CE 440 Introduction to Operating System

Lecture 16: File System
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Slides courtesy of Manuel Egele, Ryan Huang and Baris Kasikci

Administrivia

Lab 3a and 3b is out

- **Start the project early**

Homework 4 is out

File System Not Fun

File systems: a challenging OS design topic

- More papers on FSes than any other single topic

Main tasks of file system:

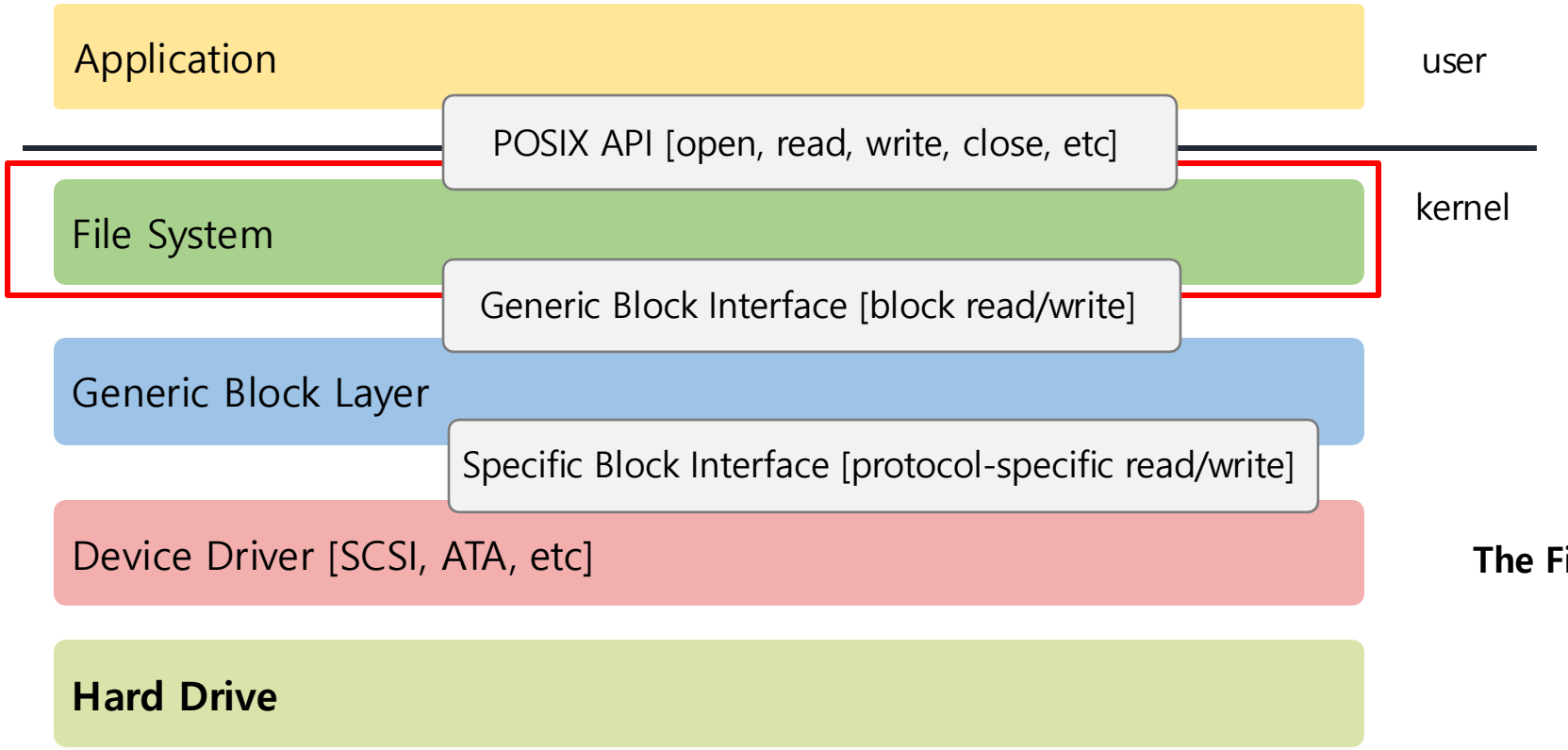
- Don’t go away (ever)
- Associate bytes with name (files)
- Associate names with each other (directories)
- Can implement file systems on disk, over network, in memory, in non-volatile
- ram (NVRAM), on tape, w/ paper.
- We’ll focus on disk and generalize later

