

Log Structured File Systems



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.



“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

Also, section 4.3.5 in textbook.



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



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 Descriptors | Data Block Bitmap | Inode Bitmap | Inode Table | Data blocks |
|-------------|-------------------|-------------------|--------------|-------------|-------------|



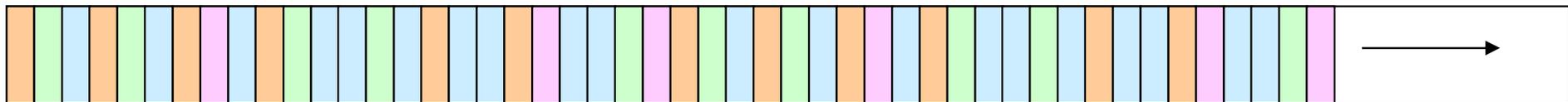
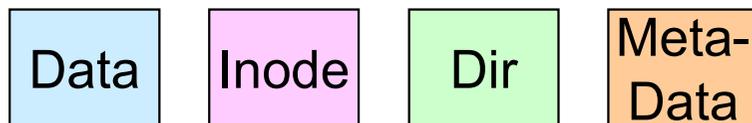
Motivating Observations

- 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.



Basic Idea!!!

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



Disk

Example



Advantages

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

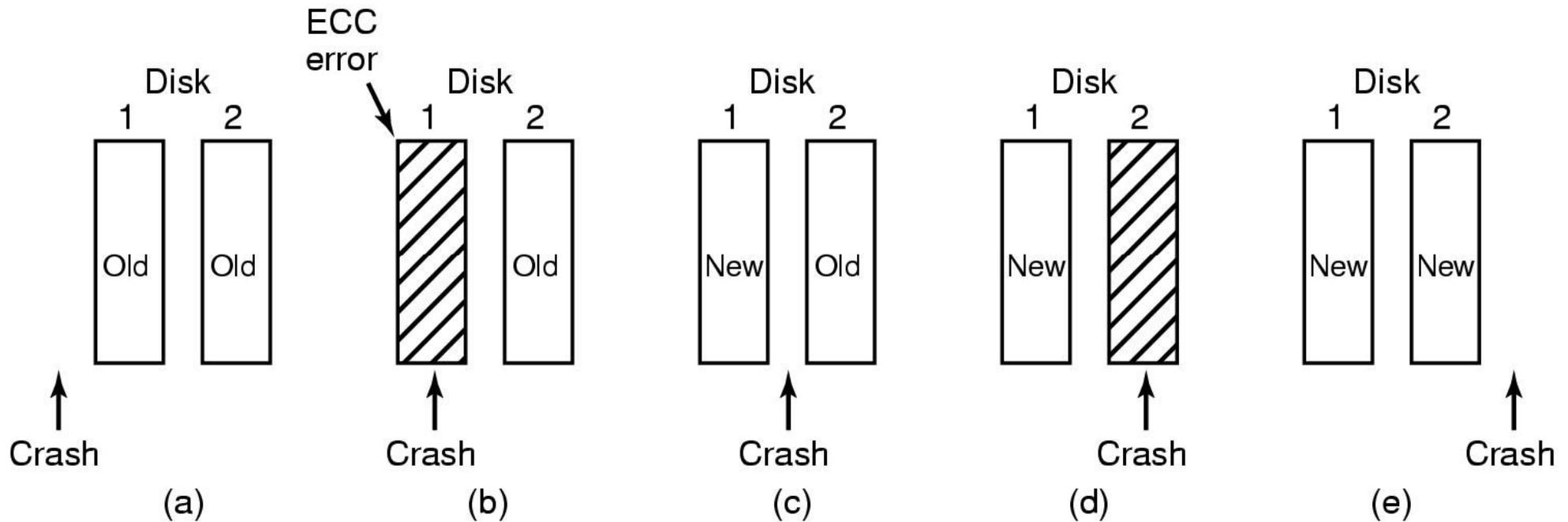


How to locate i-nodes?

- 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 with 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.



