Storage

R&G Chapter 9

(slides adapted from content by J.Gehrke, J.Shanmugasundaram, and/or C.Koch)

Review

Operation	**Sym**	**Meaning**
Selection	σ	Select a subset of the input rows
Projection	π	Delete unwanted columns
Cross-product	x	Combine two relations
Set-difference	-	Tuples in Rel 1, but not Rel 2
Union	U	Tuples either in Rel 1 or in Rel 2

Also: Intersection, **Join**, Division, Renaming
(Not essential, but very useful)

Review

Find the Last Names of all captains of a ship located in Federation Territories

Affiliation

Location,	Affiliation
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[Risa,	Federation]
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But we can do this more efficiently:

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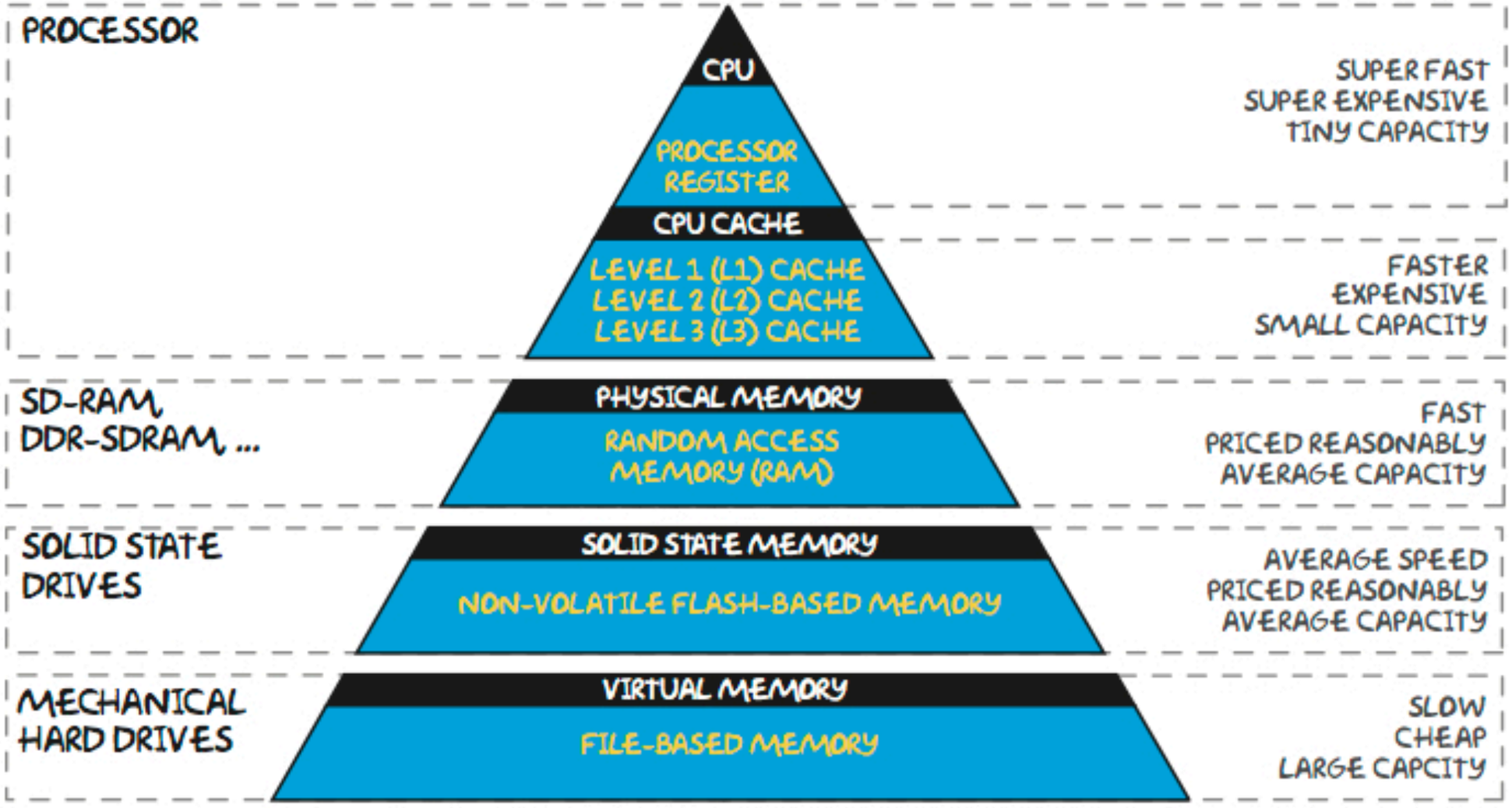
A query optimizer can find this, given the first solution

