Skylight – A Window on Shingled Disk Operation

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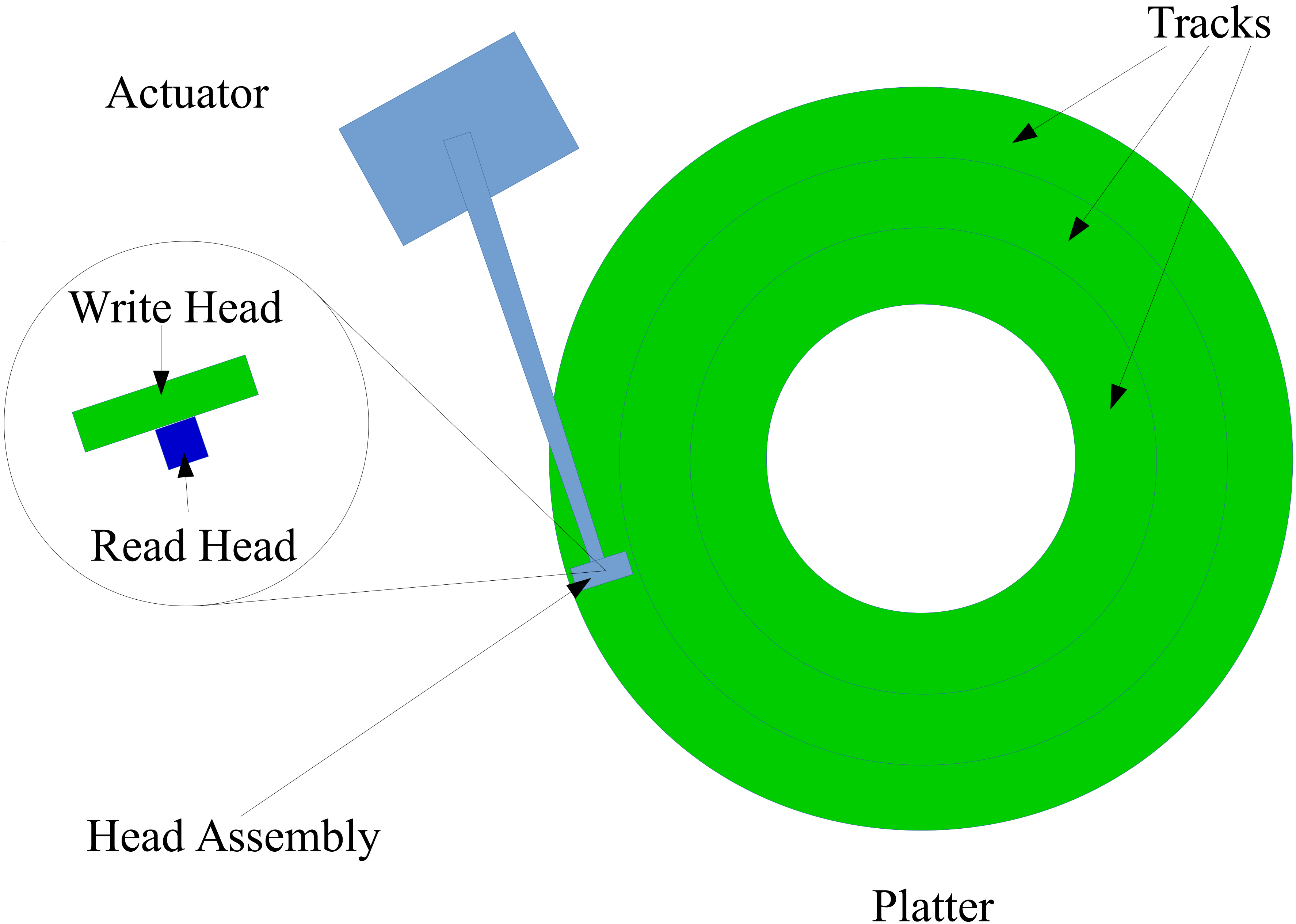
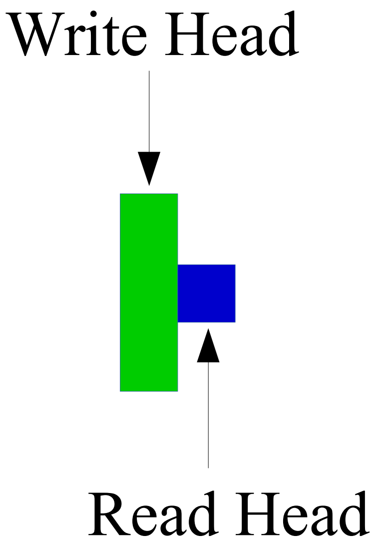
What is Shingled Magnetic Recording (SMR)?

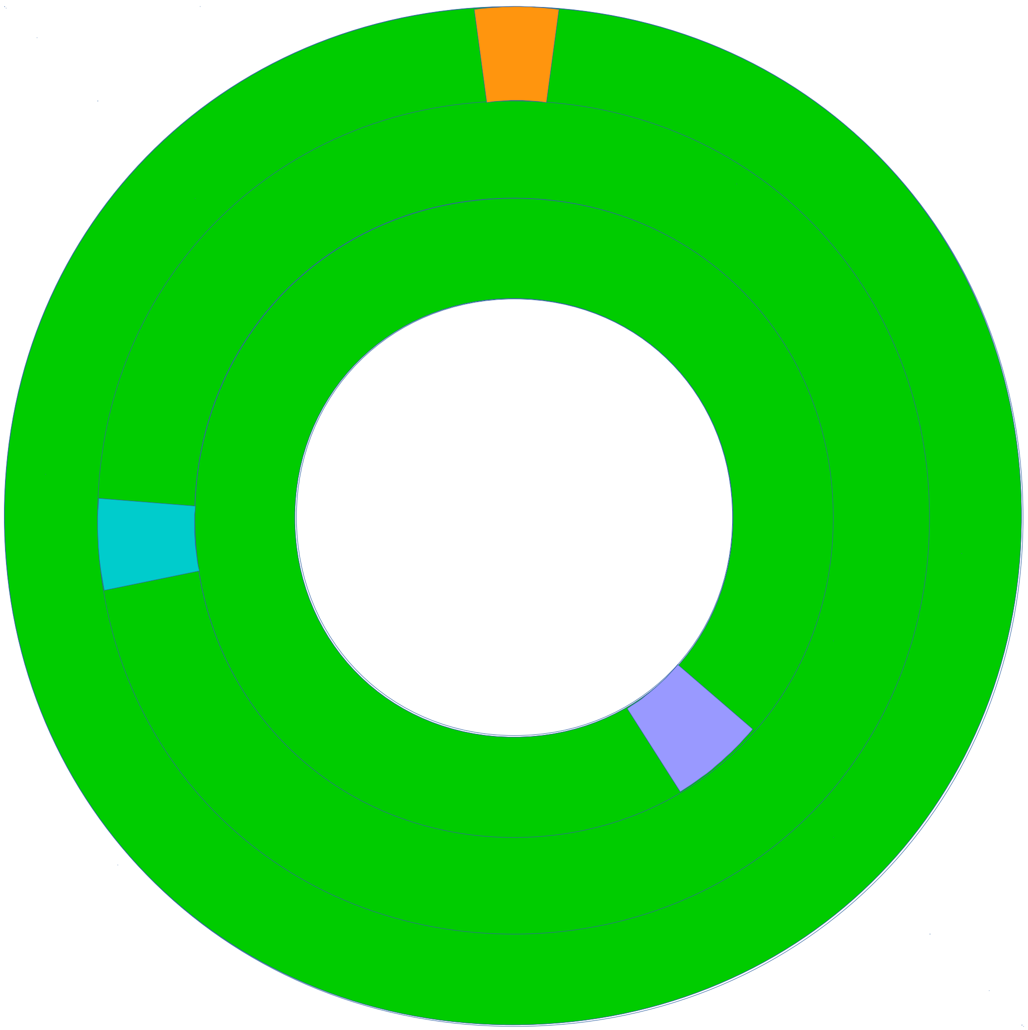
- A new way of recording tracks on the disk platter.
- Evolutionary – uses existing infrastructure.
- Fits more tracks onto platter → increases capacity.
- Disallows random writes → increases complexity.

