# Lecture 10: File Systems
# Operating Systems – EDA093/DIT401

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# Reading instructions

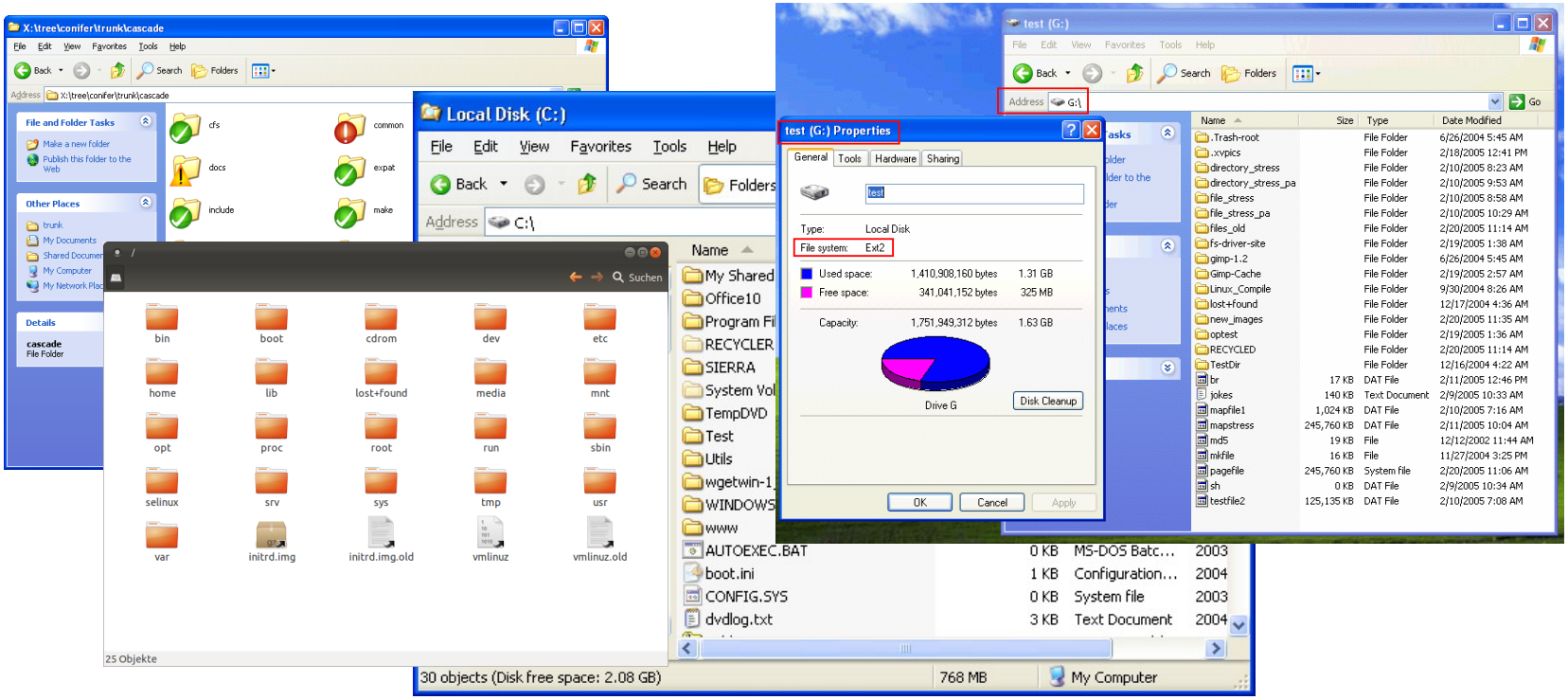
- Chapter 4.1 to 4.4

  (extra facultative reading: 10.1-10.3.6,10.4-10.6,11.1-11.2,11.4-11.5 from Silberschatz Operating System Concepts)

# Which are the most visible aspects of a File System?

Files

Directories



# Objectives

- To explain the function of file systems
- To describe the interfaces to file systems
- To discuss file-system design tradeoffs, including access methods, file sharing, file locking, and directory structures
- To explore file-system protection
- To discuss block allocation and free-block algorithms and trade-offs

# AGENDA

- File concept

*What extra information / overheads / interfaces does the OS need to provide file and directory abstractions to users?*

- Access methods

*How to we access files and which is the minimum unit we can read/write from secondary storage?*

- Disk structure (Self reading)

*How is the physical disk organized in order to maintain 1 (or more) file systems?*

*How can we organize directories (and files) in a file system?*

- Directory structure

*How is a file system organized in layers?*

- File-system structure

*How do we know where each file is?*

- Allocation methods

*How do we know what portions of a file systems are free?*

- Free-space management

*How do we share and protect files among different users?*

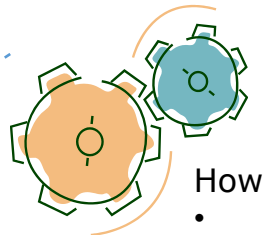
- File sharing and protection

# AGENDA

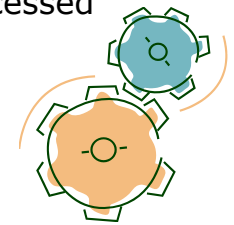
- File concept
- Access methods
- Disk structure
- Directory structure (Self reading)
- File-system structure
- Allocation methods
- Free-space management
- File sharing and protection

*What extra information / overheads / interfaces does the OS needs to provide file and directory abstractions to users?*

# File Concept



How are files:
- Named
- Structured
- Protected
- Accessed
- …



- Minimum allocation unit for the user
- File system abstracts how they are mapped into secondary storage
- Similarly to processes, files have contiguous logical address space (but not physical)
- Different types: Data files (numeric, character, binary) and Program files
- Contents defined by file's creator! (Consider **text file, source file, executable file)**

# 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

# File Types – Name, Extension

- Operating System, Processes and File System are dependent on each other
- Extensions provide hints to the Operating System about which program to load in order to present the content to the user

| file type | usual extension | function |
|---|---|---|
| executable | exe, com, bin or none | ready-to-run machine-language program |
| object | obj, o | compiled, machine language, not linked |
| source code | c, cc, java, pas, asm, a | source code in various languages |
| batch | bat, sh | commands to the command interpreter |
| text | txt, doc | textual data, documents |
| word processor | wp, tex, rtf, doc | various word-processor formats |
| library | lib, a, so, dll | libraries of routines for programmers |
| print or view | ps, pdf, jpg | ASCII or binary file in a format for printing or viewing |
| archive | arc, zip, tar | related files grouped into one file, sometimes com-pressed, for archiving or storage |
| multimedia | mpeg, mov, rm, mp3, avi | binary file containing audio or A/V information |

# Open Files

- Providing a File System implies that the OS needs to maintain information. For instance, information about the open files:
  - **Open-file table**: tracks open files
  - File pointer:  pointer to last read/write location, per process that has the file open
  - **File-open count**: counter of number of times a file is open – to allow removal of data from open-file table when last processes closes it
  - Disk location of the file: cache of data access information
  - Access rights: per-process access mode information

Some information is specific to a process

Some information is global, system-wide

# File Operations

- File is an **abstract data type**, we need ways to operate on them:
  - **Create**
  - **Write –** at **write pointer** location
  - **Read –** at **read pointer** location
  - **Reposition within file - seek**
  - **Delete**
  - **Truncate**
- We can combine these basic operations into complex operations
- Example:
  - ***Open($F_i$)*** – search the directory structure on disk for entry ***$F_i$***, and move the content of entry to memory
  - ***Close ($F_i$)*** – move the content of entry ***$F_i$*** in memory to directory structure on disk

# System calls - Example program – 1/2

```
/* 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 */

    /* 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 */
```

Fig. Tanenbaum, Modern Operating Systems

# System calls - Example program – 2/2

```
        /* 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 */
}
```

Fig. Tanenbaum, Modern Operating Systems

# AGENDA

- File concept
- Access methods
- Disk structure
- Directory structure (Self reading)
- File-system structure
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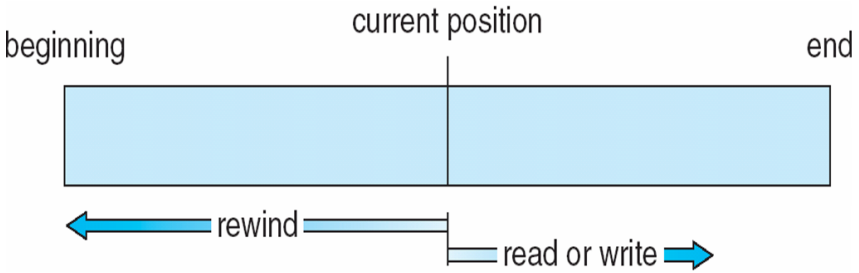
- Free-space management
- File sharing and protection

