# Track-based Translation layers for Interlaced Magnetic Recording (IMR)

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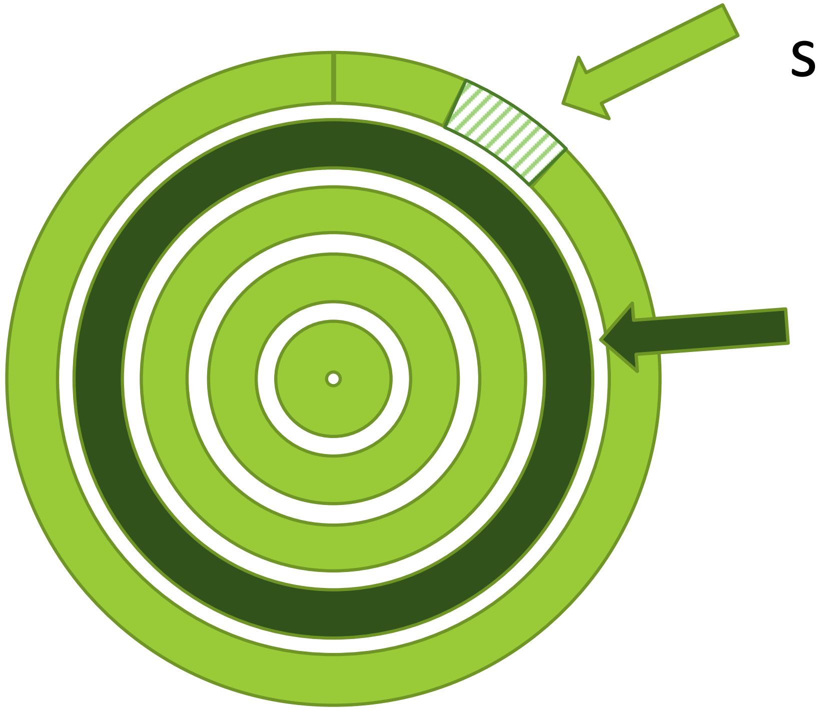
# Outline

- What is Interlaced Magnetic recording (IMR)?
- Why does it need a translation layer?
- What are our proposals?
- How do they perform?

# A quick disk overview



**Sector**
size = 512 - 4096 bytes

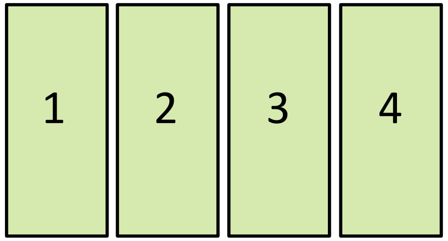
**Track**
size = 1~2MB

A 20 TB drive would have roughly about 13M tracks

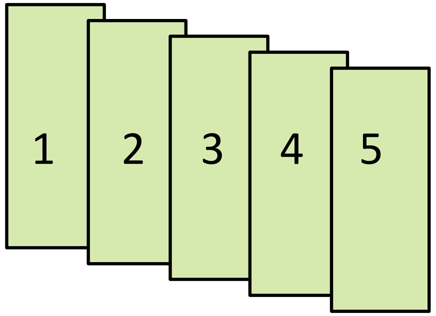
1 rotation = 8~10ms

# Magnetic recording technologies

Conventional magnetic recording (**CMR**)




Shingled magnetic recording (**SMR**)

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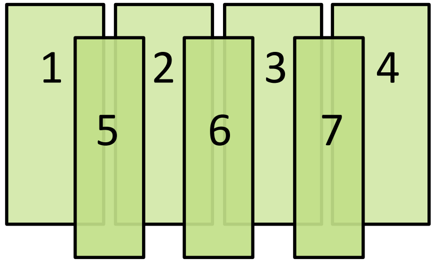


- Tracks overlap
- **25% higher capacity** than CMR
- Available commercially for 5 years
- No in-place updates allowed
- Slower than CMR

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- 40% higher capacity than CMR
- Not commercially available
- Partially in-place updates allowed
- Can be faster than SMR

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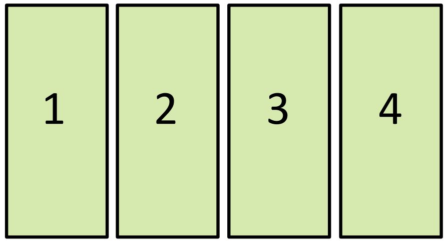


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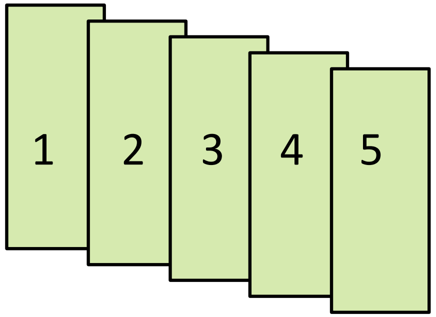


