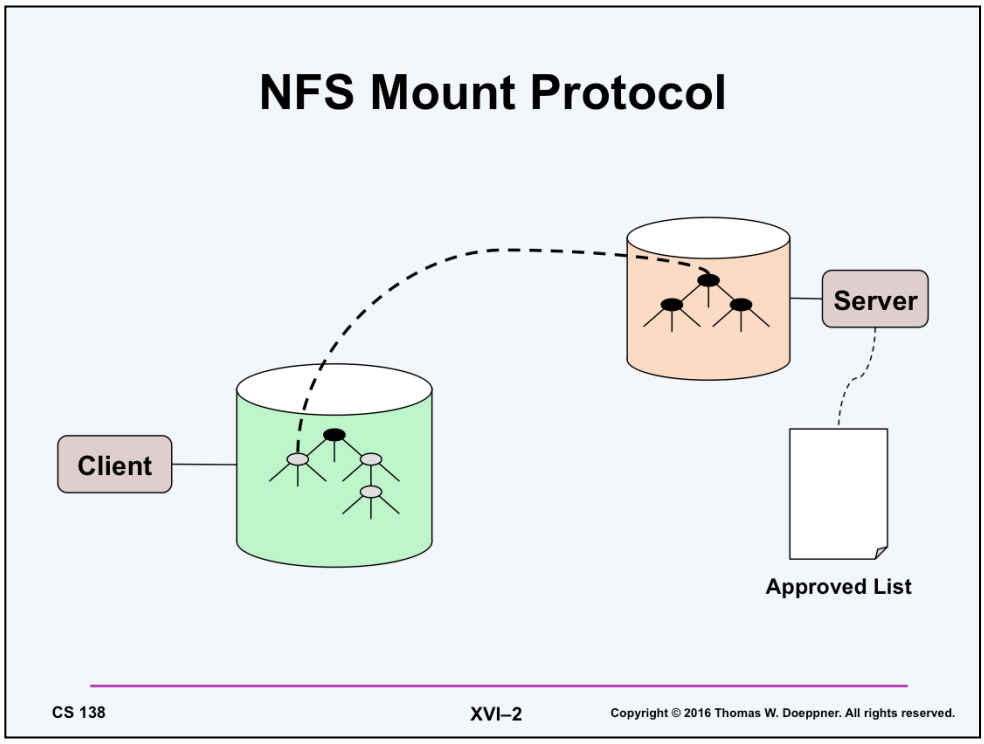
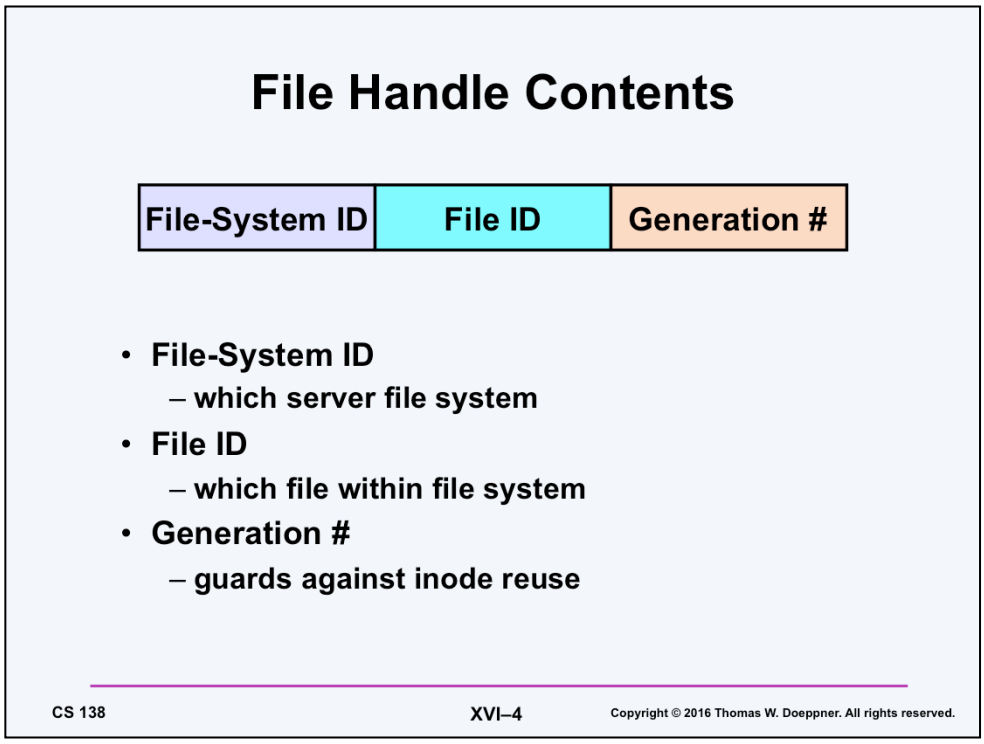
# Distributed File Systems (Part 2)



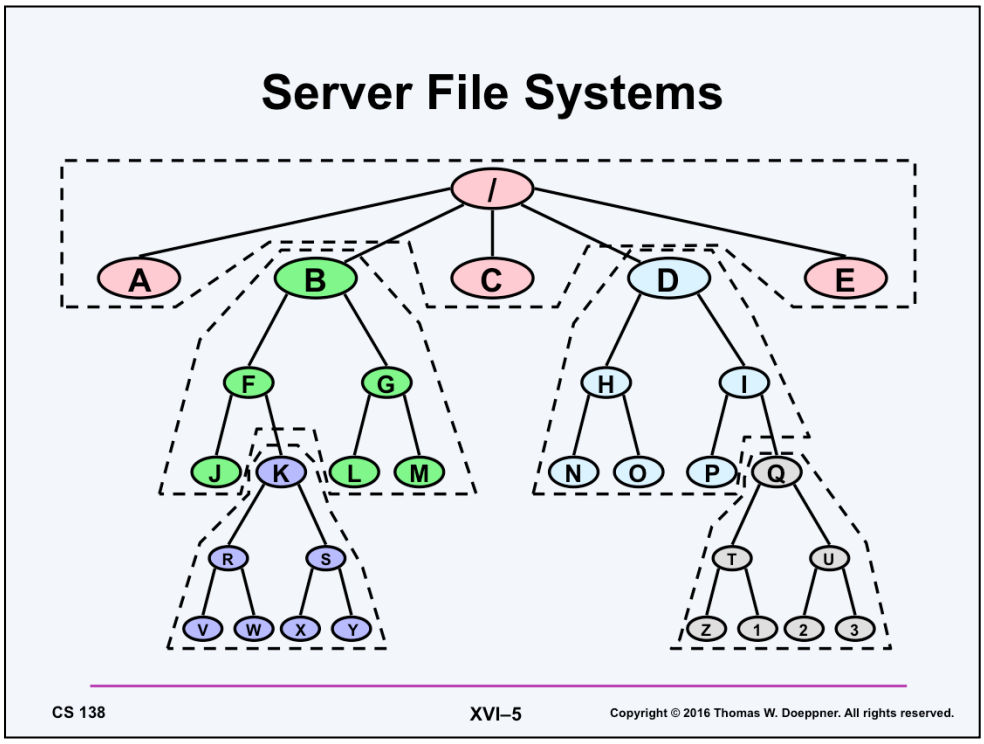

Servers divide their files up into disjoint collections called *file systems*, each of which contains a rooted directory tree naming all of its members. Servers, as specified in local configuration files, specify which file systems, or subtrees within a file system, are available to which clients. A client can then *mount* a remote file system. This entails superimposing the root of the remote file system on top of a directory in the client's current naming tree. The root of the remote file system (the mounted file system) effectively replaces the mounted-on directory. Thus the remote file system is attached to the client's naming tree at the mounted-on directory (and the previous contents of that directory are invisible as long as the remote file system remains mounted). The mount protocol provides some security (by restricting which clients are allowed to mount a file system) and gives the client node the means for fitting remote file systems into its file-system name space.

