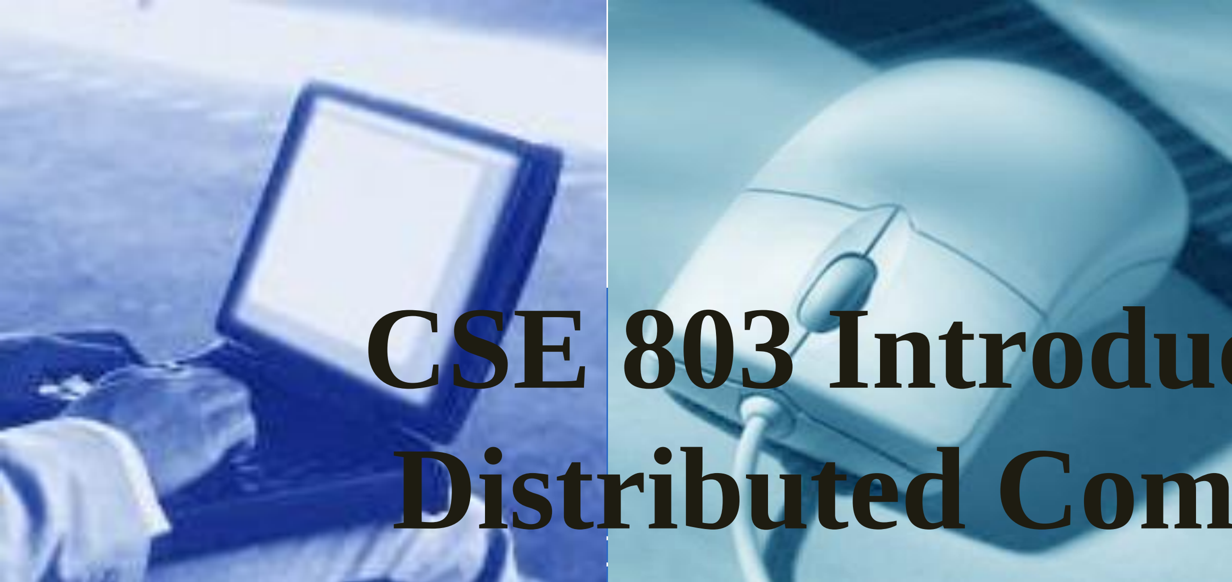

CSE 803 Introduction to Distributed Computing

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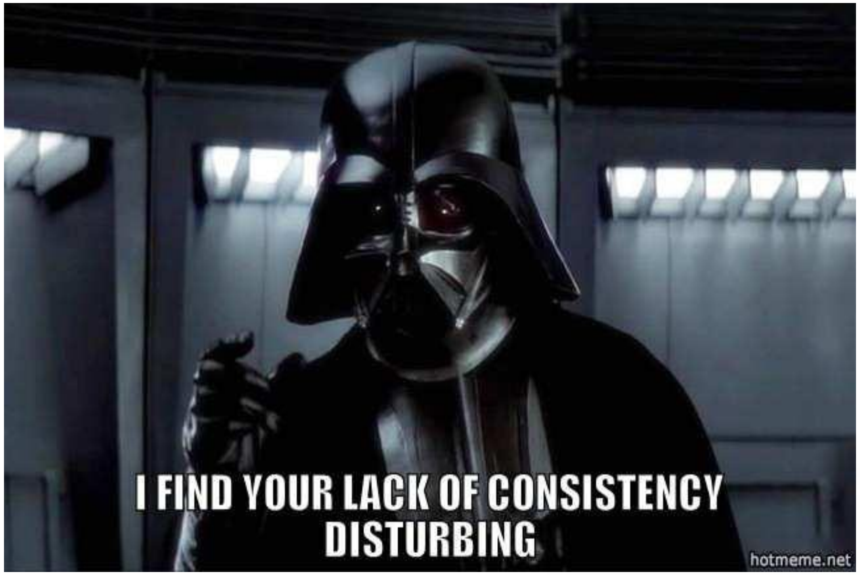
Distributed File Systems



