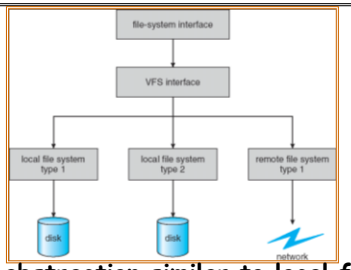
CS162
Operating Systems and Systems Programming
Lecture 24

Distributed File Systems

April 30, 2008
Prof. Anthony D. Joseph
http://inst.eecs.berkeley.edu/~cs162

Review: Virtual File System (VFS)



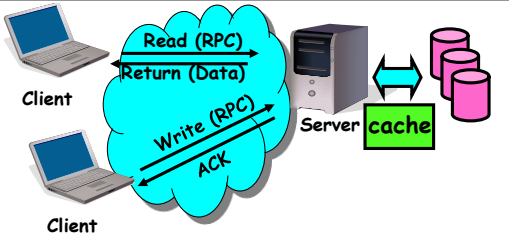
- VFS: Virtual abstraction similar to local file system
  - Instead of "inodes" has "vnodes"
  - Compatible with a variety of local and remote file systems
    - » provides object-oriented way of implementing file systems
- VFS allows the same system call interface (the API) to be used for different types of file systems
  - The API is to the VFS interface, rather than any specific type of file system

Goals for Today

- Examples of Distributed File Systems
- Cache Coherence Protocols
- Worms and Viruses

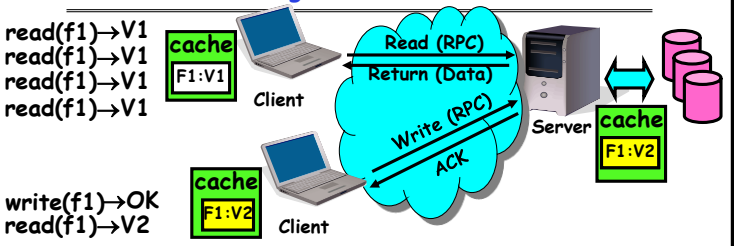
Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne. Many slides generated from my lecture notes by Kubiatowicz.

Simple Distributed File System



- Remote Disk: Reads and writes forwarded to server
  - Use RPC to translate file system calls
  - No local caching/can be caching at server-side
- Advantage: Server provides completely consistent view of file system to multiple clients
- Problems? Performance!
  - Going over network is slower than going to local memory
  - Lots of network traffic/not well pipelined
  - Server can be a bottleneck

Use of caching to reduce network load



- Idea: Use caching to reduce network load
  - In practice: use buffer cache at source and destination
- Advantage: if open/read/write/close can be done locally, don't need to do any network traffic…fast!
- Problems:
  - Failure:
    - » Client caches have data not committed at server
  - Cache consistency!
    - » Client caches not consistent with server/each other

Failures

- What if server crashes? Can client wait until server comes back up and continue as before?
  - Any data in server memory but not on disk can be lost
  - Shared state across RPC: What if server crashes after seek? Then, when client does "read", it will fail
  - Message retries: suppose server crashes after it does UNIX "rm foo", but before acknowledgment?
    - » Message system will retry: send it again
    - » How does it know not to delete it again? (could solve with two-phase commit protocol, but NFS takes a more ad hoc approach)
- Stateless protocol: A protocol in which all information required to process a request is passed with request
  - Server keeps no state about client, except as hints to help improve performance (e.g. a cache)
  - Thus, if server crashes and restarted, requests can continue where left off (in many cases)
- What if client crashes?
  - Might lose modified data in client cache

World Wide Web

- Key idea: graphical front-end to RPC protocol
- What happens when a web server fails?
  - System breaks!
  - Solution: Transport or network-layer redirection
    - » Invisible to applications
    - » Can also help with scalability (load balancers)
    - » Must handle "sessions" (e.g., banking/e-commerce)
- Initial version: no caching
  - Didn't scale well – easy to overload servers