Disk Drive Internals



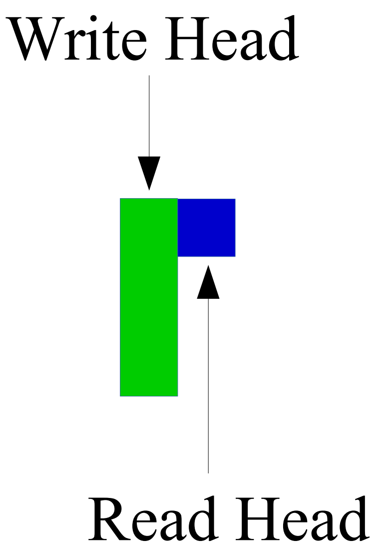
Conventional Magnetic Recording

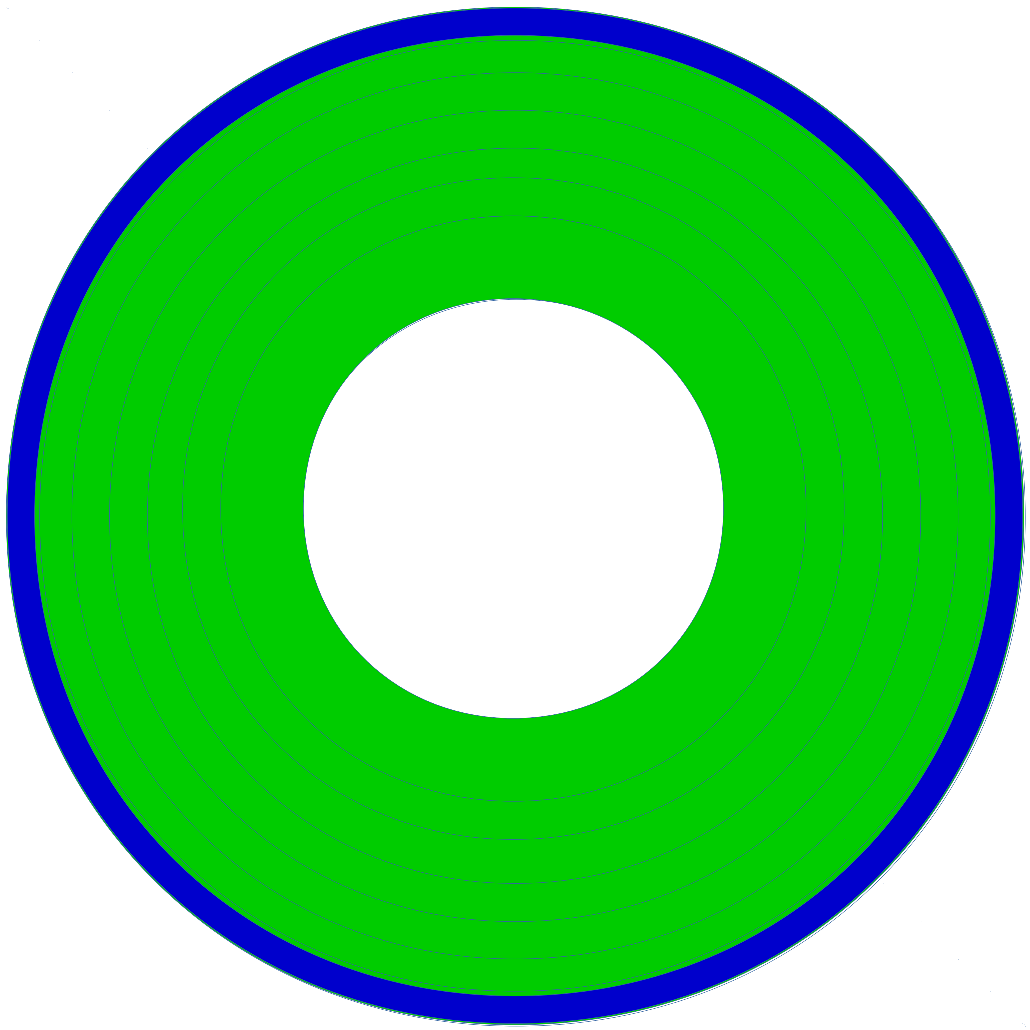




Platter

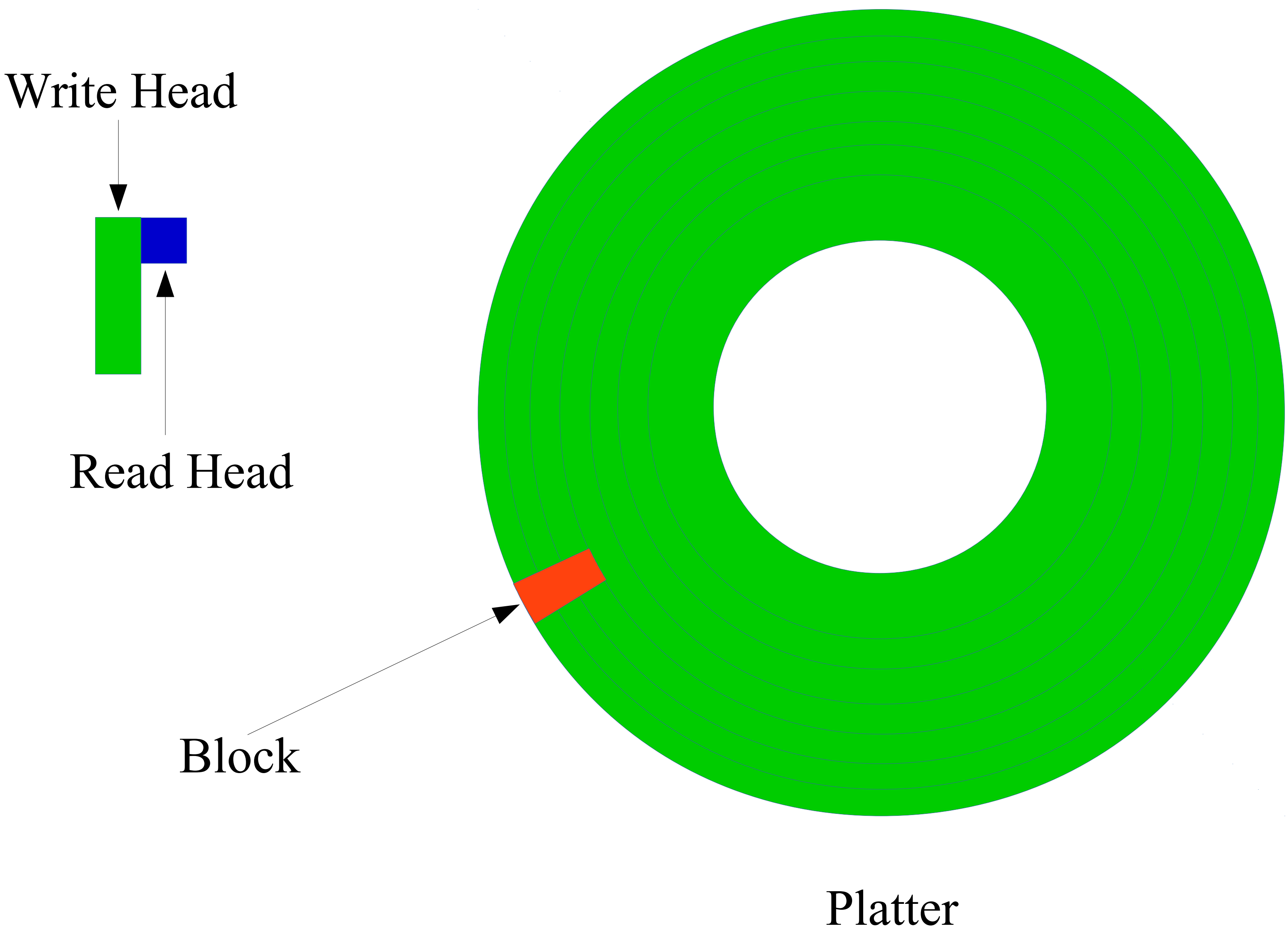
Shingled Magnetic Recording



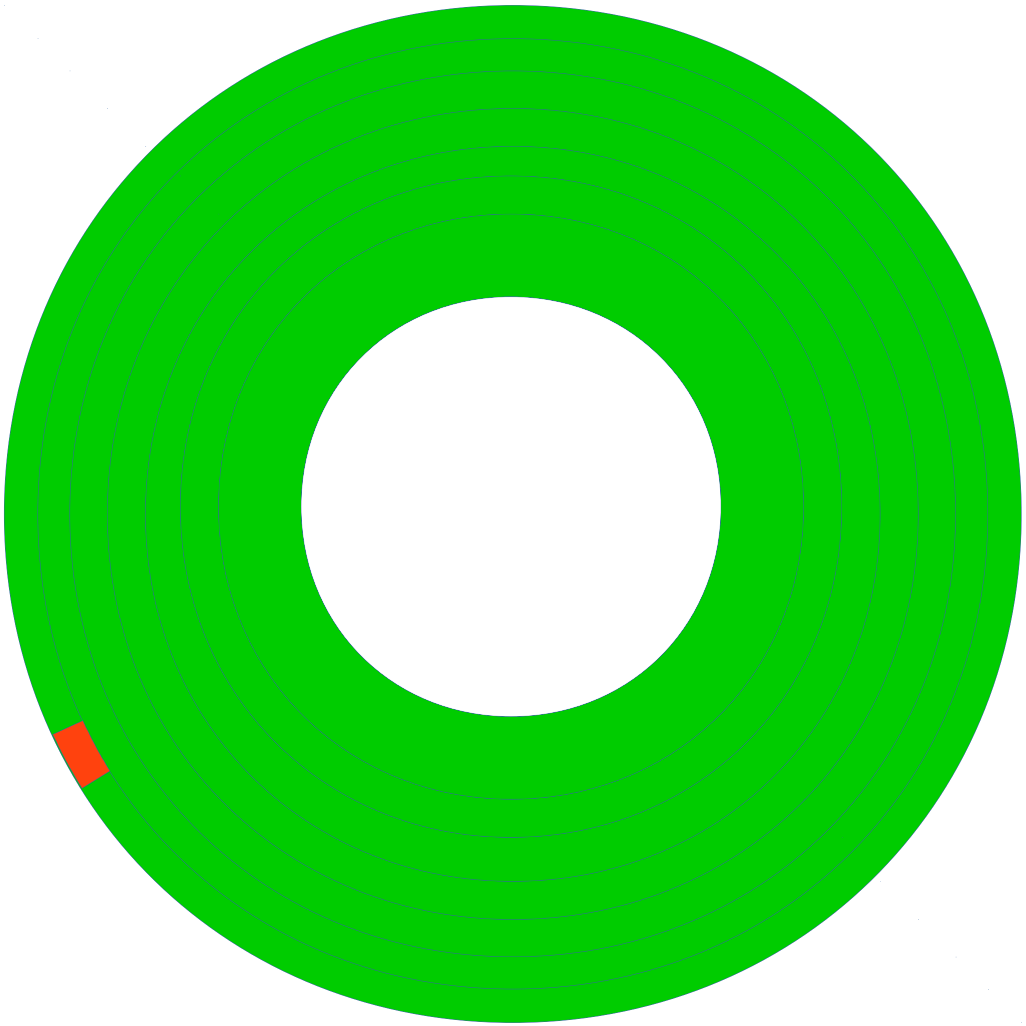


Platter

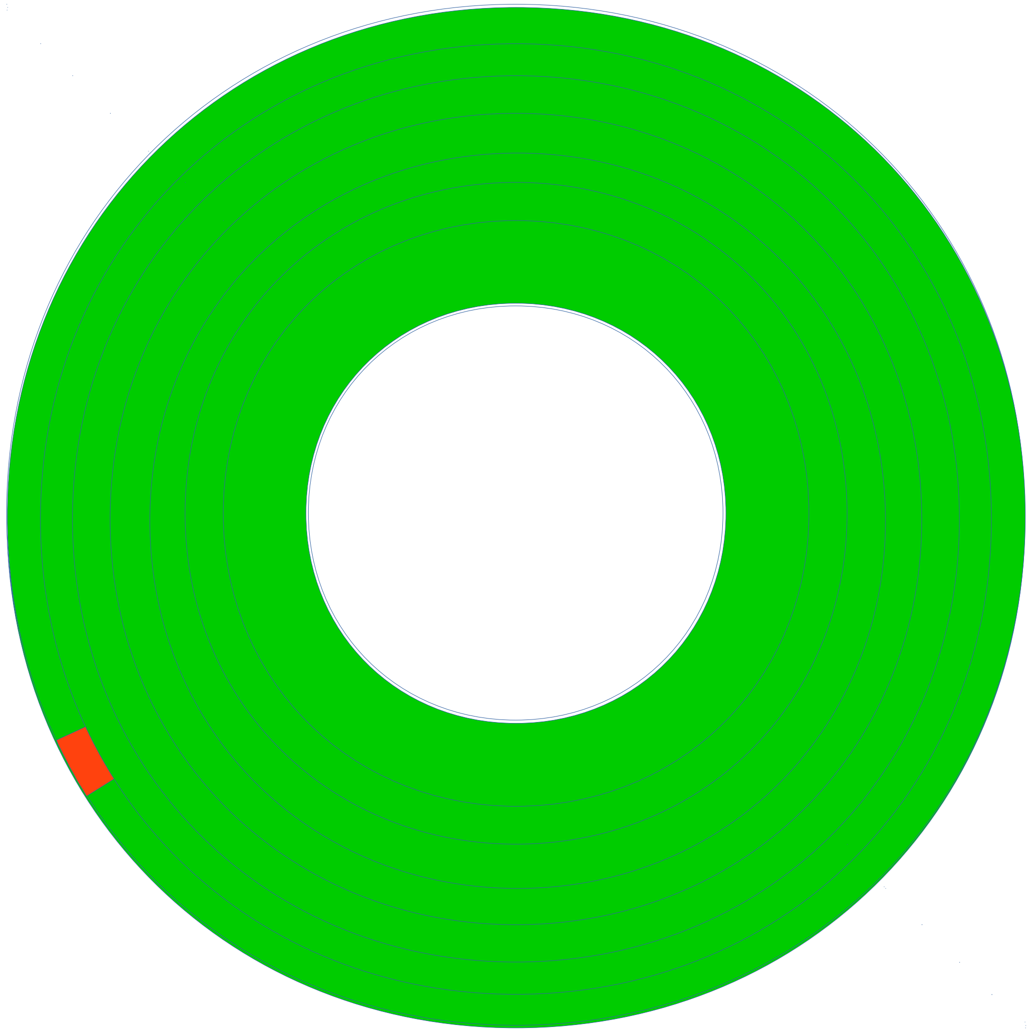