① **Introduction**

② **NFS (Network File System)**

③ **AFS (Andrew File System) & Coda**

④ **GFS (Google File System)**

INTRODUCTION

Distributed File System Paradigm:

➜ File system that is shared by many distributed clients

➜ Communication through shared files

➜ Shared data remains available for long time

➜ Basic layer for many distributed systems and applications

Clients and Servers:

➜ Clients access files and directories

➜ Servers provide files and directories

➜ Servers allow clients to perform operations on the files and directories

➜ Operations: add/remove, read/write

➜ Servers may provide different views to different clients

CHALLENGES

Transparency:

- → Location: a client cannot tell where a file is located
- → Migration: a file can transparently move to another server
- → Replication: multiple copies of a file may exist
- → Concurrency: multiple clients access the same file

Flexibility:

- → Servers may be added or replaced
- → Support for multiple file system types

Dependability:

- → Consistency: conflicts with replication & concurrency
- → Security: users may have different access rights on clients sharing files & network transmission
- → Fault tolerance: server crash, availability of files

CHALLENGES

- ➜ Requests may be distributed across servers
- ➜ Multiple servers allow higher storage capacity

Scalability:

- ➜ Handle increasing number of files and users
- ➜ Growth over geographic and administrative areas
- ➜ Growth of storage space
- ➜ No central naming service
- ➜ No centralised locking
- ➜ No central file store

THE CLIENT'S PERSPECTIVE: FILE SERVICES

Ideally, the client would perceive remote files like local ones.

File Service Interface:

- → File: uninterpreted sequence of bytes
- → Attributes: owner, size, creation date, permissions, etc.
- → Protection: access control lists or capabilities
- → Immutable files: simplifies caching and replication
- → *Upload/download model* versus *remote access model*

FILE ACCESS SEMANTICS

UNIX semantics:

➜A READ after a WRITE returns the value just written

➜When two WRITEs follow in quick succession, the second persists

➜Caches are needed for performance & write-through is expensive

➜UNIX semantics is too strong for a distributed file system

Session semantics:

➜Changes to an open file are only locally visible

➜When a file is closed, changes are propagated to the server (and other clients)

➜But it also has problems:

- What happens if two clients modify the same file simultaneously?
- Parent and child processes cannot share file pointers if running on different machines.

FILE ACCESS SEMANTICS

➜ Files allow only CREATE and READ

➜ Directories can be updated

➜ Instead of overwriting the contents of a file, a new one is created and replaces the old one

X Race condition when two clients replace the same file

X How to handle readers of a file when it is replaced?

Atomic transactions:

➜ A sequence of file manipulations is executed indivisibly

➜ Two transaction can never interfere

➜ Standard for databases

➜ Expensive to implement

THE SERVER'S PERSPECTIVE: IMPLEMENTATION

Design Depends On the Use:

- → Satyanarayanan, 1980's university UNIX use
- → Most files are small—less than 10k
- → Reading is much more common than writing
- → Usually access is sequential; random access is rare
- → Most files have a short lifetime
- → File sharing is unusual, Most process use only a few files
- → Distinct files classes with different properties exist

Is this still valid?

There are also varying reasons for using a DFS:

- → Big file system, many users, inherent distribution
- → High performance
- → Fault tolerance

STATELESS VERSUS STATEFUL SERVERS

Advantages of stateless servers:

- ➜ **Fault tolerance**
- ➜ **No OPEN/CLOSE calls needed**
- ➜ **No server space needed for tables**
- ➜ **No limits on number of open files**
- ➜ **No problems if server crashes**
- ➜ **No problems if client crashes**

Advantages of stateful servers:

- ➜ **Shorter request messages**
- ➜ **Better performance**
- ➜ **Read ahead easier**
- ➜ **File locking possible**

CACHING

We can cache in three locations:

① Main memory of the server: easy & transparent

② Disk of the client

③Main memory of the client (process local, kernel, or dedicated cache process)

Cache consistency:

➜Obvious parallels to shared-memory systems, but other trade offs

➜No UNIX semantics without centralized control

➜Plain *write-through* is too expensive; alternatives: delay WRITEs and agglomerate multiple WRITEs

➜*Write-on-close;* possibly with delay (file may be deleted)

➜Invalid cache entries may be accessed if server is not contacted whenever a file is opened

REPLICATION

Multiple copies of files on different servers:

➜**Prevent data loss**

➜**Protect system against down time of a single server**

➜**Distribute workload**

Three designs:

➜**Explicit replication: The client explicitly writes files to multiple servers (not transparent).**

➜**Lazy file replication: Server automatically copies files to other servers after file is written.**

➜**Group file replication: WRITEs simultaneously go to a group of servers.**

CASE STUDIES

- → Network File System (NFS)
- → Andrew File System (AFS) & Coda
- → Google File System (GFS)

NETWORK FILE SYSTEM (NFS)

Properties:

➜Introduced by Sun

➜Fits nicely into UNIX's idea of mount points, but does not implement UNIX semantics

➜Multiple clients & servers (a single machine can be a client and a server)

➜Stateless servers (no OPEN & CLOSE) (changed in v4)

➜File locking through separate server

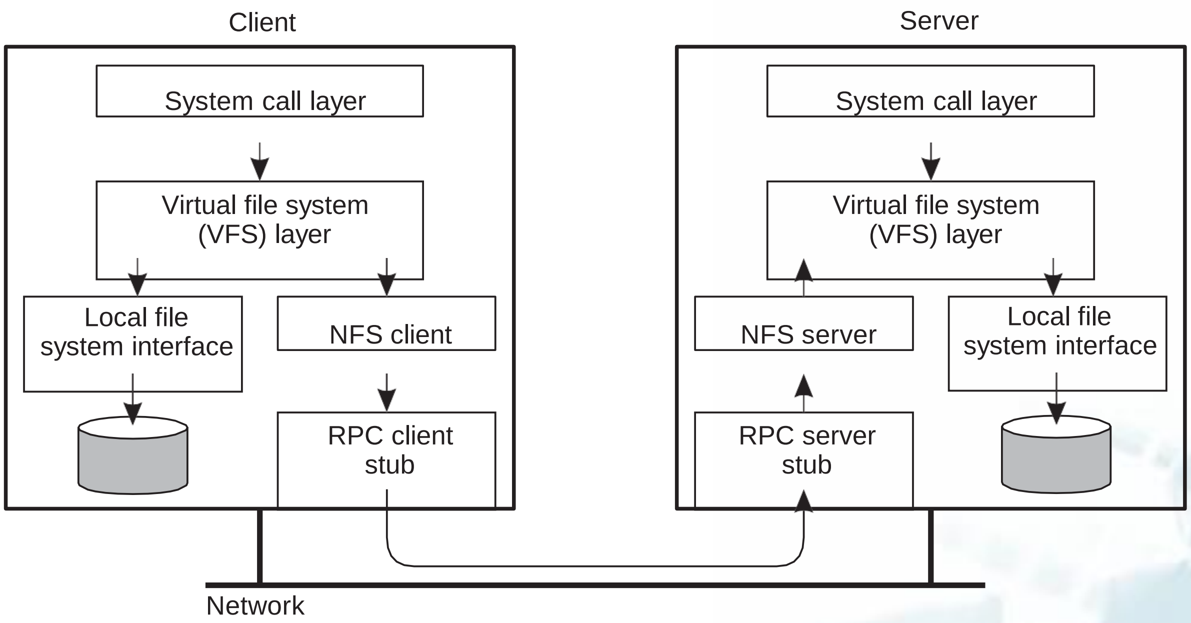
➜No replication

➜ONC RPC for communication

➜Caching: local files copies

- consistency through polling and timestamps
- asynchronous update of file after close