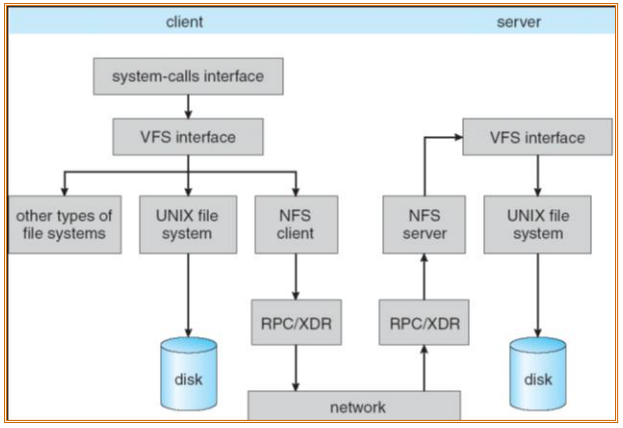
WWW Caching

- Use client-side caching to reduce number of interactions between clients and servers and/or reduce the size of the interactions:
  - Time-to-Live (TTL) fields – HTTP "Expires" header from server
  - Client polling – HTTP "If-Modified-Since" request headers from clients
  - Server refresh – HTML "META Refresh tag" causes periodic client poll
- What is the polling frequency for clients and servers?
  - Could be adaptive based upon a page's age and its rate of change
- Server load is still significant!

WWW Proxy Caches

- Place caches in the network to reduce server load
  - But, increases latency in lightly loaded case
  - Caches near servers called "reverse proxy caches"
    - » Offloads busy server machines
  - Caches at the "edges" of the network called "content distribution networks"
    - » Offloads servers and reduce client latency
- Challenges:
  - Caching static traffic easy, but only ~40% of traffic
  - Dynamic and multimedia is harder
    - » Multimedia is a big win: Megabytes versus Kilobytes
  - Same cache consistency problems as before
- Caching is changing the Internet architecture
  - Places functionality at higher levels of comm. protocols

Schematic View of NFS Architecture



Administrivia

- Project #4 design deadline is Thu 5/1 at 11:59pm
  - See newsgroup for design doc details
  - Code deadline is Wed 5/14
- Final Exam
  - May 21st, 12:30-3:30pm
- Final Topics: Any suggestions?
  - Please send them to me…

Network File System (NFS)

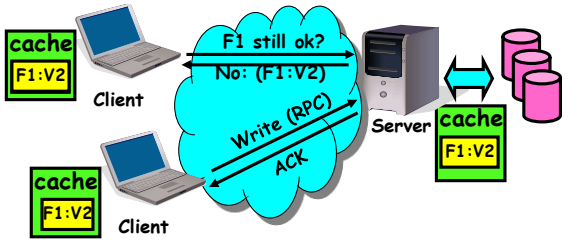
- Three Layers for NFS system
  - UNIX file-system interface: open, read, write, close calls + file descriptors
  - VFS layer: distinguishes local from remote files
    - » Calls the NFS protocol procedures for remote requests
  - NFS service layer: bottom layer of the architecture
    - » Implements the NFS protocol
- NFS Protocol: RPC for file operations on server
  - Reading/searching a directory
  - manipulating links and directories
  - accessing file attributes/reading and writing files
- Write-through caching: Modified data committed to server's disk before results are returned to the client
  - lose some of the advantages of caching
  - time to perform write() can be long
  - Need some mechanism for readers to eventually notice changes! (more on this later)

NFS Continued

- NFS servers are stateless; each request provides all arguments require for execution
  - E.g. reads include information for entire operation, such as `ReadAt(inumber,position)`, not `Read(openfile)`
  - No need to perform network open() or close() on file – each operation stands on its own
- Idempotent: Performing requests multiple times has same effect as performing it exactly once
  - Example: Server crashes between disk I/O and message send, client resend read, server does operation again
  - Example: Read and write file blocks: just re-read or re-write file block – no side effects
  - Example: What about "remove"? NFS does operation twice and second time returns an advisory error
- Failure Model: Transparent to client system
  - Is this a good idea? What if you are in the middle of reading a file and server crashes?
  - Options (NFS Provides both):
    - » Hang until server comes back up (next week?)
    - » Return an error. (Of course, most applications don't know they are talking over network)

NFS Cache consistency

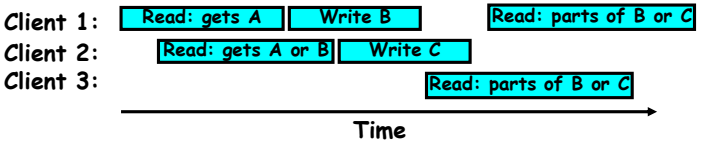
- NFS protocol: weak consistency
  - Client polls server periodically to check for changes
    - » Polls server if data hasn't been checked in last 3-30 seconds (exact timeout it tunable parameter).
    - » Thus, when file is changed on one client, server is notified, but other clients use old version of file until timeout.



