Finding a needle in Haystack: Facebook's photo storage

OSDI 2010

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Facebook.com

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Overview

- Facebook is the world's largest photosharing site
- As of 2010:
  - 260 billion images
  - 20 petabytes of data
  - 1 billion photos, 60 terabytes uploaded each week
  - Over 1 million images/second served at peak
  - News feed and albums are 98% of photo requests
- Images are written once, read often, never modified, and rarely deleted

Why Not Use a Traditional Filesystem?

- No need for most metadata (directory tree, owner, group, etc)
  - Wastes space
  - More importantly, slows access to read, check, and use it
  - Turned out to be bottleneck
- What cost? Seems small?
  - Multiplied a lot
  - Think about steps: Map name to inode (name cache, directory files), read inode, read data
  - Latency is in access, itself, not tiny transfer

Haystack Goals

- High throughput, low latency
- Fault-tolerance
- Cost-effective (It is hugely scaled, right?)
- Simple (Means matures to robustness quickly, low operational cost)

Typical Design

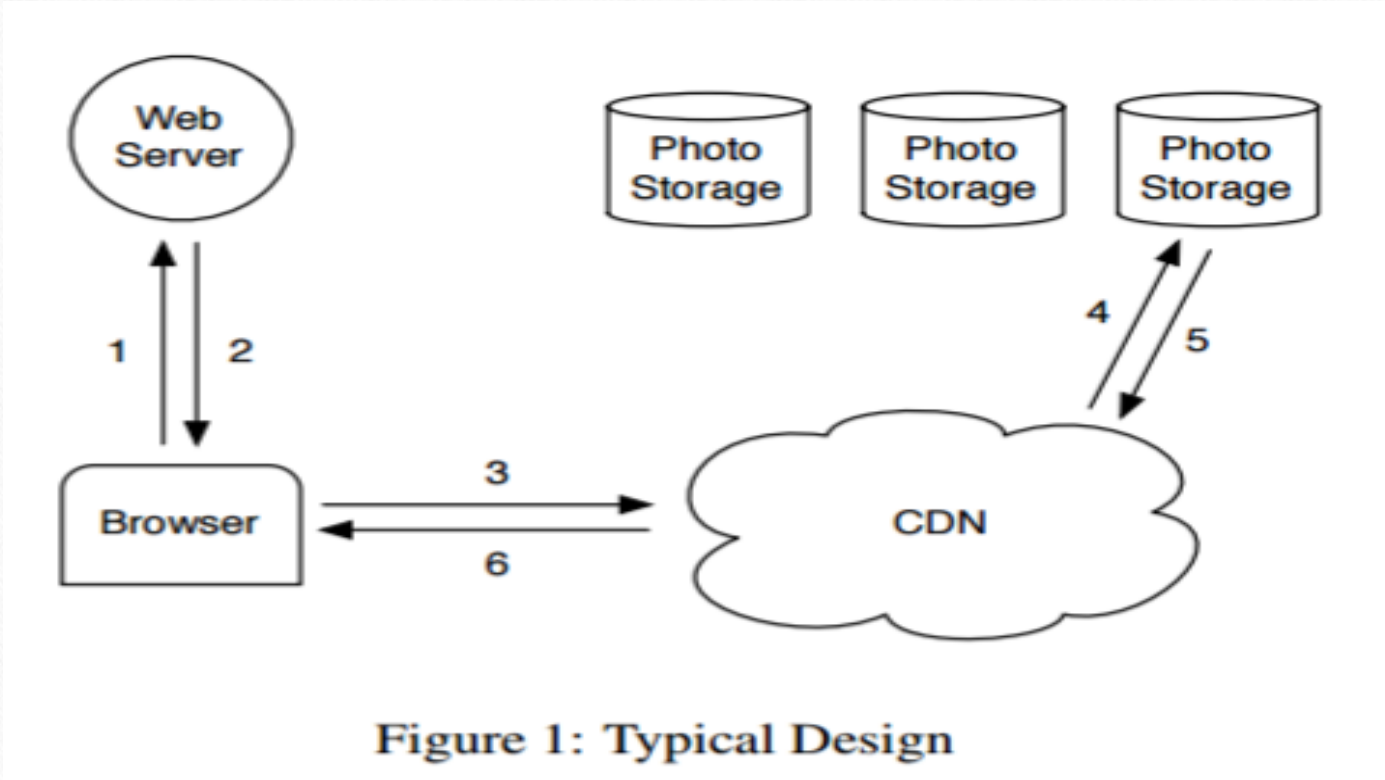


Figure 1: Typical Design

“Original” Facebook NFS-based Design

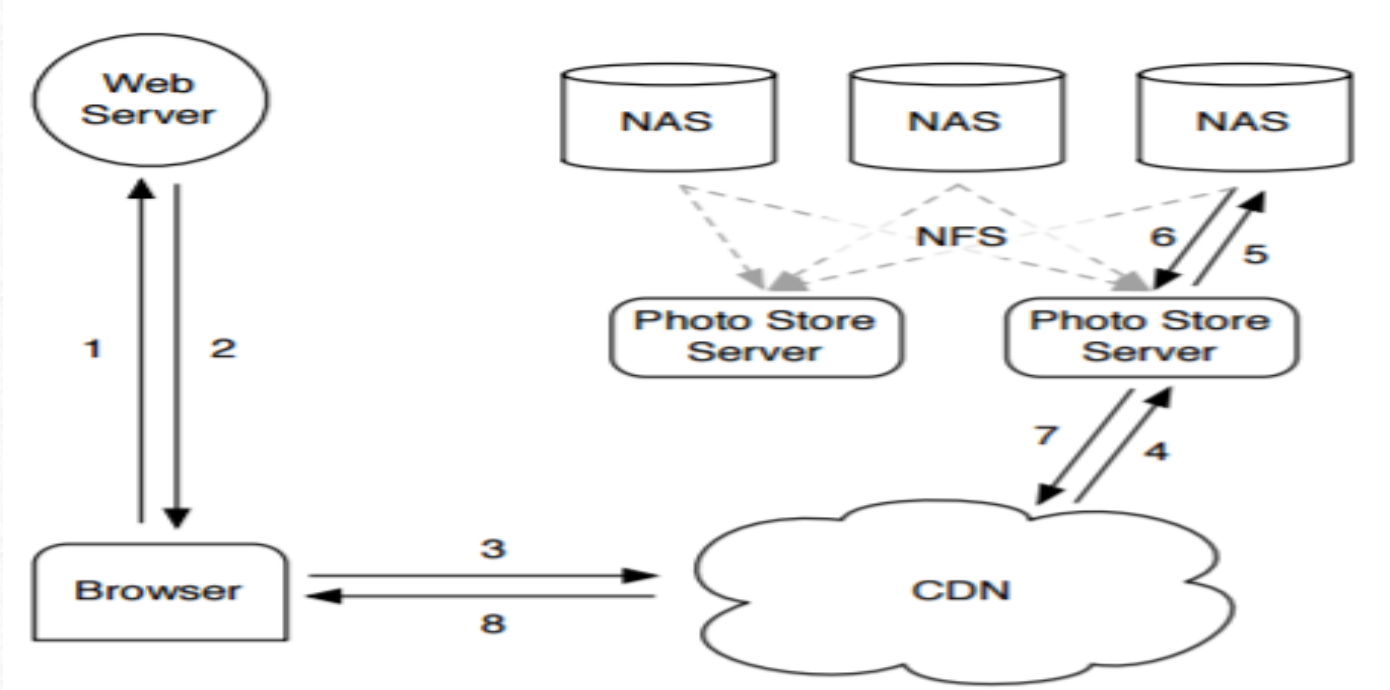


Figure 2: NFS-based Design

Lessons Learned from "Original"

- CDNs serve "hottest" photos, e.g. profile pictures, but don't help with "Long tail" of requests for older photos generated by such a large volume site
  - Significant amount of traffic, hitting backing store
  - Too many possibilities, too few used to keep in memory cache of any kind, not just via CDN
- Surprising complexity
  - Directories of thousands of images ran into metadata data inefficiencies in NAS, ~10 access/image
  - Even when optimized to hundreds of images/directory, still took 3 access: metadata, inode, file

Why Go Custom?