# File Handles

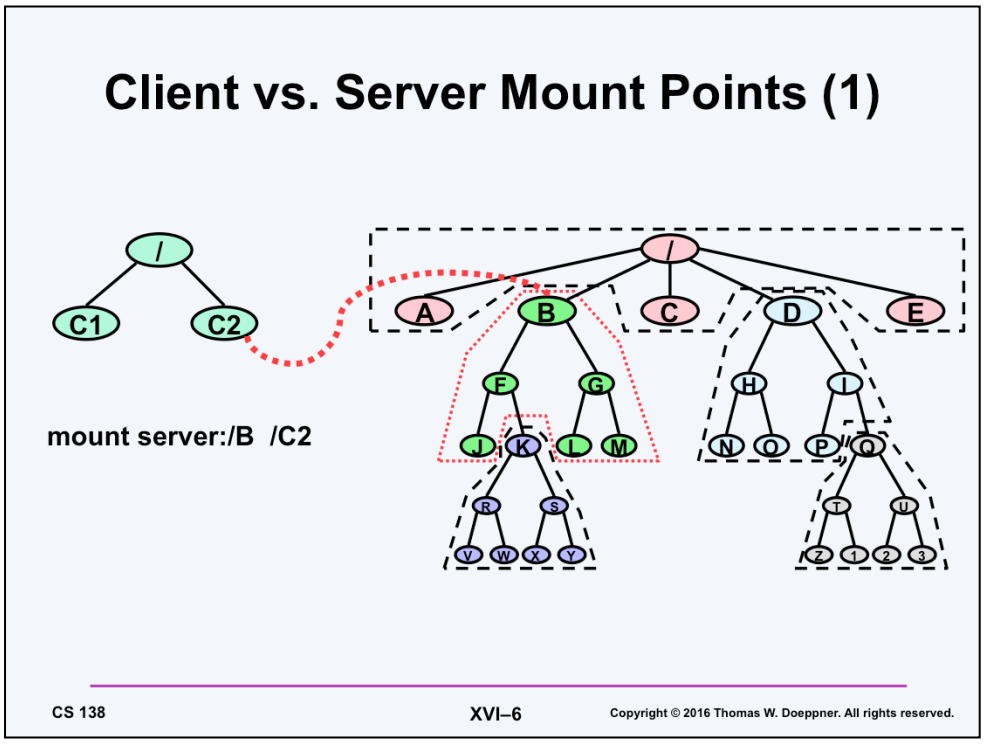
- Servers provide opaque *file handles* to clients to refer to files
  - contents mean nothing to clients
  - identify files on server
- Clients contact server via mount protocol to obtain file handles of roots of exported file systems



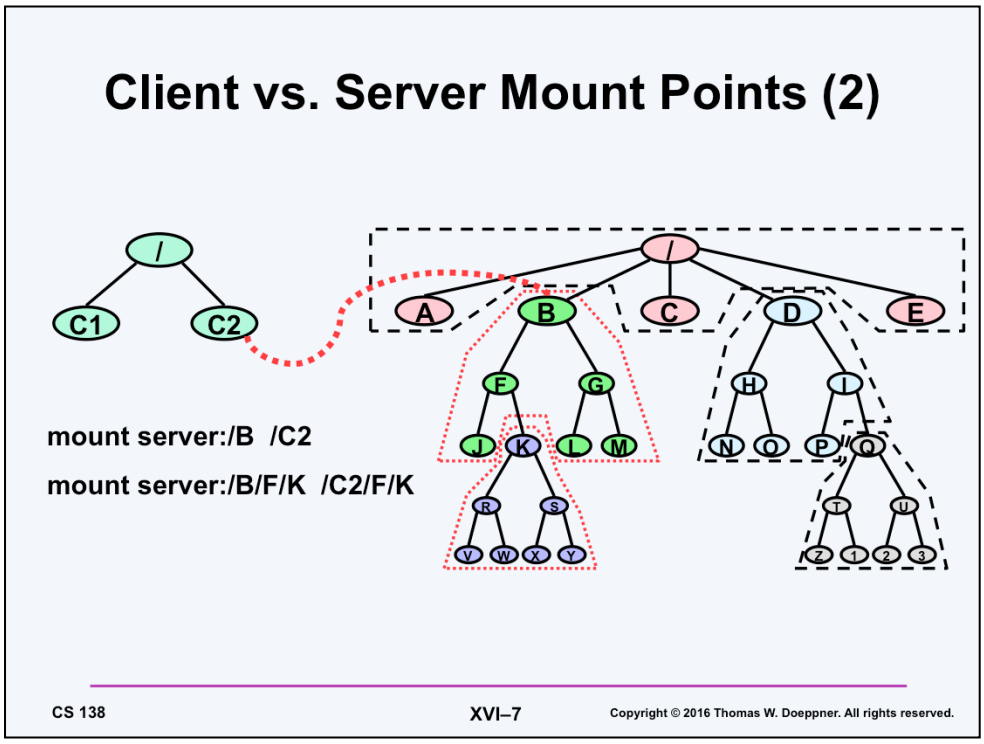

The file handle is used to identify the file to the server for all subsequent operations, including reading and writing. It consists of three items: the remote *file-system ID*, the *file ID* (relative to the file system — for example, this might be the inode number), and a *generation number*. The first two items might seem sufficient to identify a file, but the third component is necessary: Suppose that you have opened a file, but, while you have it open, someone else deletes the file. Furthermore suppose that a new file is created that reuses the inode of the original file. If the file handle consisted only of the remote file-system ID and file ID, there would be no way for it to distinguish between the old file (which no longer exists) and the new file (which has the same file ID (or inode) as the old file). The generation number is an integer that is stored with the inode and that is incremented when the file associated with the inode is deleted. Thus each use of the same inode (and hence file ID) has a different generation number, and thus, in our example, the server can determine that the file referred to by your file handle doesn't exist any more. NFS's straightforward way of telling this to you is to print the message "stale file handle" on your console.




This slide shows a stylized directory hierarchy on a server, split into its component file systems. From the point of view of applications running directly on the server, there is just one integrated tree. However, the server exports the file systems independently to its clients.




Here a client has mounted the server file system rooted at /B onto its directory /C2. Thus, from the client's perspective, the previous contents of directory C2 is replaced with the server's /B. On the server, one could follow the path /B/F/K/S, but this path crosses a mount point on the server. The corresponding path on the client would start: /C2/F/K. However, the client would not see a file system mounted at K — the mount point exists only on the server.




Now the client mounts the server's file system /B/F/K on the client's directory /C2/F/K; the client can now follow the path /C2/F/K/S.

