CSE 153
Design of Operating Systems

Fall 2018

Lecture 13: File Systems (2)—Abstractions and implementation

Plan for today

- Abstractions for the disk drive that:
  - Store information persistently
  - Allow users to organize information
  - Provide tools for controlling access

- How to implement the abstractions
  - We saw the structure of disk drives
    - » Sea of blocks
    - » Seeks are costly
    - » How to support abstractions?

File Systems

- File systems
  - Implement an abstraction (files) for secondary storage
  - Organize files logically (directories)
  - Permit sharing of data between processes, people, and machines
  - Protect data from unwanted access (security)

Files

- A file is a sequence of bytes with some properties
  - Owner, last read/write time, protection, etc.
- A file can also have a type
  - Understood by the file system
    - » Block, character, device, portal, link, etc.
  - Understood by other parts of the OS or runtime libraries
    - » Executable, dll, souce, object, text, etc.
- A file's type can be encoded in its name or contents
  - Windows encodes type in name
    - » .com, .exe, .bat, .dll, .jpg, etc.
  - Unix encodes type in contents
    - » Magic numbers, initial characters (e.g., #! for shell scripts)

Basic File Operations

Unix

- creat(name)
- open(name, how)
- read(fd, buf, len)
- write(fd, buf, len)
- sync(fd)
- seek(fd, pos)
- close(fd)
- unlink(name)

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

- Different file systems differ in the manner that data in a file can be accessed
  - Sequential access – read bytes one at a time, in order
  - Direct access – random access given block/byte number
  - Record access – file is array of fixed- or variable-length records, read/written sequentially or randomly by record #
  - Indexed access – file system contains an index to a particular field of each record in a file, reads specify a value for that field and the system finds the record via the index (DBs)
- Older systems provide more complicated methods
- What file access method do Unix, Windows provide?

Directories

- Directories serve two purposes
  - For users, they provide a structured way to organize files
  - For the file system, they provide a convenient naming interface that allows the implementation to separate logical file organization from physical file placement on the disk
- Most file systems support multi-level directories
  - Naming hierarchies (/, /usr, /usr/local/, …)
- Most file systems support the notion of a current directory
  - Relative names specified with respect to current directory
  - Absolute names start from the root of directory tree

Directory Internals

- A directory is a list of entries
  - <name, location>
  - Name is just the name of the file or directory
  - Location depends upon how file is represented on disk
- List is usually unordered (effectively random)
  - Entries usually sorted by program that reads directory
- Directories typically stored in files
  - Only need to manage one kind of secondary storage unit

Basic Directory Operations

Unix

- Directories implemented in files
  - Use file ops to create dirs
- C runtime library provides a higher-level abstraction for reading directories
  - opendir(name)
  - readdir(DIR)
  - seekdir(DIR)
  - closedir(DIR)

Windows

- Explicit dir operations
  - CreateDirectory(name)
  - RemoveDirectory(name)
- Very different method for reading directory entries
  - FindFirstFile(pattern)
  - FindNextFile()

Path Name Translation

- Let's say you want to open "/one/two/three"
- What does the file system do?
  - Open directory "/" (well known, can always find)
  - Search for the entry "one", get location of "one" (in dir entry)
  - Open directory "one", search for "two", get location of "two"
  - Open directory "two", search for "three", get location of "three"
  - Open file "three"
- Systems spend a lot of time walking directory paths
  - This is why open is separate from read/write
  - OS will cache prefix lookups for performance
    - » /a/b, /a/bb, /a/bbb, etc., all share "/a" prefix

File Sharing

- File sharing is important for getting work done
  - Basis for communication between processes and users

- Two key issues when sharing files
  - Semantics of concurrent access
    - » What happens when one process reads while another writes?
    - » What happens when two processes open a file for writing?
  - Protection

Protection

- File systems implement some kind of protection system
  - Who can access a file
  - How they can access it
- More generally…
  - Objects are "what", subjects are "who", actions are "how"
- A protection system dictates whether a given action performed by a given subject on a given object should be allowed
  - You can read and/or write your files, but others cannot
  - You can read "/etc/motd", but you cannot write to it