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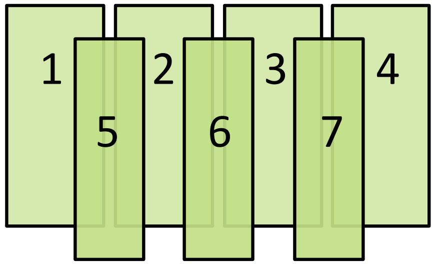
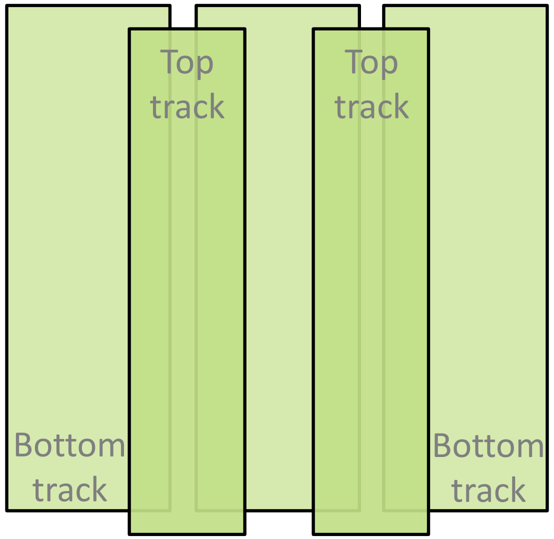



- Tracks overlap
- CMR
- Not commercially available
- Partially in-place updates allowed
- Can be faster than SMR

## How well can IMR perform?

# Interlaced magnetic recording

- Half of the tracks overlap
  - Bottom tracks are overlapped by top tracks
- Top tracks are narrower
  - Hold 80% -90% as much data
- No in-place updates are allowed for bottom tracks
  - Solution : RMW or using a translation layer

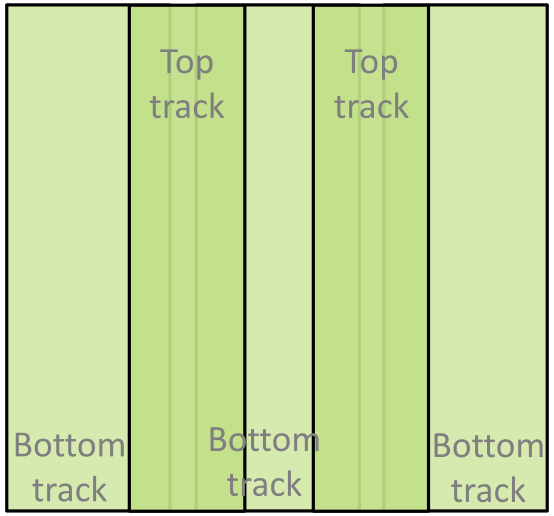


# SMR and IMR translation layers

- Goal : provide conventional block interface
- SMR drive based on translation layer location
  - Host-managed
  - Drive-managed
- IMR
  - Our focus is on drive-managed IMR

# IMR top/bottom track update

**Top track update operation**




# IMR top/bottom track update

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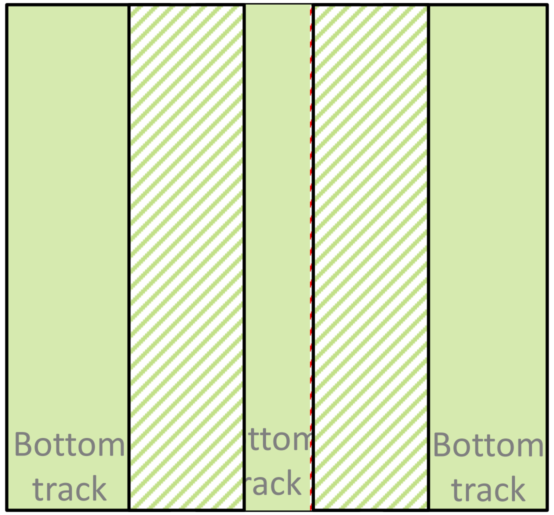