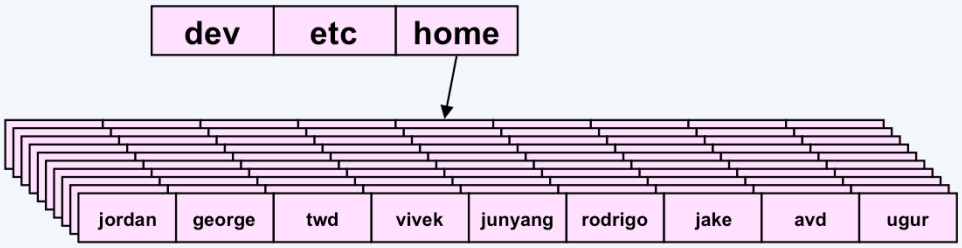
# Local vs. Global Namespace

- Local namespace
  - each host configures its own file-system namespace
  - NFS clients each mount the appropriate remote file systems
- Global namespace
  - all hosts share the same namespace
  - not done in early NFS

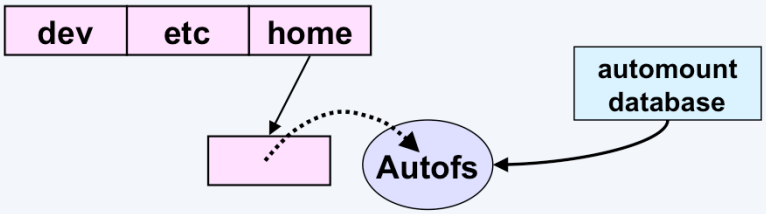
# Mount Protocol Problems

- Local namespaces don't work
- Achieve global name space by having each client mount everything consistently
  - giving each client a table listing all possible mounts is administratively difficult
  - performing all possible mounts is time consuming
    - mounting is a "heavyweight" operation

# Rather than this …



# … this



## Automounting: 2000

- Maintain description of global namespace in global database: NIS
- Do mounts only when needed
- Automount times out after period of unuse

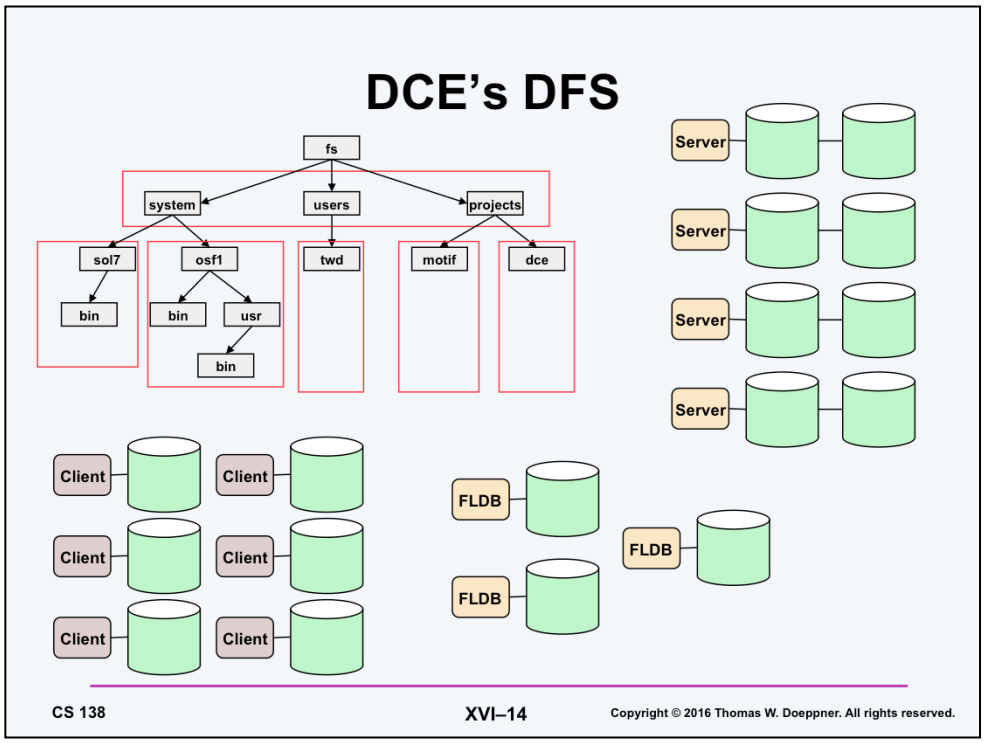
 

To provide something resembling a global namespace, the *network information system* (NIS, originally known as "Yellow Pages," until Sun discovered the name was trademarked by someone else) is used to hold information (in the form of an NIS map) describing the layout of the namespace, in particular which servers provide which file systems and where they should be mounted. NIS provides this information in the form of a completely replicated distributed database.

Automounting is the notion of having clients delay mounting remote file systems until they're needed, then using information from NIS to determine what should be mounted.

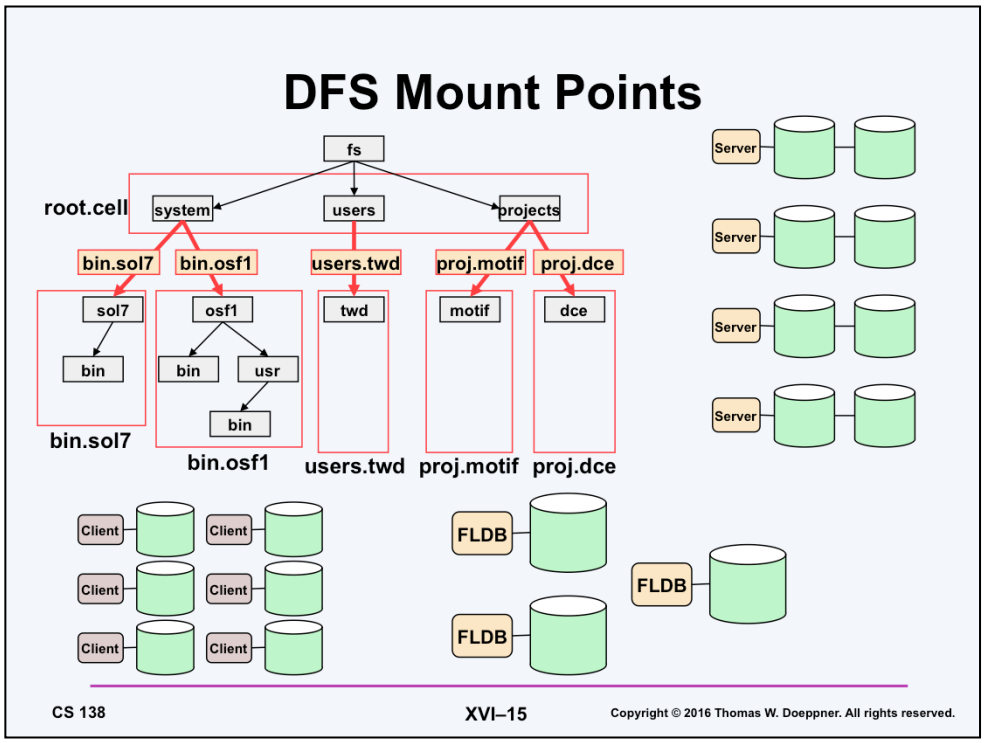
# Automounting: 2016

- Global namespace maintained in LDAP database
  - lightweight directory access protocol
    - vendor neutral
  - everything mounted at boottime
    - fewer, but larger, file systems
  - no timeout




DFS (DCE's distributed file system) provides a cell-wide file system (a cell is a potentially large collection of machines under the same administration), organized into a cell-wide directory hierarchy. This hierarchy is logically partitioned into pieces called *filesets*. These filesets are stored on the DFS servers, using the server's local file systems (e.g. FFS). This mapping of fileset to server is stored in a distributed database known as the *fileset location database* (FLDB).