Shingled Magnetic Recording



Shingled Magnetic Recording

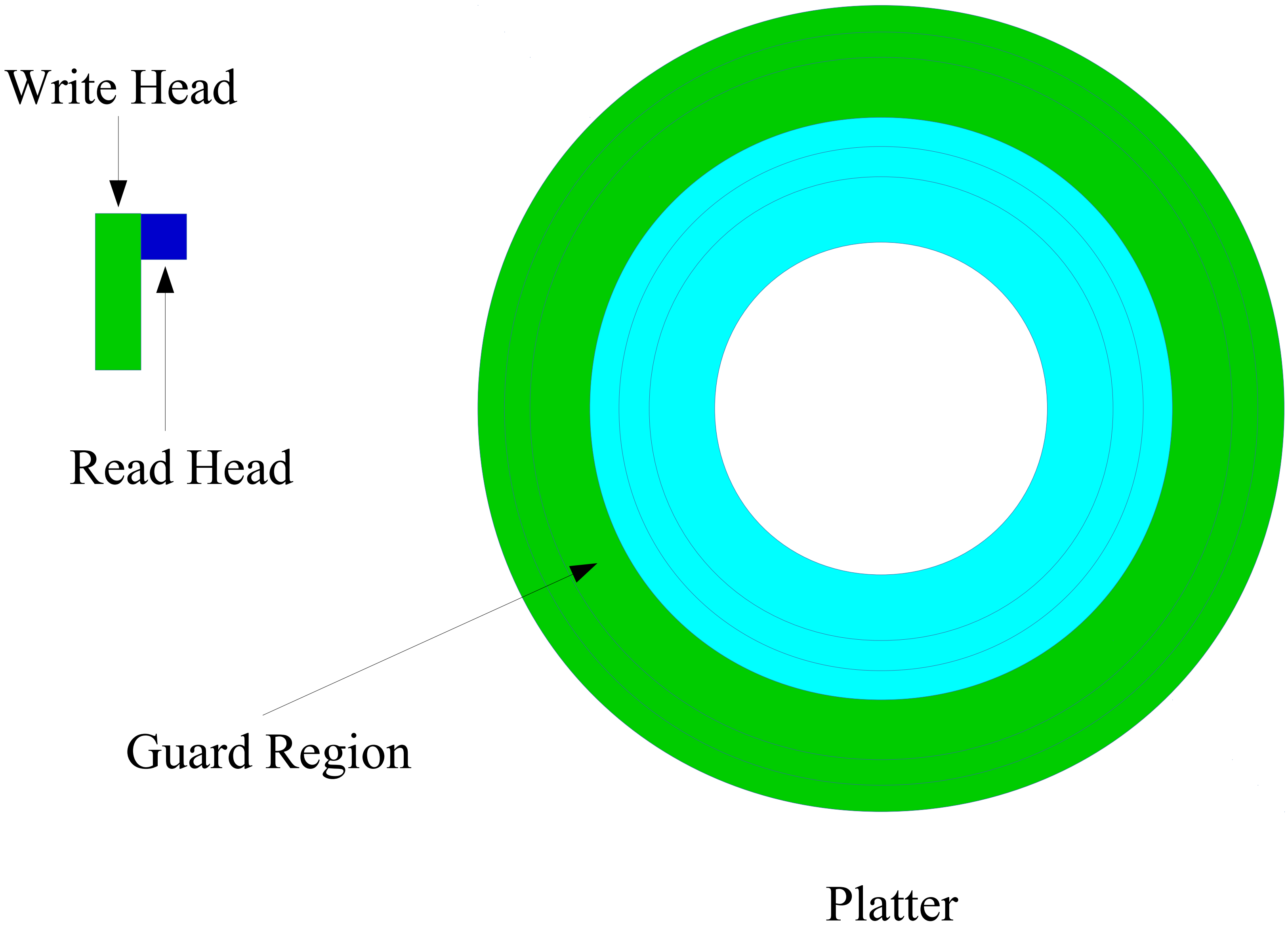


Memory



Platter

Shingled Magnetic Recording

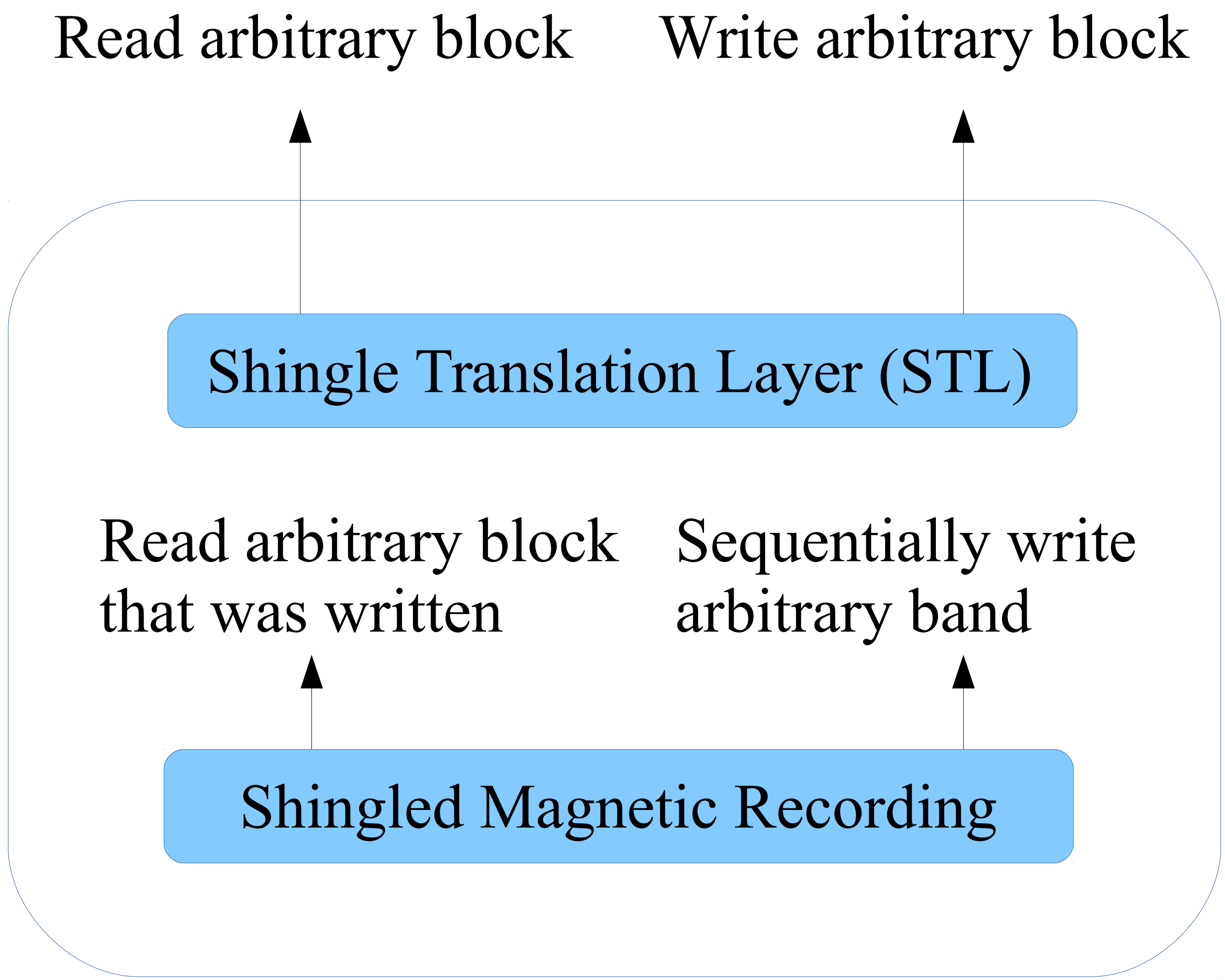


SMR Drive Implementations

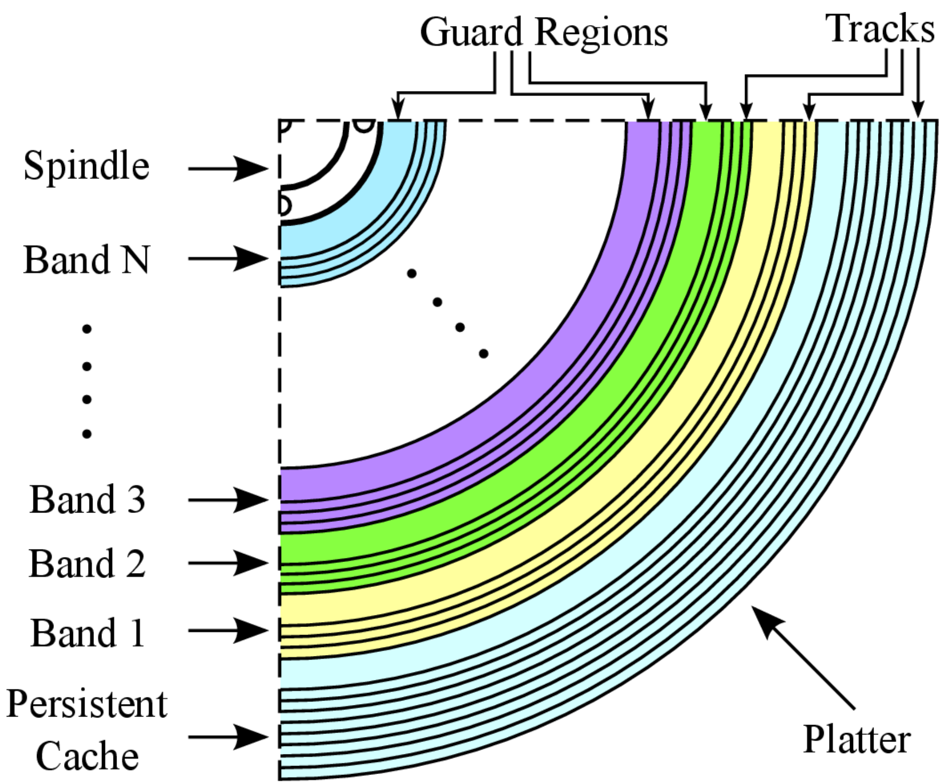
- Host-Managed
  - Reports band to host.
  - Bands must be written sequentially.