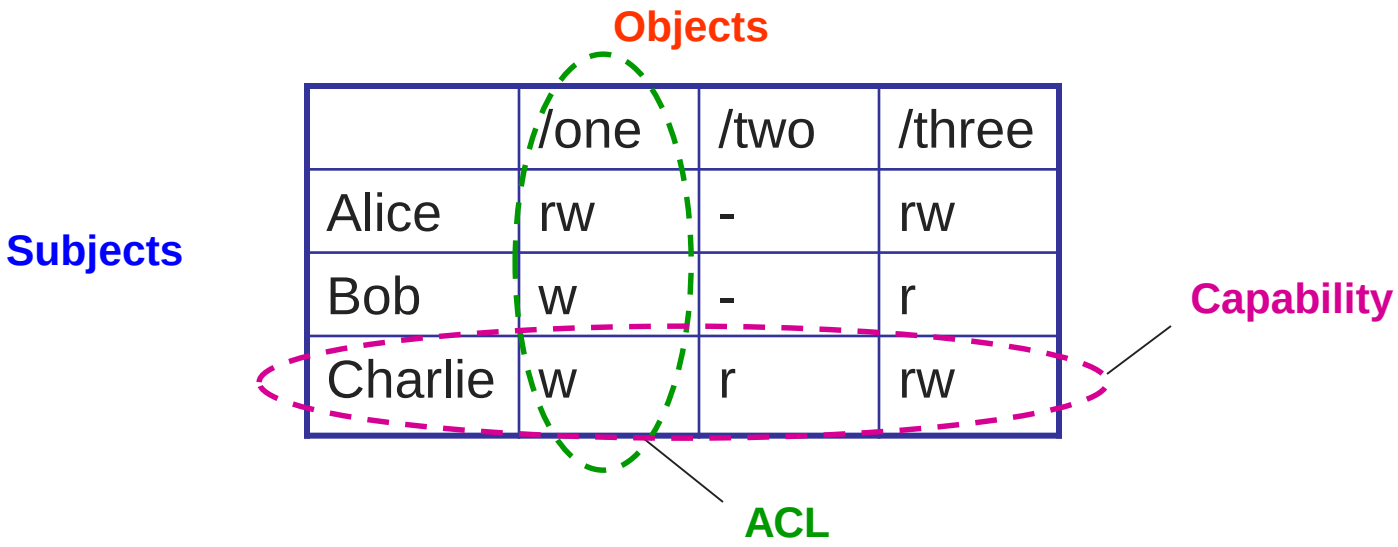
Representing Protection

Access Control Lists (ACL)

- For each object, maintain a list of subjects and their permitted actions

Capabilities

- For each subject, maintain a list of objects and their permitted actions



ACLs and Capabilities

- The approaches differ only in how table is represented
  - What approach does Unix use?
- Capabilities are easier to transfer
  - They are like keys, can handoff, does not depend on subject
- In practice, ACLs are easier to manage
  - Object-centric, easy to grant, revoke
  - To revoke capabilities, have to keep track of all subjects that have the capability – a challenging problem
- ACLs have a problem when objects are heavily shared
  - The ACLs become very large
  - Use groups (e.g., Unix)

File System Layout

How do file systems use the disk to store files?

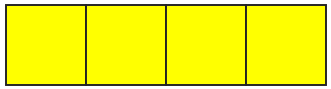
- File systems define a block size (e.g., 4KB)
  - Disk space is allocated in granularity of blocks
- A "Master Block" determines location of root directory
  - At fixed disk location, sometimes replicated for reliability
- A free map determines which blocks are free, allocated
  - Usually a bitmap, one bit per block on the disk
  - Also stored on disk, cached in memory for performance
- Remaining blocks store files (and dirs), and swap!

