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An SMR-aware Append-only File System

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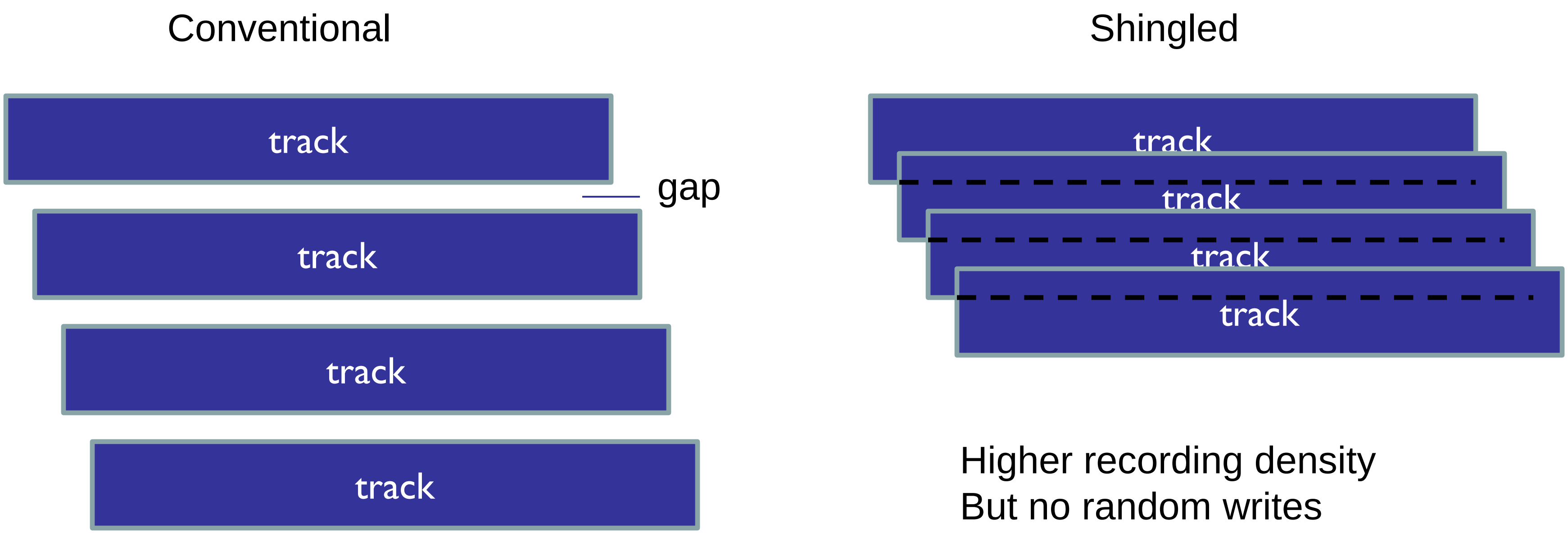
SMR Technology (1)

- Future disk drives will be based on **shingled magnetic recording**.



Higher recording density
But no random writes

SMR Technology (2)

- Drive divided into large “zones”.
  - Typically 256 Mbytes each.
- Per-zone **write pointer** for next write loc’n.
  - Write pointer advances as data is written.
  - Can **reset write pointer** on per-zone basis.
- Zone may be empty, full, or partially full.
  - Unwritten area filled with initialization pattern.

SMR Technology (3)

- Three kinds of SMR drives:
  - Drive managed
    - Has STL layer that accepts random I/Os.
    - Existing software runs correctly, poor performance.
  - Host managed
    - Writes must be performed at write pointer.
    - Requires new software to be written.
  - **Host aware**
    - Has STL layer that accepts random I/Os, but:
    - “Prefers” writes performed at write pointer.
    - Existing software may be tweaked to run better.

SMR Translation Layer (STL)

- Part of drive is reserved to buffer random I/Os.
- The data in this area is eventually moved to its home location after a read-modify-write cycle.
- Operation is performed in the background
  - When possible.
- Disk space could be replaced by flash memory
  - At a significant cost, but higher performance.