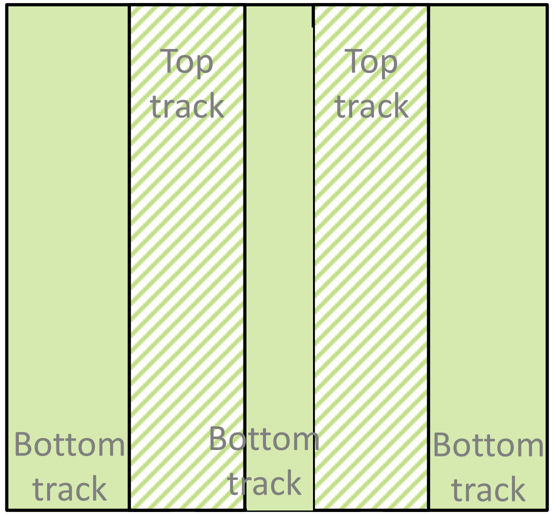


Bottom tracks still could be read if top tracks are updated

# IMR top/bottom track update

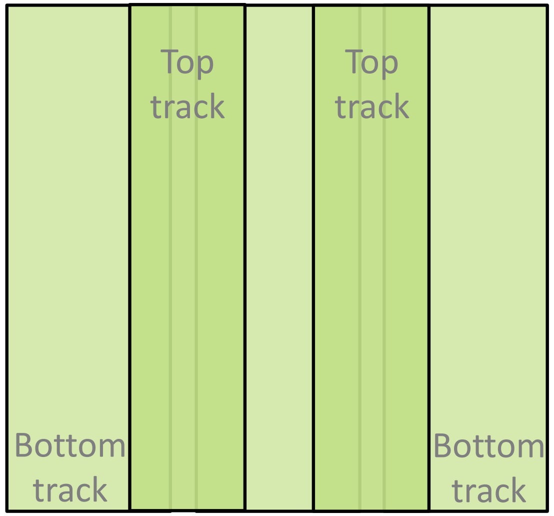
Write head
Read head

### Top track update operation




Bottom tracks still could be read if top tracks are updated

### Bottom track update operation



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Write head

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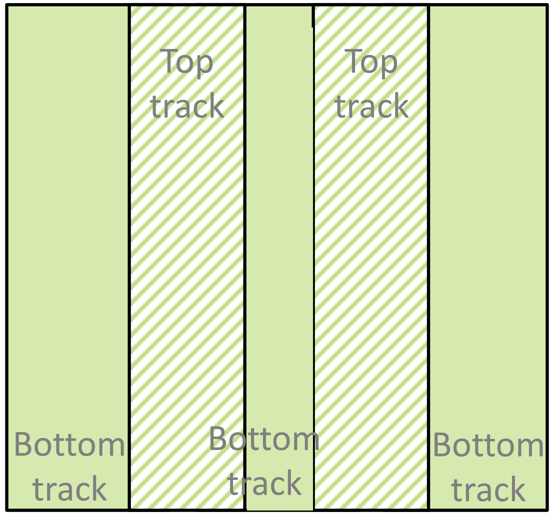


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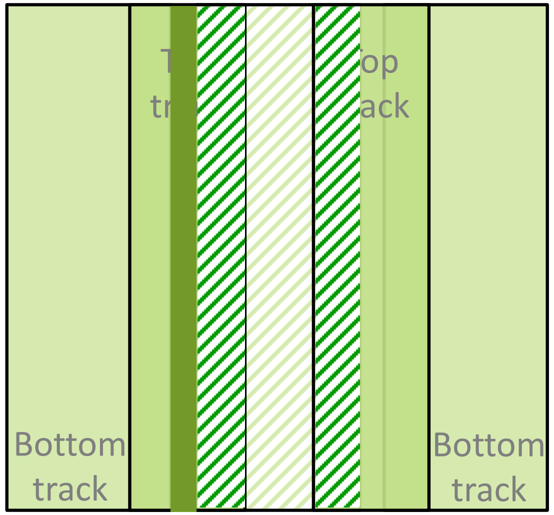
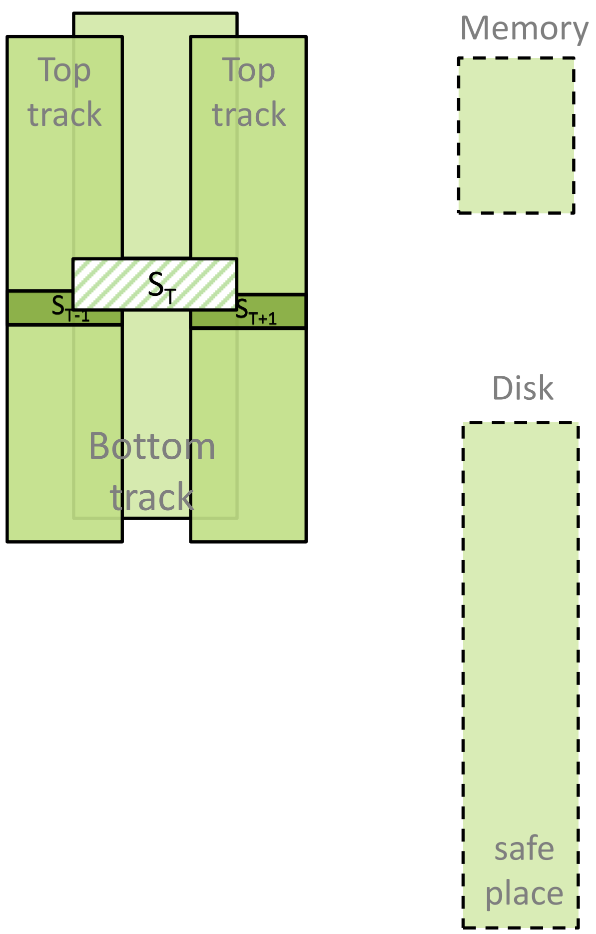



Due to bottom track update, top track data is **corrupted** and therefore cannot be read

