Review 04

Yajin Zhou (http://yajin.org)

Zhejiang University

Acknowledgement: Some slides are based on Zhi Wang (FSU)'s slides.

11: storage

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

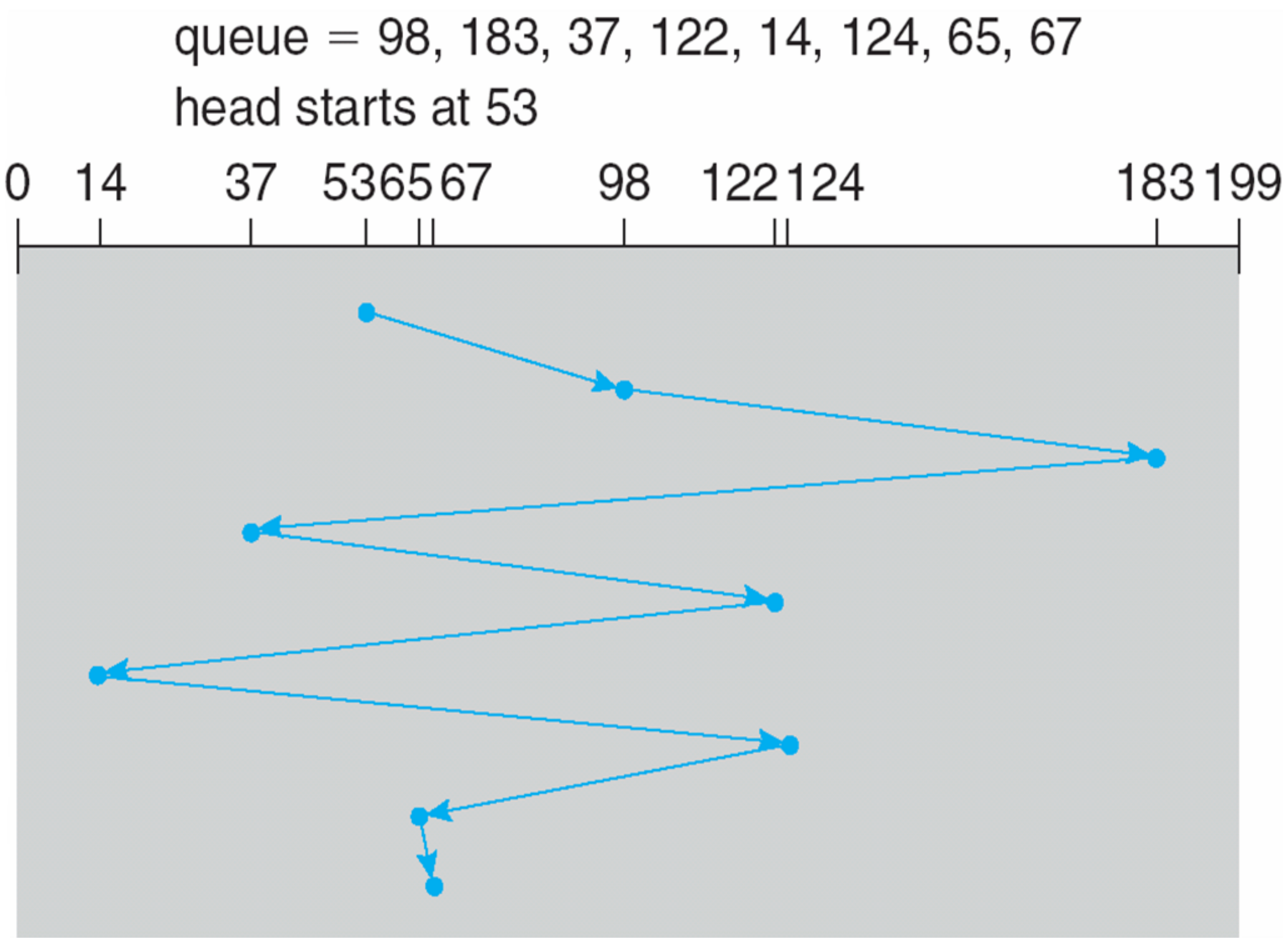
- **Disk scheduling** chooses which **pending disk request to service next**
  - concurrent sources of disk I/O requests include OS, system/user processes
  - idle disk can immediately work on a request, otherwise os queues requests
    - each request provide I/O mode, disk & memory address, and # of 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

