416 Distributed Systems

Distributed File Systems: AFS

Sep 20, 2018

Outline

- Why Distributed File Systems?
- Basic mechanisms for building DFSs
  - Using NFS and **AFS** as examples
- Design choices and their implications
  - Caching
  - Consistency
  - Naming
  - Authentication and Access Control

Client Caching in NFS v2

- Cache both clean and dirty file data and file attributes
  - Memory cache
  - Sub-file caching granularity
- File attributes (e.g., last modified time) in the cache expire after 60 seconds (file data doesn't expire)
  - ➢ Will retrieve updated attributes from server every 60s
- If server has a more recent modified time, grab the up-to-date data in cache from server
- Dirty data are buffered (in cache) on the client until file close or up to 30 seconds
  - If the machine crashes before then, the changes are lost

Let’s look back at NFS

- NFS gets us partway there, but
  - Probably doesn’t handle scale (* - you can buy huge NFS appliances today that will, but they’re $$$-y).
  - Is very sensitive to network latency
    - Consistency is.. what do we even call that? Highly implementation specific.
- How can we improve this?
  - More aggressive caching (AFS caches on disk in addition to just in memory)
  - Prefetching (on open, AFS gets entire file from server, making later ops local & fast).

Client Caching in AFS

- Callbacks! Clients register with server that they have a copy of file;
  - Server tells them (calls them back): “Invalidate” if the file changed (but only does so on file close!)
  - This trades state (at server) for improved consistency
- Key AFS bit: read from local disk copy unless server indicates new copy exists (via callback)
- What if server crashes? Lose all callback state!
  - Reconstruct callback information from clients
    - ask everyone “who has which files cached?”

AFS v2 RPC Procedures

- Procedures that are not in NFS
  - Fetch: from client to server, return status and optionally data of (entire) file or directory, and add a callback on it
  - **RemoveCallBack**: from C to S, specify a file that the client has flushed from the local machine
  - **BreakCallBack**: from S to C, revoke the callback on a file or directory (this is the callback **call** to client)
  - Store: from S to C, store the status and optionally data of a file

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  - **BreakCallBack**: from S to C, revoke the callback on a file or directory (this is the callback **call** to client)
    - What should the client do if a callback is revoked?
      - Delete existing cached copy / refetch from server on open
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Topic 2: File Access Consistency

- In UNIX local file system, concurrent file reads and writes have "sequential" consistency semantics
  - Each file read/write from user-level app is an atomic operation
    - The kernel locks the file vnode
  - Each file write is immediately visible to all file readers
- Neither NFS nor AFS provides such concurrency control between distributed processes
  - NFS: "sometime within 30 seconds"
  - AFS: session semantics consistency (next slide)
    - Same machine processes in AFS do have seq. consistency

Session Semantics in AFS v2

- What it means:
  - A file write is visible to processes on the same box immediately, but not visible to processes on other machines until the file is closed
  - When a file is closed, changes are visible to new opens, but are not visible to “old” opens
    - Last closer wins!
    - AFS writebacks the *entire* file (not a mix of updates like NFS)
  - All other file operations are visible everywhere immediately
- Implementation
  - Dirty data are buffered at the client machine until file close, then flushed back to server, which leads the server to send “break callback” to other clients