Common File Systems on SMR Drives

- Due to Dr. Hannes Reinecke (SUSE Labs)
  - btrfs “is nearly there”.
    - Writes sequentially due to its CoW nature.
    - Very few fixed data locations.
  - xfs “might be an option”
    - Roughly same zone usage as btrfs.
    - Hardly any sequential writes.
    - Report by Dave Chinner for adoption for SMR drives.

Changes to ext4 for SMR (SMRFFS)

- See https://github.com/Seagate/SMR_FS-EXT4
- Optimizes sequential file layout
  - In-order writes and idle-time garbage collection
- Block groups laid out to match zone alignments
- Allocator changed to follow forward-write rqmts
- New extent layout
- Many more changes throughout stack

Append-only Applications

- Scientific sensor data.
- Financial time series data.
- Temporal business data.
- Surveillance data.
- Web logs.
- RocksDB / LevelDB (LSM-tree).

Circular Append-only Applications

- Probability of access to data in most append-only applications decreases with the age of data.
- Depending on the requirements, old data could be purged or migrated to cool storage.
- In both cases, it would be advantageous to design such applications to circularly append data.

Log-structured File Systems

- File system data and metadata are written to a large circular buffer called a log.
- Reads are satisfied from a large memory cache.
  - Unrealistic in practice.
- Disk seeks are minimized for writes, not reads.
- Garbage collection becomes frequent as file system fills up.
- Seemingly good match for SMR drives.
  - No update in place.

