Secondary Storage: Q & A

- What is Secondary Storage?
  - *It is a non-volatile repository for (both user and system) data and programs*
- Who manages Secondary Storage?
  - *File System – part of the OS*
- What kind of data can be stored in Secondary Storage?
  - Programs (source, object), temporary storage, virtual memory

Secondary Storage: Q & A

- What are the main requirements on file systems?
  - Should provide persistent storage
  - Handle very large information (large chunks, large numbers)
  - Concurrent access
- What are main user requirements?
  - How the storage appears to them
  - File naming and protection, operations allowed on files

File concept

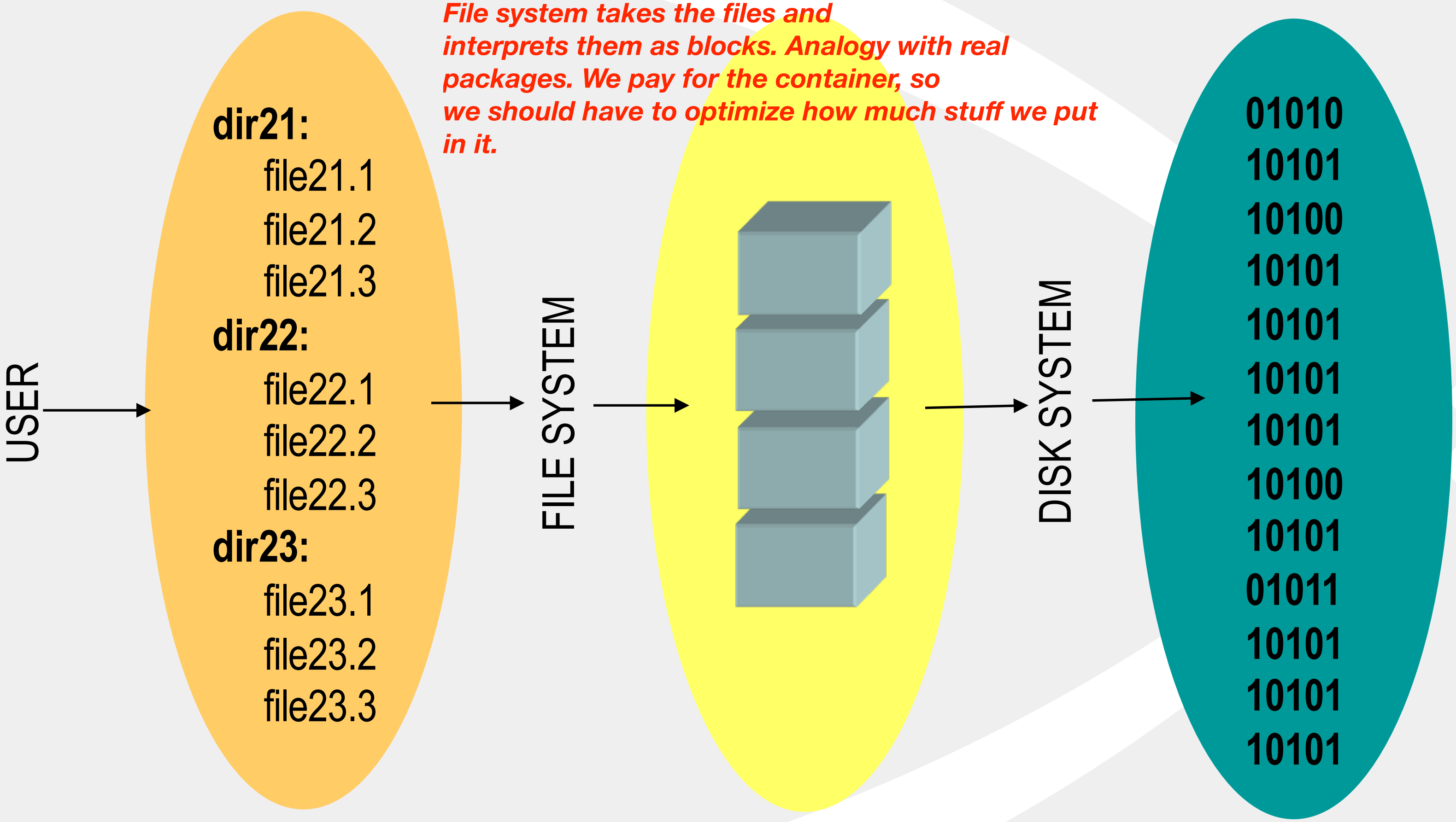
- A file is a *named* collection of related information, usually as a sequence of bytes, with two views:
  - *Logical (programmer's) view*, as the users see it.
  - *Physical (operating system) view*, as it actually resides on secondary storage.

File concept…

- What is the difference between a file and a data structure in memory?
  - files are intended to be non-volatile; hence in principle, they are long lasting,
  - files are intended to be moved around (i.e., copied from one place to another), accessed by different programs and users

A view of storage management

File system takes the files and interprets them as blocks. Analogy with real packages. We pay for the container, so we should have to optimize how much stuff we put in it.

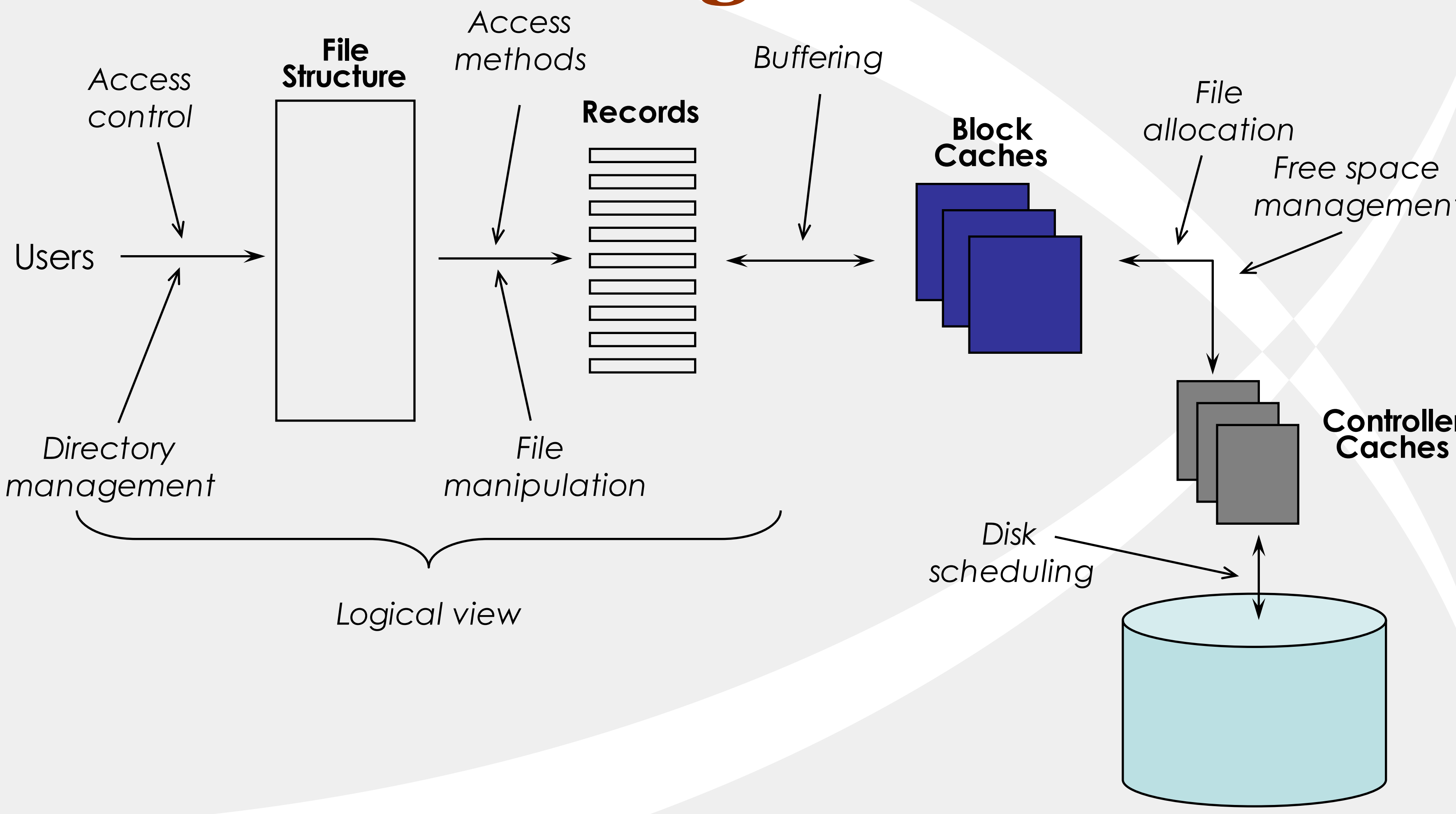


File system based view – content visible as files and directories

Block based view content considered as blocks of data

Physical view – all data just a stream of bits

Elements of storage management



File attributes

- Each file is associated with a collection of information, known as *attributes*:
  - NAME, owner, creator
  - type (e.g., source, data, binary)
  - location (e.g., I-node or disk address)
  - organization (e.g., sequential, indexed, random)
  - access permissions
  - time and date (creation, modification, and last accessed)
  - size
  - variety of other (e.g., maintenance) information.

Given a file, unix can determine what type of file a file is. FILE command exists on linux.

File names

- Files provide a way to store and retrieve data from backing storage using **file names**
- Many OSs support two or more parts separated by a period in names
- In UNIX, files extensions are just conventions and not enforced by OS
- Applications like C compiler might enforce their own conventions
- MS-Windows associates programs with files using file extensions.

File types

- Commonly used extensions:

File type	Extension	Function
Executable	exe, com, bin	ready-to-run code
Text	txt, doc	textual data, documents
Source	c, f77, asm	source in various languages
Object	obj, o	object code
Library	lib, a	library routines
Archive	tar, zip, arc	grouped files
Compressed	Z, gz	compressed
Print/view	ps, eps	printing or viewing
Word processor	ppt, wp, tex	various word processors

Directories

- What is a directory?
  - Is a *symbol table* that can be searched for information about the files. Implemented as a file.
- Directories give a name space for the objects (files) to be placed.
- *Directory entry* contains information (attributes) about a file
  - entries are added in a directory as files are created, and are removed when files are deleted.

Name spaces

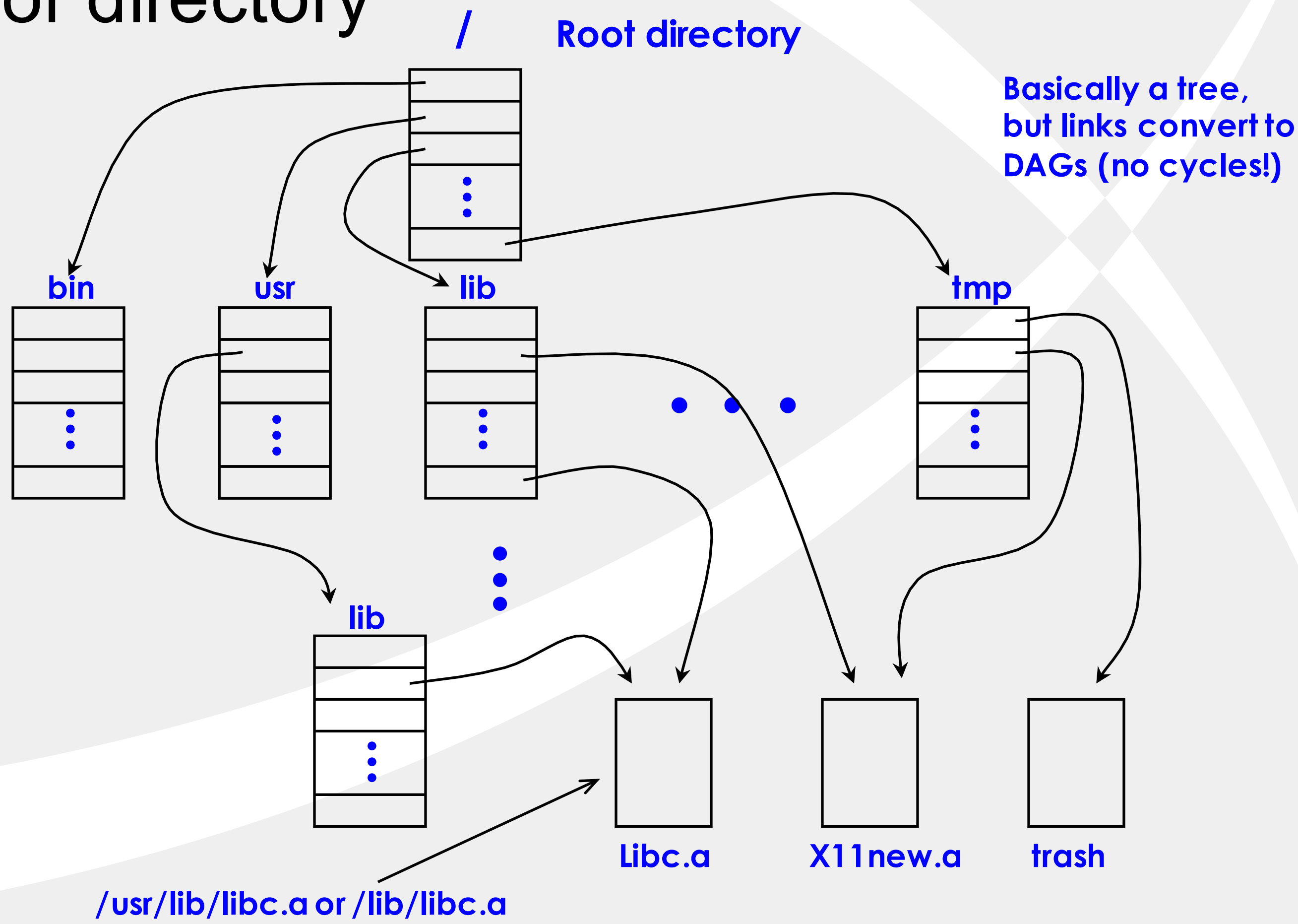
- Write down well known name spaces
- Classify them as hierarchical or flat
- For hierarchical ones, identify the depth
- Advantages versus disadvantages?

Directories

- Common directory structures are:
  - **Single-level (flat):** shared by *all* users – worlds' first supercomputer CDC 6600 also had
  - **Two-level:** one level for *each* user – should have some form of "user" login to identify the user and locate the user's files.
  - **Tree:** arbitrary (sub)-tree for *each* user – login required.

