File Systems (III)

(Chapters 39-43,45)

CS 4410

Operating Systems

Cornell CIS

COMPUTING AND INFORMATION SCIENCE

[R. Agarwal, L. Alvisi, A. Bracy, M. George, F.B. Schneider, E. Sirer, R. Van Renesse]

File Storage Layout Options

- ✓ Contiguous allocation

  All bytes together, in order

- ✓ Linked-list

  Each block points to the next block

- ✓ Indexed structure (FFS)

  Index block points to many other blocks

- Log structure

  Sequence of segments, each containing updated blocks

- File systems for distributed systems

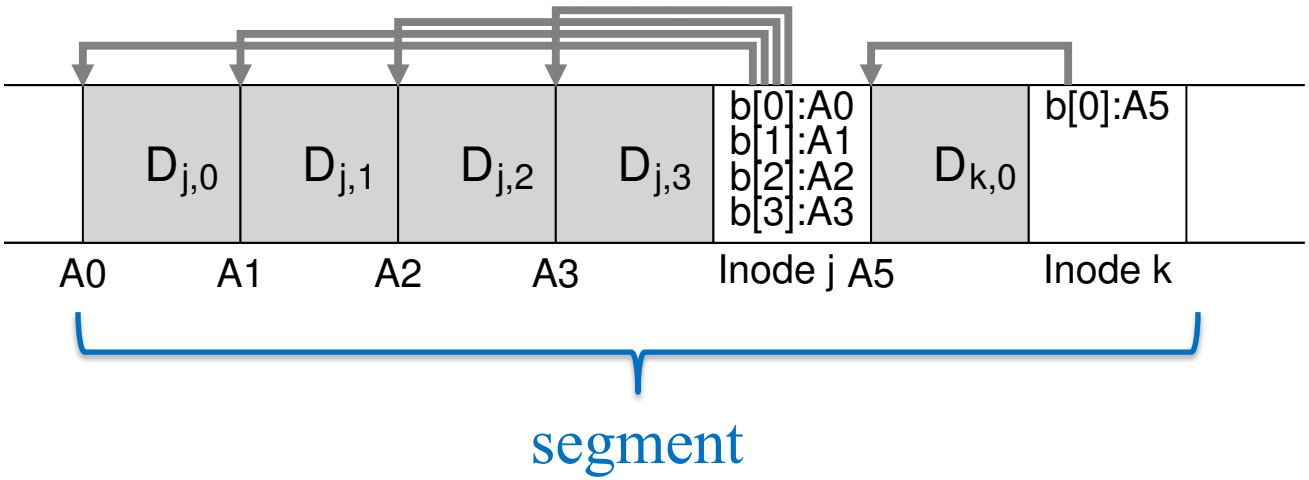
Log-Structured File Systems

Technological drivers:

- System memories are getting larger
  - Larger disk cache
  - Reads mostly serviced by cache
  - Traffic to disk mostly writes.
- Sequential disk access performs better.
  - Avoid seeks for even better performance.

Idea: Buffer sets of writes and store as single log entry (“segment”) on disk. File system implemented as a log!

Storing Data on Disk



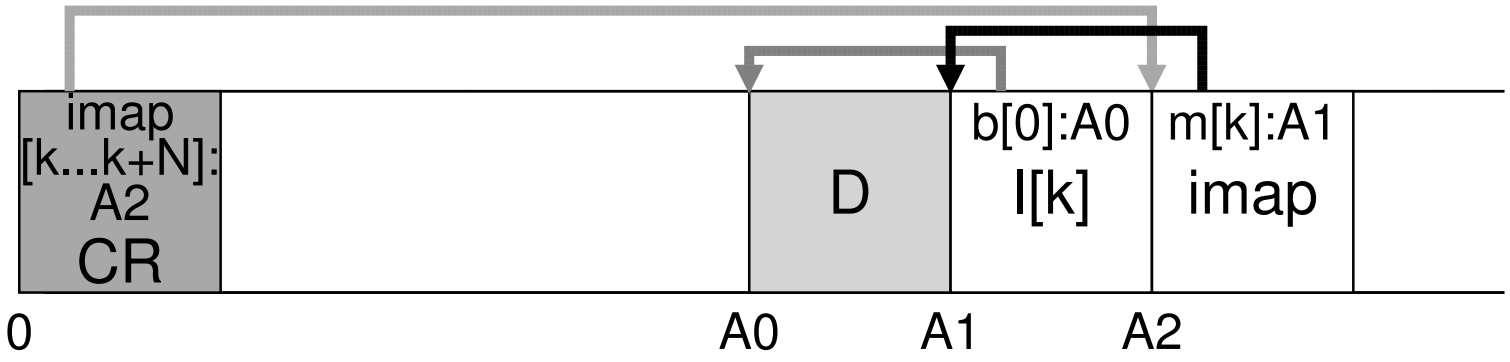
- Updates to file j and k are buffered.
- Inode for a file points to log entry for data
- An entire segment is written at once.