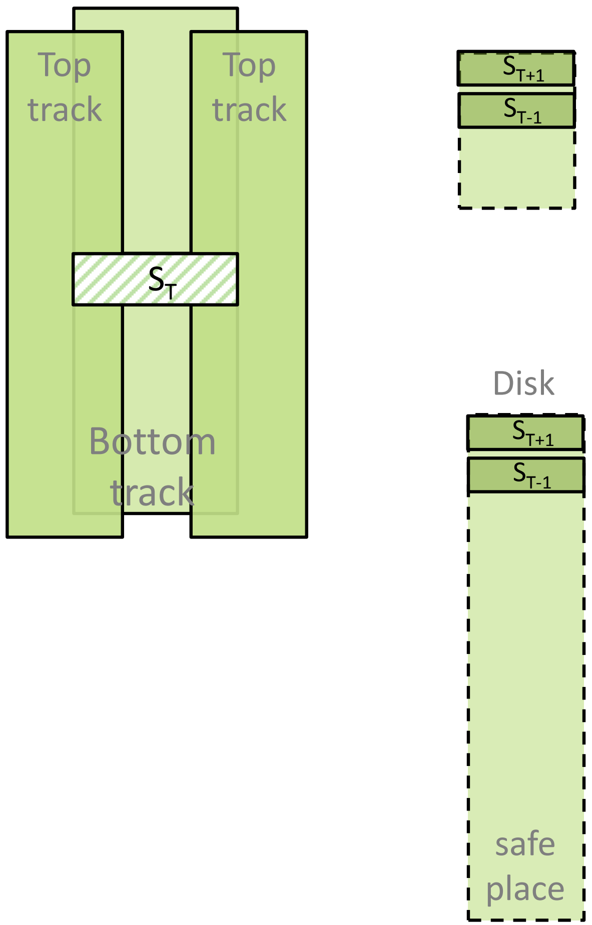
# Read-modify-write: a simple translation layer