*How to we access files and which is the minimum unit we can read/write from secondary storage?*

# Access Methods

- **Sequential Access**

```
read next
write next
reset
```



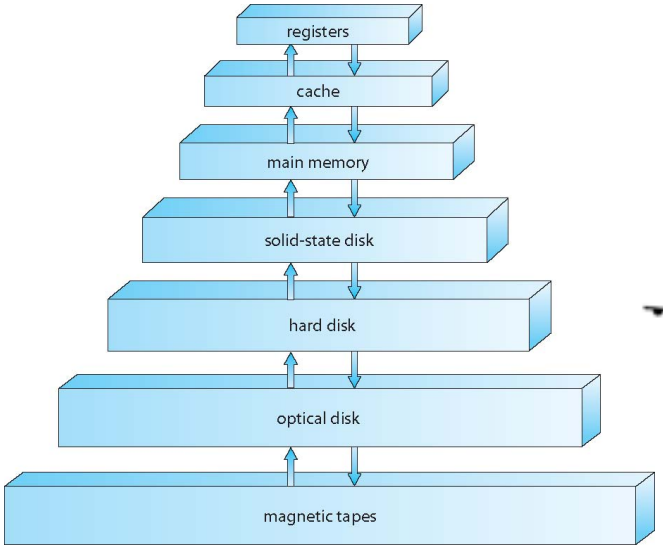

- **Direct Access –** file is fixed length logical records

```
read n
write n
position to n
  read next
  write next
rewrite n
```

*n* = relative block number
(0 being the beginning of the file)

*Why do we read blocks and not just bytes?*

# Reading / Writing blocks




I need the byte at position X from the disk!

System call…
Context switch…
Moving to waiting queue…
I/O disk…
Interrupts…
More context switch…

If we pay this price for each bytes it does not pay off…

# Block Size 1/2

- Which is the appropriate size of a block?
- Large block
  - +: Less blocks to read (➔faster reading)
  - • : More wasted space if files are small
- Small block
  - +: Less space wasted
  - • : More blocks to read (➔slower reading)

# Block Size 2/2

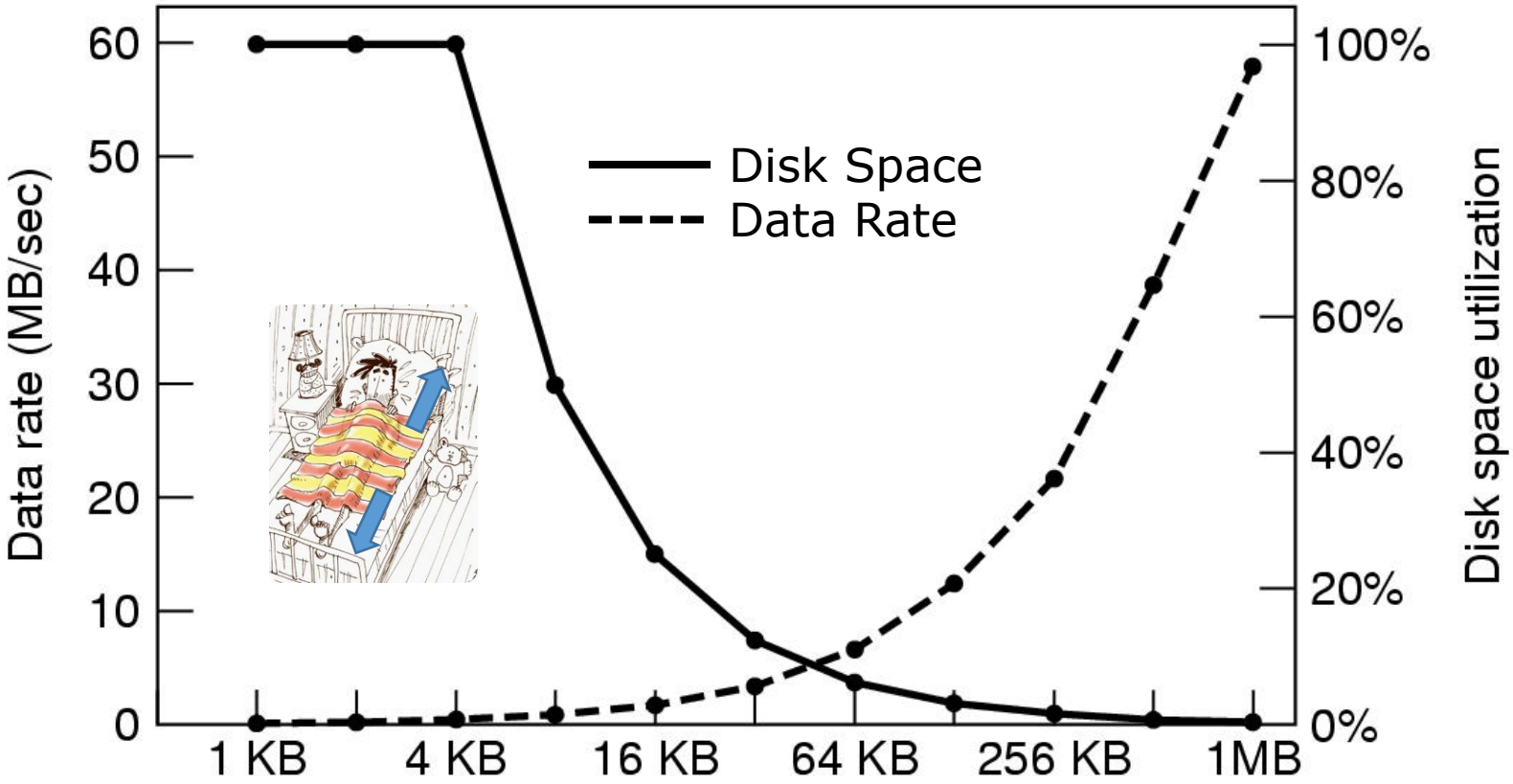



Fig. Tanenbaum, Modern Operating Systems

*Why is it so challenging to chose the right block size?*

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*How is the physical disk organized in order to maintain 1 (or more) file systems?*