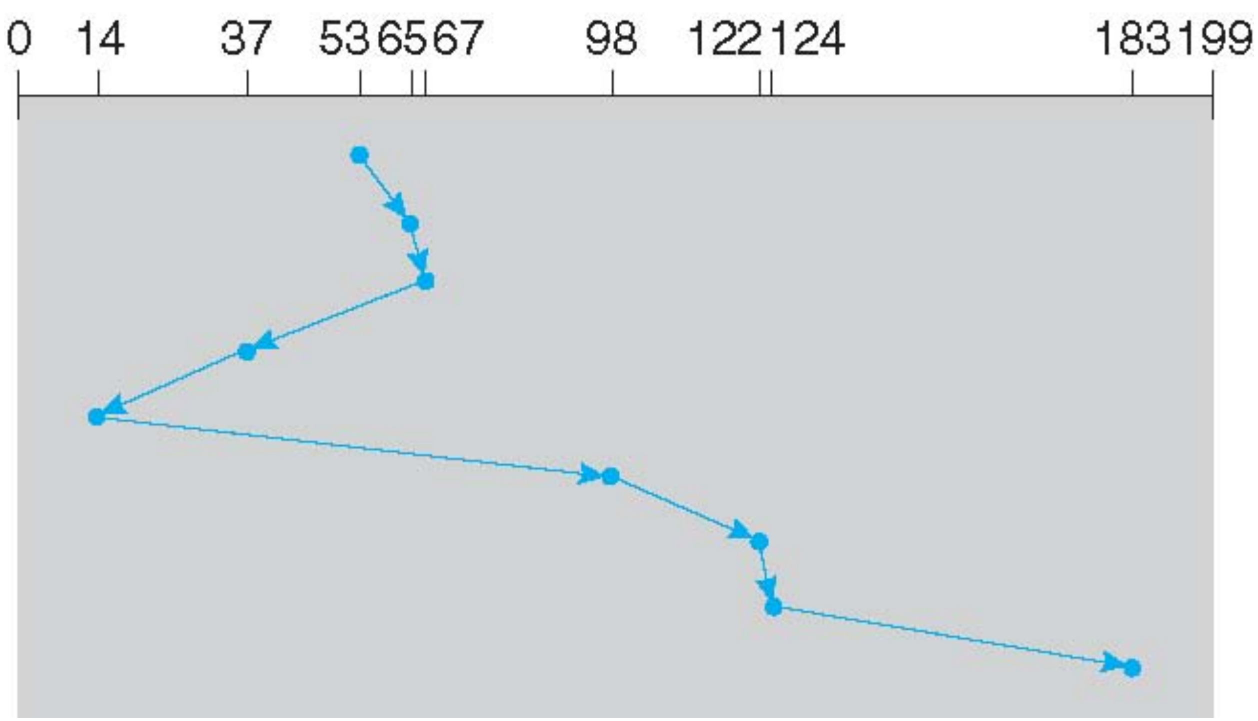


SSTF

- 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

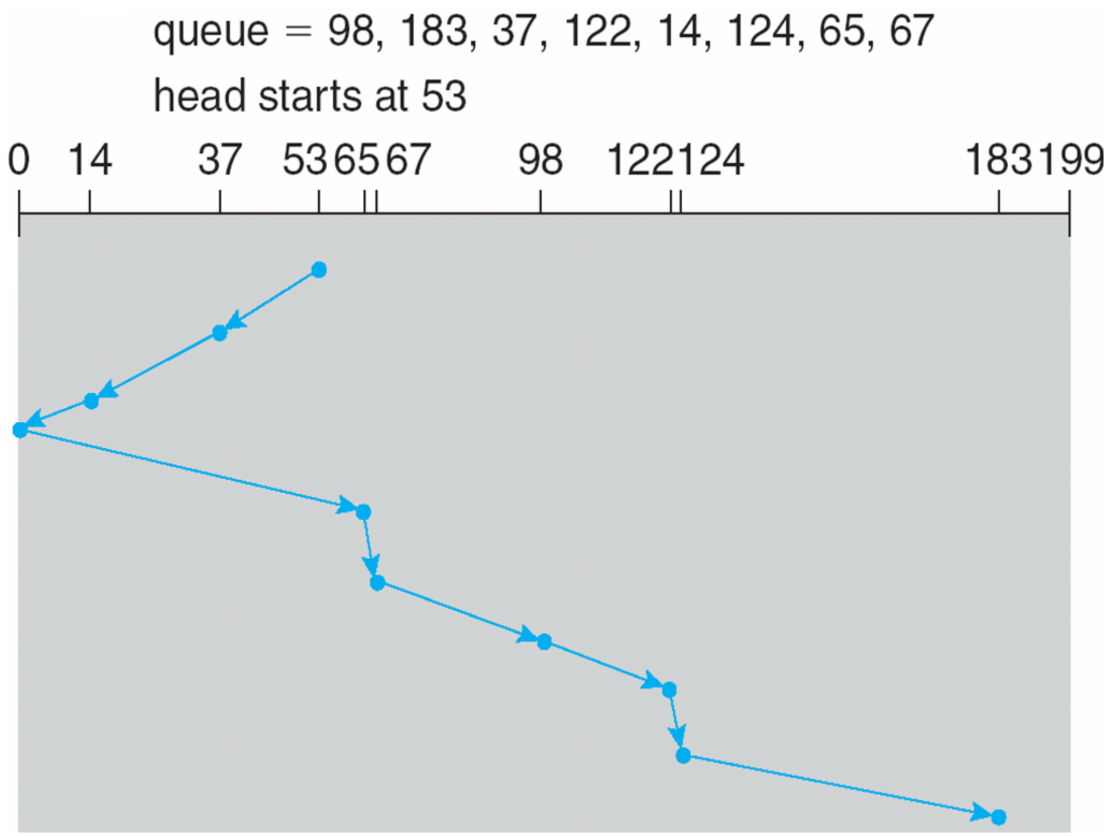
queue = 98, 183, 37, 122, 14, 124, 65, 67

head starts at 53



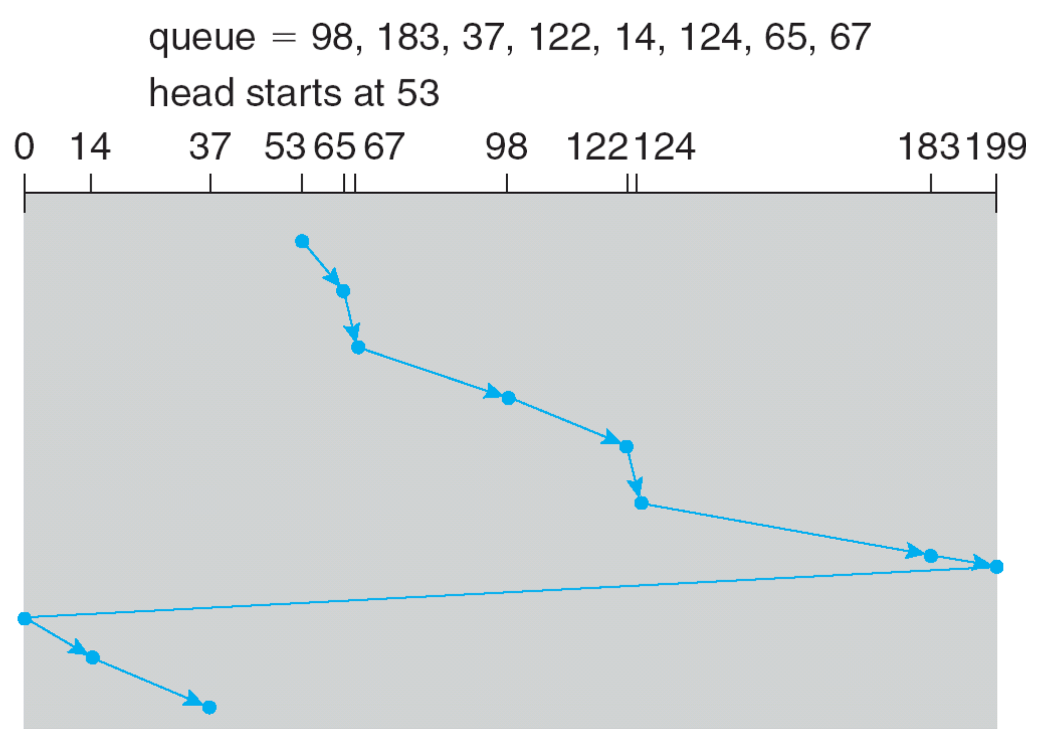
SCAN

- 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.