File systems

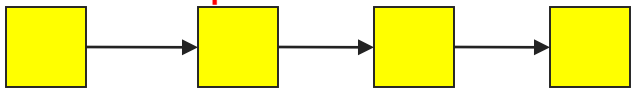
- File system design: how to allocate and keep track of files and directories
- Does it matter? What is the difference?
  - Performance, reliability, limitations on files, overhead, …
- Many different file systems have been proposed and continue to be proposed
- Lets talk about some general ideas first

Disk Layout Strategies

- Files span multiple disk blocks
- How do you find all of the blocks for a file?
  1. Contiguous allocation
     - » Like memory
     - » Fast, simplifies directory access
     - » Inflexible, causes fragmentation, needs compaction



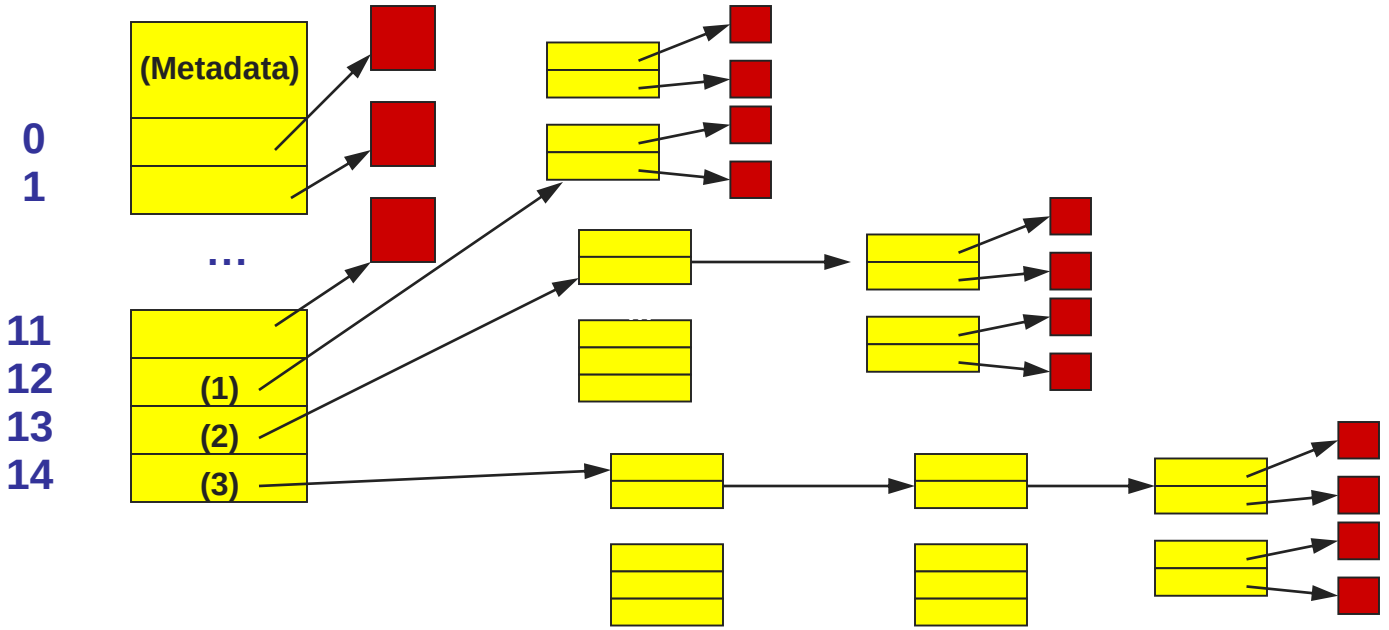
  2. Linked structure
     - » Each block points to the next, directory points to the first
     - » Bad for random access patterns



  3. Indexed structure (indirection, hierarchy)
     - » An "index block" contains pointers to many other blocks
     - » Handles random better, still good for sequential
     - » May need multiple index blocks (linked together)

Unix Inodes

- Unix inodes implement an indexed structure for files
  - Also store metadata info (protection, timestamps, length, ref count…)
- Each inode contains 15 block pointers
  - First 12 are direct blocks (e.g., 4 KB blocks)
  - Then single, double, and triple indirect



