Filesystems 2

Filesystems

- Last time: Looked at how we could use RPC to split filesystem functionality between client and server
- But pretty much, we didn't change the design
- We just moved the entire filesystem to the server
  - and then added some caching on the client in various ways

You can go farther...

- But it requires ripping apart the filesystem functionality into modules
- and placing those modules at different computers on the network
- So now we need to ask...
  what does a filesystem do, anyway?

- Well, there's a disk...
  - disks store bits. in fixed-length pieces called sectors or blocks
- but a filesystem has ... files. and often directories. and maybe permissions. creation and modification time. and other stuff *about* the files. ("metadata")

Filesystem functionality

- Directory management (maps entries in a hierarchy of names to files-on-disk)
- File management (manages adding, reading, changing, appending, deleting) individual files
- Space management: *where* on disk to store these things?
- Metadata management

Conventional filesystem

- Wraps all of these up together
- Useful concepts: [pictures]
  - "Superblock" -- well-known location on disk where top-level filesystem info is stored (pointers to more structures, etc.)
  - "Free list" or "Free space bitmap" -- data structures to remember what's used on disk and what's not. Why? Fast allocation of space for new files.
  - "inode" - short for index node - stores all metadata about a file, plus information pointing to where the file is stored on disk
    - Small files may be referenced entirely from the inode; larger files may have some indirection to blocks that list locations on disk
  - Directory entries point to inodes
  - "extent" - a way of remembering where on disk a file is stored. Instead of listing all blocks, list a starting block and a range. More compact representation, but requires large contiguous block allocation.

Filesystem "VFS" ops

- VFS: ('virtual filesystem'): common abstraction layer inside kernels for building filesystems -- interface is common across FS implementations
  - Think of this as an abstract data type for filesystems
  - has both syntax (function names, return values, etc) and semantics ("don't block on this call", etc.)
- One key thing to note: The VFS itself may do some caching and other management...
  - in particular: often maintains an inode cache

FUSE

- The lab will use FUSE
  - FUSE is a way to implement filesystems in user space (as normal programs), but have them available through the kernel -- like normal files
- It has a kinda VFS-like interface

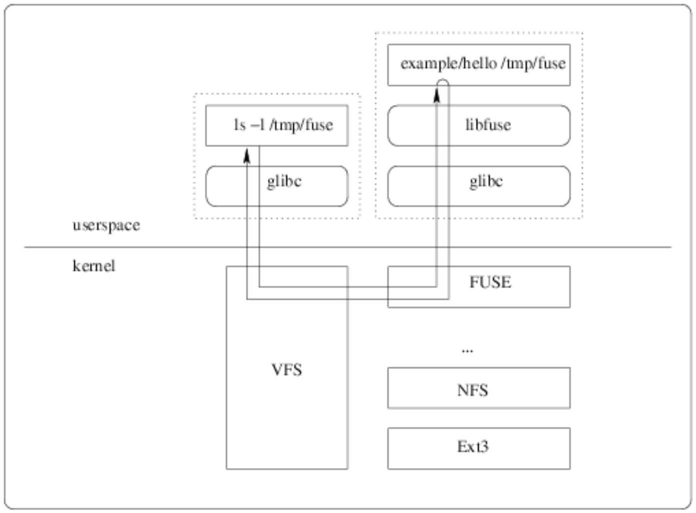


Figure from FUSE documentation

Directory operations

- readdir(path) - return directory entries for each file in the directory
- mkdir(path) -- create a new directory
- rmdir(path) -- remove the named directory

File operations

- mknod(path, mode, dev) -- create a new "node" (generic: a file is one type of node; a device node is another)
- unlink(path) -- remove link to inode, decrementing inode's reference count
  - many filesystems permit "hard links" -- multiple directory entries pointing to the same file
- rename(path, newpath)
- open -- open a file, returning a file handle
- , read, write
- truncate -- cut off at particular length
- flush -- close one handle to an open file
- release -- completely close file handle