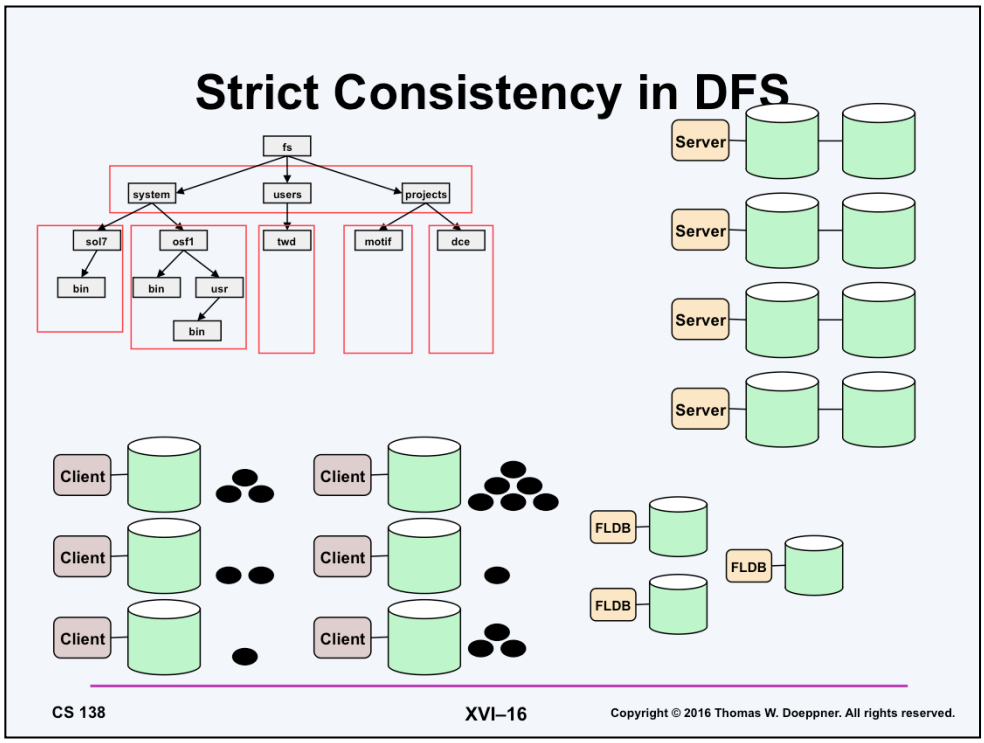
Clients contact the FLDB to determine the locations of filesets. To minimize network use, server load, and average client access time, the clients buffer portions of files on the clients' local disks.




Filesets are named in a space that is independent of the directory hierarchy. This fileset name space is mapped via a distributed database called the *fileset location database* into the servers that manage them.

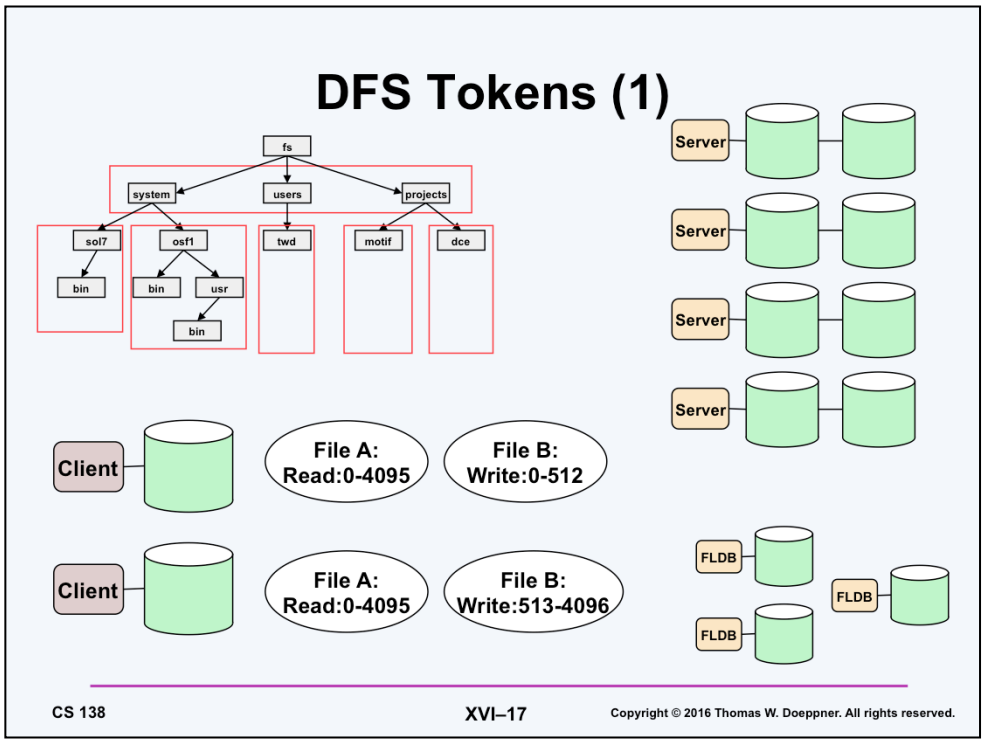
DFS mount points are implemented as symbolic links, where the value of the link is the name of the fileset mounted in the directory. A client traversing such a mount point looks up the fileset name in the fileset location database, which tells it which server hosts the fileset. The client then contacts that server to follow the rest of the path.

The effect is that DFS provides a single global name space that is shared by all clients. Unlike NFS, the name space isn't assembled on each client, but is built into the directory hierarchy.




DFS maintains a cache of recent file requests on disk (or, for diskless workstations, in memory). DFS file servers hand to a client an object known as a token (the dark ovals in the slide), which informs a client that its cached copy of the file (within a range of bytes) is (still) valid. There are a number of different types of tokens, e.g. read tokens and write tokens, depending upon what the client is doing with the file. As long as the client's *cache manager* holds that token, operations on the file can be satisfied locally without any network requests for data. Tokens are revoked when a request comes into the file server that is incompatible with the tokens held by clients, e.g. a write request that changes data on the server while clients hold read tokens for the same file and same byte range.

