Final Review 04

Operating Systems
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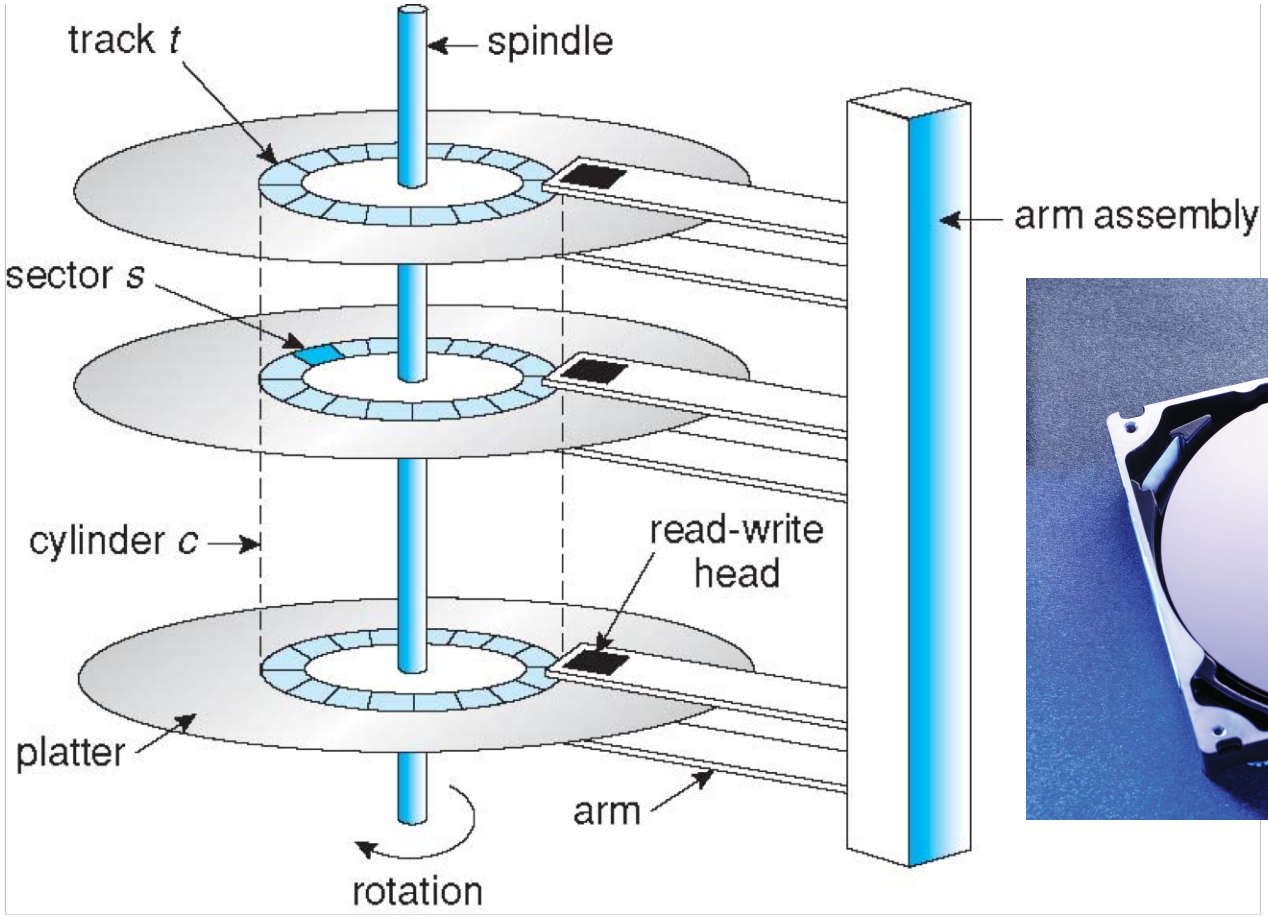
Acknowledgement: Some slides are based on Yajin Zhou@ZJU slides.

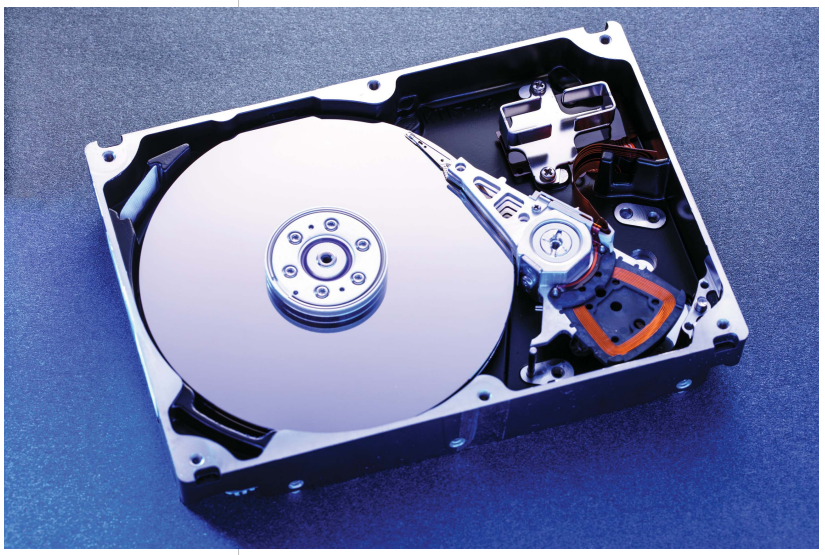
11: Mass storage

Disk Structure

- Disk drives are addressed as a 1-dimensional arrays of logical blocks (LBA)
  - logical block is the smallest unit of transfer
- Logical blocks are mapped into **sectors** of the disk sequentially
  - sector 0 is the first sector of the first track on the outermost cylinder
  - mapping proceeds in order
    - first through that **track**
    - then the rest of the tracks in that **cylinder**
    - then through the rest of the cylinders from outermost to innermost
  - logical to physical address should be easy
    - except for bad sectors

Moving-head Magnetic Disk





Nonvolatile Memory Devices

- If disk-drive like, then called solid-state disks (SSDs)
- Other forms include **USB drives** (thumb drive, flash drive), DRAM disk replacements, surface-mounted on motherboards, and main
- Can be **more reliable** than HDDs
- More expensive per MB
- Maybe have shorter life span – need careful management
- Less capacity, but much faster
- Busses can be too slow -> connect directly to PCI for example
- No moving parts, so no seek time or rotational latency
  - First come first served is good

Disk Scheduling

- OS is responsible for using hardware efficiently
  - for the disk drives: a fast access time and high disk bandwidth
  - **access time**: seek time (roughly linear to seek distance) + rotational latency
  - **disk bandwidth** is the speed of data transfer, data /time
    - data: total number of bytes transferred
    - time: between the first request and completion of the last transfer

