Distributed File Systems

Distributed File Systems

- DFS : distributed implementation of a file system
  - Files, file servers, and users are all dispersed around the network
- Main goal: DFS should look like a centralized file system to an user
  - Ability to open & update any file on any machine on network
  - Ability to share files same as shared local files

Design Goals

- Network transparency
  - Same set of file operations for both local and remote files
  - Uniform naming scheme for local and remote files
  - Similar access time for local and remote files
- High availability
  - Files should not become unavailable for "small" failures
- Scalability
  - no. of users, file servers, files handled etc.
- Concurrency
  - Handle concurrent access by different clients in the network

DFS Architecture

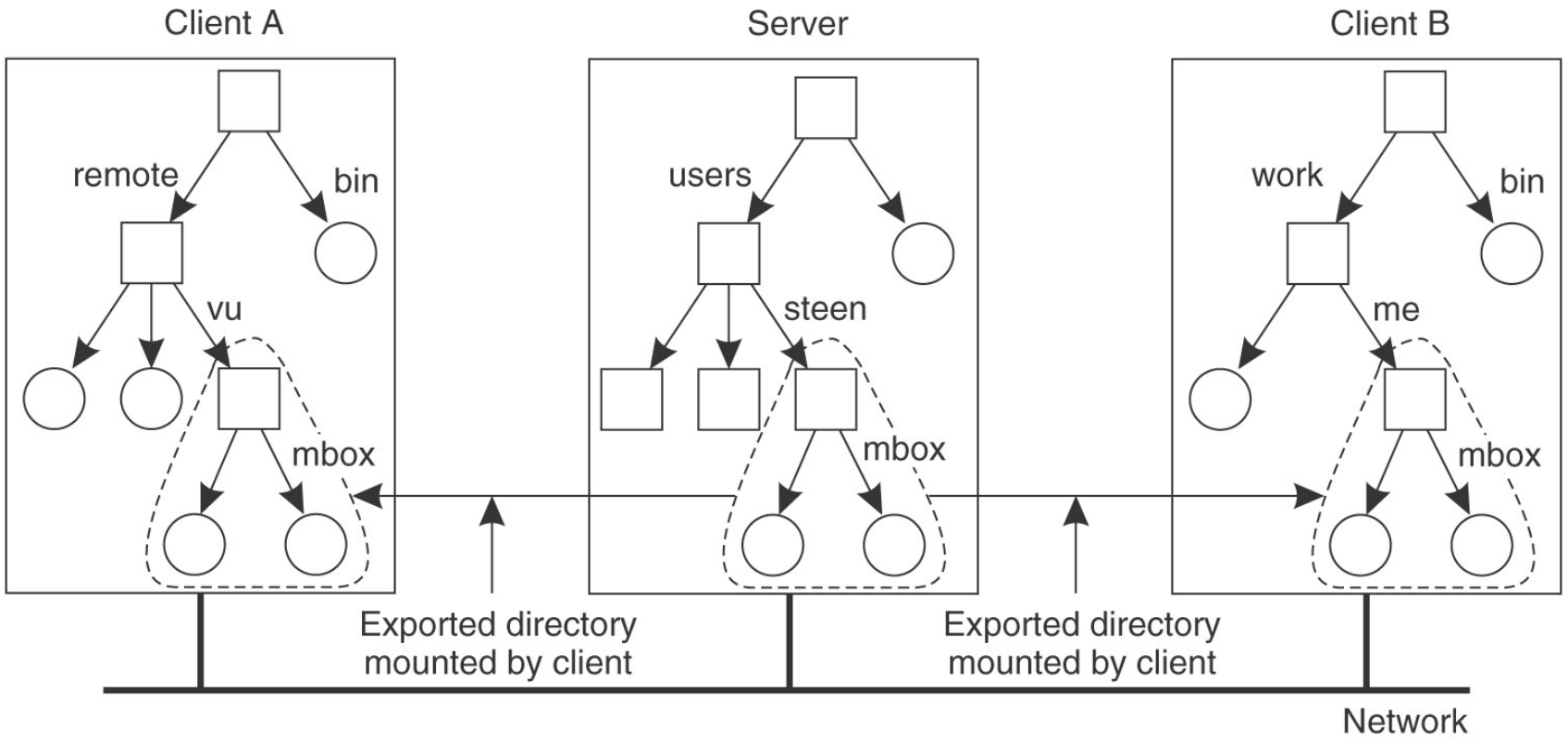
- Client Server Architecture
  - Network File System (NFS)
- Cluster Based
  - Google File Systems