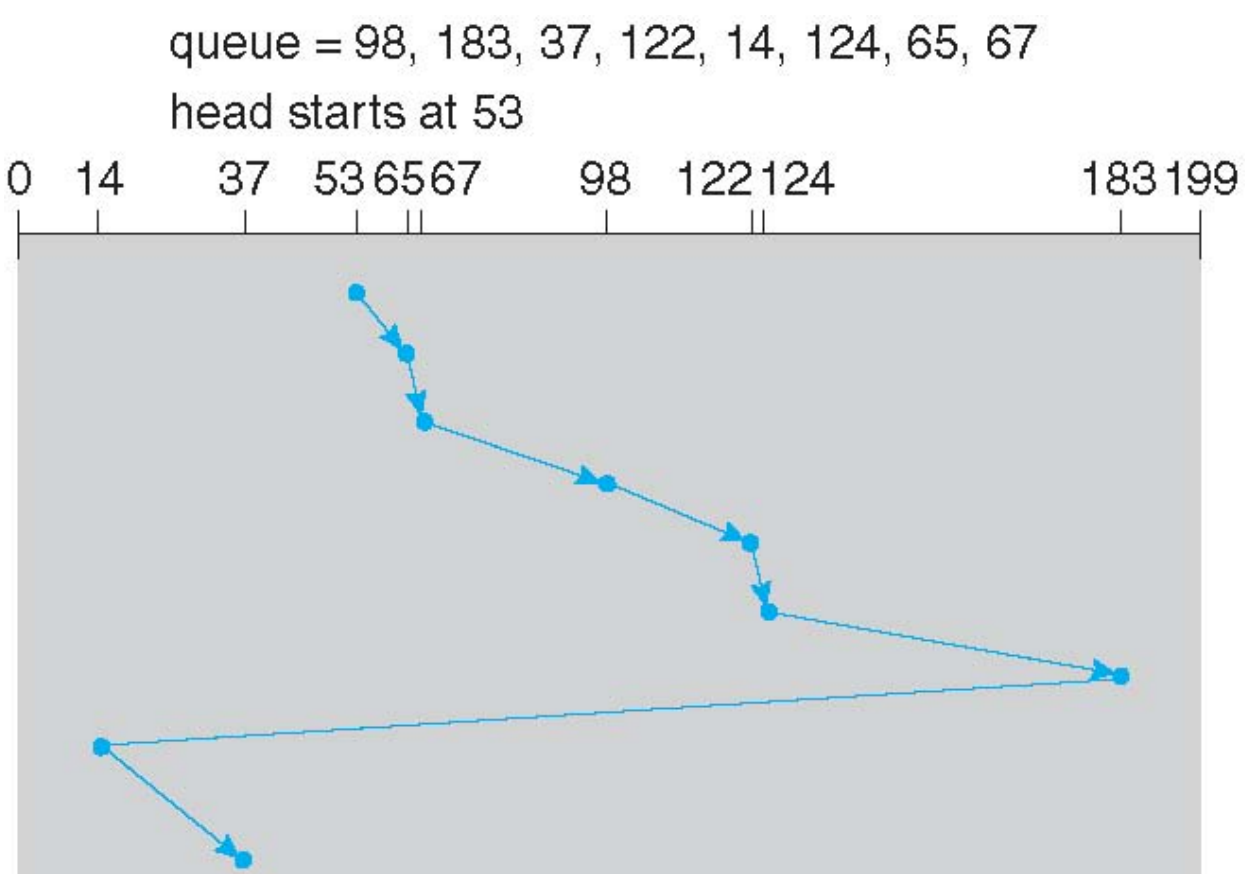
C-SCAN

- 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**

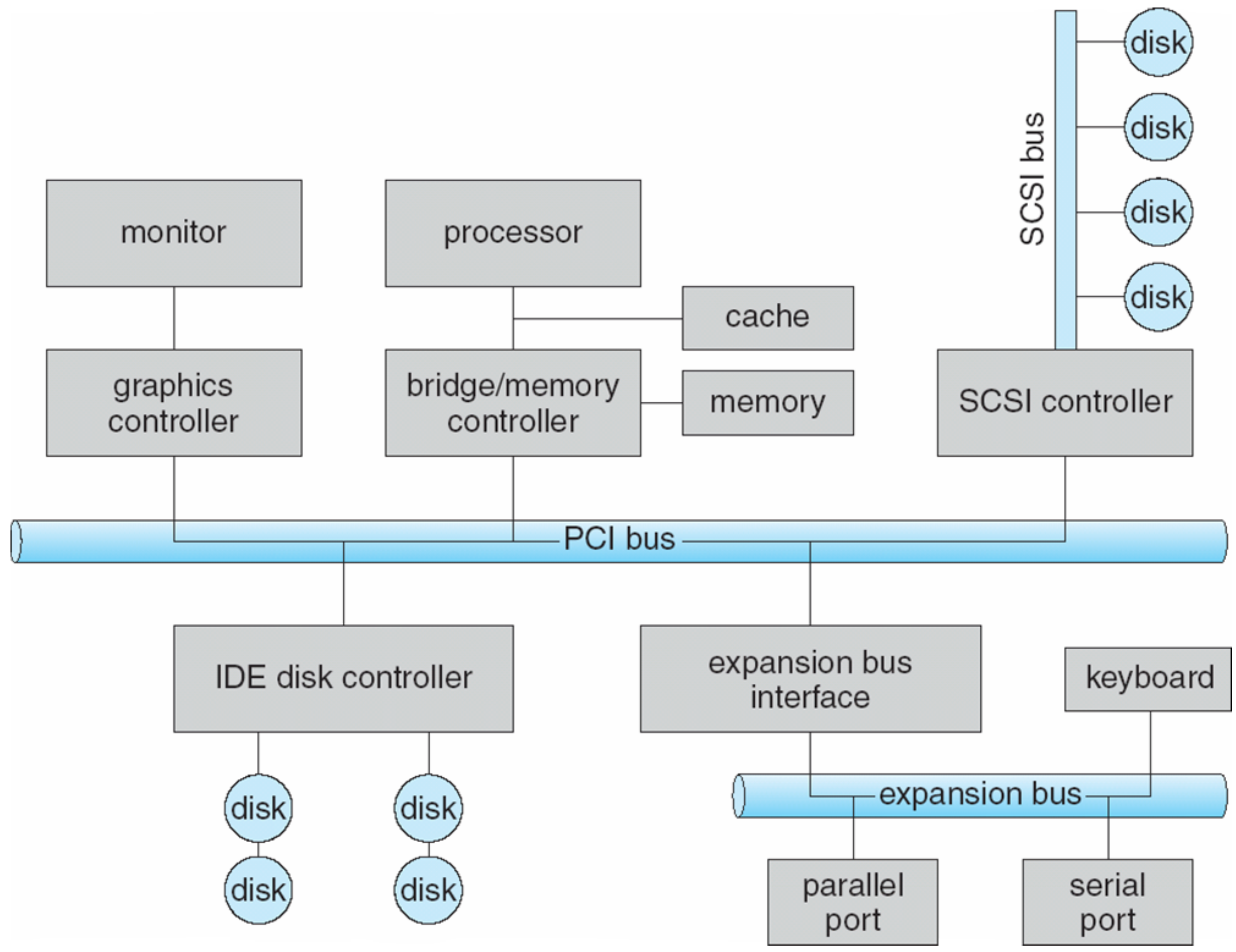


RAID

- **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

Direct Memory Access

- DMA transfer data directly between I/O device and memory
  - OS only need to issue commands, data transfers bypass the CPU
  - no programmed I/O (one byte at a time), data transferred in large blocks
  - it requires DMA controller in the device or system
- OS issues commands to the DMA controller
  - a command includes: operation, memory address for data, count of bytes…
  - usually it is the pointer of the command written into the command register
  - when done, device interrupts CPU to signal completion