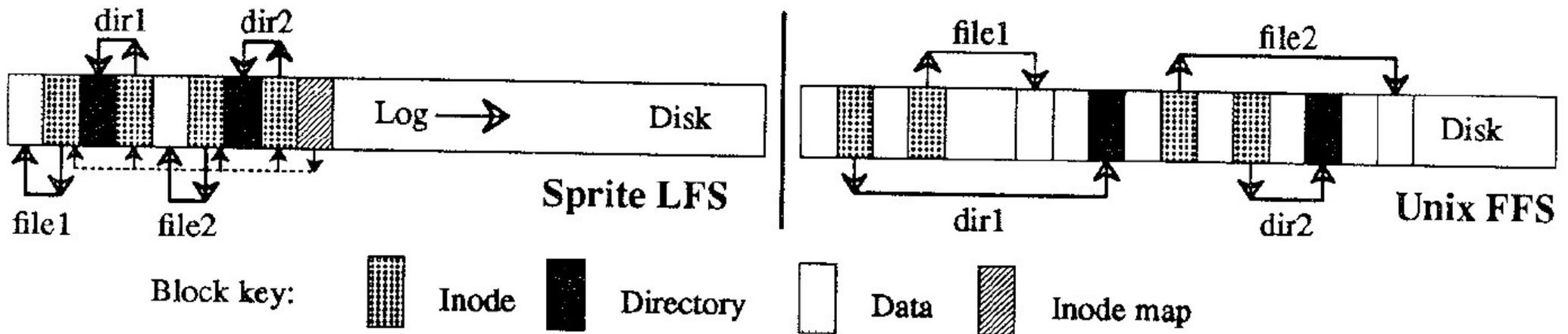
Implementing Stable Storage



- 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
- Can do the same with disk blocks.

LFS versus FFS

- Comparison of creating two small files



Issue

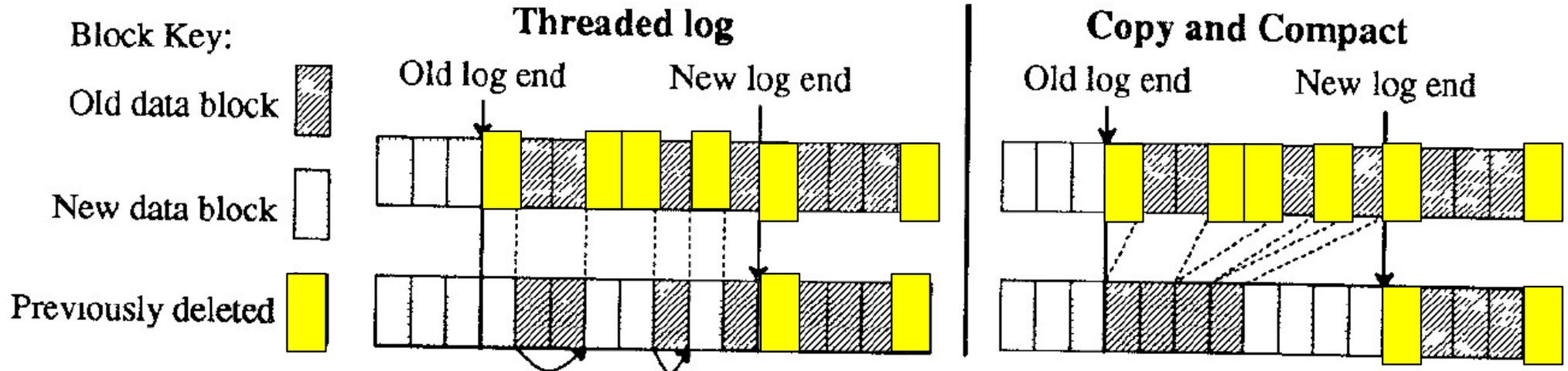
Disks are Finite in Size

- 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



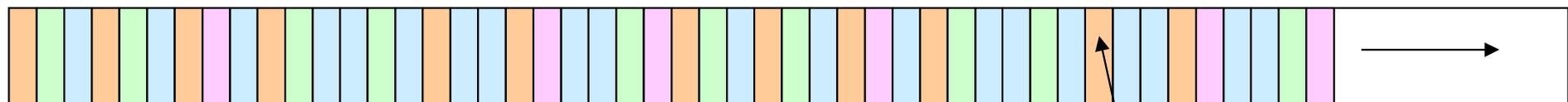
Cleaner

- Uses a combination of threaded log and copy and compact



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
 - Writes update the log (no update in place), so previous checkpoint is always consistent