An example: UNIX directories

- UNIX uses *directed acyclic-graph (DAG)* structure for directory

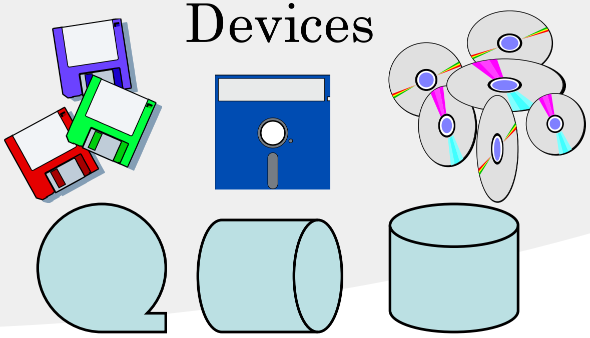


File systems

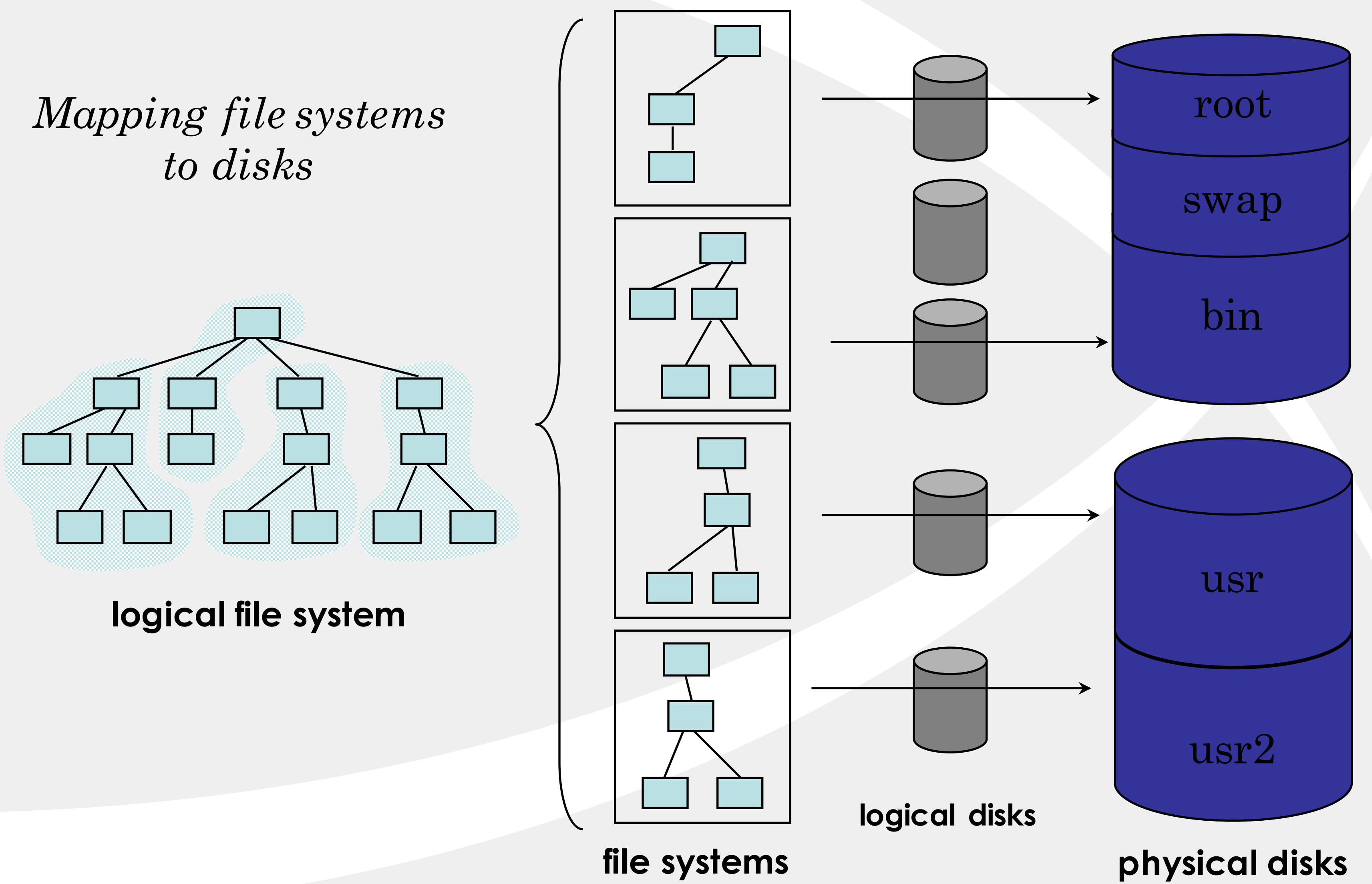
- The basic services of a file system include:
  - keeping track of files (knowing location),
  - I/O support, especially the transmission mechanism to and from main memory,
  - management of secondary storage,
  - sharing of I/O devices,
  - providing protection mechanisms for information held on the system.

File system abstraction

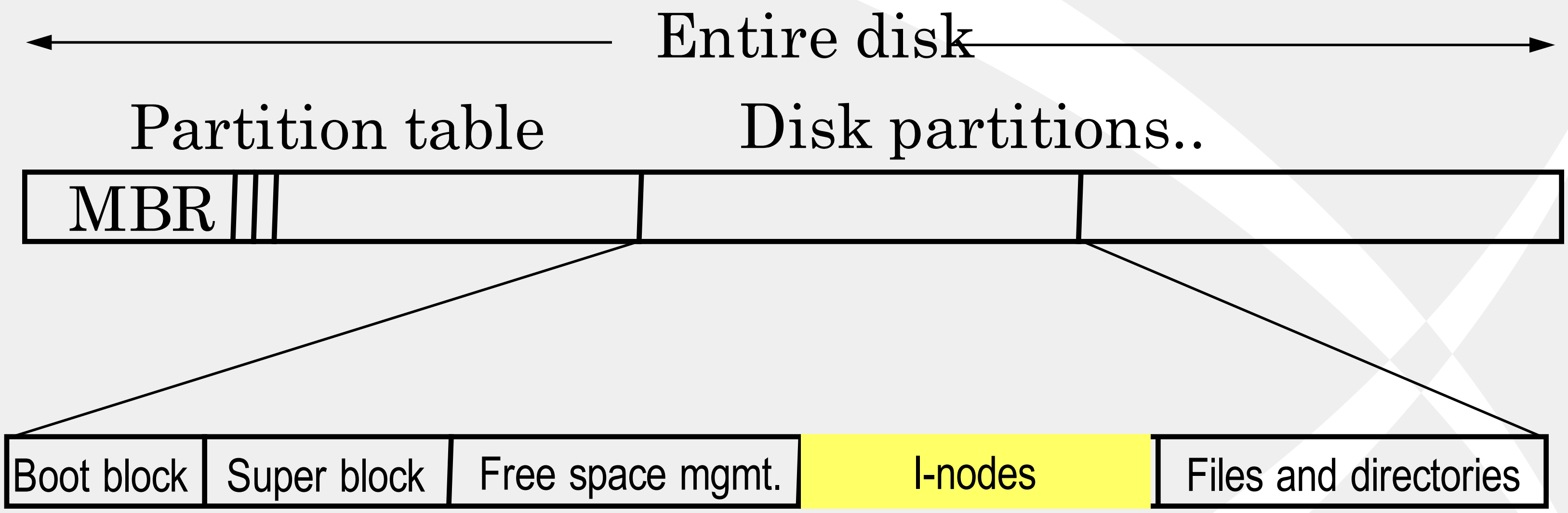
	Objects	*Typical operations*
Interactive (Shells)	files	copy, delete, rename
Applications and system programs	logical elements (records)	open/close, buffering seek (logical)
File System	file system check soft repair partitioning	
Devices	physical elements (head, cylinder, ...)	raw read/write, seek (physical) low-level format



Example —UNIX file system



File system layout

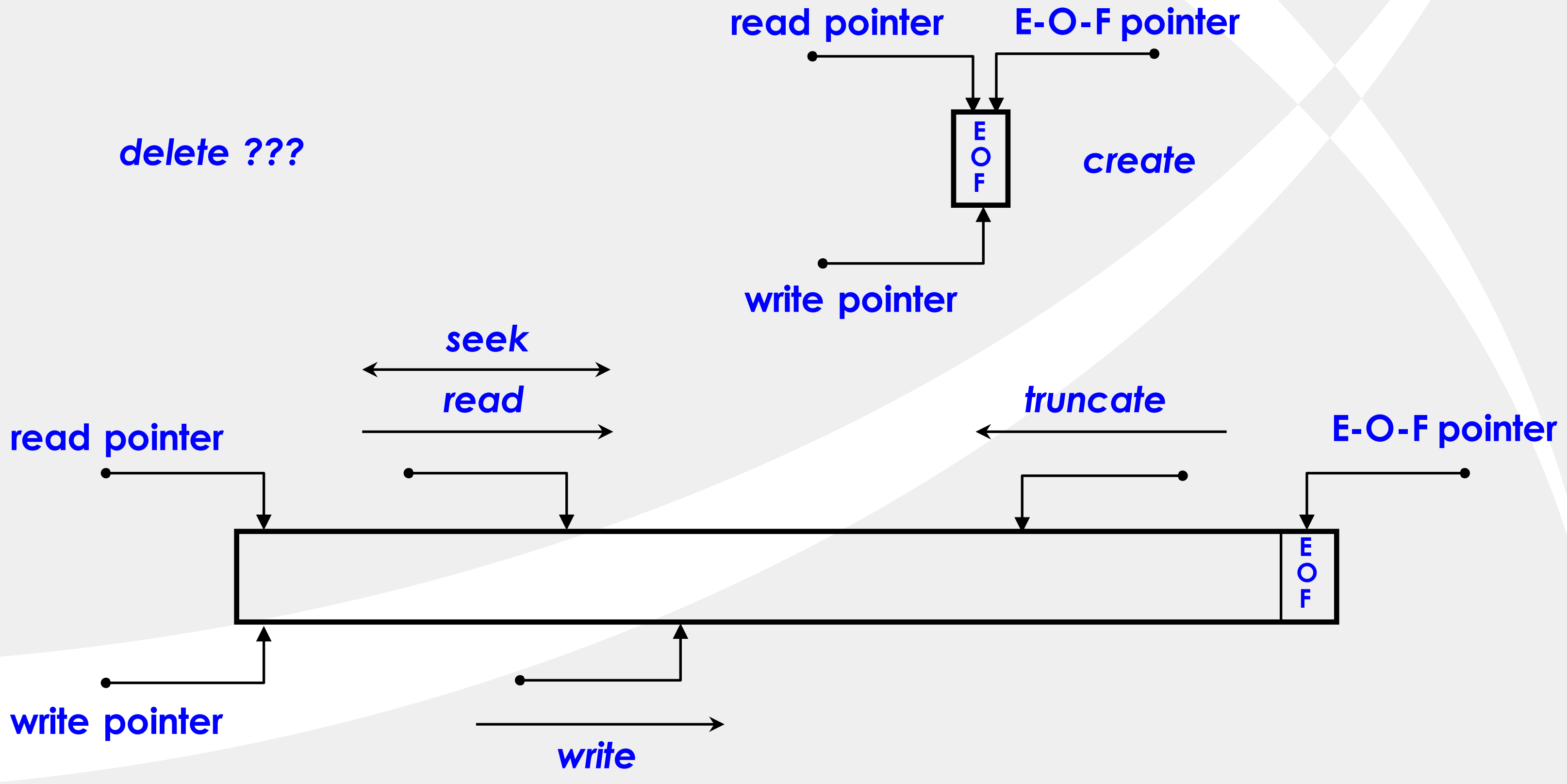


File sharing

- File sharing raises the issue of **protection**
- One approach is to provide *controlled access* to files through a set of operations such as read, write, delete, list, and append
- One popular protection mechanism is a condensed version of access list containing: user, group, and other

File operations

- Six basic operations for file manipulation: *create, write, read, delete, reposition r/w pointer* (a.k.a. *seek*), and *truncate* (rare)



File operations

- Create
  - file is created with no data
  - sets some file attributes
- Delete
  - file is no longer needed
  - storage released to free pool
- Open
  - process first opens a file -- fetch the attributes and list of disk addresses into main memory
- Close
  - frees the internal table space
  - OSs enforce by limiting number of open files

File operations

- Read
  - comes from current position in file
  - bytes to read and where to put specified
- Seek
  - repositions the file pointer for random access
  - after seeking data can be read or written
- Write
  - data written to file at current position
  - If current position is at end-of-file, file’s size increases

Example C program

```
/* File copy program. Error checking and reporting is minimal. */

#include <sys/types.h>                    /* include necessary header files */
#include <fcntl.h>
#include <stdlib.h>
#include <unistd.h>

int main(int argc, char *argv[]);         /* ANSI prototype */

#define BUF_SIZE 4096                     /* use a buffer size of 4096 bytes */
#define OUTPUT_MODE 0700                  /* protection bits for output file */

int main(int argc, char *argv[])
{
     int in_fd, out_fd, rd_count, wt_count;
     char buffer[BUF_SIZE];

     if (argc != 3) exit(1);              /* syntax error if argc is not 3 */
```

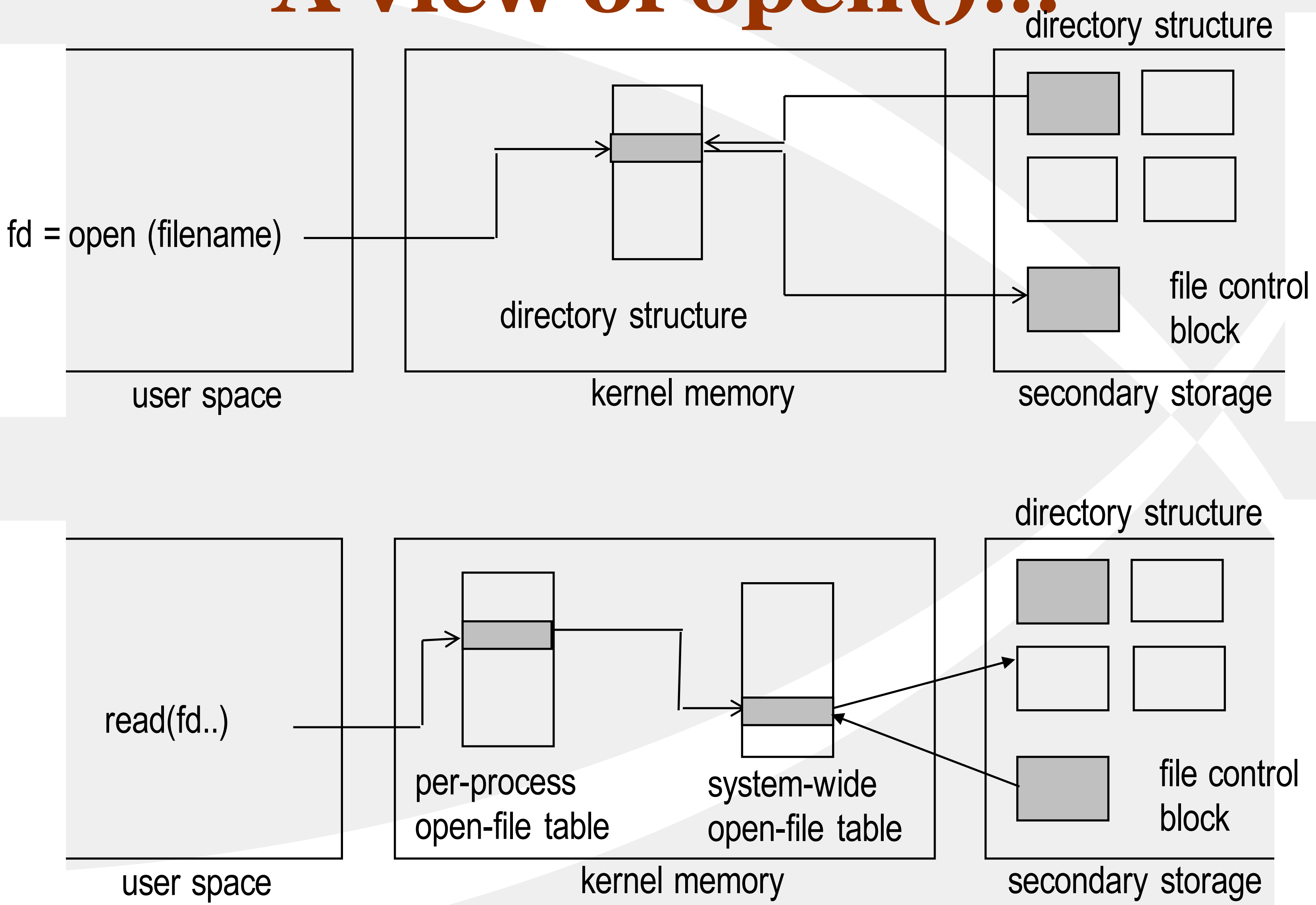
Example C program…

```
/* Open the input file and create the output file */
in_fd = open(argv[1], O_RDONLY);            /* open the source file */
if (in_fd < 0) exit(2);                     /* if it cannot be opened, exit */
out_fd = creat(argv[2], OUTPUT_MODE);       /* create the destination file */
if (out_fd < 0) exit(3);                    /* if it cannot be created, exit */

/* Copy loop */
while (TRUE) {
    rd_count = read(in_fd, buffer, BUF_SIZE); /* read a block of data */
if (rd_count <= 0) break;                   /* if end of file or error, exit loop */
    wt_count = write(out_fd, buffer, rd_count); /* write data */
    if (wt_count <= 0) exit(4);             /* wt_count <= 0 is an error */
}

/* Close the files */
close(in_fd);
close(out_fd);
if (rd_count == 0)                          /* no error on last read */
    exit(0);
else
    exit(5);                                /* error on last read */
}
```

A view of open()...



