# Distributed File Systems and Network File Systems

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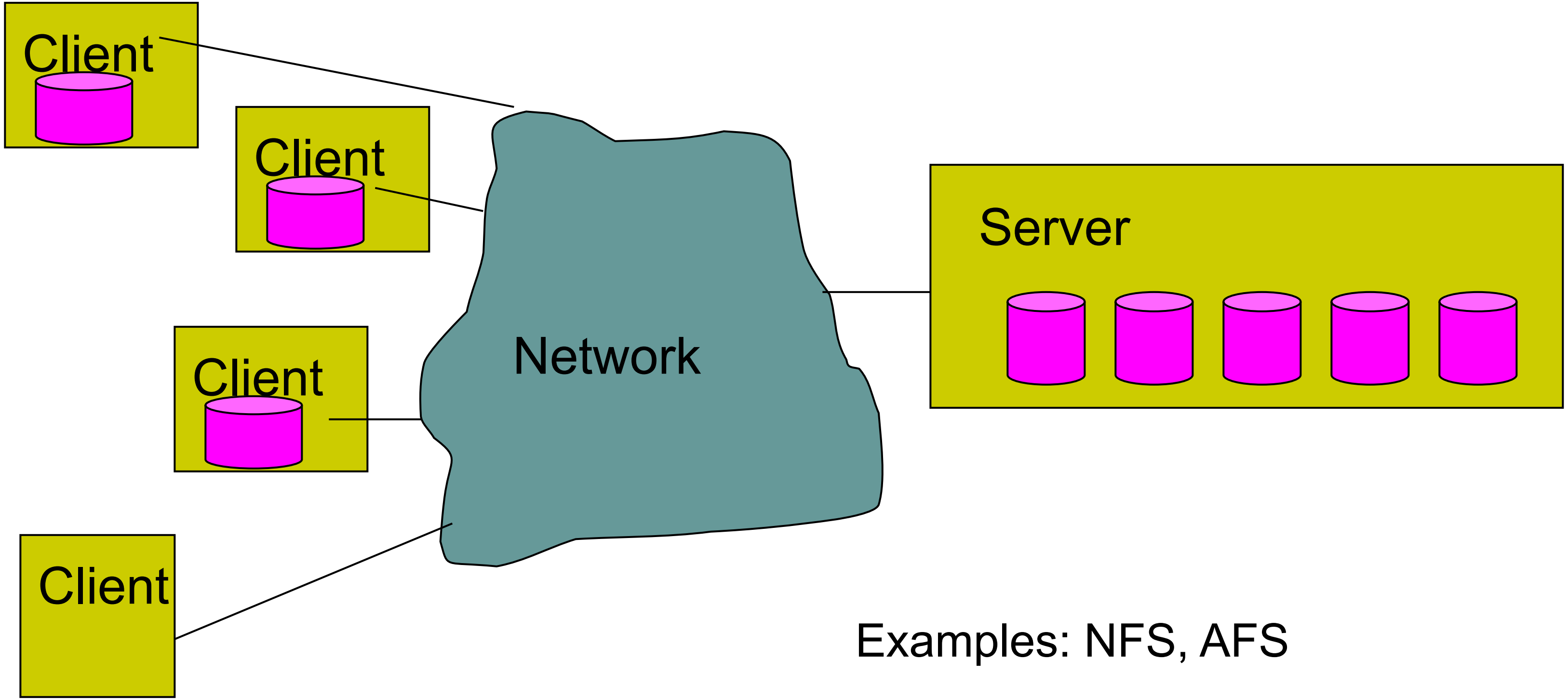
# Distributed File Systems




Examples: NFS, AFS

# Client/Server Model

- **Service** – software entity running on one or more machines and providing a particular type of function to a priori unknown clients
- **Server** – which runs the service software to provide the service
- **Client** – process that can invoke a service using a set of operations that forms its *client interface*
- Traditional DFS uses client/server model

# Distributed File Systems (DFS)

- You can login to any instructional machine on campus, your home dir is always there!