Session semantics in AFS

- P1 and P2 local to Client1
- Clients 1,2 concurrent

Client$_1$			Client$_2$		Server	*Comments*
P_1	P_2	Cache	P_3	Cache	Disk	
open(F)		-		-	-	File created
write(A)		A		-	-	
close()		A		-	A	
	open(F)	A		-	A	
	read() $\rightarrow$ A	A		-	A	
	close()	A		-	A	
open(F)		A		-	A	
write(B)		B		-	A	
	open(F)	B		-	A	Local processes
	read() $\rightarrow$ B	B		-	A	see writes immediately
	close()	B		-	A	
		B	open(F)	A	A	Remote processes
		B	read() $\rightarrow$ A	A	A	do not see writes...
		B	close()	A	A	
close()		B		~~A~~	B	... until close()
		B	open(F)	B	B	has taken place
		B	read() $\rightarrow$ B	B	B	
		B	close()	B	B	
		B	open(F)	B	B	
open(F)		B		B	B	
write(D)		D		B	B	
		D	write(C)	C	B	
		D	close()	C	C	
close()		D		~~C~~	D	
		D	open(F)	D	D	Unfortunately for P_3
		D	read() $\rightarrow$ D	D	D	the last writer wins
		D	close()	D	D	

AFS Write Policy

- Writeback cache (in contrast with write through)
  - Opposite of NFS “every write is sacred”
  - Store contents back to server
    - When cache overflows
    - AFS: On last user close() : last closer “wins”
  - ...or don't (if client machine crashes)
- Is writeback crazy?
  - Write conflicts “assumed rare”
  - Who wants to see a half-written file?

Dealing with crashes in AFS

- Client crashes
  - Cache is suspect (could miss a break callback)
  - Have to check with server if caching latest state
- Server crashes
  - Lose all callback state (kept in memory)
  - All clients must detect server failure + treat their local caches as suspect (as above, but across **all** clients)

- Contrast this with NFS in which clients don’t even notice server crashes

Results for AFS

- Lower server load than NFS
  - More files cached on clients
  - Callbacks: server not busy if files are read-only (common case)
- But maybe slower: Access from local disk is much slower than from another machine's memory over LAN (better with SSD: ~1ms to read 1MB)
- For both:
  - Central server is bottleneck: all reads and writes hit it at least once;
  - is a single point of failure.
  - is costly to make them fast, beefy, and reliable.

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Topic 3: Name-Space Construction and Organization