# File system layout

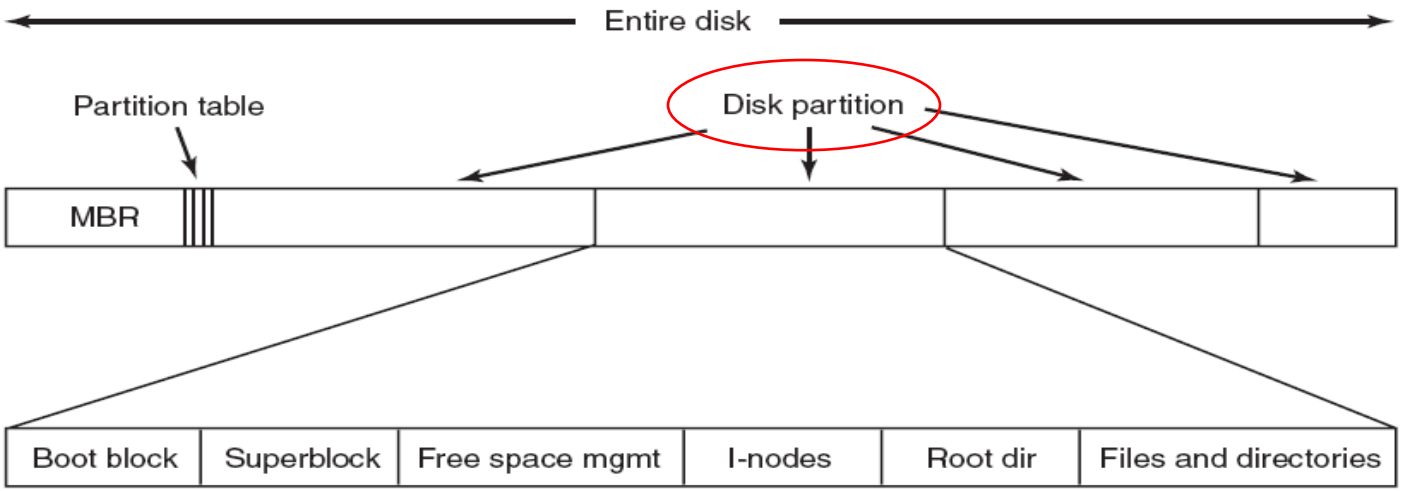


Fig. Tanenbaum, Modern Operating Systems

Disk partitions: 1 (or more) independent file systems

# File system layout

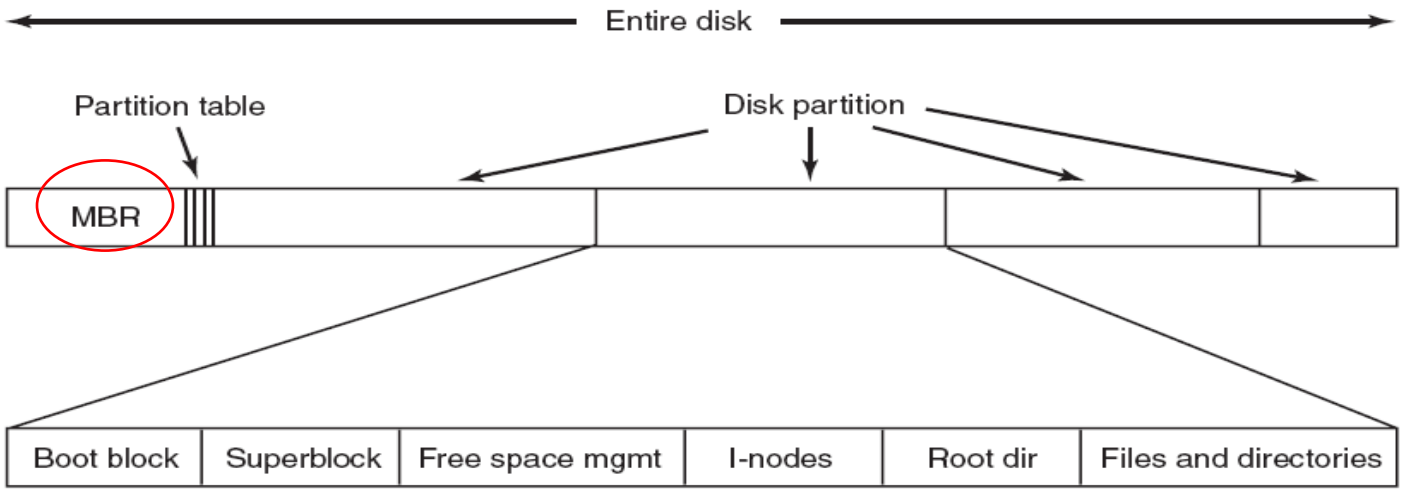


Fig. Tanenbaum, Modern Operating Systems

MBR: Master Boot Record. Starts at sector 0 and is used to boot the computer. At the end, it contains the partition table.

# File system layout

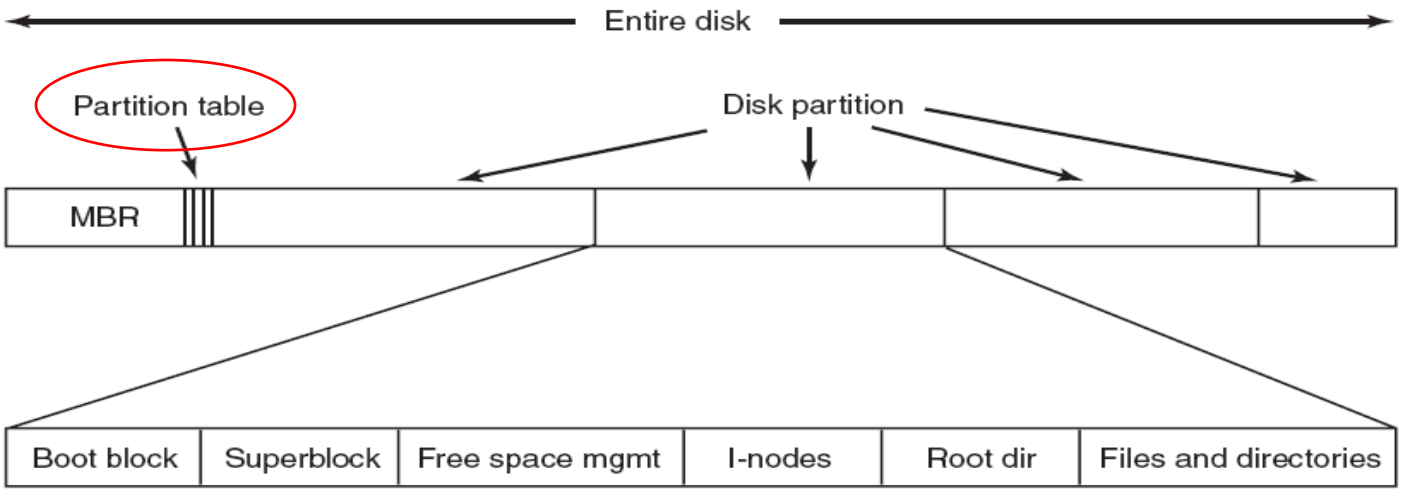


Fig. Tanenbaum, Modern Operating Systems

Partition table: starting and ending addresses of each partition.
One of the partitions is marked as active. Boot sequence:

1. Read the MBR
2. Locate the active partition
3. Read Boot block

# File system layout

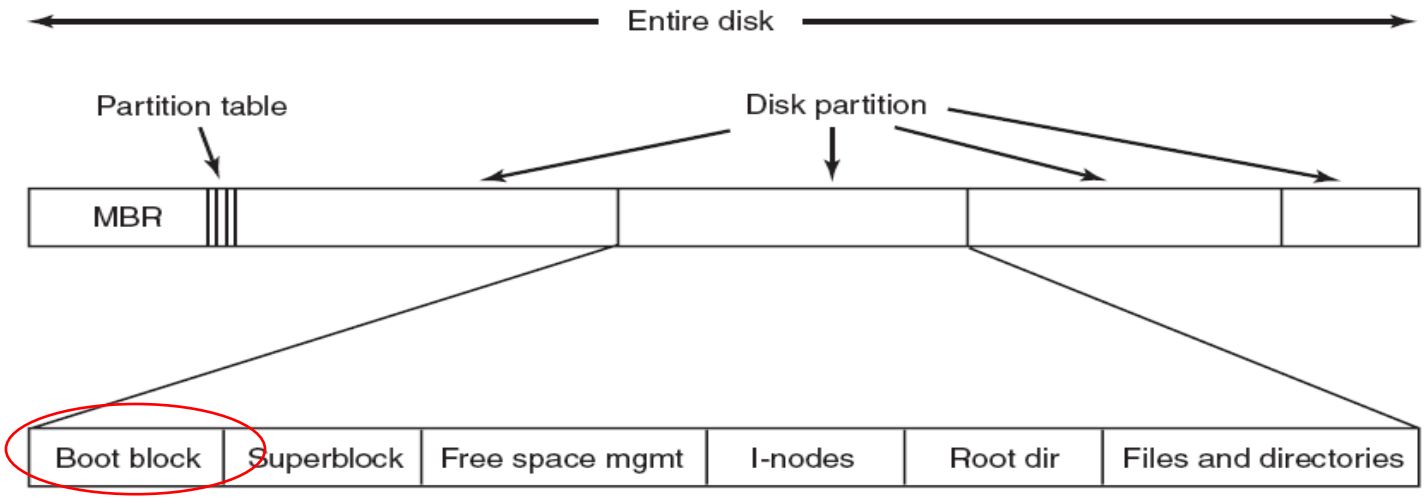


Fig. Tanenbaum, Modern Operating Systems

The Boot block is used to load the operating system of the partition

# File system layout

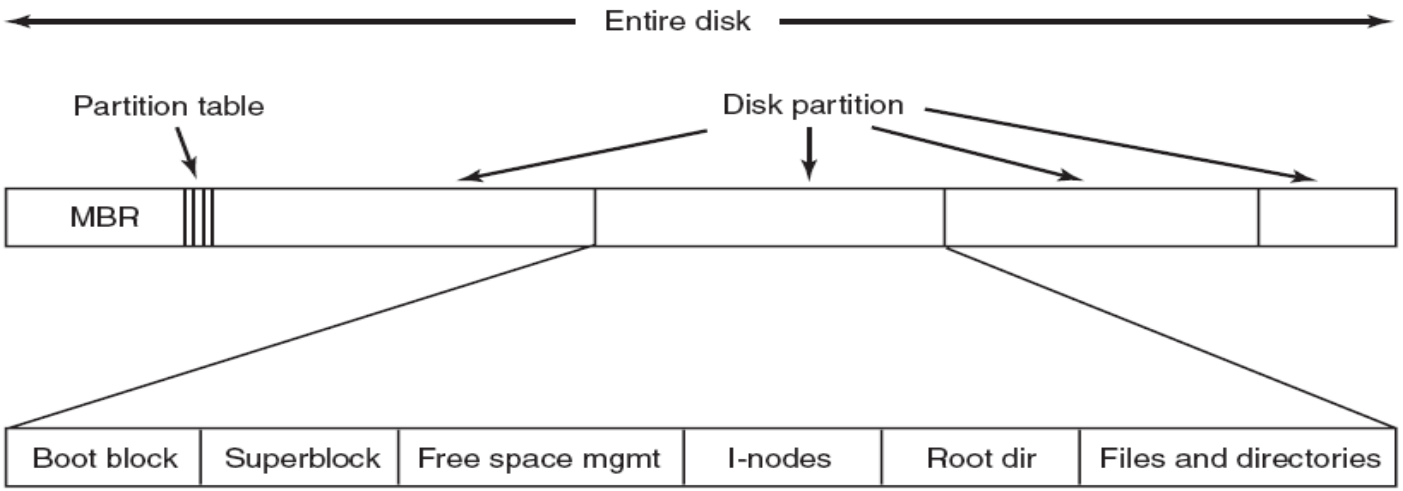


Fig. Tanenbaum, Modern Operating Systems

What there is after the boot block depends on the operating system.
Superblock usually contain key information specific to each operating system.

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*How can we organize directories (and files) in a file system?*

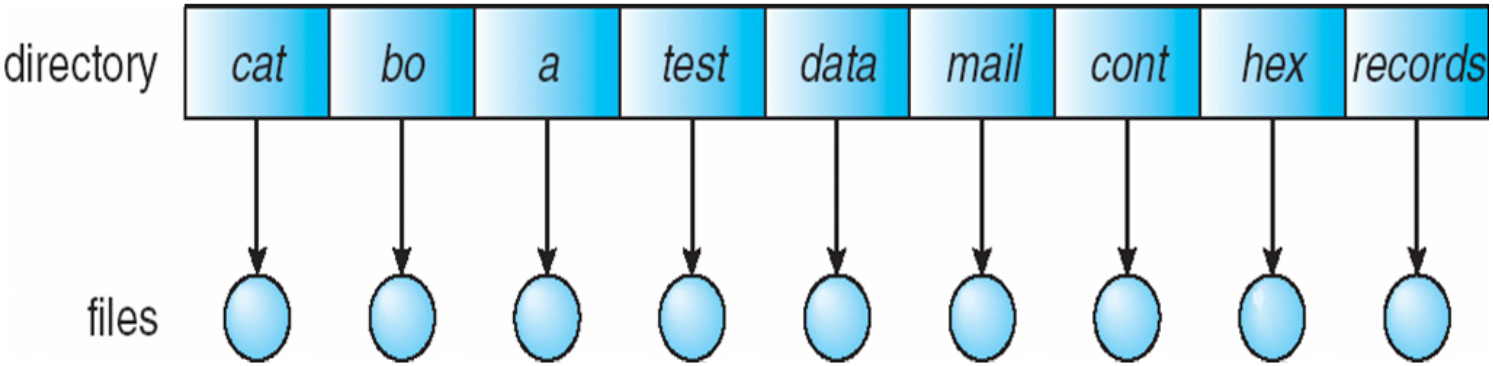
# What should directories allow us to do?

- Search for a file (or search all the files with a given extension)
- Create a file
- Delete a file
- List a directory
- Rename a file
- Traverse the file system
- Locate a file quickly
- Provide convenient naming (Two users can have same name for different files)
- logical grouping of files by properties, (e.g., all Java programs, all games, …)

The following is a list of common schemes for the logical structure of a directory

# Single-Level Directory

- A single directory for all users

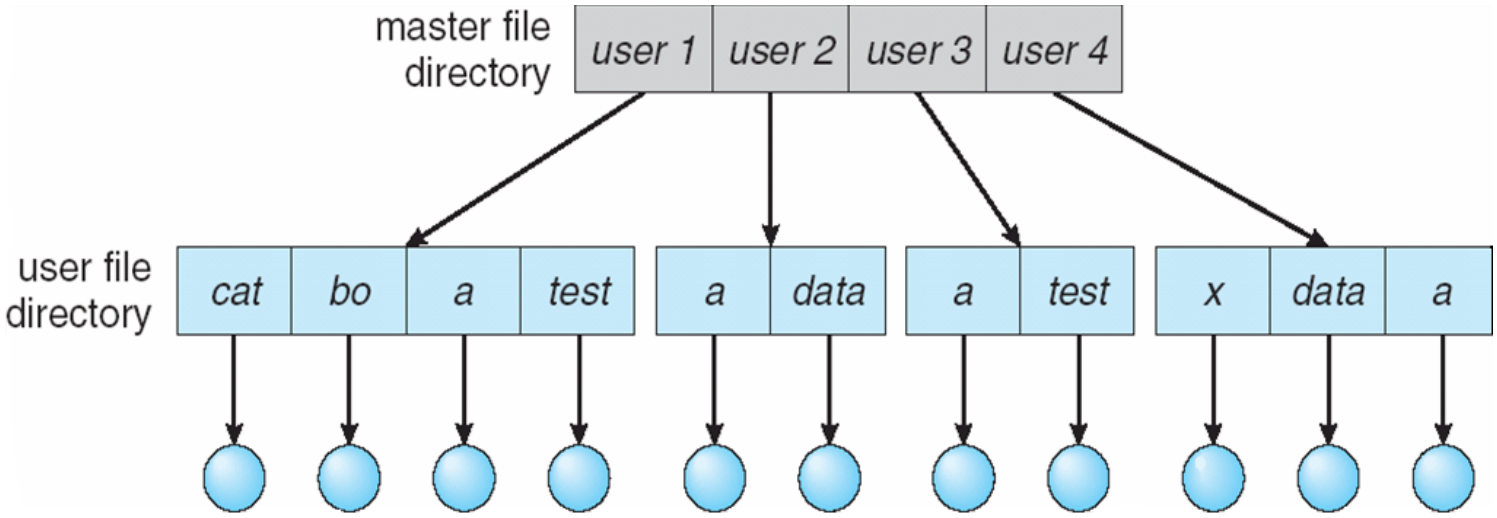



- Simple (good for small devices)
- Easy to locate files

- Different users / same file name?

# Two-Level Directory

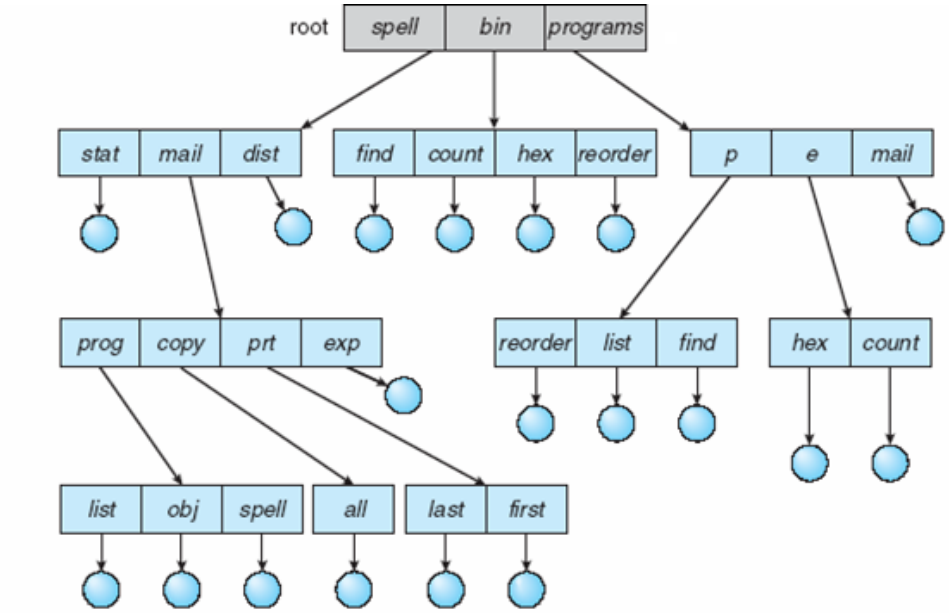
- Separate directory for each user




- Same file for different users
- Better searching

- Will require a sort of login
- Not convenient for large number of files
- Will require a path name (the file name is not enough to access it)