- Needed better RAM:Disk ratio
- Unachievable, because would need too much RAM
- Had to reduce demand for RAM by reducing metadata

Reality and Goal

- Reality: Can't keep all files in memory, or enough for long-tail
- Achievable Goal: Shrink metadata so it can fit in memory
- Result: 1 disk access per photo, for the photo, itself (not metadata)

Haystack's Design

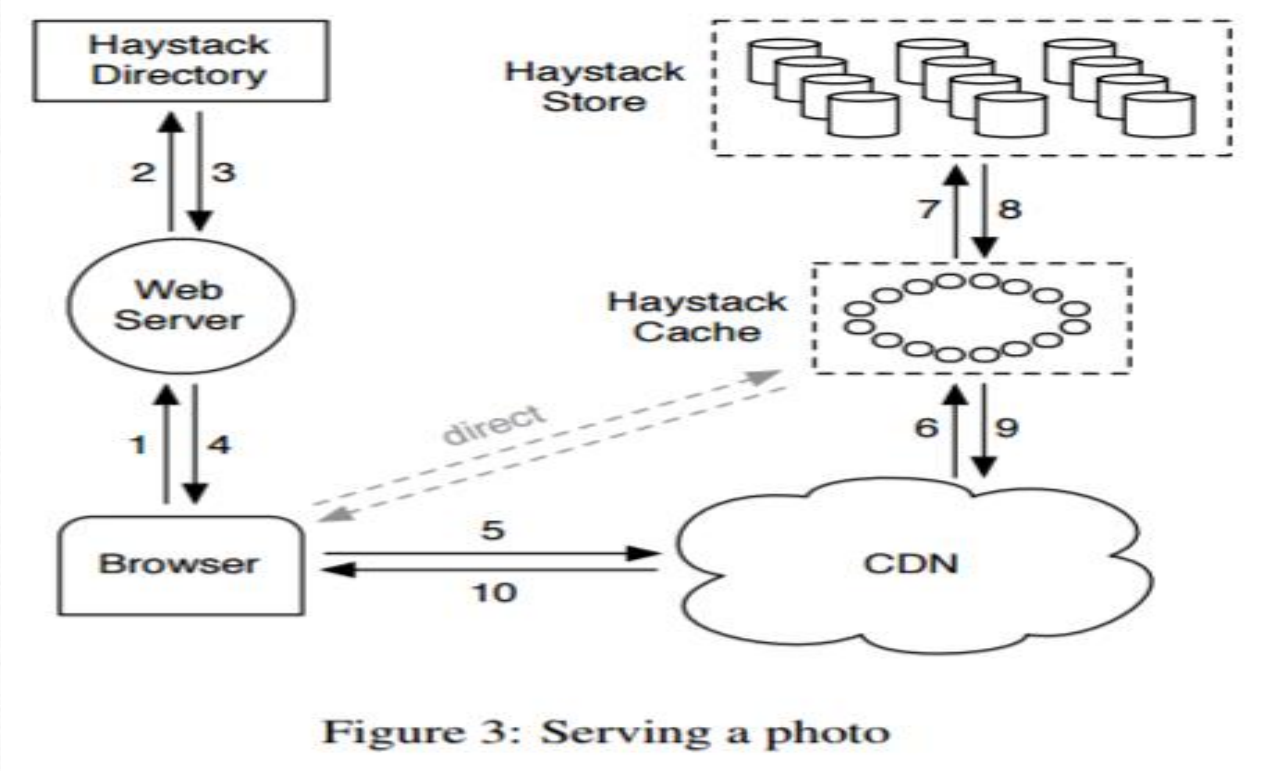


Figure 3: Serving a photo

Photo URL

- http://<CDN>/<Cache>/<Machine id>/<Logical volume, Photo>
- Specifies steps to retrieving the photos
  - CDN Looks up <Logical volume, Photo>. If hit, great. If not,
  - CDN strips <CDN> component, and asks the Cache. If Cache hits, great. If not,
  - Cache strips <Cache> component and asks back-end Haystack Store machine
  - If not in CDN just starts at second step.