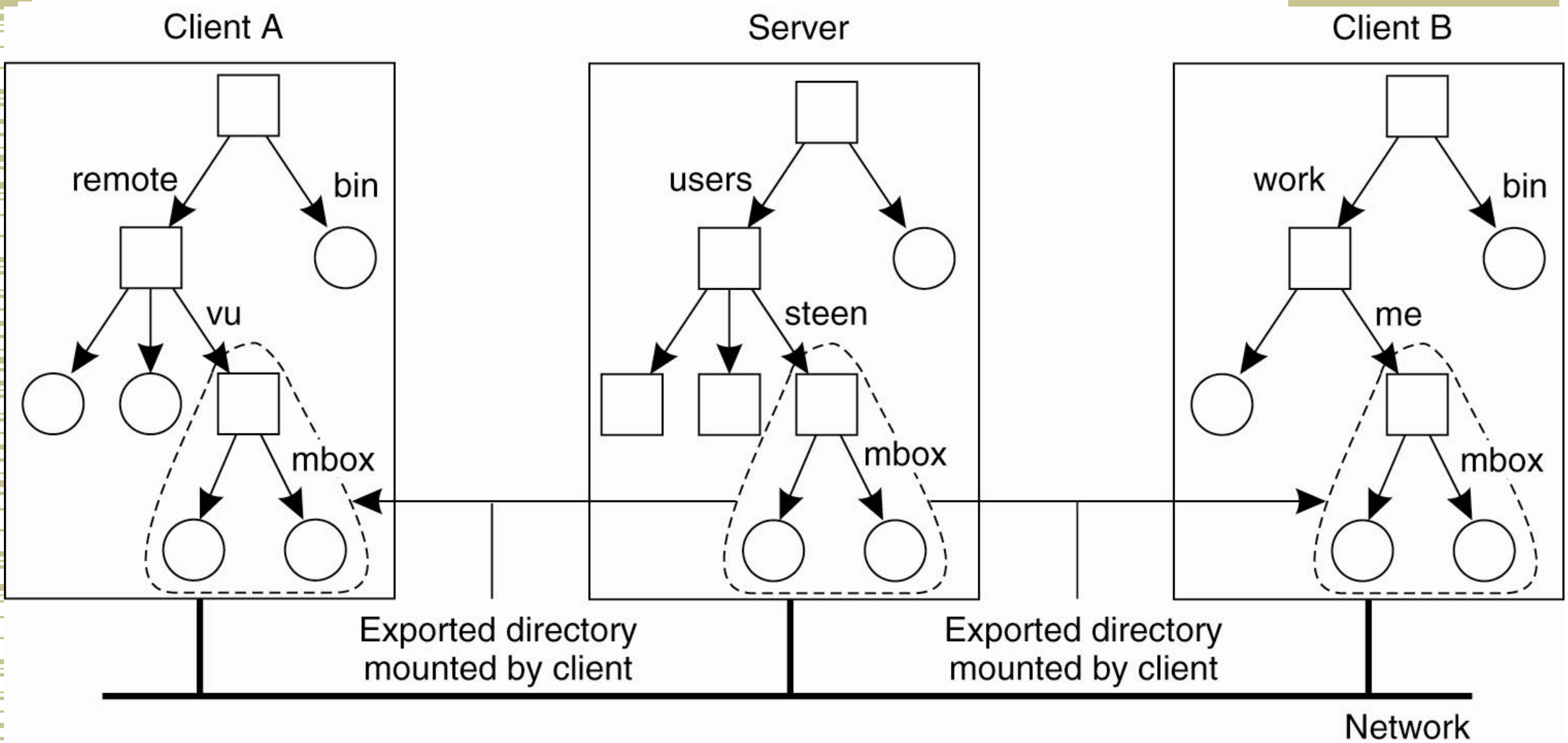
- NFS: per-client linkage
  - Server: export /root/fs1/
  - Client: mount server:/root/fs1 /fs1
- AFS: global name space
  - Name space is organized into Volumes
    - Global directory /afs;
    - /afs/cs.wisc.edu/vol1/…; /afs/cs.stanford.edu/vol1/…
  - Each file is identified as fid = <vol_id, vnode #, unique identifier>
  - All AFS servers keep a copy of "volume location database", which is a table of vol_id→ server_ip mappings
  - Can move volumes between servers to balance load