Checkpoint

Location



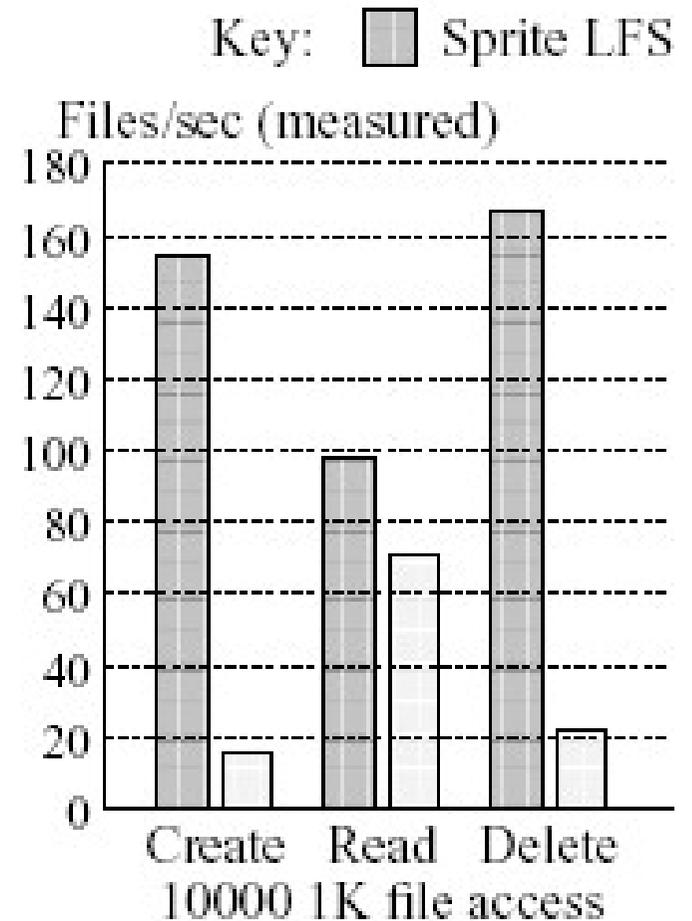
Reliability

- 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.



