CSci555: Advanced Operating Systems
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File Systems

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File Systems

- Provide set of primitives that abstract users from details of storage access and management.

Distributed File Systems

- Promote sharing across machine boundaries.
- Transparent access to files.
- Make diskless machines viable.
- Increase disk space availability by avoiding duplication.
- Balance load among multiple servers.

Sun Network File System 1

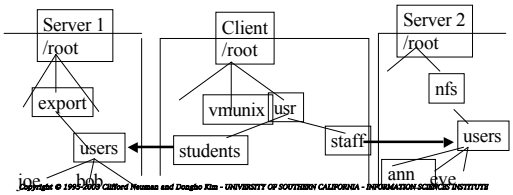
- De facto standard:
  - Mid 80's.
  - Widely adopted in academia and industry.
- Provides transparent access to remote files.
- Uses Sun RPC and XDR.
  - NFS protocol defined as set of procedures and corresponding arguments.
  - Synchronous RPC

Sun NFS 2

- Stateless server:
  - Remote procedure calls are self-contained.
  - Servers don't need to keep state about previous requests.
    - _Flush all modified data to disk before returning from RPC call.
  - Robustness.
    - _No state to recover.
    - _Clients retry.

Location Transparency

- Client's file name space includes remote files.
  - Shared remote files are *exported* by server.
  - They need to be *remote-mounted* by client.



Achieving Transparency 1

- Mount service.
  - Mount remote file systems in the client's local file name space.
  - Mount service process runs on each node to provide RPC interface for mounting and unmounting file systems at client.
  - Runs at system boot time or user login time.

Achieving Transparency 2

- Automounter.
  - Dynamically mounts file systems.
  - Runs as user-level process on clients (daemon).
  - Resolves references to unmounted pathnames by mounting them on demand.
  - Maintains a table of mount points and the corresponding server(s); sends probes to server(s).
  - Primitive form of replication

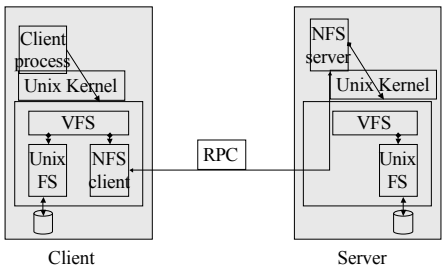
Transparency?

- Early binding.
  - Mount system call attaches remote file system to local mount point.
  - Client deals with host name once.
  - But, mount needs to happen before remote files become accessible.

Other Functions

- NFS file and directory operations:
  - read, write, create, delete, getattr, etc.
- Access control:
  - File and directory access permissions.
- Path name translation:
  - Lookup for each path component.
  - Caching.

Implementation



Virtual File System

- VFS added to UNIX kernel.
  - Location-transparent file access.
  - Distinguishes between local and remote access.
- @ client:
  - Processes file system system calls to determine whether access is local (passes it to UNIX FS) or remote (passes it to NFS client).
- @ server:
  - NFS server receives request and passes it to local FS through VFS.

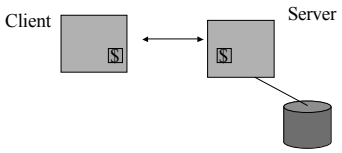
VFS

- If local, translates file handle to internal file id's (in UNIX i-nodes).
- V-node:
  - _ If file local, reference to file's i-node.
  - _ If file remote, reference to file handle.
- File handle: uniquely distinguishes file.

File system id	I-node #	I-node generation #

NFS Caching

- File contents and attributes.
- Client versus server caching.



Server Caching

- Read:
  - Same as UNIX FS.
  - Caching of file pages and attributes.
  - Cache replacement uses LRU.
- Write:
  - Write through (as opposed to delayed writes of conventional UNIX FS). Why?
  - [Delayed writes: modified pages written to disk when buffer space needed, sync operation (every 30 sec), file close].

Client Caching 1

- Timestamp-based cache validation.
- Read:
  - Validity condition:
    $(T-Tc < TTL)$ V $(Tm_C=Tm_S)$
- Write:
  - Modified pages marked and flushed to server at file close or sync.

Client Caching 2

- Consistency?
  - Not always guaranteed!
  - e.g., client modifies file; delay for modification to reach servers + 3-sec (TTL) window for cache validation from clients sharing file.

Cache Validation

- Validation check performed when:
  - First reference to file after TTL expires.
  - File open or new block fetched from server.
- Done for all files, even if not being shared.
  - Why?
- Expensive!
  - Potentially, every 3 sec get file attributes.
  - If needed invalidate all blocks.
  - Fetch fresh copy when file is next accessed.

The Sprite File System

- Main memory caching on both client and server.
- Write-sharing consistency guarantees.
- Variable size caches.
  - VM and FS negotiate amount of memory needed.
  - According to caching needs, cache size changes.

Sprite

- Sprite supports concurrent writes by disabling caching of write-shared files.
  - If file shared, server notifies client that has file open for writing to write modified blocks back to server.
  - Server notifies all client that have file open for read that file is no longer cacheable; clients discard all cached blocks, so access goes through server.

Sprite

- Sprite servers are stateful.
  - Need to keep state about current accesses.
  - Centralized points for cache consistency.
    - _Bottleneck?
    - _Single point of failure?
- Tradeoff: consistency versus performance/robustness.