**Update $S_T$:**

1. Read $S_{T-1}$ and $S_{T+1}$ and make copies
2. Update $S_T$

# Read-modify-write: a simple solution




**Update $S_T$:**

1 Read $S_{T-1}$ and $S_{T+1}$ and make copies

2 Update $S_T$

2 Write back $S_{T-1}$ and $S_{T+1}$

RMW imposed 2 and 3 additional reads and writes for a single update

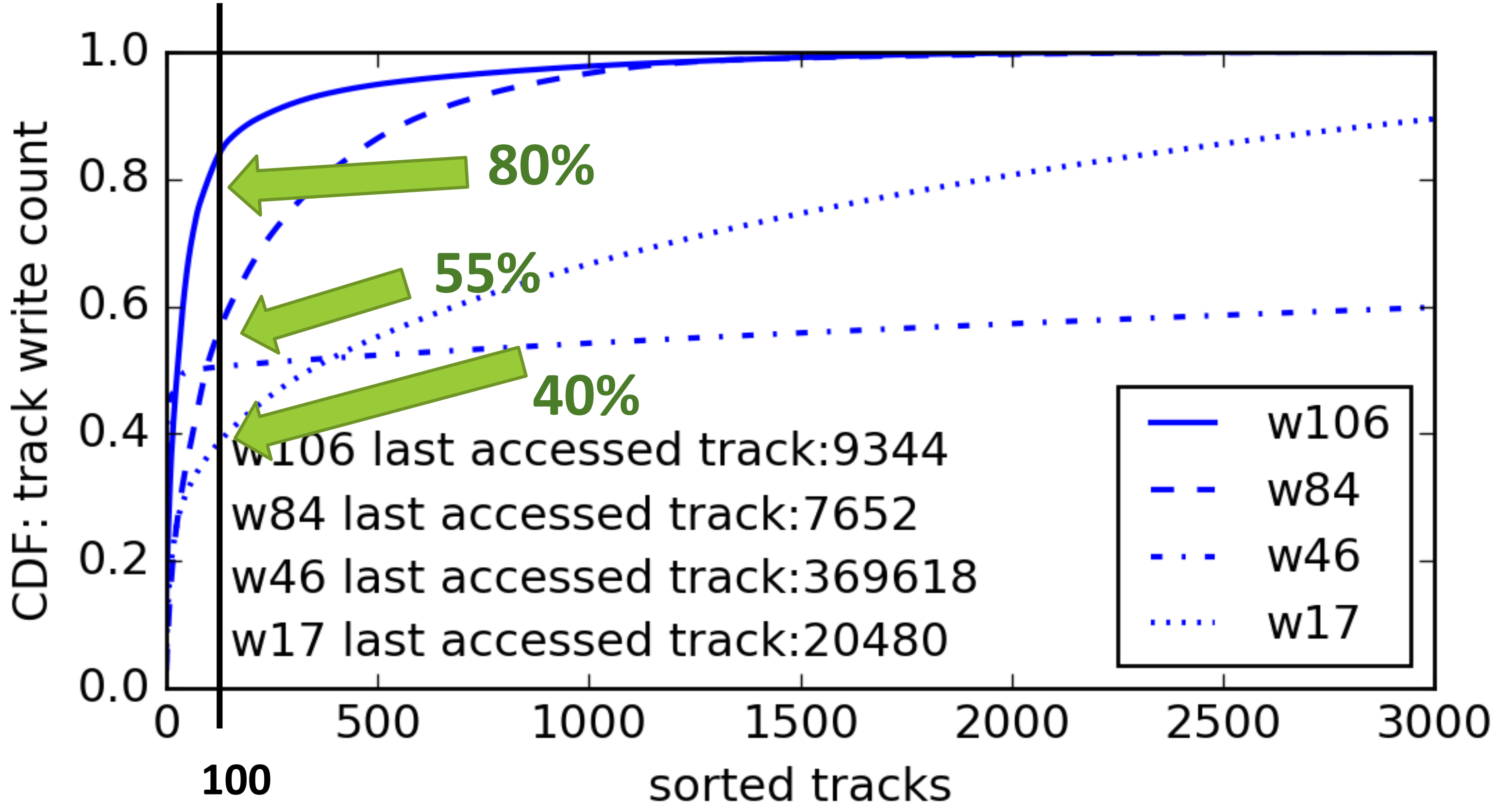
# RMW performance

- Synchronous
- Overhead per bottom track update:
  - Short writes
    - $RMW\ Latency \approx\ t_{seek} + 4 * t_{rotation} + t_{transfer}$
  - Large writes
    - $RMW\ Latency \approx\ t_{seek} + 5 * t_{rotation} + t_{transfer}$
  - Poor performance compared to CMR
    - $Conventional\ drive\ latency\ \approx t_{seek} + \frac{1}{2} t_{rotation}$

# Improving RMW

- Our Strategy: Get the hot data out of bottom tracks
  - Minimize RMW operation
- But what granularity?
  - Per sector?
    - Too much memory to keep the sector map
    - Fragmentation and large number of seeks
  - Single track maybe?

# Track access pattern and locality




A small number of tracks receives majority of writes

# Proposed IMR track-based translation layers

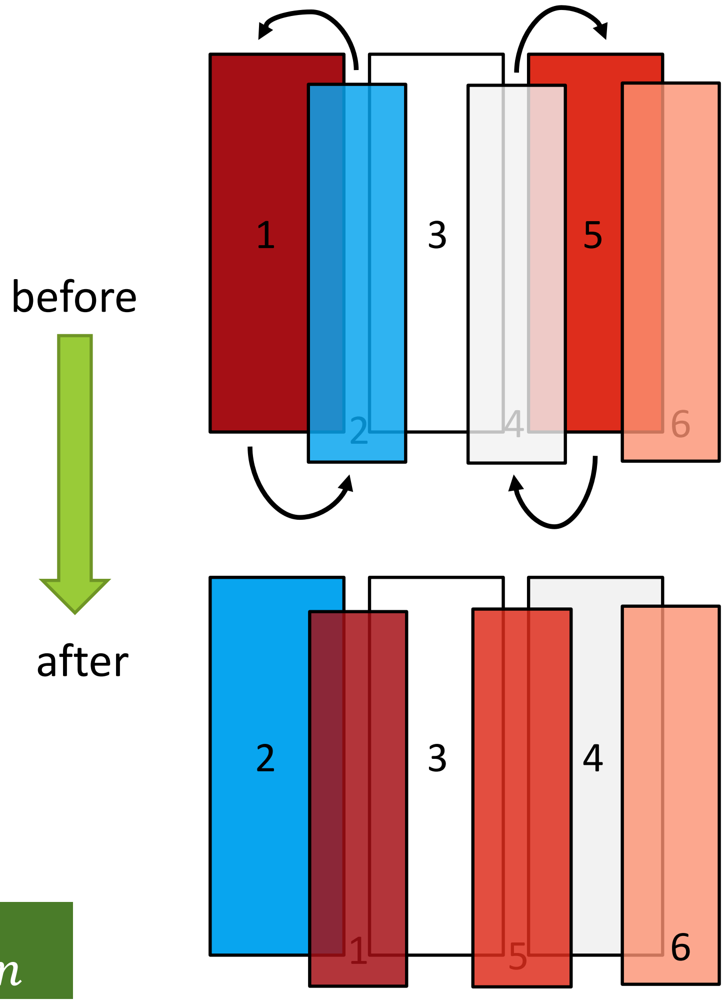
- Algorithms
  - Track flipping
  - Selective track caching
  - Dynamic track mapping
- Runs periodically (e.g., every 20K  write operations = every few minutes) and in the background
- Limited number of tracks remapped every iteration
  - Limited performance overhead
- Still need RMW

