COP 4610

Operating System Principles

File System Interface

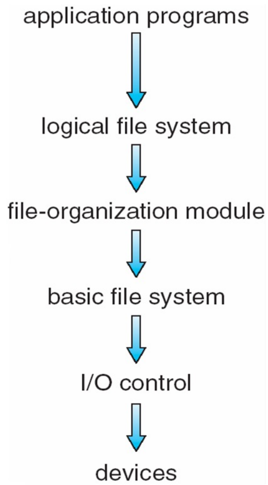
1

File-System Structure

- File structure
  - Logical storage unit
  - Collection of related information
- **File system** resides on secondary storage (disks)
  - Provided user interface to storage, mapping logical to physical
  - Provides efficient and convenient access to disk by allowing data to be stored, located retrieved easily
- **File control block** – storage structure consisting of information about a file
- File system organized into layers

2

Layered File System



3

File System Layers

- **Device drivers** manage I/O devices at the I/O control layer
  - Given commands like "read drive 1, cylinder 72, track 2, sector 10, into memory location 1060" outputs low-level hardware specific commands to hardware controller

4

File System Layers

- **Basic file system** given command like “retrieve block 123” translates to device driver
  - Also manages memory buffers and caches (allocation, freeing, replacement)
    - Buffers hold data in transit
    - Caches hold frequently used data

5

File System Layers

- **File organization module** understands files, logical address, and physical blocks
  - Translates logical block # to physical block #
  - Manages free space, disk allocation
  - Sits above the file system
  - “Understands” both sides

6

File System Layers (Cont.)

- **Logical file system** manages metadata information
  - Translates file name into file number, file handle, location
    - **File control blocks**
  - Directory management
  - Protection

File System Layers (Cont.)

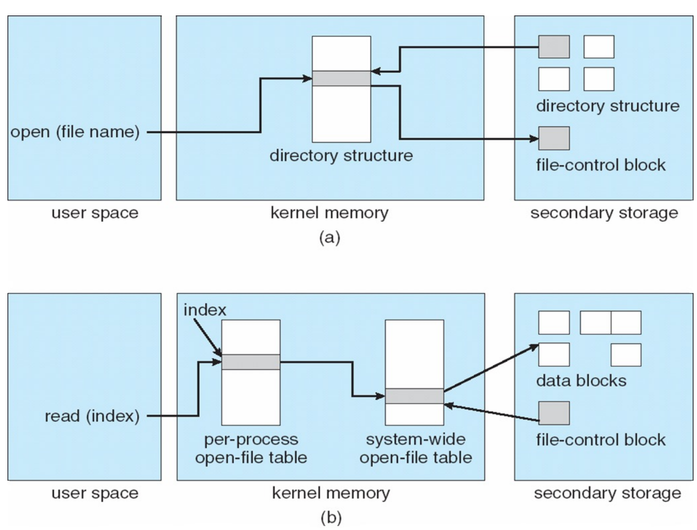
- Many file systems, sometimes many within an operating system
  - Each with its own format (CD-ROM is ISO 9660; Unix has **UFS**, FFS; Windows has FAT, FAT32, NTFS as well as floppy, CD, DVD Blu-ray, Linux has more than 40 types, with **extended file system** such as ext2/ext3/ext4 leading; plus distributed file systems, etc.)
  - May newer ones designed for performance, data types, applications, etc.: ZFS, GoogleFS, Oracle ASM, FUSE

A Typical File Control Block

file permissions
file dates (create, access, write)
file owner, group, ACL
file size
file data blocks or pointers to file data blocks