- but sometimes it is very slow…

# DFS

- Definition: a distributed implementation of the classical time-sharing model of a file system, where multiple users share files and storage resources

- Many DFS have been proposed and developed

# Motivation

- Why are distributed file systems useful?
  - Access from multiple clients
    - Same user on different machines can access same files
  - Simplifies sharing
    - Different users on different machines can read/write to same files
  - Simplifies administration
    - One shared server to maintain (and backup)
  - Improve reliability
    - Add RAID storage to server

# Challenges

- Transparent access
  - User sees single, global file system regardless of location
- Scalable performance
  - Performance does not degrade as more clients are added
- Fault Tolerance
  - Client and server identify and respond appropriately when other crashes
- Consistency
  - See same directory and file contents on different clients at same time
- Security
  - Secure communication and user authentication
- Tension across these goals
  - Example: Caching helps performance, but hurts consistency

# NFS (Network File System)

- First commercially successful distributed file system:
  - Developed in 1984 by Sun Microsystems for their diskless workstations
  - Designed for robustness and “adequate performance”
  - Multiple versions (v2, v3, v4)
  - Widely used today

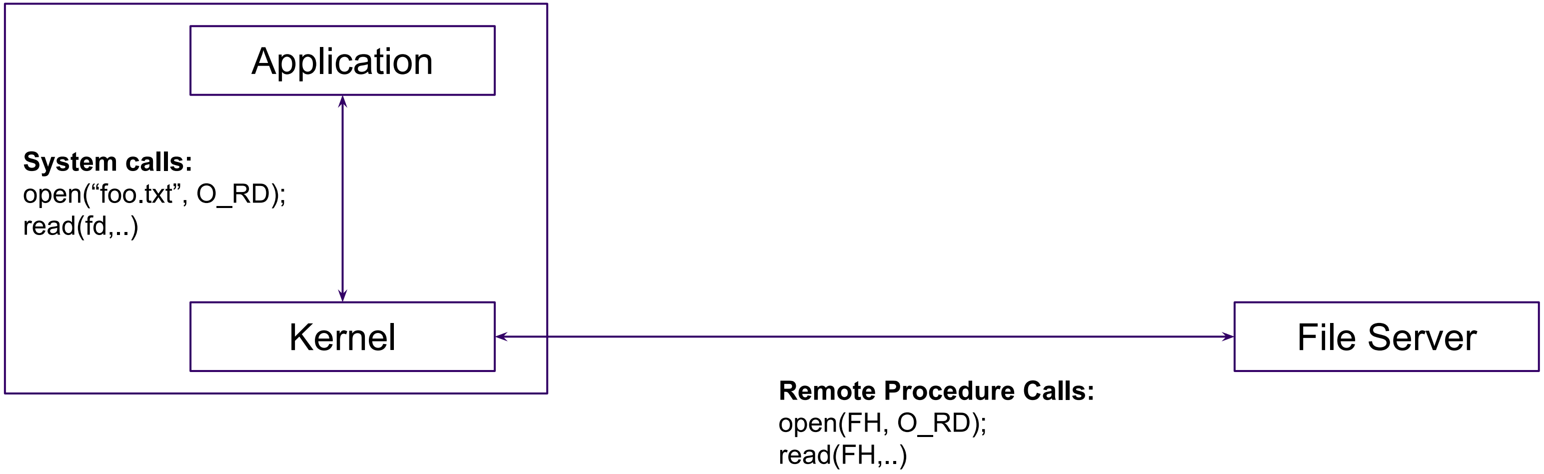
# NFS Overview

- Remote Procedure Calls (RPC) for communication between client and server

- Client Implementation
  - Provides transparent access to NFS file system
    - UNIX contains Virtual File system layer (VFS)
    - Vnode: interface for procedures on an individual file
  - Translates vnode operations to NFS RPCs

- Server Implementation
  - Stateless: Must not have anything only in memory
  - Implication: All modified data written to stable storage before return control to client
    - Servers often add NVRAM to improve performance

# NFS Overview



# NFS Design Objectives

- ***Machine and Operating System Independence***
  - Could be implemented on low-end machines of the mid-80's
- ***Transparent Access***
  - Remote files should be accessed in exactly the same way as local files
- ***Fast Crash Recovery***
  - Major reason behind stateless design
- ***"Reasonable" performance***
  - Robustness and preservation of UNIX semantics were much more important

# Implementation of Transparency

- *"All computer science problems can be solved with an extra level of indirection"*