  - Random writes or reads before writes will fail.
- Host-Aware
  - Reports band to host.
  - Also handles random writes – backward compatible.
- Drive-Managed
  - Hides SMR details.
  - Drop-in replacement for existing drives.

This talk is about characterizing Drive-Managed SMR drives.

Drive-Managed SMR

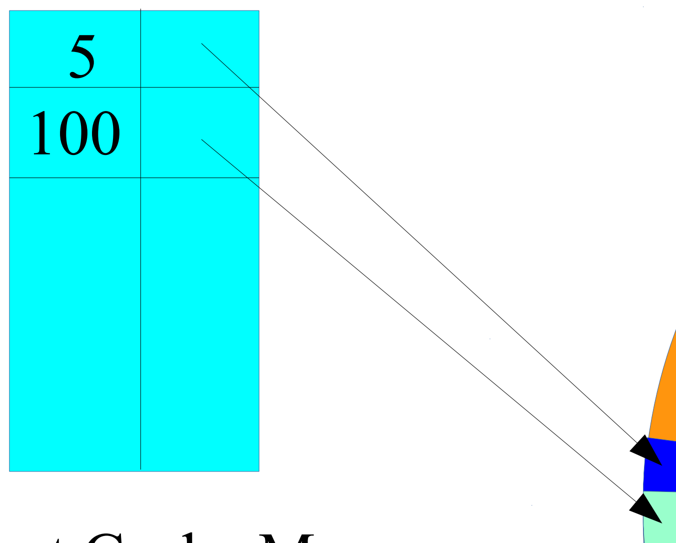


Drive-Managed SMR

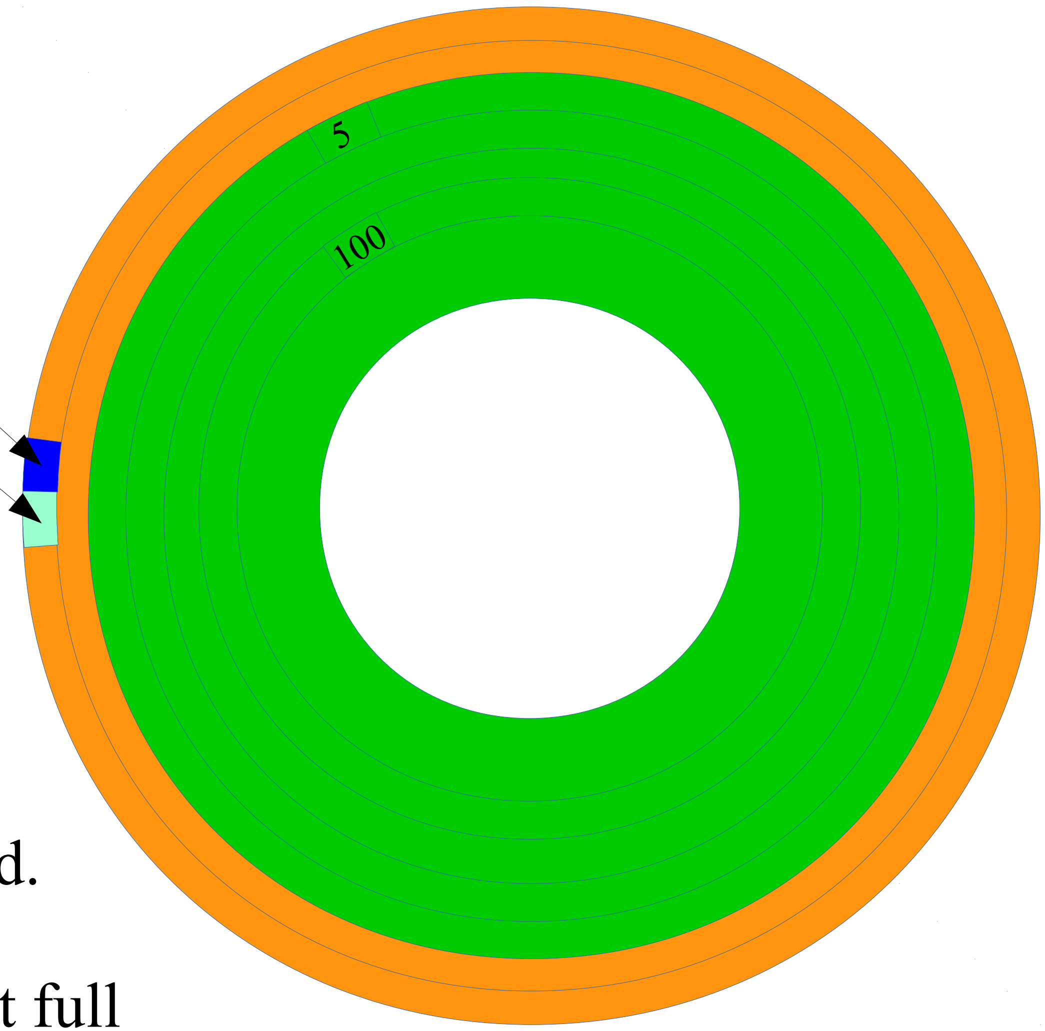


- Small region of disk, called persistent cache, used for staging random writes.
- Other non-volatile memory like flash can also be used for persistent cache.
- Disk is mapped at band granularity; persistent cache uses extent mapping.