13: File System Interface

File Concept

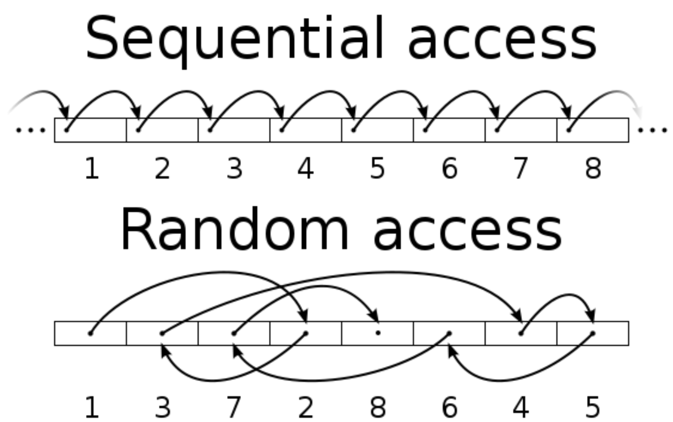
- **File** is a contiguous logical address space for storing information
  - database, audio, video, web pages…
- There are different types of file:
  - data: numeric, character, binary
  - program
  - special one: proc file system - use file-system interface to retrieve system information

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

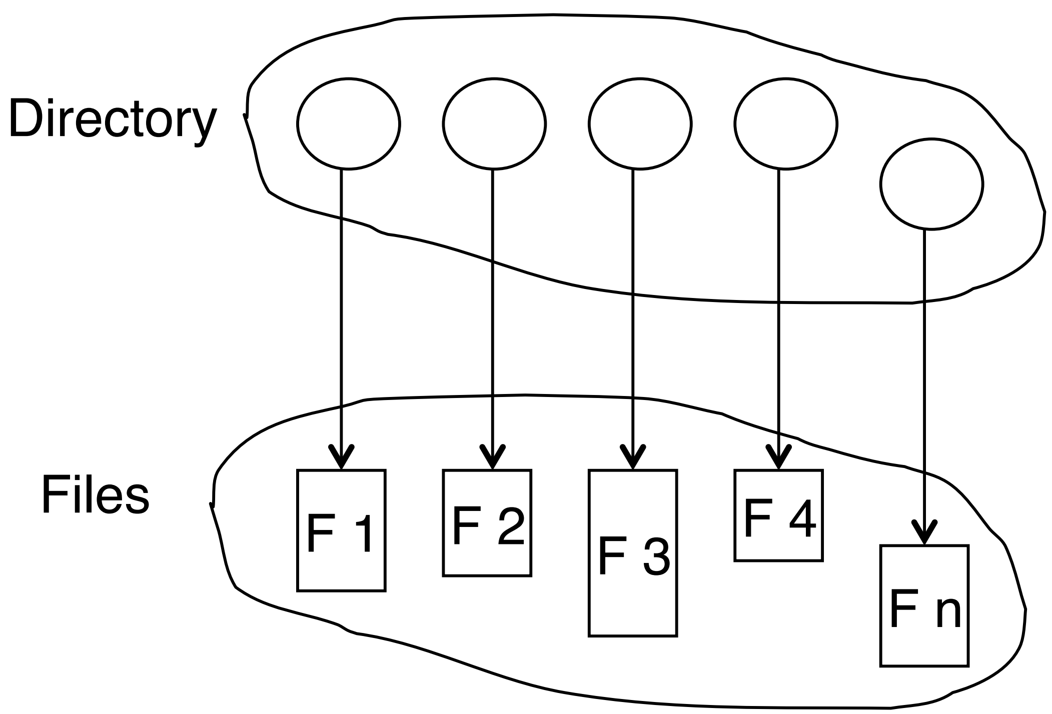
Access Methods

- 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

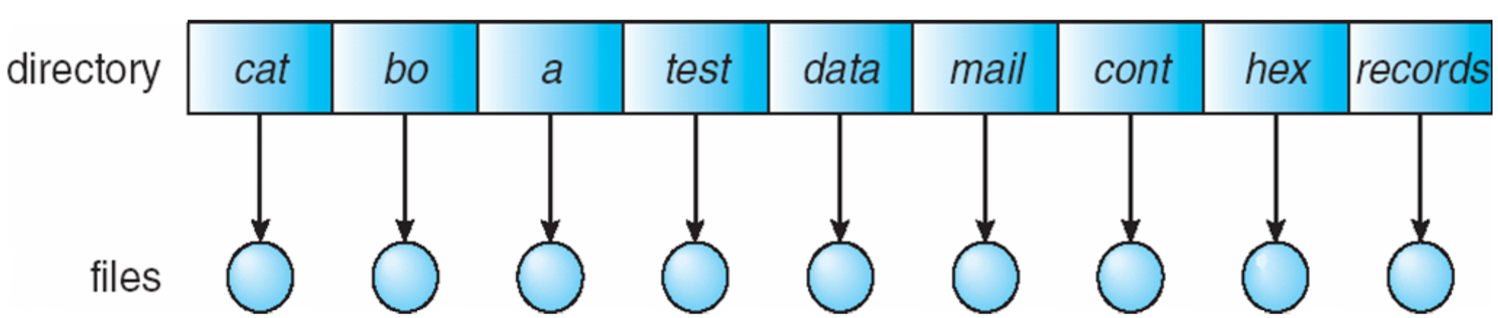
- Directory is a collection of nodes containing information about all files



