File Management

Tanenbaum, Chapter 4

COMP3231

Operating Systems

Outline

- Files and directories from the programmer (and user) perspective
- Files and directory internals – the operating system perspective

Files

- Named repository for data
  - Potentially large amount of data
    - Beyond that available in memory
  - File lifetime is independent of process lifetime
  - Used to share data between processes
- Convenience
  - Input to applications is by means of a file
  - Output is saved in a file for long-term storage

File Management

- File management system is considered part of the operating system
  - Manages a trusted, shared resource
  - Bridges the gap between:
    - low-level disk organisation (an array of blocks),
    - and the programmer's views (a stream or collection of records)
- Also includes tools outside the kernel
  - E.g. formatting, recovery, defrag, consistency, and backup utilities.

Objectives for a File Management System

- Provide a convenient naming system for files
- Provide uniform I/O support for a variety of storage device types
  - Same file abstraction for disk, network, tape….
- Provide a standardized set of I/O interface routines
  - Storage device drivers interchangeable
- Ensure that the data in the file is valid
- Optimise performance
- Minimize or eliminate the potential for lost or destroyed data
- Provide I/O support and access control for multiple users
- Support system administration (e.g., backups)

File Names

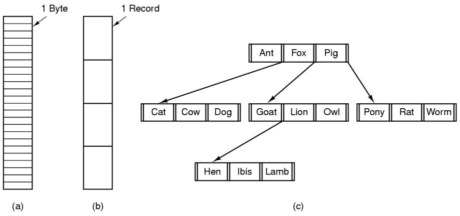
- File system must provide a convenient naming scheme
  - Textual Names
  - May have restrictions
    - Only certain characters
      - E.g. no '/' characters
    - Limited length
    - Only certain format
      - E.g DOS, 8 + 3
  - Case (in)sensitive
  - Names may obey conventions (.c files or C files)
    - Interpreted by tools (UNIX)
    - Interpreted by operating system (Windows)

File Naming

Extension	Meaning
file.bak	Backup file
file.c	C source program
file.gif	Compuserve Graphical Interchange Format image
file.hlp	Help file
file.html	World Wide Web HyperText Markup Language document
file.jpg	Still picture encoded with the JPEG standard
file.mp3	Music encoded in MPEG layer 3 audio format
file.mpg	Movie encoded with the MPEG standard
file.o	Object file (compiler output, not yet linked)
file.pdf	Portable Document Format file
file.ps	PostScript file
file.tex	Input for the TEX formatting program
file.txt	General text file
file.zip	Compressed archive

Typical file extensions.

File Structure



- Three kinds of files
  - byte sequence
  - record sequence
  - key-based, tree structured
    - e.g. IBM's indexed sequential access method (ISAM)

File Structure

- Stream of Bytes
  - OS considers a file to be unstructured
  - Simplifies file management for the OS
  - Applications can impose their own structure
  - Used by UNIX, Windows, most modern OSes
- Records
  - Collection of bytes treated as a unit
    - Example: employee record
  - Operations at the level of records (read_rec, write_rec)
  - File is a collection of similar records
  - OS can optimise operations on records

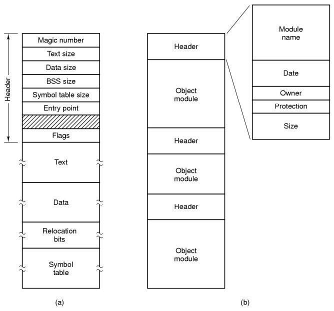
File Structure

- Tree of Records
  - Records of variable length
  - Each has an associated key
  - Record retrieval based on key
  - Used on some data processing systems (mainframes)
    - Mostly incorporated into modern databases

File Types

- Regular files
- Directories
- Device Files
  - May be divided into
    - Character Devices – stream of bytes
    - Block Devices
- Some systems distinguish between regular file types
  - ASCII text files, binary files
- At minimum, all systems recognise their own executable file format
  - May use a *magic number*

File Types



(a) An executable file (b) An archive (libxyz.a)

File Access Types

- Sequential access
  - read all bytes/records from the beginning
  - cannot jump around, could rewind or back up
  - convenient when medium was mag tape
- Random access
  - bytes/records read in any order
  - essential for data base systems
  - read can be …
    - move file pointer (seek), then read or
      - lseek(location,…);read(…)
    - each read specifies the file pointer
      - read(location,…)