# Tree-Structured Directories




- Users decide how to organize their data
- Even better searching

- Arbitrary numbers of directories (in practice, each directory becomes a file…)
- Introduces **current directory**
- Introduces more operations on directories

# Path names

- Absolute path name
- Relative path name (given working directory)

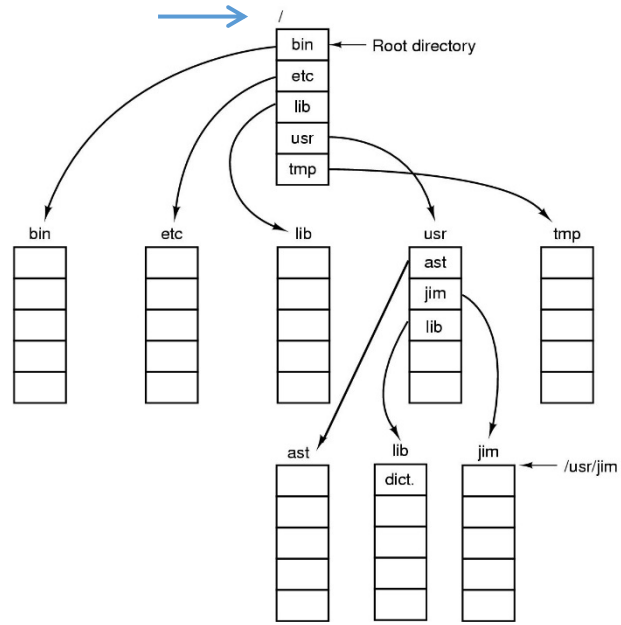



Fig. Tanenbaum, Modern Operating Systems

cd /bin ← **absolute path name change working directory**

ls . ← **list files of this folder (.)**

ls .. ← **list files of parent folder (.)**

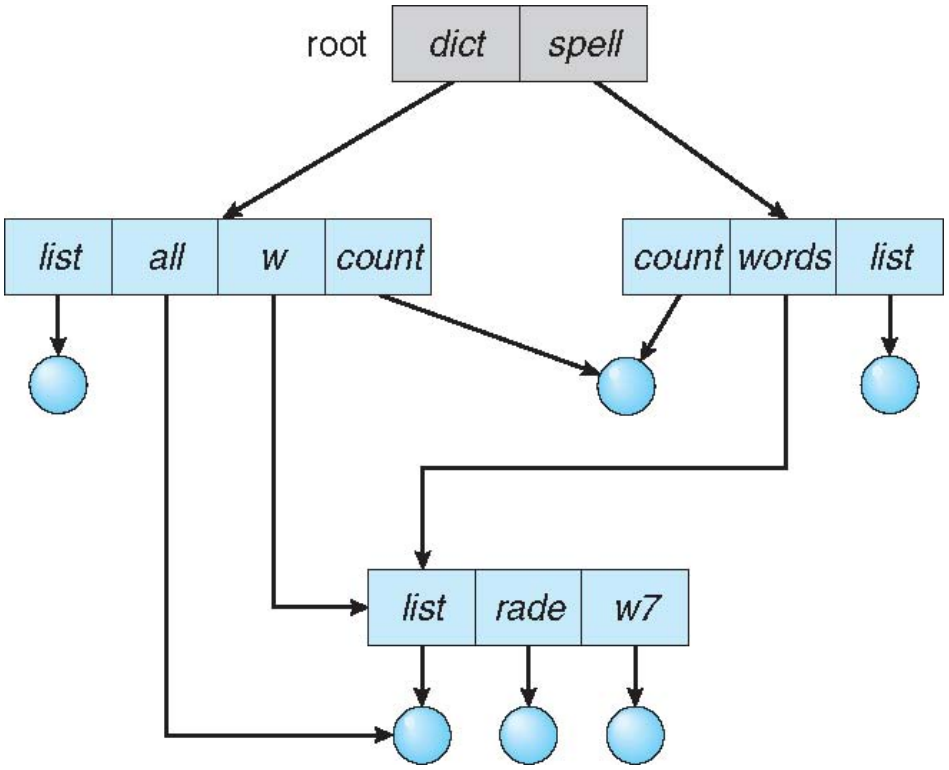
cd ../lib ← **relative path name change working directory**

cp ../usr/lib/hello.txt /tmp/hello.txt

**relative path name**
**absolute path name**

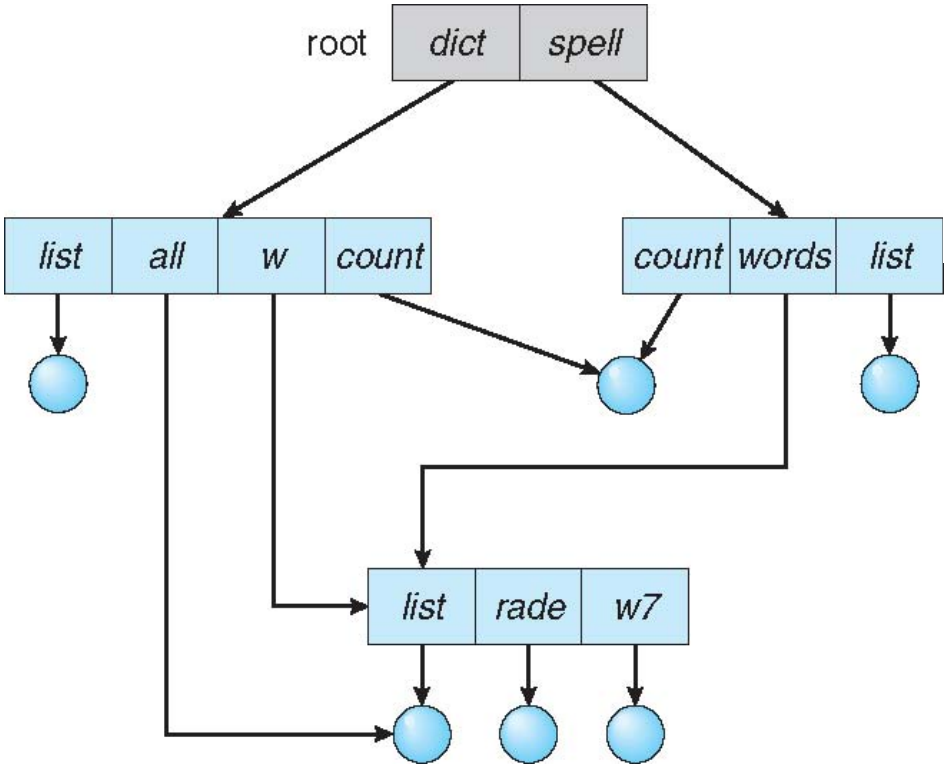
# Acyclic-Graph Directories

- Have shared subdirectories and files




In this case, we have a new type of file, the **link**
(a pointer to an existing file)

# Acyclic-Graph Directories bring trade-offs…




*Suppose we are in spell/words and we delete list. Should we delete it from dict/w too?*

*Let's say we remove it, should we update the links of other references or not?*

*Let's say we remove it and update the links of other references, how do we know how many references we have?*

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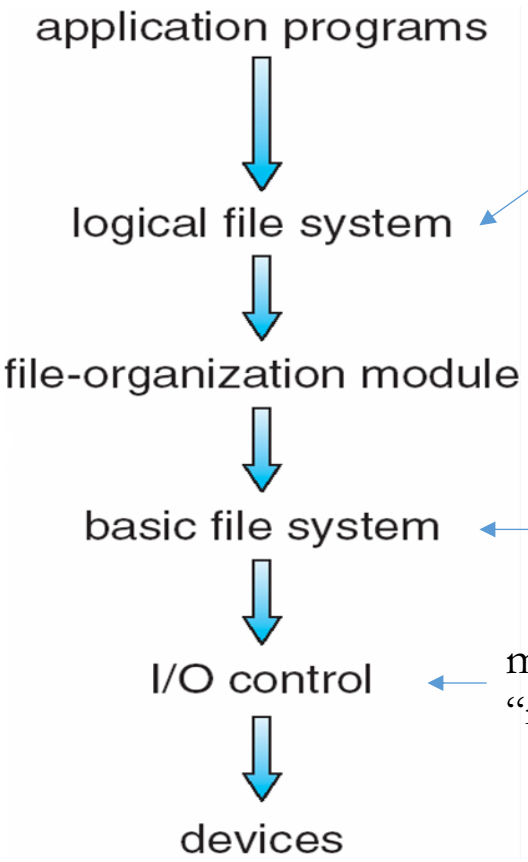
*How is a file system organized in layers?*

# Layered File System




Manages metadata information
Translates file name into file number, file handle, location by maintaining file control blocks (**inodes** in Unix)
Directory management
Protection

Understands files, logical address, and physical blocks
Manages free space, disk allocation
Translates logical block # to physical block #

manages memory buffers and caches
"retrieve block 123"

manage I/O devices at the I/O control layer
"read drive1, cylinder 72, track 2, sector 10, into memory location 1060"

# Virtual File Systems

- Suppose a system has multiple partitions with different file systems, how can you integrate all of them?