File access methods

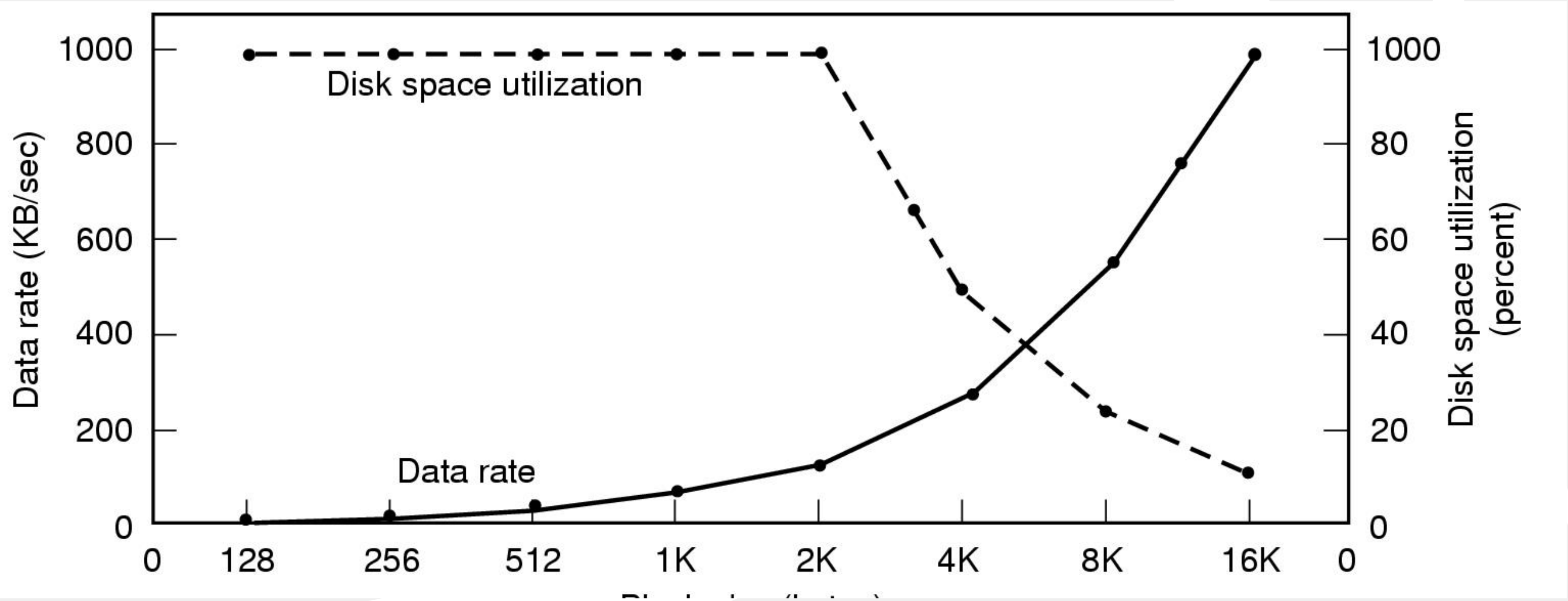
- The information stored in a file can be accessed in a variety of methods:
  - *Sequential*: in order, one record after another. Convenient with sequential access devices (e.g., magnetic tape).
  - *Direct (random)*: in any order, skipping the previous records.
  - *Indexed*: in any order, but accessed using particular key(s); e.g., hash table or dictionary. *Database access (e.g., patient database in a hospital).*

What is the file allocation problem?

- Allocating disk space for files
- File allocation impacts space and time
  - Space usage on disk (wastage due to fragmentation)
  - Access speed (latency of access)
- Common file allocation techniques are:
  - Contiguous
  - Chained (linked)
  - Indexed

What is the file allocation problem?

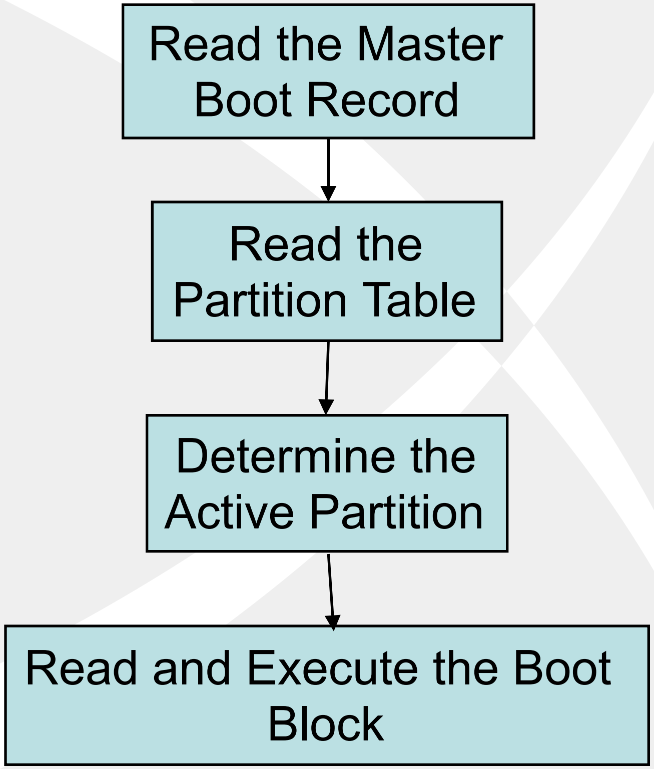
- Disk space is allocated on a block basis



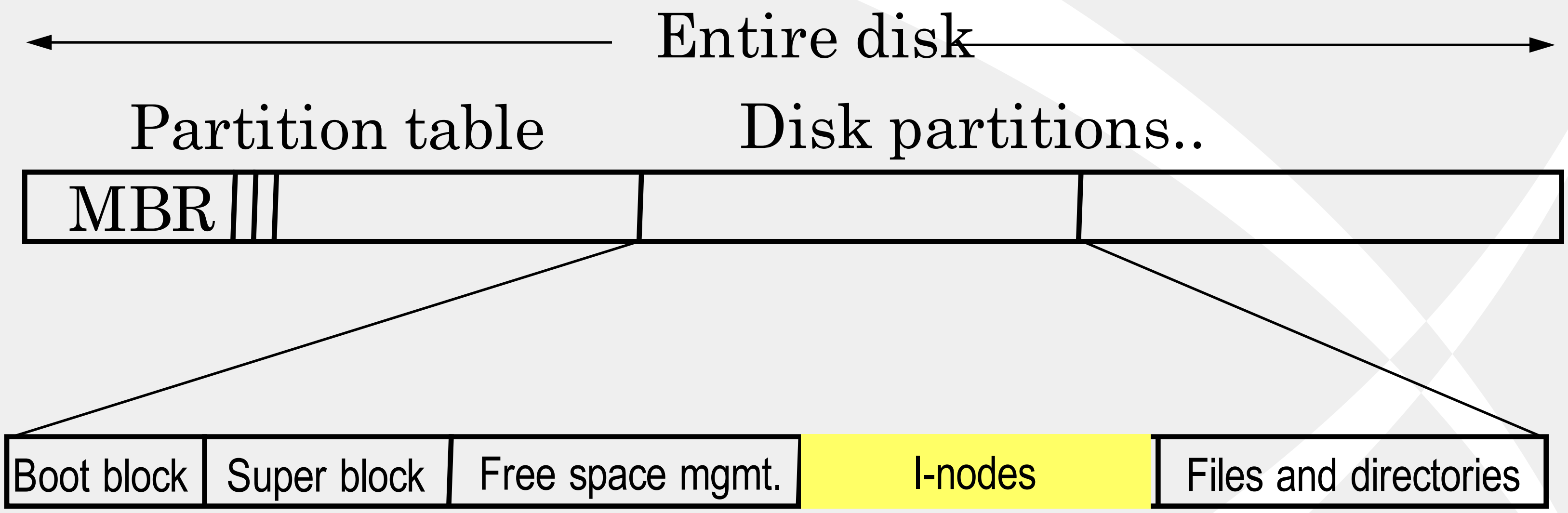
Block size

File system layout

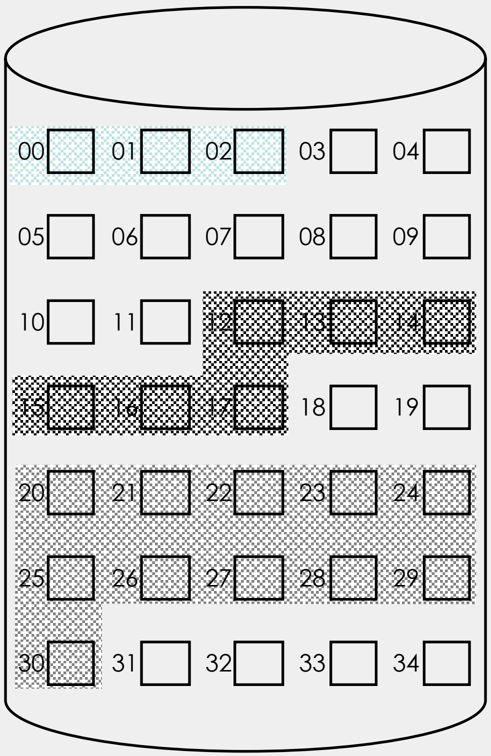
- File systems are stored on disk partitions
- Sector 0 of the disk is called the **MBR (master boot record)**



File system layout



Contiguous allocation

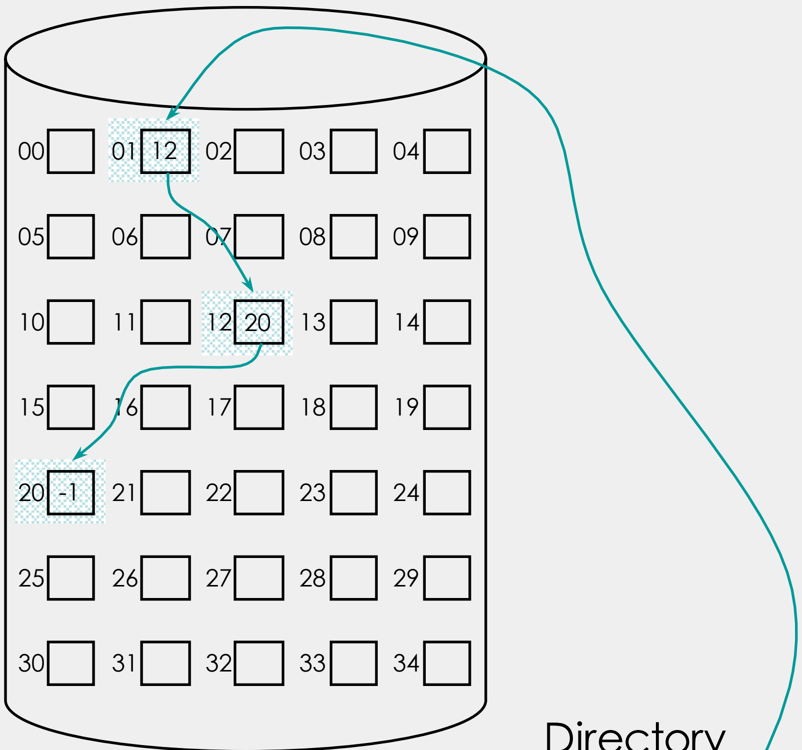


Directory

name	*start*	*len.*
a.out	00	3
hw1.c	12	6
report.tex	20	11

- Keep a free list of unused disk space.
- *Advantages*:
  - easy access, both sequential and random
  - simple
  - few seeks
- *Disadvantages*:
  - external fragmentation
  - may not know the file size in advance

Chained (linked) allocation

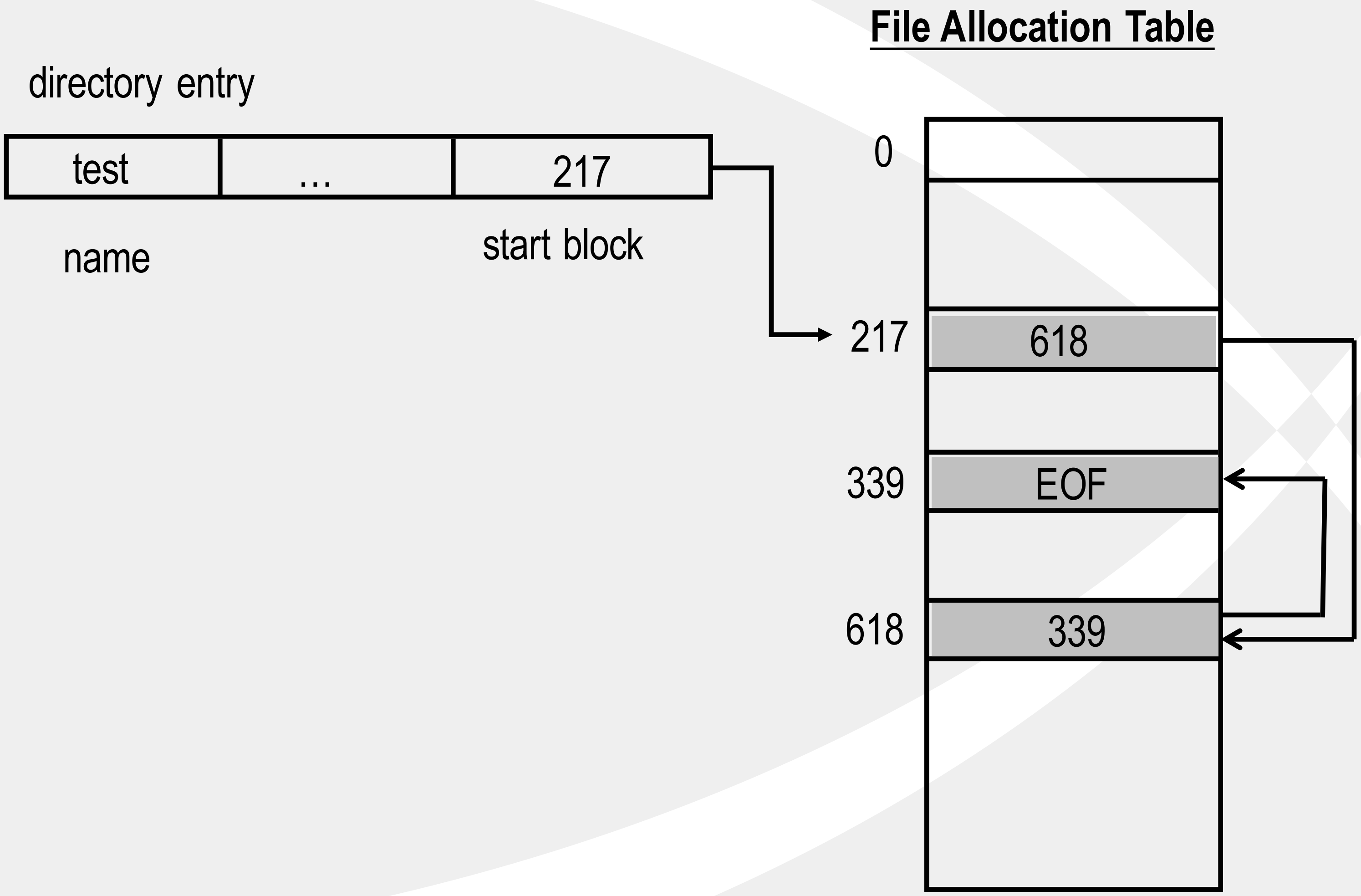


Directory

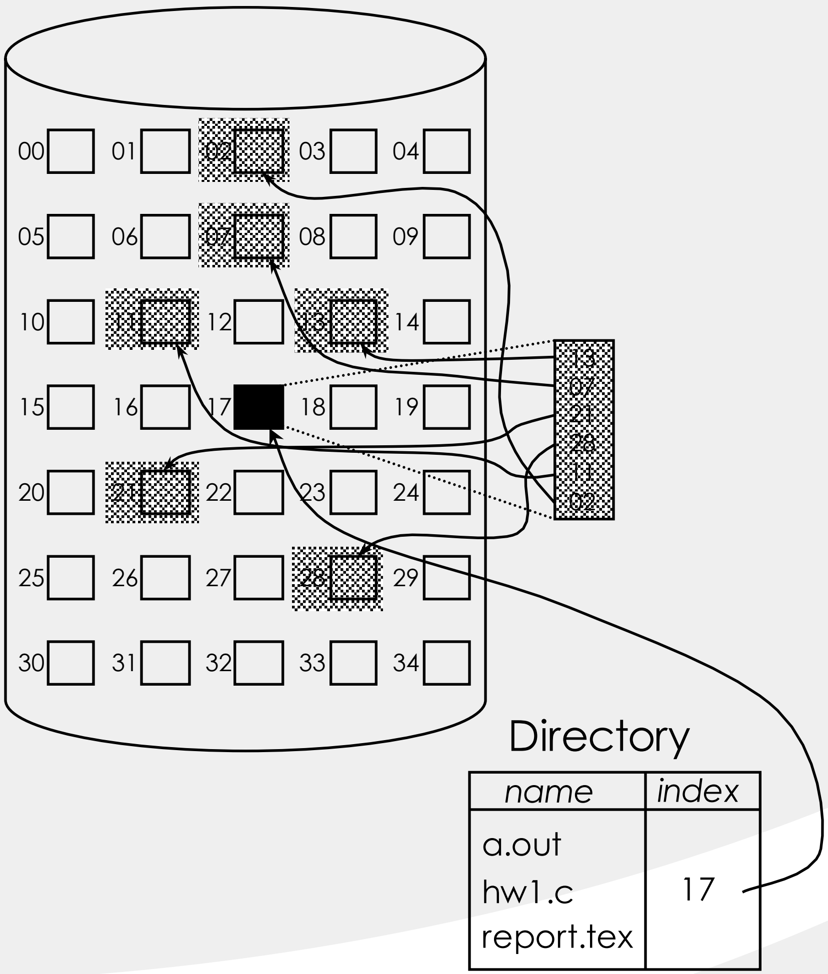
name	start	len.
a.out	01	3
hw1.c		
report.tex		

- Mark allocated blocks as in-use.
- *Advantages*:
  - no external fragmentation
  - files can grow easily
- *Disadvantages*:
  - lots of seeking
  - random access difficult
- *Enhancements:*
  - Can be enhanced with a in-memory table – called File allocation table (FAT)

File allocation table



Indexed allocation



Allocate an array of pointers during file creation. Fill the array as new disk blocks are assigned.