both the directory structure and the files reside on disk

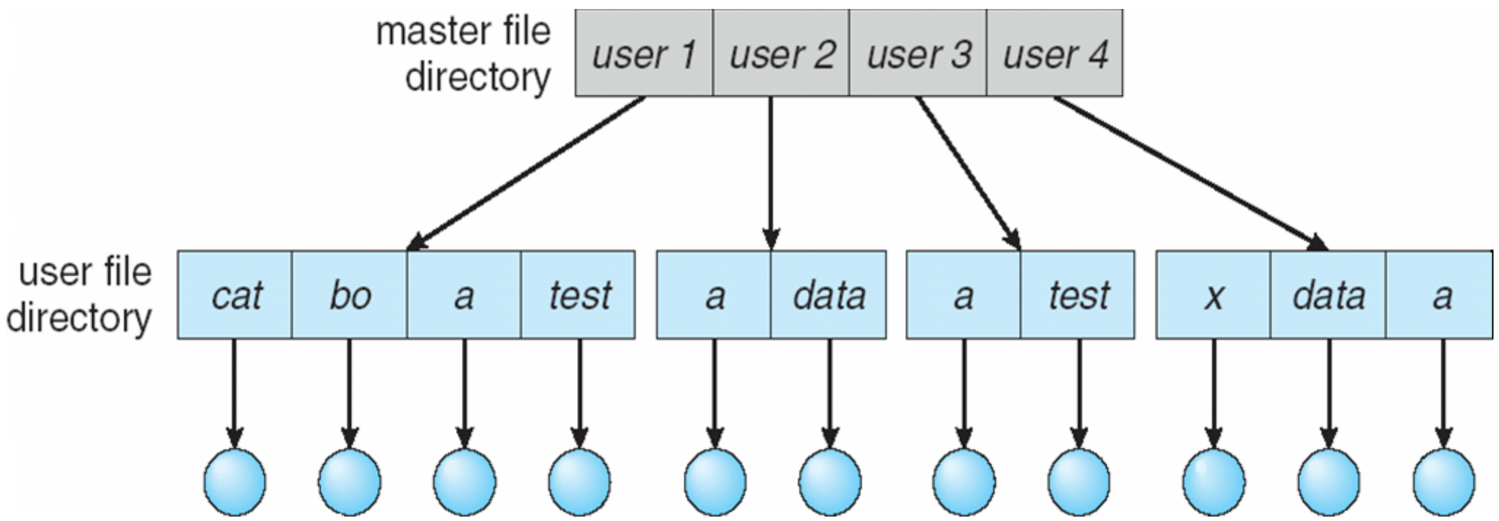
Single-Level Directory

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



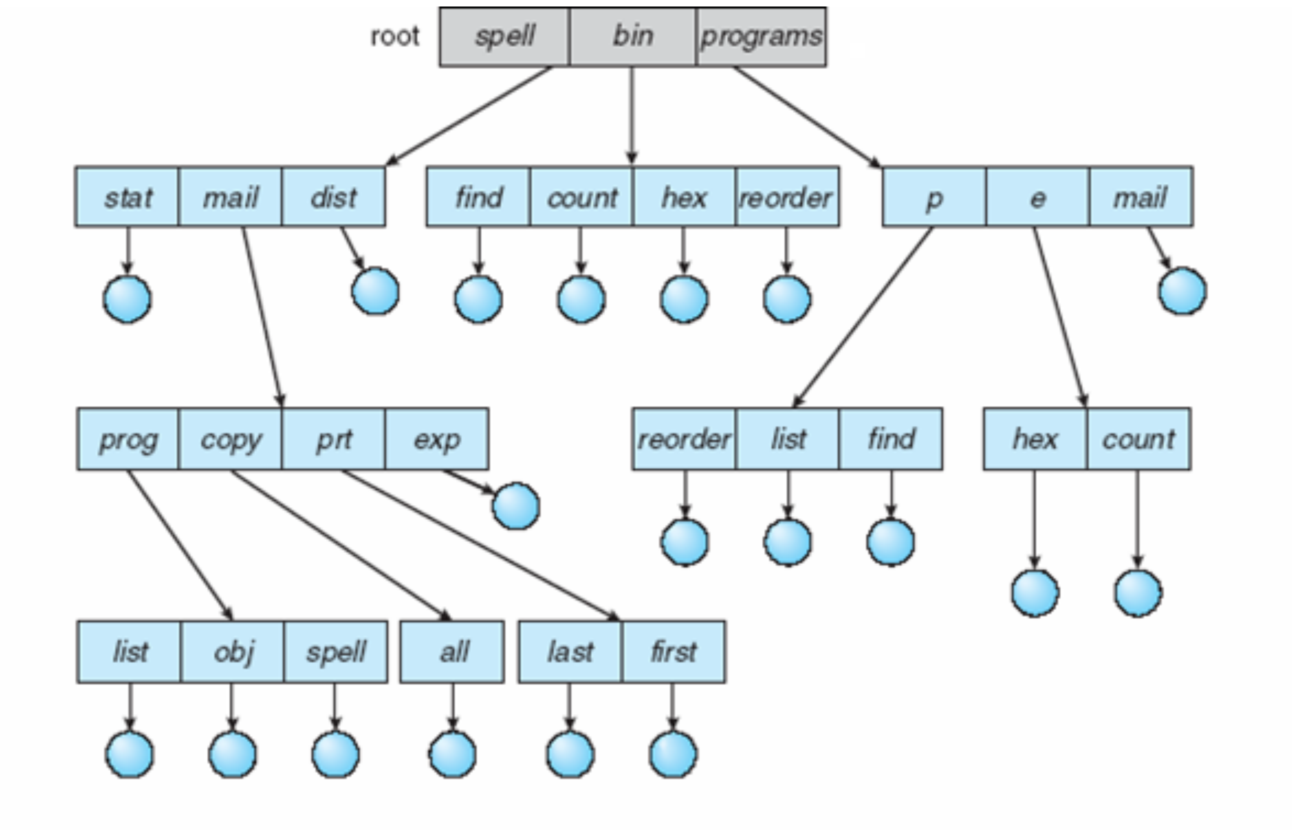
Two-Level Directory

- 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

Symbolic links

```
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$ _
```

- What happens if one file is deleted for the symbolic link?

14: File System Implementation

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, created when a file is created!**
- File system is usually implemented and organized into **layers**

File-System Implementation

- partition == volume == file system storage space
- File-system needs to maintain **on-disk** and **in-memory** structures
  - on-disk for data storage, in-memory for data access
- **On-disk structure** has several control blocks
  - **boot control block** contains info to boot OS from that volume - per volume
    - only needed if volume contains OS image, usually first block of volume
  - **volume control block** (e.g., *superblock*) contains volume details - per volume
    - total # of blocks, # of free blocks, block size, free block pointers, free FCB count, free FCB pointers
  - **directory structure** organizes the directories and files - per file system
    - A list of **(file names and associated inode numbers)**
  - **per-file file control block** contains many **details about the file - per file**
    - permissions, size, dates, data blocks or pointer to data blocks

In-Memory File System Structures

- **In-memory structures** reflects and extends **on-disk structures**
  - **Mount table** storing file system mounts, mount points, file system types
  - In-memory directory-structure cache: holds the directory information about recently accessed directories
  - **system-wide open-file table contains a copy of the FCB of each file and other info.**
  - **per-process open-file table** contains pointers to appropriate entries in system-wide open-file table as well as other info
  - **I/O Memory Buffers**: hold file-system blocks while they are being read from or written to disk