How to Find Inode on Disk

In FFS: F: inode nbr → location on disk
In LFS: location of inode on disk changes…

LFS: Maintain **inode Map** (imap) in pieces and store updated pieces on disk. imap: inode number → disk addr

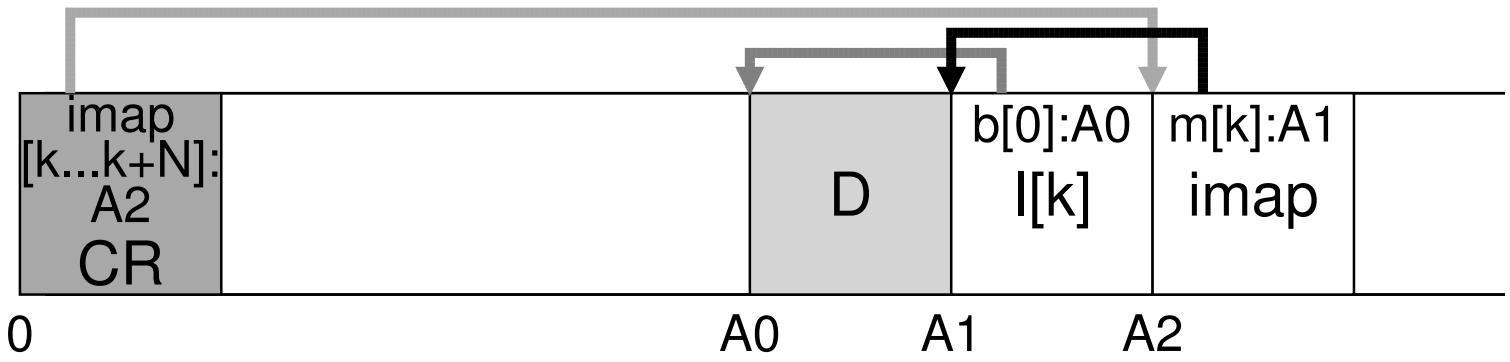
- For write performance: Put piece(s) at end of segment
- **Checkpoint Region (CR)**: Points to <u>all</u> inode map pieces and is updated every 30 secs. *Located at fixed disk address*. Also buffered in memory.



To Read a File in LFS

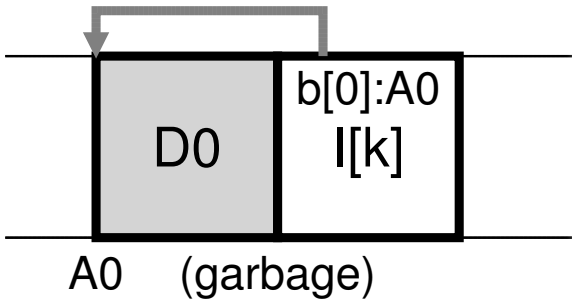
- [Load checkpoint region CR into memory]
- [Copy inode map into memory]
- Read appropriate inode from disk if needed
- Read appropriate file (dir or data) block

[…] = step not needed if information already cached.



Garbage Collection

Eventually disk will fill. But many blocks (“garbage”) not reachable via CP, because they were overwritten.