# Track flipping

- **Hot bottom tracks** are **swapped** with neighboring **cold top tracks**

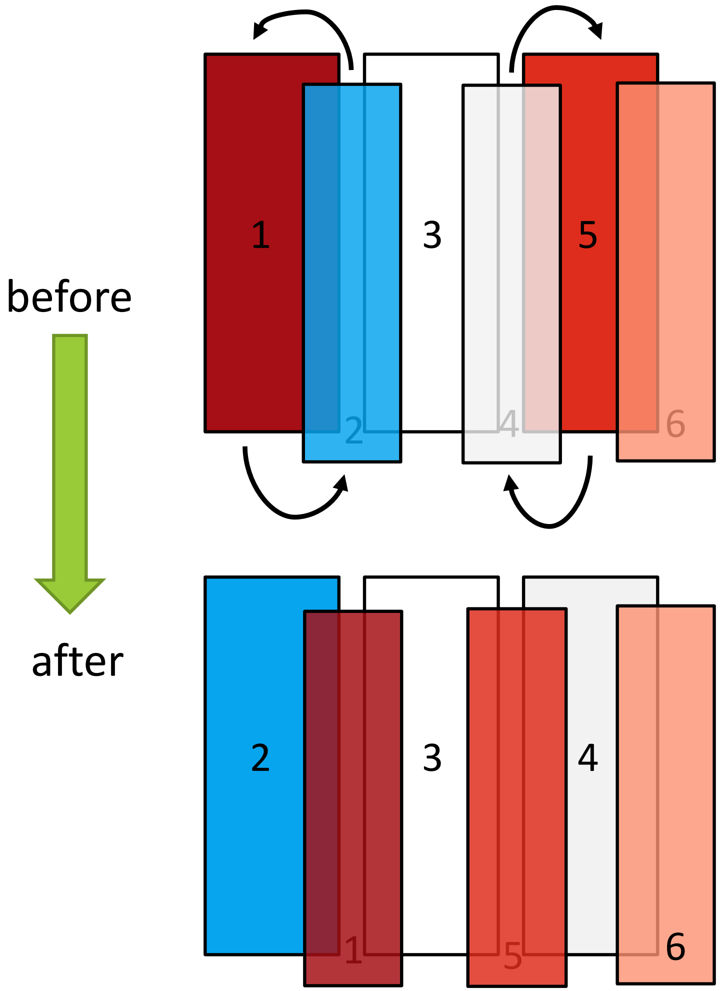
- Challenges and limitations:
  - Differing top/bottom track sizes
    - Solution: move either low or high LBAs, whichever is hotter
  - No improvement if both neighboring top tracks are hot as well

$$cost \approx 3t_{seek} + 8t_{rotation}$$



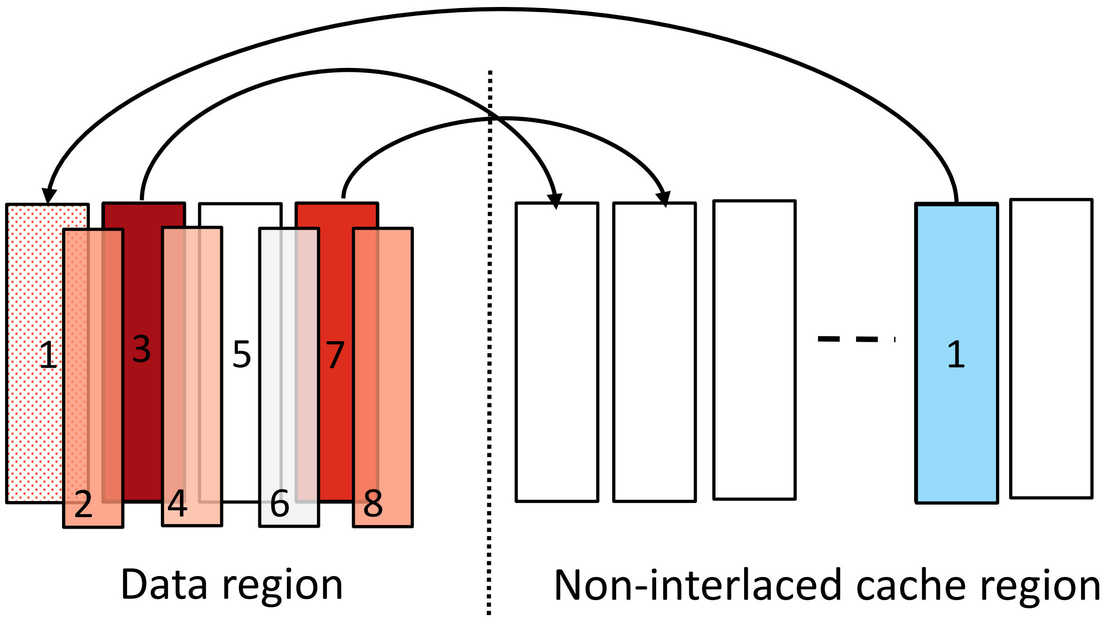
# Track flipping – memory requirement

- Hot track detection
  - logging the written track
    - Less than **0.25 MB**
- Track map
  - 5 states for each bottom track (Non-flipped, 4 flipped states)
  - 3 bits per two tracks
    - **2.5 MB** for a 20T drive



# Selective track caching

- Hot bottom tracks are cached in a small non-interlaced reserved area
  - Hot bottom tracks are promoted to the cache
  - Cold tracks are  demoted to their home locations
- Addresses the limitations of track flipping