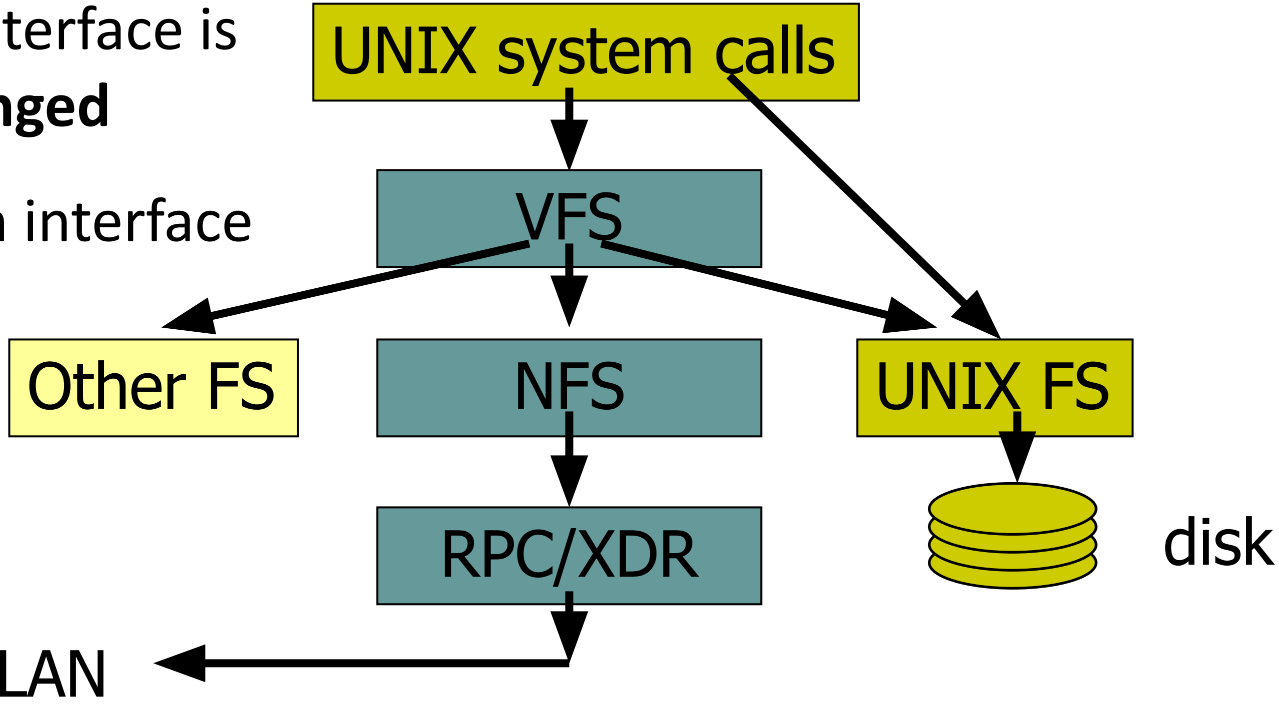
  -- David Wheeler

- What were the earlier manifestations of this in this class?

# Client Side

User interface is **unchanged**

Common interface



# NFS Key Ideas

- NFS key idea #1: Stateless server
  - Server not required to remember anything (in memory)
    - Which clients are connected, which files are open, …
  - Implication: All client requests have all the information to complete op
    - Example: Client specifies offset in file to write to
  - Why is this important for fast crash recovery?

- NFS Key idea #2: Idempotent server operations
  - Operation can be repeated with same result (no side effects)
  - Example: idempotent: a=b+1; Not idempotent: a=a+1;
  - Why is this important for crash recovery?

# Consequence of Statelessness

- read and write calls must specify offset
  - Server does not keep track of current position in the file
- But user will still use conventional UNIX APIs
- Client must maintain a local offset to be used for read/write.