Advantages:

- small internal fragmentation
- easy sequential and random access

Disadvantages:

- lots of seeks if the file is big
- maximum file size is limited by the size of a block

Example:

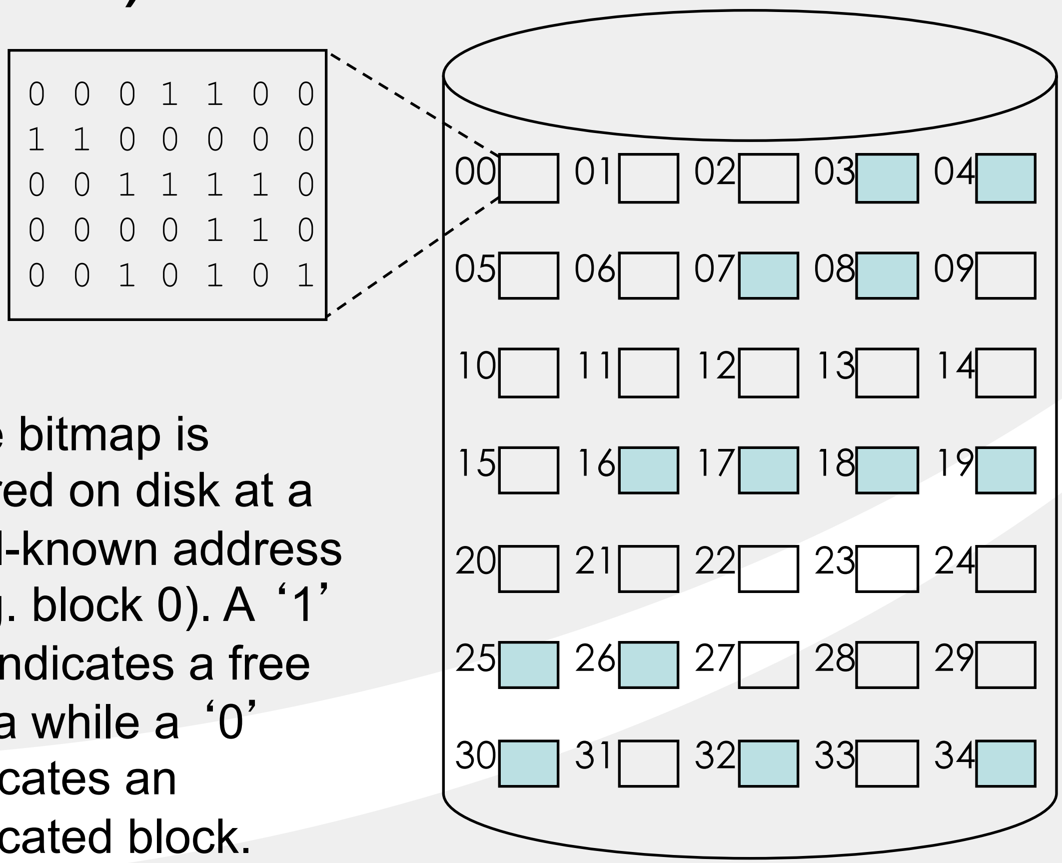
UNIX file system

Free space management

- Disk space is fixed
  - Need to reuse space freed by deleted files
  - Need to keep track of free space as in main memory management
- Can use following techniques for free space management:
  - *Bit vectors*
  - *Linked lists or chains*
    - single list of a set of free block lists
  - *Indexing*
    - single level, multiple levels

Free space management—bit vectors

- Use 1 bit per fixed size free area (e.g. block) on disk.

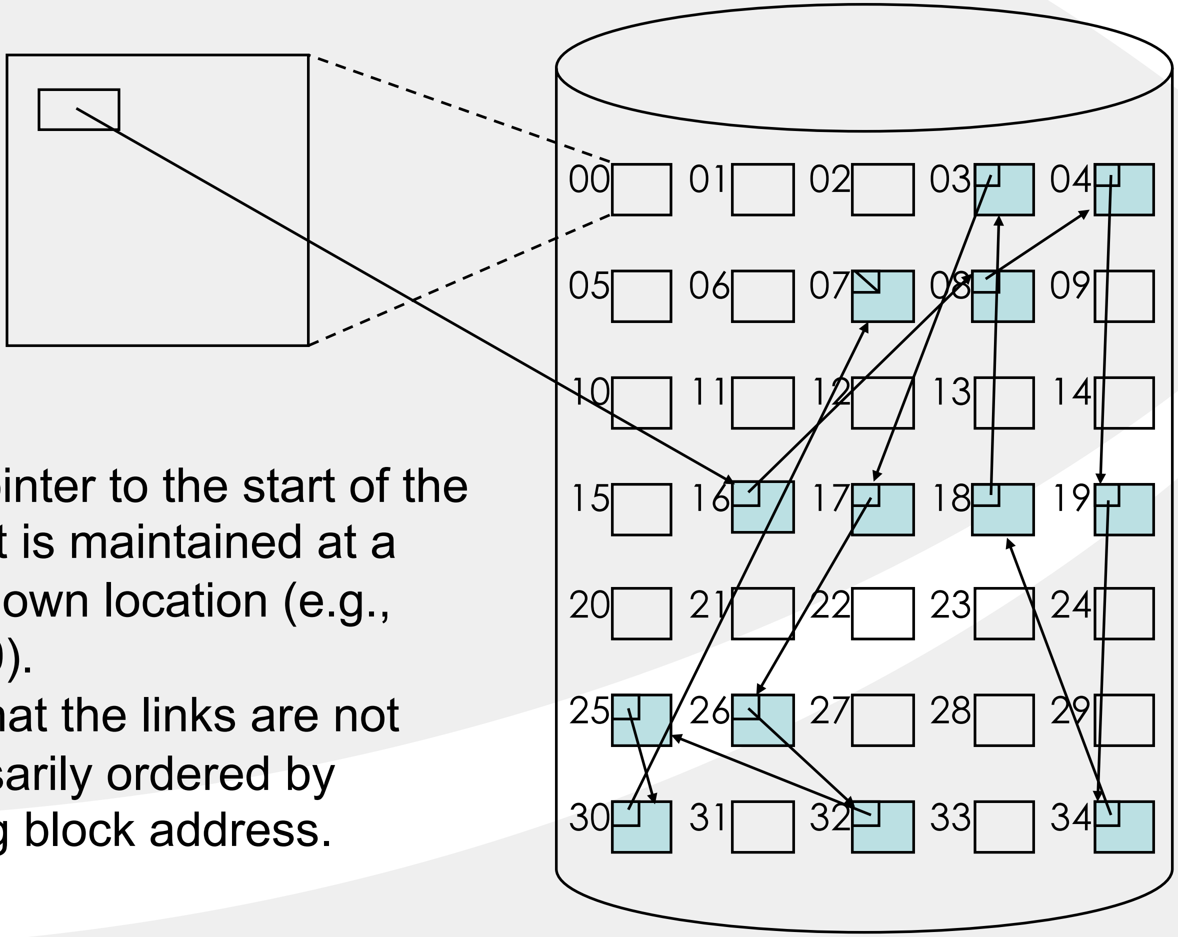


Free blocks on disk are shown shaded

The bitmap is stored on disk at a well-known address (e.g. block 0). A ‘1’ bit indicates a free area while a ‘0’ indicates an allocated block.

Free space management—chains

- Chain/link pointers are stored *in* each disk block.

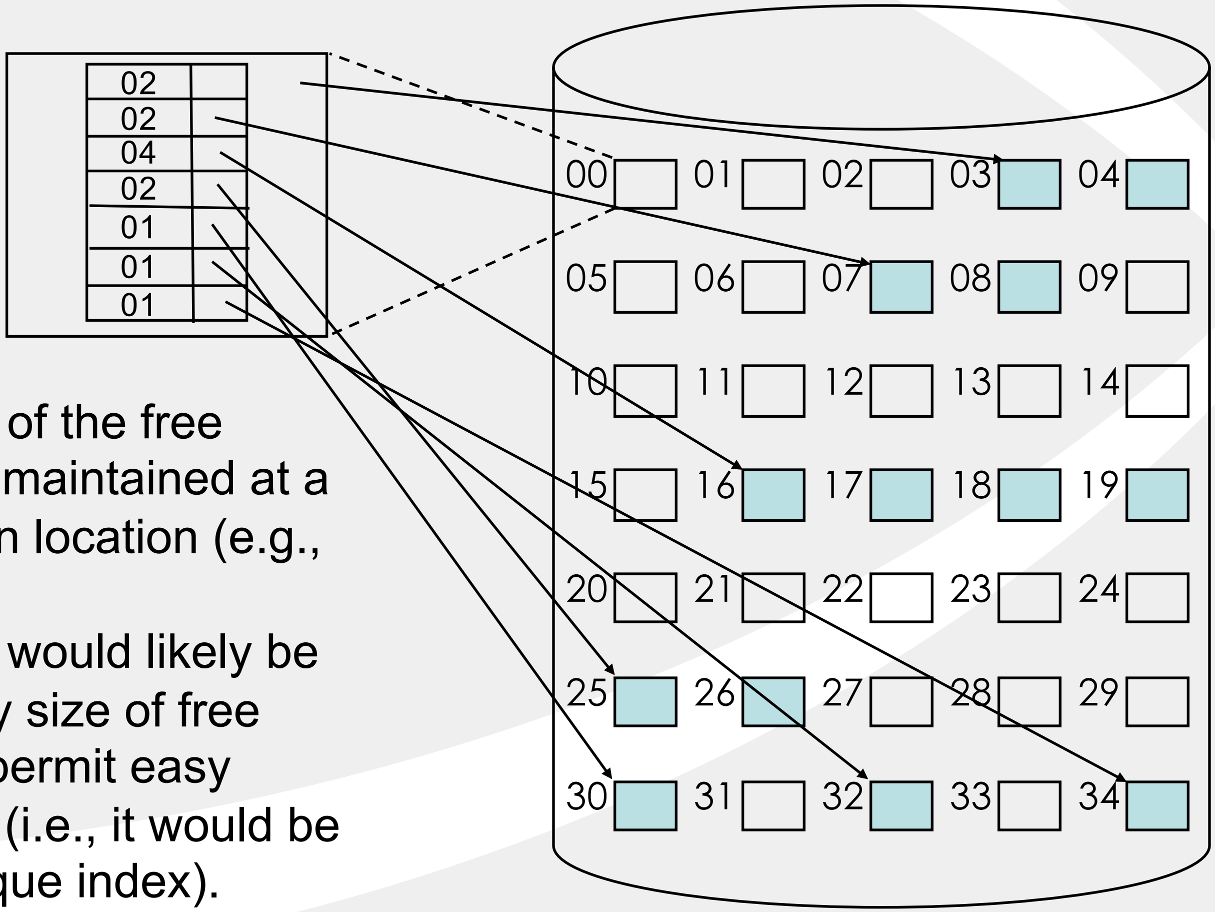


Free blocks on disk are shown shaded

The pointer to the start of the free list is maintained at a well-known location (e.g., block 0).
Note that the links are not necessarily ordered by starting block address.

Free space management—indexed

- Maintain index pointing to all free blocks



Free blocks on disk are shown shaded

The index of the free regions is maintained at a well-known location (e.g., block 0). The index would likely be ordered by size of free region to permit easy searching (i.e., it would be a non-unique index).

Finding free space

- We must be able to search for free space of a specific size and how this is done depends on the free space management technique used
  - ***Bitmaps***—search bitmap for a sequence of sufficient 1 bits
    - Can use hardware instructions on some machines (e.g. find first one – `FFO`)
  - ***Index***—store the number of available blocks in each index entry and order index by size
    - e.g., Starting Block Number of Free Blocks

Finding free space
cont.

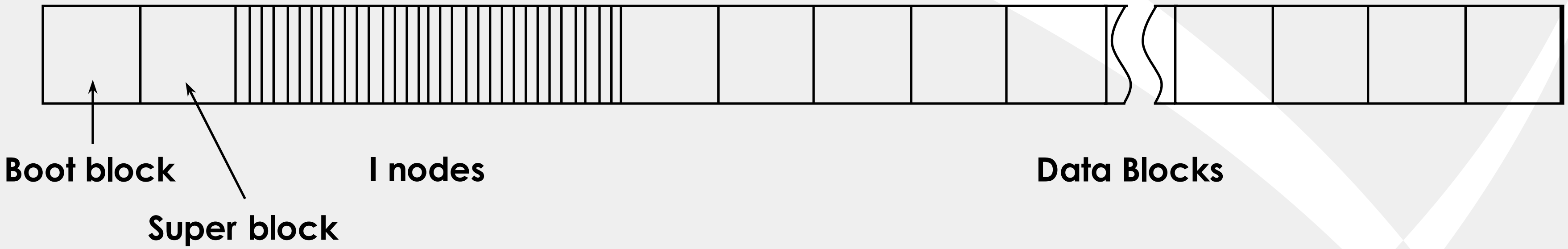
- ***Chained***
  - **First Fit**—find the first block on the chain big enough to accommodate the request
  - **Best Fit**—find the region on the chain nearest in size but at least as large as the request
  - **Worst Fit**—allocate from the largest region on the chain
  - **Next Fit**—like first fit but continue searching on the chain from where you last left off
    - Maintain chain in circular fashion
    - Avoids constant allocation in localized region of memory

Other file system issues

- *Disk blocking*
  - multiple sectors per block for efficiency
- *Disk quotas*
- *Reliability*
  - Backup/restore (disaster scenarios)
  - File system (consistency) check (e.g., UNIX **`fsck`**)
- *Performance*
  - Block or buffer caches (a collection of blocks kept in memory)