9

In-Memory File System Structures



10

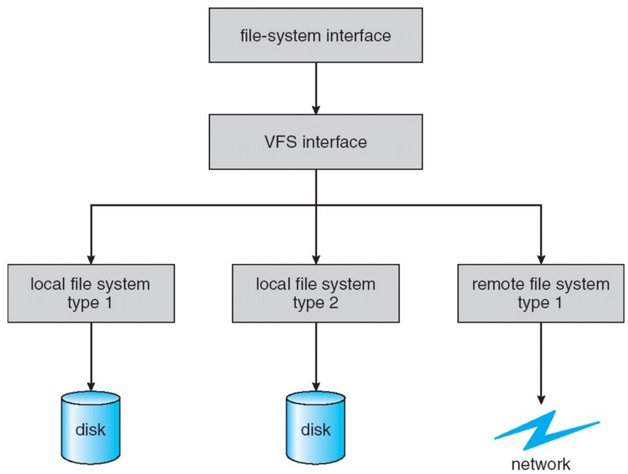
Partitions and Mounting

- Partition can be a volume containing a file system ("cooked") or **raw** – just a sequence of blocks with no file system
- Boot block can point to boot volume or boot loader set of blocks that contain enough code to know how to load the kernel from the file system
  - Or a boot management program for multi-os booting
- **Root partition** contains the OS, other partitions can hold other Oses, other file systems, or be raw
  - Mounted at boot time
  - Other partitions can mount automatically or manually
- At mount time, file system consistency checked
  - Is all metadata correct?
    - If not, fix it, try again
    - If yes, add to mount table, allow access

Virtual File Systems

- Virtual File Systems (VFS) on Unix provide an object-oriented way of implementing file systems
- VFS allows the same system call interface (the API) to be used for different types of file systems
  - Separates file-system generic operations from implementation details
  - Implementation can be one of many file systems types, or network file system
    - Implements vnodes which hold inodes or network file details
  - Then dispatches operation to appropriate file system implementation routines
- The API is to the VFS interface, rather than any specific type of file system

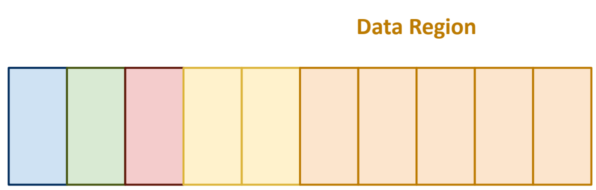
Schematic View of Virtual File System



13

File Systems Overview

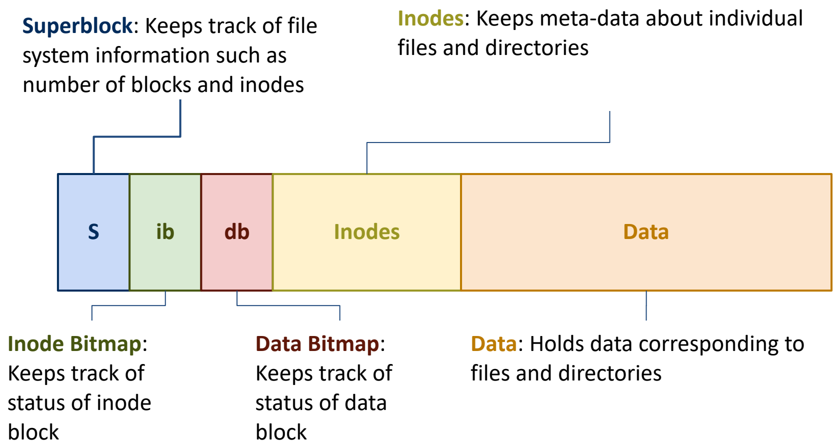
We need to use **data structures** to organize the data on disk:



- Divide disk into fixed-sized **blocks** (usually **4**KB)
- Use portion of disk to store **metadata**
- Use another portion to store **allocation structures**
- Use final portion to store **filesystem information**

14

File System Organization



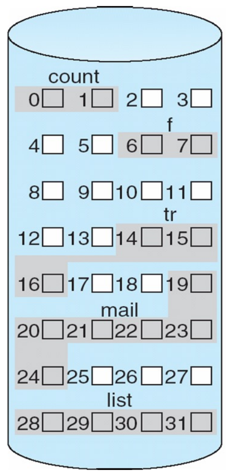
15

Allocation Methods - Contiguous

- An allocation method refers to how disk blocks are allocated for files:
- **Contiguous allocation** – each file occupies set of contiguous blocks
  - Best performance in most cases
  - Simple – only starting location (block #) and length (number of blocks) are required
  - Problems include finding space for file, knowing file size, external fragmentation, need for **compaction off-line** (**downtime**) or **on-line**