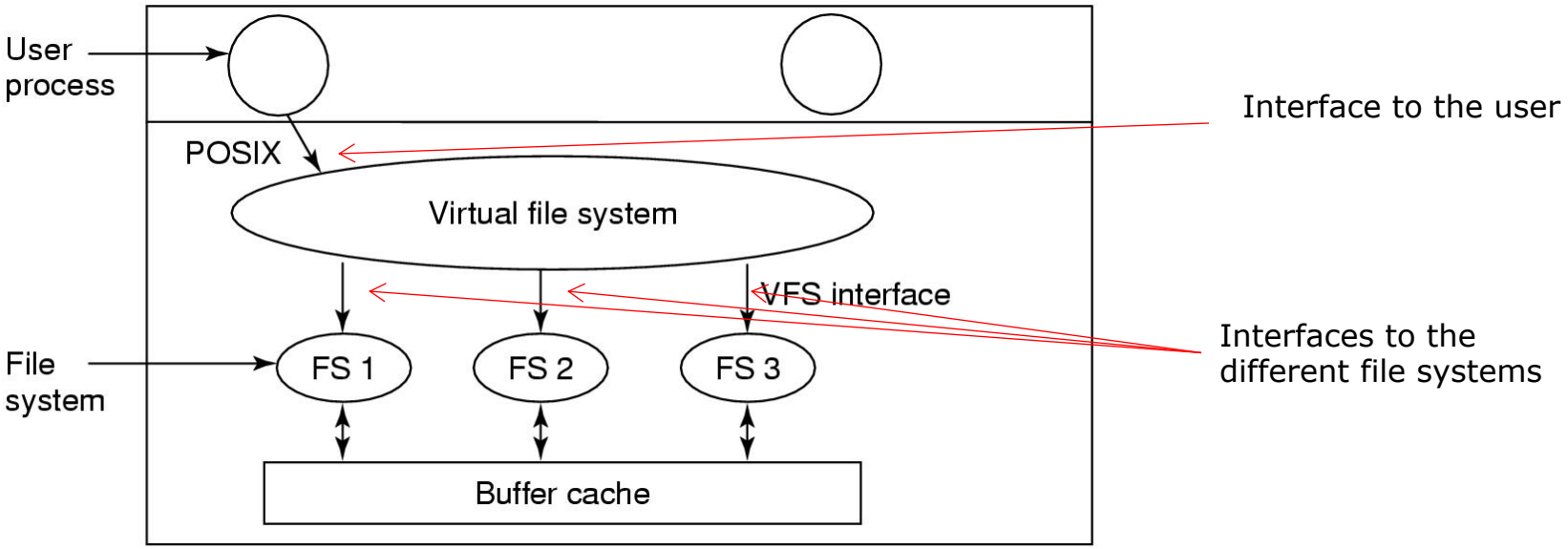
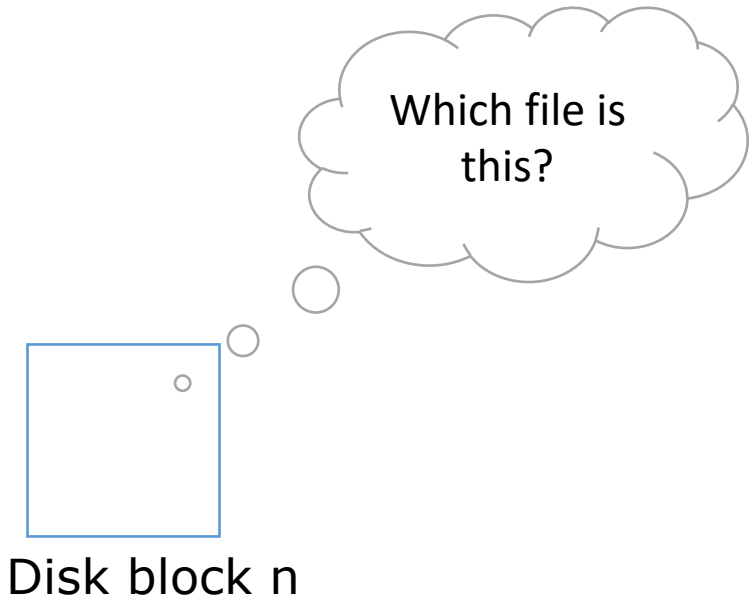



Fig. Tanenbaum, Modern Operating Systems

# Implementing Files




- Contiguous allocation
- Linked List allocation
  - FAT (File Allocation Table)
- I-nodes (Index-nodes)

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*How do we know where each file is?*

# Contiguous allocation

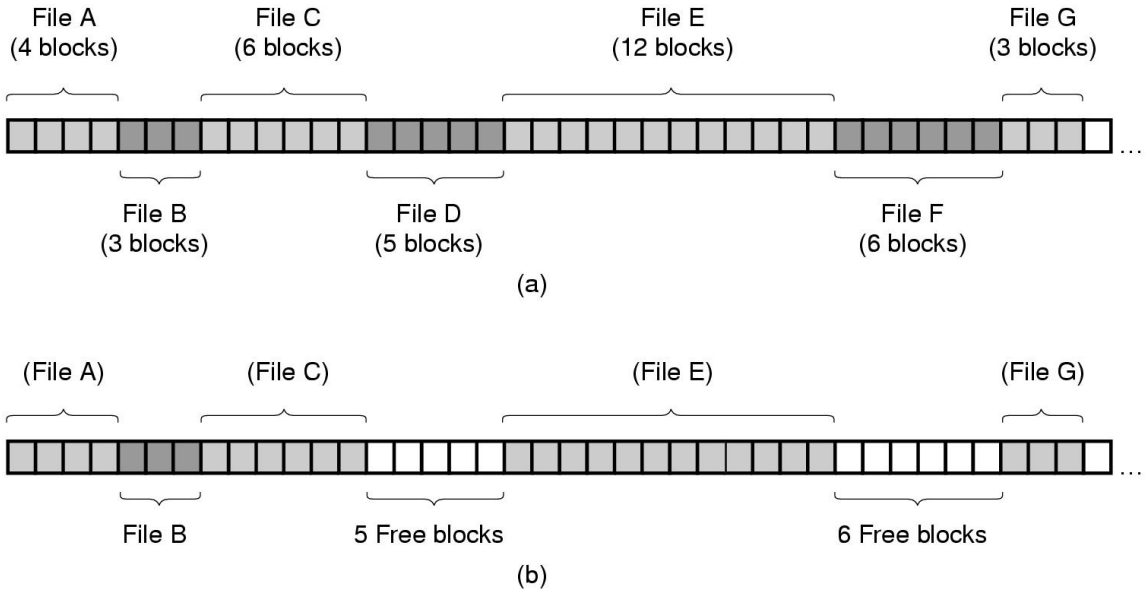


Fig. Tanenbaum, Modern Operating Systems

- Need to maintain 2 numbers per file (first address, number of blocks).
- Read performance (single scan).

- Fragmentation.
- New file size required in advance.