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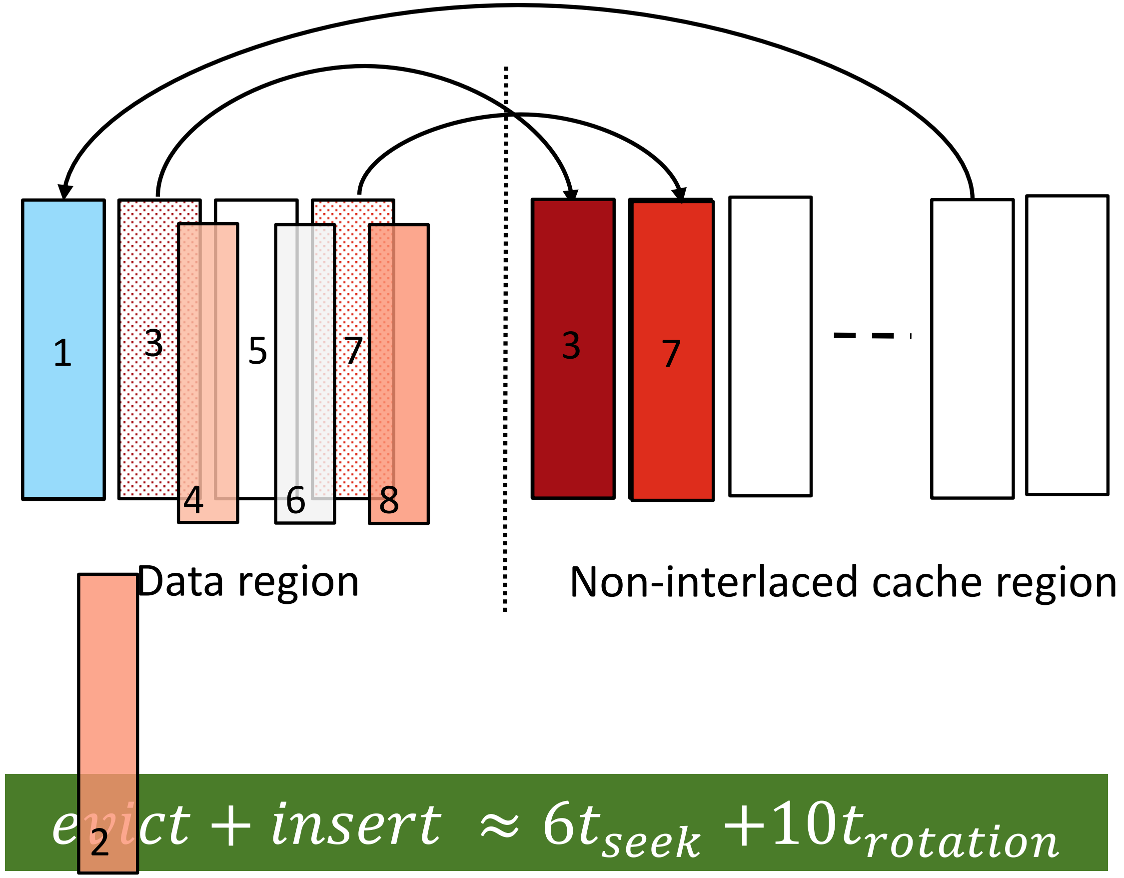



$$evict + insert \approx 6t_{seek} + 10t_{rotation}$$

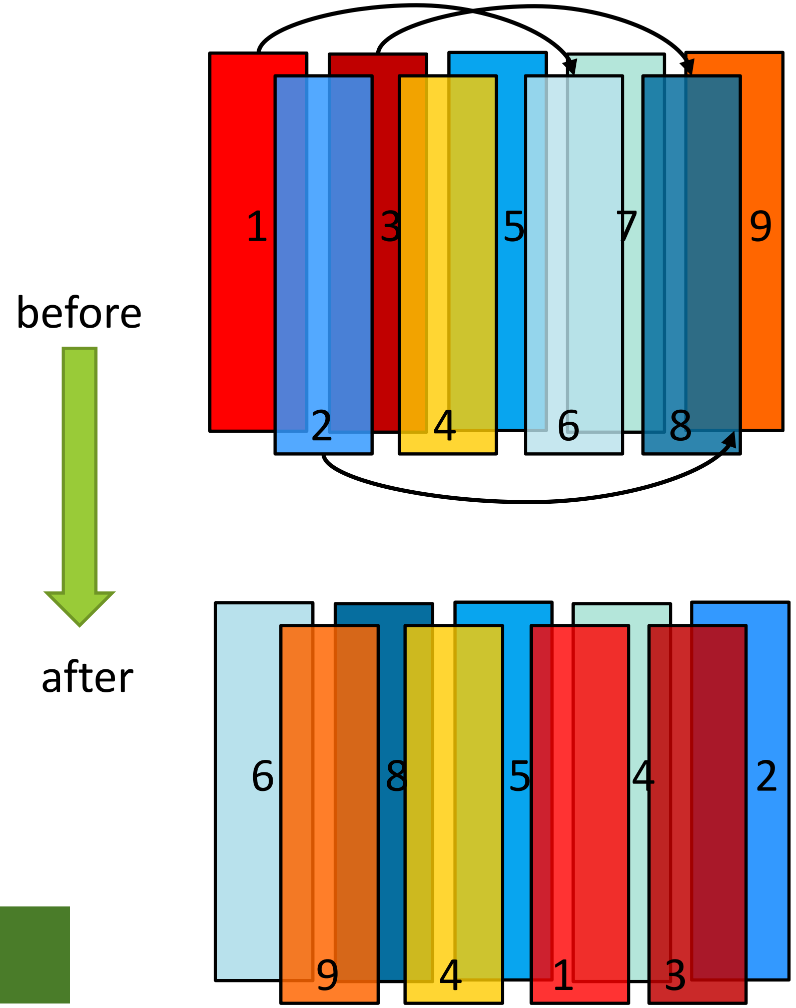
# Selective track caching - memory requirement