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



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

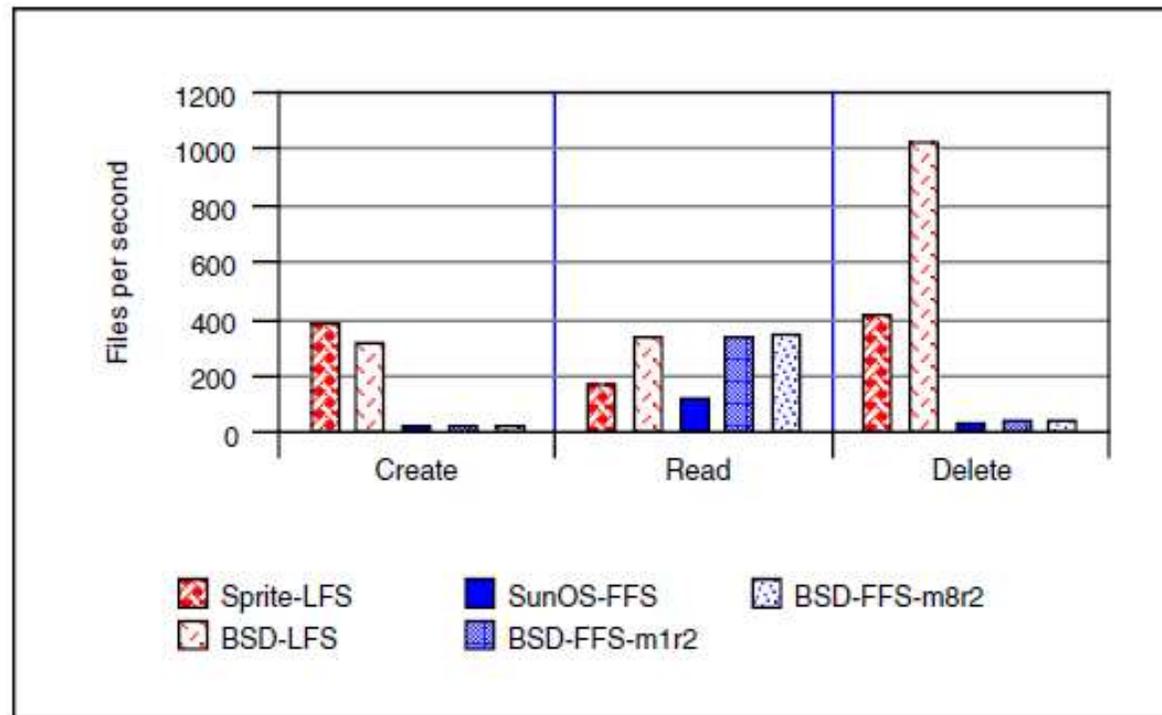


Clustering



Original Sprite-LFS Benchmarks

Small file



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

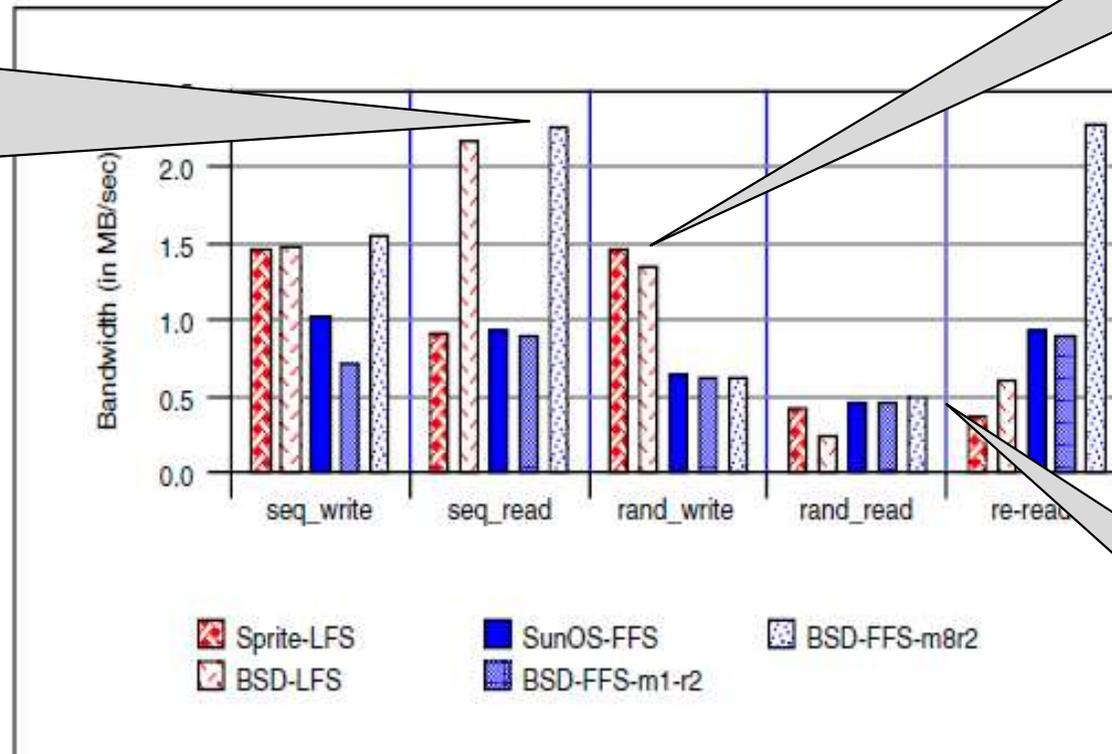