Today: files, directories

File System Abstraction

File system specifics of which disk class it is using.

- It issues **block read** and **write** request to the generic block layer.



The File System Stack

Files

File: named bytes on disk

- Data with some properties
- Contents, size, owner, last read/write time, protection, etc.

How is a file's data managed by the file system?

- Next lecture's topic
- Basic idea (in Unix): a struct called an index node or inode
  - Describe where on the disk the blocks for a file are placed
  - Disk stores an array of inodes, inode # is the index in this array

File Types

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, source, 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)

Windows

- 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

FS usually provides different file access methods:

- Sequential access
  - read bytes one at a time, in order
  - by far the most common mode
- Random 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

What file access method does Unix, Windows provide?

Directories

Problem: referencing files

Users remember where on disk their files are (disk sector no.)?...

- E.g., like remembering your social security or bank account #

...People want human digestible names

Directories serve two purposes

- For users, they provide a structured way to organize files
- For FS, they provide a convenient naming interface that allows the separation of logical file organization from physical file placement on the disk

A Short History of Directories

Approach 1: Single directory for entire system

- Put directory at known disk location. If one user uses a name, no one else can
- Many ancient personal computers work this way

Approach 2: Single directory for each user

- Still clumsy, and running `ls` on 10,000 files is a real pain

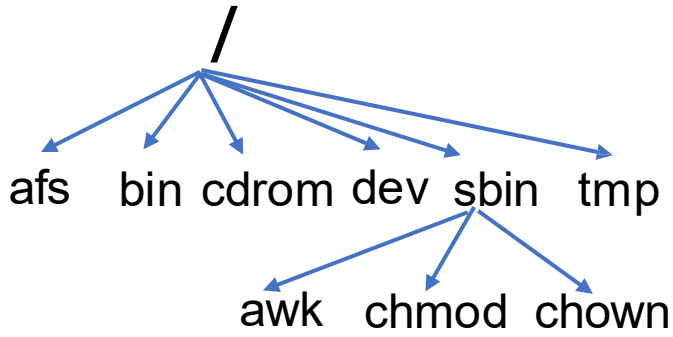
Approach 3: Hierarchical name spaces

- Allow directory to map names to files or other dirs
- File system forms a tree (or graph, if links allowed)

Hierarchical Directory

Used since CTSS (1960s)

- Unix picked up and used really nicely



Large name spaces tend to be hierarchical

- ip addresses, domain names, scoping in programming languages, etc.

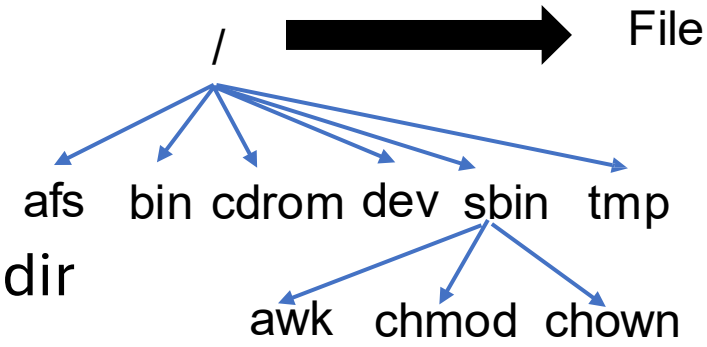
Directory Internals

A directory is a list of entries

- <name, location> tuple, location is typically the *inode #* (more next lecture)
- An inode describes where on the disk the blocks for a file are placed

Directories stored on disk just like regular files

- File type set to directory
- User's can read just like any other file
- Only special syscalls can write (why?)
- File pointed to by the location may be another dir
- Makes FS into hierarchical tree



File content for '/'

<afs,1021>
<tmp,1020>
<bin,1022>
<cdrom,4123>
<dev,1001>
<sbin,1011>
…

Simple, plus speeding up file ops speeds up dir ops!