Drive-Managed SMR



Persistent Cache Map



- Aggressive Cleaning
  starts when idleness is detected.
- Lazy Cleaning
  starts when the cache is almost full

Bands are shown in green.
Persistent Cache is shown in orange.

Outline

- Introduction to SMR
- Characterization goals and test setup
- Test results

Characterization Goals

- Drive Type
- Persistent Cache Type
- Cache Location and Layout
- Cache Size
- Cache Map Size
- Band Size
- Block Mapping
- Cleaning Type
- Cleaning Algorithm
- Band Cleaning Time
- Zone Structure
- Shingling Direction

Skylight Components

- Software part:
  - Launch crafted I/O operations using **`fio`**.
  - Disable kernel read-ahead, drive look-ahead, on-board volatile cache.
  - Use latency to infer drive properties.
- Hardware part:
  - Install a transparent window on the drive.
  - Track the head movements using a high-speed camera.
  - Convert movements to head position graphs.

Emulation Strategy

- STLs from the literature implemented as Linux device-mapper targets.

Drive-Managed SMR with persistent disk cache

Drive-Managed SMR with persistent flash cache

Tested Drives

- Emulated Drives

Drive Name	Cache Type	Cache Location	Band Size	Capacity
Emulated-SMR-1	Disk	Single at ID	40 MiB	3.9 TB
Emulated-SMR-2	Flash	N/A	25 MiB	3.9 TB
Emulated-SMR-3	Disk	Multiple	20 MiB	3.9 TB

  - All were emulated using a 4TB conventional Seagate drive.
- Real Drives
  - 5TB and 8TB Seagate drive-managed SMR drives.
  - We only show 5TB results – labeled as Seagate-CMR.
- All disk drives are 5900RPM => ~10 ms rotation time.

Outline

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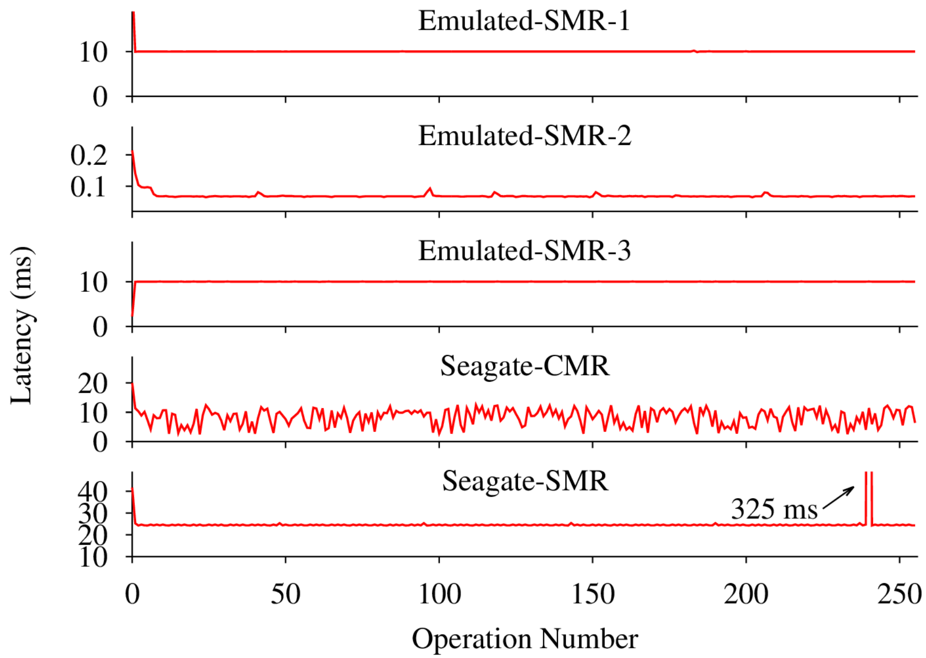
Test 1: Discovering the drive type and the persistent cache type

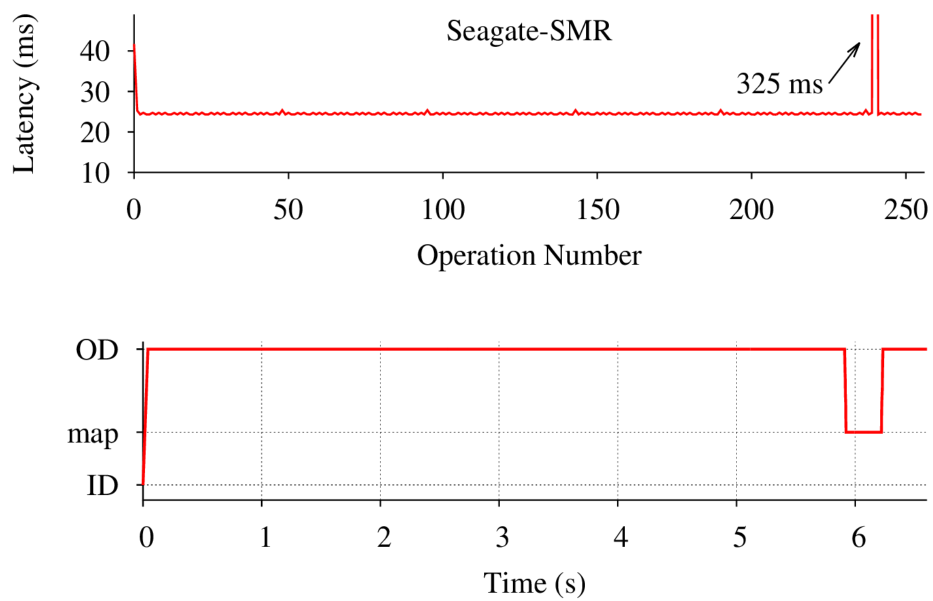
- Test exploits unusual random write behavior in SMR drives.
- Write blocks in the first 1GiB in random order.
- If latency is fixed then the drive is SMR, otherwise it is a conventional magnetic recording (CMR).
- Sub-millisecond latency indicates a drive with a persistent flash cache.

Random Write latency



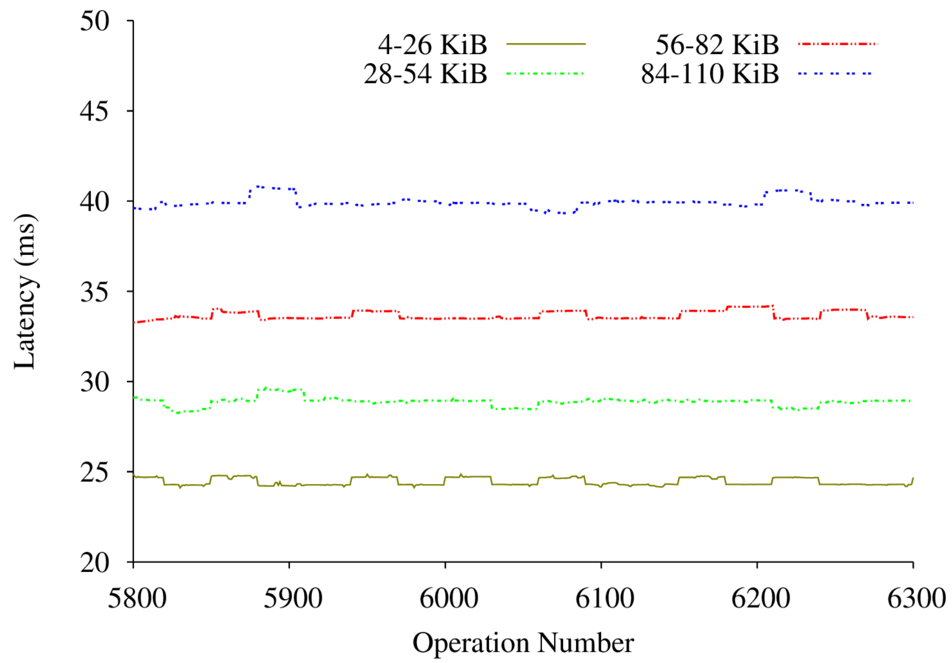
- Y-axis varies in each graph.
- Conventional drive (Seagate-CMR) stands out from the rest.
- Emulated drive with persistent flash cache has sub-ms latency.
- Latency is high for the real SMR drive.

