Log Structured File Systems

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Learning Outcomes

- An understanding of the performance of Inode-based files systems when writing small files.
- An understanding of how a log structured file system can improve performance, and increase reliability via improved consistency guarantees without the need for file system checkers.
- An understanding of "cleaning" and how it might detract from performance.

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"The Design and Implementation of a Log-Structured File System"
Mendel Rosenblum and John K. Ousterhout
ACM Transactions on Computer Systems, Vol 10, No. 1, February 1992, Pages 26-52

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Original Motivating Observations

- Memory size is growing at a rapid rate
- ⇒ Growing proportion of file system reads will be satisfied by file system buffer cache
- ⇒ Writes will increasingly dominate reads

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Motivating Observations

- Creation/Modification/Deletion of small files form the majority of a typical workload
- Workload poorly supported by traditional Inode-based file system (e.g. BSD FFS, ext2fs)
  - Example: create 1k file results in: 2 writes to the file inode, 1 write to data block, 1 write to directory data block, 1 write to directory inode
    - ⇒ 5 small writes scattered within group
  - Synchronous writes (write-through caching) of metadata and directories make it worse
    - Each operation will wait for disk write to complete.
- Write performance of small files dominated by cost of metadata writes

Super Block	Group Descrip-tors	Data Block Bitmap	Inode Bitmap	Inode Table	Data blocks

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Motivating Observations

- Consistency checking required for ungraceful shutdown due to potential for sequence of updates to have only partially completed.
- File system consistency checkers are time consuming for large disks.
- Unsatisfactory boot times where consistency checking is required.

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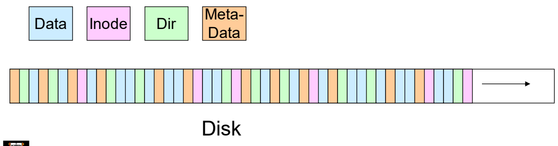
Basic Idea!!!

- Buffer sequence of updates in memory and write all updates sequentially to disk in one go.



Example

Advantages

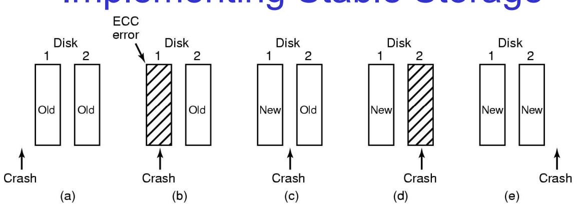
- Writes are now sequential
  - Good performance for many small writes

How to locate i-nodes?

- How do we now find I-nodes that are scattered around the disk?

⇒ Keep a map of inode locations
  - Inode map is also "logged"
  - Assumption is I-node map is heavily cached and rarely results in extra disk accesses
  - To find block in the I-node map, use two fixed locations on the disk contain the address of blocks of the inode map
    - Two copies of the inode map addresses so we can recover if error during updating map.

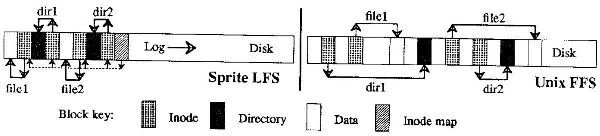
Implementing Stable Storage



- Use two disks to implement stable storage
  - Problem is when a write (update) corrupts old version, without completing write of new version
  - Solution: Write to one disk first, then write to second after completion of first

LFS versus FFS

- Comparison of creating two small files



Issue
Disks are Finite in Size

- File system “cleaner” runs in background
  - Recovers blocks that are no longer in use by consulting current inode map
    - Identifies unreachable blocks
  - Compacts remaining blocks on disk to form contiguous segments for improved write performance

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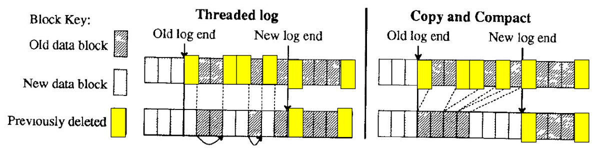
Cleaner

