



Chapter 16 Distributed-File Systems

- Background
- Naming and Transparency
- Remote File Access
- Stateful versus Stateless Service
- File Replication
- Example Systems




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Background

- Distributed file system (DFS) – a distributed implementation of the classical time-sharing model of a file system, where multiple users share files and storage resources.
- A DFS manages set of dispersed storage devices
- Overall storage space managed by a DFS is composed of different, remotely located, smaller storage spaces.
- There is usually a correspondence between constituent storage spaces and sets of files.




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DFS Structure

- **Service** – software entity running on one or more machines and providing a particular type of function to a priori unknown clients.
- **Server** – service software running on a single machine.
- **Client** – process that can invoke a service using a set of operations that forms its *client interface*.
- A client interface for a file service is formed by a set of primitive *file operations* (create, delete, read, write).
- Client interface of a DFS should be transparent, i.e., not distinguish between local and remote files.




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Naming and Transparency

- *Naming* – mapping between logical and physical objects.
- Multilevel mapping – abstraction of a file that hides the details of how and where on the disk the file is actually stored.
- A *transparent* DFS hides the location where in the network the file is stored.
- For a file being replicated in several sites, the mapping returns a set of the locations of this file's replicas; both the existence of multiple copies and their location are hidden.




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Naming Structures

- **Location transparency** – file name does not reveal the file's physical storage location.
 - ✦ File name still denotes a specific, although hidden, set of physical disk blocks.
 - ✦ Convenient way to share data.
 - ✦ Can expose correspondence between component units and machines.
- **Location independence** – file name does not need to be changed when the file's physical storage location changes.
 - ✦ Better file abstraction.
 - ✦ Promotes sharing the storage space itself.
 - ✦ Separates the naming hierarchy from the storage-devices hierarchy.




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Naming Schemes – Three Main Approaches

- Files named by combination of their host name and local name; guarantees a unique systemwide name.
- Attach remote directories to local directories, giving the appearance of a coherent directory tree; only previously mounted remote directories can be accessed transparently.
- Total integration of the component file systems.
 - ✦ A single global name structure spans all the files in the system.
 - ✦ If a server is unavailable, some arbitrary set of directories on different machines also becomes unavailable.




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Remote File Access

- Reduce network traffic by retaining recently accessed disk blocks in a cache, so that repeated accesses to the same information can be handled locally.
 - ♦ If needed data not already cached, a copy of data is brought from the server to the user.
 - ♦ Accesses are performed on the cached copy.
 - ♦ Files identified with one master copy residing at the server machine, but copies of (parts of) the file are scattered in different caches.
 - ♦ *Cache-consistency* problem – keeping the cached copies consistent with the master file.




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Cache Location – Disk vs. Main Memory

- Advantages of disk caches
 - ♦ More reliable.
 - ♦ Cached data kept on disk are still there during recovery and don't need to be fetched again.
- Advantages of main-memory caches:
 - ♦ Permit workstations to be diskless.
 - ♦ Data can be accessed more quickly.
 - ♦ Performance speedup in bigger memories.
 - ♦ Server caches (used to speed up disk I/O) are in main memory regardless of where user caches are located; using main-memory caches on the user machine permits a single caching mechanism for servers and users.




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Cache Update Policy

- **Write-through** – write data through to disk as soon as they are placed on any cache. Reliable, but poor performance.
- **Delayed-write** – modifications written to the cache and then written through to the server later. Write accesses complete quickly; some data may be overwritten before they are written back, and so need never be written at all.
 - ♦ Poor reliability; unwritten data will be lost whenever a user machine crashes.
 - ♦ Variation – scan cache at regular intervals and flush blocks that have been modified since the last scan.
 - ♦ Variation – *write-on-close*, writes data back to the server when the file is closed. Best for files that are open for long periods and frequently modified.




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Consistency

- Is locally cached copy of the data consistent with the master copy?
 - Client-initiated approach
 - ♦ Client initiates a validity check.
 - ♦ Server checks whether the local data are consistent with the master copy.
 - Server-initiated approach
 - ♦ Server records, for each client, the (parts of) files it caches.
 - ♦ When server detects a potential inconsistency, it must react.




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Comparing Caching and Remote Service

- In caching, many remote accesses handled efficiently by the local cache; most remote accesses will be served as fast as local ones.
- Servers are contacted only occasionally in caching (rather than for each access).
 - ♦ Reduces server load and network traffic.
 - ♦ Enhances potential for scalability.
- Remote server method handles every remote access across the network; penalty in network traffic, server load, and performance.
- Total network overhead in transmitting big chunks of data (caching) is lower than a series of responses to specific requests (remote-service).




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Caching and Remote Service (Cont.)

- Caching is superior in access patterns with infrequent writes. With frequent writes, substantial overhead incurred to overcome cache-consistency problem.
- Benefit from caching when execution carried out on machines with either local disks or large main memories.
- Remote access on diskless, small-memory-capacity machines should be done through remote-service method.
- In caching, the lower intermachine interface is different from the upper user interface.
- In remote-service, the intermachine interface mirrors the local user-file-system interface.