Design Issues: Naming Schemes

- Files named by combination of host name and local name
  - Not location transparent
- Single global namespace spanning all files
  - Location transparent
  - All systems see the same directory structure
  - A server crash affects all machines
  - Example: Andrew File System (AFS)

- Mount remote directories to local directories
  - Location transparent
  - Directory structure seen by different machines possibly different
  - Mount only when needed, what is needed
  - Mounted remote directories can be accessed transparently
  - Example: Network File System (NFS)

Mounting Remote Directories (NFS)



Pathname Translation

- Consider /remote/vu/mbox in A
- /remote/vu looked up in A the usual way
- Low level entry for vu contains information that it is actually /users/steen in server
- Request sent to server to look up /users/steen/mbox
- What if the name crosses multiple machine boundaries?

Caching to Improve Performance

- Reduce network traffic by retaining recently accessed disk blocks in local cache
  - Repeated accesses to the same information can be handled locally from the cached copy
- If data accessed not in cache, copy of data brought from the server to the local cache
  - Copies of parts of file may be scattered in different caches.
- Cache-consistency problem – keeping the cached copies consistent with the master file in the presence of write operations

Design Issue: Caching

- Cache location
- Granularity of cached data
- Update policy
- Cache consistency

Cache Location

- In client memory
  - Faster access
  - Good when local usage is transient
  - Enables diskless workstations
- On client disk
  - Good when local usage dominates
  - Can cache larger files
  - Helps protect clients from server crashes

Granularity of Cached Data

- Whole file
  - Easier to maintain consistency
  - High transfer time, specially if only a small part of the file is accessed
- One or more blocks
  - Low transfer time, transfer as and when needed
  - More complex consistency issues
- In general, increasing granularity means higher chance of finding next accessed data, but also higher transfer time

Cache Update Policies

- When is cached data at the client updated in the master file?
- Write-through – write data through to disk when cache is updated
  - Reliable, but poor performance
- Delayed-write – cache and then write to the server later
  - Write operations complete quickly; some data may be overwritten in cache, saving needless network I/O
  - Poor reliability
    - Unwritten data may be lost when client machine crashes
    - Inconsistent data
  - Variation – write dirty blocks back at regular intervals

Cache Consistency

- Is locally cached copy of the data consistent with the master copy?
- Client-initiated approach
  - Client initiates a validity check with server
  - Server verifies local data with the master copy
    - Can use timestamps, version no….
- Server-initiated approach
  - Server records (parts of) files cached in each client
  - When server detects a potential inconsistency, it invalidates the client caches

Sharing Semantics in DFS

- Unix Semantics
  - Read after write
  - Every change becomes instantly visible to all processes
- Session Semantics
  - Same as unix semantics for local clients of a file
  - For remote clients, changes to a file are initially visible to the process that modified the file. Only when the file is closed, the changes are visible to other processes.
- Immutable files

Stateless vs Stateful Service

- Stateless service
  - No open and close calls to access files
  - Each request identifies the file and position in file
  - No client state information in server by making each request self-contained
  - Advantages
    - Better failure recovery
  - Disadvantage
    - Longer request messages, longer processing time

- Stateful Service
  - Client opens a file
  - Server fetches information about file from disk, stores in server memory
    - Returns to client a connection identifier unique to client and open file
    - Identifier used for subsequent accesses until session ends
  - Server must reclaim space used by no longer active clients
  - Advantages
    - Increased performance; fewer disk accesses
  - Disadvantages
    - Poor failure recovery

Network File System (NFS)

