CSE 451: Operating Systems Winter 2009

Module 14
File Systems

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File systems

- The concept of a file system is simple
  - the implementation of the abstraction for secondary storage
    - abstraction = files
  - logical organization of files into directories
    - the directory hierarchy
  - sharing of data between processes, people and machines
    - access control, consistency, …

Files

- A file is a collection of data with some properties
  - contents, size, owner, last read/write time, protection …
- Files may also have types
  - understood by file system
    - device, directory, symbolic link
  - understood by other parts of OS or by runtime libraries
    - executable, dll, source code, object code, text file, …
- Type can be encoded in the file's name or contents
  - windows encodes type in name (and contents)
    - .com, .exe, .bat, .dll, .jpg, .mov, .mp3, …
  - old Mac OS stored the name of the creating program along with the file
  - unix does both as well
    - in content via magic numbers or initial characters (e.g., #!)

Basic operations

Unix

- create(name)
- open(name, mode)
- read(fd, buf, len)
- write(fd, buf, len)
- sync(fd)
- seek(fd, pos)
- close(fd)
- unlink(name)
- rename(old, new)

NT

- CreateFile(name, CREATE)
- CreateFile(name, OPEN)
- ReadFile(handle, …)
- WriteFile(handle, …)
- FlushFileBuffers(handle, …)
- SetFilePointer(handle, …)
- CloseHandle(handle, …)
- DeleteFile(name)
- CopyFile(name)
- MoveFile(name)

File access methods

- Some file systems provide different access methods that specify ways the application will access data
  - sequential access
    - read bytes one at a time, in order
  - direct access
    - random access given a block/byte #
  - record access
    - file is array of fixed- or variable-sized records
  - indexed access
    - FS contains an index to a particular field of each record in a file
    - apps can find a file based on value in that record (similar to DB)
- Why do we care about distinguishing sequential from direct access?
  - what might the FS do differently in these cases?

Directories

- Directories provide:
  - a way for users to organize their files
  - a convenient file name space for both users and FS’s
- Most file systems support multi-level directories
  - naming hierarchies (c:\, c:\DocumentsAndSettings, c:\DocumentsAndSettings\MarkZ, …)
- Most file systems support the notion of current directory
  - absolute names: fully-qualified starting from root of FS

    `C:\> `**`cd c:\Windows\System32`**
  - relative names: specified with respect to current directory

    `C:\> `**`c:\Windows\System32`** (absolute)

    `C:\Windows\System32> `**`cd Drivers`**

    (relative, equivalent to cd **`c:\Windows\System32\Drivers`**)

Directory internals

- A directory is typically just a file that happens to contain special metadata
  - directory = list of (name of file, file attributes)
  - attributes include such things as:
    - size, protection, location on disk, creation time, access time, …
  - the directory list can be unordered (effectively random)
    - when you type “ls” or “dir /on” , the command sorts the results for you.
    - some file systems organize the directory file as a BTree, giving a “natural” ordering
      - What case to use for sort?
      - What about international issues?

Path name translation

- Let’s say you want to open “C:\one\two\three”

```
success = CreateFile(“c:\\one\\two\\three”, …);
```

- What goes on inside the file system?
  - open directory “c:\” (well known, can always find)
  - search the directory for “one”, get location of “one”
  - open directory “one”, search for “two”, get location of “two”
  - open directory “two”, search for “three”, get loc. of “three”
  - open file “three”
  - (of course, permissions are checked at each step)
- FS spends lots of time walking down directory paths
  - this is one reason why open is separate from read/write (session state)
  - FS will cache prefix lookups to enhance performance
    - C:\Windows, C:\Windows\System32, C:\Windows\System32\Drivers all share the “C:\Windows” prefix

File protection

- FS must implement some kind of protection system
  - to control who can access a file (user)
  - to control how they can access it (e.g., read, write, or delete)
- More generally (wait until security/protection lecture):
  - generalize files to objects (the "what")
  - generalize users to principals (the "who", user or program)
  - generalize read/write to actions (the "how", or operations)
- A protection system dictates whether a given action performed by a given principal on a given object should be allowed
  - e.g., you can read or write your files, but others cannot
  - e.g., your can read `C:\Windows\System32\ntoskrnl.exe` but you cannot write to it

Model for representing protection

- Two different ways of thinking about it:
  - access control lists (ACLs)
    - for each object, keep list of principals and principals’ allowed actions
  - capabilities
    - for each principal, keep list of objects and principal’s allowed actions
- Both can be represented with the following matrix:

objects

	C:\boot.ini	C:\DocumentsAndSettings/Markz/desktop
Administrator	rw	rw
markz	r	rw
guest		

principals

capability

ACL

ACLs vs. Capabilities

- Capabilities are easy to transfer
  - they are like keys: can hand them off
  - they make sharing easy
- ACLs are easier to manage
  - object-centric, easy to grant and revoke
    - to revoke capability, need to keep track of principals that have it
    - hard to do, given that principals can hand off capabilities
- ACLs grow large when object is heavily shared
  - can simplify by using “groups”
    - put users in groups, put groups in ACLs
  - additional benefit
    - change group membership, affects ALL objects that have this group in its ACL