Implications on Location Transparency

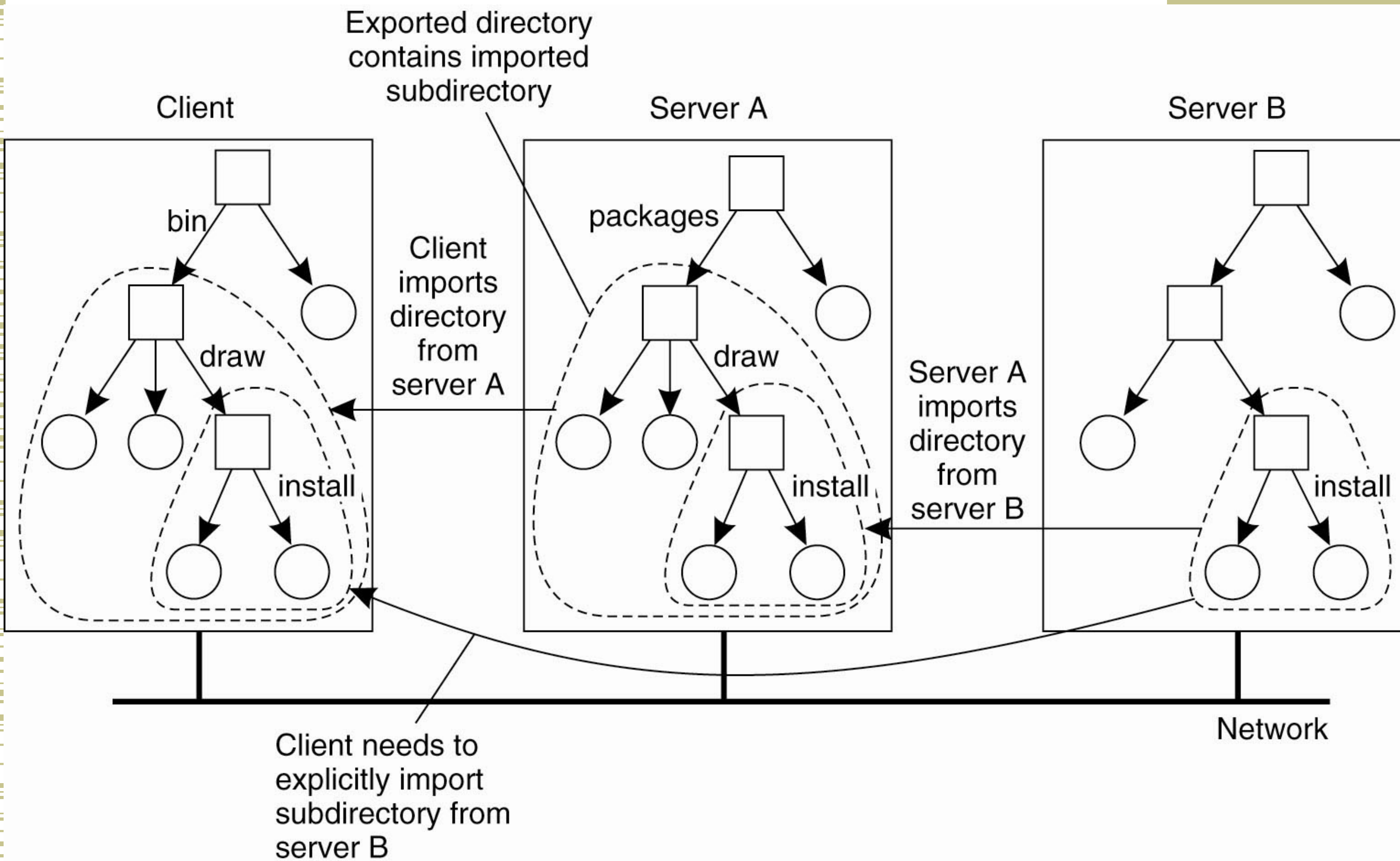
- NFS: no transparency
  - If a directory is moved from one server to another, client must remount

- AFS: transparency
  - If a volume is moved from one server to another, only the volume location database on the servers needs to be updated (clients do not need to observe the change)

Naming in NFS (1)



Naming in NFS (2)



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Topic 4: User Authentication and Access Control