Unix Inodes and Path Search

- Unix Inodes are not directories
- Inodes describe where on disk the blocks for a file are placed
  - Directories are files, so inodes also describe where the blocks for directories are placed on the disk
- Directory entries map file names to inodes
  - To open "/one", use Master Block to find inode for "/" on disk
  - Open "/", look for entry for "one"
  - This entry gives the disk block number for the inode for "one"
  - Read the inode for "one" into memory
  - The inode says where first data block is on disk
  - Read that block into memory to access the data in the file
- This is why we have *open* in addition to *read* and *write*

Symbolic and hard links

A link is a pointer to a file.

- Basically create a file that points at another file
- Two types:
  - Symbolic or soft link (file points to the other file's meta data)
    - » This metadata index the file
  - Hard link (file points to the other file's data directly)
    - » Repeats the indexing information

Hard Links

- Hard link is a reference to the physical data on a file system
- All named files are hard links
- More than one name can be associated with the same physical data
- Hard links can only refer to data that exists on the ***same*** file system
- You can **not** create hard link to a directory

Hard Links

Example:

- Assume you used “vi” to create a new file, you create the first hard link (vi myfile)
- To Create the 2nd, 3rd and etc. hard links, use the command:

```
»ln myfile link-name
```

Display Hard Links info

- Create a new file called “myfile”
- Run the command “ls -il” to display the ***i-node number*** and ***link counter***

```
38753 -rw-rw-r--  1 uli  uli    29 Oct 29 08:47 myfile
  ^               ^
  |-- inode #     |-- link counter (one link)
```

Display Hard Link Info

- Create a 2nd link to the same data:

  ln myfile mylink

- Run the command "ls -il":

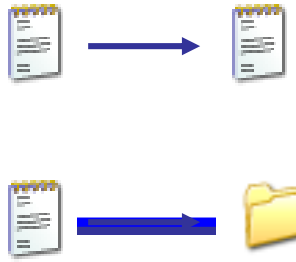
```
38753 -rw-rw-r-- 2 uli  uli    29 Oct 29 08:47 myfile
38753 -rw-rw-r-- 2 uli  uli    29 Oct 29 08:47 mylink
 ^                 ^
 |-- inode #       |--link counter (2 links)
```

Removing a Hard Link

When a file has more than one link, you can remove any one link and still be able to access the file through the remaining links.

Hard links are a good way to backup files without having to use the copy command!

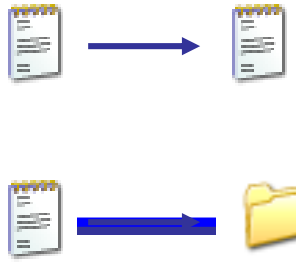
Symbolic Links



Also Known As (a.k.a.): Soft links or Symlinks

- A Symbolic Link is an indirect pointer to a file – a pointer ***to*** the hard link ***to*** the file
- You can create a symbolic link to a directory
- A symbolic link can point to a file on a different file system
- A symbolic link can point to a nonexistent file (referred to as a “broken link”)

Symbolic Links



- To create a symboic link to the file “myfile”, use

  ln -s myfile symlink **or**

  ln --symbolic myfile symlink

```
[uli@seneca courses] ls -li myfile
44418 -rw-rw-r-- 1 uli uli   49 Oct 29 14:33 myfile

[uli@seneca courses] ln -s myfile symlink
[uli@seneca courses] ls -li myfile symlink
44418 -rw-rw-r-- 1 uli uli  49 Oct 29 14:33 myfile
44410 lrwxrwxrwx 1 uli uli   6 Oct 29 14:33 symlink -> myfile
```

Different i-node

File type: (symbolic link)

Can we create loops?

- Yes, with symbolic links
  - E.g., /usr/nael/hi/there/link_to_hi@
  - Try it ☺
  - If you do a recursive command it will get stuck…
- Not possible with hard links since we cannot create a hard link to a directory
  - There is no difference between the hard link and the original file
  - Bad idea to allow loops/links to directories