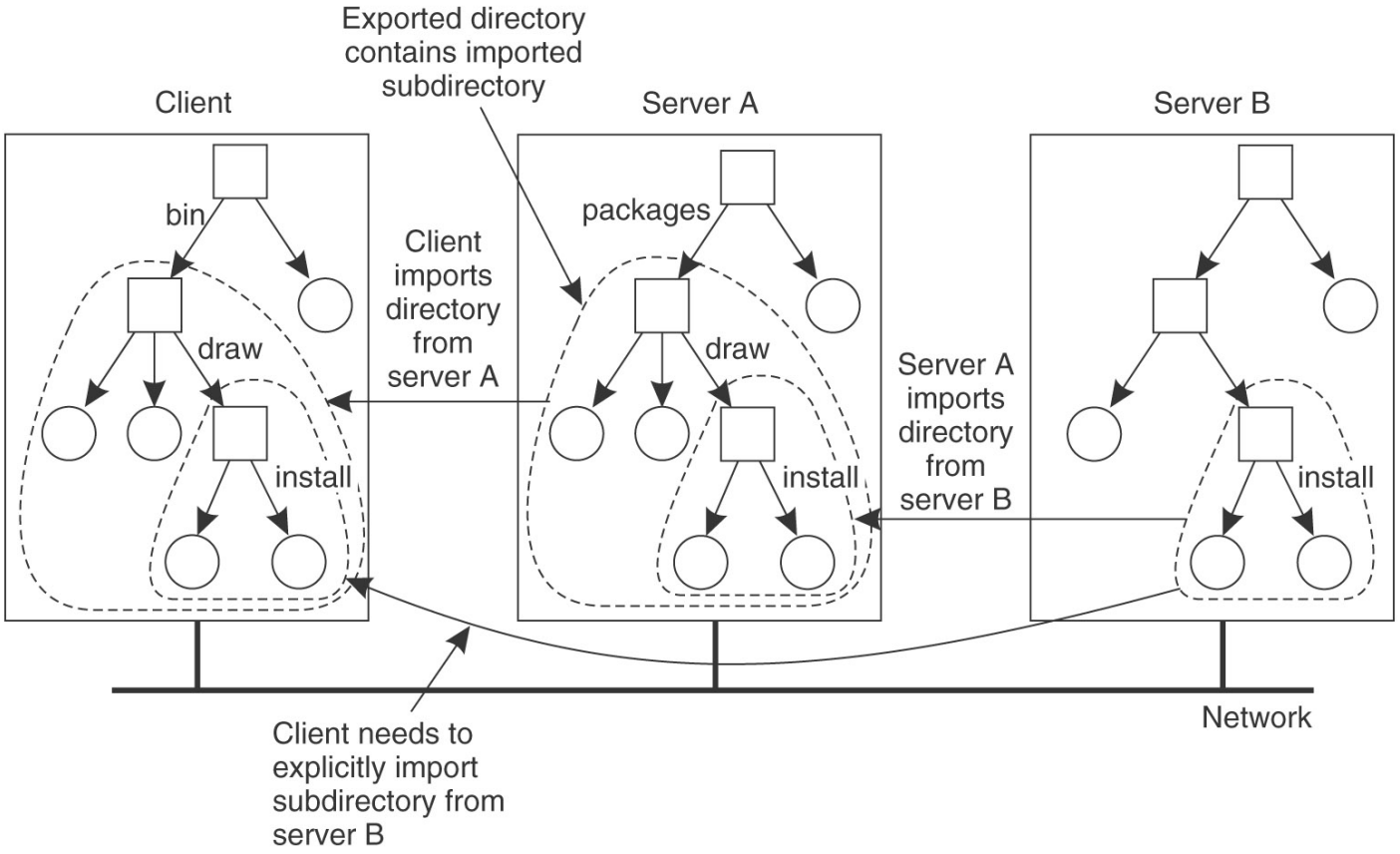
NFS

- Introduced by Sun Microsystems in 1984
- v2 in 1989, v3 in 1995, v4 in 2000 (updated in 2003)
- de facto standard for distributed file access
  - NFSv3 still widely used
  - Current OSs support both v3 and v4
- NFS normally runs over LAN
  - Can run on WAN also, though slower
- Any system may be both a client and server