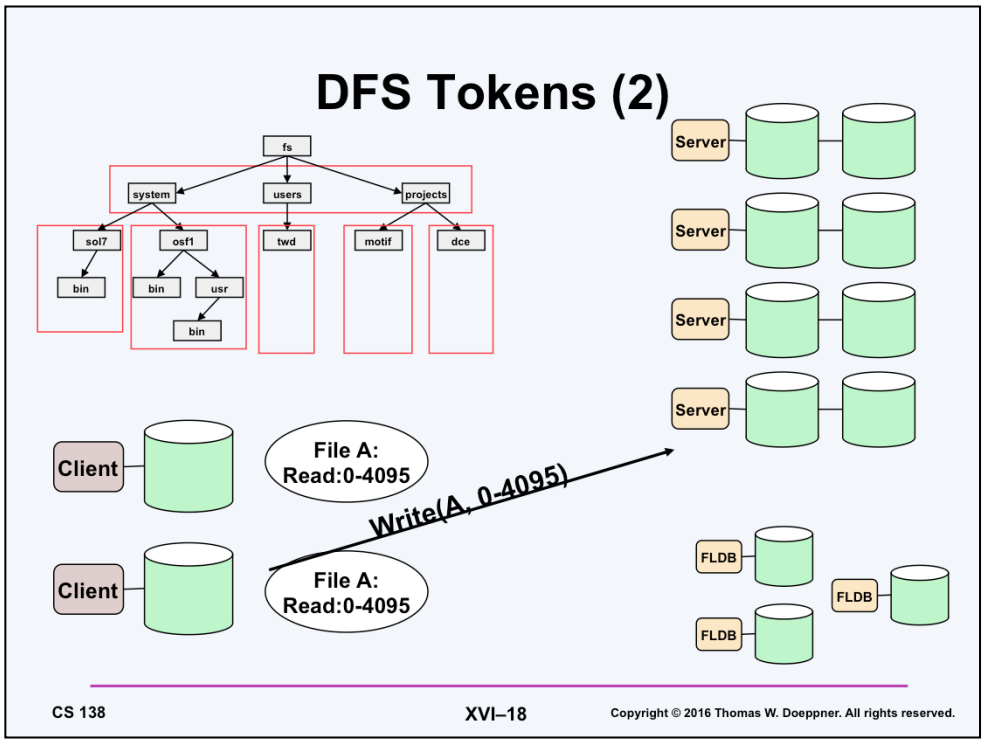
Files are copied between DFS file servers and DFS clients in units called *chunks*. The default chunk size for clients with caches stored on disk is 64K, but it can range from 8K to 256K.



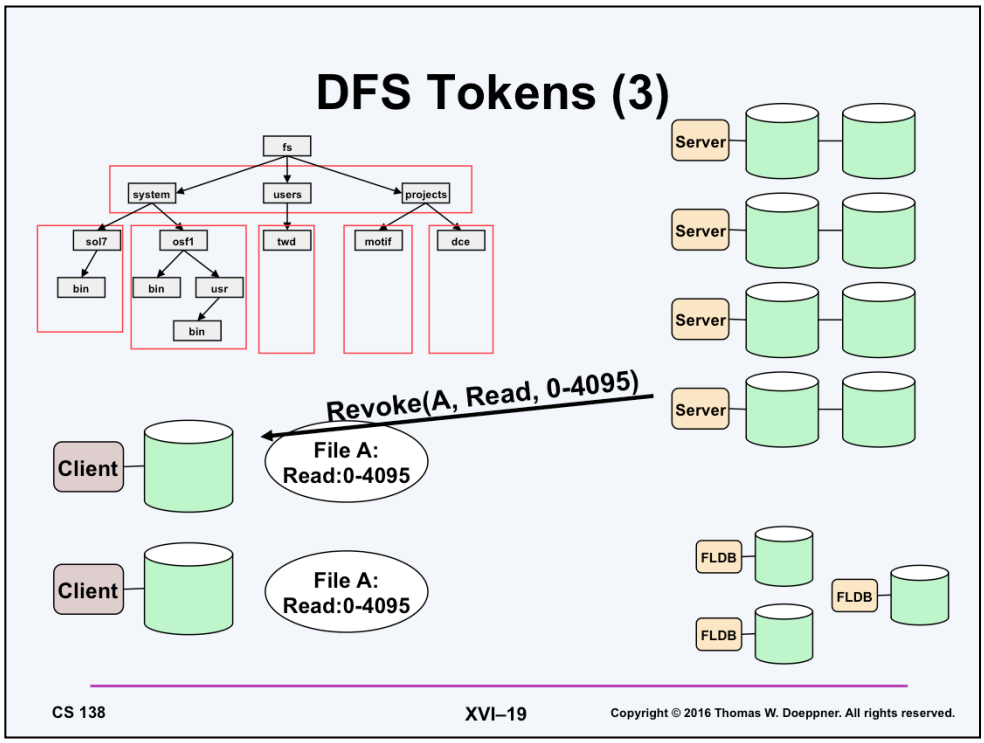

DFS uses *tokens* to ensure Unix single-system semantics across a distributed environment.

A token can be thought of as a certificate, manufactured by the file server and delivered to the client, that gives the client a set of rights to perform certain specified operations in its cache. Tokens contain a type field that specifies the particular operation (DATA_READ, DATA_WRITE, STATUS_READ, STATUS_WRITE, LOCK_READ, LOCK_WRITE, OPEN_EXCLUSIVE, OPEN_READ, OPEN_WRITE, OPEN_SHARED, OPEN_DELETE, OPEN_PRESERVE, SPOT_HERE, SPOT_THERE). In addition, DATA and LOCK tokens contain a byte range and apply only to data within that range.

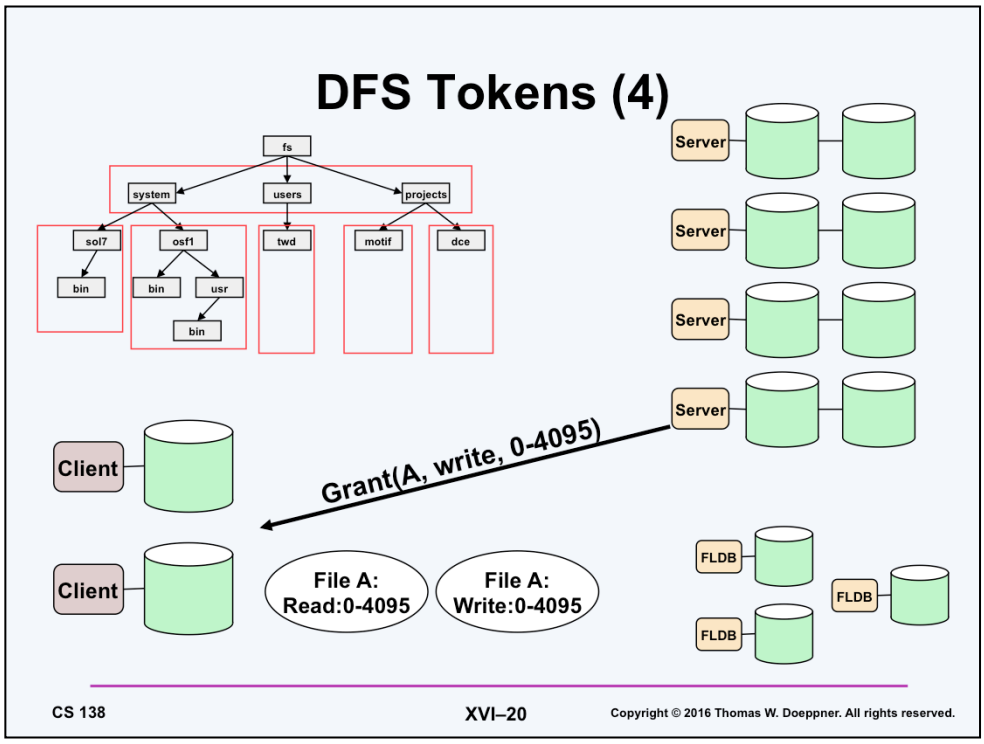
Two tokens are said to be *compatible* if they can be held by different clients simultaneously, for example, two DATA_READ tokens for the same range of bytes in the same file. Tokens are said to be incompatible if the semantics of the two tokens conflicts. For example, if a client requests a DATA_WRITE token for a particular range of bytes in a file, any outstanding DATA_READ or DATA_WRITE tokens must first be revoked and returned to the file server.