Disk Scheduling

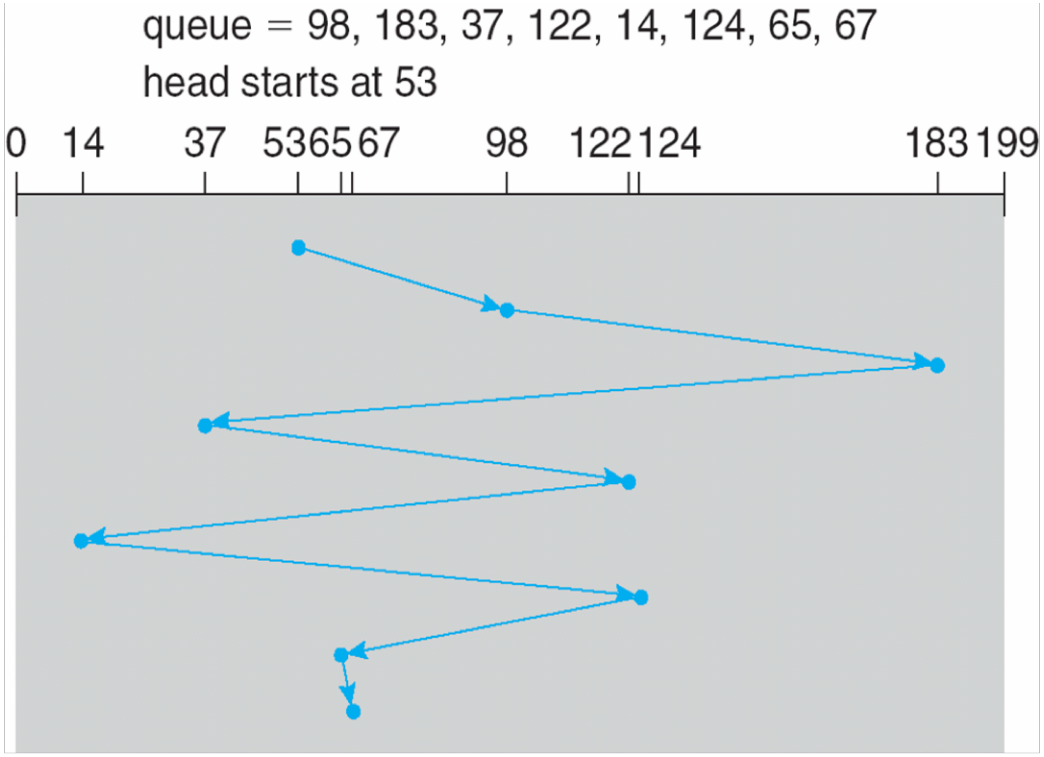
- **Disk scheduling** chooses which **pending disk request to service next**
  - concurrent sources of disk I/O requests include OS, system/user processes
  - idle disk can immediately work on a request, otherwise os queues requests
    - each request provide I/O mode, disk & memory address, and # of sectors
    - OS maintains a queue of requests, per disk or device
    - optimization algorithms only make sense when a queue exists
  - In the past, operating system responsible for queue management, disk drive head scheduling
    - Now, **built into the storage devices, controllers - firmware**
    - Just provide **LBAs**, handle sorting of requests
      - Some of the algorithms they use described next

Disk Scheduling

- Disk scheduling usually tries to minimize **seek time**
  - rotational latency is difficult for OS to calculate
- There are many disk scheduling algorithms
  - FCFS
  - SSTF
  - SCAN
  - C-SCAN
  - C-LOOK
- We use a request queue of "**98, 183, 37, 122, 14, 124, 65, 67**" (**[0, 199]**), and initial head position **53** as the example

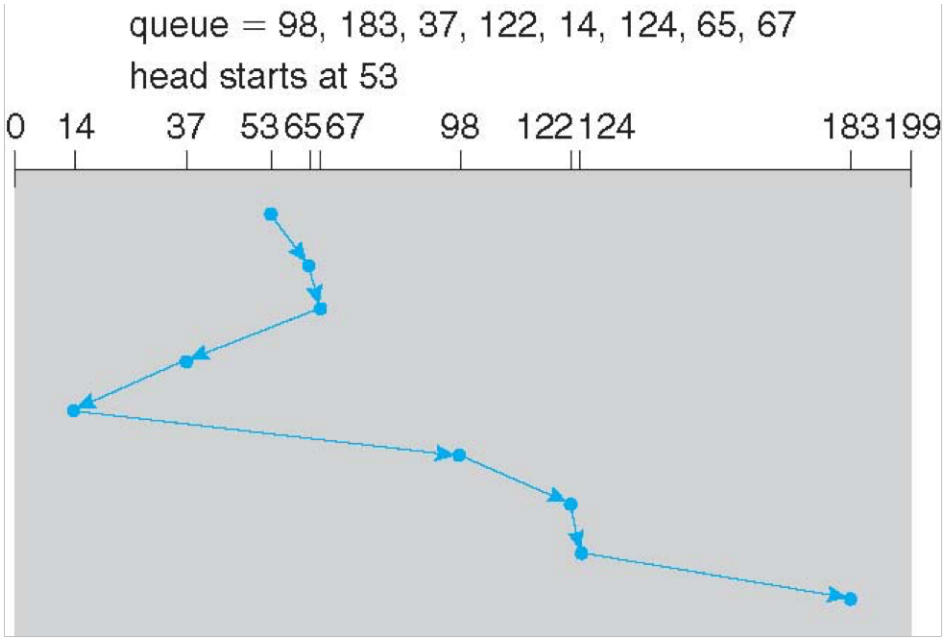
FCFS

- First-come first-served, simplest scheduling algorithm
- Total head movements of *640* cylinders



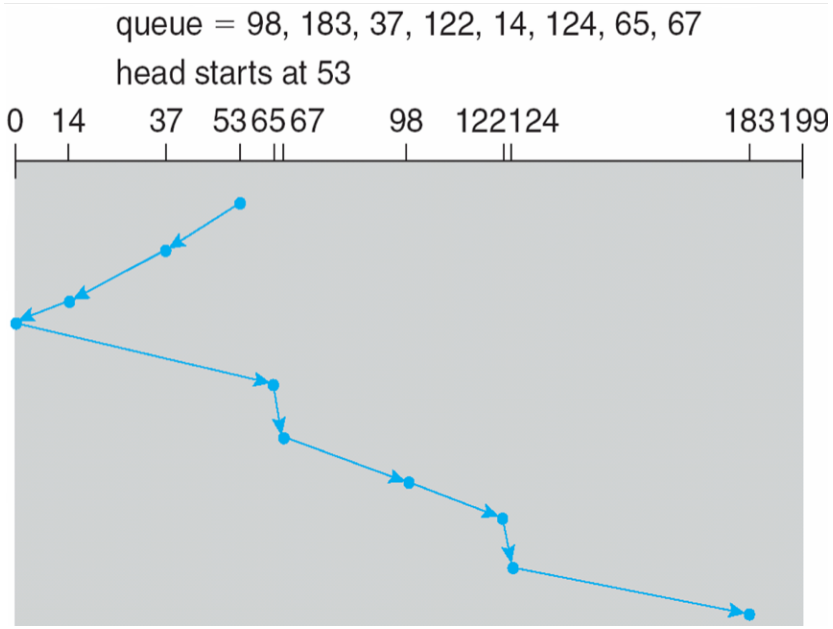
SSTF

- SSTF: shortest seek time first
  - selects the request with minimum seek time from the **current** head position
  - SSTF scheduling is a form of SJF scheduling, **starvation** may exist
    - unlike SJF, SSTF **may not** be **optimal**
- Total head movement of 236 cylinders