The Memory Hierarchy

Fast (but small)



Big (but slow)

image credit: teachbook

The Memory Hierarchy

Fast (but small)

RAM

Flash Memory

Hard Disks

Tape Drives

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What are some characteristics of each form of data storage?

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The Memory Hierarchy

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Flash Memory

Hard Disks

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Which layers are needed by a DBMS?

Big (but slow)

Storage

- How do we…
  - …go deeper into the memory hierarchy?
  - …use the right data access pattern for the storage medium we're using?
  - …organize data to minimize access costs?
- These ideas are incorporated into the **Buffer Manager** of a DBMS.

Data Organization

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Records stored in any order	Records stored in sorted order	Secondary file used to organize data records

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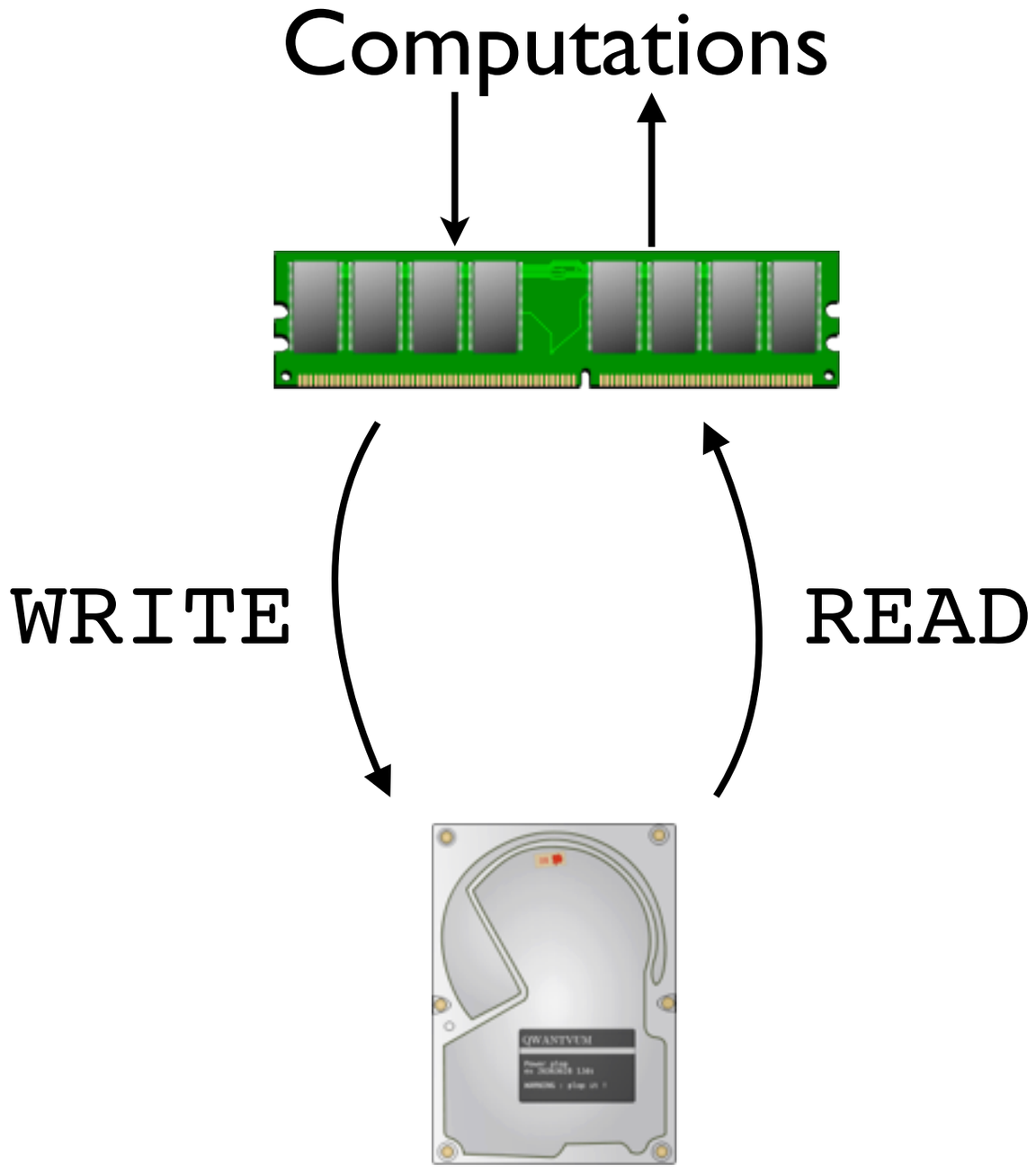
When do we use each method?

