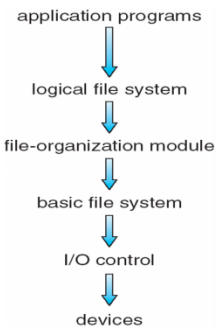
Operating System

Unit 2

Part III - File System Implementation

File System Structure

- Disks provide most of the secondary storage on which file systems are maintained. Two characteristics make them convenient for this purpose:
  1. A disk can be rewritten in place; it is possible to read a block from the disk, modify the block, and write it back into the same place.
  2. A disk can access directly any block of information it contains. Thus, it is simple to access any file either sequentially or randomly, and switching from one file to another requires only moving the read–write heads and waiting for the disk to rotate.
- To improve I/O efficiency, I/O transfers between memory and disk are performed in units of **blocks**. Each block has one or more sectors. Depending on the disk drive, sector size varies from 32 bytes to 4,096 bytes; the usual size is 512 bytes.
- **File systems** provide efficient and convenient access to the disk by allowing data to be stored, located, and retrieved easily. A file system poses two quite different design problems.
- The first problem is defining how the file system should look to the user. This task involves defining a file and its attributes, the operations allowed on a file and the directory structure for organizing files.
- The second problem is creating algorithms and data structures to map the logical file system onto the physical secondary-storage devices.
- The file system itself is generally composed of many different levels. Each level in the design uses the features of lower levels to create new features for use by higher levels.
- The **I/O control** level consists of device drivers and interrupts handlers to transfer information between the main memory and the disk system. A device driver can be thought of as a translator.
- The **basic file system** needs only to issue generic commands to the appropriate device driver to read and write physical blocks on the disk.
- The **file-organization module** knows about files and their logical blocks, as well as physical blocks. By knowing the type of file allocation used and the location of the file, the file-organization module can translate logical block addresses to physical block addresses for the basic file system to transfer.
- The **logical file system** manages metadata information. Metadata includes all of the file-system structure except the actual data (or contents of the files).



File-System Implementation

- Several on-disk and in-memory structures are used to implement a file system. These structures vary depending on the operating system and the file system, but some general principles apply.
- On disk, the file system may contain information about how to boot an operating system stored there, the total number of blocks, the number and location of free blocks, the directory structure, and individual files.
- A **boot control block** (per volume) can contain information needed by the system to boot an operating system from that volume. If the disk does not contain an operating system, this block can be empty. It is typically the first block of a volume. In UFS, it is called the **boot block**. In NTFS, it is the **partition boot sector**.
- A **volume control block** (per volume) contains volume (or partition) details, such as the number of blocks in the partition, the size of the blocks, a free-block count and free-block pointers, and a free-FCB count and FCB pointers. In UFS, this is called a **superblock**. In NTFS, it is stored in the **master file table**.
- A directory structure (per file system) is used to organize the files. In UFS, this includes file names and associated inode numbers. In NTFS, it is stored in the master file table.
- A per-file FCB contains many details about the file. It has a unique identifier number to allow association with a directory entry. In NTFS, this information is actually stored within the master file table, which uses a relational database structure, with a row per file.
- The in-memory information is used for both file-system management and performance improvement via caching. The data are loaded at mount time, updated during file-system operations, and discarded at dismount.
- Several types of structures may be included.
    a. An in-memory **mount table** contains information about each mounted volume.
    b. An in-memory directory-structure cache holds the directory information of recently accessed directories. (For directories at which volumes are mounted, it can contain a pointer to the volume table.)
    c. The **system-wide open-file table** contains a copy of the FCB of each open file, as well as other information.
    d. The **per-process open-file table** contains a pointer to the appropriate entry in the system-wide open-file table, as well as other information.
    e. Buffers hold file-system blocks when they are being read from disk or written to disk.

Partitions and Mounting

- The layout of a disk can have many variations, depending on the operating system. A disk can be sliced into multiple partitions, or a volume can span multiple partitions on multiple disks.
- Each partition can be either “raw,” containing no file system, or “cooked,” containing a file system. **Raw disk** is used where no file system is appropriate.
- Boot information can be stored in a separate partition, as it has its own format, because at boot time the system does not have the file-system code loaded and therefore cannot interpret the file-system format.

