CSE 451: Operating Systems
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Module 23
Distributed File Systems

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Distributed File Systems

- A distributed file systems supports network-wide sharing of files and devices
- A DFS typically presents clients with a "traditional" file system view
  - there is a single file system namespace that all clients see
  - files can be shared
  - one client can observe the side-effects of other clients' file system activities
  - in many (but not all) ways, an ideal distributed file system provides clients with the illusion of a shared, local file system
- But …with a distributed implementation
  - read blocks / files from remote machines across a network, instead of from a local disk

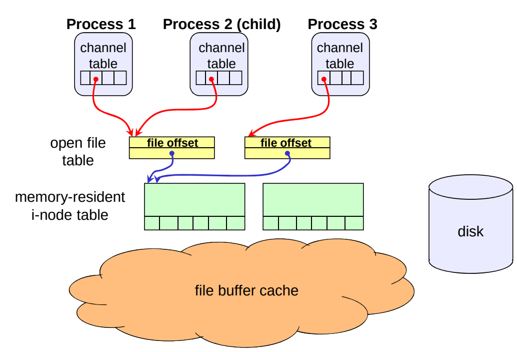
DFS issues

- What is the basic abstraction
  - a remote file system?
    - open, close, read, write, …
  - a remote disk?
    - read block, write block
- Naming
  - how are files named?
  - are those names location transparent?
    - is the file location visible to the user?
    - do the names change if the file moves?
    - do the names change if the user moves?

- Caching
  - caching exists for performance reasons
  - where are file blocks cached?
    - on the file server?
    - on the client machine?
    - both?
- Sharing and coherency
  - what are the semantics of sharing?
  - what happens when a cached block/file is modified?
  - how does a node know when its cached blocks are stale?
    - if we cache on the client side, we're presumably caching on multiple client machines if a file is being shared

- Replication
  - replication can exist for performance and/or availability
  - can there be multiple copies of a file in the network?
  - if multiple copies, how are updates handled?
  - what if there's a network partition? Can clients work on separate copies? If so, how does reconciliation take place?
- Performance
  - what is the performance of remote operations?
  - what is the additional cost of file sharing?
  - how does the system scale as the number of clients grows?
  - what are the performance bottlenecks: network, CPU, disks, protocols, data copying?

Reminder: Single-system Unix file sharing



Example: Sun's Network File System (NFS)

- The Sun Network File System (NFS) has become a common standard for distributed UNIX file access
- NFS runs over LANs (even over WANs – slowly)
- Basic idea
  - allow a remote directory to be "mounted" (spliced) onto a local directory
  - gives access to that remote directory and all its descendants as if they were part of the local hierarchy
- Pretty similar (except for implementation and performance) to a "local mount" or "link" on UNIX
  - I might link
    /cse/www/education/courses/451/13sp/
    as
    /u4/lazowska/451
    to allow easy access to my web data from my home directory:
    cd
    ln –s /cse/www/education/courses/451/13sp 451

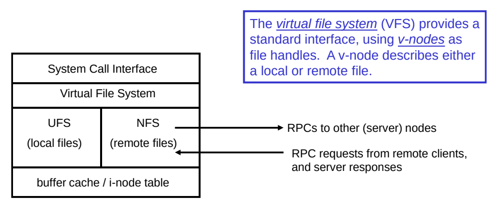
NFS particulars

- *ginger.cs* exports the directory ginger.cs:/u4/lazowska
- *norton.cs* mounts this on /faculty/edl
  - programs on *norton.cs* can access the remote directory ginger.cs:/u4/lazowska using the local path /faculty/edl
- if, on *ginger.cs*, I had a file /u4/lazowska/myfile.txt
  - programs on *norton.cs* could access it as /faculty/edl/myfile.txt
- note that different clients might mount the same exported directory, but on different local paths
  - e.g., *forkbomb.cs* might mount it on /facultyfiles/edlazowska
  - then, the file ginger.cs:/u4/lazowska/myfile.txt could be accessed with three different names
    - on ginger.*cs:* /u4/lazowska/myfile.txt
    - on norton.*cs:* /faculty/edl/myfile.txt
    - on *forkbomb.cs:* /facultyfiles/edlazowska/myfile.txt

NFS implementation

- NFS defines a set of RPC operations for remote file access:
  - searching a directory
  - reading directory entries
  - manipulating links and directories
  - reading/writing files
- Every node may be a client, a server, or both
  - E.g., a given machine might export some directories and import others

- NFS defines new layers in the Unix file system



NFS caching / sharing

- On a file open, the client asks the server whether the client's cached blocks are up to date (good!)
  - but, once a file is open, different clients can perform concurrent reads and writes to it and get inconsistent data (bad!)
- Modified data is flushed back to the server every 30 seconds
  - the good news is this bounds the amount of inconsistency to a window of 30 seconds, and that this is simple to implement and understand
  - the bad news is that the inconsistency can be severe
    - e.g., data can be lost, different clients can see inconsistent states of the files at the same time

Example: CMU's Andrew File System (AFS)

- Developed at CMU to support all of its student computing
- Consists of workstation clients and dedicated file server machines (differs from NFS)
- Workstations have local disks, used to cache files being used locally (originally whole files, subsequently 64K file chunks) (differs from NFS)
- Andrew has a single name space – your files have the same names everywhere in the world (differs from NFS)
- Andrew is good for distant operation because of its local disk caching: after a slow startup, most accesses are to local disk

AFS caching/sharing

- Need for scaling required reduction of client-server message traffic
  - Once a file is cached, all operations are performed locally
  - On close, if the file has been modified, it is replaced on the server
- The client assumes that its cache is up to date, unless it receives a *callback* message from the server saying otherwise
  - on file open, if the client has received a callback on the file, it must fetch a new copy; otherwise it uses its locally-cached copy (differs from NFS)
- What if two users are accessing the same file?

