Chapter 16 Title - Notes

16.3 Learning Objectives:

- Explain the basic filesystem organization.
- Understand the role of the VFS.
- Know w hat filesystems are available in Linux and w hich ones can be used on your actual system.
- Grasp w hy journalling filesystems represent significant advances.
- Discuss the use of special filesystems in Linux.

16.4 Filesystem Basics

Application programs -> read/w rite files, rather than dealing w ith physical locations on actual hardw are (w here files are stored).

Files (and their names) -> abstraction camouflaging physical I/O layer. Directly w riting to disk in **raw** fashion (ignoring **filesystem** layer)-> *very dangerous*, only done by low -level operating system softw are, never by user application.

Local filesystems generally reside w ithin disk partition (w hich can be physical partition on disk, or logical partition controlled by **Logical Volume Manager** (LVM)). Filesystems can also be part of netw ork nature, true physical embodiment completely hidden to local system across netw ork.

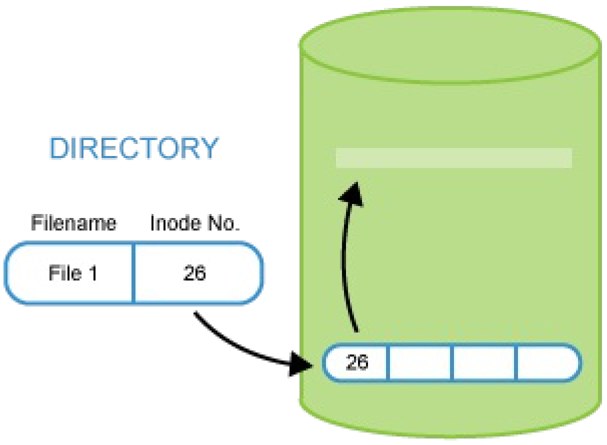
16.5 Inodes

Inode: data structure on disk that describes and stores file attributes, including location. Every file associated w ith ow n inode. Information stored in inode:

- Permissions
- User and group ow nership
- Size
- Timestamps (nanoseconds)
  - Last access time
  - Last modification time
  - Change time

Note: File names **not** stored in file's inode, but instead stored in **directory** file.

All I/O activity concerning file usually also involves file's inode, as information must be updated.



Data storage in an inode vs. data storage in a directory file

16.6 Hard and Soft Links

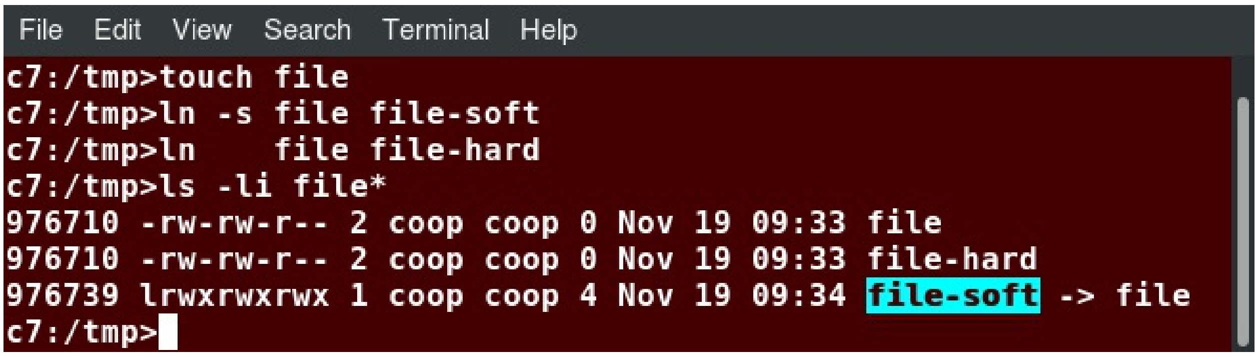
Directory file: particular type of file used to associate file names and inodes. Two ways to associate (or link) file name with inode:

- **Hard** links point to an inode
- **Soft** (or **symbolic**) links point to a file name which has an associated inode

Link: each association of directory file contents and inode. Additional links can be created using **ln**.

Because possible (+ quite common) for two or more directory entries to point to same inode (hard links), a file can be known by multiple names, each of which has its own place in directory structure. However, can only have one inode, no matter which name being used.