- Rather, boot information is usually a sequential series of blocks, loaded as an image into memory. Execution of the image starts at a predefined location, such as the first byte.
- This **boot loader** in turn knows enough about the file-system structure to be able to find and load the kernel and start it executing.
- The **root partition**, which contains the operating-system kernel and sometimes other system files, is mounted at boot time. Other volumes can be automatically mounted at boot or manually mounted later, depending on the operating system.
- As part of a successful mount operation, the operating system verifies that the device contains a valid file system. It does so by asking the device driver to read the device directory and verifying that the directory has the expected format.
- If the format is invalid, the partition must have its consistency checked and possibly corrected, either with or without user intervention.
- Finally, the operating system notes in its in-memory mount table that a file system is mounted, along with the type of the file system. The details of this function depend on the operating system.

Directory Implementation

The selection of directory-allocation and directory-management algorithms significantly affects the efficiency, performance, and reliability of the file system.

Linear List

- The simplest method of implementing a directory is to use a linear list of file names with pointers to the data blocks. This method is simple to program but time-consuming to execute.
- To create a new file, we must first search the directory to be sure that no existing file has the same name. Then, we add a new entry at the end of the directory.
- To delete a file, we search the directory for the named file and then release the space allocated to it.
- The real disadvantage of a linear list of directory entries is that finding a file requires a linear search. Directory information is used frequently, and users will notice if access to it is slow.
- In fact, many operating systems implement a software cache to store the most recently used directory information.

Hash Table

- Another data structure used for a file directory is a hash table. Here, a linear list stores the directory entries, but a hash data structure is also used.
- The hash table takes a value computed from the file name and returns a pointer to the filename in the linear list. Therefore, it can greatly decrease the directory search time.
- Insertion and deletion are also fairly straightforward, although some provision must be made for collisions—situations in which two file names hash to the same location.

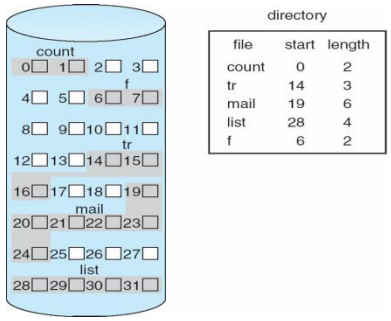
Allocation Methods

- The direct-access nature of disks gives us flexibility in the implementation of files.
- In almost every case, many files are stored on the same disk.

- The main problem is how to allocate space to these files so that disk space is utilized effectively and files can be accessed quickly.
- Three major methods of allocating disk space are in wide use: contiguous, linked, and indexed.

Contiguous Allocation

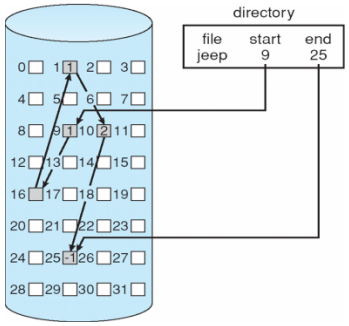
- Contiguous allocation requires that each file occupy a set of contiguous blocks on the disk. Disk addresses define a linear ordering on the disk.
- Contiguous allocation of a file is defined by the disk address and length (in block units) of the first block.
- If the file is *n* blocks long and starts at location *b*, then it occupies blocks *b*, *b* + 1, *b* + 2, ..., *b* + *n* − 1. The directory entry for each file indicates the address of the starting block and the length of the area allocated for this file
- Accessing a file that has been allocated contiguously is easy. For sequential access, the file system remembers the disk address of the last block referenced and, when necessary, reads the next block. For direct access to block *i* of a file that starts at block *b*, we can immediately access block *b* + *i*.
- Thus, both sequential and direct access can be supported by contiguous allocation.



Contiguous allocation of disk space.

Linked Allocation

- Linked allocation solves all problems of contiguous allocation. With linked allocation, each file is a linked list of disk blocks; the disk blocks may be scattered anywhere on the disk.
- The directory contains a pointer to the first and last blocks of the file. To create a new file, we simply create a new entry in the directory.
- With linked allocation, each directory entry has a pointer to the first disk block of the file. This pointer is initialized to null (the end-of-list pointer value) to signify an empty file.



Linked allocation of disk space.

