferenced, and mark free
  - Check if any block double referenced, and update reference counts

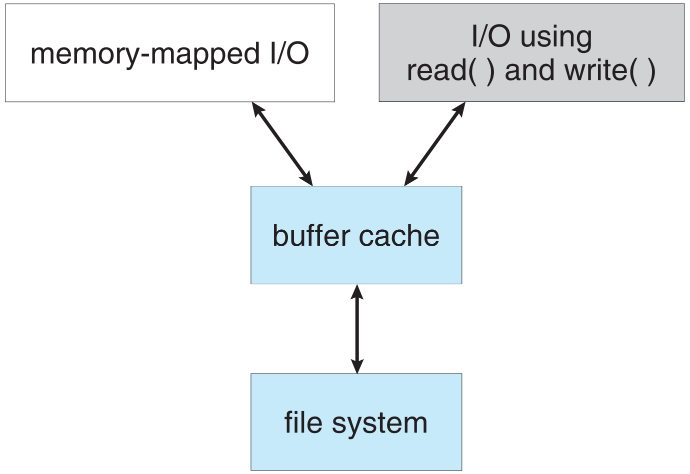
Efficiency and performance

- Efficiency depends on, e.g,
  - Disk allocation and directory algorithms
    - Similar challenges to memory of allocation, fragmentation, compaction
  - Types of metadata in directory entries
    - E.g., file creation time vs last written time vs last accessed time
  - Pre-allocation or as-needed allocation of metadata structures
    - Fixed-size or varying-size data structures
- Performance measures include
  - Keep data and metadata close together
  - Create a buffer cache, a separate part of memory for often used blocks
    - Synchronous writes sometimes requested by apps or needed by OS
    - Require no buffering / caching – writes must hit the disk before acknowledgement
    - Asynchronous writes more common, can be buffered, are faster

Buffer caches



- Not unified
  - **Page cache** caches pages not disk blocks, using virtual memory techniques and addresses
  - Memory-mapped I/O uses a page cache while routine I/O through the file system uses the **buffer (disk) cache**
- Unified
  - A single **buffer cache** uses a single page cache for both memory-mapped I/O and normal disk I/O



Summary

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  - Solid state disks
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  - Shortest Seek Time First (SSTF)
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