File Attributes

Attribute	Meaning
Protection	Who can access the file and in what way
Password	Password needed to access the file
Creator	ID of the person who created the file
Owner	Current owner
Read-only flag	0 for read/write; 1 for read only
Hidden flag	0 for normal; 1 for do not display in listings
System flag	0 for normal files; 1 for system file
Archive flag	0 for has been backed up; 1 for needs to be backed up
ASCII/binary flag	0 for ASCII file; 1 for binary file
Random access flag	0 for sequential access only; 1 for random access
Temporary flag	0 for normal; 1 for delete file on process exit
Lock flags	0 for unlocked; nonzero for locked
Record length	Number of bytes in a record
Key position	Offset of the key within each record
Key length	Number of bytes in the key field
Creation time	Date and time the file was created
Time of last access	Date and time the file was last accessed
Time of last change	Date and time the file has last changed
Current size	Number of bytes in the file
Maximum size	Number of bytes the file may grow to

Possible file attributes

Typical File Operations

1. Create
2. Delete
3. Open
4. Close
5. Read
6. Write
7. Append
8. Seek
9. Get attributes
10. Set Attributes
11. Rename

An Example Program Using File System Calls (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 */
```

An Example Program Using File System Calls (2/2)

```
     /* 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 */
}
```

File Organisation and Access

Programmer's Perspective

- Given an operating system supporting unstructured files that are a *stream-of-bytes,*
  how can one organise the contents of the files?

File Organisation and Access
Programmer's Perspective

- Performance considerations:
  - File system performance affects overall system performance
  - Organisation of the file system on disk affects performance
  - File organisation (data layout inside file) affects performance
    - indirectly determines access patterns
- Possible access patterns:
  - Read the whole file
  - Read individual blocks or records from a file
  - Read blocks or records preceding or following the current one
  - Retrieve a set of records
  - Write a whole file sequentially
  - Insert/delete/update records in a file
  - Update blocks in a file

Classic File Organisations

- There are many ways to organise a file's contents, here are just a few basic methods
  - Unstructured Stream (Pile)
  - Sequential Records
  - Indexed Sequential Records
  - Direct or Hashed Records

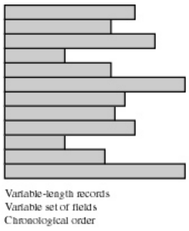
Criteria for File Organization

Things to consider when designing file layout

- Rapid access
  - Needed when accessing a single record
  - Not needed for batch mode
    - read from start to finish
- Ease of update
  - File on CD-ROM will not be updated, so this is not a concern
- Economy of storage
  - Should be minimum redundancy in the data
  - Redundancy can be used to speed access such as an index
- Simple maintenance
- Reliability

Unstructured Stream

- Data are collected in the order they arrive
- Purpose is to accumulate a mass of data and save it
- Records may have different fields
- No structure
- Record access is by exhaustive search

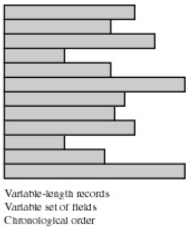


(a) Pile File

Figure 12.3 Common File Organizations

Unstructured Stream Performance

- Update
  - Same size record - okay
  - Variable size - poor
- Retrieval
  - Single record - poor
  - Subset – poor
  - Exhaustive - okay

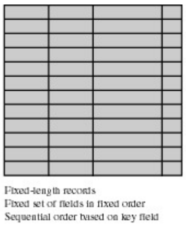


(a) Pile File

Figure 12.3 Common File Organizations

The Sequential File

- Fixed format used for records
- Records are the same length
- Field names and lengths are attributes of the file
- One field is the key field
  - Uniquely identifies the record
  - Records are stored in key sequence


Fixed-length records
Fixed set of fields in fixed order
Sequential order based on key field

(b) Sequential File

Figure 12.3 Common File Organizations