*In which support is contiguous allocation actually a good idea?*

# Linked List allocation

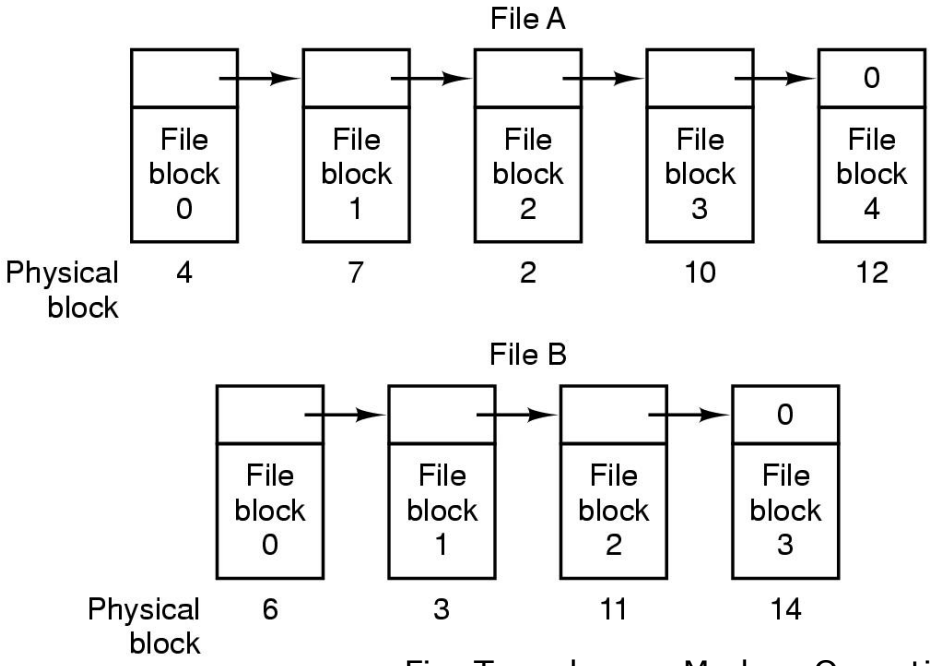


Fig. Tanenbaum, Modern Operating Systems

- Need to maintain 1 number per file (first address).

- Get block n?
- Less space available per block.

# Linked List allocation using FAT

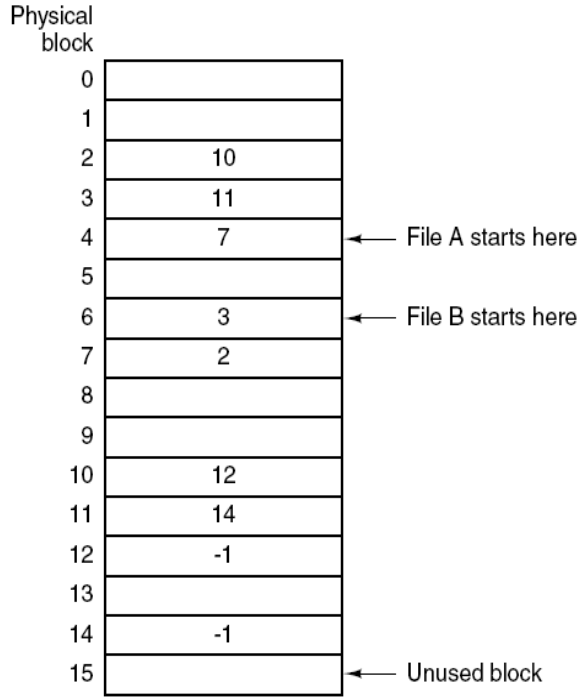


Fig. Tanenbaum, Modern Operating Systems

Disk: 40 GB
Block size: 1 KB
Table entry: 3 B

How much memory?

40 x 1024 x 1024 blocks * 3 bytes/block
120 MB

- When loaded in memory, disk blocks used only for data.
- Faster random access.

- Need to keep the table in memory.

# I-nodes

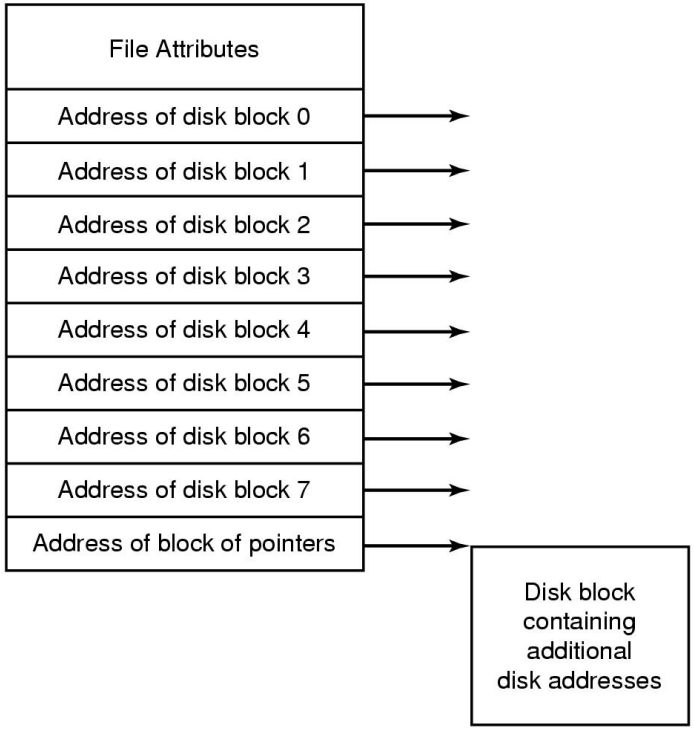


Fig. Tanenbaum, Modern Operating Systems

- If loading I-nodes only for opened files → Less memory needed.
- Memory needed proportional to the maximum number of open files.

- Complex if file grows beyond number of addresses.

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*How do we know what portions of a file systems are free?*