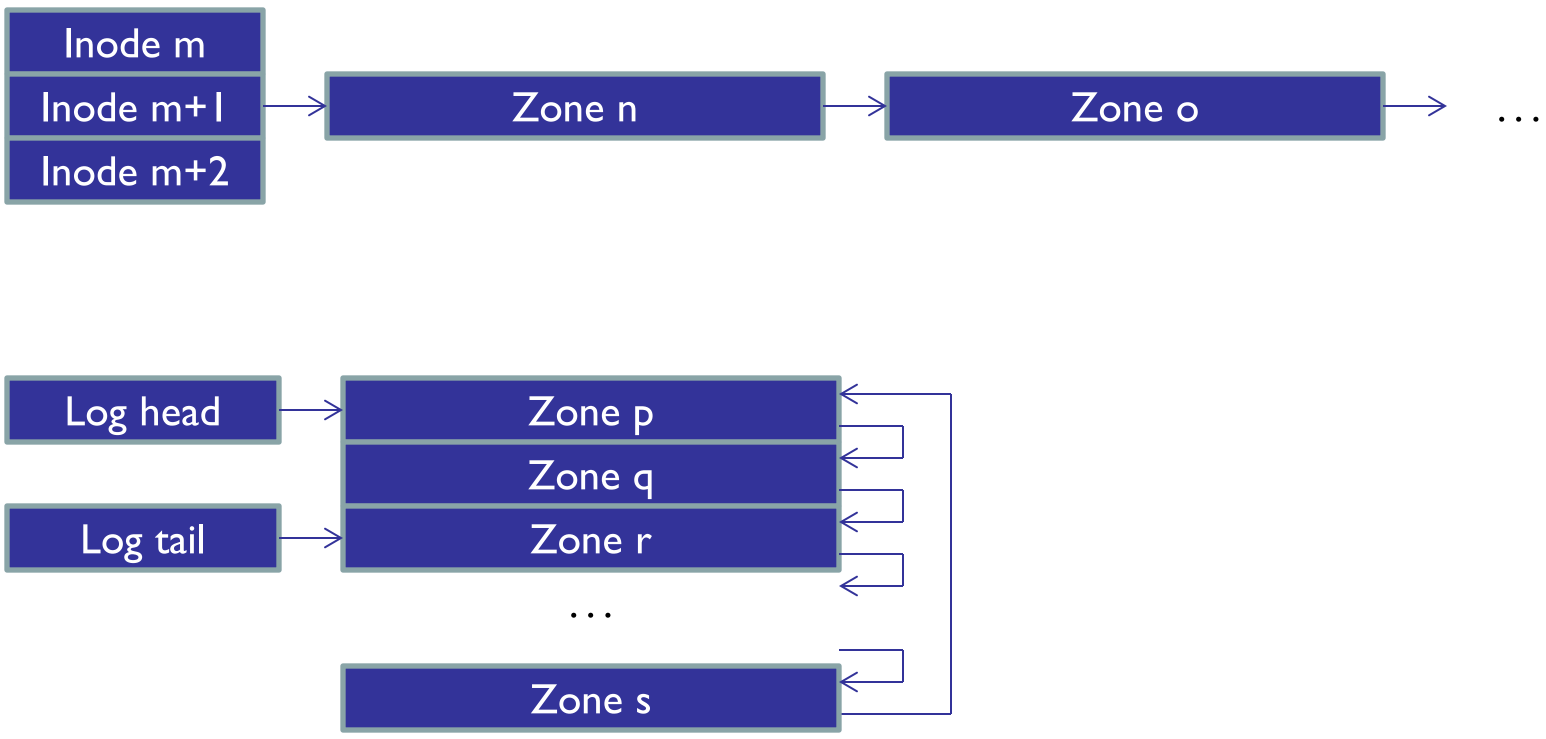
SMR-aware Append-only FS Overview

- Combination of a log-structured file system and a conventional file system.
  - Log is a (large) list of zones.
  - File comprises a zone or a list of zones.