NETWORK FILE SYSTEM (NFS)



NETWORK FILE SYSTEM (NFS)

Operation	v3	v4	Description
Create	Yes	No	Create a regular file
Create	No	Yes	Create a nonregular file
Link	Yes	Yes	Create a hard link to a file
Symlink	Yes	No	Create a symbolic link to a file
Mkdir	Yes	No	Create a subdirectory in a given directory
Mknod	Yes	No	Create a special file
Rename	Yes	Yes	Change the name of a file
Remove	Yes	Yes	Remove a file from a file system
Rmdir	Yes	No	Remove an empty subdirectory from a directory
Open	No	Yes	Open a file
Close	No	Yes	Close a file
Lookup	Yes	Yes	Look up a file by means of a file name
Readdir	Yes	Yes	Read the entries in a directory
Readlink	Yes	Yes	Read the path name stored in a symbolic link
Getattr	Yes	Yes	Get the attribute values for a file
Setattr	Yes	Yes	Set one or more attribute values for a file
Read	Yes	Yes	Read the data contained in a file
Write	Yes	Yes	Write data to a file

ANDREW FILE SYSTEM (AFS) & CODA

Properties:

➜From Carnegie Mellon University (CMU) in the 1980s.

➜Developed as campus-wide file system: Scalability

➜Global name space for file system (divided in *cells*, e.g. /afs/cs.cmu.edu, /afs/ethz.ch)