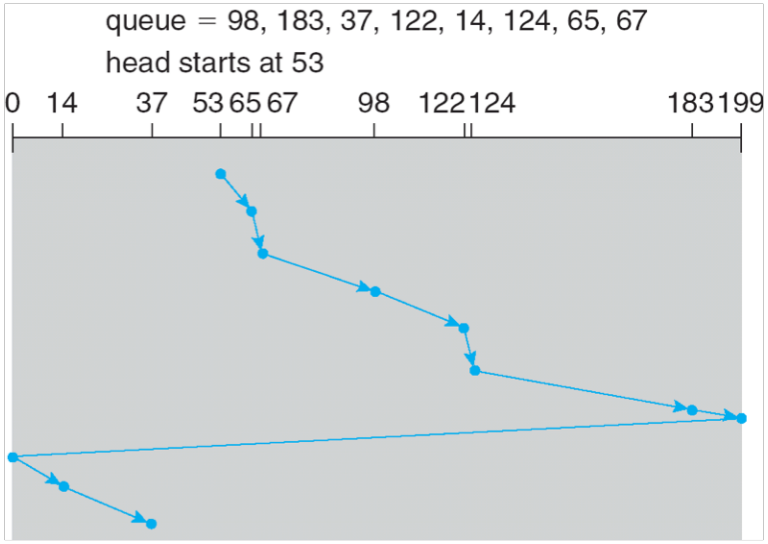
SCAN

- SCAN algorithm sometimes is called the **elevator** algorithm
  - disk arm starts at one **end** of the disk, and moves toward the **other end**
  - service requests during the movement until it gets to the other end
  - then, the head movement is reversed and servicing continues.



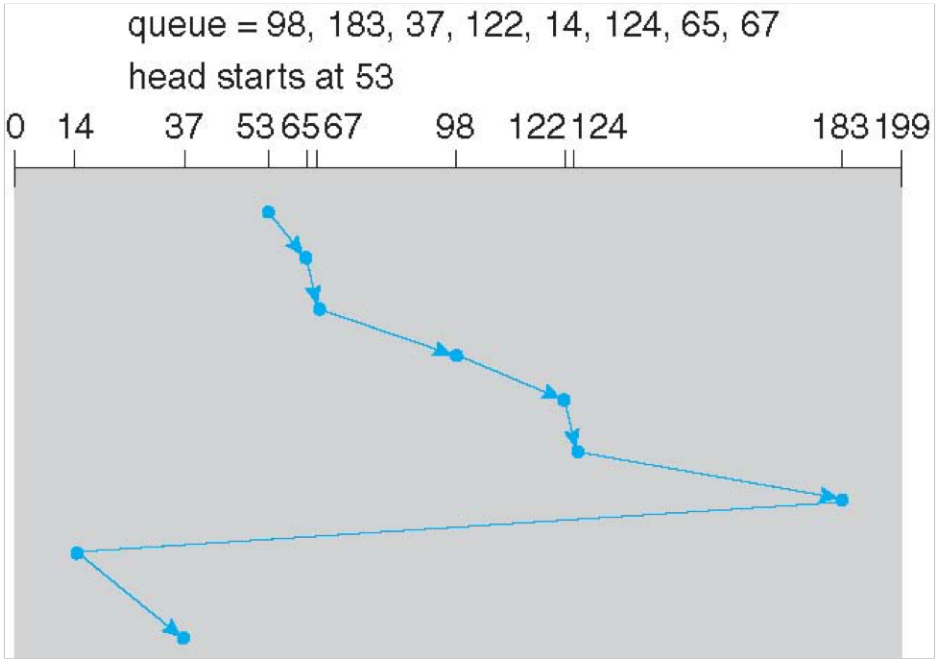
C-SCAN

- Circular-SCAN is designed to provides a more uniform wait time
  - head moves from **one end** to **the other**, servicing requests while going
  - when the head reaches the end, it immediately returns to the beginning
    - **without** servicing any requests on the return trip
  - it essentially treats the cylinders as a circular list



LOOK/C-LOOK

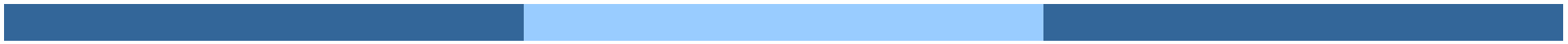
- SCAN and C-SCAN moves head end to end, even no I/O in between
  - in implementation, head only goes as far as **last request** in each direction
  - **LOOK** is a version of **SCAN**, **C-LOOK** is a version of **C-SCAN**



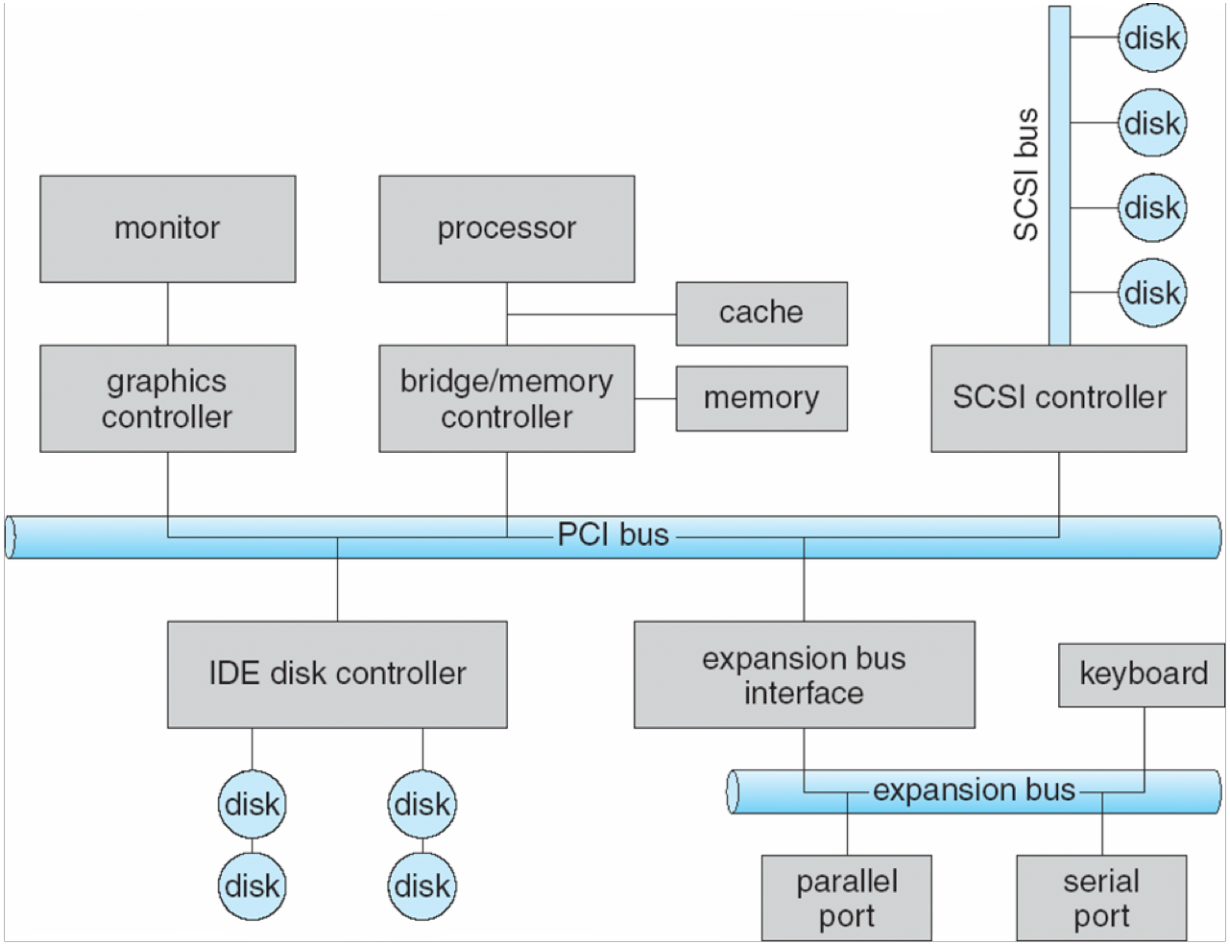
RAID

- **RAID – redundant array of inexpensive disks**
  - multiple disk drives provides reliability via **redundancy**
- Increases the **mean time to failure**