The IO Problem



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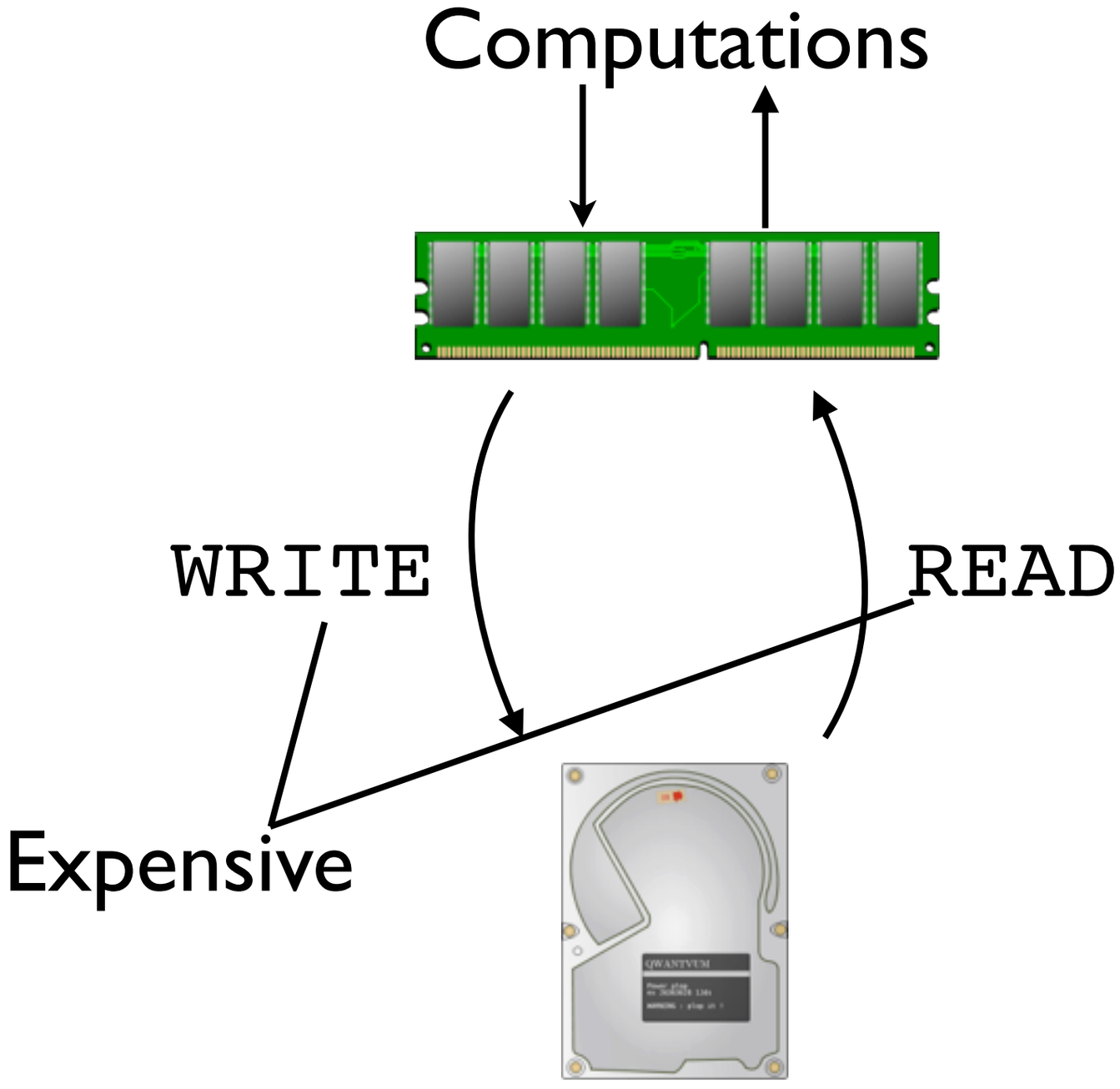