Indexed Allocation

- In the absence of a FAT, linked allocation cannot support efficient direct access, since the pointers to the blocks are scattered with the blocks themselves all over the disk and must be retrieved in order.
- **Indexed allocation** solves this problem by bringing all the pointers together into one location: the **index block**.
- Each file has its own index block, which is an array of disk-block addresses. The i^{th} entry in the index block points to the i^{th} block of the file. The directory contains the address of the index block.
- To find and read the i^{th} block, we use the pointer in the i^{th} index-block entry. When the file is created, all pointers in the index block are set to null.
- When the i^{th} block is first written, a block is obtained from the free-space manager, and its address is put in the i^{th} index-block entry.
- Indexed allocation supports direct access, without suffering from external fragmentation, because any free block on the disk can satisfy a request for more space.

Free-Space Management

- Since disk space is limited, we need to reuse the space from deleted files for new files, if possible. To keep track of free disk space, the system maintains a **free-space list**.
- The free-space list records all free disk blocks—those not allocated to some file or directory. To create a file, we search the free-space list for the required amount of space and allocate that space to the new file.
- This space is then removed from the free-space list. When a file is deleted, its disk space is added to the free-space list.

Bit Vector

- Frequently, the free-space list is implemented as a **bit map** or **bit vector**. Each block is represented by 1 bit. If the block is free, the bit is 1; if the block is allocated, the bit is 0.
- For example, consider a disk where blocks 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 17, 18, 25, 26, and 27 are free and the rest of the blocks are allocated. The free-space bit map would be 001111001111110001100000011100000 ...
- The main advantage of this approach is its relative simplicity and its efficiency in finding the first free block or *n* consecutive free blocks on the disk.

Linked List

- Another approach to free-space management is to link together all the free disk blocks, keeping a pointer to the first free block in a special location on the disk and caching it in memory.
- This first block contains a pointer to the next free disk block, and so on.

Grouping

- A modification of the free-list approach stores the addresses of *n* free blocks in the first free block. The first $n-1$ of these blocks are actually free.
- The last block contains the addresses of another *n* free blocks and so on. The addresses of a large number of free blocks can now be found quickly, unlike the situation when the standard linked-list approach is used.

Counting

- Another approach takes advantage of the fact that, generally, several contiguous blocks may be allocated or freed simultaneously, particularly when space is allocated with the contiguous-allocation algorithm or through clustering.
- Thus, rather than keeping a list of *n* free disk addresses, we can keep the address of the first free block and the number (*n*) of free contiguous blocks that follow the first block.

Efficiency and Performance

Disks tend to represent a major bottleneck in system performance, since they are the slowest main computer component.

Efficiency

- The efficient use of disk space depends heavily on the disk-allocation and directory algorithms in use. For instance, UNIX inodes are preallocated on a volume. Even an empty disk has a percentage of its space lost to inodes.
- However, by preallocating the inodes and spreading them across the volume, we improve the file system's performance.
- This improved performance results from the UNIX allocation and free-space algorithms, which try to keep a file's data blocks near that file's inode block to reduce seek time.

Performance

- Even after the basic file-system algorithms have been selected, we can still improve performance in several ways.
- Some systems maintain a separate section of main memory for a **buffer cache**, where blocks are kept under the assumption that they will be used again shortly. Other systems cache file data using a **page cache**.
- The page cache uses virtual memory techniques to cache file data as pages rather than as file-system-oriented blocks. Caching file data using virtual addresses is far more efficient than caching through physical disk blocks, as accesses interface with virtual memory rather than the file system.

Recovery

- Files and directories are kept both in main memory and on disk, and care must be taken to ensure that a system failure does not result in loss of data or in data inconsistency.
- A system crash can cause inconsistencies among on-disk file-system data structures, such as directory structures, free-block pointers, and free FCB pointers.
- Many file systems apply changes to these structures in place. A typical operation, such as creating a file, can involve many structural changes within the file system on the disk.

Consistency Checking

- Whatever the cause of corruption, a file system must first detect the problems and then correct them. For detection, a scan of all the metadata on each file system can confirm or deny the consistency of the system.
- Unfortunately, this scan can take minutes or hours and should occur every time the system boots. The **consistency checker**—a systems program such as fsck in UNIX— compares the data in the directory structure with the data blocks on disk and tries to fix any inconsistencies it finds.
- The allocation and free-space management algorithms dictate what types of problems the checker can find and how successful it will be in fixing them.

Backup and Restore

- System programs can be used to **back up** data from disk to another storage device, such as a magnetic tape or other hard disk.
- Recovery from the loss of an individual file, or of an entire disk, may then be a matter of **restoring** the data from backup.
- If the backup program knows when the last backup of a file was done, and the file's last write date in the directory indicates that the file has not changed since that date, then the file does not need to be copied again.

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