1 Log Structured File System

Vocabularies

Question Are the diagrams of LFS on chapter 43, the diagram in memory segment or hard drive?

1. **Log-Structured File System**
   - Is a file system that buffers all updates including metadata to a circular buffer.
   - When full, is written to a disk in a one long sequential transfer to an unused part of the disk
2. **Segment**
   - Means a storage of fixed size to put the large chunk of updates, so writes can be performed at one time
3. **Metadata**
   - Means data about data
   - It is used to summarize basic information about data which can make tracking and working with specific data easier

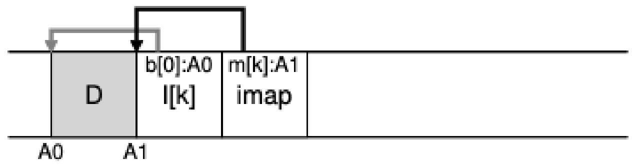
     Example

     - Time and date of creation
     - Creator or author of data
     - Number of free blocks in hard drive
     - File Size
4. **Inode**
   - Is a short form for **index node**
   - Has a low-level name called **i-number**
   - Contains all the information you need about a file (i.e. metadata)
5. **Write Buffering**
   - Is a region of a physical memory storage used to temporarily store data before writing to disk
6. **Amortization**
   - Means the action or process of gradually writing off the initial cost of an asset.

- In this context, means the more you write, the better, and closer you get to achieving peak bandwidth.

7. **Inode map**

   - Is a table indicating where each inode is on the disk

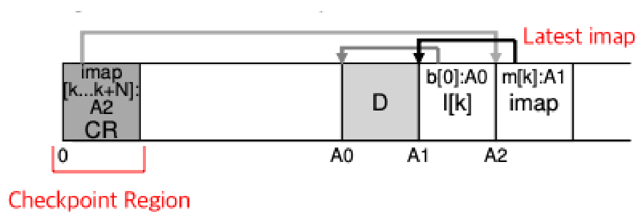


8. **Overhead**

   - Is any combination of excess or indirect resources that are required to perform a specific task

9. **Checkpoint Region**

   - Is a fixed location on disk storing pointer to latest pieces of imap



10. **Recursive Update Problem**

    - Is the problem concerned with a file system never updating in place but to new locations on disk

11. **Garbage**

    - Is old versions of file structures scattered throughout the disk after write

12. **Clean**

    - Means removal of old dead versions of file data, inodes, and other structures to make blocks on disk free again for use in subsequent writes

13. **Garbage Collection**

    - Is a technique that arises in programming languages that automatically free unused memory for programs

14. **Hole**
    - Is an unallocated block between allocated blocks in disk space
15. **Compaction**
    - Refers to combining all the empty spaces together.
16. **Segment Summary Block***
    - I need to come back on this one
    - Is a block that contains a pointer to the next summary block to link segments into one long chain that LFS treats as a linear log
17. **Roll Forward***
    - I need to come back on this one
18. **Shadow Paging**
    - Is the process of writing to an unused portion of the disk, and then reclaim the old space through cleaning

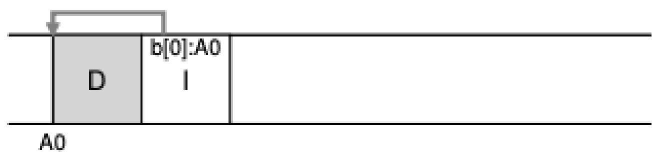
1.1 Log-Structured File Systems

- Motivations
  1. **System memories are growing**
     - Exploits memory getting bigger year after year
     - Serve reads through cache → disk traffic is increasingly consists of writes
     - File performance now determined write performance
  2. **There is a large gap between random I/O performance and sequential I/O performance**
     - Hard-drive transfer bandwidth increased over the years
       * Due to more more bits packed to surface of a drive
     - Hard drive's seek and rotation delay decreased slowly
       * Hard to cheaply make motor that runs faster
     - Sequential read gives sizeable performance advantage than causing seeks and rotations
  3. **Existing file systems perform poorly on many common workloads**
     - FFS
       * Requires a large number of writes to create a new file with one new block
       * Incurs many short seeks and subsequent rotational delays and performance falls
  4. **File systems are not raid aware**