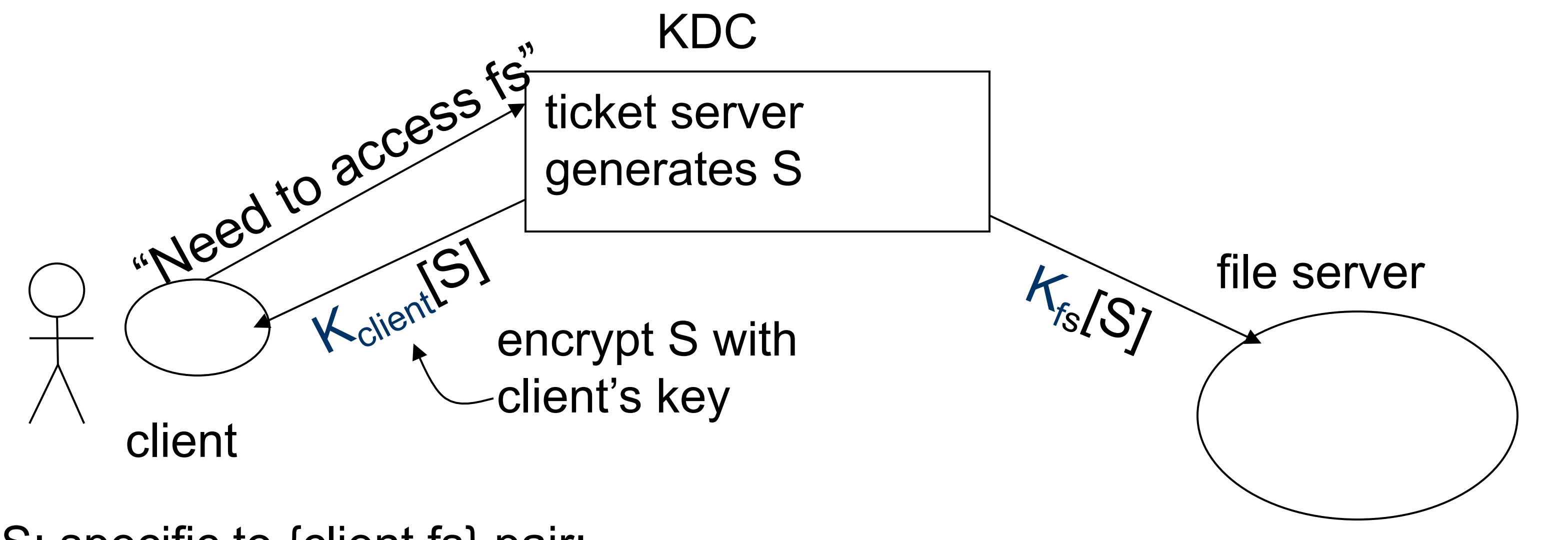
- User X logs onto workstation A, wants to access files on server B
  - How does A tell B who X is?
  - Should B believe A?
- Choices made in NFS V2
  - All servers and all client workstations share the same <uid, gid> name space → B send X's <uid,gid> to A
    - Problem: root access on any client workstation can lead to creation of users of arbitrary <uid, gid>
  - Server believes client workstation unconditionally
    - Problem: if any client workstation is broken into, the protection of data on the server is lost;
    - <uid, gid> sent in clear-text over wire → request packets can be faked easily

User Authentication (cont'd)

- How do we fix the problems in NFS v2
  - Hack 1: root remapping → strange behavior
  - Hack 2: UID remapping → no user mobility
  - Real Solution: use a centralized Authentication/Authorization/Access-control (AAA) system

A Better AAA System: Kerberos

- Basic idea: shared secrets
  - User proves to KDC who he is; KDC generates shared secret between client and file server



S: specific to {client,fs} pair;
"short-term session-key"; expiration time (e.g. 8 hours)

Today’s bits

- Distributed filesystems almost always involve a tradeoff: consistency, performance, scalability.
- We’ve learned a lot since NFS and AFS (and can implement faster, etc.), but the general lesson holds. Especially in the wide-area.
- We’ll see a related tradeoff, also involving consistency, in a while: the CAP tradeoff. Consistency, Availability, Partition-resilience.

More bits

- Client-side caching is a fundamental technique to improve scalability and performance
  - But raises important questions of cache consistency
- Timeouts and callbacks are common methods for providing (some forms of) consistency.
- AFS picked close-to-open (session) consistency as a good balance of usability (the model seems intuitive to users), performance, etc.
  - AFS authors argued that apps with highly concurrent, shared access, like databases, needed a different model

Failure Recovery in AFS & NFS

- What if the file server fails?
- What if the client fails?
- What if both the server and the client fail?
- Network partition
  - How to detect it? How to recover from it?
  - Is there anyway to ensure absolute consistency in the presence of network partition?
    - Reads
    - Writes
- What if all three fail: network partition, server, client?

Key to Simple Failure Recovery

- Try not to keep any state on the server
- If you must keep some state on the server
  - Understand why and what state the server is keeping
  - Understand the worst case scenario of no state on the server and see if there are still ways to meet the correctness goals
  - Revert to this worst case in each combination of failure cases