An example: UNIX file system

Disk (partition) layout in traditional UNIX systems

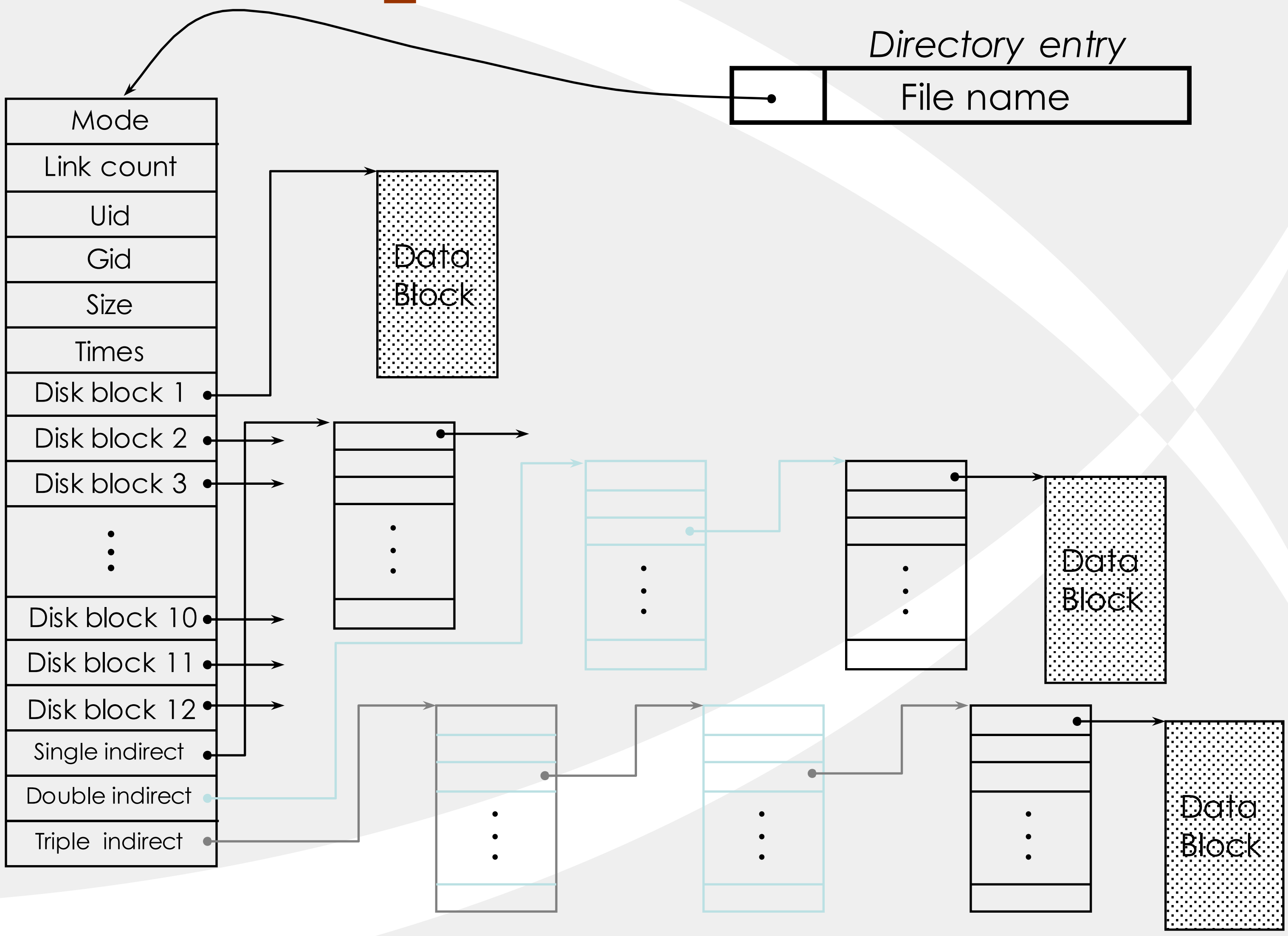


The boot block usually contains (bootstrap) code to boot the system.

The super block contains critical information about the layout of the file system, such as number of I-nodes and the number of disk blocks.

Each I-node entry contains the file attributes, except the name. The first I-node points to the block containing the root directory of the file system.

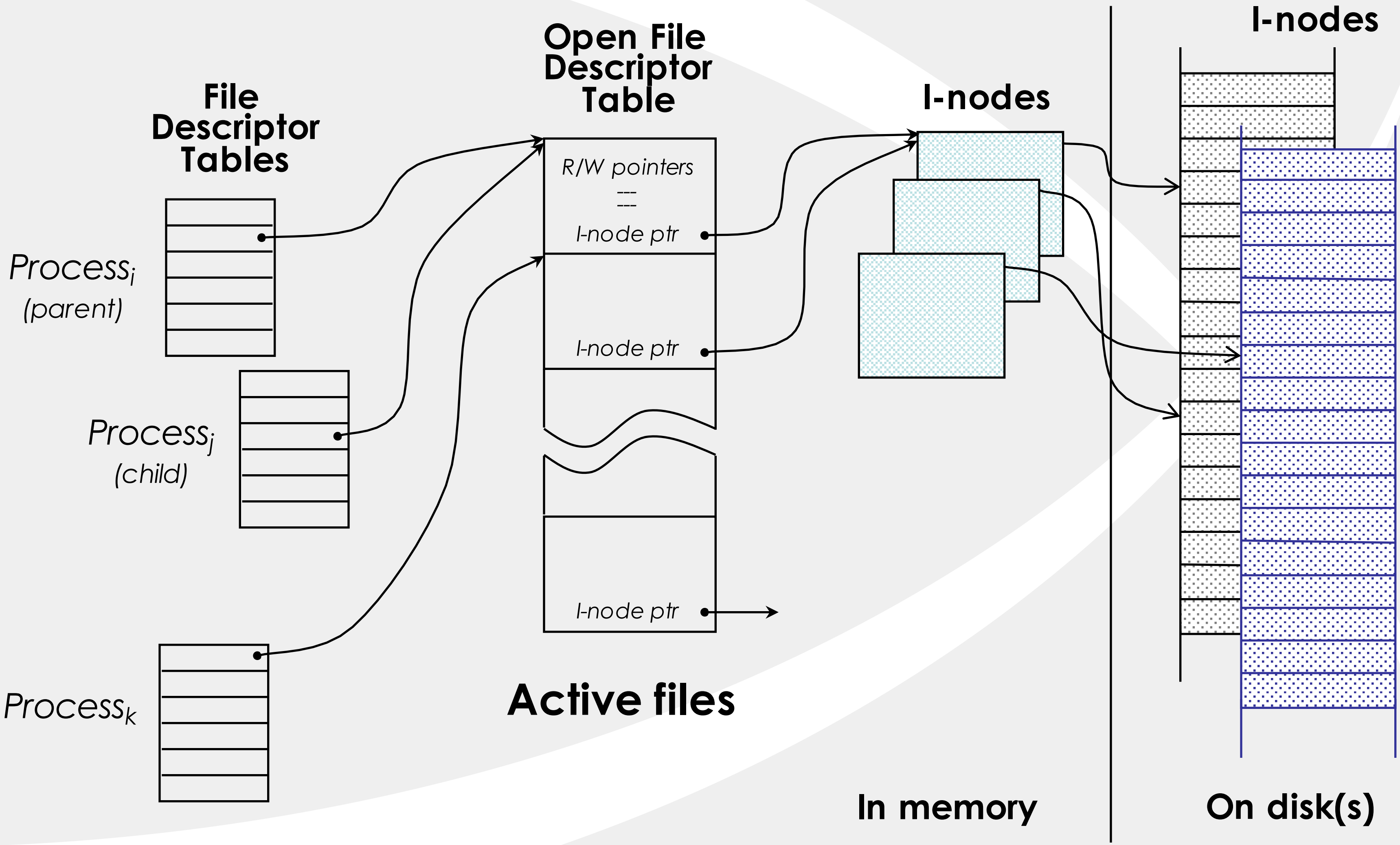
An example: UNIX I-nodes



An example: UNIX file system

- There are three different indirection to access a file:
  - *File Descriptor Table:* one per process, keeping track of open files.
  - *Open File Table*: one per system, keeping track of all the files currently open.
  - *I-node Table:* one per system (disk volume or partition) keeping track all files.

