Introduction to DBMS Internals

DBMS Architecture

Data storage

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Reading: R & G Chapter 9

Course Overview

- Unit 1: Relational model and SQL
- Unit 2: Storage and indexing
- Unit 3: Query execution
- Unit 4: Query optimization
- Unit 5: Transactions
- Unit 6: Recovery
- Unit 7: Conceptual design
- Unit 8: Advanced topics (time permitting)

DBMS Architecture

Architecture of a DBMS: SQL Client

- How is a SQL query executed?

DBMS: Parsing & Optimization

Purpose:

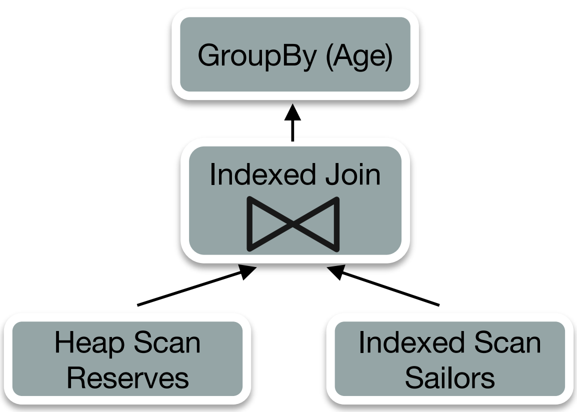
Parse, check, and verify the SQL

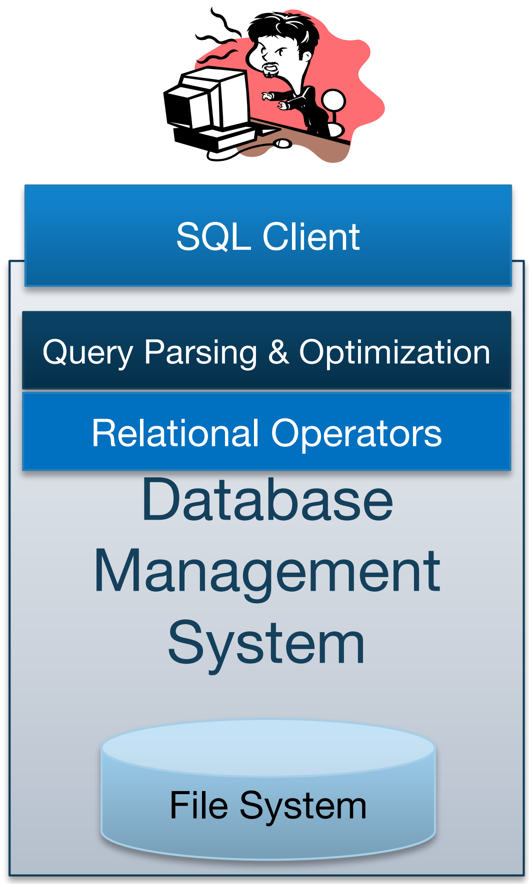
```
SELECT S.sid, S.sname, R.bid
FROM Sailors R, Reserves R
WHERE S.sid = R.sid and S.age > 30
GROUP BY age
```