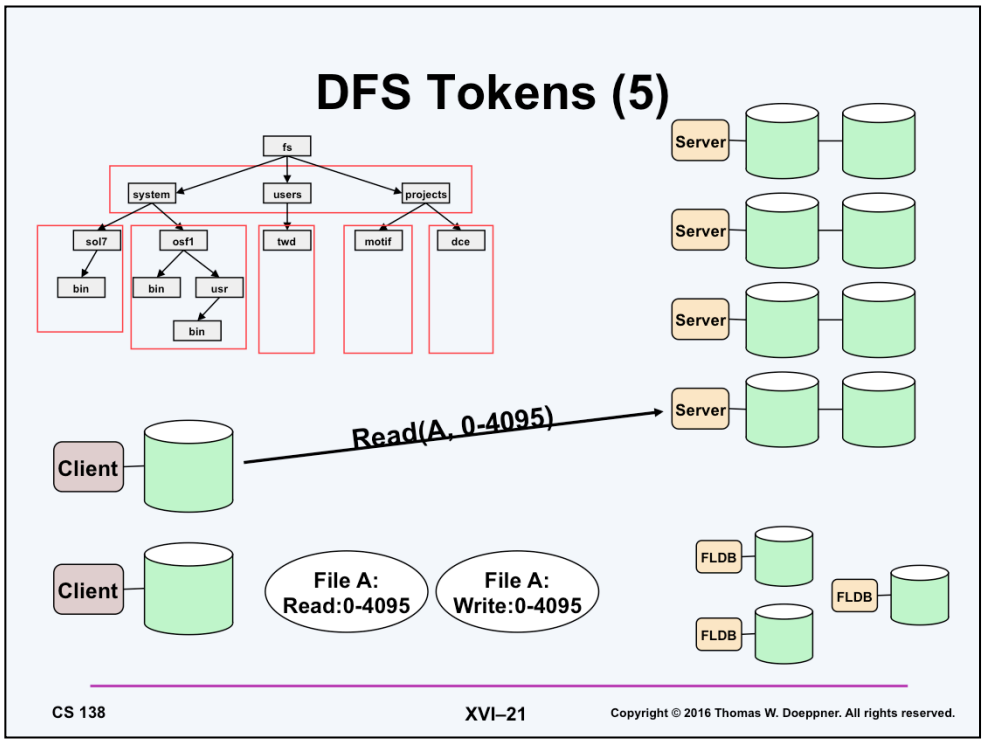

In the next few slides we go through an example in which two clients are sharing a file. At the moment, both clients have read tokens for a portion of the file in their caches and can read without interference. However, one of the clients desires to modify the file. In response to the user's *write* request, the DFS code on the client sends a request to the server asking for a write token.



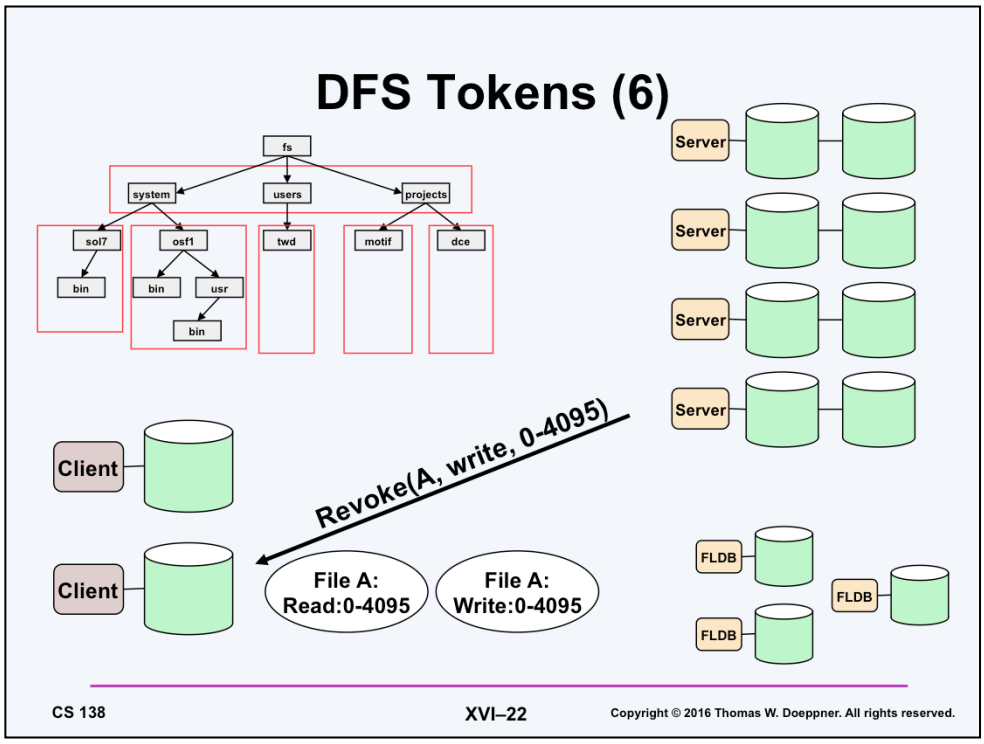

If one client is to be modifying the file, then, for consistency, no other clients should be reading the file. Thus the server sends a *revoke* request to the other client, demanding that it give back its read token for the file.



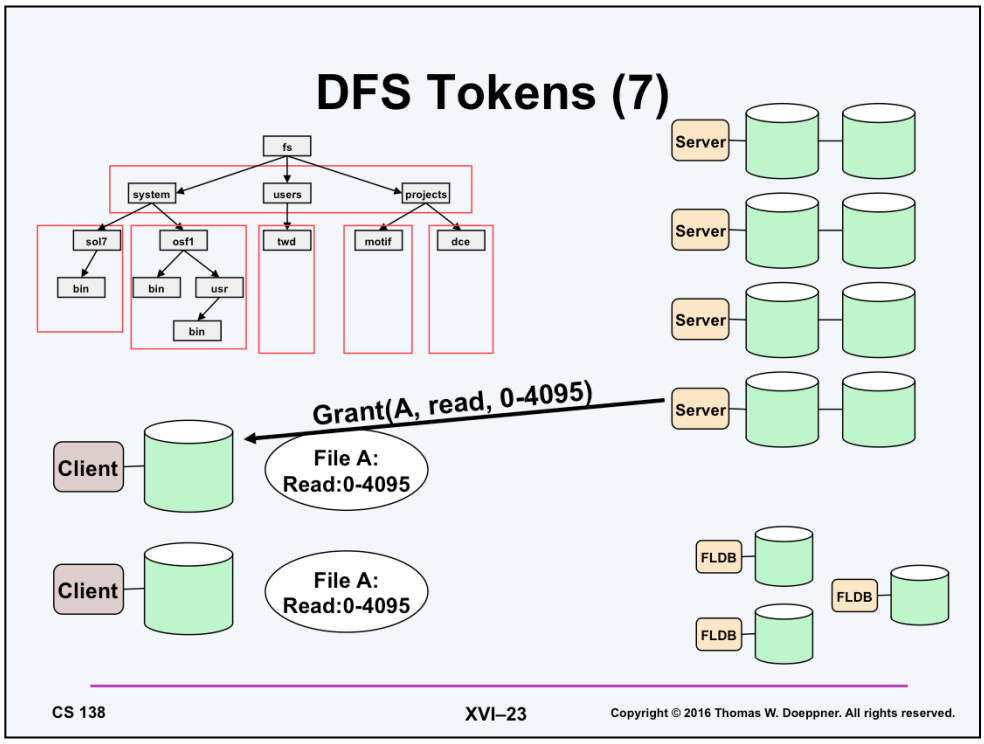

The server now grants write access to the original client by giving it a write token for the desired portion of the file.