Photo Upload

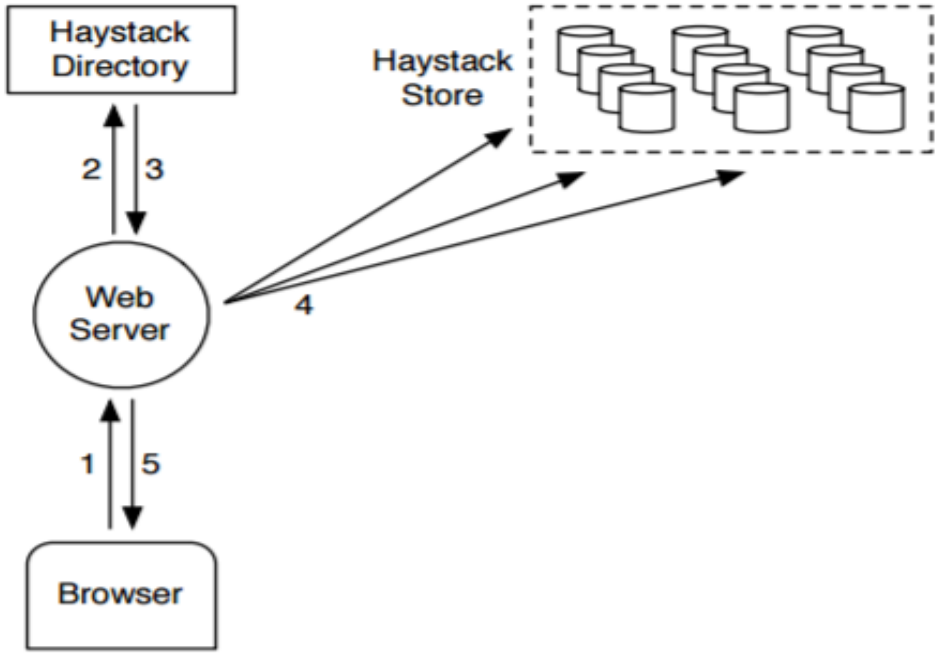


Figure 4: Uploading a photo

- Request goes to Web server
- Web server requests a write-enabled logical volume from the Haystack Directory
- Web server assigns unique ID to photo and uploads it to each physical volume associated with logical volume

Haystack Directory

- Functions:
  - Logical volume to physical volumes mapping
  - Load balances writes across logical volumes and reads across physical volumes
  - Determines if the request should be handed by CDN or Cache
  - Makes volumes read-only, if full, or for operational reasons (Machine-level granularity)
  - Removes failed physical volumes, replaces with new Store
  - Replicated database with memcache

Haystack Cache

- Distributed hash table with photo ID as key
- Cache photo iff
  - Request is from end user (not CDN) – CDN much bigger than cache. Miss there, unlikely to hit in smaller Cache.
  - Volume is write-enabled
    - Volumes perform better when reading or writing, but not mix, so doing one or the other is helpful
    - Shelter reads, letting focus on writes (No need to shelter, once volume is full – no more writes)
    - Could pro-actively push newly uploaded files into cache.