File Creation

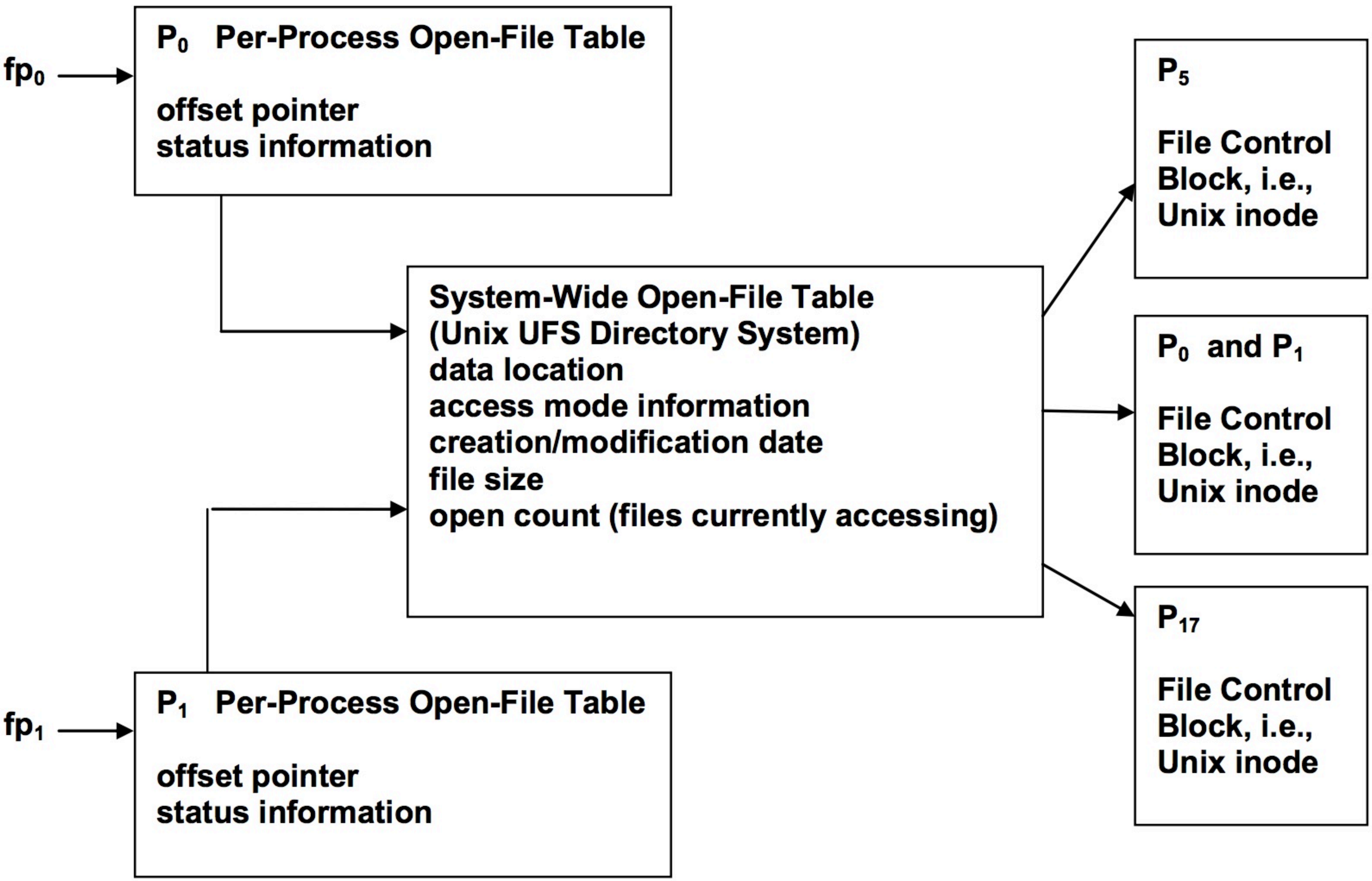
- application process requests the creation of a new file
- **logical file system allocates a new FCB, i.e., *inode* structure in linux**
- appropriate directory is updated with the new file name and FCB, i.e., inode

Operations - open()

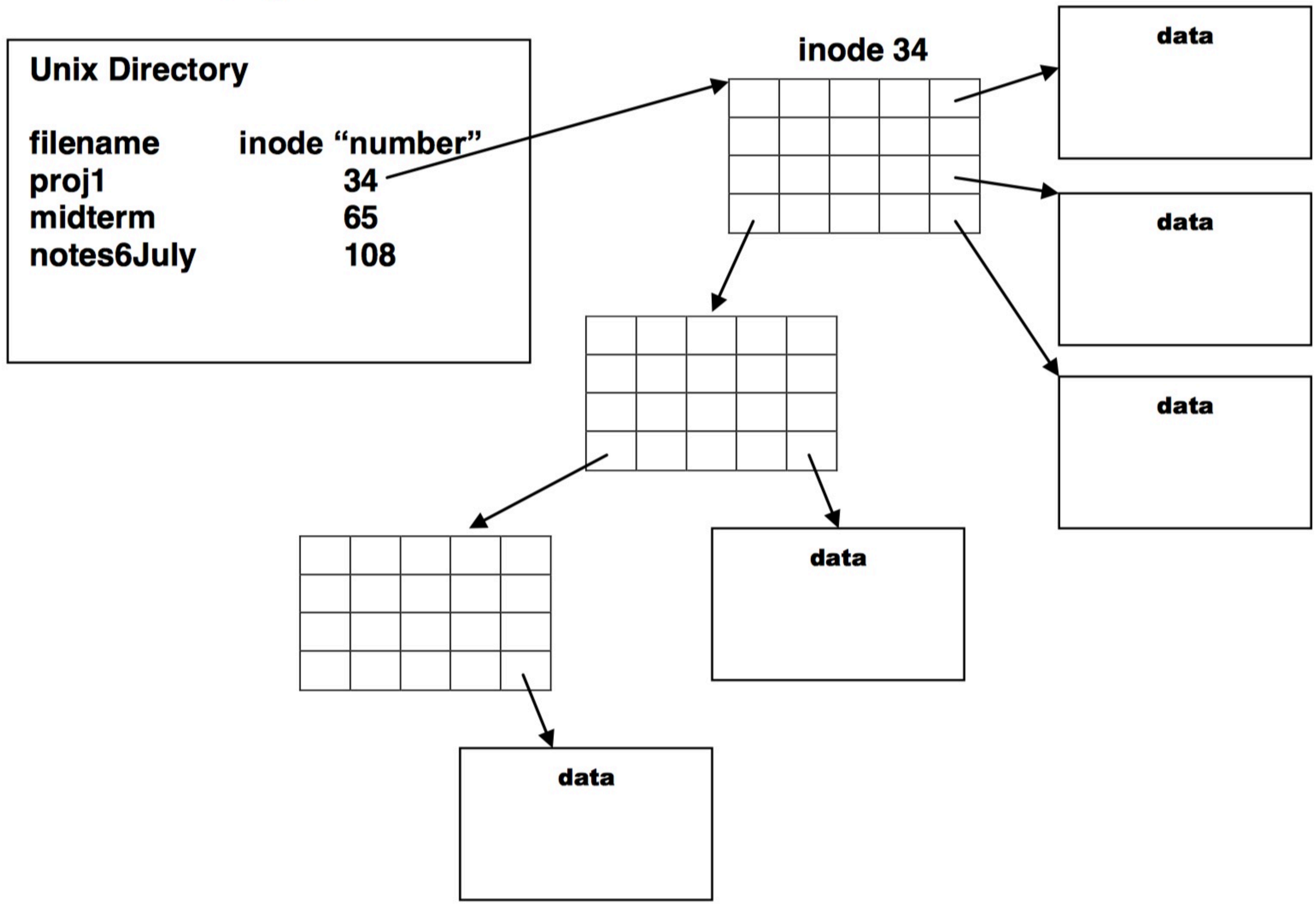
- search **System-Wide Open-File Table** to see if file is currently in use
  - if it is, create a Per-Process Open-File table entry pointing to the existing System-Wide Open-File Table
  - if it is not, **search the directory for the file name; once found, place the FCB in the System-Wide Open-File Table**
- make an entry, i.e., Unix file descriptor, Windows file handle 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