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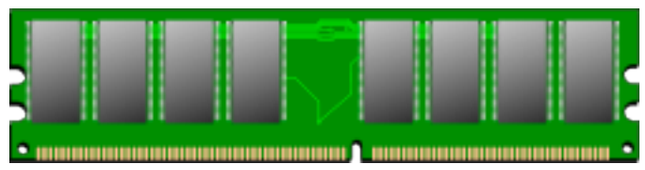
Why not use just RAM?

- RAM is more expensive than HD
  - 200 MB/$ vs 10 GB/$
- RAM is smaller
  - 128 GB vs 10 TB
- RAM is volatile



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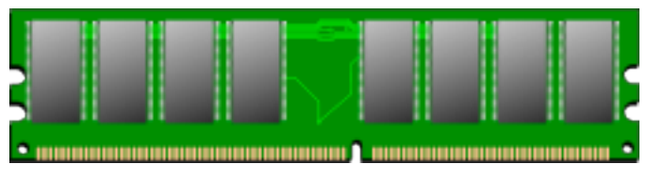

Are in-memory databases still viable? (Hint: Yes)

image credit: openclipart.org

In-Memory DBs

- Why use In-Memory DBs?
  - Faster processing (especially for random access)
- How can we provide persistence?
  - … with respect to local failures (crashes)
  - … with respect to global failures (hurricanes)
- How do we provide scale?
  - Some DBs need TB/PB of space.

Hard Disks (and Flash)

- Data is stored on ~4KB (or more) **pages**
- Tuples are typically < 4KB
- Need to store multiple tuples per page.
- Why is this expensive?
- How can we mitigate the cost?

image credit: openclipart.org

Components of a Disk

- Platters spin (e.g., at 5400 rpm).
- The arm assembly moves in/out to a desired track (like a record player).
- A cylinder is the set of tracks in the same place on each platter.
- One head at time reads/writes.
- One block is read/written to/ from the disk at a time.