# Advantages of Statelessness

- Crash recovery is very easy:
  - When a server crashes, client just resends request until it gets an answer from the rebooted server
  - Client cannot tell difference between a server that has crashed and recovered and a slow server

- Server state does not grow with more clients

- Simplifies the protocol
  - Client can always repeat any request

# Basic NFS Protocol

- Operations at NFS layer (applications do not execute these)
  - lookup(dirfh, name) returns (fh, attributes)
    - Use mount protocol for root directory
  - create(dirfh, name, attr) returns (newfh, attr)
  - remove(dirfh, name) returns (status)
  - read(fh, offset, count) returns (attr, data)
  - write(fh, offset, count, data) returns attr
  - gettattr(fh) returns attr

  - What’s missing here?
    - close No need to tell server: stateless server, more later

# Remote Lookup

- Returns a **file handle** instead of a file desc.
  - File handle specifies *unique location* of file

- **lookup(dirfh, name)** *returns* **(fh, attr)**
  - Returns file handle **fh** and attributes of named file in directory **dirfh**
  - Fails if client has no right to access directory **dirfh**

# Remote Lookup

- To lookup **“/usr/joe/6360/list.txt”**

**lookup(rootfh, “usr”) returns (fh0, attr)**
**lookup(fh0, “joe”) returns (fh1, attr)**
**lookup(fh1, “6360”) returns (fh2, attr)**
**lookup(fh2, “list.txt”) returns (fh, attr)**

# Mapping UNIX System calls to NFS Operations

- Unix system call: fd = open(“/dir/foo”)
  - Traverse pathname to get filehandle for foo
    - dir_fh = lookup(root_dir_fh, “dir”);
    - fh = lookup(dir_fh, “foo”);
  - Record mapping from fd file descriptor to fh NFS filehandle
  - Set initial file offset to 0 for fd
  - Return fd file descriptor

# Mapping UNIX System calls to NFS Operations

- Unix system call: read(fd,buffer,bytes)
  - Get current file offset for fd
  - Map fd to fh NFS filehandle
  - Call data = read(fh, offset, bytes) and copy data into buffer
  - Increment file offset by bytes

# Mapping UNIX System calls to NFS Operations

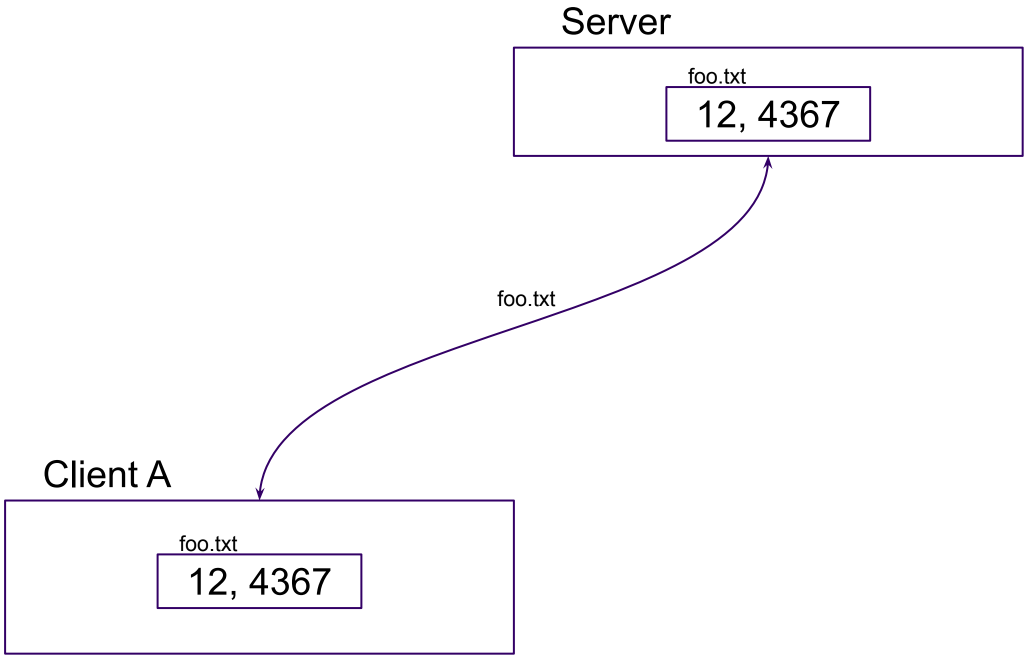
- Unix system call: close(fd)
  - Free resources associated with fd
  - No need to tell server: stateless server

# Identifying Files in NFS

- Can we still use inode?
- NFS use File handles
- **File handle** consists of
  - ***Filesystem id*** identifying disk partition
  - ***i-node number*** identifying file within partition
  - ***i-node generation number*** changed every time i-node is reused to store a new file

| | | |
|---|---|---|
| Filesystem id | i-node number | i-node generation number |