12: I/O Systems



A Typical PC Bus Structure



Application I/O Interface

- I/O system calls encapsulate device behaviors in generic classes
  - in Linux, devices can be accessed **as files**; low-level **access with ioctl**
- **Device-driver layer** hides differences among I/O controllers from kernel
  - each OS has its own I/O subsystem and device driver frameworks
  - new devices talking already-implemented protocols need no extra work

13&14: File System

File Concept

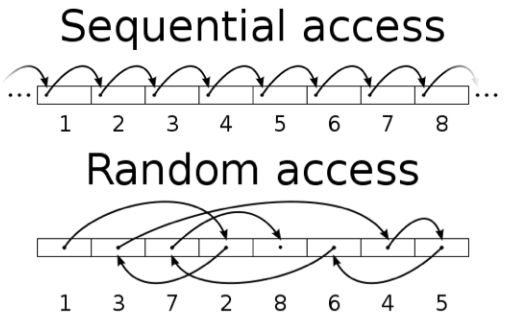
- **File** is a contiguous logical address space for storing information
  - database, audio, video, web pages…
- There are different types of file:
  - data: numeric, character, binary
  - program
  - special one: proc file system - use file-system interface to retrieve system information

File Attributes

- **Name** – only information kept in **human-readable form**
- **Identifier** – unique tag (number) identifies file **within file system**
- **Type** – needed for systems that support different types
- **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
- Information about files are kept in the directory structure, which is maintained on the disk
- Many variations, including **extended file attributes** such as file checksum

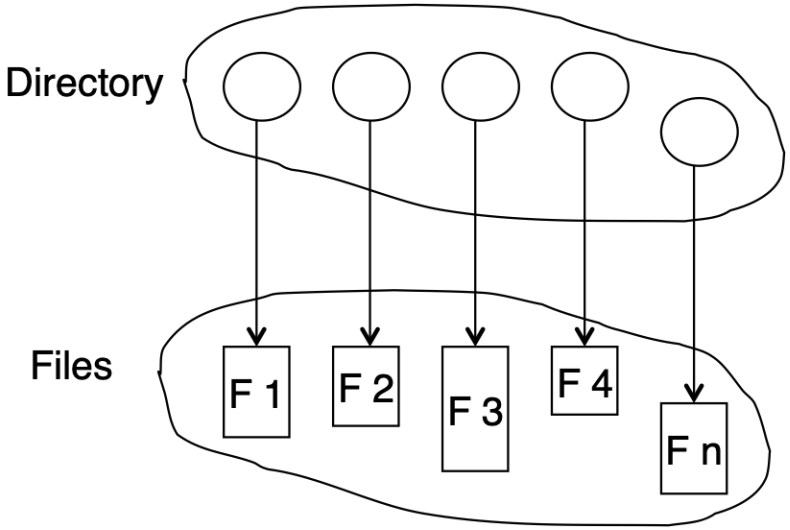
Access Methods

- Sequential access
  - a group of elements is access **in a predetermined order**
  - for some media types, the only access mode (e.g., **tape**)
- Direct access
  - access an element at an **arbitrary position** in a sequence in (roughly) **equal time**, independent of sequence size
    - it is possible to emulate random access in a tape, but access time varies
  - sometime called random access



Directory Structure

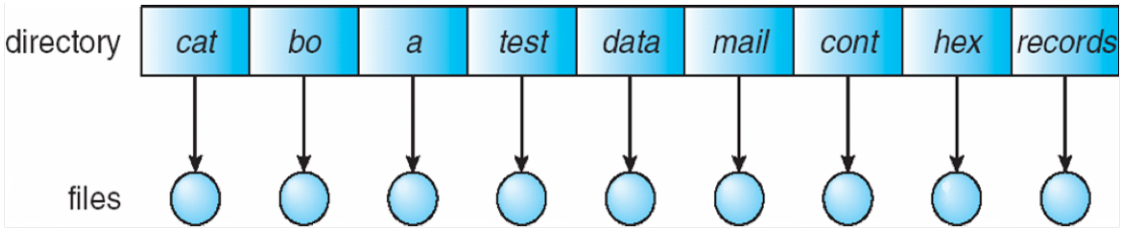
- Directory is a collection of nodes containing information about all files



both the directory structure and the files reside on disk

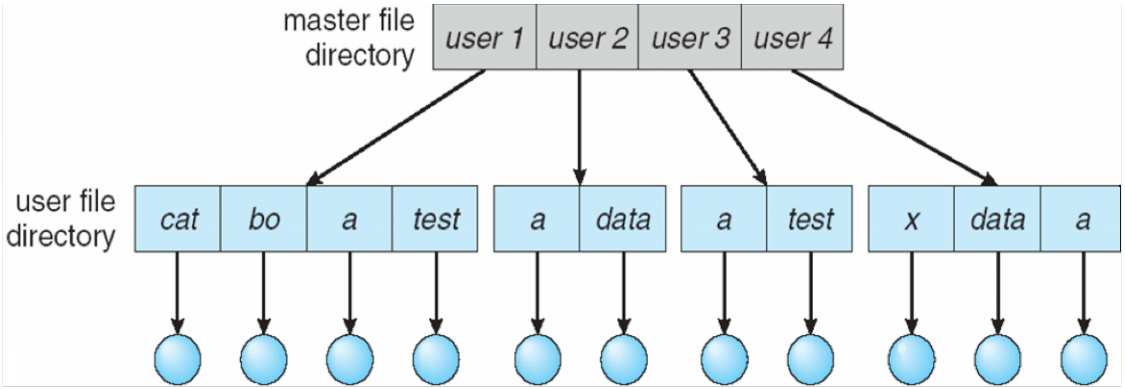
Single-Level Directory

- A single directory for all users
  - naming problems and grouping problems
    - Two users want to have same file names
    - Hard to group files



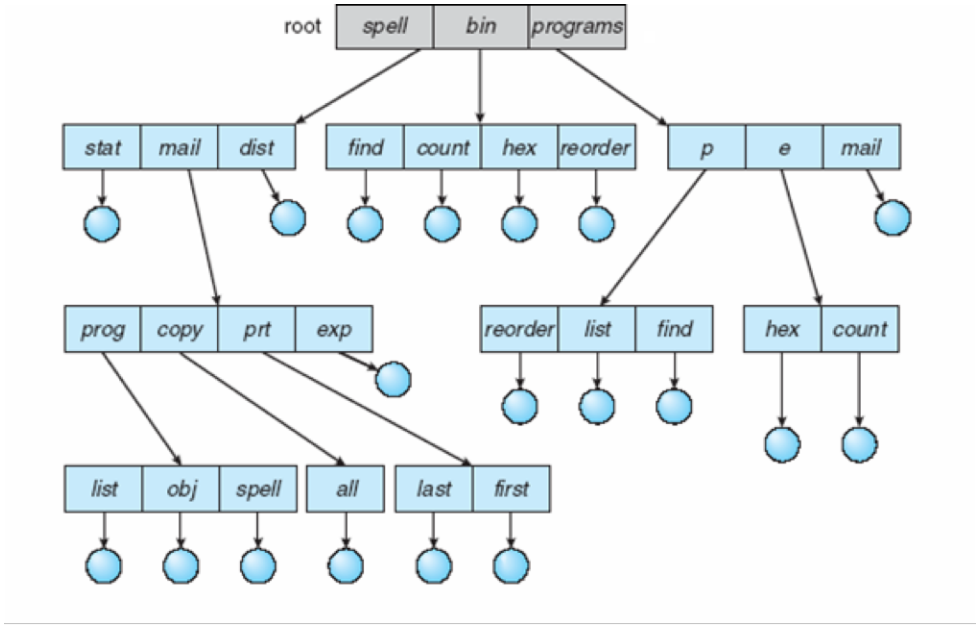
Two-Level Directory

- Separate directory for each user
  - different user can have the same name for different files
    - Each user has his own user file directory (UFD), it is in the master file directory (MFD)
  - efficient to search, cannot group files
  - How to share files between different users, and how to share the system files?