Random Write Latency + Head Position



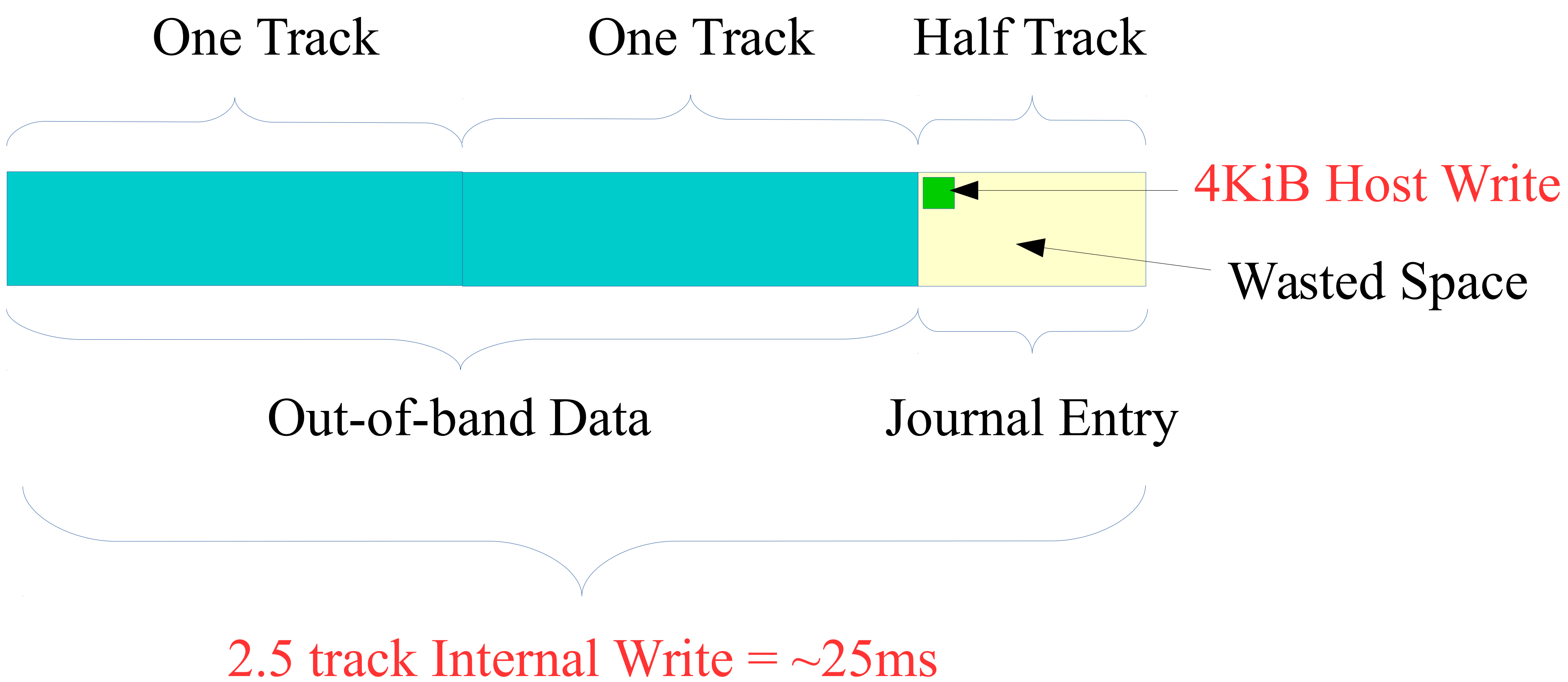
- There is a persistent cache at the outer diameter (OD).
- Writes are (likely) piggy backed with out-of-band data.
- There is (likely) a persistent cache map stored at the middle diameter.

Random Writes with Max Queue Depth

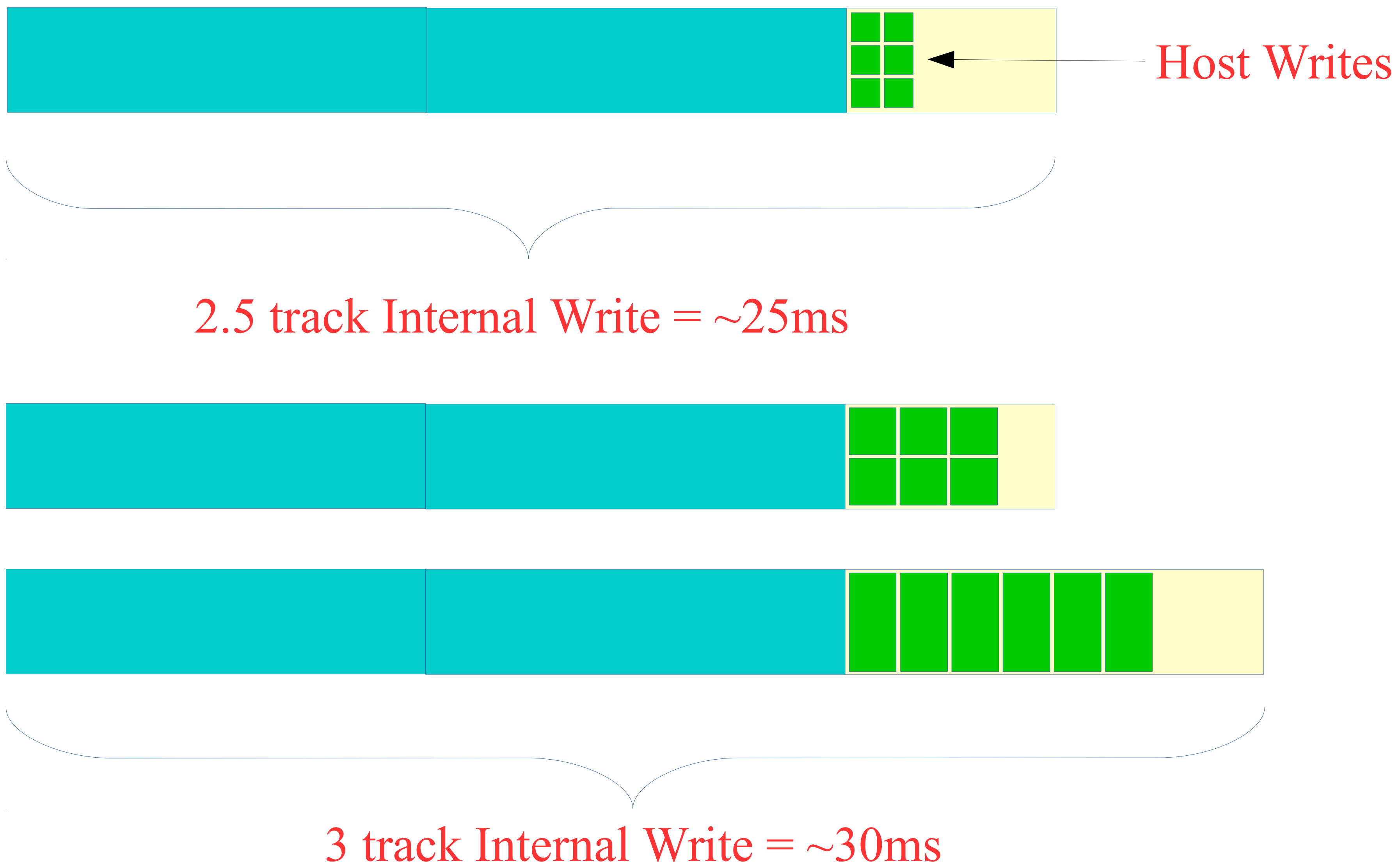


- Different write sizes produce equal latencies.
- Latency increases in ~5ms jumps.
- Given ~10ms rotation time, ~5ms is ~ half-track increase in write size.