# Why not only i-node number?



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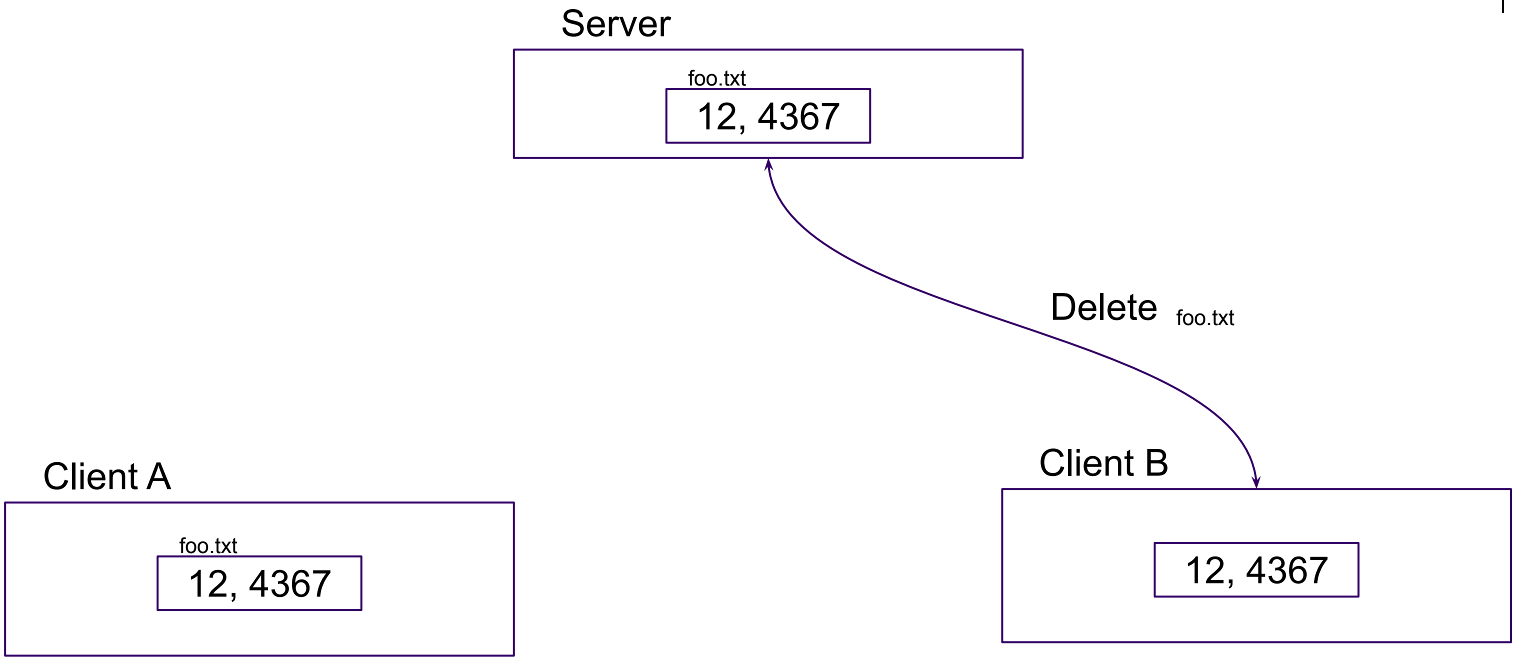