Large File Performance

100 Meg file

Read-ahead improve performance sequential reads

Writes effectively sequential



Read-ahead hurts performance for random



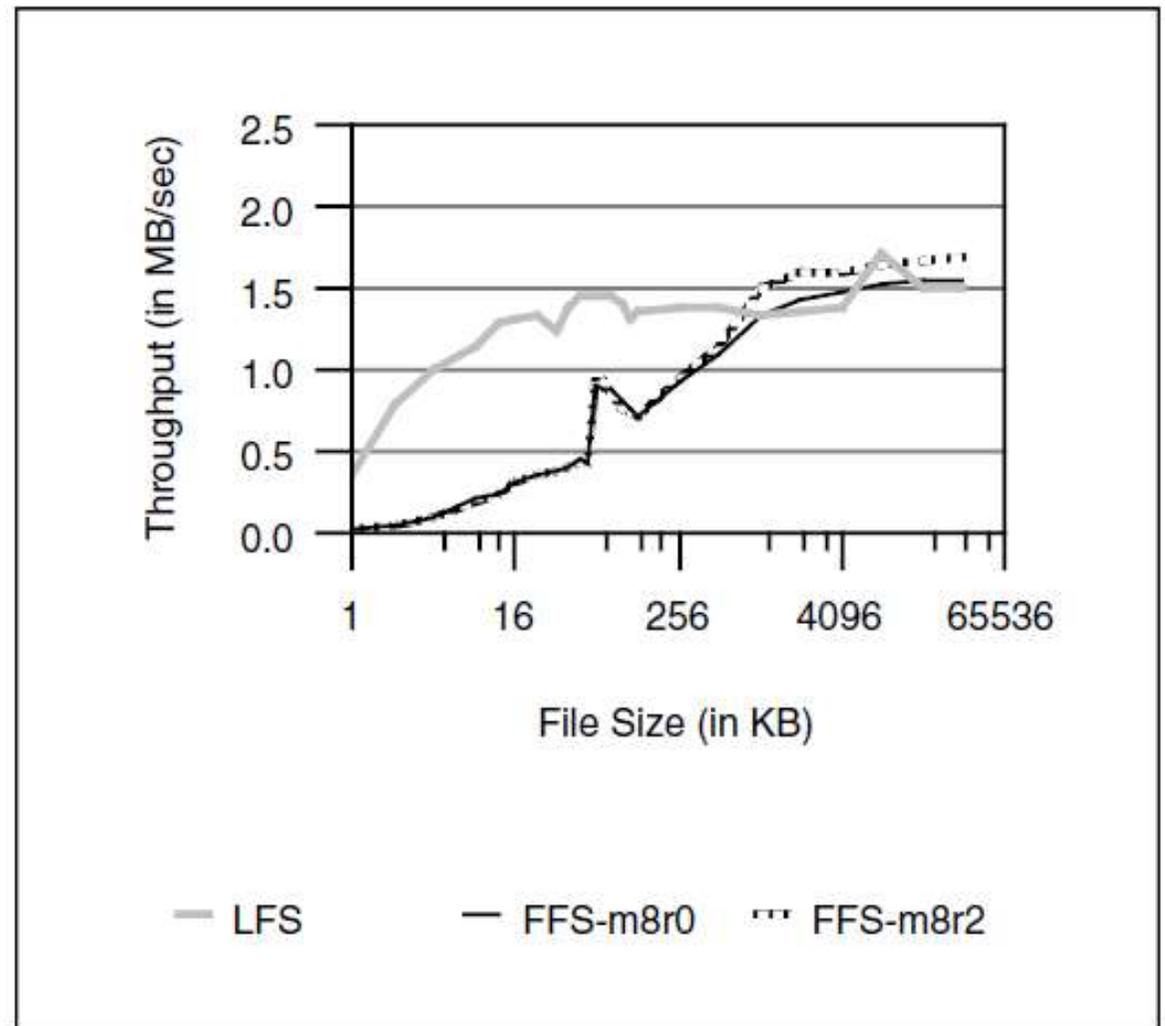
Observations

- 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.