16

Contiguous Allocation



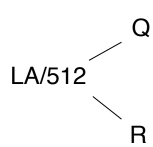
directory

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

17

Contiguous Allocation

- Mapping from logical to physical



18

Extent-Based Systems

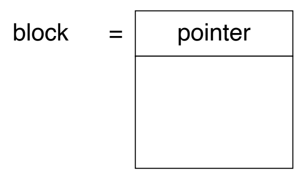
- Some file systems (i.e., Veritas File System) use a modified contiguous allocation scheme
- Extent-based file systems allocate disk blocks in extents
- An **extent** is a contiguous group of blocks
  - Extents are allocated for file allocation
  - A file consists of one or more extents

Allocation Methods - Linked

- **Linked allocation** – each file a linked list of blocks
  - File ends at nil pointer
  - No external fragmentation
  - Each block contains pointer to next block
  - Free space management system called when new block needed
  - Improve efficiency by clustering blocks
  - Reliability can be a problem
  - Locating a block can take many I/Os and disk seeks
- **FAT (File Allocation Table)** variation
  - Beginning of volume has table, indexed by block number
  - Much like a linked list, but faster on disk and cacheable
  - New block allocation simple

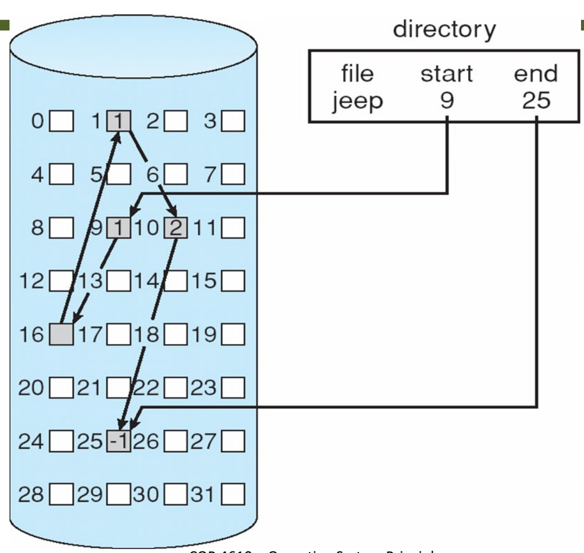
Linked Allocation

- Each file is a linked list of disk blocks: blocks may be scattered anywhere on the disk



21

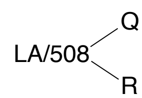
Linked Allocation



22

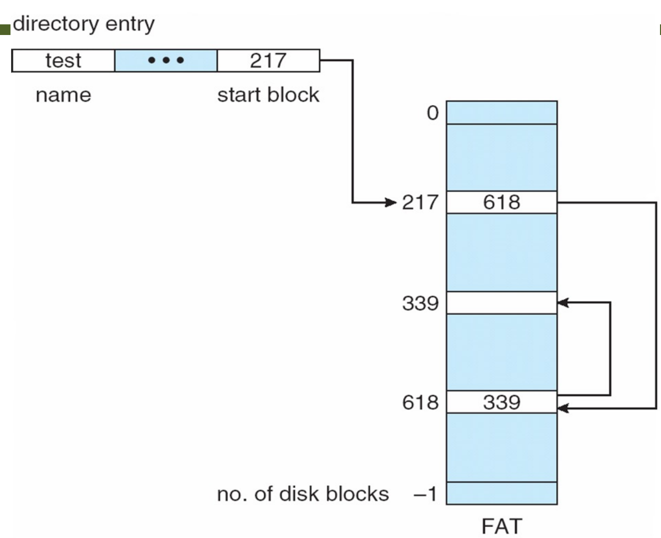
Linked Allocation

- Mapping (Pointer size = 4 bytes)