Andrew

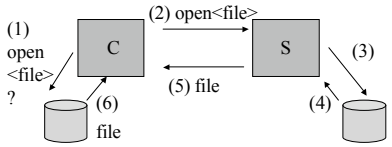
- Distributed computing environment developed at CMU.
- Campus wide computing system.
  - Between 5 and 10K workstations.
  - 1991: ~ 800 workstations, 40 servers.

Andrew FS

- Goals:
  - Information sharing.
  - Scalability.
    - _ Key strategy: caching of whole files at client.
    - _ Whole file serving
      - Entire file transferred to client.
    - _ Whole file caching
      - Local copy of file cached on client's local disk.
      - Survive client's reboots and server unavailability.

Whole File Caching

- Local cache contains several most recently used files.

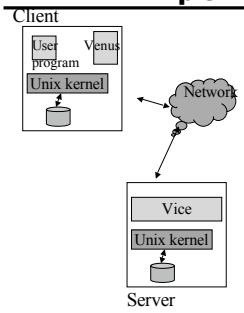


- Subsequent operations on file applied to local copy.
- On close, if file modified, sent back to server.

Implementation 1

- Network of workstations running Unix BSD 4.3 and Mach.
- Implemented as 2 user-level processes:
  - Vice: runs at each Andrew server.
  - Venus: runs at each Andrew client.

Implementation 2

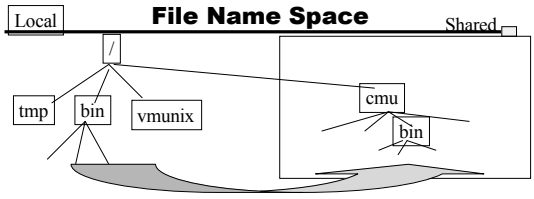


- Modified BSD 4.3 Unix kernel.
  - At client, intercept file system calls (open, close, etc.) and pass them to Venus when referring to shared files.
- File partition on local disk used as cache.
- Venus manages cache.
  - LRU replacement policy.
  - Cache large enough to hold 100's of average-sized files.

File Sharing

- Files are *shared* or *local*.
  - Shared files
    - Utilities (/bin, /lib): infrequently updated or files accessed by single user (user's home directory).
    - Stored on servers and cached on clients.
    - Local copies remain valid for long time.
  - Local files
    - Temporary files (/tmp) and files used for start-up.
    - Stored on local machine's disk.

File Name Space



- Regular UNIX directory hierarchy.
- "cmu" subtree contains shared files.
- Local files stored on local machine.
- Shared files: symbolic links to shared files.

AFS Caching

- AFS-1 uses timestamp-based cache invalidation.
- AFS-2 and 3 use *callbacks*.
  - When serving file, Vice server promises to notify Venus client when file is modified.
  - Stateless servers?
  - Callback stored with cached file.
    - Valid.
    - Canceled: when client is notified by server that file has been modified.

AFS Caching

- Callbacks implemented using RPC.
- When accessing file, Venus checks if file exists and if callback valid; if canceled, fetches fresh copy from server.
- Failure recovery:
  - When restarting after failure, Venus checks each cached file by sending validation request to server.
  - Also periodic checks in case of communication failures.

AFS Caching

- At file close time, Venus on client modifying file sends update to Vice server.
- Server updates its own copy and sends callback cancellation to all clients caching file.
- Consistency?
- Concurrent updates?

AFS Replication

- Read-only replication.
  - Only read-only files allowed to be replicated at several servers.

Coda

- Evolved from AFS.
- Goal: constant data availability.
  - Improved replication.
    - Replication of read-write volumes.
  - Disconnected operation: mobility.
    - Extension of AFS's whole file caching mechanism.
- Access to shared file repository (servers) versus relying on local resources when server not available.

Replication in Coda

- Replication unit: file volume (set of files).
- Set of replicas of file volume: volume storage group (VSG).
- Subset of replicas available to client: AVSG.
  - Different clients have different AVSGs.
  - AVSG membership changes as server availability changes.
  - On write: when file is closed, copies of modified file broadcast to AVSG.

Optimistic Replication

- Goal is availability!
- Replicated files are allowed to be modified even in the presence of partitions or during disconnected operation.

Disconnected Operation

- AVSG = { }.
- Network/server failures or host on the move.
- Rely on local cache to serve all needed files.
- Loading the cache:
  - User intervention: list of files to be cached.
  - Learning usage patterns over time.
- Upon reconnection, cached copies validated against server's files.

Normal and Disconnected Operation

- During normal operation:
  - Coda behaves like AFS.
  - Cache miss transparent to user; only performance penalty.
  - Load balancing across replicas.
  - Cost: replica consistency + cache consistency.
- Disconnected operation:
  - No replicas are accessible; cache miss prevents further progress; need to load cache before disconnection.

Replication and Caching

- Coda integrates server replication and client caching.
  - On cache hit and valid data: Venus does not need to contact server.
  - On cache miss: Venus gets data from an AVSG server, i.e., the preferred server (PS).
    - PS chosen at random or based on proximity, load.
  - Venus also contacts other AVSG servers and collect their versions; if conflict, abort operation; if replicas stale, update them off-line.