- Hot track detection
  - logging the written track
    - Less than **0.25 MB**
- Look-aside cache map
  - Proportional to the number of tracks in cache
  - Tiny (for 100 track cache in our experiments)

# Dynamic track mapping

- Arbitrary permutation of tracks within zones
  - Concatenate all LBAs and group them in fixed size pseudo-tracks
  - Requires about 12.5 MB for a 20TB drive with zone size of 256 tracks
  - Requires 0.25 MB for hot pseudo-track detection
- Addresses the limitation of track flipping

swap 2 tracks ≈ $5t_{seek} + 13t_{rotation}$



# Simulation setup: traces and disk

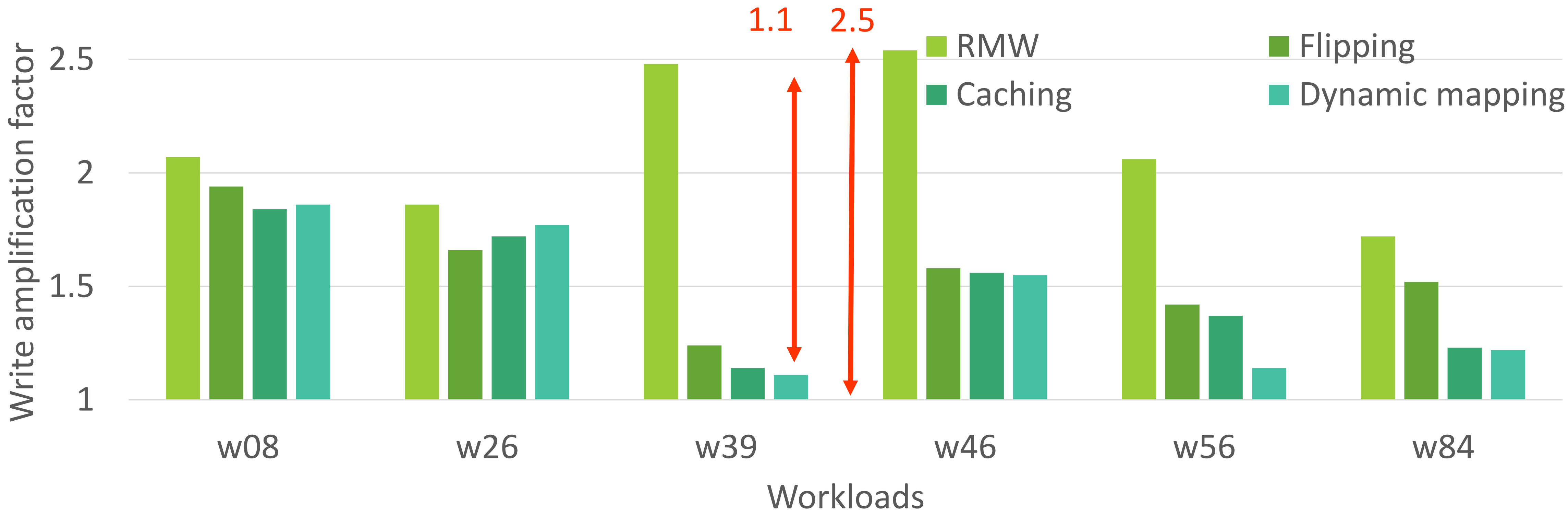
- CloudPhysics traces
  - Block traces from VMs running Linux and Windows
  - LBA range of 10s of GBs to 1.5 TB
  - Very short inter-arrival time
- Disk Model
  - 6K rpm disk
  - Ignore head switch
  - Rotational delay = ½ plater revolution
  - Seek time : 2ms to 20ms LBA range dependent
  - Track size = 2MB for both top and bottom tracks
  - Write cache enabled

# Simulation setup: I/O latency model

- IO latency includes:
  - Host and device queuing
    - Depth of 64
  - Seek time
  - Rotational delay
  - Transfer time

$$Latency \approx t_{queuing} + t_{seek} + \frac{1}{2} t_{\mathrm{rotation}} + t_{transfer}$$

# Results: write amplification factor




High WAF due to RMW

Proposed translation layers reduce WAF

# Results: normalized mean latency

# Summary

- Interlaced magnetic recording
  - Half of the tracks overlap
  - Higher capacity compared to conventional and shingled drives
  - Relaxed constraints relative to SMR
- Read-modify-write is a solution
  - Poor performance
- Proposed alternatives translation layers
  - Track flipping
  - Track caching
  - Dynamic track mapping
  - Take advantage of the IMR flexibility
  - Improve the performance significantly

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**Questions?**