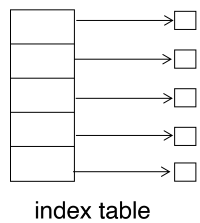
Block to be accessed is the Qth block in the linked chain of blocks representing the file.
Displacement into block = R + 4 (if pointer at beginning of block)

File-Allocation Table

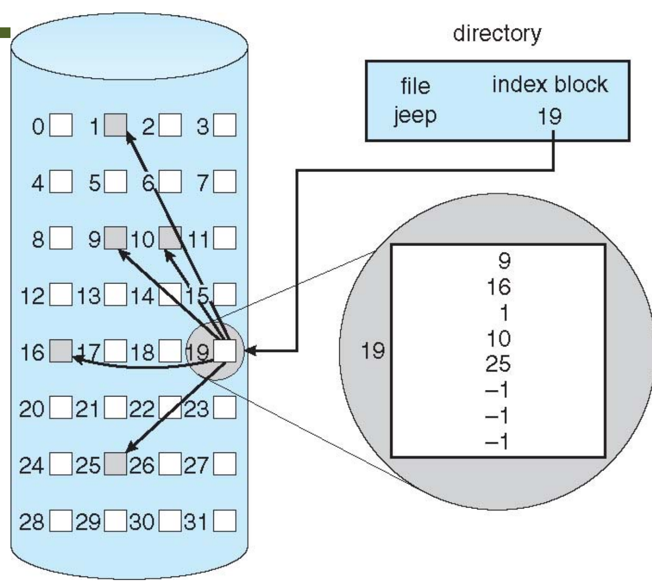


Allocation Methods - Indexed

- **Indexed allocation**
  - Each file has its own **index block**(s) of pointers to its data blocks
- Logical view



Example of Indexed Allocation



Indexed Allocation (Cont.)

- Need index table
- Access: index block + data block
- Reliability?
- No external fragmentation
- "Waste" of space? (at least 1 block per file)
- Maximum file size?
  - block size of 512 bytes
  - each pointer = 1 byte
  - size = 256KB
  - larger files: linked list or hierarchical index tables

Indexed Allocation (Hierarchical)

- Two-level index (4K blocks could store 1,024 four-byte pointers in outer index -> 1,048,567 data blocks and file size of up to 4GB)

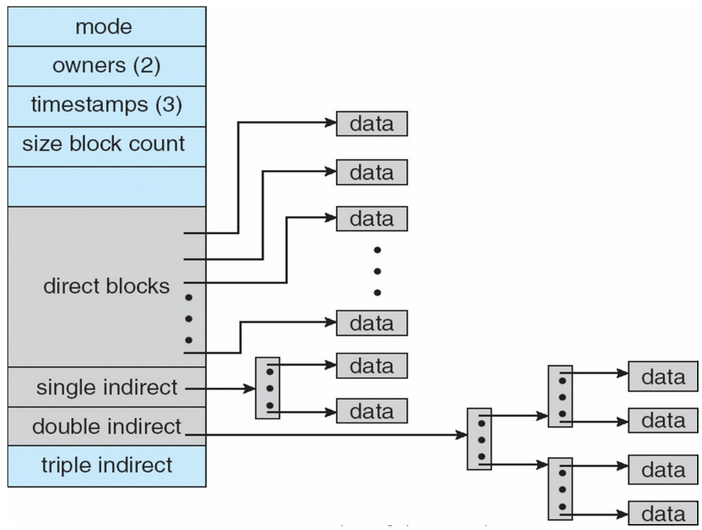
Q_1 = displacement into outer-index
R_1 is used as follows:

LA / (512 x 512) → Q_1, R_1

Q_2 = displacement into block of index table
R_2 displacement into block of file:

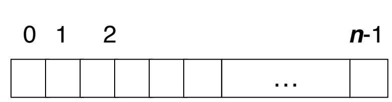
R_1 / 512 → Q_2, R_2

Combined Scheme: UNIX UFS
(4K bytes per block, 32-bit addresses)



Free-Space Management

- File system maintains **free-space list** to track available blocks/clusters
  - (Using term "block" for simplicity)
- **Bit vector** or **bit map** (*n* blocks)



bit[*i*] = { 1 ⇒ block[*i*] free; 0 ⇒ block[*i*] occupied }

Block number calculation

(number of bits per word) * (number of 0-value words) + offset of first 1 bit

CPUs have instructions to return offset within word of first "1" bit

Free-Space Management (Cont.)