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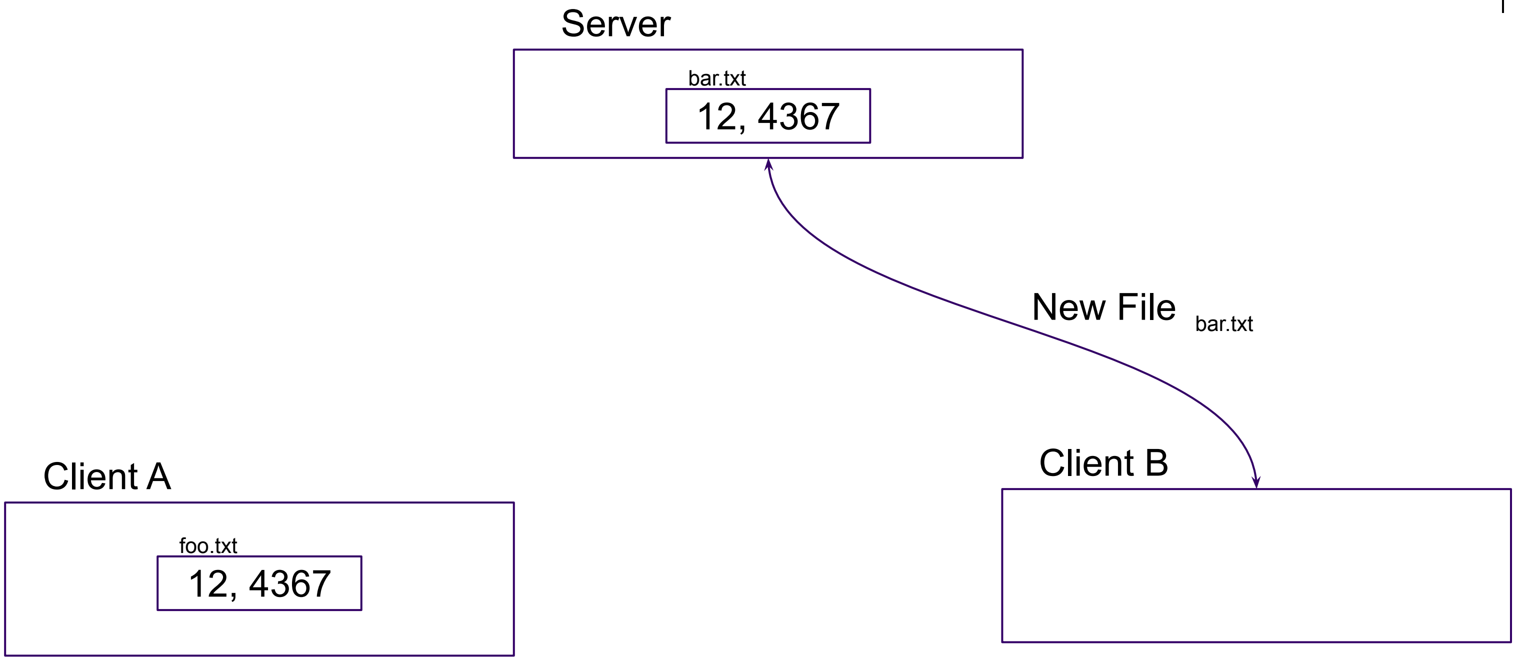

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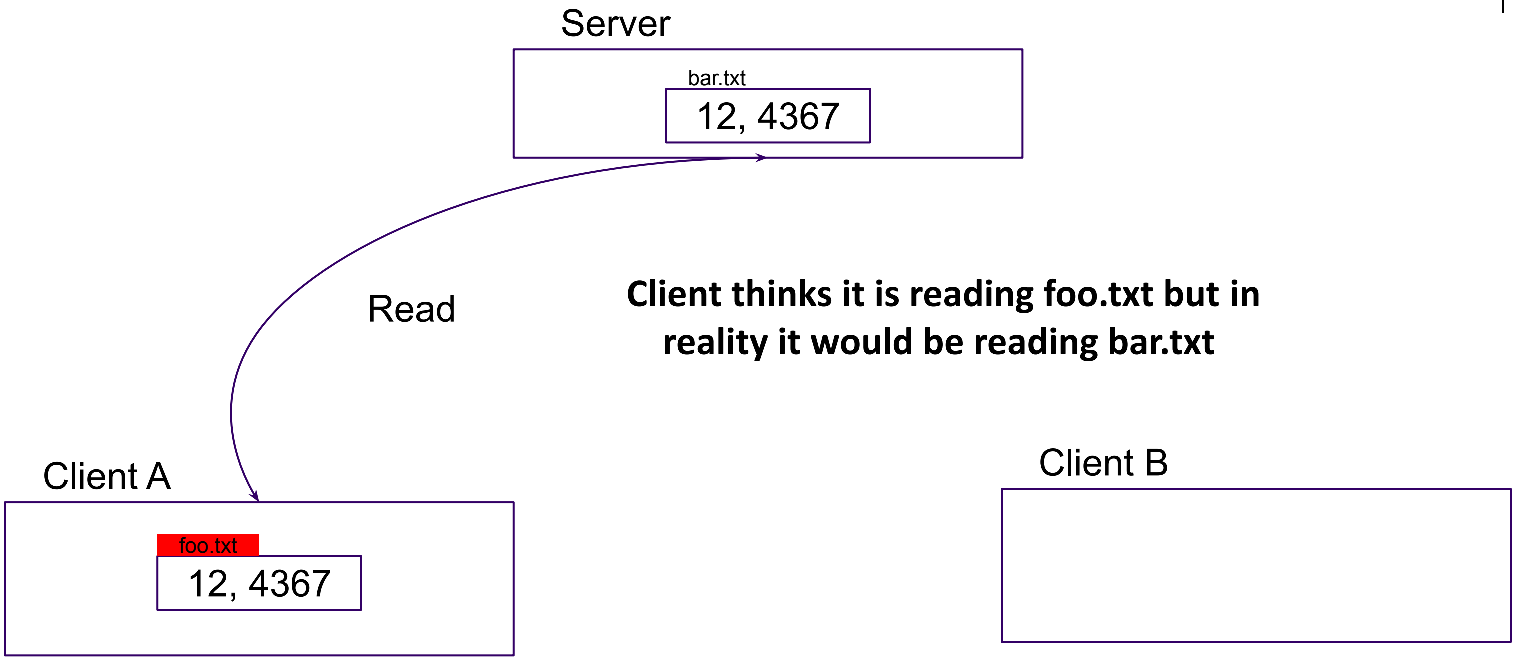