Metadata ops

- getattr(path) -- return metadata struct
- chmod / chown (ownership & perms)

Back to goals of DFS

- Users should have same view of system, be able to share files
- Last time:
  - Central fileserver handles *all* filesystem operations -- consistency was easy, but overhead high, scalability poor
  - Moved to NFS and then AFS: Added more and more caching at client; added cache consistency problems
    - Solved using timeouts or callbacks to expire cached contents

Protocol & consistency

- Remember last time: NFS defined operations to occur on unique inode #s instead of names... why? *idempotency*. Wanted operations to be unique.
  - Related example for today when we're considering splitting up components: moving a file from one directory to another
  - What if this is a complex operation ("remove from one", "add to another"), etc.
    - Can another user see intermediate state?? (e.g., file in both directories or file in neither?)
- Last time: Saw issue of *when* things become consistent
  - Presented idea of close-to-open consistency as a compromise

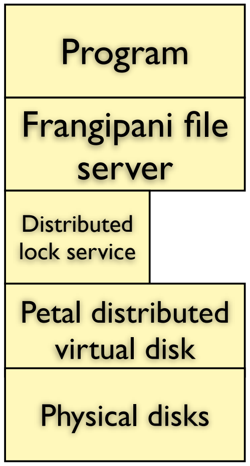
Scaling beyond...

- What happens if you want to build AFS for all of CMU? More disks than one machine can handle; more users than one machine can handle
- Simplest idea: Partition users onto different servers
  - How do we handle a move across servers?
  - How to divide the users? Statically? What about load balancing for operations & for space? Some files become drastically more popular?

"Cluster" filesystems

- Lab inspired by Frangipani, a scalable distributed filesystem.
- Think back to our list of things that filesystems have to do
  - Concurrency management
  - Space allocation and data storage
  - Directory management and naming

Frangipani design



Frangipani stores all data (inodes, directories, data) in petal; uses lock server for consistency (eg, creating file)

Petal aggregates many disks (across many machines_ into one big "virtual disk". Simplifying abstraction for both design &implementation. exports extents - provides allocation, deallocation, etc.
Internally: maps (virtual disk, offset) to (server, physical disk, offset)

Consequential design

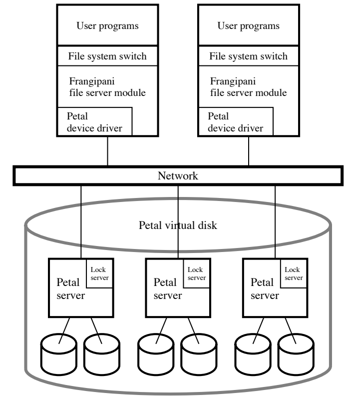


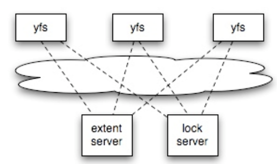
Figure 2: **Frangipani structure.** *In one typical Frangipani configuration, some machines run user programs and the Frangipani file server module; others run Petal and the distributed lock service. In other configurations, the same machines may play both roles.*

Compare with NFS/AFS

- In NFS/AFS, clients just relay all FS calls to the server; central server.
- Here, clients run enough code to know *which* server to direct things to; are active participants in filesystem.
- (n.b. -- you could, of course, use the Frangipani/Petal design to build a scalable NFS server -- and, in fact, similar techniques are how a lot of them actually are built. See upcoming lecture on RAID, though: replication and redundancy management become key)

Lab 2: YFS

- Yet-another File System. :)
- Simpler version of what we just talked about: only one extent server (you don't have to implement Petal; single lock server)



- Each server written in C++
- yfs_client interfaces with OS through fuse
- Following labs will build YFS incrementally, starting with the lock server and building up through supporting file & directory ops distributed around the network

Warning

- This lab is difficult.
  - Assumes a bit more C++ than lab 1 did.
- Please please please get started early; ask course staff for help.
- It will not destroy you; it will make you stronger. But it may well take a lot of work and be pretty intensive.