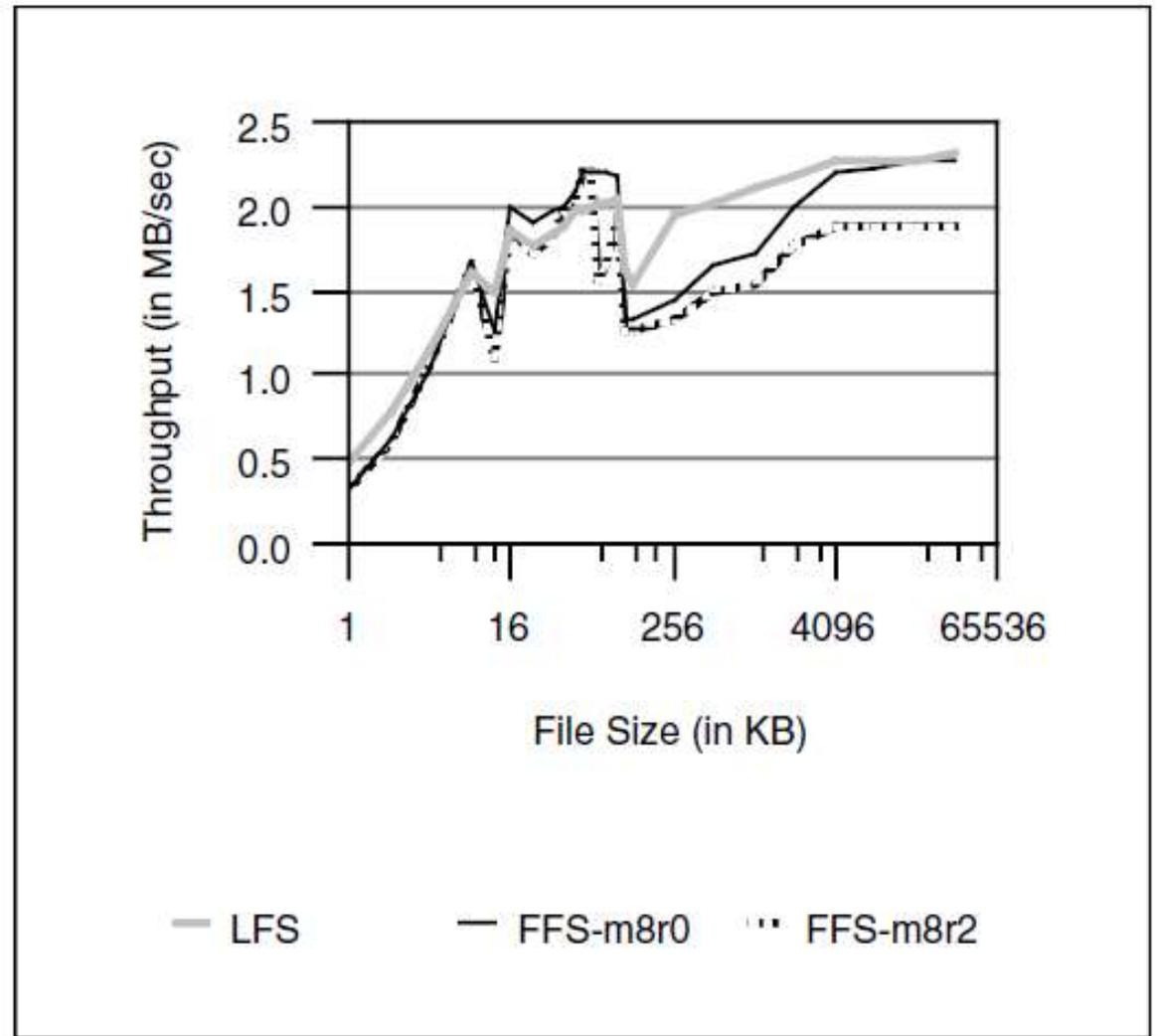
Create performance

- 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.