**Client thinks it is reading foo.txt but in reality it would be reading bar.txt**

# Performance

- Evey read and write requires a network access
- How can we avoid this frequent network access?

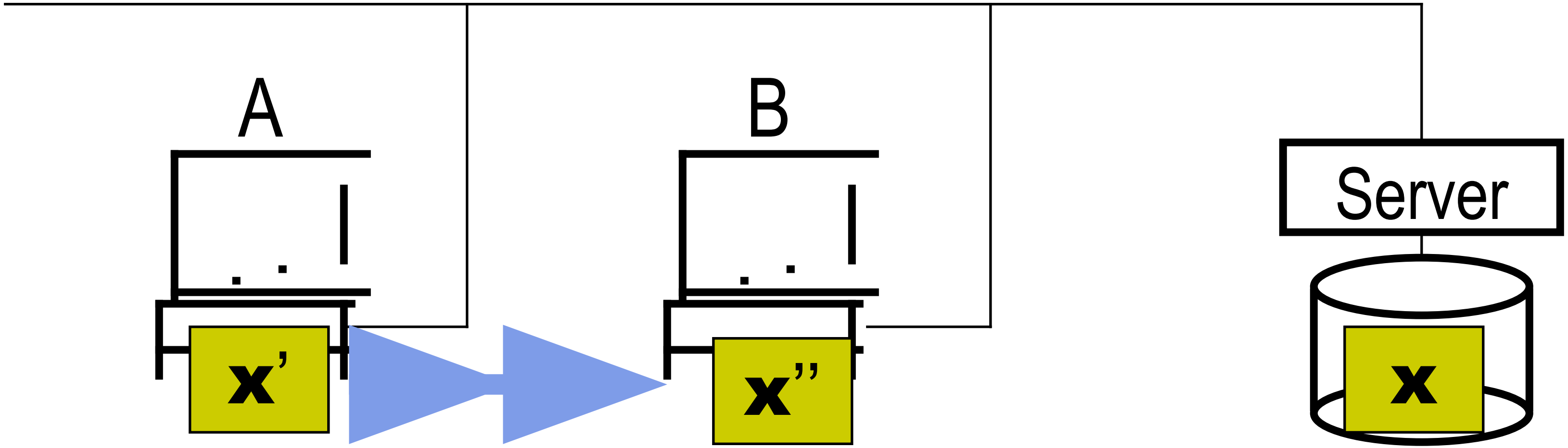
# Client-Side Caching

- Caching needed to improve performance
  - Reads: Check local cache before going to server
  - Writes: Only periodically write-back data to server
  - Why avoid contacting server
    - Avoid slow communication over network
    - Server becomes scalability bottleneck with more clients
- Two types of client caches
  - data blocks
  - attributes (metadata)