When process refers to pathname, kernel searched directories to find corresponding inode number. After name converted to inode number, inode loaded into memory + used by subsequent requests.



```
c7:/tmp>touch file
c7:/tmp>ln -s file file-soft
c7:/tmp>ln    file file-hard
c7:/tmp>ls -li file*
976710 -rw-rw-r-- 2 coop coop 0 Nov 19 09:33 file
976710 -rw-rw-r-- 2 coop coop 0 Nov 19 09:33 file-hard
976739 lrwxrwxrwx 1 coop coop 4 Nov 19 09:34 file-soft -> file
c7:/tmp>
```

16.7 Filesystem Tree organization

All Linux systems use inverted tree hierarchy branching off the root (`/`) directory. While entire tree may be contained in one local filesystem in one partition, usually there are multiple partitions (or network filesystems) joined together at **mount points**. Can also include removable media, eg. USB drives, optical drives, etc.

In addition, certain **virtual pseudo filesystems** (useful abstractions which exist only in memory) will be mounted within tree. Include `/proc` , `/sys` , `/dev` , maybe `/tmp` and `/run` .

Each element mounted within tree *may* have own filesystem variety. But, to applications and operating system, all appears in one unified tree structure.

16.8 Virtual File System (VFS)

Linux implements Virtual File System (VFS), as do all modern operating systems. When application needs to access file, interacts w ith VFS abstraction layer, w hich then translates all I/O system calls (reading, w riting, etc.) into specific code relevant to particular filesystem.

Thus, applications do not need to consider neither specific actual filesystem or physical media/hardw are on w hich it resides, and netw ork filesystems (such as NFS) can be handled transparently.

This permits Linux to w ork w ith more filesystem varieties than any other operating system. Democratic attribute has been large factor in success.

Most filesystems have full read/w rite access, w hile few have only read access, perhaps experimental w rite access. Some filesystem types, especially non-UNIX based ones, may require more manipulation in order to be represented in VFS.

Variants such as **vfat** do not have distinct read/w rite/execute permissions for ow ner/group/w orld fields. VFS has to make assumption about how to specify distinct permissions for the three types of user, such behavior can be influenced by mounting operations. There are non-kernel filesystem implementations, eg. read/w rite ntfs_3g, w hich are reliable but have w eaker performance than in-kernel filesystems.

16.9 Available Filesystems

Linux supports many filesystem varieties, most w ith full read/w rite access:

- **ext4**: Linux native filesystem (and earlier ext2 and ext3)
- **XFS**: high-performance filesystem originally created by SGI
- **JFS**: high-performance filesystem originally created by IBM
- Window s-nativesL **FAT12**, **FAT16**, **FAT32**, **VFAT**, **NTFS**
- **Pseudo-filesystem**s resident only in memoery, including **proc**, **sysfs**, **devfs**, **debugfs**
- Netw ork filesystems such as **NFS**, **coda**, **afs**
- etc.

Democratic flexibility large factor in success. Most filesystems have full read/w rite access, w hile few have read only access.

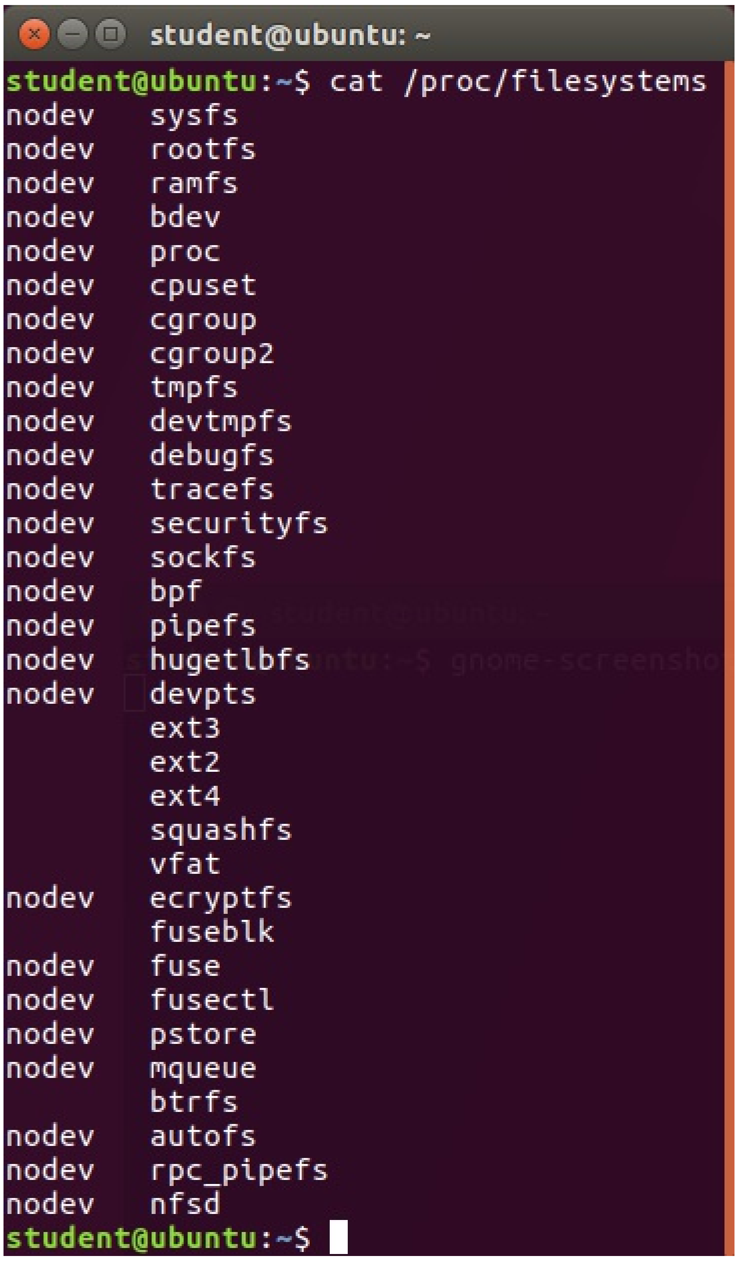
Commonly used filesystems include **ext4**, **xfs**, **btrfs**, **squashfs**, **nfs**, **vfat**. A list of currently supported filesystems at `/proc/filesystems`.