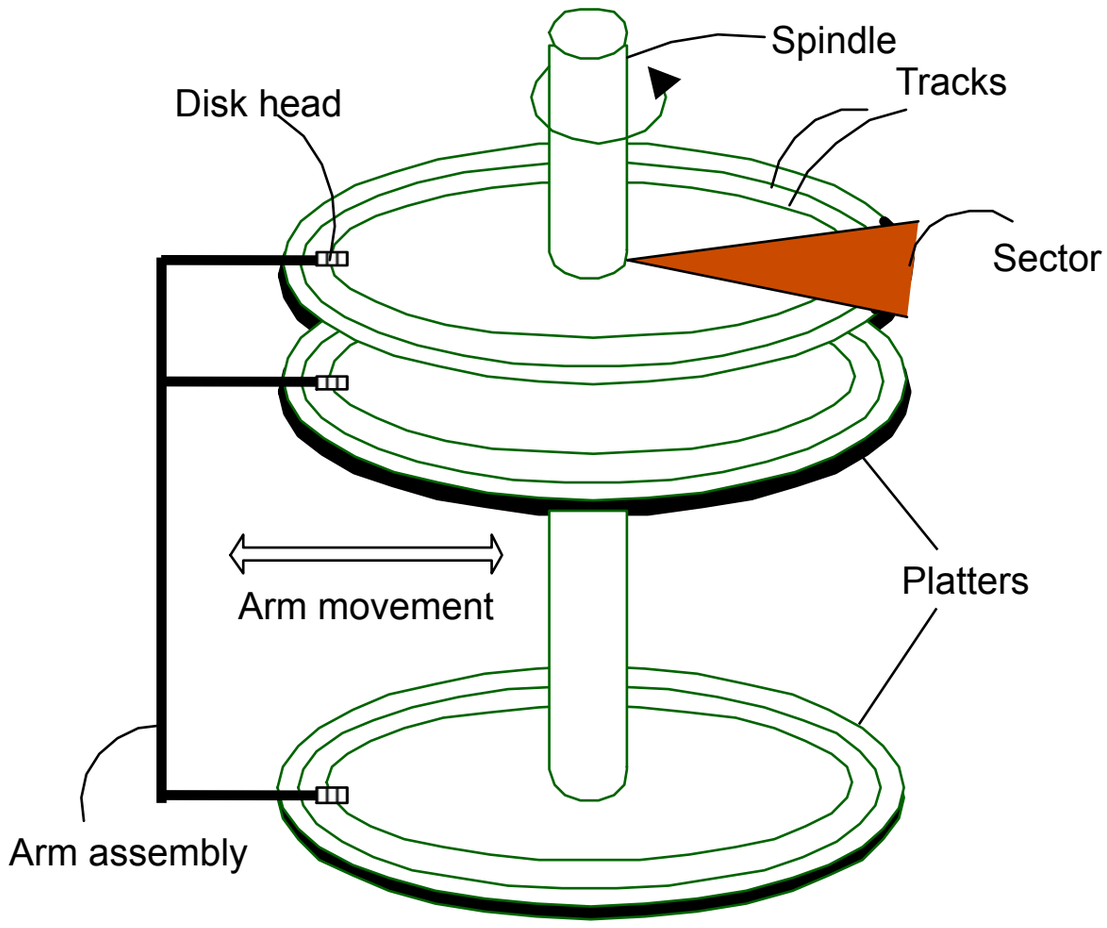

image credit: R&G

Accessing the Disk

- **Seek Time**: The time to move the arm assembly/disk head to the right track (1-20 ms).
- **Rotational Delay**: Waiting for the block to rotate under the disk head (0-10ms).
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How do we make reads/writes more efficient?

“Nearby” Blocks

- Blocks in a file should be kept nearby…
  - …within a track.
  - …in the same cylinder.
    - …in adjacent cylinders.
- Minimize seek/rotational delay to get nearby blocks in a file.
- Bulk transfers of adjacent blocks are cheap!

Flash Memory

(The same stuff that's in your cellphone/camera)

- Two types: NOR/NAND-based
  - NAND is denser and provides bit-addressing
- Bit-at-a-time writes (unset operation on bits)
  - Block-at-a-time erasure (set operation on blocks)
- Erasure wears out the chip
  - 100,000-1,000,000 read/write cycles per block.
  - "Wear leveling" spreads writes between blocks.

Accessing Flash

- Different Cost Structure
  - Random Reads == Sequential Reads
  - Append to Block < Write to Block
- What kind of data-structures would work well with flash?