Tree-Structured Directories

- Files organized into trees
  - efficient in searching, can group files, convenient naming - solving file name conflicts for different users!



Tree-Structured Directories

- File can be accessed using **absolute** or **relative** path name
  - absolute path name: /home/alice/..
  - relative path is relative to the **current directory (*pwd*)**
    - creating a new file, delete a file, or create a sub-directory
    - e.g., if current directory is /mail, a **mkdir count** will create /mail/count

echo $(pwd)

Quick quiz: what 's the functionality of the set shell command?

->to set or get environment variables

Protection

- File owner/creator should be able to control
  - what can be done
  - by whom
- Types of access
  - read, write, append
  - execute
  - delete
  - list

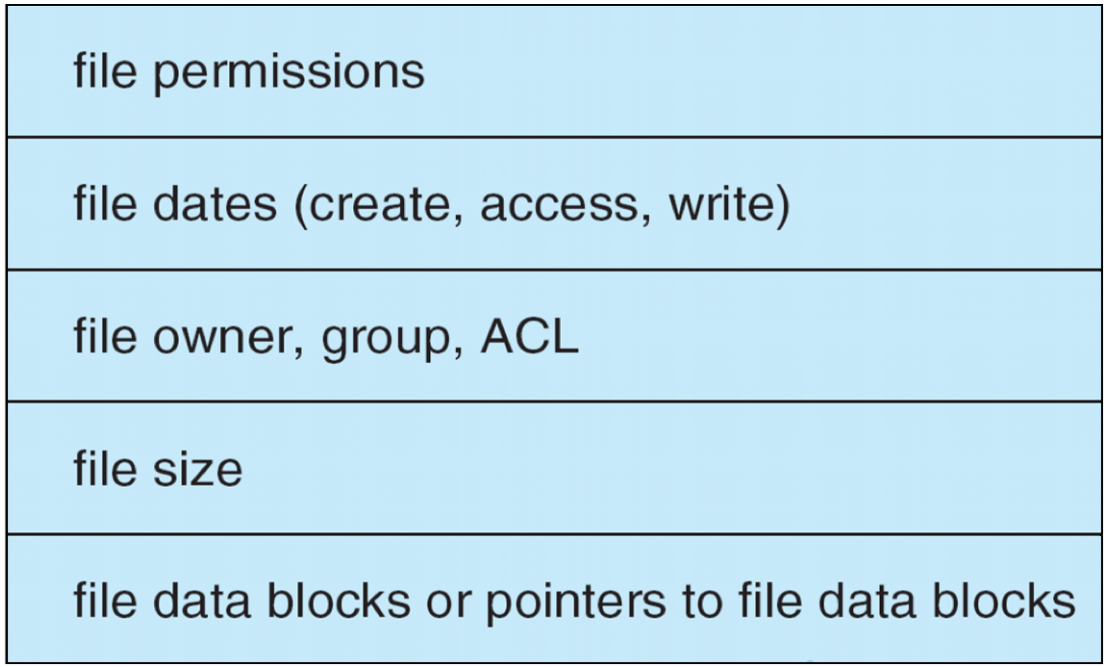
File-System Structure

- File is a logical storage unit for a collection of related information
- There are many file systems; OS may support several **simultaneously**
  - Linux has Ext2/3/4, Reiser FS/4, Btrfs…
  - Windows has FAT, FAT32, NTFS…
  - new ones still arriving – ZFS, GoogleFS, Oracle ASM, FUSE
- File system resides on **secondary storage** (disks)
  - disk driver provides interfaces to read/write disk blocks
  - **fs provides user/program interface to storage, mapping logical to physical**
    - file control block – storage structure consisting of information about a file
- File system is usually implemented and organized into **layers**

File System Data Structures

- The file system comprises data structures
- On-disk structures:
  - An optional boot control block
    - First block of a volume that stores an OS
    - boot block in UFS, partition boot sector in NTFS
  - A volume control block
    - Contains the number of blocks in the volume, block size, free-block count, free-block pointers, free-FCB count, FCB-pointers
    - superblock in UFS, master file table in NTFS
  - A directory
    - File names associated with an ID, FCB pointers
  - A per-file File Control Block (FCB)
    - In NTFS, the FCB is a row in a relational database
- In-memory structures:
  - A mount table with one entry per mounted volume
  - A directory cache for fast path translation (performance)
  - A global open-file table
  - A per-process open-file table
  - Various buffers holding disk blocks "in transit" (performance)