- Bit map requires extra space
  - Example:

    block size = 4KB = 2^{12} bytes

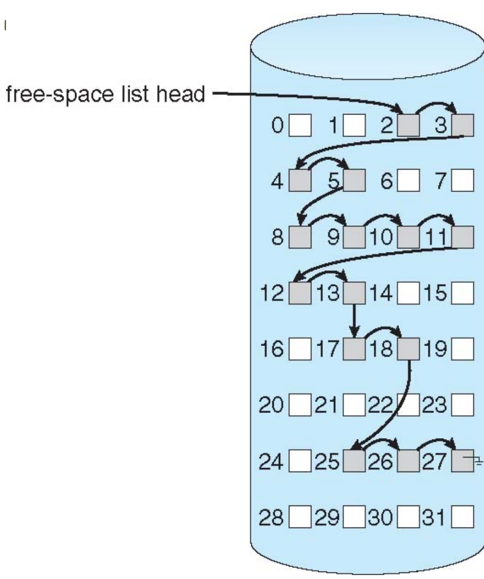
    disk size = 2^{40} bytes (1 terabyte)

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

    if clusters of 4 blocks -> 64MB of memory
- Easy to get contiguous files
- Linked list (free list)
  - Cannot get contiguous space easily
  - No waste of space
  - No need to traverse the entire list (if # free blocks recorded)

31

Linked Free Space List on Disk



- Linked list (free list)
  - Cannot get contiguous space easily
  - No waste of space
  - No need to traverse the entire list (if # free blocks recorded)

32

Free-Space Management (Cont.)

- Grouping
  - Modify linked list to store address of next *n-1* free blocks in first free block, plus a pointer to next block that contains free-block-pointers (like this one)
- Counting
  - Because space is frequently contiguously used and freed, with contiguous-allocation allocation, extents, or clustering
    - Keep address of first free block and count of following free blocks
    - Free space list then has entries containing addresses and counts

Example Part 1

- Consider a **multi-indexed file system** with a **32**-bit block address, **4**KB block size, and an inode structure with **4** direct pointers and one indirect pointer:
  - What is the largest **disk** this file system can use?

Largest Disk = *# of Blocks * Block Size*
= 2^{32} * 4KB
= $2^{32} * 2^{12}$
= 2^{44}
= **16TB**

Example Part 2

- What is the largest **file** that this file system could store?

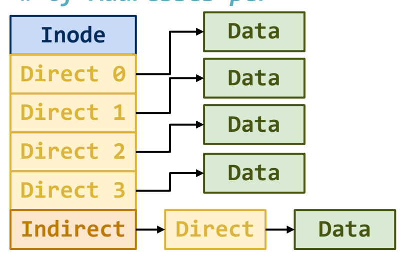
```
largest file = direct blocks + indirect blocks
direct = # of Direct Blocks * Block Size
```

$= 4 * 4KB$
$= 2^2 * 2^{12}$
$= 2^{14}$
$=$ **16KB**

indirect = *# of Indirect Blocks * # of Addresses per Block * Block Size*

$= 1 * 4KB / 4bytes * 4KB$
$= 1 * 2^{12} / 2^2 * 2^{12}$
$= 2^{22}$
$=$ **4MB**

largest file = **4MB + 16KB**



Example Part 3

- Assuming a disk of **128GB**, how big is the **free block bitmap**?

We need an entry (bit) in our free block bitmap for each block

Free Block Bitmap Size = *Disk Size / Block Size / 8 Bits*

$= 128GB / 4KB / 8$
$= 2^{37} / 2^{12} / 2^3$
$= 2^{22}$
$=$ **4MB**

Free Block Bitmap Size = ***2^{37} bytes x block/2^{12} bytes x 1 byte/2^3 blocks***