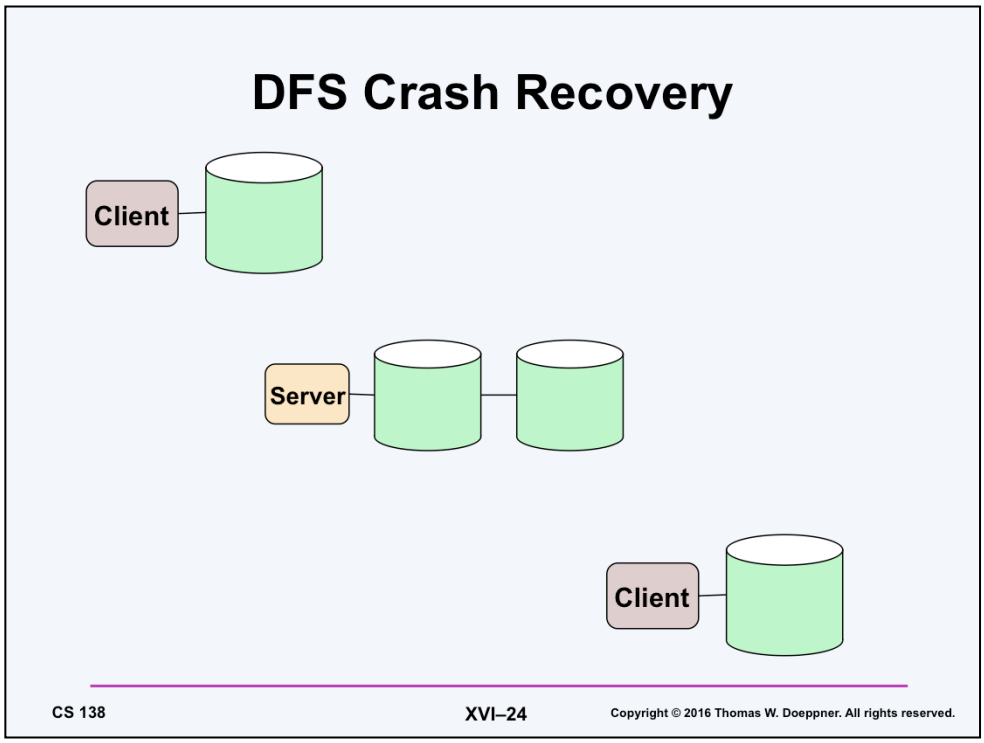

Now the other client decides to read from the file again.




The server must now send a revoke request to the first client, asking for both the write token and the modified portion of the file.




Finally, a new read token is granted to the second client.




Since DFS must maintain a lot of state information (e.g., which tokens are out), its crash recovery is much more complicated than Basic NFS's. Three independent things could go wrong:

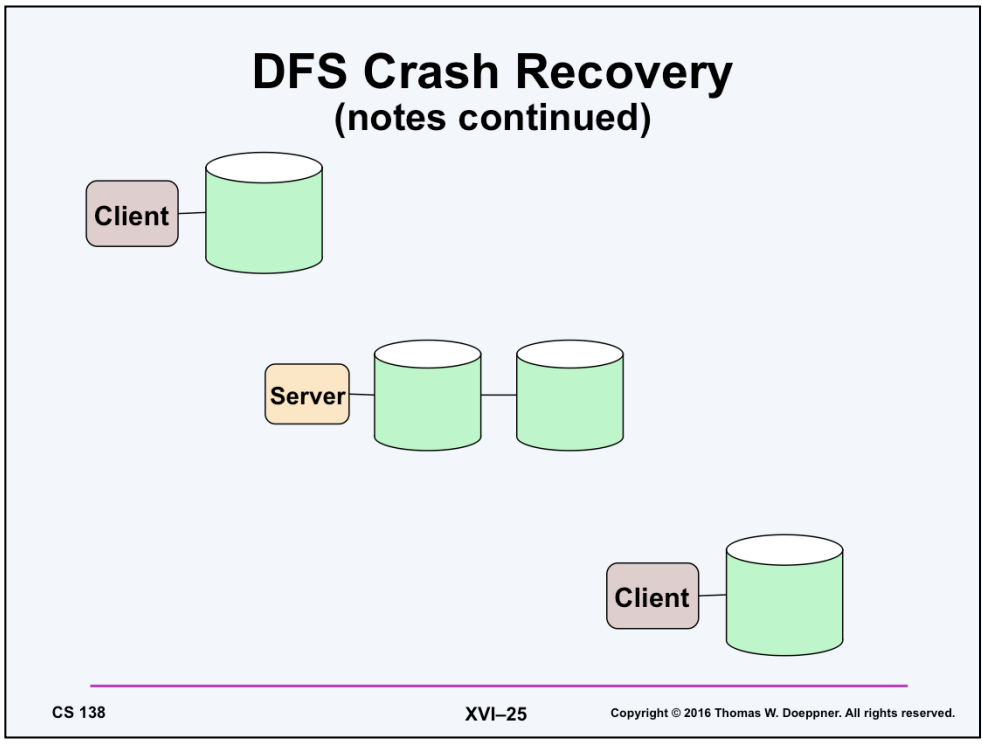
- A client could crash: thus the server will need to reclaim all the tokens that were held by the client.
- A server could crash: token information is not held in non-volatile storage. It must somehow be recreated when the server comes back up.
- The network could fail: though both client and server remain up, neither can communicate with the other.

There are two features that we would like DFS to provide:

- The client should be able to use its cache even if the server is down or not accessible.
- The server should be able to revoke tokens from a client if the client is down or not accessible.

If either the server or the client has crashed, then providing these two features is not difficult. But if a network outage occurs and the server and client become separated from each other but both continue to run, then the two features conflict with each other.

DFS is forced to use a compromise approach (there is no other alternative). If the client cannot contact the server, then it will continue to use its cache until its tokens expire — they are typically good for two hours, though they are normally refreshed every minute or so. However, if the server is actually up and running, but is somehow disconnected from the client, then the server might want to revoke the tokens. If the server has no need to revoke tokens, then it does nothing. But if some other client that is communicating with the server attempts an operation that conflicts with the unresponsive client's tokens, then the server is forced to take action.




If the server hasn't heard from the client for a few minutes, then it can unilaterally revoke the client's tokens. This means that when the client does resume communication with the server, it may discover that not only are some of its tokens no longer good, but some of its modifications to files may be rejected.

To protect client applications from such unexpected bad news, the client-side DFS code will cause attempts to modify a file to fail if it has discovered that the server is not responding. A client program can take measures to deal with this problem by repeatedly retrying operations until the server comes back to life.

# DFS Recovery Problems

- Client application must participate!
  - must recognize that operation returns "timed-out" error
  - must retry
- Due to semantics of tokens, it isn't feasible to provide NFS-style hard mount




Another way of stating the last bullet is that it's the weak semantics of (stateless) NFSv2 and v3 that makes the hard mount possible.

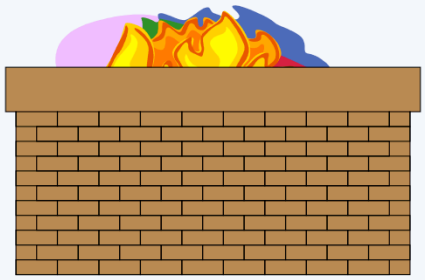
# NFS Version 4

- Better than …
  - NFS version 2
  - NFS version 3
  - CIFS
  - DFS
  - (why aren't we running it?)