- Uses a combination of threaded log and copy and compact



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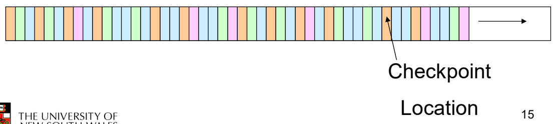
Issue
Recovery

- File system is check-pointed regularly which saves
  - A pointer to the current head of the log
  - The current Inode Map blocks
- On recovery, simply restart from previous checkpoint.
  - Can scan forward in log and recover any updates written after previous checkpoint
  - Write updates to log (no update in place), so previous checkpoint always consistent



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Reliability

- Updated data is written to the log, not in place.
- Reduces chance of corrupting existing data.
  - Old data in log always safe.
  - Crashes only affect recent data
    - As opposed to updating (and corrupting) the root directory.

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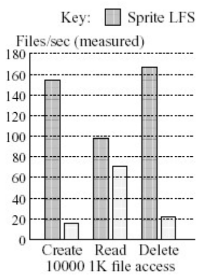
Performance

- Comparison between LFS and SunOS FS
  - Create 10000 1K files
  - Read them (in order)
  - Delete them
- Order of magnitude improvement in performance for small writes



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LFS a clear winner?

Margo Seltzer and Keith A. Smith and Hari Balakrishnan and Jacqueline Chang and Sara Mcmains and Venkata Padmanabhan
"File System Logging Versus Clustering: A Performance Comparison"

- Authors involved in BSD-LFS
  - log structured file system for BSD 4.4
  - enable direct comparison with BSD-FFS
    - including recent clustering additions
- Importantly, a critical examination of cleaning overhead

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Clustering

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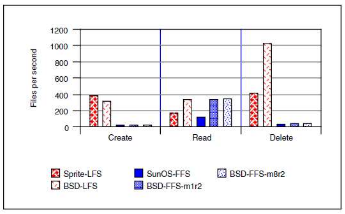
Original Sprite-LFS Benchmarks Small file



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Large File Performance 100 Meg file

- Benchmarks
  1. Create the file by sequentially writing 8 KB units.
  2. Read the file sequentially in 8 KB units.
  3. Write 100 KB of data randomly in 8 KB units.
  4. Read 100 KB of data randomly in 8 KB units.
  5. Re-read the file sequentially in 8 KB units

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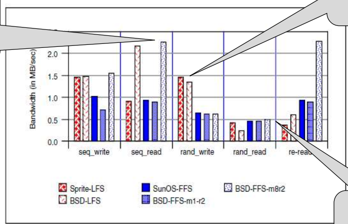
Large File Performance 100 Meg file

Read-ahead improve performance sequential reads

Writes effectively sequential



Read-ahead hurts performance for random

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Observations

- Read-ahead helps in BSD sequential case, but hurts in random.
- Read ahead algorithm is triggered on successful read-ahead on sequential, turned off on a miss. Worst case for 8K reads with 4K blocks.

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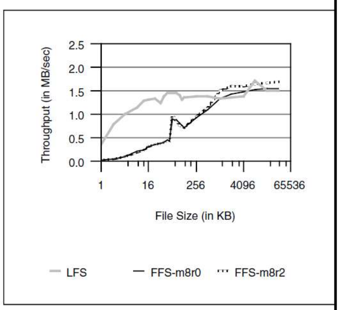
Create performance

- 32 megabytes of data overall, made up of how ever many files required to make 32 megs give the file size on the x-axis
- When the speed of meta-data operations dominates (for small files less than a few blocks or 64 KB), LFS performance is anywhere from 4 to 10 times better than FFS.
- As the write bandwidth of the system becomes the limiting factor, the two systems perform comparably.