Read Performance

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



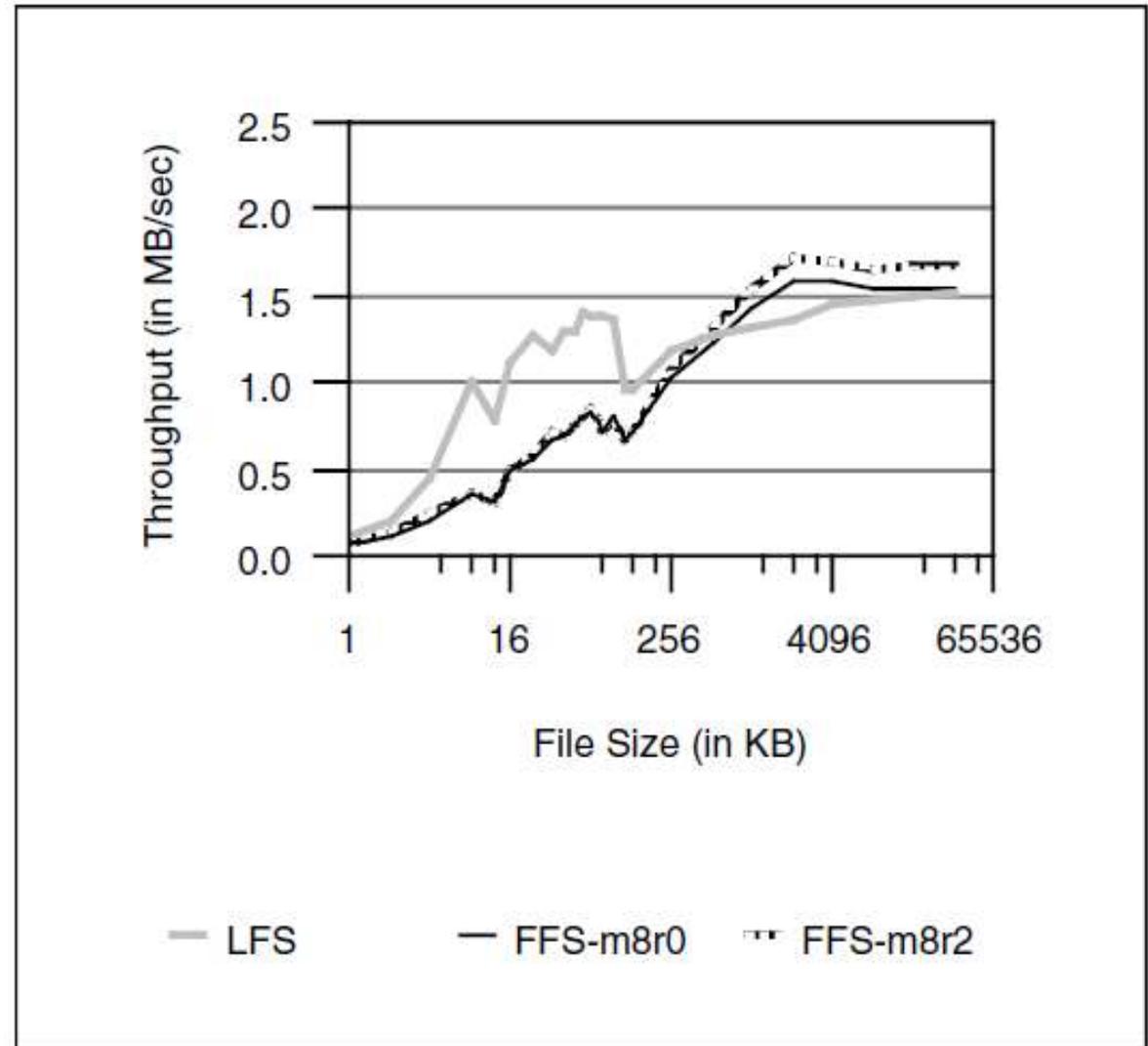
Observations

- 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.