Hard Disks vs Flash

- Flash has faster read/write times
- Flash supports random read access
- Hard disks are more durable
- Hard disks are bigger
- Erasing flash is slow (can make writes slow)

RAID

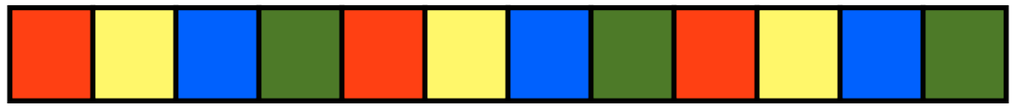
- Redundant Array of Independent Disks
- Combine several disks into a single ‘virtual’ disk.
- Goals: Increased performance and redundancy.
- **Striping**: spread data across multiple disks.
  - Allows for parallel data access.
- **Mirroring**: Copies of data allow for redundancy.

RAID

- **Level 0**: Striping only
  - N disks = Reads/Writes @ N x disk bandwidth
- **Level 1**: Mirroring only (Exactly 2 disks)
  - Parallel reads, Serial writes
  - 2 disks: Reads @ 2x disk bandwidth, Writes @ 1x
- **Level 0+1**: Stripe over mirrored pairs
  - Parallel reads, Writes serial on 2 disks
  - N disks: Reads @ N x disk bandwidth, Writes @ (N/2)x

RAID

- **Level 2-4**: Striped with parity bits, bytes, or blocks (respectively)



Can lose any 3 drives and still reconstruct all data

image credit: openclipart.org

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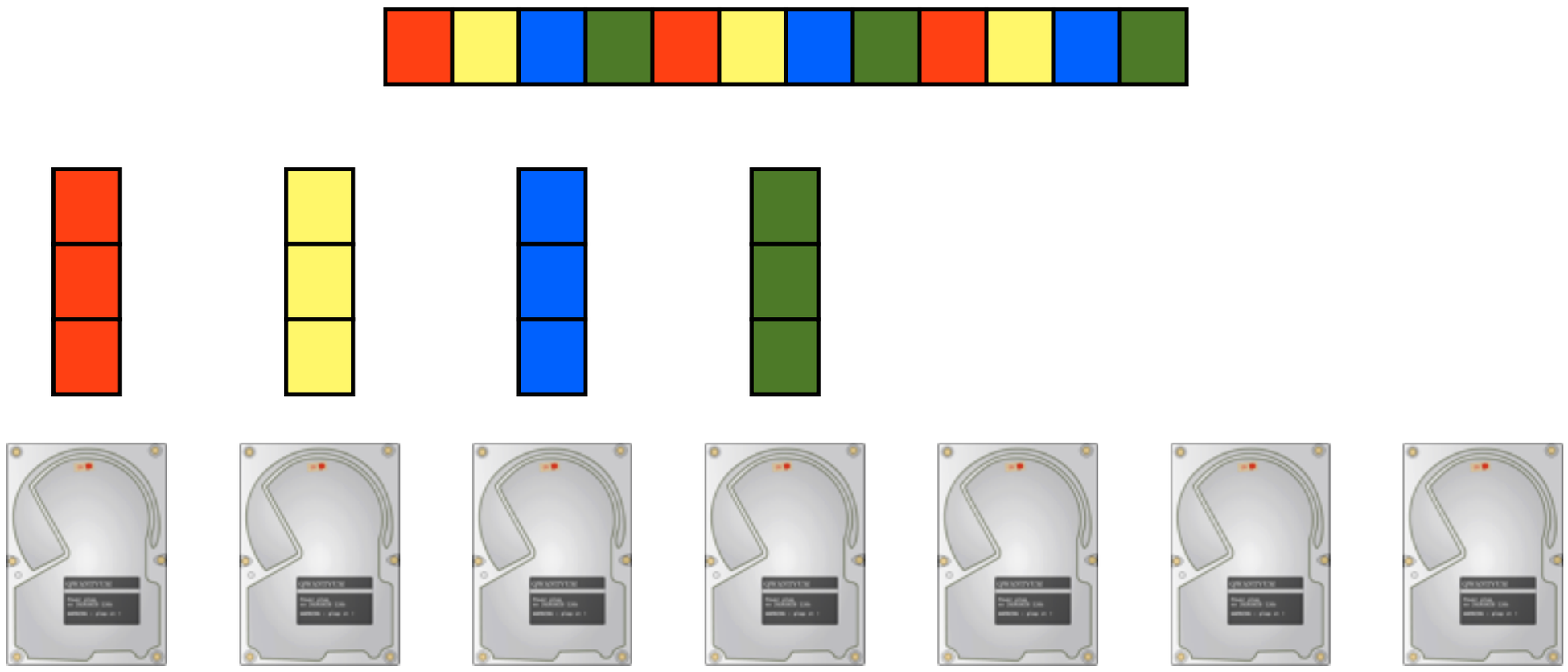