16.10 Current Filesystem Types

Can see list of filesystem types currently registered + understood by current running Linux kernel by doing:

```
$ cat /proc/filesystems
```

Note: additional filesystem types may have their code loaded only w hen system tries to access a partition that uses them.



```
student@ubuntu:~$ cat /proc/filesystems
nodev   sysfs
nodev   rootfs
nodev   ramfs
nodev   bdev
nodev   proc
nodev   cpuset
nodev   cgroup
nodev   cgroup2
nodev   tmpfs
nodev   devtmpfs
nodev   debugfs
nodev   tracefs
nodev   securityfs
nodev   sockfs
nodev   bpf
nodev   pipefs
nodev   hugetlbfs
nodev   devpts
        ext3
        ext2
        ext4
        squashfs
        vfat
nodev   ecryptfs
        fuseblk
nodev   fuse
nodev   fusectl
nodev   pstore
nodev   mqueue
        btrfs
nodev   autofs
nodev   rpc_pipefs
nodev   nfsd
student@ubuntu:~$
```

16.12 Journaling Filesystems

Number of new er, high performance filesystems include full **journalling** capability.

Journalling filesystems recover from system crashes/ungrateful shutdow ns w ith little or no corruption + very rapidly. Comes at price of having some more operations to do, but additional enhancements can more than offset price.

In journalling filesystem, operations grouped into **transactions**. Transaction must be completed w ithout error, **atomically**. Otherw ise, filesystem not changed. Log file maintained of transactions. When error occurs, usually only last transaction needs to be examined.

Follow ing journalling filesystems freely available under Linux:

- **ext3**: extension of earlier non-journalling ext2 filesystem
- **ext4**: vastly enhanced outgrow th of ext3. Features include extents, 48-bit block numbers, and up to 16TB size. Most linux distributions have used ext4 as default filesystem for quite a few years
- **reiserfs**: first journalling implementation used in Linus, but lost its leadership and further development w as abandoned
- **JFS**: originally product of IBM, w as ported from IBM's AIX operating system

- **XFS**: originally product of SGI, w as ported from SGI's IRIX operating systems. RHEL 7 has adopted XFS as default filesystem **btrfs**: new est of journalling filesystems, still under rapid development

16.13 Special Filesystems

Linux w idely employs use of **special filesystems** for certain tasks. Particularly useful for accessing various kernel data structures + tuning kernel behavior, or for implementing particular functions. Note: some of these special filesystems have no mount point. This means user applications don't interact w ith them, but kernel uses them, taking advantage of VFS layers + code.

Special Filesystems

Filesystem	Mount Point	Purpose
rootfs	None	During kernel load, provides an empty root directory
hugetlbfs	Anyw here	Provides an extended page access (2 or 4 MB on **X86**)
bdev	None	Used for block devices
proc	`/proc`	Pseudo filesystem access to many kernel structures and subsystems
sockfs	None	Used by **BSD Sockets**
tmpfs	Anyw here	RAM disk w ith sw apping, re-sizing
shm	None	Used by System V IPC Shared Memory
pipefs	None	Used for pipes
binfmt_misc	Anyw here	Used by various executable formats
devpts	`/dev/pts`	Used by **Unix98** pseudo-terminals
usbfs	`/proc/bus/usb`	Used by **USB** sub-system for dynamical devices
sysfs	`/sys` (or elsew here)	Used as a **device tree**
debugfs	`/sys/kernel/debug` (or elsew here)	Used for simple debugging file access

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