The Sequential File

- Update
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- Retrieval
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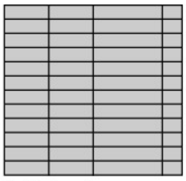
  - Subset – poor
  - Exhaustive - okay



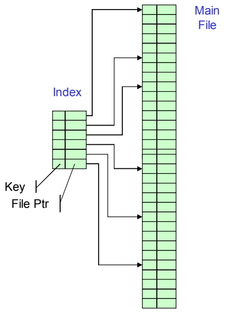
Fixed-length records
Fixed set of fields in fixed order
Sequential order based on key field

(b) Sequential File

Figure 12.3 Common File Organizations

Indexed Sequential File

- Index provides a lookup capability to quickly reach the vicinity of the desired record
  - Contains key field and a pointer to (location in) the main file
  - Indexed is searched to find highest key value that is equal or less than the desired key value
  - Search continues in the main file at the location indicated by the pointer



Comparison of sequential and indexed sequential lookup

- Example: a file contains 1 million records
- On average 500,000 accesses are required to find a record in a sequential file
- If an index contains 1000 entries, it will take on average 500 accesses to find the key, followed by 500 accesses in the main file. Now on average it is 1000 accesses

Indexed Sequential File

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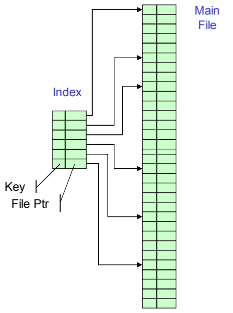
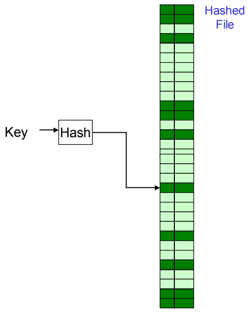
- Retrieval
  - Single record - good
  - Subset – poor
  - Exhaustive - okay



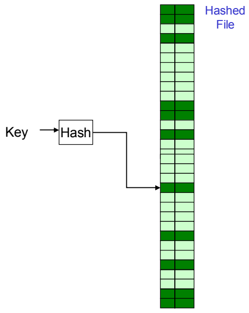
The Direct, or Hashed File

- Key field required for each record
- Key maps directly or via a hash mechanism to an address within the file
- Directly access a data record at a the known address
- Note: File is sparsely populated



The Direct, or Hashed File

- Update
  - Same size record - good
  - Variable size – No
    - Fixed sized records used
- Retrieval
  - Single record - excellent
  - Subset – poor
  - Exhaustive - poor

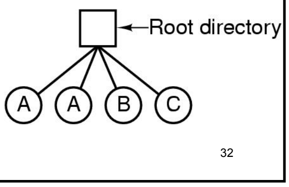


File Directories

- Contains information about files
  - – Attributes
  - – Location
  - – Ownership
- Directory itself is a file owned by the operating system
- Provides mapping between file names and the files themselves

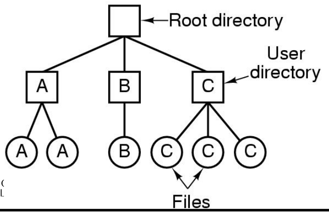
Simple Structure for a Directory

- List of entries, one for each file
- Sequential file with the name of the file serving as the key
- Provides no help in organising the files
- Forces user to be careful not to use the same name for two different files
- Large number of files inefficient to manage both from user and operating system perspective.



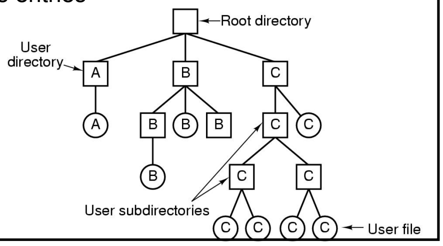
Two-level Scheme for a Directory

- One directory for each user and a master directory
- Master directory contains entry for each user
  - – Provides access control information
- Each user directory is a simple list of files for that user
- Still provides no help in structuring collections of files



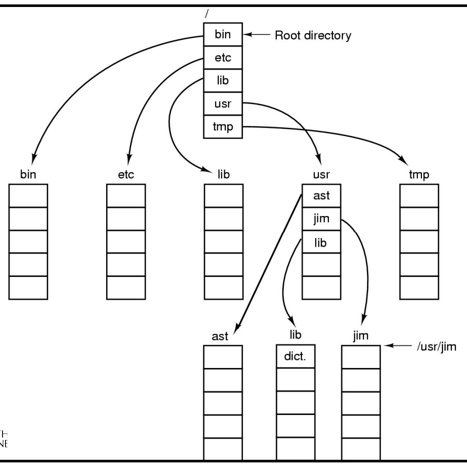
Hierarchical, or Tree-Structured Directory

- Master directory with user directories underneath it
- Each user directory may have subdirectories and files as entries



Hierarchical, or Tree-Structured Directory

- Files can be located by following a path from the root, or master, directory down various branches
  - – This is the *absolute* pathname for the file
- Can have several files with the same file name as long as they have unique path names
- Directories are generally smaller and thus more efficient to manage.



Current *Working Directory*

- Always specifying the absolute pathname for a file is tedious!
- Introduce the idea of a *working directory*
  - Files are referenced relative to the working directory
- Example: cwd = /home/kevine

  .profile = /home/kevine/.profile

Relative and Absolute Pathnames

- Absolute pathname
  - A path specified from the root of the file system to the file
- A *Relative* pathname
  - A pathname specified from the cwd
- Note: '.' (dot) and '..' (dotdot) refer to current and parent directory

Example: cwd = /home/kevine