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Stateful File Service

- Mechanism.
 - ♦ Client opens a file.
 - ♦ Server fetches information about the file from its disk, stores it in its memory, and gives the client a connection identifier unique to the client and the open file.
 - ♦ Identifier is used for subsequent accesses until the session ends.
 - ♦ Server must reclaim the main-memory space used by clients who are no longer active.
- Increased performance.
 - ♦ Fewer disk accesses.
 - ♦ Stateful server knows if a file was opened for sequential access and can thus read ahead the next blocks.




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Stateless File Server

- Avoids state information by making each request self-contained.
- Each request identifies the file and position in the file.
- No need to establish and terminate a connection by open and close operations.




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Distinctions Between Stateful & Stateless Service

- Failure Recovery.
 - ♦ A stateful server loses all its volatile state in a crash.
 - ✓ Restore state by recovery protocol based on a dialog with clients, or abort operations that were underway when the crash occurred.
 - ✓ Server needs to be aware of client failures in order to reclaim space allocated to record the state of crashed client processes (orphan detection and elimination).
 - ♦ With stateless server, the effects of server failure and recovery are almost unnoticeable. A newly reincarnated server can respond to a self-contained request without any difficulty.




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Distinctions (Cont.)

- Penalties for using the robust stateless service:
 - ♦ longer request messages
 - ♦ slower request processing
 - ♦ additional constraints imposed on DFS design
- Some environments require stateful service.
 - ♦ A server employing server-initiated cache validation cannot provide stateless service, since it maintains a record of which files are cached by which clients.
 - ♦ UNIX use of file descriptors and implicit offsets is inherently stateful; servers must maintain tables to map the file descriptors to inodes, and store the current offset within a file.




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File Replication

- Replicas of the same file reside on failure-independent machines.
- Improves availability and can shorten service time.
- Naming scheme maps a replicated file name to a particular replica.
 - ♦ Existence of replicas should be invisible to higher levels.
 - ♦ Replicas must be distinguished from one another by different lower-level names.
- Updates – replicas of a file denote the same logical entity, and thus an update to any replica must be reflected on all other replicas.
- Demand replication – reading a nonlocal replica causes it to be cached locally, thereby generating a new nonprimary replica.




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Example System - ANDREW

- A distributed computing environment under development since 1983 at Carnegie-Mellon University.
- Andrew is highly scalable; the system is targeted to span over 5000 workstations.
- Andrew distinguishes between client machines (workstations) and dedicated *server machines*. Servers and clients run the 4.2BSD UNIX OS and are interconnected by an internet of LANs.



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ANDREW (Cont.)

- Clients are presented with a partitioned space of file names: a *local name space* and a *shared name space*.
- Dedicated servers, called Vice, present the shared name space to the clients as an homogeneous, identical, and location transparent file hierarchy.
- The local name space is the root file system of a workstation, from which the shared name space descends.
- Workstations run the Virtue protocol to communicate with Vice, and are required to have local disks where they store their local name space.
- Servers collectively are responsible for the storage and management of the shared name space.



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ANDREW (Cont.)

- Clients and servers are structured in clusters interconnected by a backbone LAN.
- A cluster consists of a collection of workstations and a *cluster server* and is connected to the backbone by a *router*.
- A key mechanism selected for remote file operations is *whole file caching*. Opening a file causes it to be cached, in its entirety, on the local disk.



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ANDREW Shared Name Space

- Andrew's volumes are small component units associated with the files of a single client.
- A fid identifies a Vice file or directory. A fid is 96 bits long and has three equal-length components:
 - ♦ volume number
 - ♦ vnode number – index into an array containing the inodes of files in a single volume.
 - ♦ uniquifier – allows reuse of vnode numbers, thereby keeping certain data structures, compact.
- Fids are location transparent; therefore, file movements from server to server do not invalidate cached directory contents.
- Location information is kept on a volume basis, and the information is replicated on each server.



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ANDREW File Operations

- Andrew caches entire files from servers. A client workstation interacts with Vice servers only during opening and closing of files.
- Venus – caches files from Vice when they are opened, and stores modified copies of files back when they are closed.
- Reading and writing bytes of a file are done by the kernel without Venus intervention on the cached copy.
- Venus caches contents of directories and symbolic links, for path-name translation.
- Exceptions to the caching policy are modifications to directories that are made directly on the server responsibility for that directory.



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ANDREW Implementation

- Client processes are interfaced to a UNIX kernel with the usual set of system calls.
- Venus carries out path-name translation component by component.
- The UNIX file system is used as a low-level storage system for both servers and clients. The client cache is a local directory on the workstation's disk.
- Both Venus and server processes access UNIX files directly by their inodes to avoid the expensive path name-to-inode translation routine.



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ANDREW Implementation (Cont.)

- Venus manages two separate caches:
 - ♦ one for status
 - ♦ one for data
- LRU algorithm used to keep each of them bounded in size.
- The status cache is kept in virtual memory to allow rapid servicing of *stat* (file status returning) system calls.
- The data cache is resident on the local disk, but the UNIX I/O buffering mechanism does some caching of the disk blocks in memory that are transparent to Venus.



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