    - Design also supports multiple files per zone.
  - Data initially written to log, then migrated to file.
    - Happens during log compaction, instead of LFS's generational garbage collection.

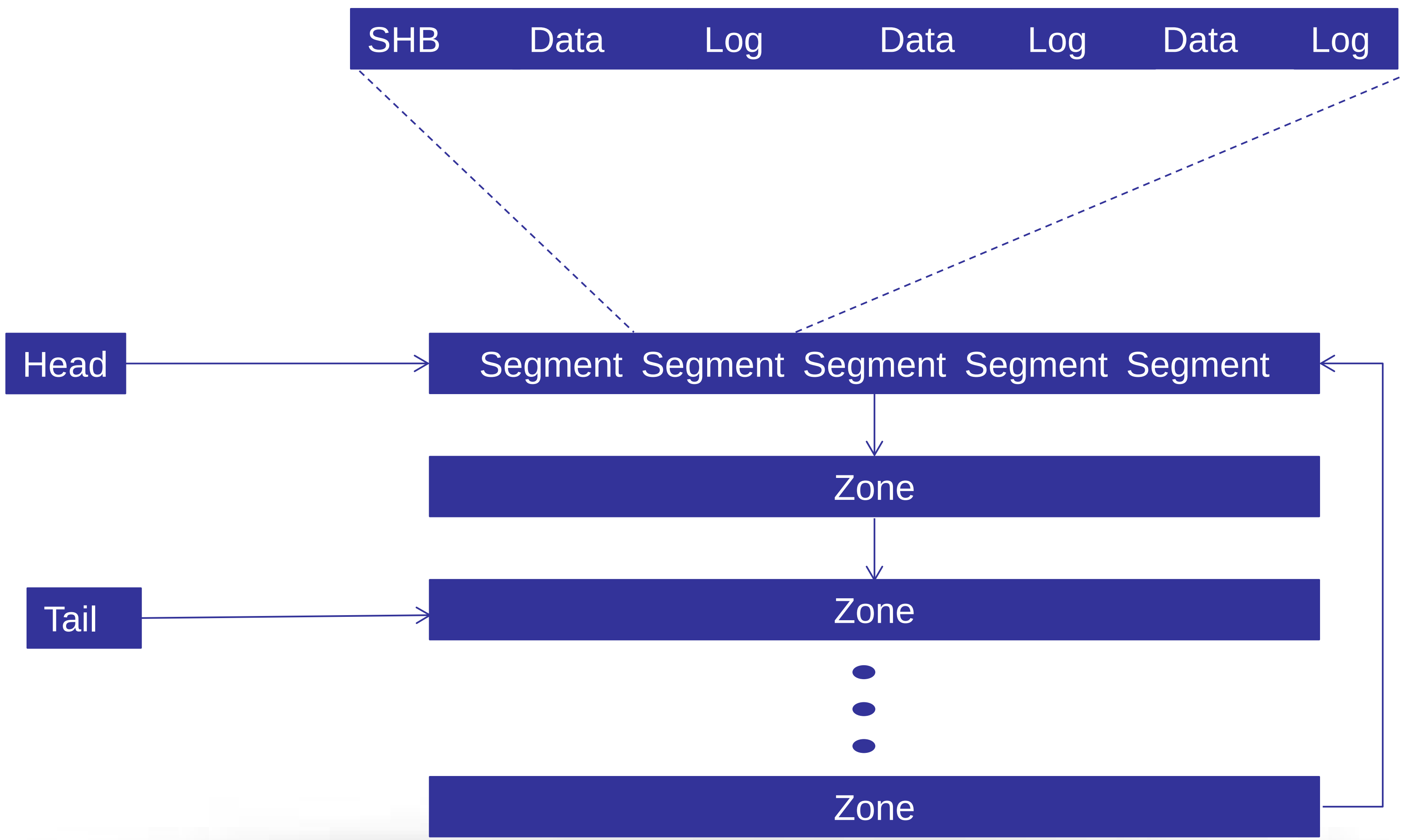
SMR-aware Append-only FS Overview (2)

