File I/O
File Systems

Topics

- Can we do anything more than just use data files?
- How are file systems organized?
- What are hard/soft links?

The Universality of I/O

Everything is a File

- UNIX I/O model gives access to many things via files:
  - Actual files!
  - ..
  - Networks
  - Process information
- /proc File System
  - Shows system and process information using open() / read() / etc.
  - ..
  - But they are not "real files" stored on disks.

Example: /proc file system

• /proc/cpuinfo	CPU info
• /proc/meminfo	memory info
• /proc/PID/status	process info
• /proc/PID/fd	file descriptor info
• /proc/PID/task/TID	thread info

E.g., Terminal

- Universality of file IO: Terminal
  - 3 standard file descriptors that are always open.
    - These are..
    - fork() clones some opened file descriptors; so child processes also has them.

File Descriptor	**Purpose**	**POSIX Name**	**stdio stream**
0	Standard Input	STDIN_FILENO	stdin
1	Standard Output	STDOUT_FILENO	stdout
2	Standard Error	STDERR_FILENO	stderr

E.g., Device Files

- Many devices have a "device file" in /dev/
  - This is called a node.
- Some are..
  - e.g., a mouse, a disk.
- Some are..
  - /dev/null provides a "black hole" of all data written to it.
  - /dev/zero provides infinite null characters.
  - /dev/random and /dev/urandom are pseudorandom number generators.

    ```
    $ od -vAn -N2 -tu2 < /dev/urandom
    ```

E.g., /sys File System

- File IO in /sys file system
  - /sys..
    e.g., various device setups, kernel subsystem info, etc.
- Examples
  - Controlling LEDs
  - Accessing secondary processors
  - Communicating to an accelerometer, etc.
- ioctl syscall
  - Extra syscall for I/O for things
    ..
  - E.g., Change the speed of a serial port.

Disk Partitions

Disk Partitions

- ..
  - /proc/partitions shows the partition info.
  - In Windows, partitions are C:, D: , etc.
- A partition is typically used as a file system
  - A file system is
    ..
  - Many different types of file systems.
  - Each partition can have a different file system.
- E.g., BeagleY-AI board has 2 partitions on its micro-SD card:
  - One is Fat32, accessible to Windows and storing configuration data.
  - One is EXT4, used by Linux to store rest of the root file system.

Disk Partitions (cont)

- User's perspective
  - ..
    starts with root directory /.
  - Each partition contains a different tree
    (More later when talking about mounting)
- Swap Partition
  - A partition is also used as a swap space for memory management
    e.g., ..
  - /proc/swaps shows the swap space info.
    (Don't always need to have swap space)

I-Nodes

I-Nodes

- A file is associated with an i-node.
  - ..
    e.g., file type, permissions, owner, timestamps, etc.
  - An i-node is identified by a number.
    ls -li shows i-node numbers (1st column).
- stat(), lstat(), and fstat()
  - Functions that work with file metadata mostly from the i-node.
  - Read man 2 stat and man 3 stat for more details.

Activity: I-Node

- Activity: use stat() to display if path is file or directory
  - Use command line argument to get filename (arg[1] likely)
  - Read man inode, especially about st_mode.
    - Check out S_ISREG(...), and S_ISDIR(...)
  - Print "Regular file" if it's a file.
  - Print "Directory" if its a directory.
  - Print "Other" otherwise.

Hard and Soft Links

Hard Links

- Hard links
  ..
  - A hard link is giving another name to an existing file.
- Hard link limitations
  - Cannot hard link a directory
    This prevents circular links,
    i.e., a child directory that links to the parent directory.
  - Hard links should be within the same file system,
    because a hard link is giving another name to an existing file.

Activity: Hard Links

- [5 min] Activity:
  Use ln to create a hard link to a file.
  - Read man ln to figure out how to create a hard link.
  - Run ls -li for both the original file and the hard link.
    (They're exactly the same)
    - ls -li shows the number of links as well (the third column)
    - # links should increase as more hard links are created
- Modify content of original file
  - Check contents of the hard link (and vice versa).
  - They should be the same.

How rm works (aside)

- rm only deletes the hard link.
  - ..

    (there's a system call used for deleting a file: unlink())

    (There's also a more convenient one, remove())
  - Only when there's no link left any more, the file gets deleted.

Soft Links (Symbolic Links)

- Soft links

  ..

  - Unlike a hard link,..
    The content of the file is the path to the original file.
  - There's a system call symlink().
- No limitations like hard links
  - Sym links are allowed for directories.
  - Sym links do not have to be within the same file system.

Activity: Soft Links

- (5 min) Activity
  Create a sym link with ln -s
  - Run ls -li
    - They each have a unique i-node number, meaning they are two different files.
    - The hard link count does not change even if you create a sym link: it's because it's a different file.
  - The sym link will point to nothing if the original gets deleted.
    - This is called a dangling link.

Optional:
Bits - setuid, setguid, sticky

Setuid / Setguid bits

- Program Permission
  - Normally, programs you run will run with your permission.
- Setuid bit: if set, the user that runs the program can act as the owner of the program.
  - E.g., passwd sets a user's password.
    It must write to the password file (/etc/shadow), which is owned by the root.
  - So, use the setuid bit:
  - When a user runs passwd, the program can act as root to modify the password file.
- Setgid bit: if set, the user that runs the program can act as if the user belonged to the group of the program.

Sticky Bit

- Sticky bit:
  - Can be set on a shared directory for better control.
  - When set, only able to delete/rename file if:

    a) you own it

    b) you have write permission for it
    (It affects the directory, not the file access permissions)

Sticky Example

- Situation 1: Regular Directory
  - Create a shared_photos/ directory that is write-open for others (e.g., rw-rw-rw-).
  - User dr-evil creates a file selfie.jpg in it.
  - User boogieman can delete selfie.jpg.
- Situation 2: Sticky Bit!
  - Set sticky bit on shared_photos/
    chmod +t shared_photos/l
  - User dr-evil creates a file selfie.jpg in it.
  - User boogieman cannot delete selfie.jpg.

VFS - Virtual File System

and

Mount/Unmount

VFS (Virtual File System)

- VFS (Virtual File System)

  ..

  - Interface includes: open, read, write, close, etc.
    VFS in kernel define a function to handle each.
  - It's not a file system of real files,

    ..
- If a file system implements this interface,
  it can be used as a Linux file system.
  - E.g.,: /sys, /proc, /dev, ...

Mounting

- Linux presents all file systems as a single tree
  - Starts at root directory /
- In reality, this single file tree

  ..
- Recall:
  - A partition contains a file tree
  - There can be multiple partitions on a single disk.
  - There can be multiple disks for a single machine.

Mounting and Unmounting

- Mounting
    ..
    - All file systems (from different partitions/disks) are mounted and form a single file tree.
- mount command mounts a file tree (a file system) to a specific directory
    - This target directory is called a mount point
    - The mount command also shows the current setup. (Shows the same information as /proc/mounts).
- The umount command unmounts a file system.

Summary

- Everything is a file
  - Use file operations to access almost anything.
  - /proc for process info
  - /dev for devices
  - /sys for system info
- Partitions split up disks
- I-Nodes used for meta data about each file/directory.
- Hard/soft links allow two entries for one file.
- Mounting places one file tree inside another.