An example: UNIX file system



UNIX File System Example

Root directory

1	.
1	..
4	bin
7	dev
14	lib
9	etc
6	usr
8	tmp

Looking up usr yields i-node 6

I-node 6 is for /usr

Mode size times
132

I-node 6 says that /usr is in block 132

Block 132 is /usr directory

6	•
1	••
19	dick
30	erik
51	jim
26	ast
45	bal

/usr/ast is i-node 26

I-node 26 is for /usr/ast

Mode size times
406

I-node 26 says that /usr/ast is in block 406

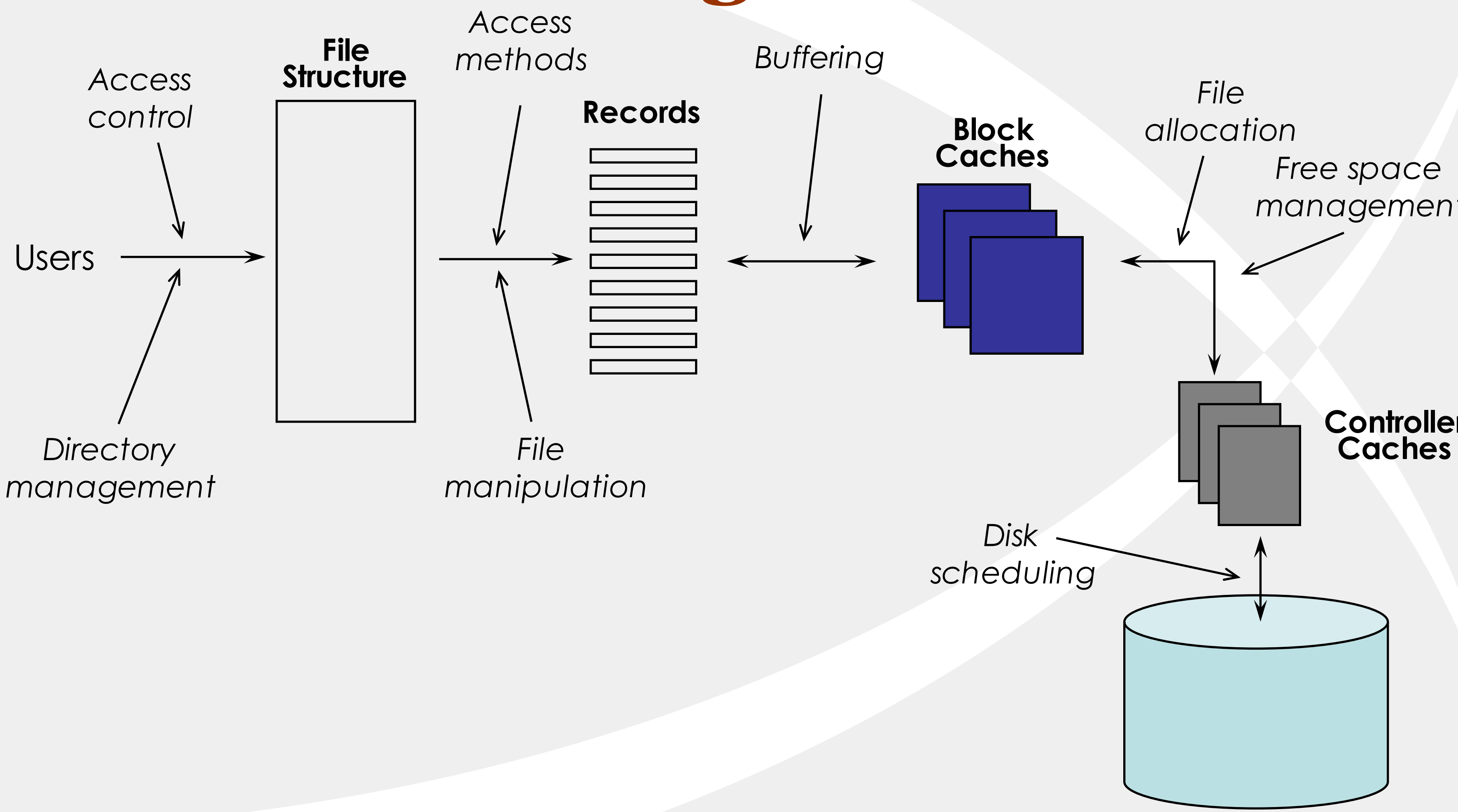
Block 406 is /usr/ast directory

26	•
6	••
64	grants
92	books
60	mbox
81	minix
17	src

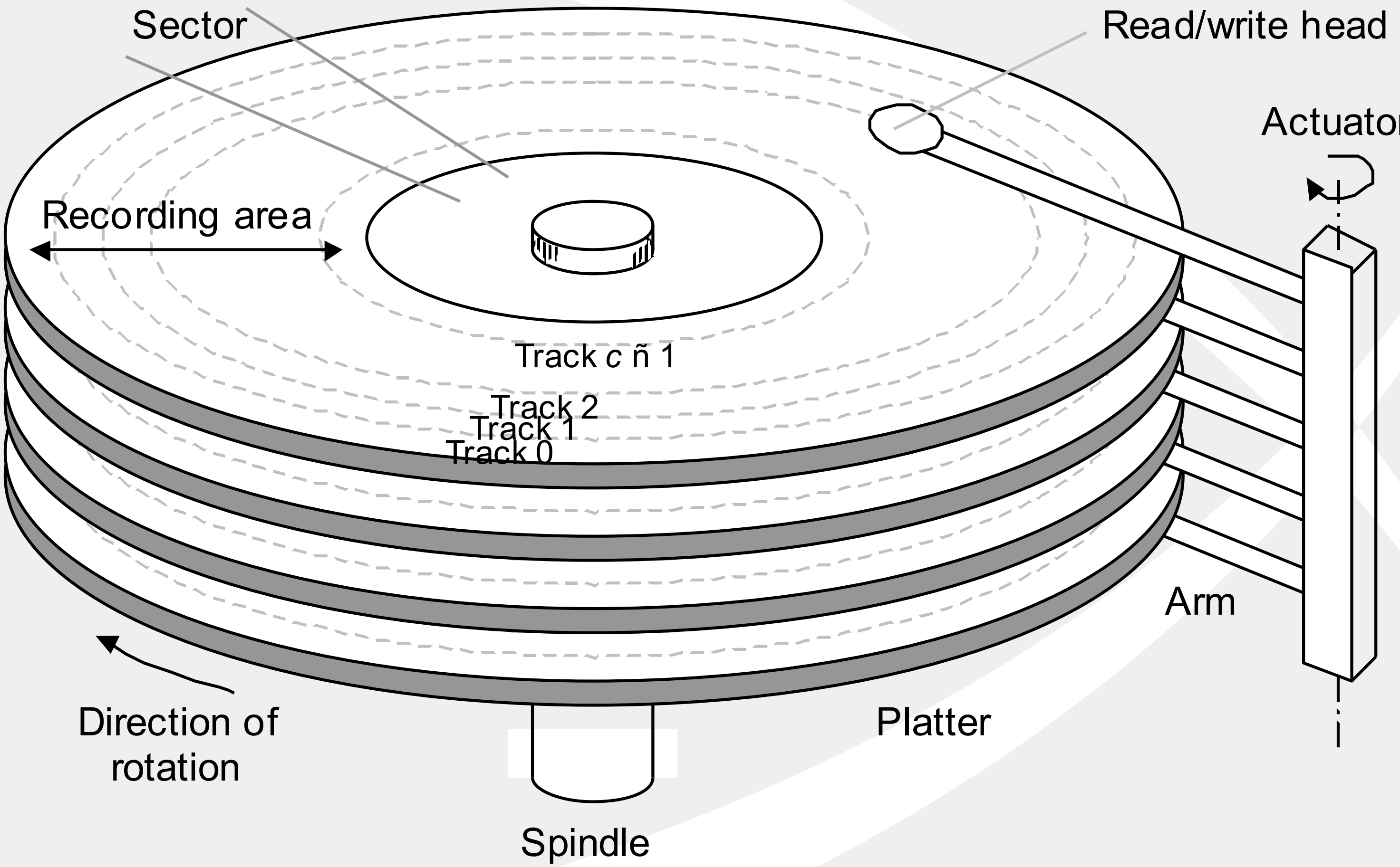
/usr/ast/mbox is i-node 60

The steps in looking up */usr/ast/mbox*

Elements of storage management

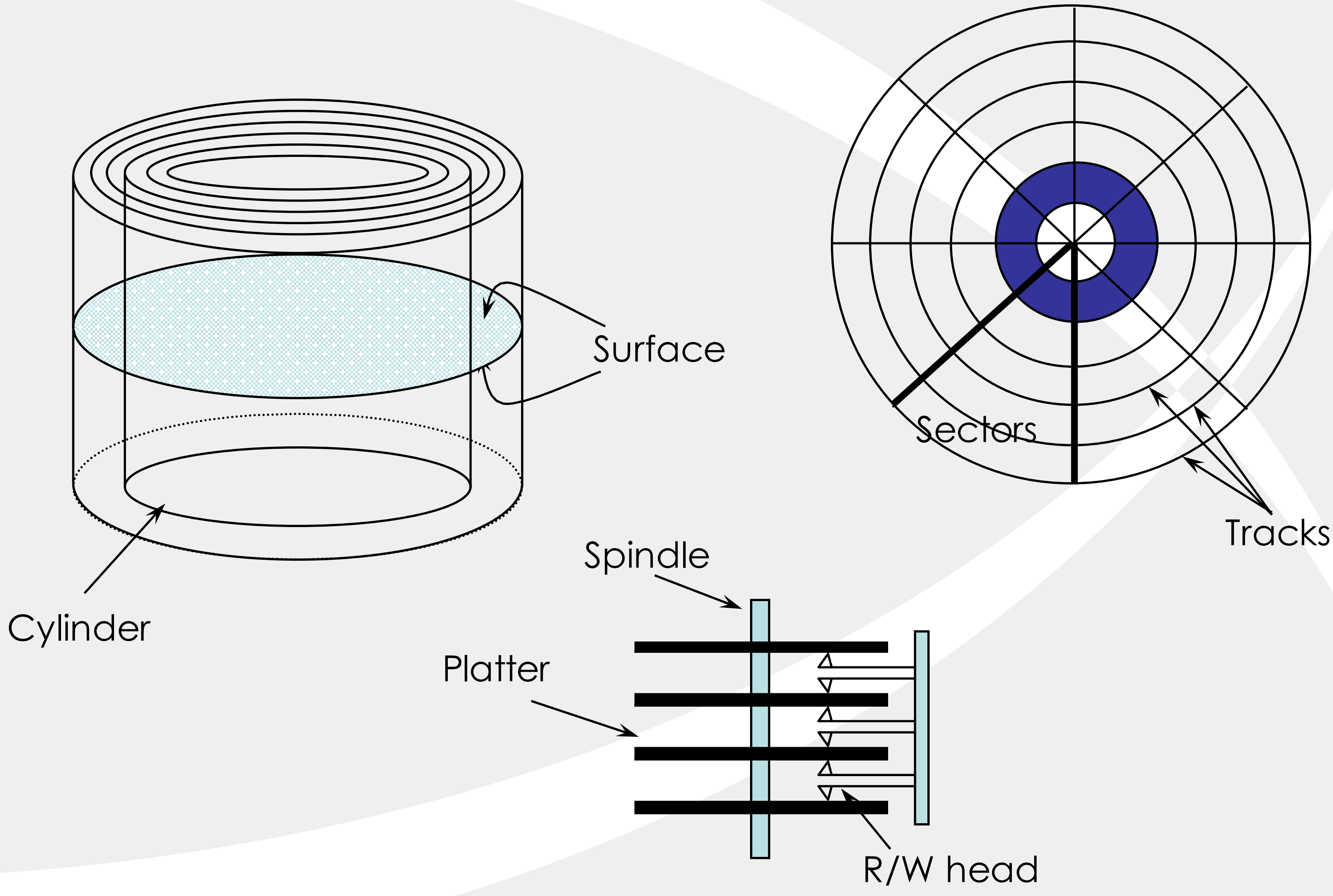


Disk Memory Basics

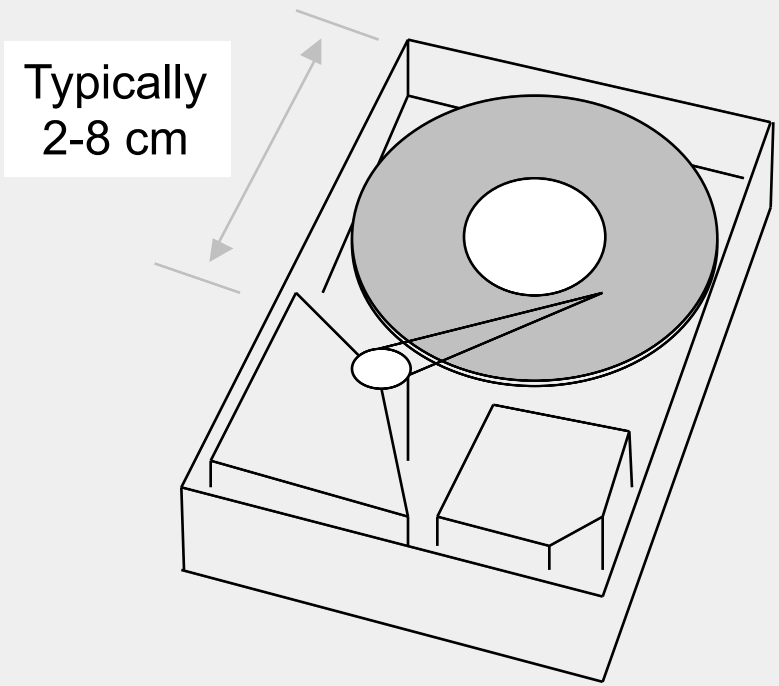


Disk memory elements and key terms.

Disk structure (another view)



Disk Drives



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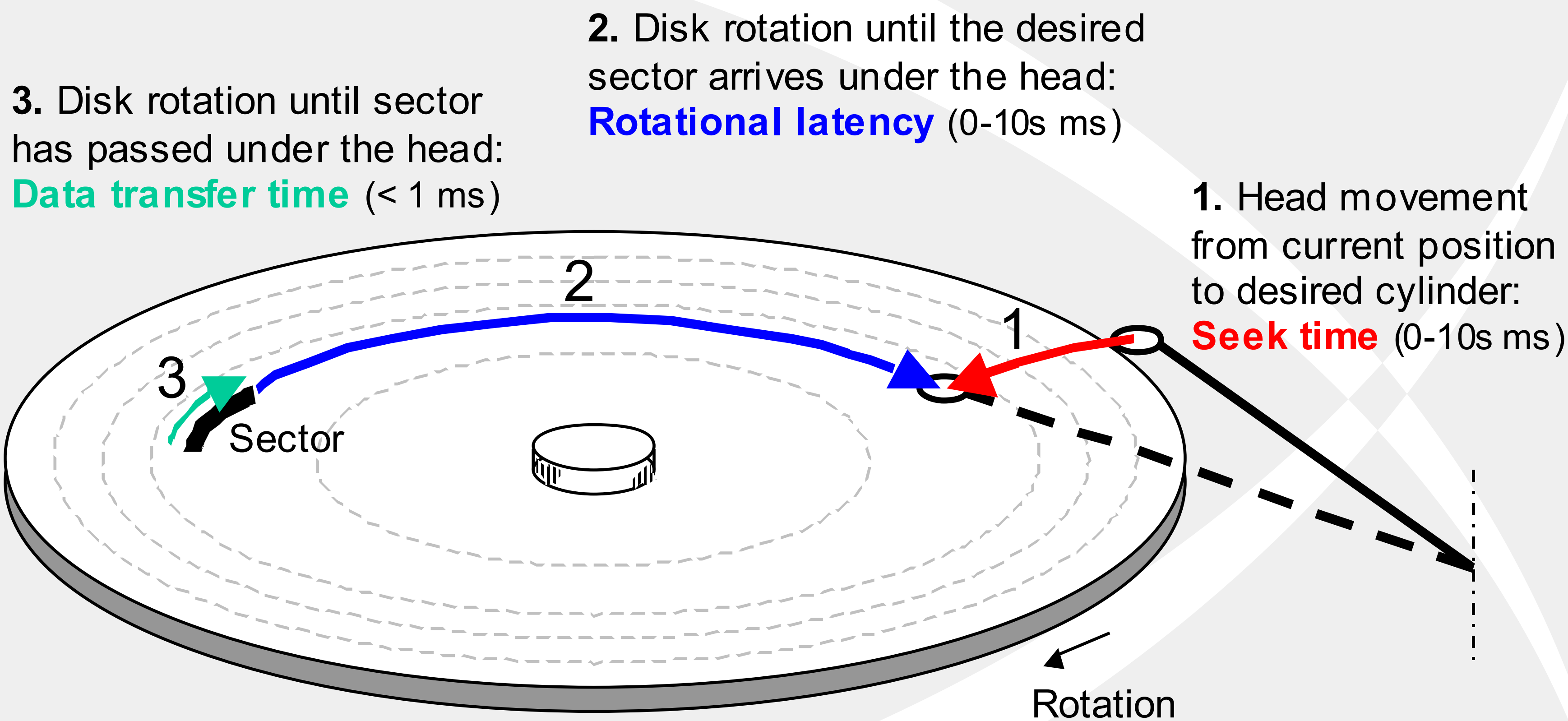
Comprehensive info about disk memory: http://www.storageview.com/guide/

Access Time for a Disk



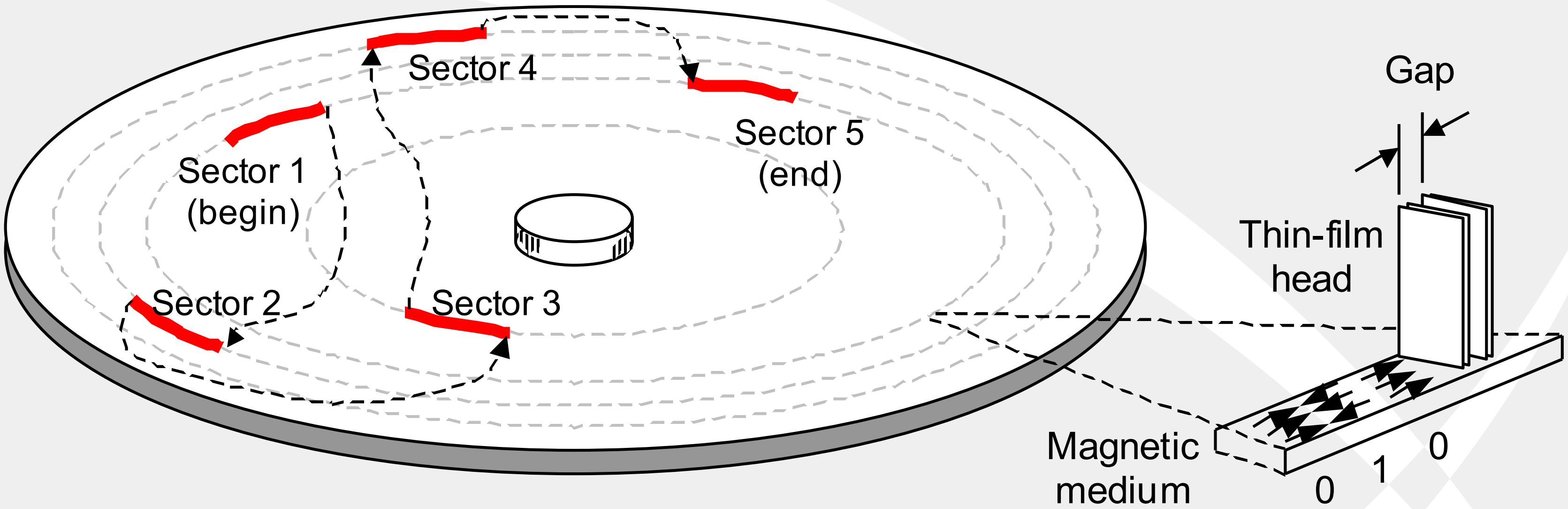
The three components of disk access time. Disks that spin faster have a shorter average and worst-case access time.

Representative Magnetic Disks

Key attributes of three representative magnetic disks, from the highest capacity to the smallest physical size (ca. early 2003).

Manufacturer and Model Name	Seagate Barracuda 180	Hitachi DK23DA	IBM Microdrive
Application domain	Server	Laptop	Pocket device
Capacity	180 GB	40 GB	1 GB
Platters / Surfaces	12 / 24	2 / 4	1 / 2
Cylinders	24 247	33 067	7 167
Sectors per track, avg	604	591	140
Buffer size	16 MB	2 MB	1/8 MB
Seek time, min,avg,max	1, 8, 17 ms	3, 13, 25 ms	1, 12, 19 ms
Diameter	3.5″	2.5″	1.0″
Rotation speed, rpm	7 200	4 200	3 600
Typical power	14.1 W	2.3 W	0.8 W

Organizing Data on Disk



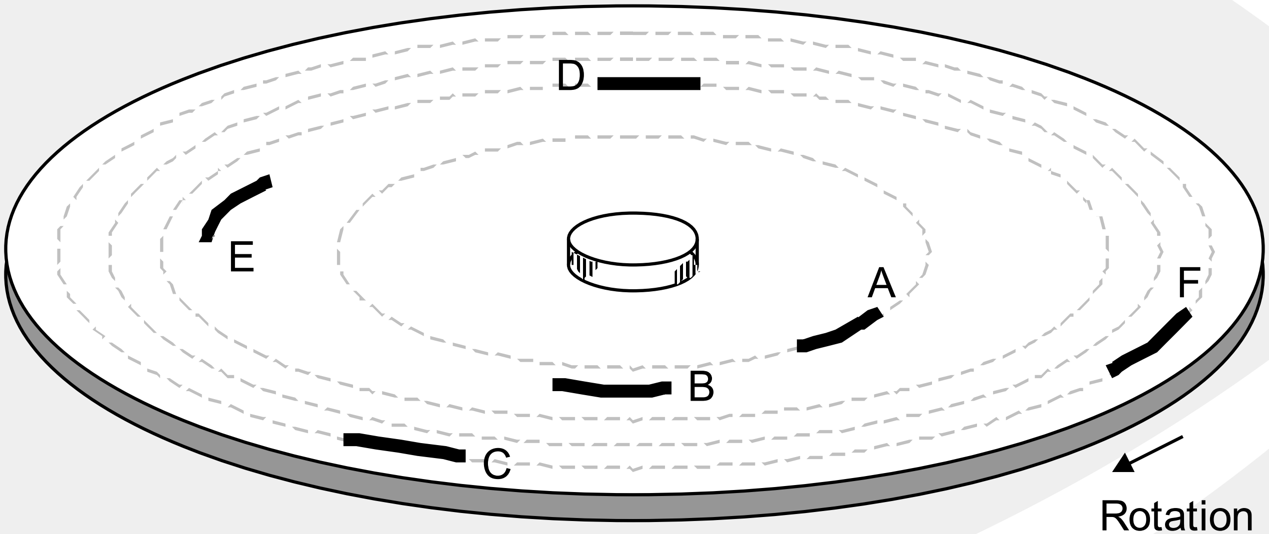
Magnetic recording along the tracks and the read/write head.

	0	16	32	48	1	17	33	49	2		Track i
	30	46	62	15	31	47	0	16	32		Track $i + 1$
	60	13	29	45	61	14	30	46	62		Track $i + 2$
	27	43	59	12	28	44	60	13	29		Track $i + 3$

Logical numbering of sectors on several adjacent tracks.

Disk Performance

Average rotational latency = 30 / rpm s = 30 000 / rpm ms



Arrival order of access requests:

A, B, C, D, E, F

Possible out-of-order reading:

C, F, D, E, B, A

Reducing average seek time and rotational latency by performing disk accesses out of order.