- Some FS data structures are rewritten in place
  - E.g., inodes, allocation maps
    - Host-aware drives support a small number of random I/O zones (e.g., 16)
- Log and files (frequently updated) written in order within zones, from start to finish.
- Log compaction “eats” a zone at a time

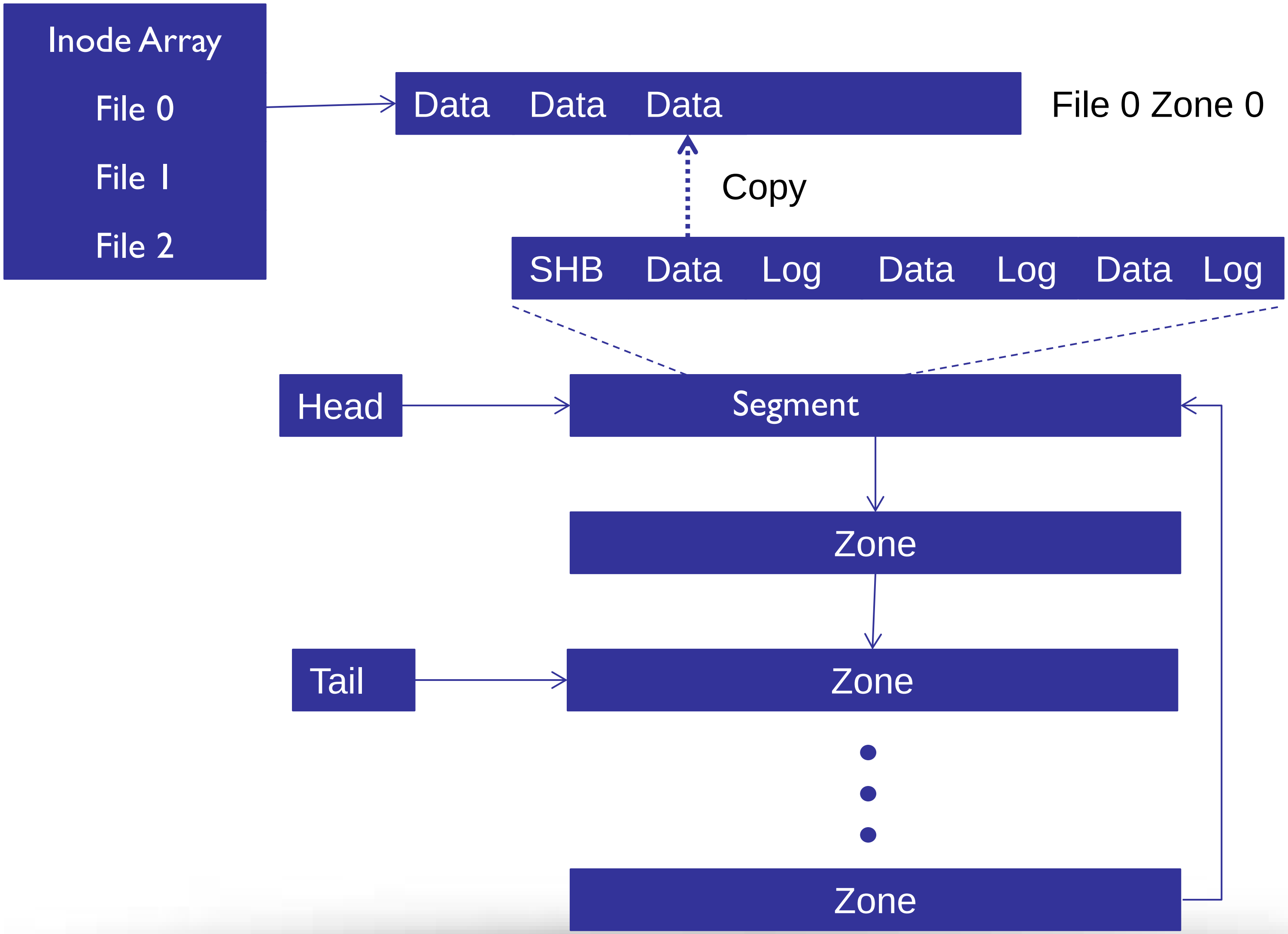
SAFS Layout


Inode m
Inode m+1
Inode m+2
Zone n
Zone o
. . .
Log head
Log tail
Zone p
Zone q
Zone r
. . .
Zone s

Segment Structure



Compaction



Inode Array
File 0
File 1
File 2
Data Data Data
File 0 Zone 0
Copy
SHB Data Log Data Log Data Log
Head
Segment
Zone
Tail
Zone
Zone

SAFS Implementation

- Implemented with CSIM 20 simulator on Linux
- Coupled with Seagate 5TByte HA SMR drive
- Measured Performance of append-only applic’ns
- 256 zones in file system, 16 zones random RW, 16 Gbytes of DRAM, x86-64 system

Disclaimer

- Not a production file system
- Purposes:
  - Explore potential of HA SMR drives
  - Explore combination of LFS and conventional file systems
  - Explore append-only file systems

CSIM 20 Discrete Event Simulator

- Use CSIM event to simulate semaphores
- Use CSIM ports to simulate IPC
- Use CSIM virtual time to account for SMR disk processing time
- Use CSIM processes to simulate POSIX threads
- SMR disk I/O performed via HA SMR drive

SAFS Simulator Components

- Workload simulation module
- File system commands simulation module
- Buffer cache simulation module
- Segment system simulation module
- Journaling system simulation module
- Lock manager simulation module
- SMR disk simulation module

Measured SAFS Applications (1)

- Creates four files
- Appends to all files (one block at a time to each file) until the system is ½ full
- Reads each file (one block at a time from each file) to the end
- Deletes all four files

Performance (1)

- File system size was 64 GBytes
- Total amount of data read/written was 64 GBytes
- Total time was 458 seconds
- Average processing rate was 143.1 MBytes/sec

Performance Comparison (1)

- Ran same steps on other file systems using a 4TByte conventional drive:

File System	Time	Rate
SAFS*	458 sec	143.1 MB/sec
F2FS	504 sec	130.0 MB/sec
NILFS2	510 sec	128.5 MB/sec
EXT4	571 sec	114.8 MB/sec

  - * Simulated, on a 5TByte, HA SMR drive.

Measured SAFS Applications (2)

- Creates four files
- Appends to all files (one block at a time to each file) until the system is ¾ full
- Deletes a file, re-creates and appends to it until the system is ¾ full again (for all four files)
- Deletes all four files

Performance (2)

- File system size was 64 GBytes
- Total amount of data written was 96 GBytes
- Total time was 698 seconds
- Average ingestion rate was 140.8 MBytes/sec

Performance Comparison (2)

- Ran same steps on other file systems using a 4TByte conventional drive:

File System	Time	Rate
SAFS*	698 sec	140.8 MB/sec
NILFS2	742 sec	132.5 MB/sec
EXT4	988 sec	99.4 MB/sec
F2FS	DNF	N/A

  - * Simulated, on a 5TByte, HA SMR drive.

Conclusion

- Simulated SAFS on HA SMR drive performs better than modern production LFS and production conventional file system on conventional disk under append-only workload.

Questions?