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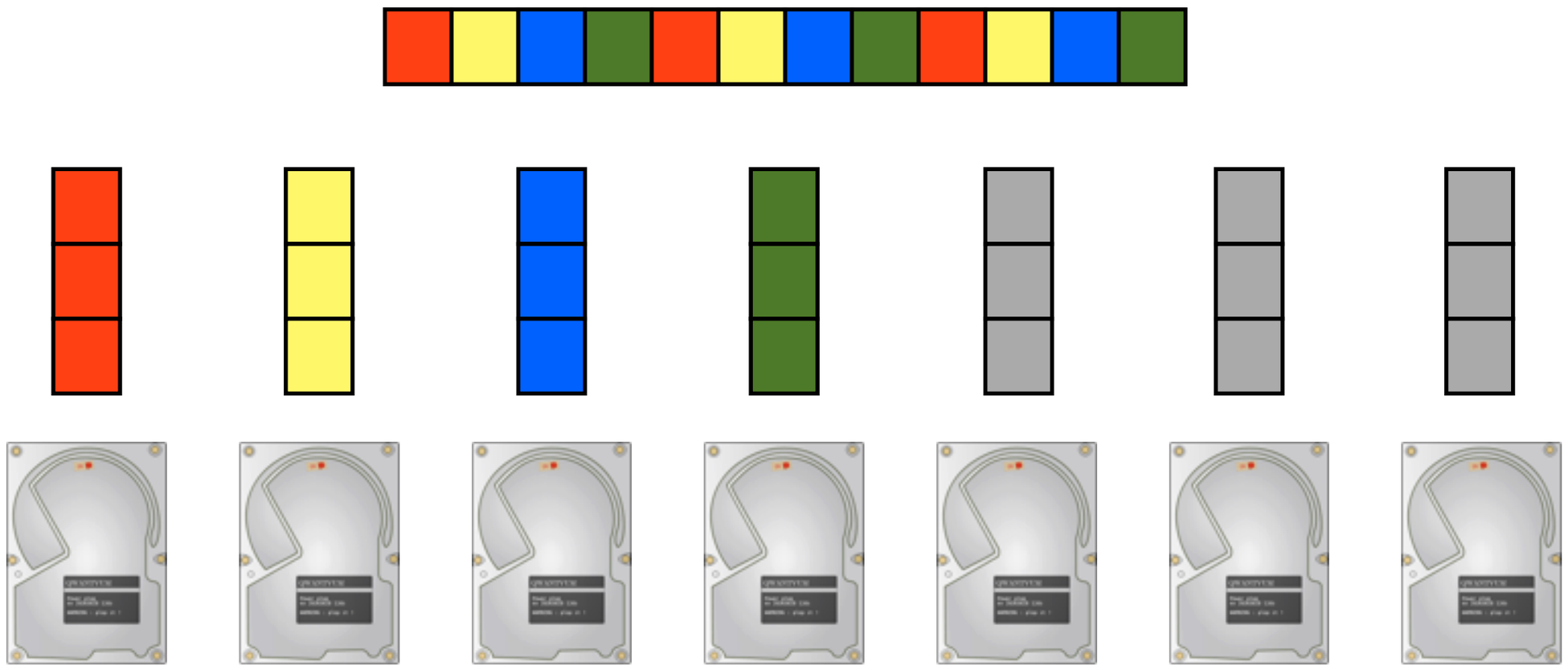