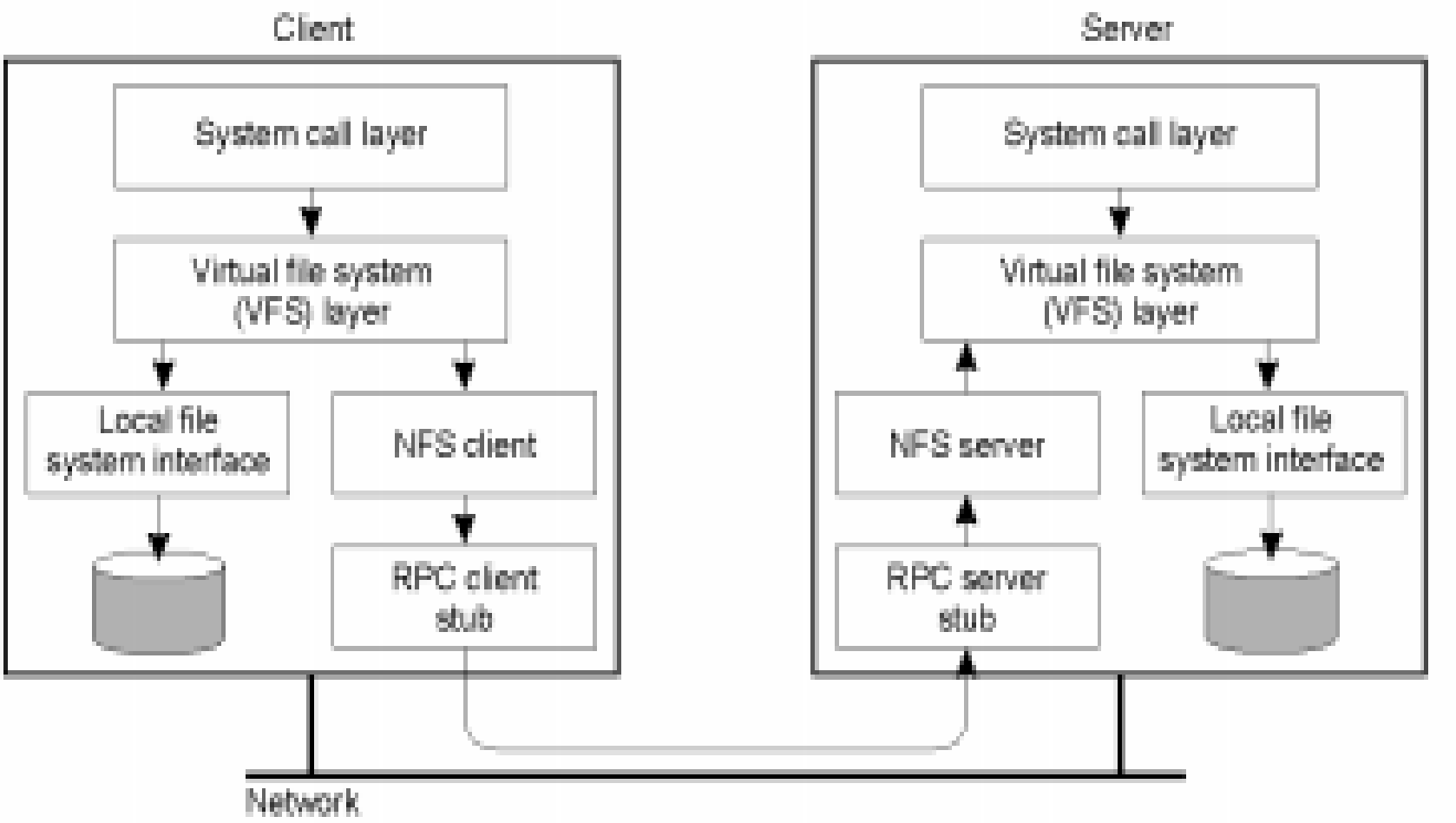
Main Idea

- Server exports parts of a filesystem to clients (Ex. specified in /etc/exports file in Linux)
- Clients "mount" server exported namespace at specific mount points in its namespace tree (specified in /etc/fstab in Linux; can be mounted separately by mount command also)
- Same server filesystem can be mounted at different mount points at different clients, so no single global name space
- Mounts can be cascaded
  - But client must mount from different servers explicitly itself