```
../../etc/passwd
/etc/passwd
../kevine/../.././etc/passwd
```

Are all the same file

Typical Directory Operations

1. Create
2. Delete
3. Opendir
4. Closedir
5. Readdir
6. Rename
7. Link
8. Unlink

Nice properties of UNIX naming

- Simple, regular format
  - Names referring to different servers, objects, etc., have the same syntax.
    - Regular tools can be used where specialised tools would be otherwise be needed.
- Location independent
  - Objects can be distributed or migrated, and continue with the same names.

An example of a bad naming convention

- From, Rob Pike and Peter Weinberger, "The Hideous Name", Bell Labs TR

UCBVAX::SYS$DISK:[ROB.BIN]CAT_V.EXE;13

File Sharing

- In multiuser system, allow files to be shared among users
- Two issues
  - Access rights
  - Management of simultaneous access

Access Rights

- None
  - User may not know of the existence of the file
  - User is not allowed to read the user directory that includes the file
- Knowledge
  - User can only determine that the file exists and who its owner is

Access Rights

- Execution
  - The user can load and execute a program but cannot copy it
- Reading
  - The user can read the file for any purpose, including copying and execution
- Appending
  - The user can add data to the file but cannot modify or delete any of the file's contents

Access Rights

- Updating
  - The user can modify, deleted, and add to the file's data. This includes creating the file, rewriting it, and removing all or part of the data
- Changing protection
  - User can change access rights granted to other users
- Deletion
  - User can delete the file

Access Rights

- Owners
  - Has all rights previously listed
  - May grant rights to others using the following classes of users
    - Specific user
    - User groups
    - All for public files

Case Study: UNIX Access Permissions

```
total 1704
drwxr-x---    3 kevine   kevine       4096 Oct 14 08:13 .
drwxr-x---    3 kevine   kevine       4096 Oct 14 08:14 ..
drwxr-x---    2 kevine   kevine       4096 Oct 14 08:12 backup
-rw-r-----    1 kevine   kevine     141133 Oct 14 08:13 eniac3.jpg
-rw-r-----    1 kevine   kevine    1580544 Oct 14 08:13 wk11.ppt
```

- First letter: file type

  d for directories

  - for regular files)
- Three user categories

  user, ***g***roup, and ***o***ther

UNIX Access Permissions

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total 1704
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-rw-r-----    1 kevine   kevine    1580544 Oct 14 08:13 wk11.ppt
```

- Three access rights per category

  read, ***w***rite, and e***x***ecute

drwxrwxrwx

user group other

UNIX Access Permissions

```
total 1704
drwxr-x---    3 kevine   kevine       4096 Oct 14 08:13 .
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-rw-r-----    1 kevine   kevine    1580544 Oct 14 08:13 wk11.ppt
```

- Execute permission for directory?
  - Permission to access files in the directory
- To list a directory requires read permissions
- What about **`drwxr-x—x`**?

UNIX Access Permissions

- Shortcoming
  - The three user categories a rather coarse
- Problematic example
  - Joe owns file **`foo.bar`**
  - Joe wishes to keep his file private
    - Inaccessible to the general public
  - Joe wishes to give Bill read and write access
  - Joe wishes to give Peter read-only access
  - How????????

Simultaneous Access

- Most Oses provide mechanisms for users to manage concurrent access to files
  - Example: lockf(), flock() system calls
- Typically
  - User may lock entire file when it is to be updated
  - User may lock the individual records during the update
- Mutual exclusion and deadlock are issues for shared access