  - What if multiple clients write to same file?
    - » In NFS, can get either version (or parts of both)
    - » Completely arbitrary!

Sequential Ordering Constraints

- What sort of cache coherence might we expect?
  - i.e. what if one CPU changes file, and before it's done, another CPU reads file?
- Example: Start with file contents = "A"



- What would we actually want?
  - Assume we want distributed system to behave exactly the same as if all processes are running on single system
    - » If read finishes before write starts, get old copy
    - » If read starts after write finishes, get new copy
    - » Otherwise, get either new or old copy
  - For NFS:
    - » If read starts more than 30 seconds after write, get new copy; otherwise, could get partial update

NFS Pros and Cons

- NFS Pros:
  - Simple, Highly portable
- NFS Cons:
  - Sometimes inconsistent!
  - Doesn't scale to large # clients
    - » Must keep checking to see if caches out of date
    - » Server becomes bottleneck due to polling traffic

Andrew File System

- Andrew File System (AFS, late 80's) → DCE DFS (commercial product)
- Callbacks: Server records who has copy of file
  - On changes, server immediately tells all with old copy
  - No polling bandwidth (continuous checking) needed
- Write through on close
  - Changes not propagated to server until close()
  - Session semantics: updates visible to other clients only after the file is closed
    - » As a result, do not get partial writes: all or nothing!
    - » Although, for processes on local machine, updates visible immediately to other programs who have file open
- In AFS, everyone who has file open sees old version
  - Don't get newer versions until reopen file

Andrew File System (con't)

- Data cached on local disk of client as well as memory
  - On open with a cache miss (file not on local disk):
    - » Get file from server, set up callback with server
  - On write followed by close:
    - » Send copy to server; tells all clients with copies to fetch new version from server on next open (using callbacks)
- What if server crashes? Lose all callback state!
  - Reconstruct callback information from client: go ask everyone "who has which files cached?"
- AFS Pro: Relative to NFS, less server load:
  - Disk as cache ⇒ more files can be cached locally
  - Callbacks ⇒ server not involved if file is read-only
- For both AFS and NFS: central server is bottleneck!
  - Performance: all writes→server, cache misses→server
  - Availability: Server is single point of failure
  - Cost: server machine's high cost relative to workstation

Summary

- VFS: Virtual File System layer
  - Provides mechanism which gives same system call interface for different types of file systems
- Distributed File System:
  - Transparent access to files stored on a remote disk
    - » NFS: Network File System
    - » AFS: Andrew File System
  - Caching for performance
- Cache Consistency: Keeping contents of client caches consistent with one another
  - If multiple clients, some reading and some writing, how do stale cached copies get updated?
  - NFS: check periodically for changes
  - AFS: clients register callbacks so can be notified by server of changes

BREAK

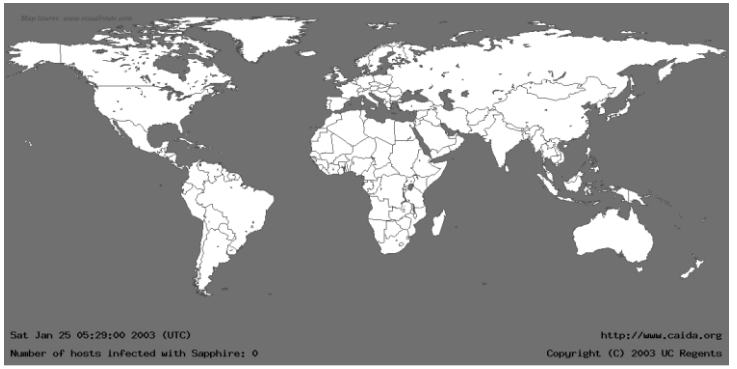
Internet Worms

- Self-replicating, self-propagating code and data
- Use network to find potential victims
- Typically exploit vulnerabilities in an application running on a machine or the machine's operating system to gain a foothold
- Then search the network for new victims

