NFS, REVIEW, SUMMARY

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CS 537, Spring 2019
Project 4a, 4b grades out. Regrade requests by tomorrow.

Final Exam:
- Everything up to NFS.
- May 8th at 2.45PM at Agr Hall 125

No discussion this week!

Review session on Friday at 5pm
AGENDA / LEARNING OUTCOMES

What are consistency properties provided NFS?

What is the role of OS in context of cloud computing?
RECAP
DISTRIBUTED SYSTEMS
GOALS FOR DISTRIBUTED FILE SYSTEMS

Transparent access → as if the FS is local
- can’t tell accesses are over the network
- normal UNIX semantics

Fast + simple crash recovery: both clients and file server may crash

Reasonable performance? Partial failure
NFS Architecture

File Server

Local FS

RPC

Client

Client

Client

RPC

RPC

RPC

RPC

Disk

Protocol

SUN

Export

Read
file handles

\[ fh = \text{open}(\text{char } *\text{path}); \]
\[ \text{pread}(fh, \text{buf}, \text{size}, \text{offset}); \]
\[ \text{pwrite}(fh, \text{buf}, \text{size}, \text{offset}); \]

File Handle = \(<\text{volume ID, inode #, } \text{generation #}>\)  
Opaque to client (client should not interpret internals)
Directory

FH for a file or dir

NFSPROC_GETATTR
  expects: file handle
  returns: attributes

NFSPROC_SETATTR
  expects: file handle, attributes
  returns: nothing

NFSPROC_LOOKUP
  expects: directory file handle, name of file/directory to look up
  returns: file handle

NFSPROC_READ
  expects: file handle, offset, count
  returns: data, attributes

NFSPROC_WRITE
  expects: file handle, offset, count, data
  returns: attributes

NFSPROC_CREATE
  expects: directory file handle, name of file, attributes
  returns: nothing

NFSPROC_REMOVE
  expects: directory file handle, name of file to be removed
  returns: nothing

NFSPROC_MKDIR
  expects: directory file handle, name of directory, attributes
  returns: file handle

NFSPROC_RMDIR
  expects: directory file handle, name of directory to be removed
  returns: nothing

NFSPROC_READDIR
  expects: directory handle, count of bytes to read, cookie
  returns: directory entries, cookie (to get more entries)
CRASHES WITH IDEMPOTENT OPERATIONS

int fd = open("foo", O_RDONLY);
read(fd, buf, MAX);
write(fd, buf, MAX);
...

Server crash!

L⇒ Applying op multiple times produces same outcome

Client: retry requests

Server

write

write

write

retries

read

read

FH
OVERVIEW

Architecture

Network API

Write Buffering

Cache
Server acknowledges write before write is pushed to disk; What happens if server crashes?
SERVER WRITE BUFFER LOST

client:

write A to 0
write B to 1
write C to 2
write X to 0
write Y to 1
write Z to 2

server acknowledges write before write is pushed to disk

server mem: X Y Z
server disk: A B C

not ABC or XYZ partial updates on disk after a failure
SERVER WRITE BUFFER LOST

Client:

write A to 0
write B to 1
write C to 2
write X to 0
write Y to 1
write Z to 2

server mem: 

server disk: 

Problem:
No write failed, but disk state doesn’t match any point in time

Solutions?
Don’t use server write buffer. Problem: Slow?

Use persistent write buffer (more expensive)
Architecture

Network API

Write Buffering

Cache
Cache Consistency

NFS can cache data in three places:
- server memory
- client disk
- client memory

When is data cached?
How to make sure all versions are in sync?
DISTRIBUTED CACHE

Client 1

A → B

NFS cache: A

Server

Local FS cache: A

Client 2

NFS cache:

delete file
@modify file

read

A
“Update Visibility” problem: server doesn’t have latest version

What happens if Client 2 (or any other client) reads data?
“Stale Cache” problem: client 2 doesn’t have latest version

What happens if Client 2 reads data?
When client buffers a write, how can server (and other clients) see update? Client flushes cache entry to server.

**When** should client perform flush?

NFS solution: flush on fd close
SOLVING STALE CACHE

Problem: Client 2 has stale copy of data; how can it get the latest?

NFS solution:
- Clients recheck if cached copy is current before using data
Client cache records time when data block was fetched (t1)
Before using data block, client does a STAT request to server
- get’s last modified timestamp for this file (t2) (not block…)
- compare to cache timestamp
- refetch data block if changed since timestamp (t2 > t1)
NFS developers found `stat` accounted for 90% of server requests.

