Chapter 17:
Distributed-File Systems

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- Background
- Naming and Transparency
- Remote File Access
- Stateful versus Stateless Service
- File Replication
- An Example: AFS

Chapter Objectives

- To explain the naming mechanism that provides location transparency and independence
- To describe the various methods for accessing distributed files
- To contrast stateful and stateless distributed file servers
- To show how replication of files on different machines in a distributed file system is a useful redundancy for improving availability
- To introduce the Andrew file system (AFS) as an example of a distributed file system

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.

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.

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

Naming Structures

- **Location transparency** – file name does not reveal the file’s physical storage location
- **Location independence** – file name does not need to be changed when the file’s physical storage location changes

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

Remote File Access

- **Remote-service mechanism** is one transfer approach
- 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
    - Could be called **network virtual memory**

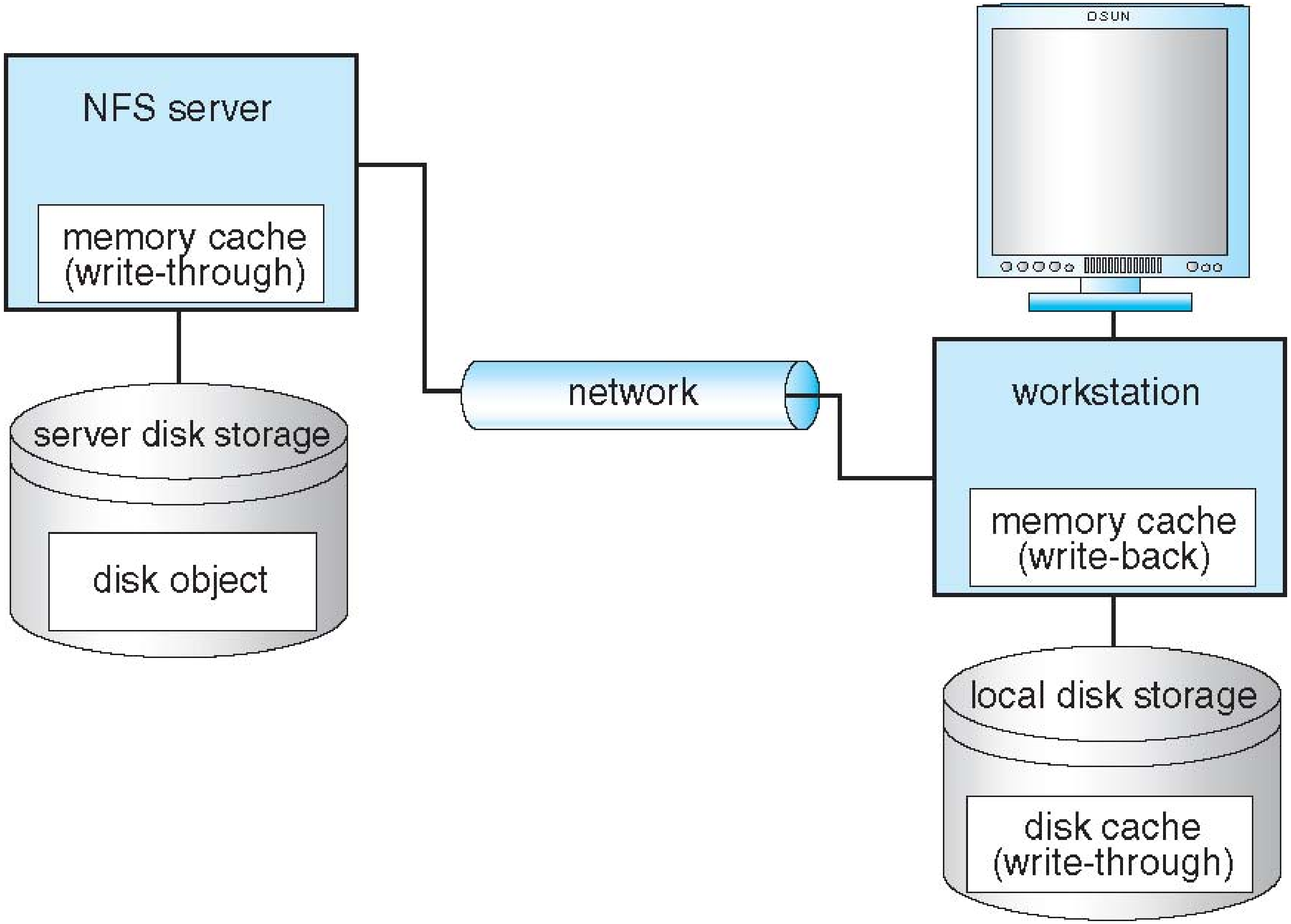
Cache Location – Disk vs. Main Memory

- 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

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

Cachefs and its Use of Caching



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

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 contracted 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).

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 form the upper user interface
- In remote-service, the intermachine interface mirrors the local user-file-system interface

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

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

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 sand recovery are almost unnoticeable
    - A newly reincarnated server can respond to a self-contained request without any difficulty

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.