Haystack Store

- Store needs logical volume id and offset (and size)
  - This needs to quick to get, given the photo id – no disk operations
- Keeps open file descriptors for each physical volume (preloaded fd cache)
- Keeps in-memory mapping of photo ids to fs metadata (file, offset, size)
- *Needle* represents a file stored within Haystack
  - In memory mapping from <photoid, type (size)> to <flags, size, offset>

Needle and Store File

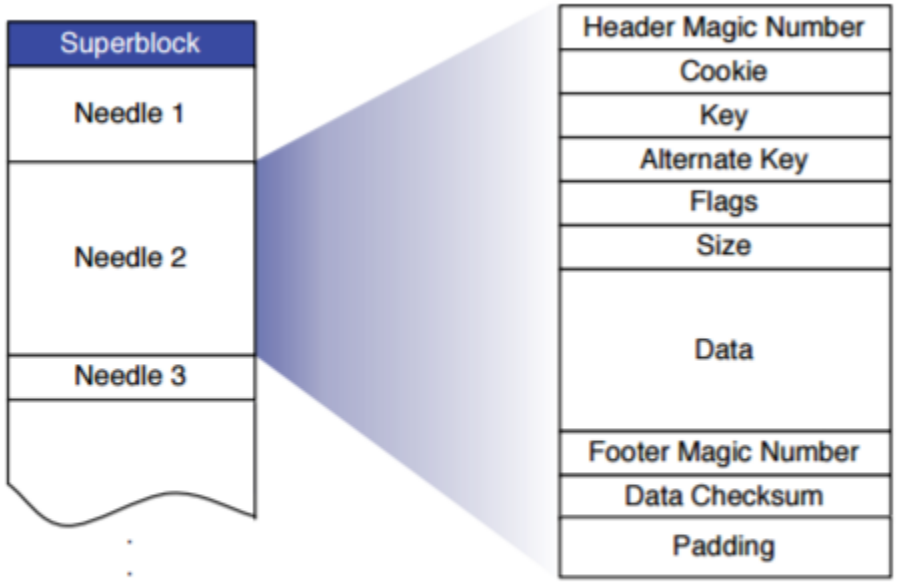


Figure 5: Layout of Haystack Store file

Field	Explanation
Header	Magic number used for recovery
Cookie	Random number to mitigate brute force lookups
Key	64-bit photo id
Alternate key	32-bit supplemental id
Flags	Signifies deleted status
Size	Data size
Data	The actual photo data
Footer	Magic number for recovery
Data Checksum	Used to check integrity
Padding	Total needle size is aligned to 8 bytes

Table 1: Explanation of fields in a needle

Reads from Store

- Cache machine requests <logical volume id, key, alternate key, cookie>
- Cookie is random number assigned/maintained by Directory upon upload.
  - Prevents brute-force lookups via photo ids
  - Store machines looks this up in in-memory metadata, if not deleted
    - Seeks to offset in volume file and reads entire needle from disk
    - Verifies cookie and data integrity
    - Returns photo to cache

Photo Write

- Web server provides <logical volume id, key, type (size), cookie, data> to store machines (all associated with logical volume)
- Store machines *synchronously appends* needle to physical volume and updates mapping
  - The append makes this much happier
  - But, if files are updated, e.g. rotated, needle can't be changed, new one must be appended – if multiple, greatest offset wins. (Directory can update for logical volumes)

Delete

- Just a delete flag – long live those party photos!

Index File

- Asynchronously updated checkpoint of in-memory data structures, in event of reboot
  - Possible to reconstruct, but much data would need to be crunched
  - Can be missing recent files and/or delete flags
- Upon reboot
  - Load checkpoint
  - Find last needle
  - Add needles after that from volume file
  - Restore checkpoint
- Store machines re-verify deleted flag after read form storage, in case index file was stale

Host Filesystem

- Store machines should use file system that:
  - Requires little memory for random seeks within a large file
  - E.g., blockmaps vs B-trees for logical to physical block mapping