➜API same as for UNIX

➜UNIX semantics for processes on one machine, but globally write-on-close

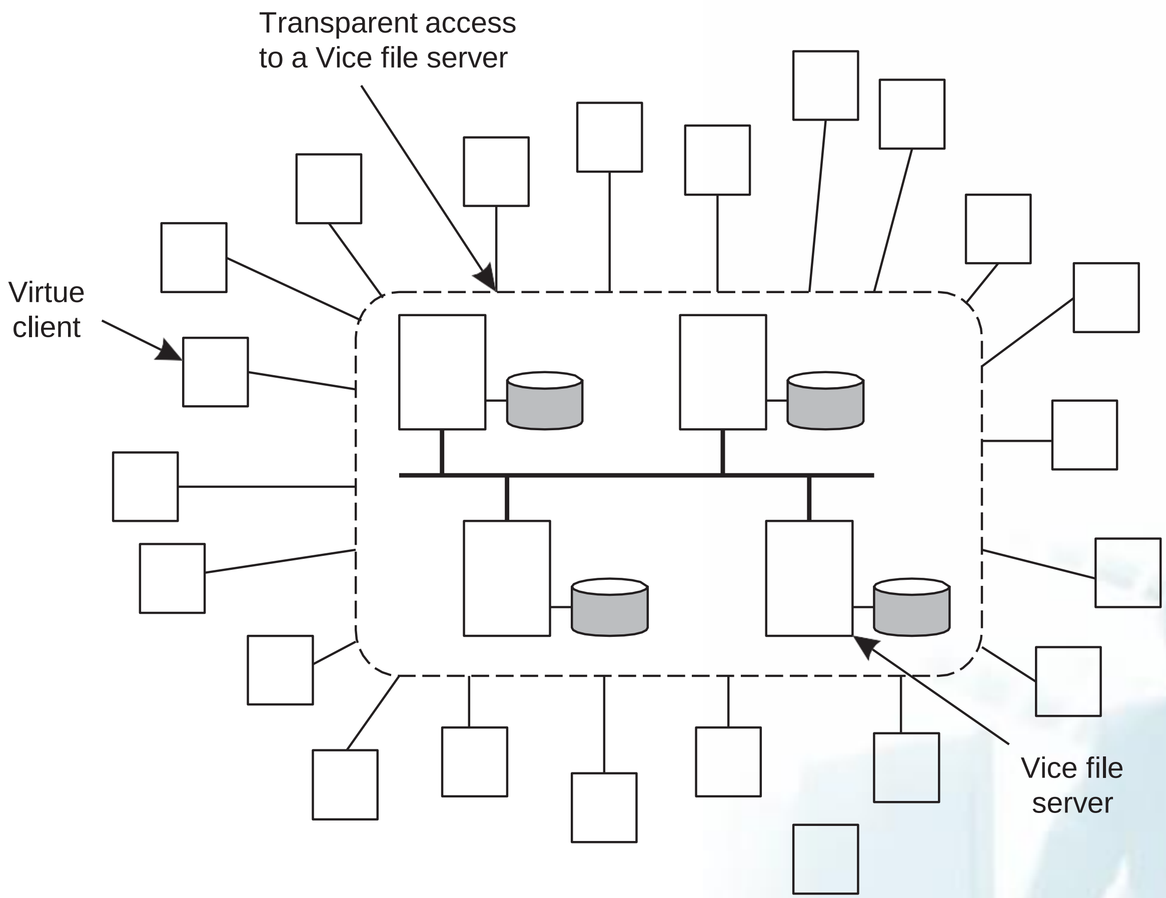
ANDREW FILE SYSTEM (AFS) & CODA

- Client: User-level process *Venus* (AFS daemon)
- Cache on local disk
- Trusted servers collectively called *Vice*

Scalability:

- Server serves whole files. Clients cache whole files
- Server invalidates cached files with callback (stateful servers)
- Clients do not validate cache (except on first use after booting)
- Result: Very little cache validation traffic

ANDREW FILE SYSTEM (AFS) & CODA



CODA

- ➜ Successor of the Andrew File System (AFS)
    - System architecture quite similar to AFS
- ➜ Supports disconnected, mobile operation of clients
- ➜ Supports replication

DESIGN & ARCHITECTURE

Disconnected operation:

➜**All client updates are logged in a *Client Modification Log (CML)***

➜**On re-connection, CML operations are replayed on the server**

➜**Trickle reintegration tradeoff: Immediate reintegration of log entries reduces chance for optimization, late reintegration increases risk of conflicts**

➜**File hoarding: System (or user) can build a user hoard database, which it uses to update frequently used files in a hoard walk**

➜**Conflicts: Automatically resolved where possible; otherwise, manual correction necessary**

Servers:

➜**Read/write replication is organized on a per volume basis**

➜**Group file replication (multicast RPCs); read from any server**

➜**Version stamps are used to recognize server with out of date files (due to disconnect or failure)**

GOOGLE FILE SYSTEM

Motivation:

- ➜ 10+ clusters
- ➜ 1000+ nodes per cluster
- ➜ Pools of 1000+ clients
- ➜ 350TB+ filesystems
- ➜ 500Mb/s read/write load
- ➜ Commercial and R&D applications

Assumptions:

- ➜ Huge files (millions, 100+MB)
- ➜ Large streaming reads
- ➜ Small random reads
- ➜ Large appends
- ➜ Concurrent appends
- ➜ Bandwidth more important than latency

GOOGLE FILE SYSTEM

No common standard like POSIX. Provides familiar file system interface:

➜Create, Delete, Open, Close, Read, Write

In addition:

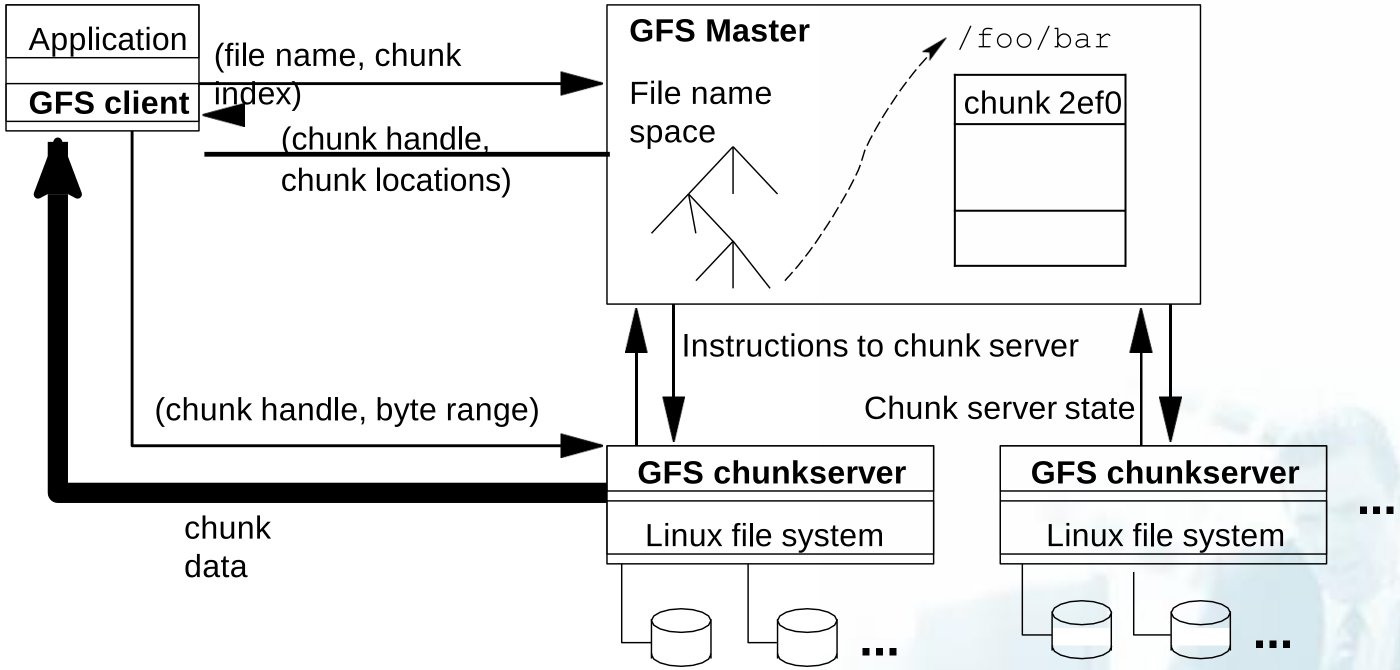
➜*Snapshot* : low cost copy of a whole file with copy-on-write operation

➜*Record append*: Atomic append operation

GOOGLE FILE SYSTEM

- Files split in fixed size *chunks* of 64 MByte
- Chunks stored on *chunk servers*
- Chunks replicated on multiple chunk servers
- GFS master manages name space
- Clients interact with master to get *chunk handles*
- Clients interact with chunk servers for reads and writes
- No explicit caching

GOOGLE FILE SYSTEM



GOOGLE FILE SYSTEM

- → Single point of failure
- → Keeps data structures in memory (speed, easy background tasks)
- → Mutations logged to *operation log*
- → Operation log replicated
- → Checkpoint state when log is too large
- → Checkpoint has same form as memory (quick recovery)
- → Note: Locations of chunks *not* stored (master periodically asks chunk servers for list of their chunks)