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

An Example: AFS

- A distributed computing environment (Andrew) under development since 1983 at Carnegie-Mellon University, purchased by IBM and released as **Transarc DFS**, now open sourced as OpenAFS.

- AFS tries to solve complex issues such as uniform name space, location-independent file sharing, client-side caching (with cache consistency), secure authentication (via Kerberos).
  - Also includes server-side caching (via replicas), high availability
  - Can span 5,000 workstations

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.

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.

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.

ANDREW File Operations

- Andrew caches entire files form 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

ANDREW Implementation

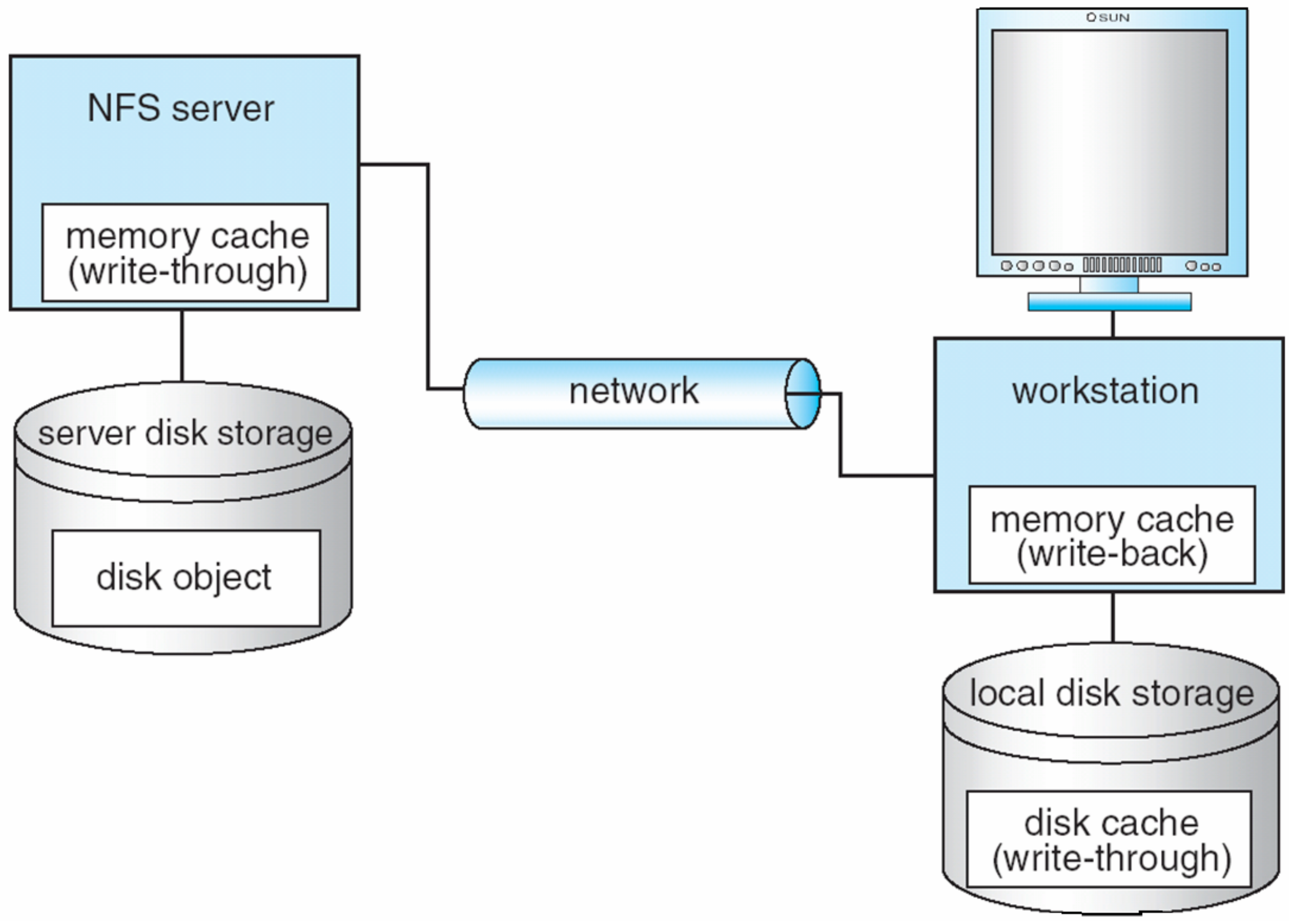
- Client processes are interfaced to a UNIX kernel with the usual set of system calls.
- Venus carries out path-name translation component by component.
- The UNIX file system is used as a low-level storage system for both servers and clients.
  - The client cache is a local directory on the workstation’s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

ANDREW Implementation (Cont.)

- Venus manages two separate caches:
  - one for status
  - one for data
- LRU algorithm are 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.

End of Chapter 17

Fig. 17.01


NFS server
memory cache (write-through)
server disk storage
disk object
network
SUN
workstation
memory cache (write-back)
local disk storage
disk cache (write-through)