Disk Caching

Same idea as processor cache: bridge main-disk speed gap

Read/write an entire track with each disk access:

“Access one sector, get 100s free,” hit rate around 90%

Disks listed in above table have buffers from 1/8 to 16 MB

Rotational latency eliminated; can start from any sector

Need back-up power so as not to lose changes in disk cache

Placement options for disk cache

In the disk controller:

Suffers from bus and controller latencies even for a cache hit

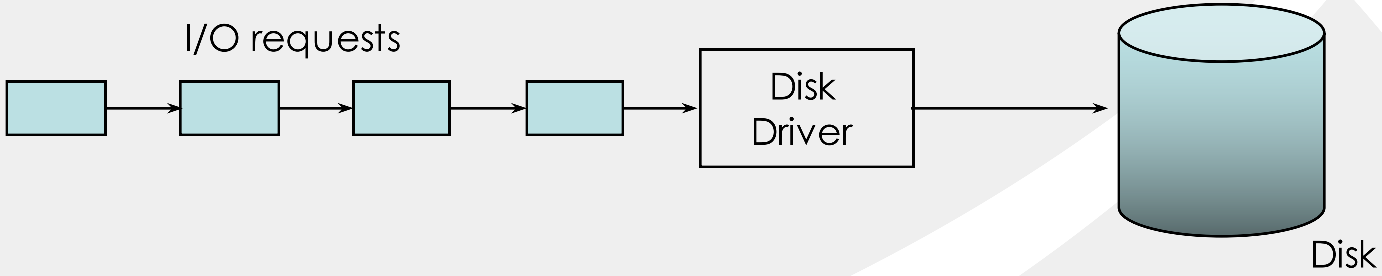
Closer to the CPU:

Avoids latencies and allows for better utilization of space

Intermediate or multilevel solutions

Disk scheduling

- Scheduling problem: maximize the throughput with concurrent I/O requests from



- Strategy: minimize the time spent by disk seeking for data – maximizes the time spent reading/writing data

Disk scheduling strategies

- Commonly used strategies include:
  - *Random*
    - select from pool randomly
    - worst performer
    - sometimes useful as a benchmark for analysis and simulation
  - *First Come First Served (FCFS) or FIFO*
    - fairest of them all; no starvation; requests are honored in the order they are received
    - works well for few processes (principle of locality)
    - approaches to r*andom* as number of processes competing for the given disk increases

Disk scheduling strategies

- *Priority*
  - access to the disk is not actually controlled by the disk management software
  - based on processes' execution priority
  - designed to meet job throughput criteria and *not* to optimize the disk usage
- *Last In First Out (LIFO)*
  - service the most recently arriving request first
  - can be useful for processing sequential files
  - real danger of starvation; once a process falls behind it can be services only if the entire list ahead of it empties

Disk scheduling strategies

- Above algorithms have based disk scheduling decision on the requestor process
- Following algorithms use requested item, i.e. the requested disk address
  - *Shortest Service Time First (SSTF)*
    - select the item requiring the shortest seek time
    - no guarantee of improved average seek time in any particular circumstance but
    - in general better average seek time than FIFO
    - random tie breaker used, if needed, to decide in which direction to move

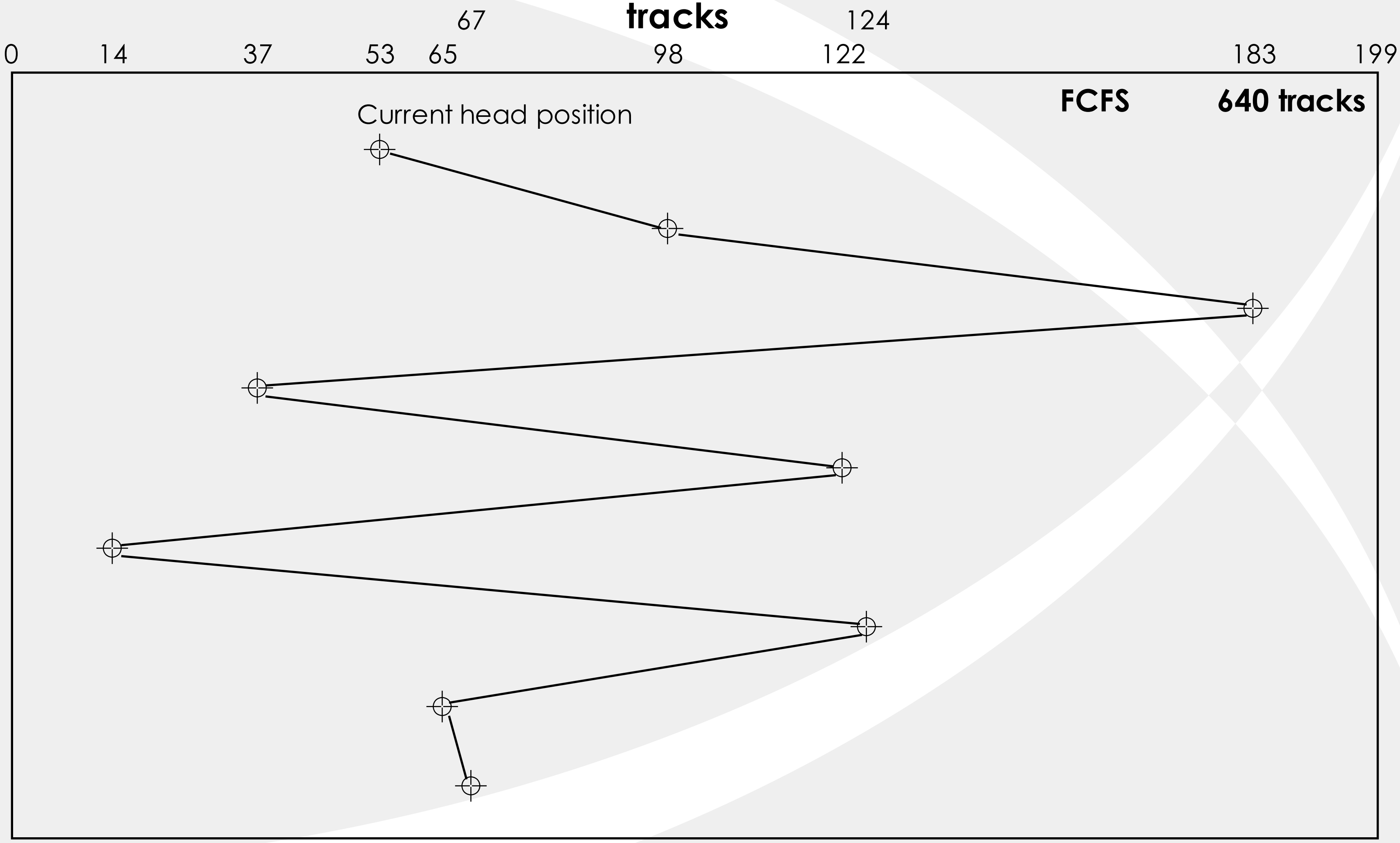
Disk scheduling strategies

- *SCAN*—back and forth over disk
  - heads move in only one direction until the last track is reached, then the direction is reversed
  - if the direction of the heads' travel is reversed once there are no more requests in that direction this method is called *LOOK*
  - no danger of starvation, but
  - biased **against** the most recently used area on the disk
    - Doesn't exploit locality as well as SSTF though or as LIFO
  - often similar to *SSTF*
- *C-SCAN*—circular SCAN or one way SCAN and fast return
  - scans in only one direction to the last track and then returns heads quickly to the beginning
  - reduces the maximum delay for new arrivals

Disk scheduling strategies

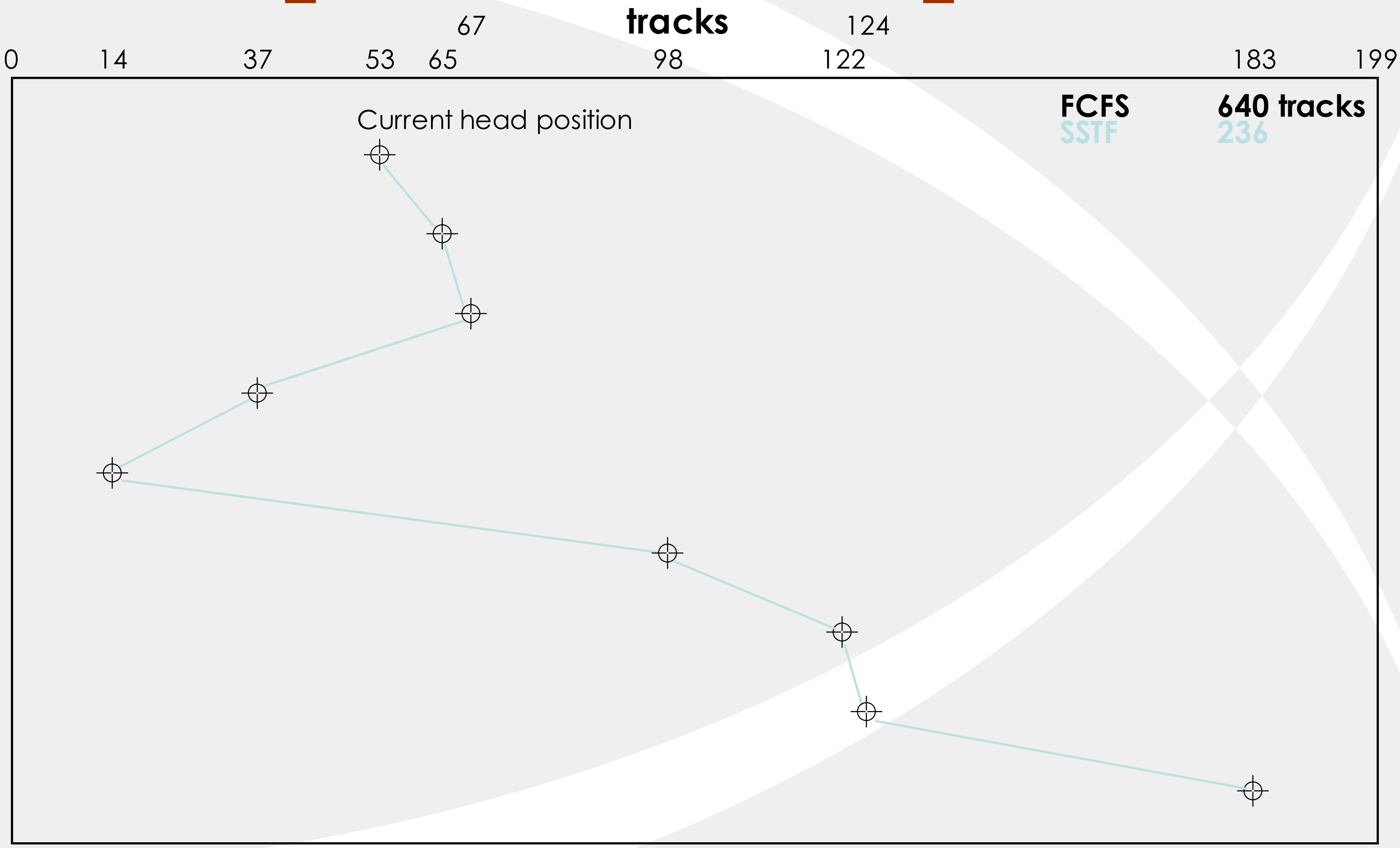
- *LOOK*—look for a request before moving in that direction
  - Heads move in only one direction until there are no more requests in that direction, then the direction is reversed.
- *C-LOOK*—circular LOOK
  - Scans in only one direction until there are no more requests in that direction and then returns heads quickly to the beginning

A comparative example—FCFS



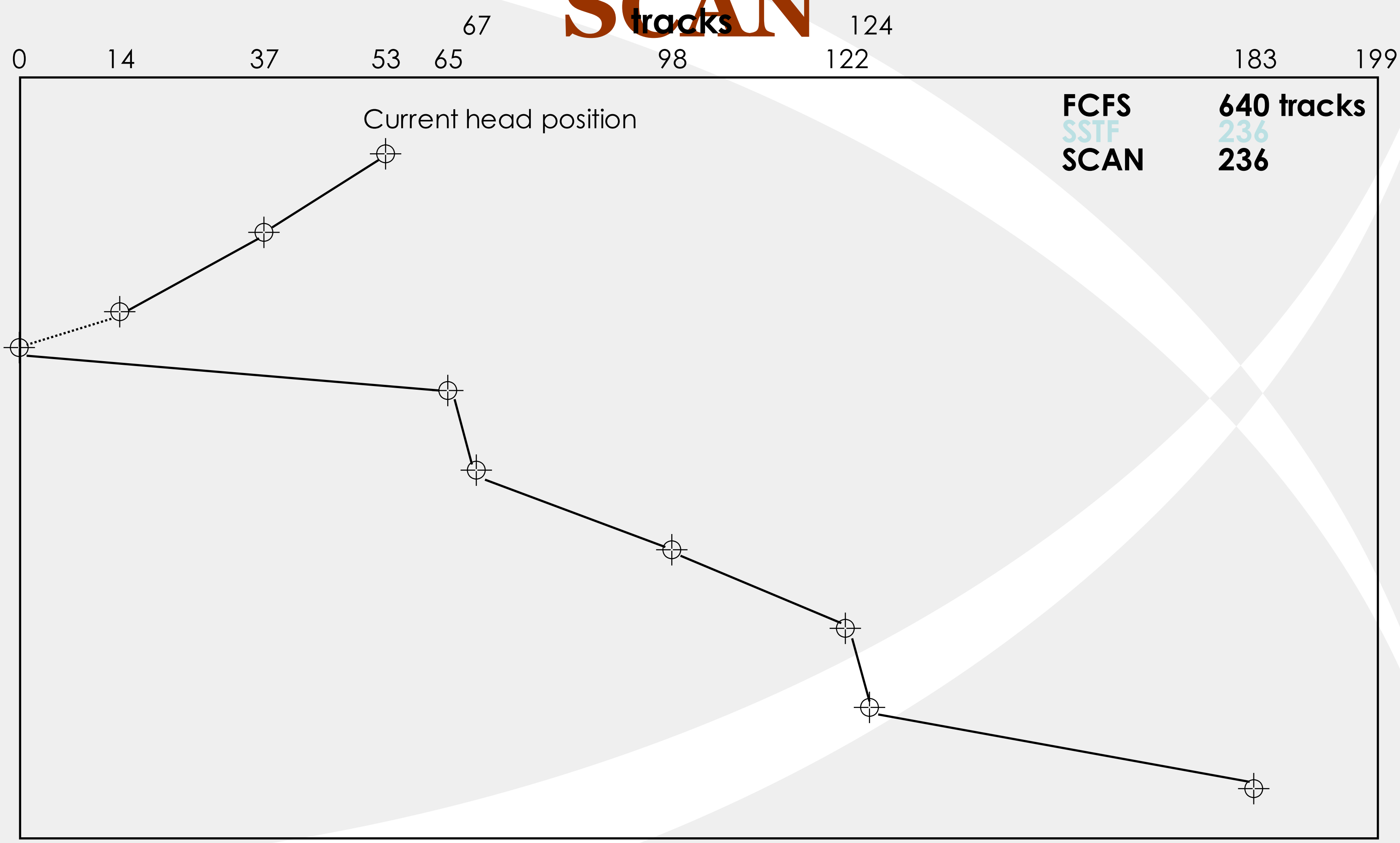
Request queue: 98, 183, 37, 122, 14, 124, 65, 67

A comparative example—SSTF



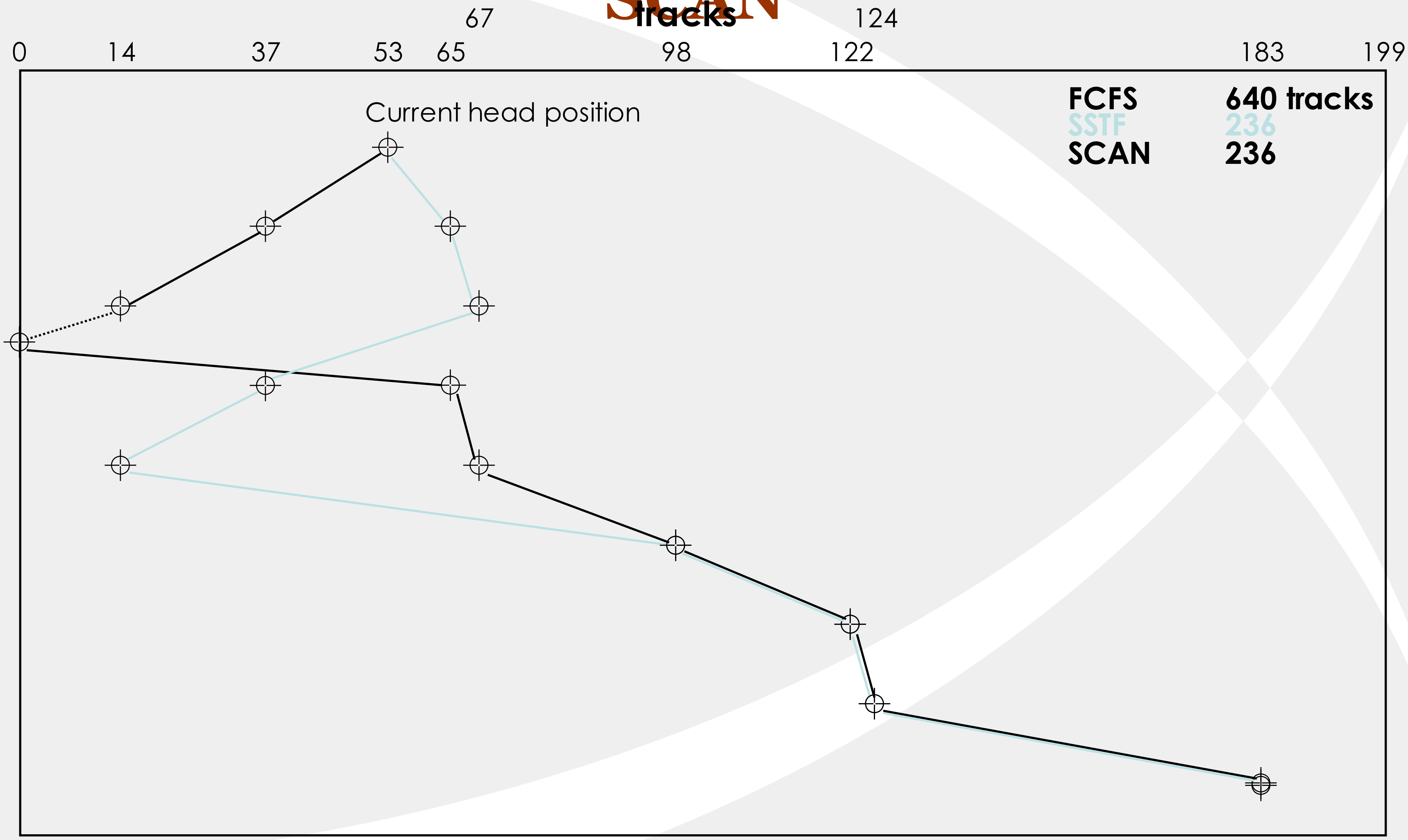
Request queue: 98, 183, 37, 122, 14, 124, 65, 67