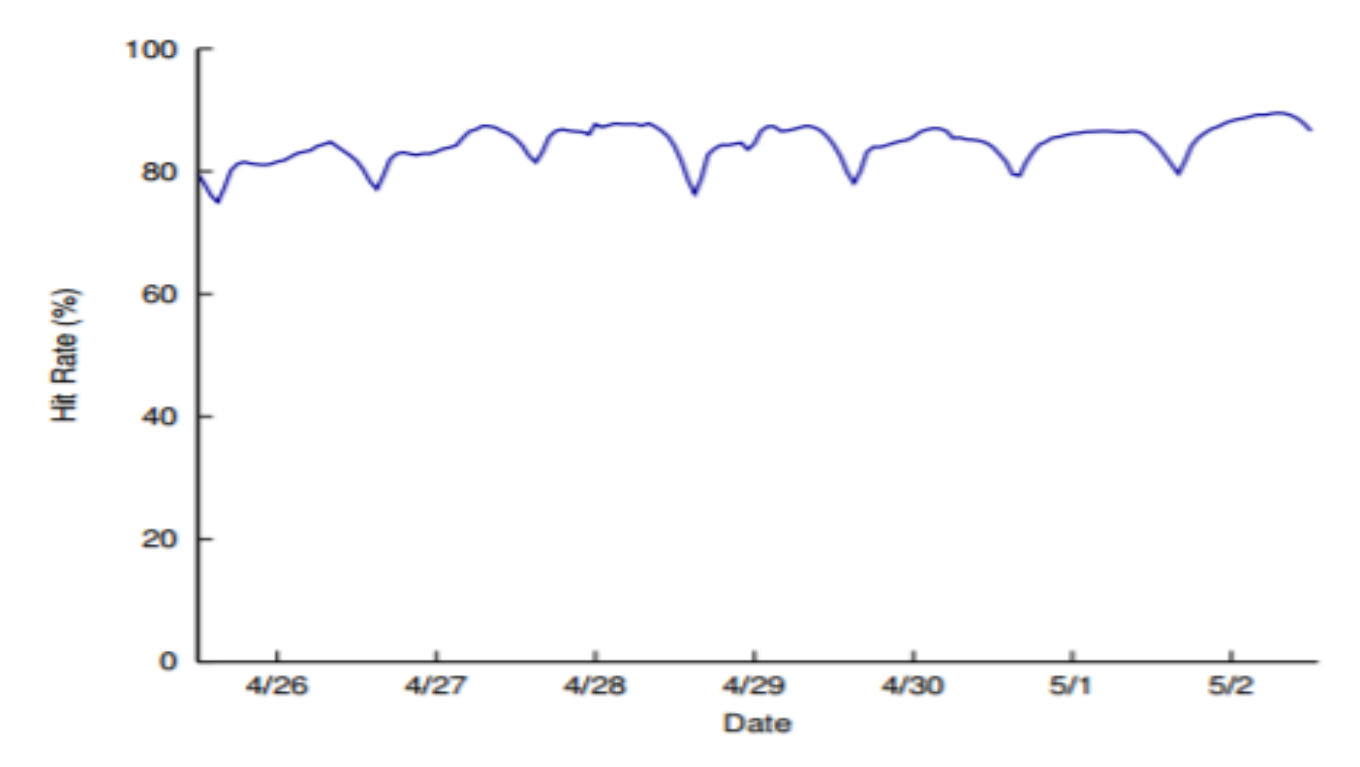
Recovering From Failure

- Failure detection
  - Proactively test Stores: Connected? Each volume available? Each volume readable?
    - Fail? Mark logical volumes on store read only and fix.
    - In worst case, copy over from other replicas (slow = hours)

Optimizations

- Compaction
  - Copies over used needles, ignoring deleted ones, locks, and atomically swaps
  - 25% of photos deleted over course of a year, more likely to be recent ones
- Batch Uploads
  - Such as when whole albums uploaded
  - Improves performance via large, sequential writes

Cache Hit Rate



Why Did We Talk About Haystack

- All the fun bits
  - Classical Browser-Server-Directory-CDN-Cache-Store Layering
- Simple, Easy Example, By Design (Simple = Robust Fast)
- Optimizes for use cases
- Memory-Disk Trade
- Focus on fitting metadata into memory
- Real-world storage concerns