# Cache Consistency

- Problem: Consistency across multiple copies (server and multiple clients)
  - How to keep data consistent between client and server?
    - If file is changed on server, will client see update?
    - Determining factor: Read policy on clients
  - How to keep data consistent across clients?
    - If write file on client A and read on client B, will B see update?
    - Determining factor: Write and read policy on clients

# Cache Consistency Problem




**Inconsistent updates**

# NFS Consistency: Reads

- Reads: How does client keep current with server state?
  - Attribute cache: Used to determine when file changes
    - File open: Client checks server to see if attributes have changed
      - If haven’t checked in past T seconds (configurable, T=3)
    - Discard entries every N seconds (configurable, N=60)
  - Data cache
    - Discard all blocks of file if attributes of the file has been modified

# NFS Consistency: Reads

- Eg: Client cache has file A’s attributes and blocks 1, 2, 3
  - Client opens A:
  - Client reads block 1 => ?
  - Client waits 70 seconds
  - Client reads block 2 => ?

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  - Client reads block 2 => cache
  - Block 3 is changed on server

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  - Block 3 is changed on server
  - Client reads block 3 => ?

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  - Client opens A:
  - Client reads block 1 => cache
  - Client waits 70 seconds
  - Client reads block 2 => cache
  - Block 3 is changed on server
  - Client reads block 3 => cache, get old value
  - Client reads block 4 => ?

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  - Client opens A:
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  - Client reads block 3 => cache, get old value
  - Client reads block 4 => fetch from server
  - Client waits 70 seconds

**Attr changed, all Data blocks are discarded.**

# NFS Consistency: Reads

- Eg: Client cache has file A’s attributes and blocks 1, 2, 3
  - Client opens A:
  - Client reads block 1 => cache
  - Client waits 70 seconds
  - Client reads block 2 => cache
  - Block 3 is changed on server
  - Client reads block 3 => cache, get old value
  - Client reads block 4 => fetch from server
  - Client waits 70 seconds
  - Client reads block 3 => ?
  - Client reads block 1 => ?

# NFS Consistency: Writes

- Writes: How does client update server?
  - Files
    - Write-back from client cache to server every 30 seconds
    - Also, Flush (write all dirty data) on close() (AKA *flush-on-close*)
  - Directories
    - Synchronously write to server (write through)

# NFS Consistency: Writes

- Example: Client X and Y have file A (blocks 1,2,3) cached
  - Clients X and Y open file A
  - Client X writes to blocks 1 and 2

# NFS Consistency: Writes

- Example: Client X and Y have file A (blocks 1,2,3) cached
  - Clients X and Y open file A
  - Client X writes to blocks 1 and 2
  - Client Y reads block 1 => cache

# NFS Consistency: Writes

- Example: Client X and Y have file A (blocks 1,2,3) cached
  - Clients X and Y open file A
  - Client X writes to blocks 1 and 2
  - Client Y reads block 1 => cache
  - 30 seconds later...

**Data blocks from X are pushed to the server.**

# NFS Consistency: Writes

- Example: Client X and Y have file A (blocks 1,2,3) cached
  - Clients X and Y open file A
  - Client X writes to blocks 1 and 2
  - Client Y reads block 1 => cache
  - 30 seconds later...
  - Client Y reads block 2 => cache, get old value

# NFS Consistency: Writes

- Example: Client X and Y have file A (blocks 1,2,3) cached
  - Clients X and Y open file A
  - Client X writes to blocks 1 and 2
  - Client Y reads block 1 => cache
  - 30 seconds later...
  - Client Y reads block 2 => cache, get old value
  - 40 seconds later...

**Attr changed, all Data blocks are discarded.**

# NFS Consistency: Writes

- Example: Client X and Y have file A (blocks 1,2,3) cached
  - Clients X and Y open file A
  - Client X writes to blocks 1 and 2
  - Client Y reads block 1 => cache
  - 30 seconds later...
  - Client Y reads block 2 => cache, get old value
  - 40 seconds later...
  - Client Y reads block 1 => server

# Conclusions

- Distributed file systems
  - Important for data sharing
  - Challenges: Fault tolerance, scalable performance, and consistency

- NFS: Popular distributed file system
  - Key features:
    - Stateless server, idempotent operations: Simplifies fault tolerance
    - Crashed server appears as slow server to clients
  - Client caches needed for scalable performance
    - Rules for invalidating cache entries and flushing data to server are not straight-forward
    - Data consistency very hard to reason about