Path Name Translation

Let's say you want to open "/one/two/three.txt"

What does the file system do?

- Directory entries map file names to location (inode #)
- Open directory "/": Where? Root directory is always inode #2
- 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"

Naming Magic

Bootstrapping: Where do you start looking?

- Root directory always inode #2 (0 and 1 historically reserved)

Special names:

- Root directory: "/"
- Current directory: "."
- Parent directory: ".."

Some special names are provided by shell, not FS:

- User's home directory: "~"
- Globbing: "foo.*" expands to all files starting "foo."

Using the given names, only need two operations to navigate the entire name space:

- cd name: move into (change context to) directory name
- ls: enumerate all names in current directory (context)

Basic Directory Operations

Unix

Directories implemented in files

- Use file ops to create dirs.

C library provides a higher-level abstraction for reading directories

- `opendir(name)`
- `readdir(DIR)`
- `seekdir(DIR)`
- `closedir(DIR)`

Windows

Explicit directory operations

- `CreateDirectory(name)`
- `RemoveDirectory(name)`

Very different method for reading directory entries

- `FindFirstFile(pattern)`
- `FindNextFile()`

Default Context: Working Directory

Cumbersome to constantly specify full path names

- In Unix, each process has a "current working directory" (cwd)
- File names *not* beginning with "/" are assumed to be relative to cwd; otherwise translation happens as before

Shells track a default list of active contexts

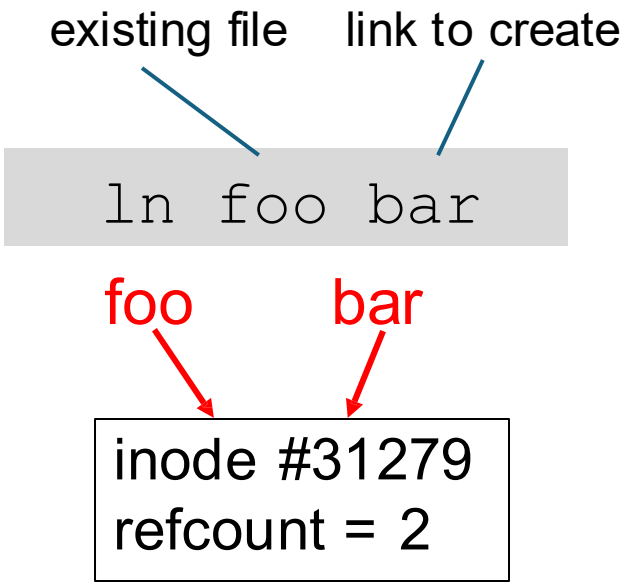
- A "search path" for programs you run
- Given a search path A:B:C, the shell will check in A, then B, then C
- Can escape using explicit paths: "./foo"