# Keeping track of free blocks

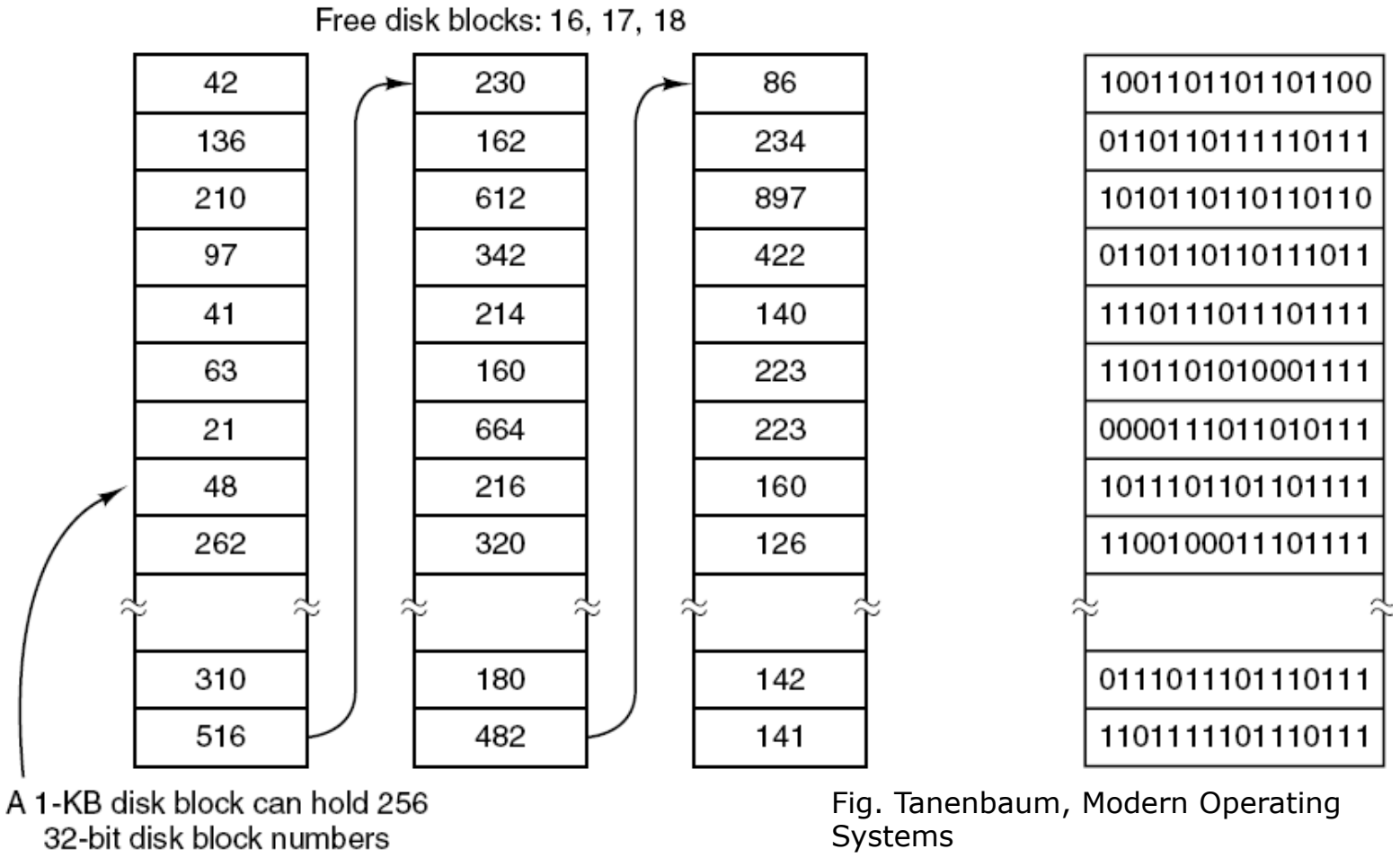



Fig. Tanenbaum, Modern Operating Systems

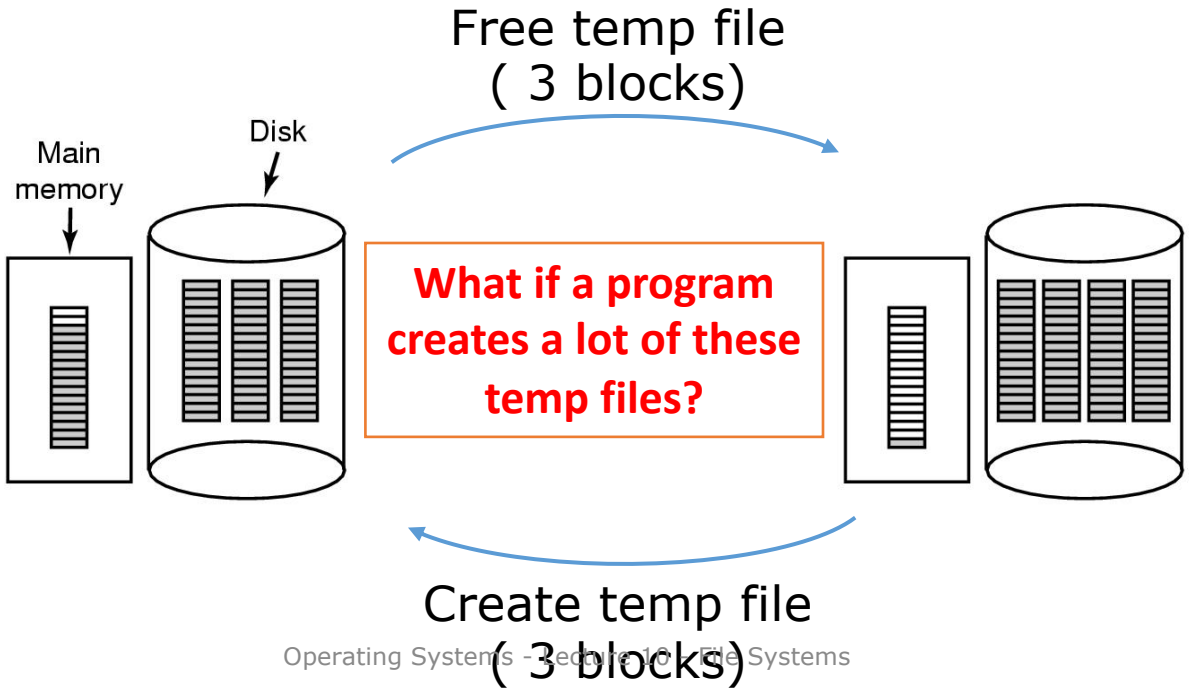
Linked List

bitmap

# Keeping track of free blocks

- Designing the right way of keeping free blocks is not trivial…

Linked List. Keep only 1 block of pointers to free blocks in memory, others are stored
- Run out of free blocks? Read the following one from disk
- New free blocks? Add them to block in memory, if full → store it.



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*How do we share and protect files among different users?*

# Protection

- File owner/creator should be able to control:
  - what can be done
  - by whom

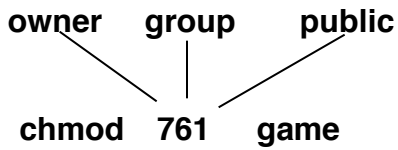
- Types of access
  - **Read**
  - **Write**
  - **Execute**
  - **Append**
  - **Delete**
  - **List**

# Access Lists and Groups

- Mode of access: read, write, execute
- Three classes of users on Unix / Linux

| | | | RWX |
|---|---|---|---|
| a) **owner access** | 7 | ⇒ | 1 1 1 |
| b) **group access** | 6 | ⇒ | RWX 1 1 0 |
| c) **public access** | 1 | ⇒ | RWX 0 0 1 |

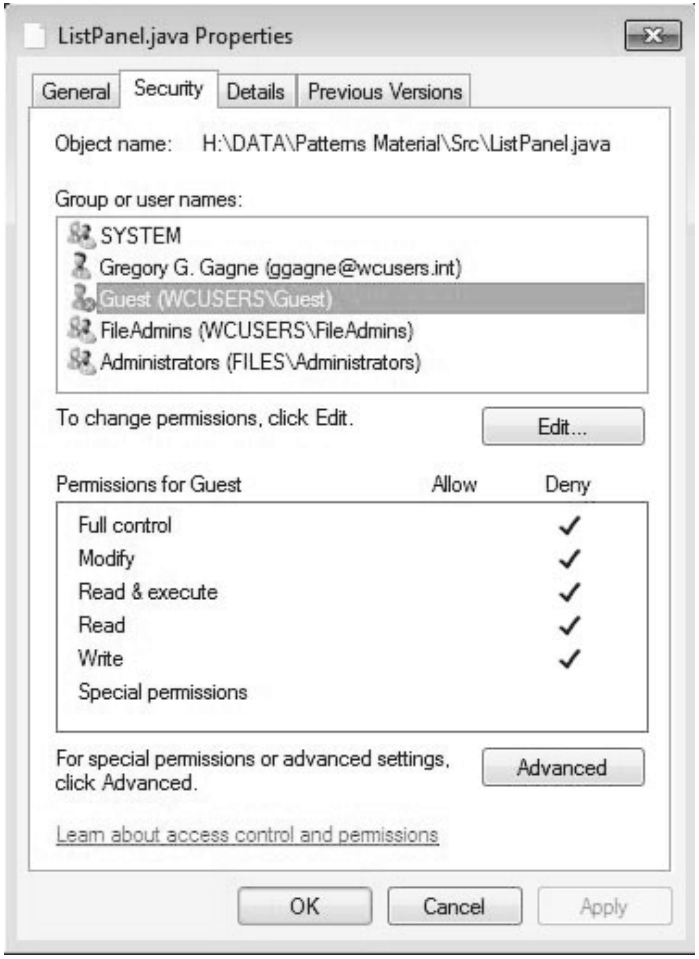
- Ask manager to create a group (unique name), say G, and add some users to the group.
- For a particular file (say *game*) or subdirectory, define an appropriate access.




Attach a group to a file

```
chgrp      G      game
```

# Windows 7 Access-Control List Management



# A Sample UNIX Directory Listing

| | | | | | |
|---|---|---|---|---|---|
| -rw-rw-r-- | 1 pbg | staff | 31200 | Sep 3 08:30 | intro.ps |
| drwx------ | 5 pbg | staff | 512 | Jul 8 09.33 | private/ |
| drwxrwxr-x | 2 pbg | staff | 512 | Jul 8 09:35 | doc/ |
| drwxrwx--- | 2 pbg | student | 512 | Aug 3 14:13 | student-proj/ |
| -rw-r--r-- | 1 pbg | staff | 9423 | Feb 24 2003 | program.c |
| -rwxr-xr-x | 1 pbg | staff | 20471 | Feb 24 2003 | program |
| drwx--x--x | 4 pbg | faculty | 512 | Jul 31 10:31 | lib/ |
| drwx------ | 3 pbg | staff | 1024 | Aug 29 06:52 | mail/ |
| drwxrwxrwx | 3 pbg | staff | 512 | Jul 8 09:35 | test/ |

# Thank you for your attention!

Please evaluate the lecture!
**https://forms.gle/Y5UQxvq4zXmo2Yf39**