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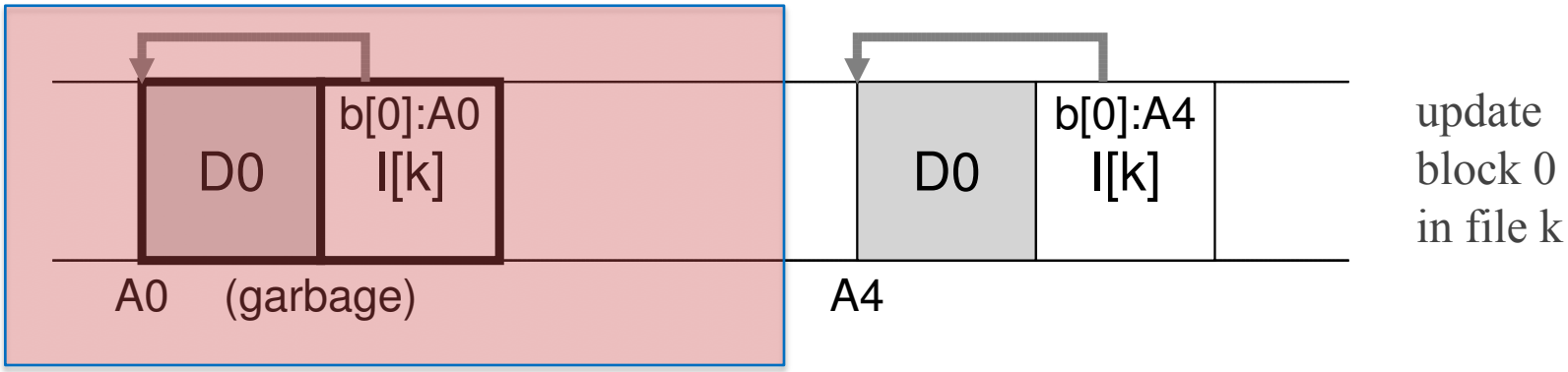

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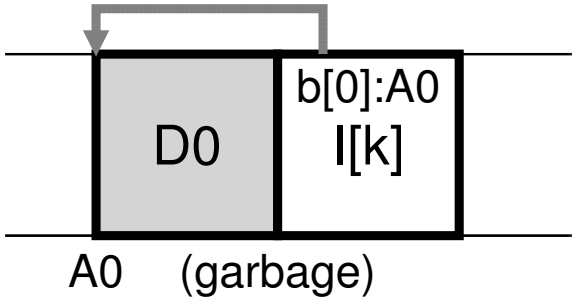
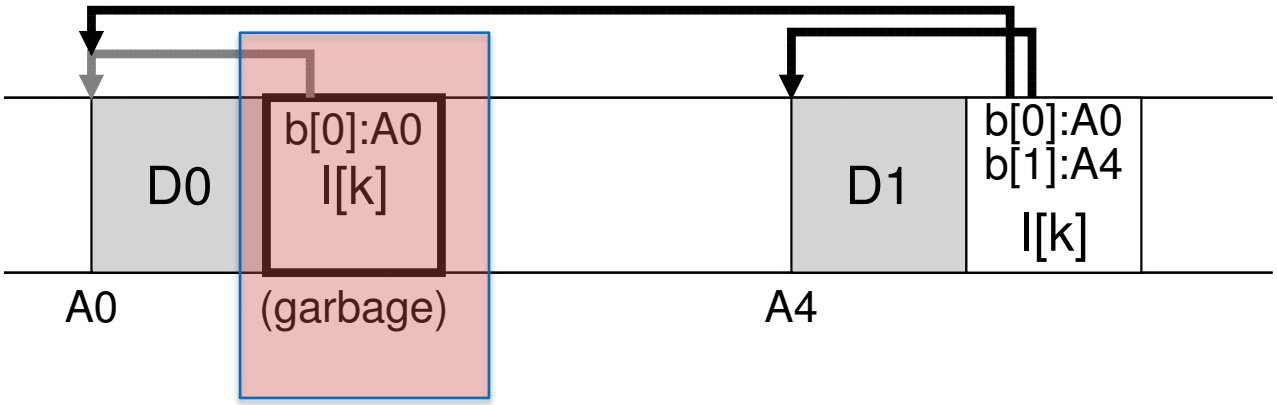




append block to file k

LFS Cleaner

Protocol:

1. read entire segment;
2. find live blocks within (see below);
3. copy live blocks to new segment;
4. append new segment to disk log

Finding live blocks: Include at strt of each LFS segment a **segment summary block** that gives for each data block D in that LFS segment:

- inode number *in*
- offset in the file *of*

Read block for < *in*, *of* > from LFS to reveal if D is live (=) or it is garbage (=!).