The original Unix file system

- Dennis Ritchie and Ken Thompson, Bell Labs, 1969
- “UNIX rose from the ashes of a multi-organizational effort in the early 1960s to develop a dependable timesharing operating system” – Multics
- Designed for a “workgroup” sharing a single system
- Did its job exceedingly well
  - Although it has been stretched in many directions and made ugly in the process
- A wonderful study in engineering tradeoffs

All disks are divided into five parts …

- Boot block
  - can boot the system by loading from this block
- Superblock
  - specifies boundaries of next 3 areas, and contains head of freelists of inodes and file blocks
- i-node area
  - contains descriptors (i-nodes) for each file on the disk; all i-nodes are the same size; head of freelist is in the superblock
- File contents area
  - fixed-size blocks; head of freelist is in the superblock
- Swap area
  - holds processes that have been swapped out of memory

So …

- You can attach a disk to a dead system …
- Boot it up …
- Find, create, and modify files …
  - because the superblock is at a fixed place, and it tells you where the i-node area and file contents area are
  - by convention, the second i-node is the root directory of the volume

The flat (i-node) file system

- Each file is known by a number, which is the number of the i-node
  - seriously – 1, 2, 3, etc.!
  - why is it called “flat”?
- Files are created empty, and grow when extended through writes

The tree (directory, hierarchical) file system

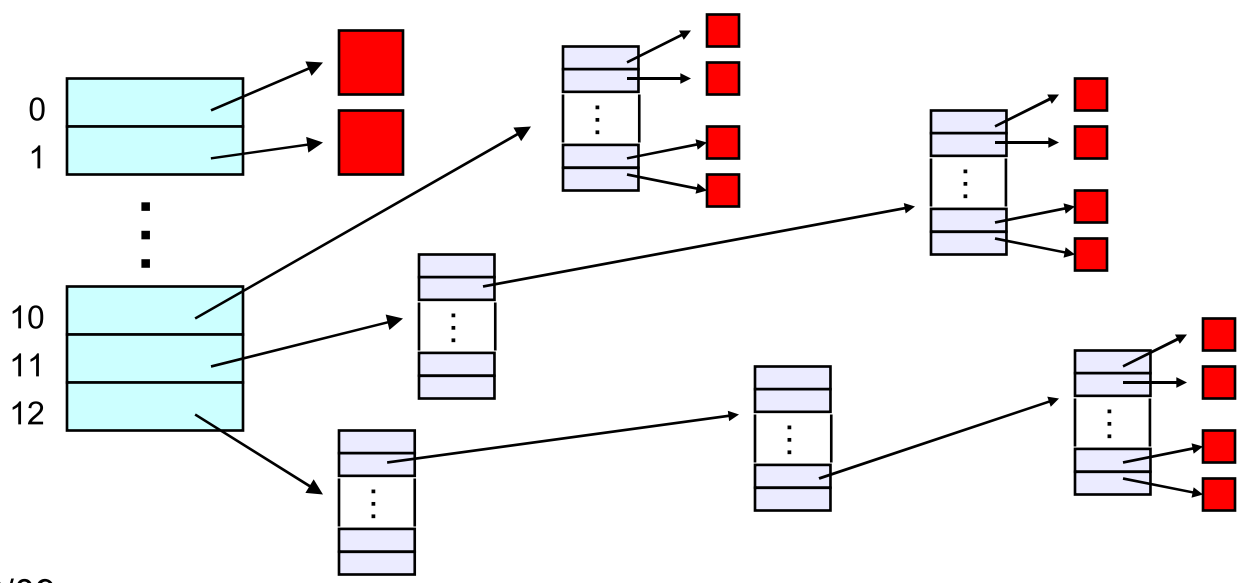
- A directory is a flat file of fixed-size entries
- Each entry consists of an i-node number and a file name

i-node number	File name
152	.
18	..
216	my_file
4	another_file
93	oh_my_god
144	a_directory

- It's as simple as that!

The “block list” portion of the i-node (Unix Version 7)

- Points to blocks in the file contents area
- Must be able to represent very small and very large files. How?
- Each inode contains 13 block pointers
  - first 10 are “direct pointers” (pointers to 512B blocks of file data)
  - then, single, double, and triple indirect pointers



File system consistency

- Both i-nodes and file blocks are cached in memory
- The “sync” command forces memory-resident disk information to be written to disk
  - system does a sync every few seconds
- A crash or power failure between sync’s can leave an inconsistent disk
- You could reduce the frequency of problems by reducing caching, but performance would suffer big-time

Consistency of the Flat file system

- Is each block accounted for?
  - Belongs to precisely one file or is on free list
  - What to do if in multiple files?
- Mark-and-sweep garbage collection
  - Start with bitmap (one bit per block) of zeros
  - For every inode, walk allocation tree setting bits
  - Walk free list setting bits
  - Bits that are one along the way?
  - Bits that are zero at the end?

Consistency of the directory structure

- Verify that directories form a tree
- Start with vector of counters, one per inode, set to zero
- Perform tree walk of directories, adjusting counters on every name reference
- At end, counters must equal link count

Protection

- Objects: individual files
- Principals: owner/groups/everyone
- Actions: read/write/execute

- This is pretty simple and rigid, but it has proven to be about what we can handle!