Example: Berkeley Sprite File System

- Unix file system developed for *diskless* workstations with large memories (differs from NFS, AFS)
- Considers memory as a huge cache of disk blocks
  - memory is shared between file system and VM
- Files are permanently stored on servers
  - servers have a large memory that acts as a cache as well
- Several workstations can cache blocks for read-only files
- If a file is being written by more than 1 machine, client caching is turned off – all requests go to the server (differs from NFS, AFS)
  - So improved coherence, at higher cost

Example: Google's File System (GFS)

NFS, etc.

GFS

Independence
Small Scale
Variety of workloads

Cooperation
Large scale
Very specific, well-understood workloads

GFS: Environment

Why did Google build its own file system?

- Google has unique FS requirements
  - huge volume of data
  - huge read/write bandwidth
  - reliability over tens of thousands of nodes with frequent failures
  - mostly operating on large data blocks
  - needs efficient distributed operations
- Google has somewhat of an unfair advantage…it has control over, and customizes, its:
  - applications
  - libraries
  - operating system
  - networks
  - even its computers!

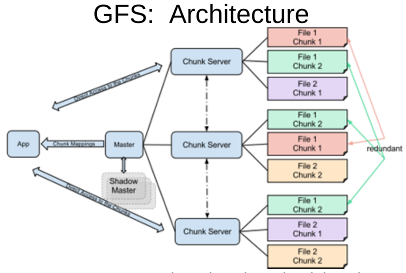
GFS: Files

- Files are huge by traditional standards (GB, TB, PB)
- Most files are mutated by appending new data rather than overwriting existing data
- Once written, the files are only read, and often only sequentially.
- Appending becomes the focus of performance optimization and atomicity guarantees
- NOTE: A major use of GFS is for storing event logs – what did you search for, which link did you follow, etc. Then these logs are mined for patterns. Hence huge, append-only, read sequentially.

GFS: Architecture

- A *GFS cluster* consists of a replicated *master* and multiple *chunk servers* and is accessed by multiple *clients*
- Each computer in the GFS cluster is typically a commodity Linux machine running a user-level server process
- Files are divided into fixed-size *chunks* identified by an immutable and globally unique 64-bit *chunk handle*
- For reliability, each chunk is *replicated* on multiple chunk servers
- The master maintains all file system metadata (like, on which chunk servers specific chunks are stored)
- The master periodically communicates with each chunk server in *HeartBeat* messages to determine its state
- Clients communicate with the master (to access metadata (e.g., to find the location of specific chunks)) and directly with chunk servers (to actually access the data)
  - Prevents the single master from becoming a bottleneck
- Neither clients nor chunk servers cache file data, eliminating cache coherence issues
  - Caching not helpful because most ops are huge sequential reads
- Clients do cache metadata, however
- If the master croaks, Paxos is used to select a new master from among the replicas

GFS: Architecture



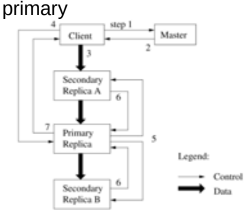
- Masters manage metadata (naming, chunk location, etc.)
- Data transfers happen directly between clients/chunkservers
- Files are broken into chunks (typically 64 MB)
  - each chunk replicated on 3 chunkservers
- Clients do not cache data!

GFS: Reading

- Single master vastly simplifies design
- Clients never read and write file data through the master. Instead, a client asks the master which chunk servers it should contact
- Using the fixed chunk size, the client translates the file name and byte offset specified by the application into a chunk index within the file
- It sends the master a request containing the file name and chunk index. The master replies with the corresponding chunk handle and locations of the replicas. The client caches this information using the file name and chunk index as the key
- The client then sends a request to one of the replicas, most likely the closest one. The request specifies the chunk handle and a byte range within that chunk

GFS: Writing

- Client asks master for identity of primary and secondary replicas (chunk servers)
- Client pushes data to memory at all replicas via a replica-to-replica "chain"
- Client sends write request to primary
- Primary orders concurrent requests, and triggers disk writes at all replicas
- Primary reports success or failure to client
- The write is *transactional*



Summary of Distributed File Systems

- There are a number of issues to deal with:
  - what is the basic abstraction?
  - naming
  - caching
  - sharing and coherency
  - replication
  - performance
  - workload
- No right answer! Different systems make different tradeoffs…

- Performance is always an issue
  - always a tradeoff between performance and the semantics of file operations (e.g., for shared files).
- Caching of file blocks is crucial in any file system
  - maintaining coherency is a crucial design issue.
- Newer systems are dealing with issues such as disconnected operation for mobile computers, and huge workloads (e.g., Google)

Think about …

- NFS, AFS, Sprite, GFS
  - How do they differ? What are the key properties of each?
  - What about the intended environment for each drove these differences?