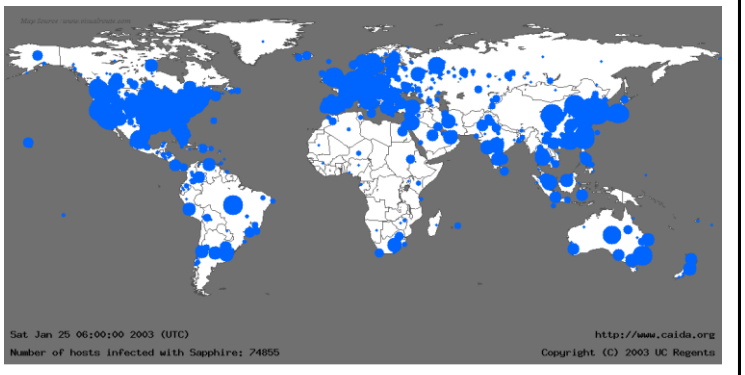
Sapphire (AKA Slammer) Worm

- January 25, 2003
- Fastest computer worm in history
  - Used MS SQL Server buffer overflow vulnerability
  - Doubled in size every 8.5 seconds, 55M scans/sec
  - Infected >90% of vulnerable hosts within 10 mins
  - Infected at least 75,000 hosts
  - Caused network outages, canceled airline flights, elections problems, interrupted E911 service, and caused ATM failures

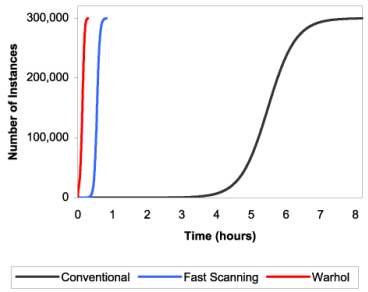
Before Sapphire



After Sapphire



Worm Propagation Behavior



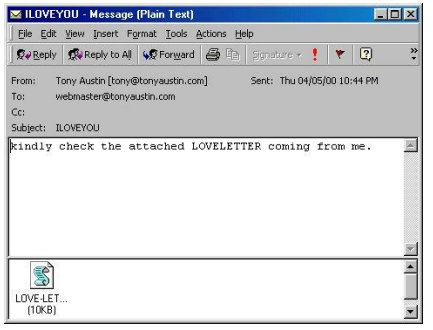
- More efficient scanning finds victims faster (< 1hr)
- Even faster propagation is possible if you cheat
  - Wasted effort scanning non-existent or non-vulnerable hosts
  - Warhol: seed worm with a "hit list" of vulnerable hosts (15 mins)

Internet Viruses

- Self-replicating code and data
- Typically requires human interaction before exploiting an application vulnerability
  - Running an e-mail attachment
  - Clicking on a link in an e-mail
  - Inserting/connecting "infected" media to a PC
- Then search for files to infect or sends out e-mail with an infected file

LoveLetter Virus (May 2000)

- E-mail message with VBScript (simplified Visual Basic)
- Relies on Windows Scripting Host
  - Enabled by default in Win98/2000
- User clicks on attachment ➔ infected!



LoveLetter's Impact

- Approx 60 – 80% of US companies infected by the "ILOVEYOU" virus
- Several US gov. agencies and the Senate were hit
- > 100,000 servers in Europe
- Substantial lost data from replacement of files with virus code
  - Backups anyone?
- Could have been worse – not all viruses require opening of attachments…

Worm/Virus Summary

- Worms are a critical threat
  - More than 100 companies, including Financial Times, ABCNews and CNN, were hit by the Zotob Windows 2000 worm in August 2005
- Viruses are a critical threat
  - FBI survey of 269 companies in 2004 found that viruses caused ~$55 million in damages
  - DIY toolkits proliferate on Internet
- How can we protect against worms and viruses?
  - Scanners
  - Firewalls
  - …