Nested Mounting (NFS v3)



Basic NFS Architecture



- Location transparent naming (host id needed only during mount)
- Pathname translation
  - Look up each component in the pathname recursively
  - Lookup call made to server when a mount point is crossed
  - Cascading mounts can involve multiple servers during translation

- Set of operations provided for operations on files
  - Lookup, read, write, mkdir, rename, rmdir, readdir, getattr, setattr…
  - No open or close calls (stateless server)
- Most data-modifying calls are synchronous
- Most calls work on an opaque (to client) file handle returned to the client by the server
  - Uniquely identifies the file in the server
- RPC (Remote Procedure Call) used to communicate between server and client

Caching in NFSv3

- Strictly not part of NFS protocol, but used in practice for performance
  - File attributes cached along with file block.
  - Cached file block used subject to consistency checks on file attributes
  - 8 Kb blocks for v2, negotiable for v3
- No locking, no synchronization as part of NFS
  - Separate centralized locking mechanism using lockd
- No clear semantics because of caching nature

Stateless Service

- Server keeps no information of client
- Every client operation provides file handle
- Server caching for performance only
  - Based on recent usage (read ahead block)
- Client caching
  - Client checks validity of cached files (using time stamps)
  - Client responsible for writing out caches
- A cache entry is valid if one of the following is true
  - Cache entry is less than t seconds old
  - Last Modified time of file at server is the same as last modified time of file on client

NFS v4 Improvements

- Improved access and good performance on the Internet
  - Transit across firewalls, perform well in high latency low bandwidth scenarios, scale to very large numbers of clients per server
- Strong security with negotiation built into the protocol
  - Provides a mechanism for clients and servers to negotiate security parameters, requires clients and servers to support a minimal set of security schemes
- Good cross-platform interoperability

NFS v4: COMPUND Operation

- Allows building more complex requests by combining one or more traditional NFS procedures
- Example: read data from a file in one request by combining LOOKUP, OPEN, and READ operations in a single COMPOUND RPC.
- Reduces the number of RPCs needed for logical file system operations
- The operations combined within a COMPOUND request are evaluated in order by the server. Once an operation returns a failing result, the evaluation ends and the results of all evaluated operations are returned to the client
- Still uses filehandle as the id of the file. Passes a filehandle from one operation to another within the sequence of operations

NFS v4: Open and Close

- The NFS version 4 protocol introduces OPEN and CLOSE operations
  - Stateful model
- The OPEN operation provides a single point where file lookup, creation, and share semantics can be combined
- The CLOSE operation also provides for the release of state accumulated by OPEN.

NFS v4: Locking

- Locking
  - No separate lock manager as in v3
  - Lease based locking model as part of NFS
  - State associated with file locks maintained at the server

NFS v4: Caching

- The client checks validity of cached file data when the file is opened
  - Checks with server if the file has been changed
  - Based on this, the client determines if the cached file data should kept or released
- When the file is closed, any modified data is written to the server
- Serializing access to file data can be done through locking

NFS v4: Open Delegation

- Server can delegate some responsibilities to the client for a file
- At OPEN, the server may provide the client either a read or write delegation for the file
  - Assures certain semantics to the client
- If the client is granted an open delegation, the client machine can locally handle open and close operations from other clients in the same machine.
- Allows the client to locally service operations such as OPEN, CLOSE, LOCK, LOCKU, READ, WRITE without immediate interaction with the server

NFS v4: Recalling Delegation

- Delegations can be recalled by the server
- If another client requests access to the file such that the access conflicts with the granted delegation, the server can recall the delegation from initial client
- Problems with delegation and stateful servers
  - Failure handling

NFS v4: Replication

- locations attribute at server can store the location of a file system
- If a file system is migrated in between, the client will receive an error when operating on the file system
- The client can then probe the server query for the new file system location.
- The attribute can also hold multiple server locations to allow replication of file systems
  - Client can use its own policies to access one of the replicas