Why? Because clients frequently recheck cache.
Solution: cache results of `stat` calls
Partial Solution:
  Make `stat` cache entries expire after a given time
  (e.g., 3 seconds) (discard t2 at client 2)

What is the consequence?
NFS handles client and server crashes very well; robust APIs that are:

- stateless: servers don’t remember clients
- idempotent: doing things twice never hurts

Caching and write buffering is harder, especially with crashes

Problems:

- Consistency model is odd (client may not see updates until 3s after file closed)
- Scalability limitations as more clients call stat() on server
BUNNY 22!

https://tinyurl.com/cs537-sp19-bunny22

FEEDBACK?

https://aefis.wisc.edu/

\[
\text{open file} \\
\begin{align*}
F_1 &= \text{lookup}(F_0, "a") \\
F_2 &= \text{lookup}(F_1, "b") \\
F_3 &= \text{lookup}(F_2, "c") \\
65 \text{ time to open file}
\end{align*}
\]

\[
\text{read file} \\
\begin{align*}
pread &\rightarrow S \\
100 \text{ times} \\
100 (S + B)
\end{align*}
\]
We'll now model the time of certain operations in NFS. The only costs to worry about are network costs. Assume any "small" message takes $S$ units of time from one machine to another, whereas a "bigger" message (e.g., size of a disk block) takes $B$ units. If a message is larger than 4KB, it should take proportionally longer (2B for 8KB). Assume we are using a file that is 100 blocks (400 KB) stored at /a/b/c.txt.

1. How long does it take to re-read a file immediately after it was read?

2. How long does it take to re-read the whole file after 10s assuming no edits to the file?
ALTERNATE DESIGN: ANDREW FILE SYSTEM (AFS)
Upon open, AFS client fetches whole file (even if huge), storing in local memory or disk. Upon close, client flushes file to server (if file was written).

Convenient and intuitive semantics:
- AFS needs to do work only for open/close
- Reads/writes are local
- Use same version of file entire time between open and close
UPDATE VISIBILITY

AFS solution:
- also flush on close
- buffer whole files on local disk; update file on server atomically

Concurrent writes?
- Last writer (i.e., last file closer) wins
- Never get mixed data on server
AFS solution: Tell clients when data is overwritten
- Server must remember which clients have this file open right now
When clients cache data, ask for “callback” from server if changes
- Clients can use data without checking all the time

Server no longer stateless!
SUMMARY
OPERATING SYSTEMS: THREE EASY PIECES

Three conceptual pieces

1. Virtualization

2. Concurrency

3. Persistence
VIRTUALIZATION

Make each application believe it has each resource to itself

**CPU and Memory**

**Abstraction:** Process API, Address spaces

**Mechanism:**
- Limited direct execution, **CPU scheduling**
- Address translation (segmentation, paging, TLB)

**Policy:** MLFQ, LRU etc.
CONCURRENCY

Events occur simultaneously and may interact with one another
Need to
  Hide concurrency from independent processes
  Manage concurrency with interacting processes

Provide abstractions (locks, semaphores, condition variables etc.)
Correctness: mutual exclusion, ordering
Performance: scaling data structures, fairness
Common Bugs!

\text{Deadlock} \rightarrow \text{strategies}
Persisting data is a key design issue in operating systems.

**Managing devices:** The key role of the OS.

- **Hard disk drives**
  - Rotational, Seek, Transfer time
  - Disk scheduling: FIFO, SSTF, SCAN

**Filesystems API**
- File descriptors, Inodes
- Directories
- Hardlinks, softlinks
**PERSISTENCE**

Very simple FS
- Inodes, Bitmaps, Superblock, Data blocks

FFS
- Placement in groups, Allocation policy

LFS
- Write optimized, Garbage collection

Journaling, FSCK

NFS: Partial failures retry, cache consistency

Bitmap bit tracks if block is used
Super blocks
Inode blocks
data blocks
Protocol liveness
Consistency checker
FSCK
OPERATING SYSTEMS FOR THE CLOUD?
The Datacenter Needs an Operating System

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1 Introduction

Clusters of commodity servers have become a major computing platform, powering not only some of today's most popular consumer applications—Internet services such as search and social networks—but also a growing number of scientific and enterprise workloads [2]. This rise in cluster computing has even led some to declare that "the datacenter is the new computer" [16, 24]. However, the tools for managing and programming this new computer are still immature. This paper argues that, due to the growing diversity of cluster applications and users, the datacenter increasingly needs an operating system.\(^1\) and Pregel steps). However, this is currently difficult because applications are written independently, with no common interfaces for accessing resources and data.

In addition, clusters are serving increasing numbers of concurrent users, which require responsive time-sharing. For example, while MapReduce was initially used for a small set of batch jobs, organizations like Facebook are now using it to build data warehouses where hundreds of users run near-interactive ad-hoc queries [29].

Finally, programming and debugging cluster applications remains difficult even for experts, and is even more challenging for the growing number of non-expert users (e.g., scientists) starting to leverage cloud computing.
DATACENTER OPERATING SYSTEMS

- Resource sharing
- Data sharing
- Programming Abstractions
- Debugging