A Typical File Control Block

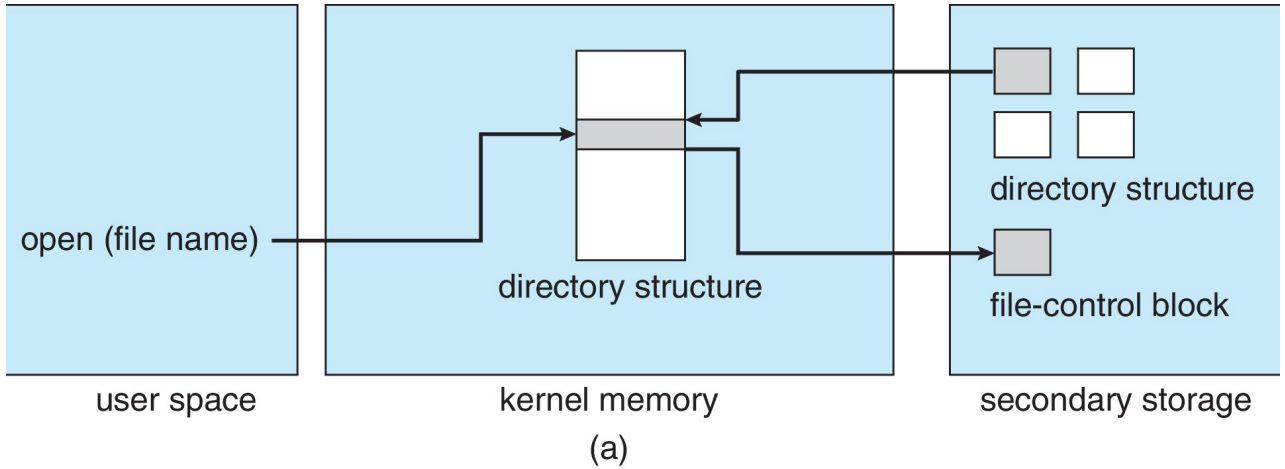


File Creation

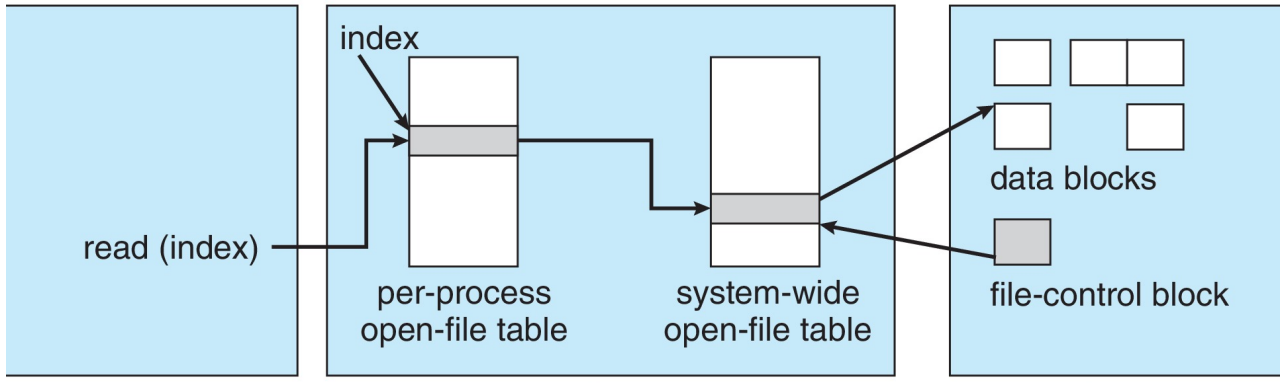
- application process requests the creation of a new file
- logical file system allocates a new FCB, i.e., inode structure
- appropriate directory is updated with the new file name and FCB, i.e., inode

Directory

- Unix – directories are treated as files containing special data
- Windows – directories differently from files;
  - they require a separate set of systems calls to create, manipulate, etc



(a)



(b)

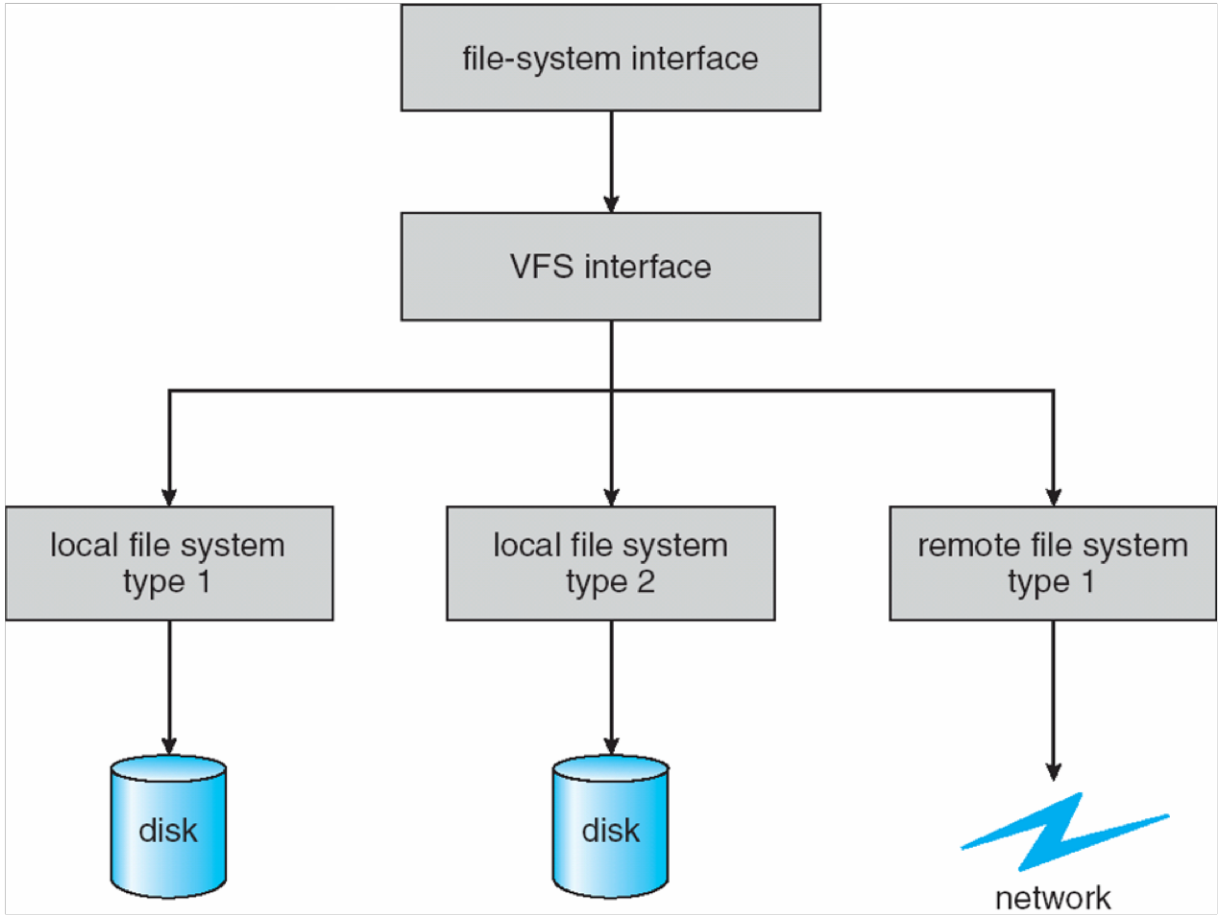
Operations - open()

- search **System-Wide Open-File Table** to see if file is currently in use
  - if it is, create a Per-Process Open-File table entry pointing to the existing System-Wide Open-File Table
  - if it is not, search the directory for the file name; once found, load the **FCB** from disk to memory and place it in the System-Wide Open-File Table
- make an entry in the **Per-Process Open-File Table**, with pointers to the entry in the **System-Wide Open-File Table** and other fields which include a pointer to the current location in the file and the access mode in which the file is open

Virtual File Systems

- **VFS** provides an **object-oriented** way of implementing file systems
  - OS defines **a common interface for FS**, all FSes implement them
  - *system call is implemented based on this common interface*
    - it allows the same syscall API to be used for different types of FS
- VFS separates FS generic operations from implementation details
  - implementation can be one of many FS types, or network file system
  - OS can dispatches syscalls to appropriate FS implementation routines

Virtual File System



Virtual File System Example

- Linux defines four **VFS object types**:
  - **superblock**: defines the file system type, size, status, and other metadata
  - **inode: contains metadata about a file (location, access mode, owners…). -FCB!!**
  - **dentry: associates names to inodes, and the directory layout**
  - **file**: actual data of the file
- VFS defines set of operations on the objects that must be implemented
  - the set of operations is saved in a function table

```
struct file_operations {
        int (*lseek) (struct inode *, struct file *, off_t, int);
        int (*read) (struct inode *, struct file *, char *, int);
        int (*write) (struct inode *, struct file *, const char *, int);
        int (*readdir) (struct inode *, struct file *, void *, filldir_t);
        int (*select) (struct inode *, struct file *, int, select_table *);
        int (*ioctl) (struct inode *, struct file *, unsigned int, unsigned long);
        int (*mmap) (struct inode *, struct file *, struct vm_area_struct *);
        int (*open) (struct inode *, struct file *);
        void (*release) (struct inode *, struct file *);
        int (*fsync) (struct inode *, struct file *);
        int (*fasync) (struct inode *, struct file *, int);
        int (*check_media_change) (kdev_t dev);
        int (*revalidate) (kdev_t dev);
};
```