- Buffers all updates in an in-memory **segment**
- Writes to disk only when buffer is full as a long sequential transfer to unused part of disk

1.2 Writing to Disk Sequentially

- Place data block first
- Place inode next to data block with its pointers pointing to the data block
  - Works the same as inodes in UNIX (e.g ext 2, ext4)



1.3 Writing Sequentially And Effectively

- Writing a block as it comes adds rotational delay
  - Write a block + wait + write second block
  - Not good at performance
- A large number of contiguous writes required for peak performance
  - Done using **Write buffer**
    - Put all updates in an in-memory **segment**
    - When full, write the segment all at once to the disk
      - Writes are efficient when segment is large enough

1.4 How much to Buffer

- Depends on the disk

1.5 Problem: Finding Inodes

- Inodes are scattered throughout the disk
- Data blocks and inodes are not fixed
  - On each update, data blocks and inode are placed on new sequential blocks
  - Need to know where they are :(

- Solution: The inode map + checkpoint region
  - Inode map
    * Takes an inode number as input
    * Produces the disk address of the most recent version of inode
    * Is read after checkpoint region
    * Is cached of its entirety
      · All imaps read and placed in memory
    * Fixes the problem of finding moving inodes
    * Problem: inode map is not fixed
  - Checkpoint region
    * Fixes the problem of moving inode map
    * Contains pointers to the latest piece of the inode map
    * Is fixed
    * Is read first

1.6 Reading A File from Disk: A Recap

- Checkpoint region is read first
- Inode maps are read second
  - All are cached in memory
- Inodes are read third
- Data blocks are read last

1.7 What About Directories

- Is identical to UNIX file systems
  - Imap points to directory inode
  - Directory inode points to directory block
  - Directory block has entries containing user-readable name and its i-number

    Example

    ```
    ("user-readible-name", i-number)
    ```
  - Imap solves **recursive update problem**
    * Changes are not written in directory
      · If it did, a small update in inode would have caused changes upto root
    * Imap has the information about latest changes

1.8 New Problem: Garbage Collection

- LFS repeatedly writes the latest version of a file to new locations on disk
- LFS also keeps the old version of file
- If used as a feature → **versioning file system**
- If to be removed → use **garbage collection**
  - Works on **segment** by segment basis
    - Periodically reads old semgments including live segments
    - Write a new segment containing only live blocks
      - Number of new blocks N are smaller than old blocks M
      - The process is called **compaction**
    - Free up old ones for writing
  - No removal by individual basis
    - External fragmentation
    - Results in drop in performance
- Two questions to consider
  - Question #1 (mechanism): How to tell which blocks in a segment is live, and which is dead?
  - Question #2 (policy): How often should cleaner run? which segments should it pick to clean?

1.9 Determining Block Liveness

- Answers the question "How to tell which blocks in a segment is live, and which is dead?"
- Is known via **segment summary block**
  - Stores
    - File number
    - Block number of file data blocks
    - Inode number
  - Determines liveness by checking if file's inode or indirect block still refers to this block; otherwise block is dead

1.10 A Policy Quetion: Which Blocks To Clean, And When?

- Answers the question "Which blocks to clean, and when?"
  - Cold segment first, hot segment second
    - * hot segment's contents frequently change
    - * cold semgnent's contents doesn't change often

1.11 A Crash Recovery and the Log

- Two questions to consider
  1. Question # 1: "What happens if the system crashes while LFS is writing to disk?"
     - LFS updates the CR every 30 seconds or so
     - Recover by reading the checkpoint region, its imap, imap's subsequent files and directories on boot
       - * Last few seconds of update are lost
  2. Question # 2: "How does LFS handle crashes during writes to these structures?"
     - Ensure CRs update automatically
       - * Keep two CRs, one at either end of the disk, and write to them alternatively
       - * Carefully update the CR with the latest pointers to the inode map and other information
         - · First, write a header (with timestamp)
         - · Second, write the body of CR
         - · Last, write the final block (with timestamp)
       - * When crash occurs, timestamp is inconsistent
         - · Recover by using the most recent CR that has consistent timestamp