Example of locality

Hard Links

More than one dir entry can refer to a given file

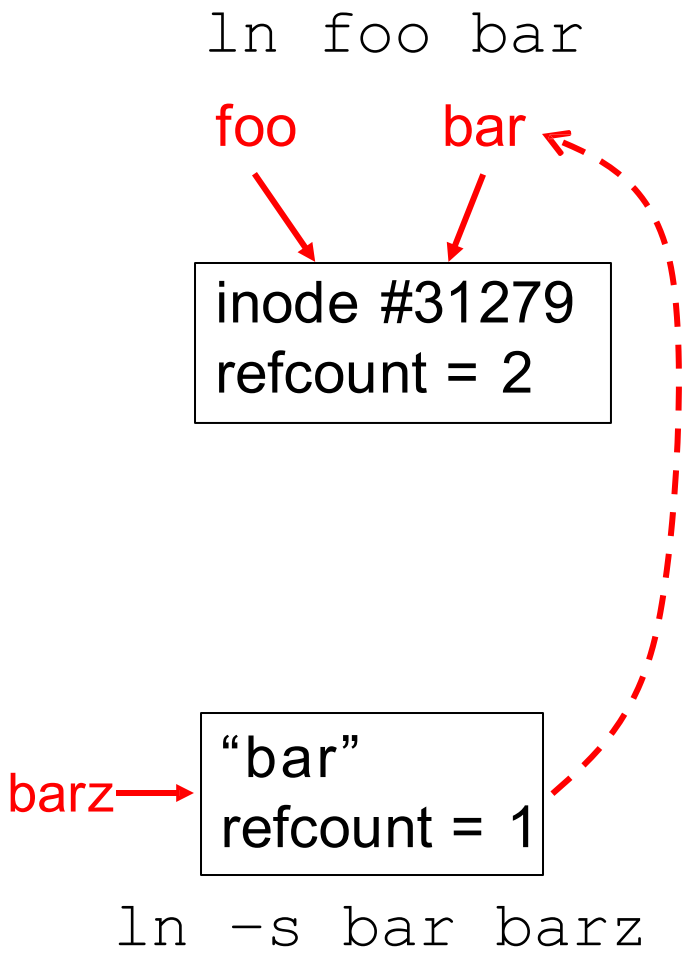
- Hard link creates a synonym for file
- Unix stores count of pointers (“hard links”) to inode
- If one of the links is removed (e.g., rm), the data are still accessible through any other link that remains
- If all links are removed, the space occupied by the data is freed.



Soft Links

Soft/symbolic links = synonyms for names

- Point to a file/dir name, but object can be deleted from underneath it (or never exist).
- Unix implements like directories: inode has special "symlink" bit set and contains name of link target
- When the file system encounters a soft link it automatically translates it (if possible).



File Sharing

File sharing has been around since timesharing

- Easy to do on a single machine
- PCs, workstations, and networks get us there (mostly)

File sharing is important for getting work done

- Basis for communication and synchronization

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?
  - What are we going to use to coordinate?
- Protection

Protection

File systems implement a 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 it