A comparative example—SCAN



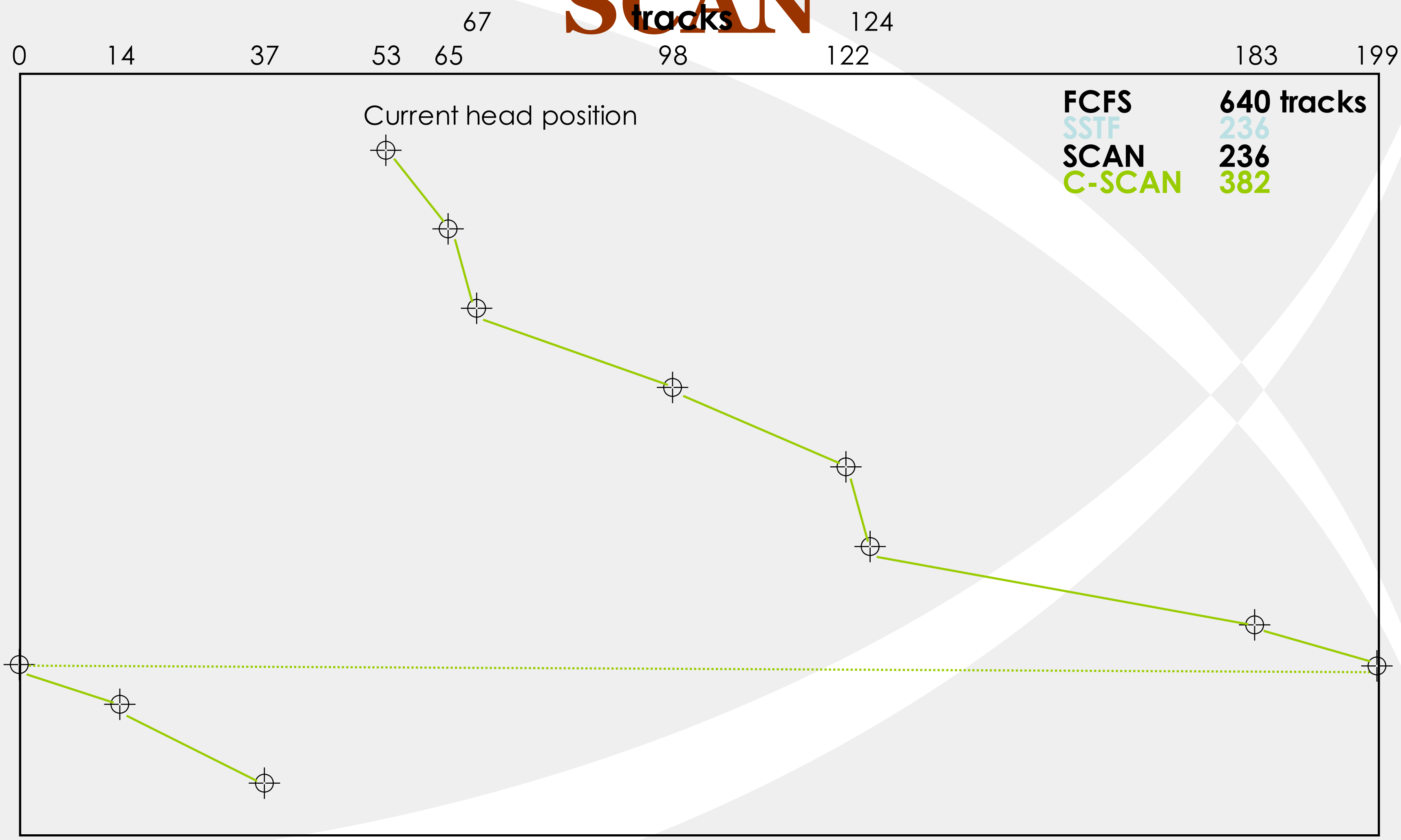
Request queue: 98, 183, 37, 122, 14, 124, 65, 67

A comparative example—SSTF vs SCAN



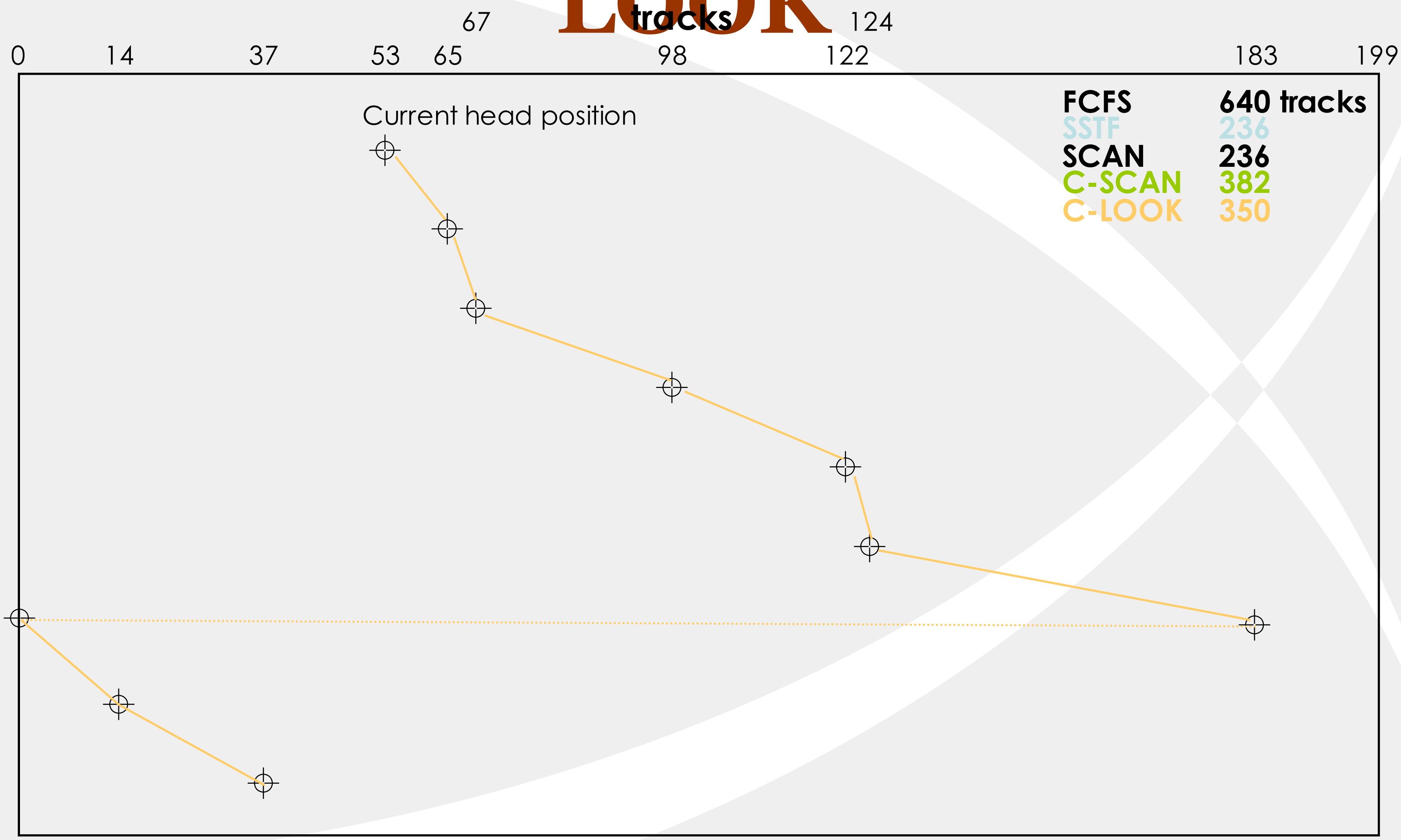
Request queue: 98, 183, 37, 122, 14, 124, 65, 67

A comparative example—C-SCAN



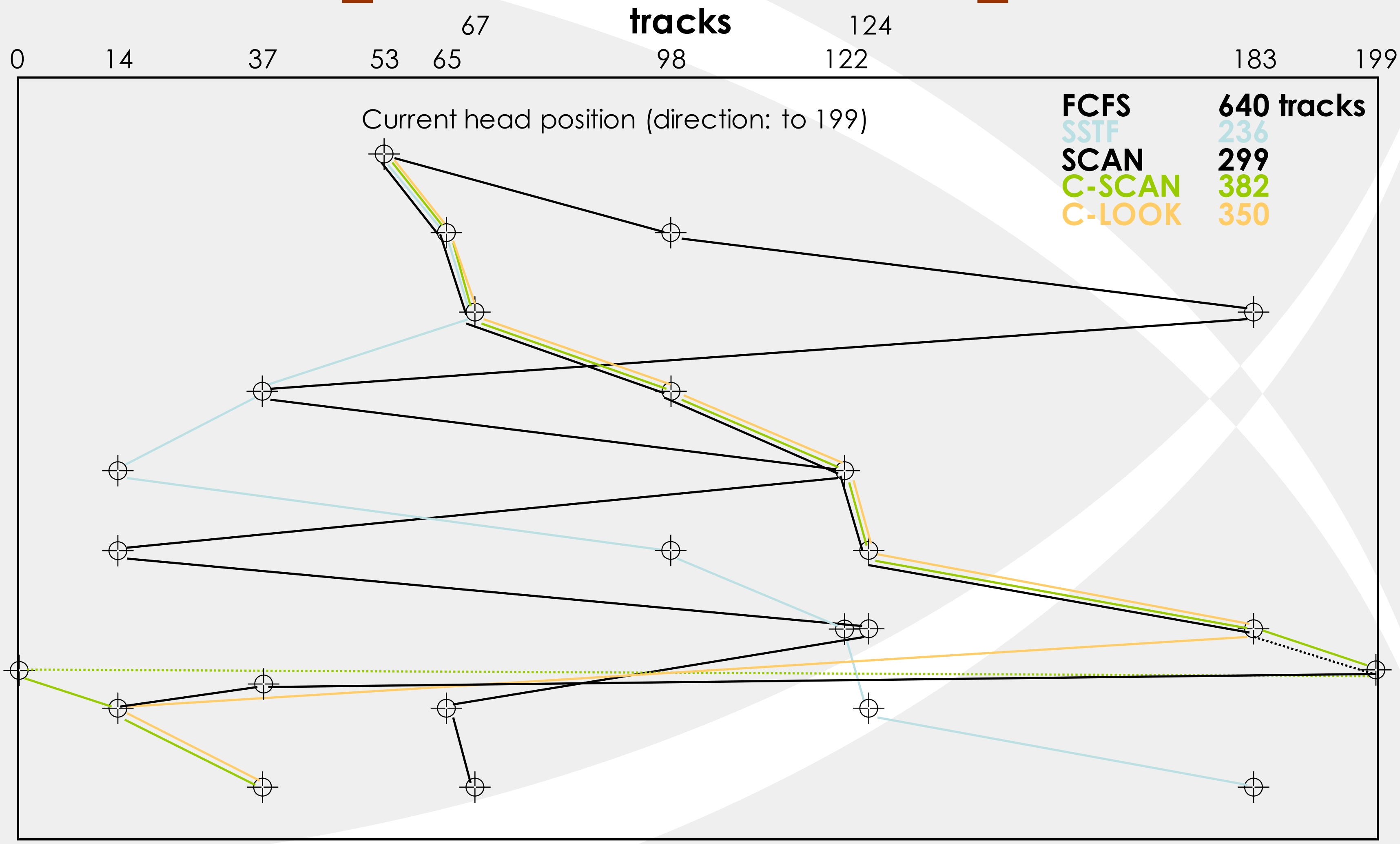
Request queue: 98, 183, 37, 122, 14, 124, 65, 67

A comparative example—C-LOOK



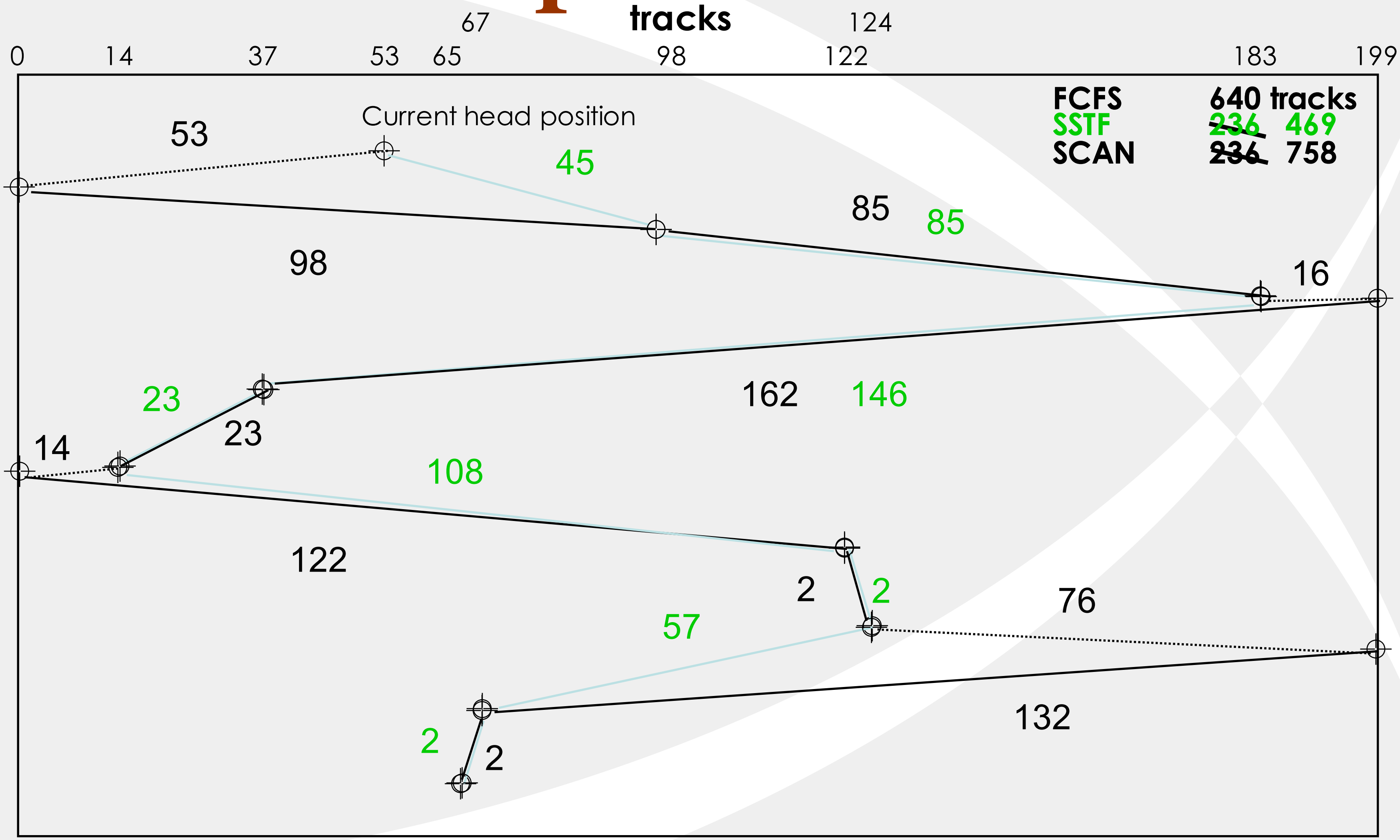
Request queue: 98, 183, 37, 122, 14, 124, 65, 67

A comparative example—All



Request queue: 98, 183, 37, 122, 14, 124, 65, 67

Grouped arrivals



Request queue: 98, 183, 37, 122, 14, 124, 65, 67
Arrivals: 98, 183; 37; 122, 14; 124, 65, 67