Crash Recovery (sketch)

LFS writes to disk: CR and segment.

After a crash:

- Find most recent consistent CR (see below)
- Roll forward by reading next segment for updates.

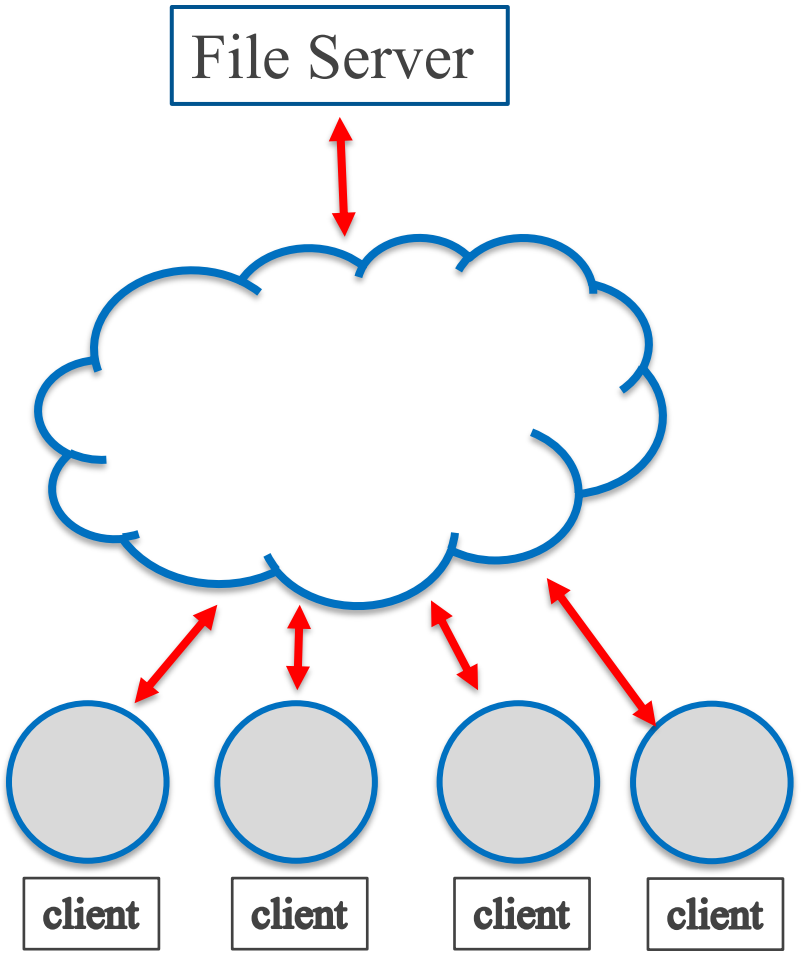
Crash-resistant atomic CR update:

- Two copies of CR: at start and end of disk.
- Updates alternate between them.
- Each CR has timestamp ts(CR,start) at start and ts(CR,end) at end.
  - CR consistent if ts(CR,start)=ts(CR,end)
- Use consistent CR with largest timestamp

Distributed File System

Challenges

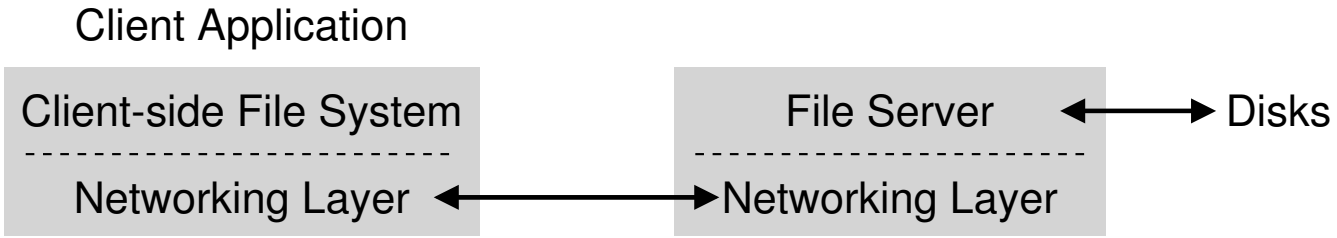
- Client Failure
- Server Failure



NFSv2 (Sun Microsystems)

Goals:

- Clients share files
- Centralized file storage
  - Allows efficient backup
  - Allows uniform management
  - Enables physical security for files
- Client side transparency
  - Same operations file sys operations:
    - open, read, write, close, …



A stateless protocol

- Server does not maintain any state about clients accessing files.
  - Eliminates possible inconsistency between state at server and state at client.
  - Requires client to maintain and send state information to server with each client operation.
- Client uses **file handle** to identify a file to the server. Components of a file handle are:
  - Volume identifier
  - Inode number
  - Generation number (allows inode number reuse)

NFS Server Operations

- Lookup: name of file → file handle
- Read: file handle, offset, count → data
- Write: file handle, offset, count, data
- …

Initially, client obtains file handle for root directory from NFS server.

NFS Client Operations

File system operations at client are translated to message exchange with server.

- fd := open(“/foo”, …) →

  send LOOKUP(roodir FH, “foo”) **to** NFS server
  receive FH_for_foo **from** NFS server
  openFileTable[i] := FH_for_foo {slot i presumed free}
  return i

- read(fd, buffer, start, MAX)

  FH := openFileTable[fd].fileHandle
  send READ(FH, offset=start, count=MAX) **to** NFS server
  receive data **from** NSF server
  buffer := data;

Etc…

Tolerating NFS Server Failures

- Asmpt: Server that fails is eventually rebooted.
- Manifestations of failures:
  - *Failed server*: no reply to client requests.
  - *Lost client request*: no reply to client request.
  - *Lost reply*: no reply to client request.

Solution: Client does retry (after timeout). And all NSF server operations are idempotent.

  - Idempotent = “Repeat of an operation generates same resp.”
    - LOOKUP, READ, WRITE
    - MKDIR (create a directory that’s already present? Return FH anyway.)
    - DELETE <resp> CREATE (failure before <resp>)
      - » Requires having a generation number in object.

Client-Side Caching of Blocks

- read ahead + write buffering improve performance by eliminating message delays.

- Client-side buffering causes problems if multiple clients access the same file concurrently.
  - **Update visibility**: Writes by client C not seen by server, so not seen by other clients C'.
    - *Solution*: flush-on-close semantics for files.
  - **Stale Cache**: Writes by client C are seen by server, but other cache at other clients stale. (Server does not know where the file is cached.)
    - *Solution*: Periodically check last-update time at server to see if cache could be invalid.

AFS: Andrew File System (CMU)

Goal:

- Support large numbers of clients

Design: AFS Version 1

- Whole file caching on local disk
  - » NFS caches blocks, not files
  - – open() copies file to local disk
    - » … unless file is already there from last access
  - – close() copies updates back
  - – read/write access copy on local disk
    - Blocks might be cached in local memory

Problems with AFS Version 1

- Full path names sent to remote file server
  - Remote file server spends too much time traversing the directory tree.
- Too much traffic between client and file server devoted to testing if local file copy is current.

Design: AFS Version 2

- callbacks added:
  - Client registers with server;
  - Server promises to inform client that a cached file has been modified.

- file identifier (FID) replaces pathnames:
  - Client caches various directories in pathname
    - Register for callbacks on each directory
    - Directory maps to FID
  - Client traverses local directories, using FID to fetch actual files if not cached.

AFS Cache Consistency

Consistency between:

- Processes on different machines:
  - Updates for file made visible at server when file closed()
    - » Last writer wins if multiple clients have file open and are updating it. (So file reflects updates by only machine.)
    - » Compare with NFS: updates blocks from different clients.
  - All clients with callbacks for that file are notified and callback cancelled.
  - Subsequent open() re-fetches the file
- Processes on the same machine
  - Updates are visible locally through shared cache.

AFS Crash Recovery

Client crash/reboot/disconnect:

- Client might miss the callback from server
- On client reboot: treat all local files as suspect and recheck with server for each file open

Server failure:

- Server forgets list of callbacks registered.
- On server reboot: Inform all clients; client must treat all local files as suspect.
  - » Impl options: client polling vs server push

File Storage Layout Options

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- ✓ Linked-list
  - Each block points to the next block
- ✓ Indexed structure (FFS)
  - Index block points to many other blocks
- ✓Log structure
  - Sequence of segments, each containing updated blocks
- ✓File systems for distributed systems

File Systems: Final Comments

I/O systems are accessed through a series of layered abstractions