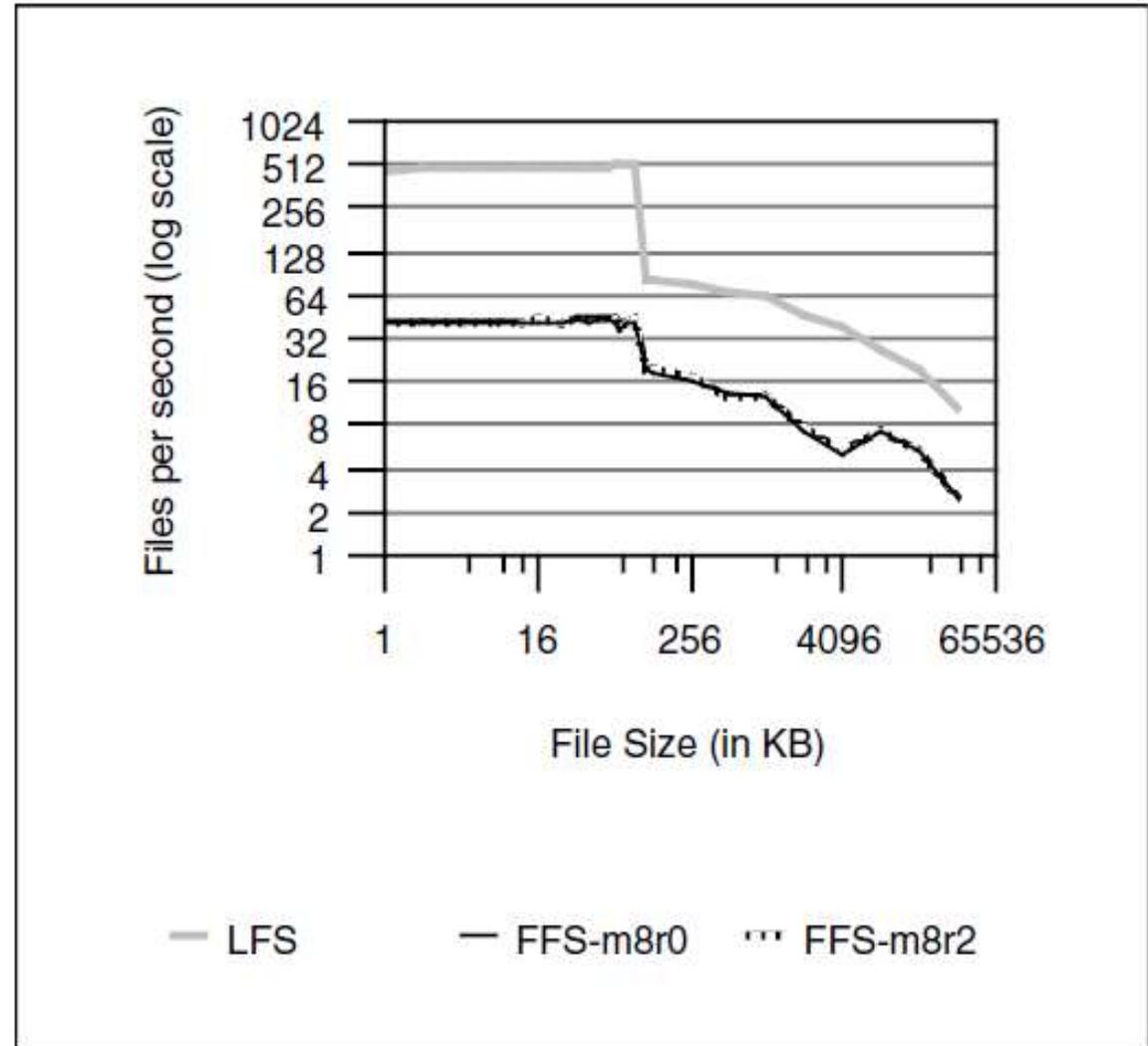
Write Performance

- 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.



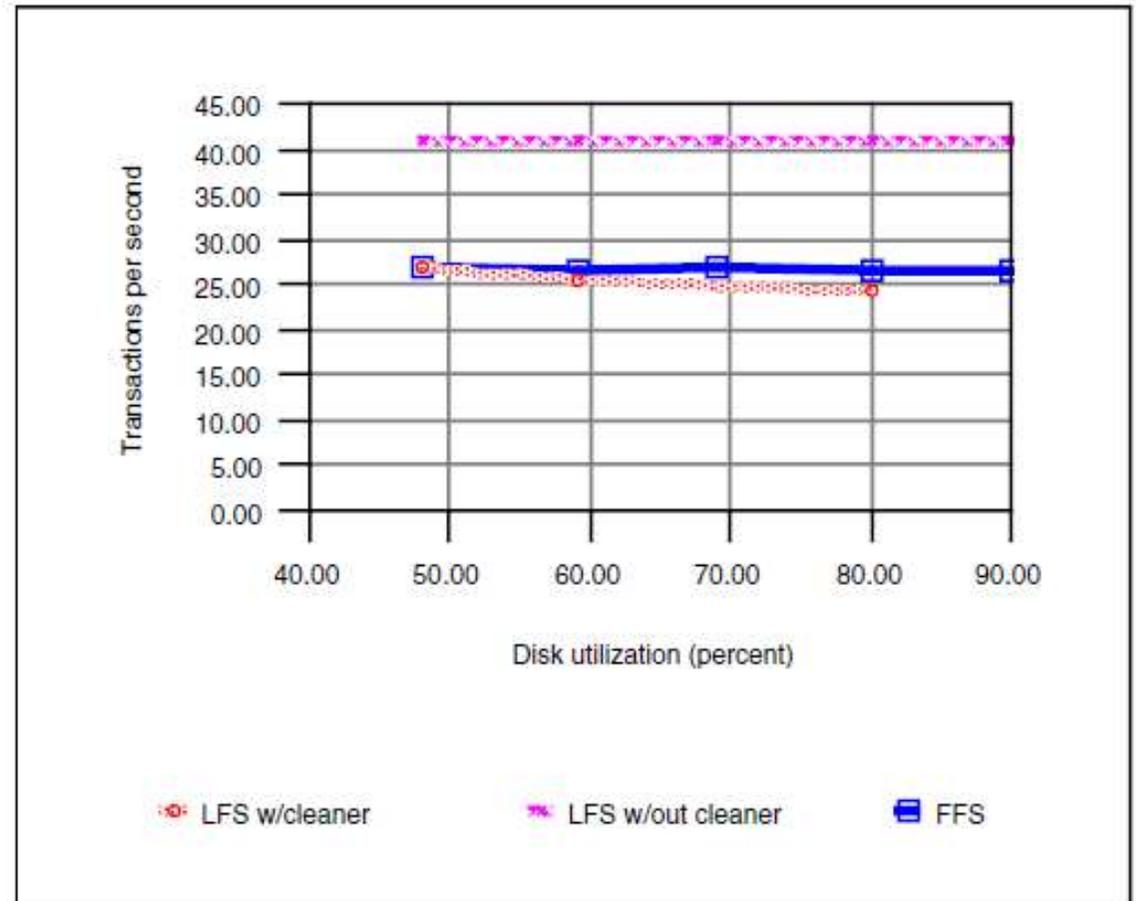
Delete Performance

- 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 operations are the bottle neck, LFS wins.
- Cleaning overhead 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