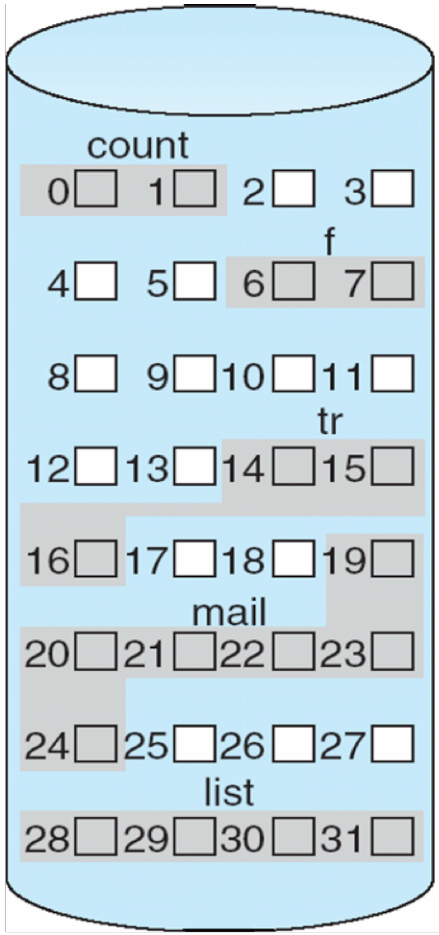
Disk Block Allocation

- **Files** need to be allocated with disk blocks to store data
  - different allocation strategies have different complexity and performance
- Many allocation strategies:
  - contiguous
  - linked
  - indexed
  - …

Contiguous Allocation

- Contiguous allocation: each file occupies set of **contiguous blocks**
  - best performance in most cases
  - simple to implement: only starting location and length are required
- Contiguous allocation is not flexible
  - how to *increase/decrease* file size?
    - need to know file size at the file creation?
  - **external fragmentation**
    - how to compact files offline or online to reduce external fragmentation
  - need for **compaction** off-line (downtime) or on-line
  - appropriate for sequential disks like **tape**
- Some file systems use **extent-based contiguous allocation**
  - extent is a set of contiguous blocks
  - a file consists of extents, extents are not necessarily adjacent to each other

Contiguous Allocation



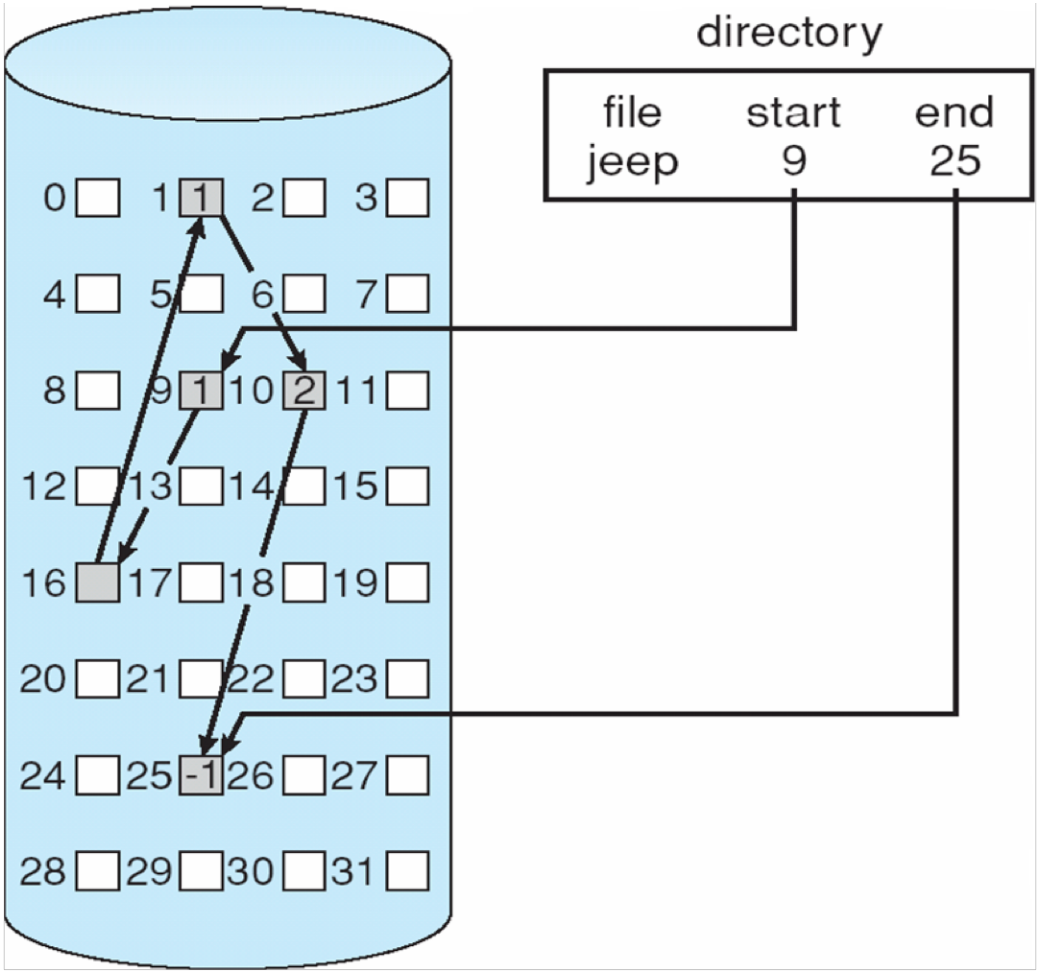
directory

file	start	length
count	0	2
tr	14	3
mail	19	6
list	28	4
f	6	2

Linked Allocation

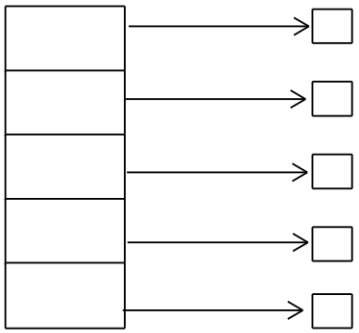
- Linked allocation: each file is a **linked list of disk blocks**
  - each block contains pointer to **next block**, file ends at nil pointer
  - blocks may be scattered anywhere on the disk (no **external fragmentation, no compaction**)
  - *Disadvantages*
    - *locating a file block can take many I/Os and disk seeks*
    - *Pointer size: 4 of 512 bytes are used for pointer - 0.78% space is wasted*
    - *Reliability: what about the pointer has corrupted!*

Linked Allocation



Indexed Allocation

- Indexed allocation: each file has its own **index blocks of pointers to its data blocks**
  - index table provides **random access** to file data blocks
  - no **external fragmentation**, but overhead of index blocks
  - allows **holes** in the file
  - Index block needs space - waste for small files