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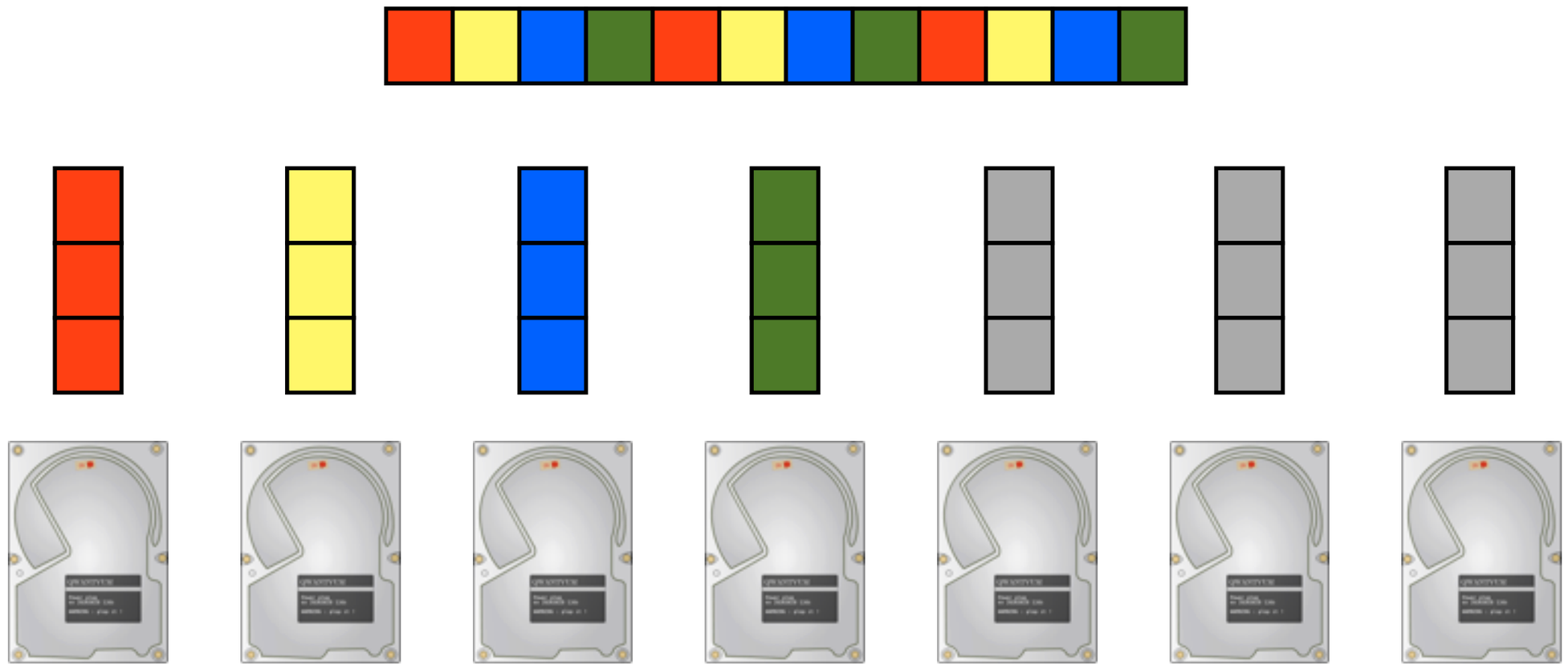

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Error Correcting Codes

- e.g. Hamming, Tornado, Reed-Solomin
- Parity Bits

- Store N data values in N+K ‘slots’
- Can lose up to K ‘slots’ of data and still reconstruct the original N data values
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Why are Raid Levels 2-4 suboptimal?

RAID

- **Level 5**: Like Level 4, but parity blocks are spread out over each disk.

More read bandwidth available

image credit: openclipart.org

Summary

- Disks provide cheap, non-volatile storage
  - Support random access, but sequential reads are faster
- DBMS vs OS filesystem
  - DBMS has a better idea of its access patterns, and can exploit this to get better filesystem performance.