Operations - open()

- increment the open cont in the System-Wide Open-File Table
- returns a pointer to the appropriate entry in the Per-Process Open-File Table
- all subsequent operations are performed with **this pointer**
- process closes file -> Per-Process Open-File Table entry is removed; **open count decremented**
- all processes close file -> copy in-memory directory information to disk and System-Wide Open-File Table is removed from memory


P_0 Per-Process Open-File Table
offset pointer
status information
fp_0
System-Wide Open-File Table
(Unix UFS Directory System)
data location
access mode information
creation/modification date
file size
open count (files currently accessing)
P_1 Per-Process Open-File Table
offset pointer
status information
fp_1
P_5
File Control Block, i.e., Unix inode
P_0 and P_1
File Control Block, i.e., Unix inode
P_{17}
File Control Block, i.e., Unix inode

Unix i-node System



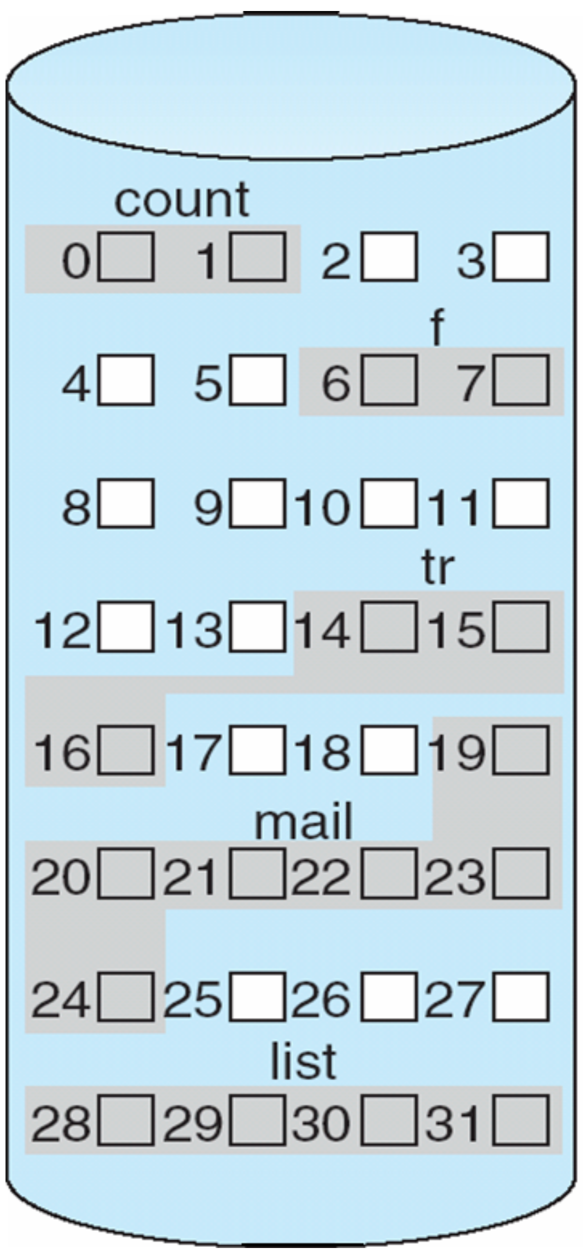
Disk Block Allocation

- **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



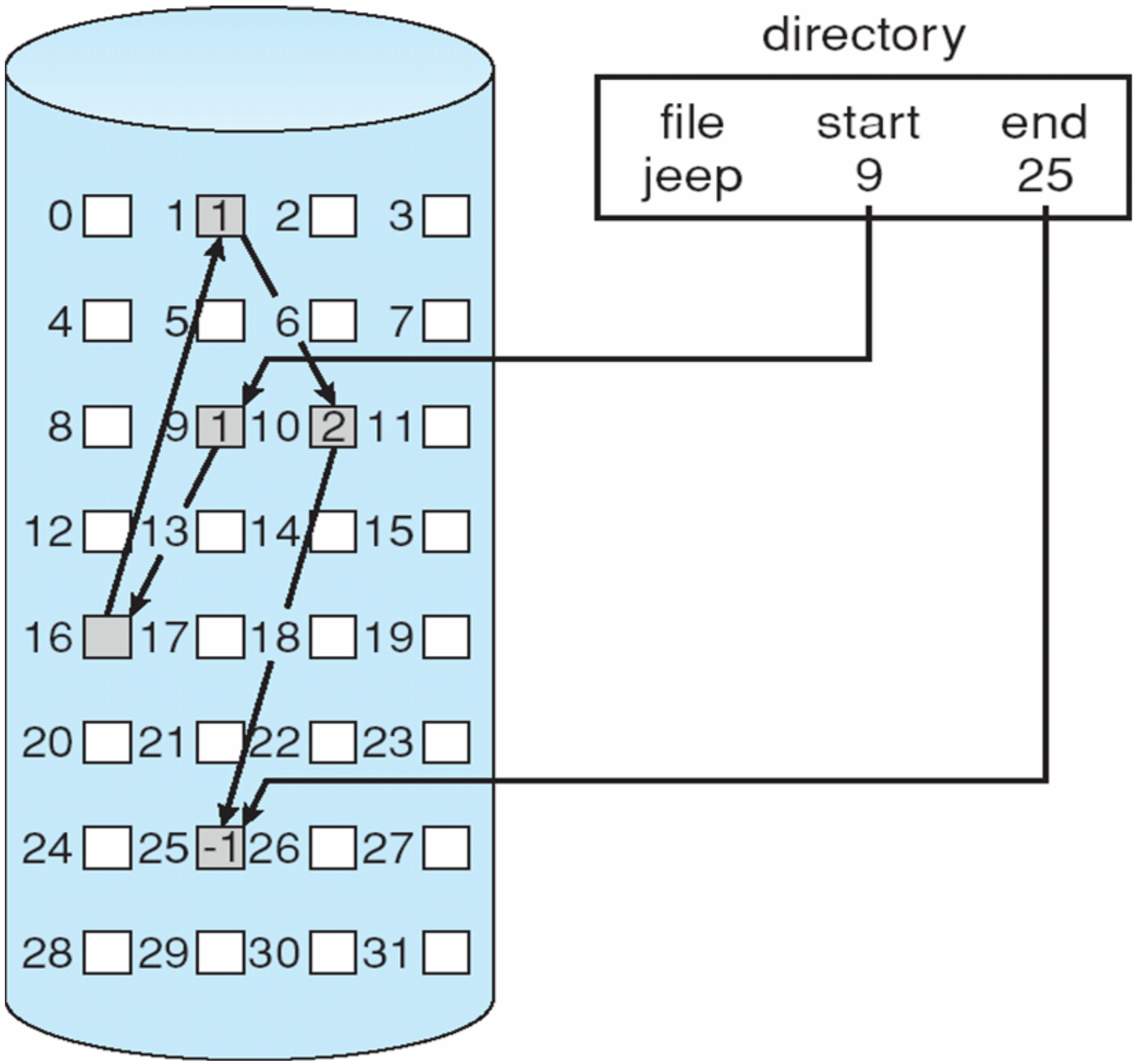
directory

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

Linked Allocation

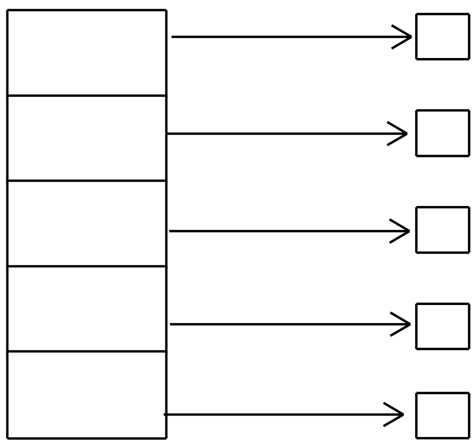
- Linked allocation: each file is a **linked list of disk blocks**
  - each block contains pointer to **next block**, file ends at nil pointer