# NFSv4: Why?

- Problems with NFSv3
  - firewalls
  - coordination
  - pathological network problems
  - security
  - high performance
  - no support for Windows clients

# Firewall Issues



- Port numbers
  - NFS (v2 and v3) protocol uses 2049
  - mount, network lock manager, and network status manager protocols use dynamic ports
    - firewalls often allow access only to certain standard ports
    - it may be impossible to access dynamic ports from outside a firewall
- Client and Server behind (different) firewalls

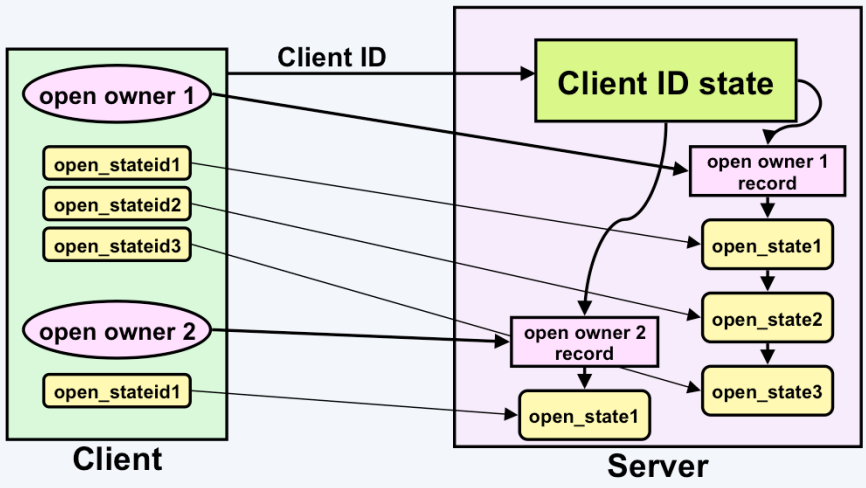



Firewalls present a challenge to the earlier versions of NFS: as explained in the slide, NFS relies on dynamically chosen port numbers, which are likely to be blocked by firewalls. (Note that this doesn't apply to the NFS protocol itself, which uses the well known port number 2049, which firewalls can be configured to accept.) Not only must client requests to the server use dynamic port numbers, but the NLM_GRANTED callback procedure (used in the network lock manager protocol) requires that the server contact the client via a dynamic port.

# Server State

- It's required!
  - mandatory locks
- Hierarchy of state
  - client information
  - open file information
  - lock information

# Open State



# Locking

- Requires additional state on server
  - must be reestablished if server crashes
  - must be removed if client crashes
- For mandatory locking, read/write calls require holding of appropriate locks
  - client must supply "lock owner" with lock requests and read/write requests
  - server must verify that read/write caller owns lock
- Blocking Locks
  - client application must be notified when lock is available

# Implementing Locks Right …

- Handle both Unix and Windows
- Get the semantics right
  - both advisory and mandatory
  - who owns a lock?
- Handle failures sanely
- Make it efficient
  - client-side caching where possible
- Make it doable
  - if lock not currently available
    - server might not be able to send callback
      - client polls server

# Mandatory Locks (1)

- Just like advisory locks, but you can't ignore them
  - require state on server
  - state is recovered after a server crash
- Nothing more to say …
  - (wrong …)

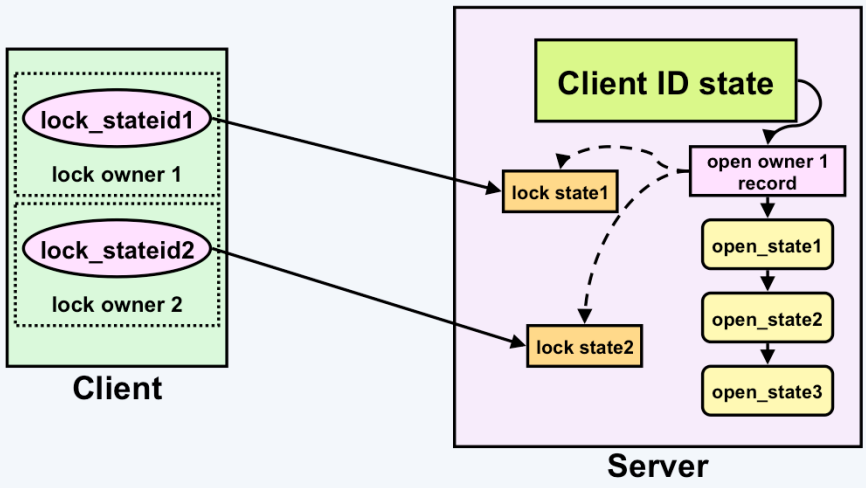
# Mandatory Locks (2)

- Unix semantics
  - locks belong to process
    - not shared among processes
  - locks apply to *file*
    - doesn't matter which file descriptor is used
  - locks disappear on close of any file descriptor for file
  - to turn on mandatory locks:
    - turn on set-gid bit
    - turn off group-execute permission bit
- Windows semantics
  - locks belong to process
    - not shared among processes
  - locks apply to file descriptor (Windows file handle)
    - matters which one is used
  - locks disappear only when appropriate file handle is closed
  - all locks are mandatory




Note that NFSv4 is to work with both Unix and Windows clients.

# Lock State



# State Recovery

- Server crash recovery
  - clients reclaim state on server
    - grace period after crash during which no new state may be established
- Client crash recovery
  - server detects crash and nullifies client state information on server

# Coping with Non-Responsiveness

- Leases
  - locks are granted for a fixed period of time
    - server-specified lease
  - if lease not renewed before expiration, server may (unilaterally) revoke locks and share reservations
    - most client RPCs renew leases
  - clients must contact server periodically
    - if *clientid* is rejected as stale, then server has restarted
    - server's grace period is equal to lease period

## Pathological Network Problems

1) Client 1 obtains a lock on a portion of a file
2) There's a network partition such that client 1 and server can no longer communicate
3) The server crashes and restarts
4) Client 2 obtains a lock on the same portion of the same file, modifies the file, and then releases the lock
5) The server crashes and restarts and the network partition is repaired
6) Client 1 recontacts the server and reclaims its lock

As far as client 1 is concerned, the server crashed at step 2 (since the client couldn't contact it) and didn't restart until step 5. If the server, at step 6, has no information about its lock state prior to the crash, it cannot recognize that client 1 should not be allowed to reclaim its lock in step 6.

# Coping …

- Possibilities
  1) server keeps all client state in non-volatile storage
  2) server keeps all client state in volatile storage and refuses all reclaim requests (effectively emulating CIFS)
  3) something in between …

# Compromise

- Keep enough client state in non-volatile memory to know which clients were active at time of crash
  - will honor reclaim requests from these clients
  - will refuse reclaim requests from others
- What to keep:
  - client ID
  - the time of the client's first acquisition of a share reservation or lock after a server reboot or client lease expiration
  - a flag indicating whether the client's most recent state was revoked because of a lease expiration

# Additional Issues

- Authentication
  - poorly supported in NFSv3
  - extensible (and well supported) in NFSv4
- Authorization
  - Windows clients require ACLs
  - NFSv4 supports Windows-like ACLs
- Parallel I/O
  - pNFS