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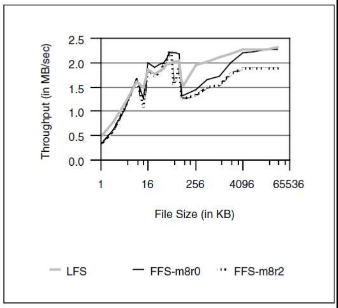
Read Performance

- Read: Each file is read in its creation order.

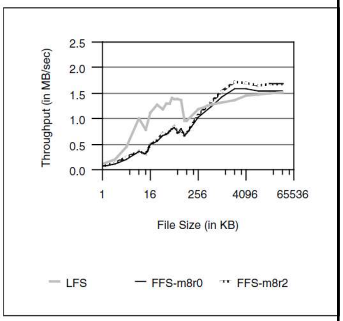


Observations

- For files of less than 64 KB, performance is comparable in all the file systems.
- At 64 KB, files are composed of multiple clusters and seek penalties rise.
- In the range between 64 KB and 2 MB, LFS performance dominates
  - because FFS is seeking between cylinder groups to distribute data evenly.

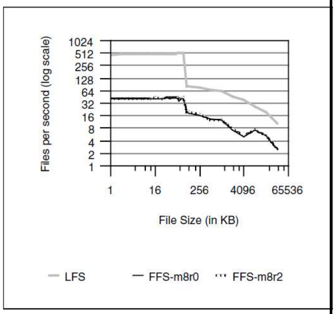
Write Performance

- Each file is rewritten in its creation order.
- The main difference between the overwrite test and the create test is that FFS need not perform synchronous disk operations and LFS must invalidate dead blocks as they are overwritten.
- As a result, the performance of the two systems is closer with LFS dominating for files of up to 256 KB and FFS dominating for larger file sizes.



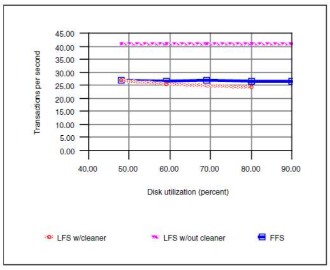
Delete Performance

- All the files are deleted
- Delete performance is a measure of metadata update performance and the asynchronous operation of LFS gives it an order of magnitude performance advantage over FFS.
- As the file size increases, the synchronous writes become less significant and LFS provides a factor of 3-4 better performance.



Transaction processing performance.

- A random access benchmark
- Without cleaner, LFS performs better due to sequential writes.
- When the cleaner runs, its performance is comparable to FFS.



LFS not a clear winner

- When LFS cleaner overhead is ignored, and FFS runs on a new, unfragmented file system, each file system has regions of performance dominance.
  - LFS is an order of magnitude faster on small file creates and deletes.
  - The systems are comparable on creates of large files (one-half megabyte or more).
  - The systems are comparable on reads of files less than 64 kilobytes.
  - LFS read performance is superior between 64 kilobytes and four megabytes, after which FFS is comparable.
  - LFS write performance is superior for files of 256 kilobytes or less.
  - FFS write performance is superior for files larger than 256 kilobytes.
- Cleaning overhead can degrade LFS performance by more than 34% in a transaction processing environment. Fragmentation can degrade FFS performance, over a two to three year period, by at most 15% in most environments but by as much as 30% in file systems such as a news partition.

Take-away

- When meta-data operation are the bottle neck, LFS wins.
- Cleaning over-head degrades LFS performance significantly as utilisation rises.
- LFS Ideas live on in more recent "snapshot"-base file systems.
  - E.g., ZFS and BTRFS
  - Garbage is a feature ☺

Journaling file systems

- Hybrid of
  - I-node based file system
  - Log structured file system (journal)
- Two variations
  - log only meta-data to journal (default)
  - log-all to journal
- Need to write-twice (i.e. copy from journal to i-node based files)
- Example – ext3
  - Main advantage is guaranteed meta-data consistency