  - blocks may be scattered anywhere on the disk (no **external fragmentation, no compaction**)
  - *Disadvantages*
    - *locating a file block can take many 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

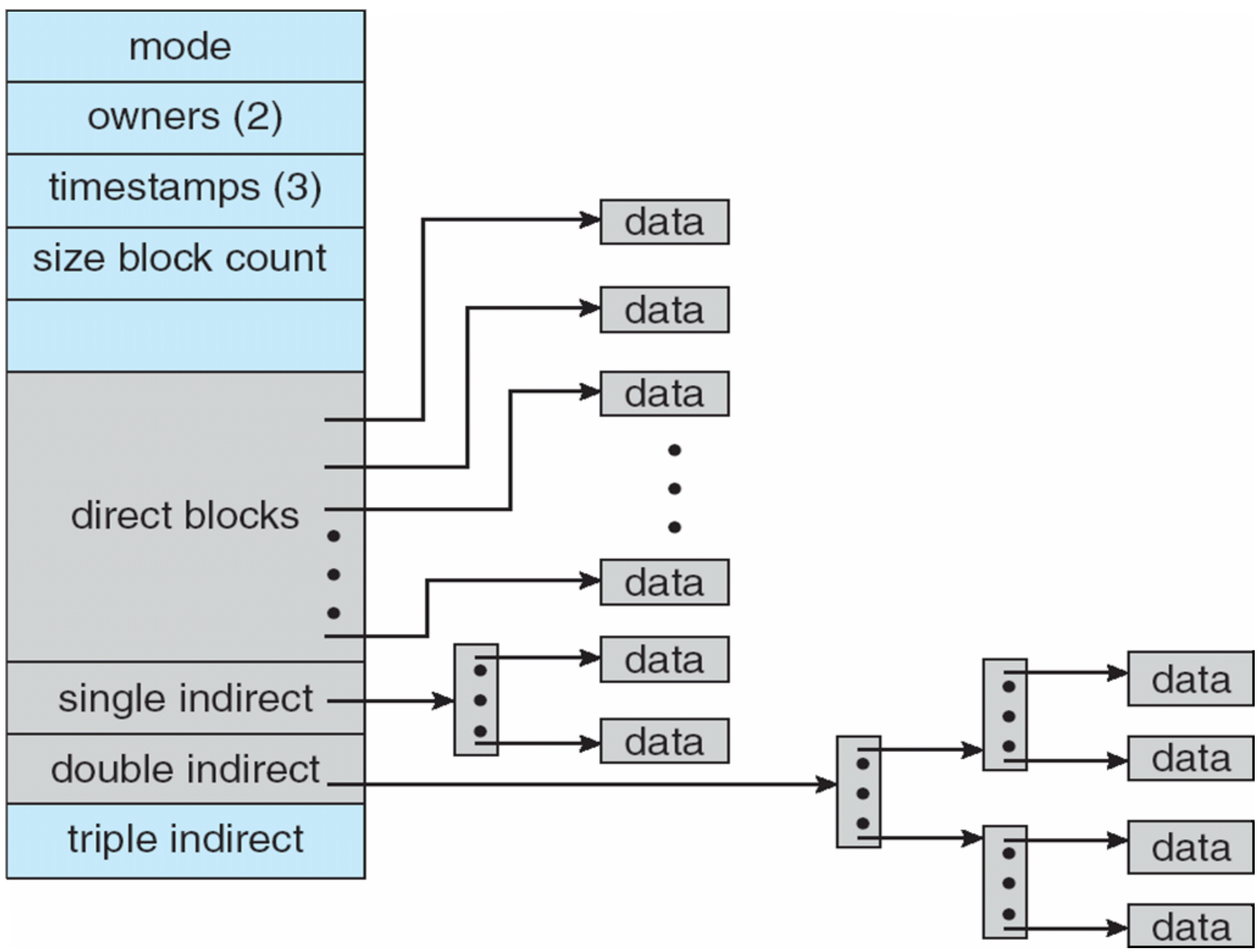


index table

What about two levels?

Indexed Allocation

- ext2: combined scheme
  - First 15 pointers are in inode
    - Direct block: first 12 pointers
    - **Indirect block: next 3 pointers**
    - **What's the biggest file for ext2 (block size 4k)?**
      - **How many blocks: 12 + (4K/4) + (4K/4)^2 + (4K/4)^3**



Free-Space Management

- File system maintains free-space list to track available blocks/clusters
  - The space of deleted files should be reclaimed
- Many allocation methods:
  - bit vector or bit map
  - linked free space
  - …

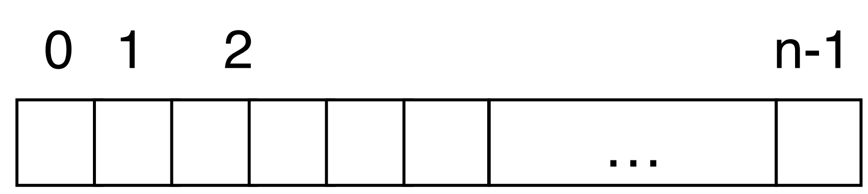
Bitmap Free-Space Management

- Use one bit for each block, track its allocation status
  - relatively easy to find contiguous blocks
  - bit map requires extra space
    - example: block size = 4KB = 2^{12} bytes

      disk size = 2^{40} bytes (1 terabyte)

      $n = 2^{40}/2^{12} = 2^{28}$ bits (or 256 MB)

      if clusters of 4 blocks -> 64MB of memory



$$\text{bit}[i] = \begin{cases} 1 \rightarrow \text{block}[i] \text{ free} \\ 0 \rightarrow \text{block}[i] \text{ occupied} \end{cases}$$