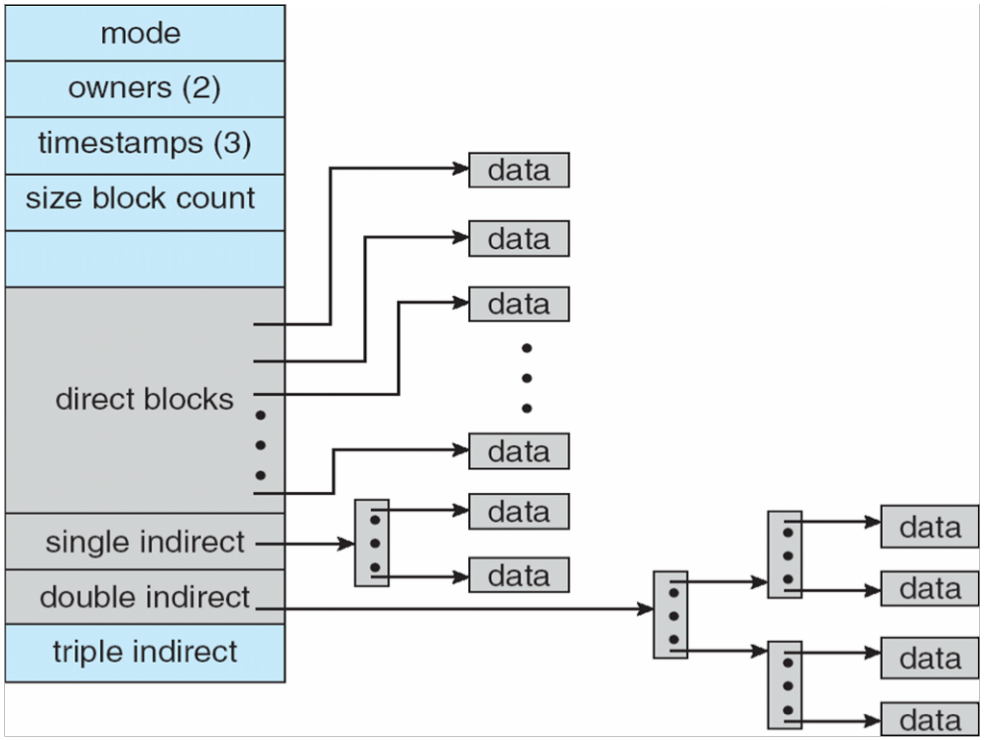


index table

What about two levels?

Indexed Allocation

- Combined scheme
- The UNIX FCB: the inode (index node)
  - First 15 pointers are in inode
    - Direct block: first 12 pointers
    - Indirect block: next 3 pointers



Hard link vs soft link

- Link
  - A file may be known by more than one name in one or more directories. Such multiple names are known as links.
  - The two kinds of links are also known as hard links and soft links.
- Hard link
  - a hard link is a directory entry that associates with a file
  - The file name "." in a directory is a hard link to the directory itself
  - The file name ".." is a hard link to the parent directory
- Soft link (a.k.a., symbolic link or symlink)
  - A symbolic link is a file containing the path name of another file
  - Soft links, unlike hard links, may point to directories and may cross file-system boundaries

Hard links

```
os@os:~/temp/foo$ rm file
os@os:~/temp/foo$ cat file2
hello
os@os:~/temp/foo$ _
```

- rm: unlink the file, and check the reference count of the **inode**

```
os@os:~/temp/foo$ echo hello >file
os@os:~/temp/foo$ stat file
  File: 'file'
  Size: 6               Blocks: 8          IO Block: 4096   regular file
Device: 801h/2049d      Inode: 1328650     Links: 1
Access: (0664/-rw-rw-r--)  Uid: ( 1000/      os)   Gid: ( 1000/      os)
Access: 2018-12-21 00:09:14.763058468 +0800
Modify: 2018-12-21 00:09:14.763058468 +0800
Change: 2018-12-21 00:09:14.763058468 +0800
 Birth: -
os@os:~/temp/foo$ ln file file2
os@os:~/temp/foo$ stat file2
  File: 'file2'
  Size: 6               Blocks: 8          IO Block: 4096   regular file
Device: 801h/2049d      Inode: 1328650     Links: 2
Access: (0664/-rw-rw-r--)  Uid: ( 1000/      os)   Gid: ( 1000/      os)
Access: 2018-12-21 00:09:14.763058468 +0800
Modify: 2018-12-21 00:09:14.763058468 +0800
Change: 2018-12-21 00:09:24.247463616 +0800
 Birth: -
os@os:~/temp/foo$ ln file2 file3
os@os:~/temp/foo$ stat file
  File: 'file'
  Size: 6               Blocks: 8          IO Block: 4096   regular file
Device: 801h/2049d      Inode: 1328650     Links: 3
Access: (0664/-rw-rw-r--)  Uid: ( 1000/      os)   Gid: ( 1000/      os)
Access: 2018-12-21 00:09:14.763058468 +0800
Modify: 2018-12-21 00:09:14.763058468 +0800
Change: 2018-12-21 00:09:33.975880487 +0800
 Birth: -
```

```
os@os:~/temp/foo$ rm file
os@os:~/temp/foo$ stat file2
  File: 'file2'
  Size: 6               Blocks: 8          IO Block: 4096   regular file
Device: 801h/2049d      Inode: 1328650     Links: 2
Access: (0664/-rw-rw-r--)  Uid: ( 1000/      os)   Gid: ( 1000/      os)
Access: 2018-12-21 00:09:14.763058468 +0800
Modify: 2018-12-21 00:09:14.763058468 +0800
Change: 2018-12-21 00:09:40.776172622 +0800
 Birth: -
os@os:~/temp/foo$ rm file2
os@os:~/temp/foo$ stat file3
  File: 'file3'
  Size: 6               Blocks: 8          IO Block: 4096   regular file
Device: 801h/2049d      Inode: 1328650     Links: 1
Access: (0664/-rw-rw-r--)  Uid: ( 1000/      os)   Gid: ( 1000/      os)
Access: 2018-12-21 00:09:14.763058468 +0800
Modify: 2018-12-21 00:09:14.763058468 +0800
Change: 2018-12-21 00:09:47.092444491 +0800
 Birth: -
```

Soft links

- rm the target file, the link will be invalided

```
os@os:~/temp/foo$ echo hello > file
os@os:~/temp/foo$ ln -s file file2
```

```
os@os:~/temp/foo$ ls -l
total 4
-rw-rw-r-- 1 os os 6 Dec 21 00:11 file
lrwxrwxrwx 1 os os 4 Dec 21 00:12 file2 -> file
os@os:~/temp/foo$ stat file
  File: 'file'
  Size: 6               Blocks: 8          IO Block: 4096   regular file
Device: 801h/2049d      Inode: 1328650     Links: 1
Access: (0664/-rw-rw-r--)  Uid: ( 1000/      os)   Gid: ( 1000/      os)
Access: 2018-12-21 00:11:54.636605978 +0800
Modify: 2018-12-21 00:11:54.636605978 +0800
Change: 2018-12-21 00:11:54.636605978 +0800
 Birth: -
os@os:~/temp/foo$ stat file2
  File: 'file2' -> 'file'
  Size: 4               Blocks: 0          IO Block: 4096   symbolic link
Device: 801h/2049d      Inode: 1328653     Links: 1
Access: (0777/lrwxrwxrwx)  Uid: ( 1000/      os)   Gid: ( 1000/      os)
Access: 2018-12-21 00:12:02.300152148 +0800
Modify: 2018-12-21 00:12:00.960229971 +0800
Change: 2018-12-21 00:12:00.960229971 +0800
 Birth: -
```

```
os@os:~/temp/foo$ rm file
os@os:~/temp/foo$ cat file2
cat: file2: No such file or directory
os@os:~/temp/foo$ ls -l
total 0
lrwxrwxrwx 1 os os 4 Dec 21 00:12 file2 -> file
os@os:~/temp/foo$
```

Takeaway

- The whole slides