Host Write vs Internal Write

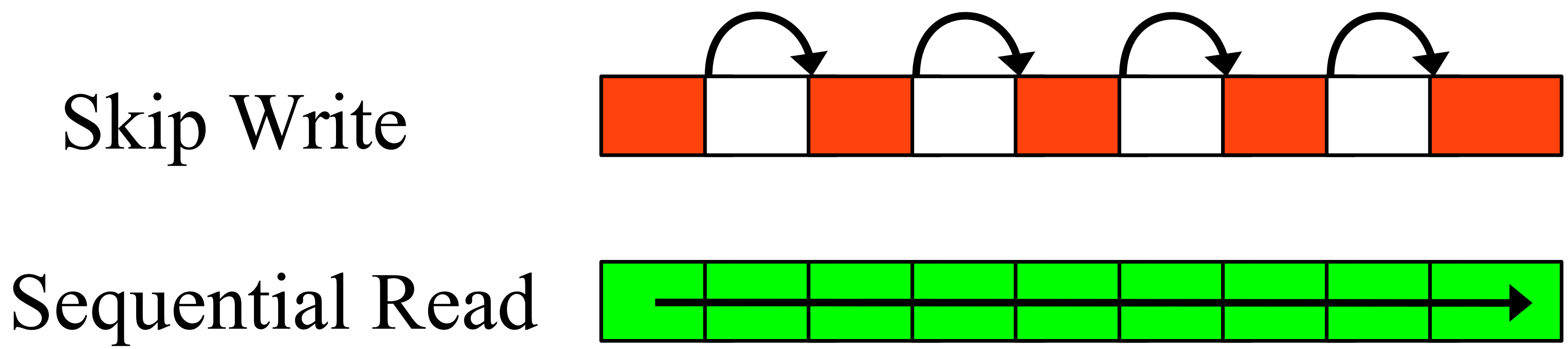


Journal Entries with Quantized Sizes



Test 2: Discovering Disk Cache Location and Structure

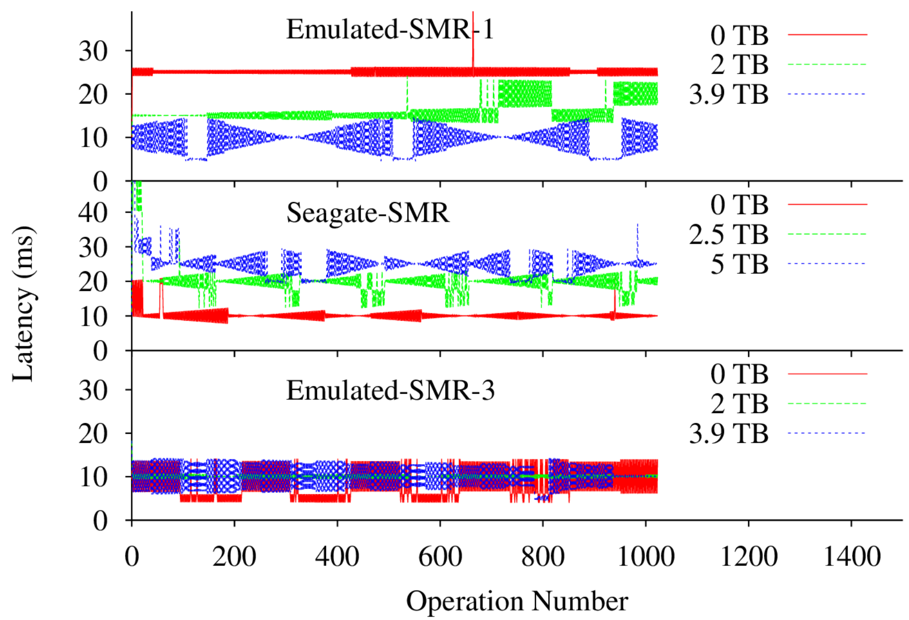
- Test exploits a phenomenon called “fragmented reads”.
- Fragmented read: during sequential read, seek to the persistent cache and back to read an updated block.
- Force fragmented reads at different offsets to infer persistent cache location based on seek time.



Fragmented Read at 5TB Offset

- Head seeks back and forth between a track and persistent cache.
- Persistent Cache is at OD, therefore, 5TB offset is at ID.
- Block numbering convention starts at OD proceeds towards ID.

Fragmented Read Latency at Low, Middle, and High Offsets

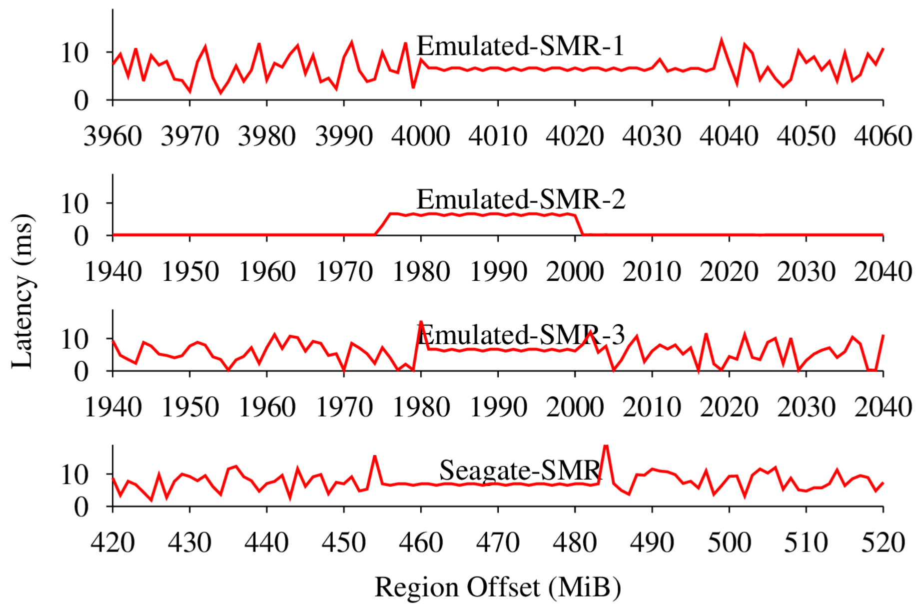


- Emulated-SMR-1: avg. latency high at low offset => cache at ID.
- Seagate-SMR: avg. latency is high at high offset => cache at OD.
- Emulated-SMR-3: avg. latency is roughly fixed => distributed cache.

Test 3: Discovering the Band Size

- Test relies on the fact that cleaning proceeds at a band granularity.
- Choose a small region (~1GiB) and write blocks in random order.
- Pause for a short (~3-5s) period, letting the cleaner to clean a few bands.
- Sequentially read the blocks in the region.
- Most latencies will be random – a streak of flat latencies will identify a band.

Sequential Read of Random Writes



- Emulated-SMR-1 band size is 40MiB.
- Emulated-SMR-2 band size is 25MiB, cache reads are sub-ms due to persistent flash cache.
- Emulated-SMR-3 band size is 20 MiB.
- Seagate-SMR band size is 36MiB, becomes smaller towards the ID.

Conclusion

- Drive-Managed SMR drives have different performance characteristics.
- Using them efficiently will require changes to software stack.
- Skylight aims to guide these changes.
- We aim for generality, more work may be needed.
- Tests, STL source code, video clips are available at

  http://sssl.ccs.neu.edu/skylight