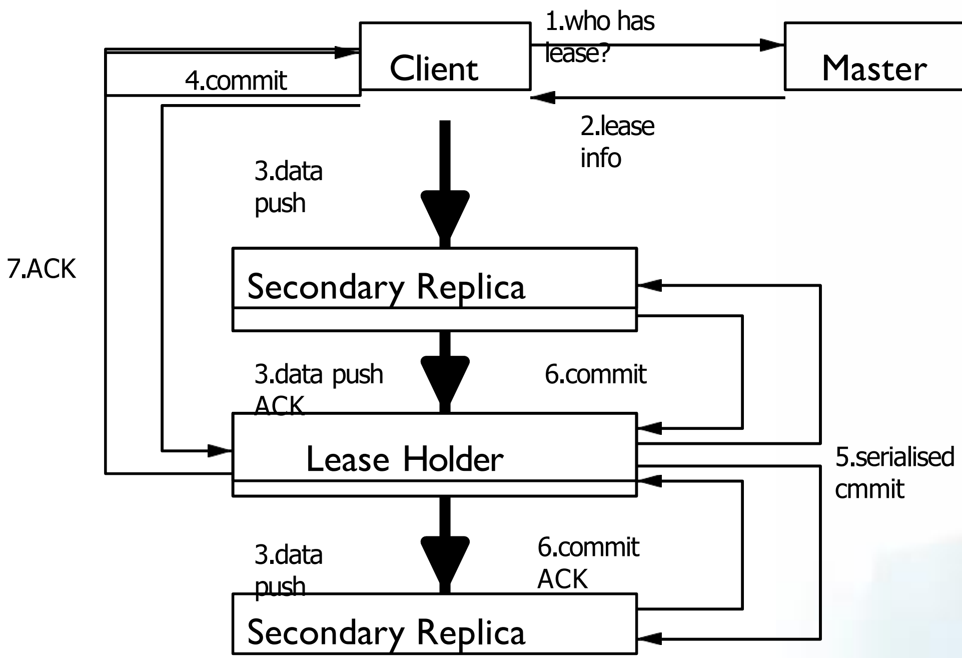
- **GFS Chunk servers:**
- → **Checksum blocks of chunks**
- → **Verify checksums before data is delivered**
- → **Verify checksums of seldom used blocks when idle**

GOOGLE FILE SYSTEM

- → Write, atomic record append, snapshot
- → Master grants *chunk lease* to one of a chunk's replicas
- → Replica with chunk becomes *primary*
- → Primary defines serial order for all mutations
- → Leases typically expire after 60 s, but are usually extended
- → Easy recovery from failed primary: master chooses another replica after the initial lease expires

GOOGLE FILE SYSTEM

Write(filename, offset, data)



RE-EVALUATING GFS AFTER 10 YEARS

Workload has changed → changed assumptions

Single Master:

- X **Too many requests for a single master**
- X **Single point of failure**
- V **Tune master performance**
- V **Multiple cells**
- V **Develop distributed masters**

File Counts:

- X **Too much meta-data for a single master**
- V **applications rely on Big Table (distributed)**

RE-EVALUATING GFS AFTER 10 YEARS

X Smaller files than expected

V Reduce block size to 1MB

Throughput vs Latency:

X Too much latency for interactive applications (e.g. Gmail)

V Automated master failover

V Applications hide latency: e.g. multi-homed model

CHUBBY

Chubby is...:

- ➜ **Lock service**
- ➜ **Simple FS**
- ➜ **Name service**
- ➜ **Synchronisation/consensus service**

Architecture:

- ➜ **Cell: 5 replicas**
- ➜ **Master:**
  - **gets all client requests**
  - **elected with Paxos**
  - **master lease: no new master until lease expires**
- ➜ **Write: Paxos agreement of all replicas**
- ➜ **Read: local by master**

CHUBBY

- Pathname: /ls/cell/some/file/name
- Open (R/W), Close, Read, Write, Delete
- Lock: Acquire, Release
- Events: file modified, lock acquired, etc.

Using Chubby: electing a leader:

```
if (open("/ls/cell/TheLeader", W)) { write(my_id);
} else {
wait until "/ls/cell/TheLeader" modified;
leader_id = read();
}
```

WHAT ELSE … ?

Colossus:

- ➜ follow up to GFS

BigTable:

- ➜ Distributed, sparse, storage map
- ➜ Chubby for consistency
- ➜ GFS/Colossus for actual storage

Megastore:

- ➜ Semi-relational data model, ACID transactions
- ➜ BigTable as storage , synchronous replication (using Paxos)
- ➜ Poor write latency (100-400 ms) and throughput

Spanner:

- ➜ Structured storage, SQL-like language
- ➜ Transactions with TrueTime, synchronous replication (Paxos)
- ➜ Better write latency (72-100ms)