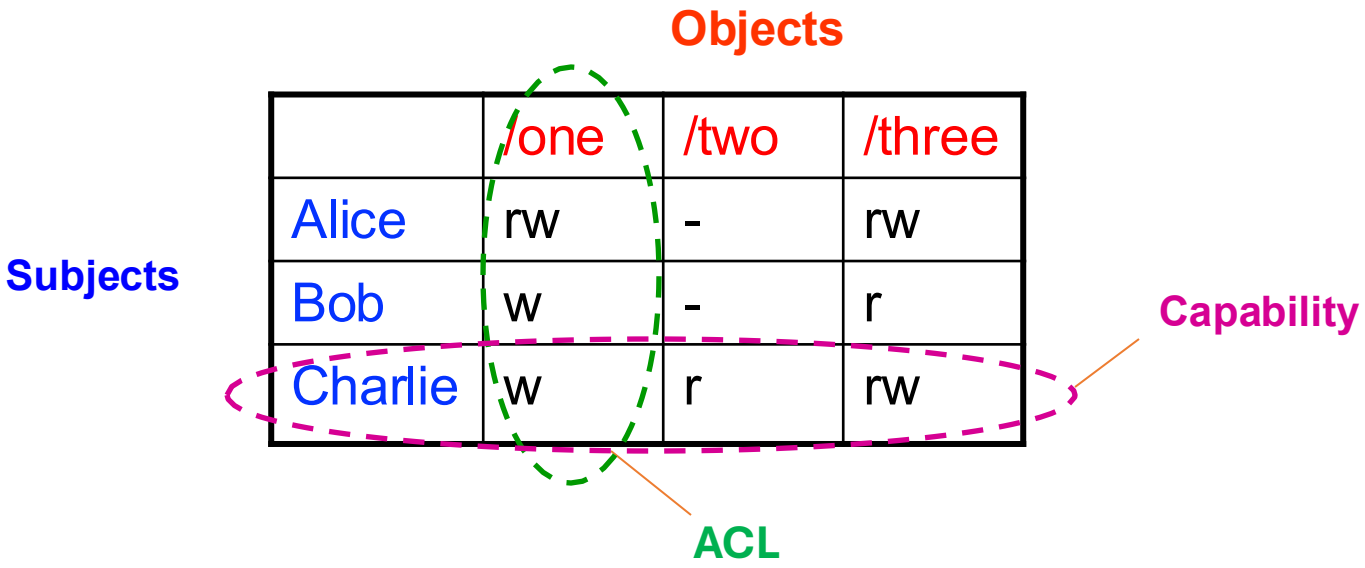
Representing Protection

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

Approaches differ only in how the table is represented

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)

Unix File Protection

What approach does Unix use in the FS?

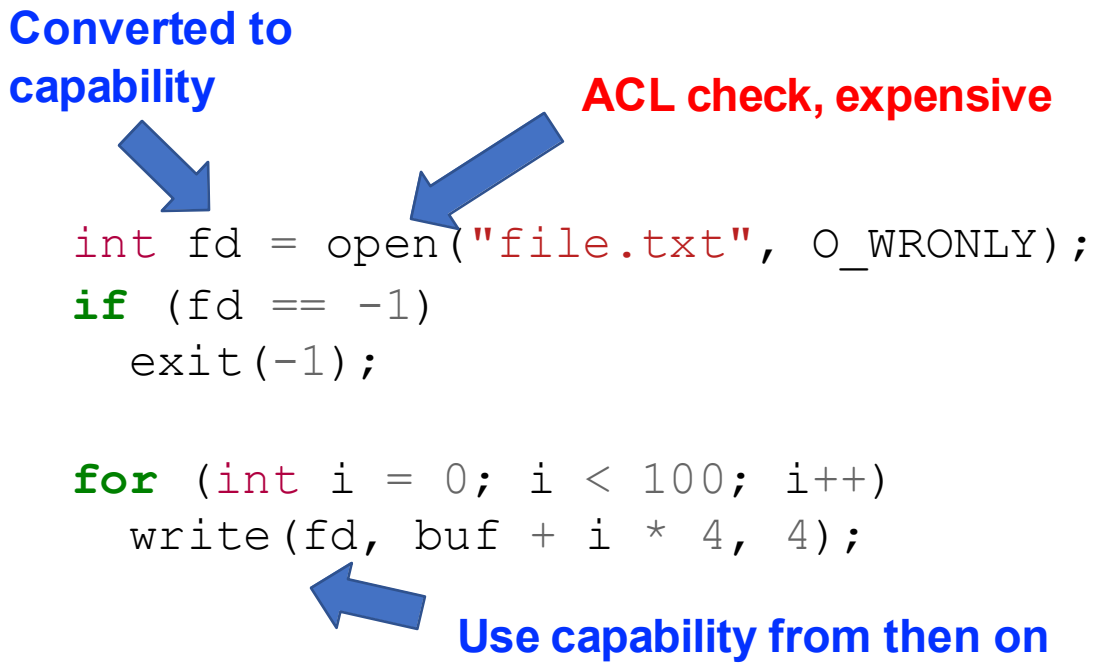
- Answer: both

ACL: Unix file permissions

Capability: file descriptors

How are they used together?

- Conversion through open()system call



Summary

Files

- Operations, access methods

Directories

- Operations, using directories to do path searches
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Sharing

Protection

- ACLs vs. capabilities

Next Chapter

Read Chapter 40, 41