And translate into an efficient relational query plan

DBMS: Relational Operators

Purpose: Execute query plan by operating on **records** and **files**

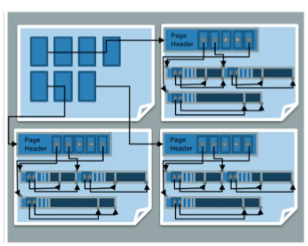


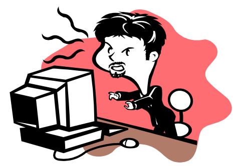


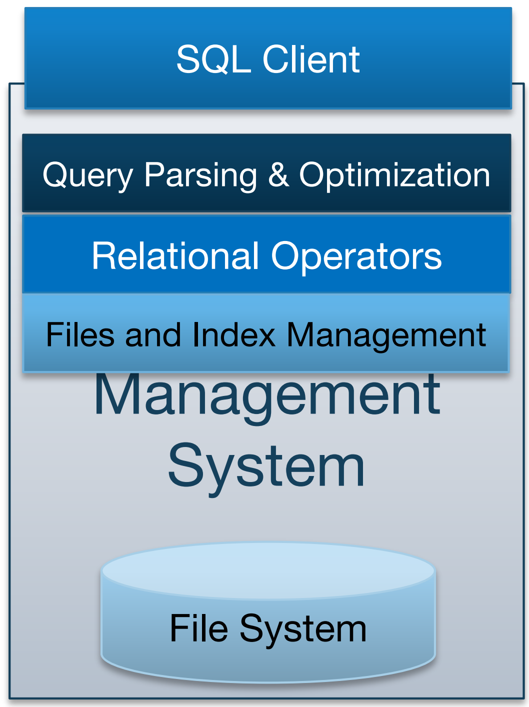
DBMS: Files and Index Management

Purpose: Organize tables and Records as groups of pages in a logical file

SSN	Last Name	First Name	Age	Salary
123	Adams	Elmo	31	$400
443	Grouc h	Oscar	32	$300
244	Oz	Bert	55	$140
134	Sande rs	Ernie	55	$400



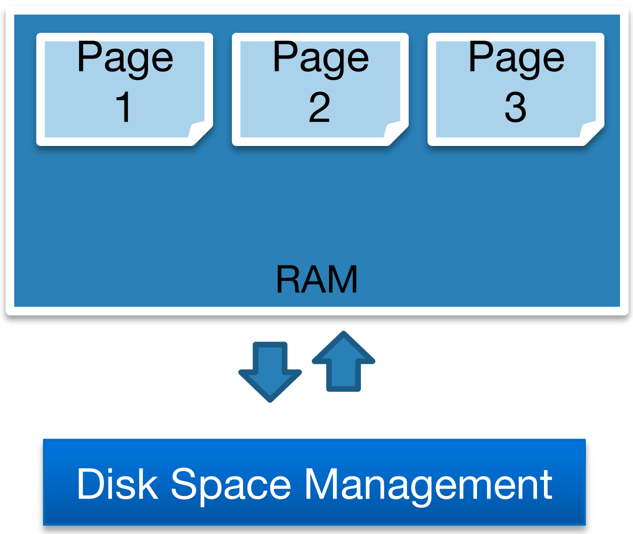


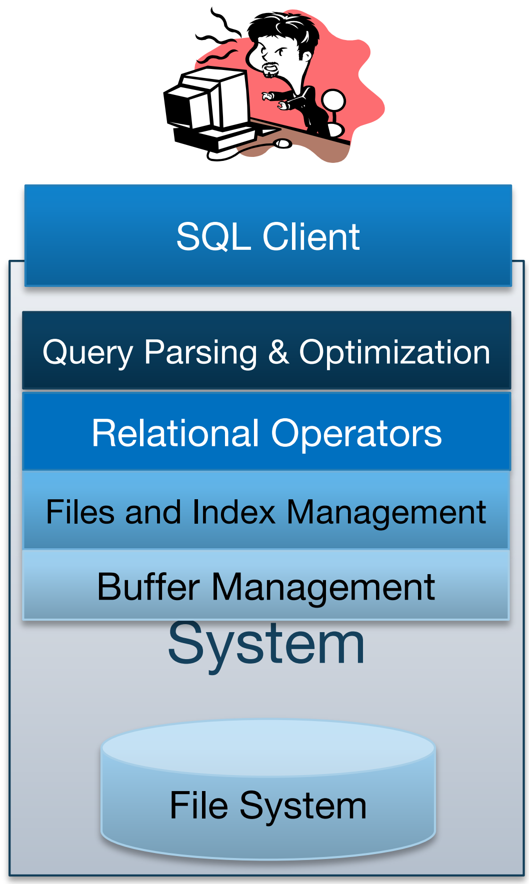


DBMS: Buffer Management

Purpose:

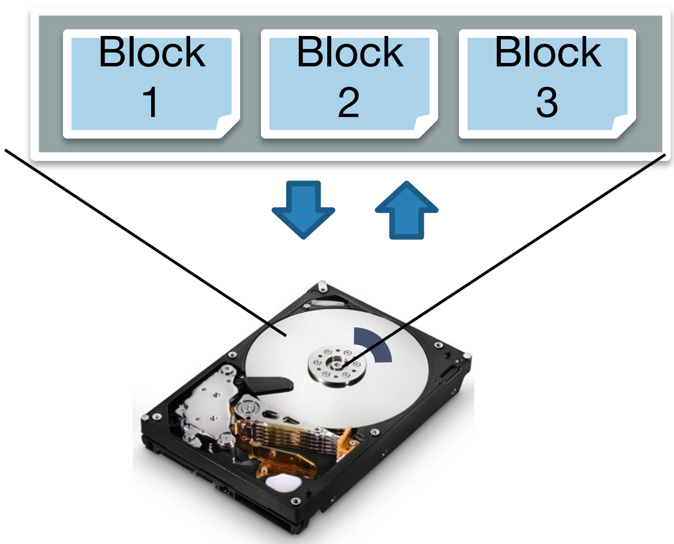
Provide the illusion of operating in memory

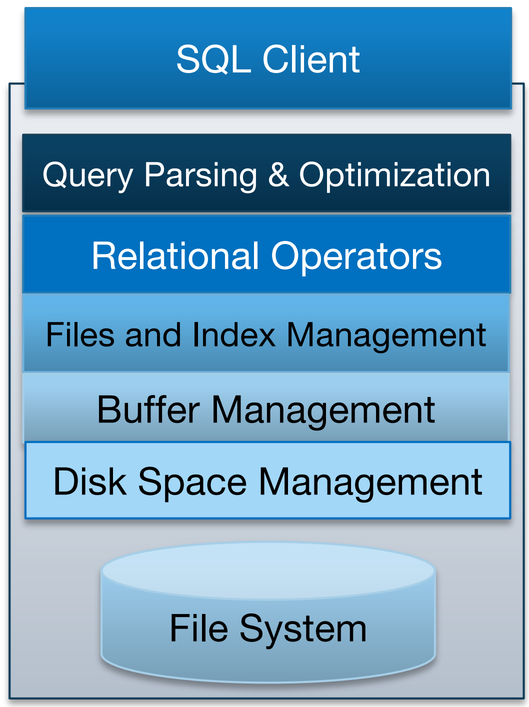




DBMS: Disk Space Management

Purpose: Translate page requests into physical bytes on one or more device(s)

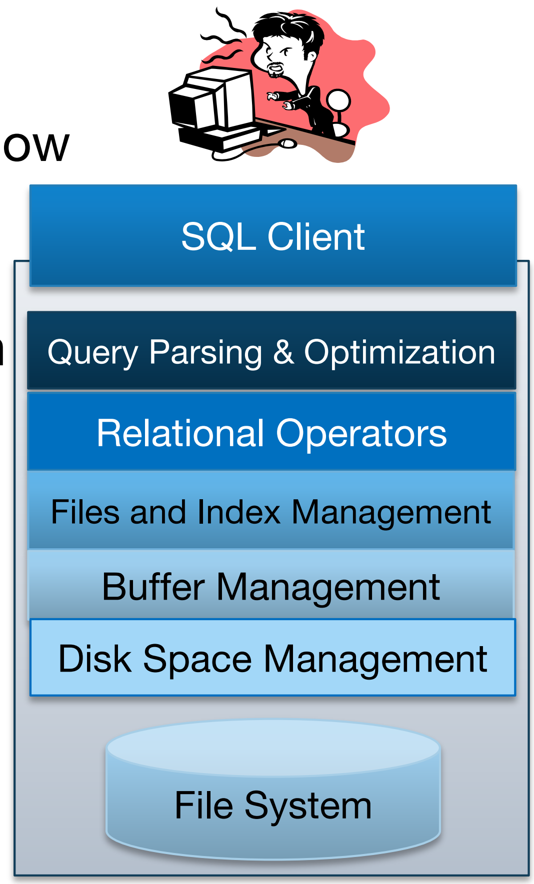




Architecture of a DBMS

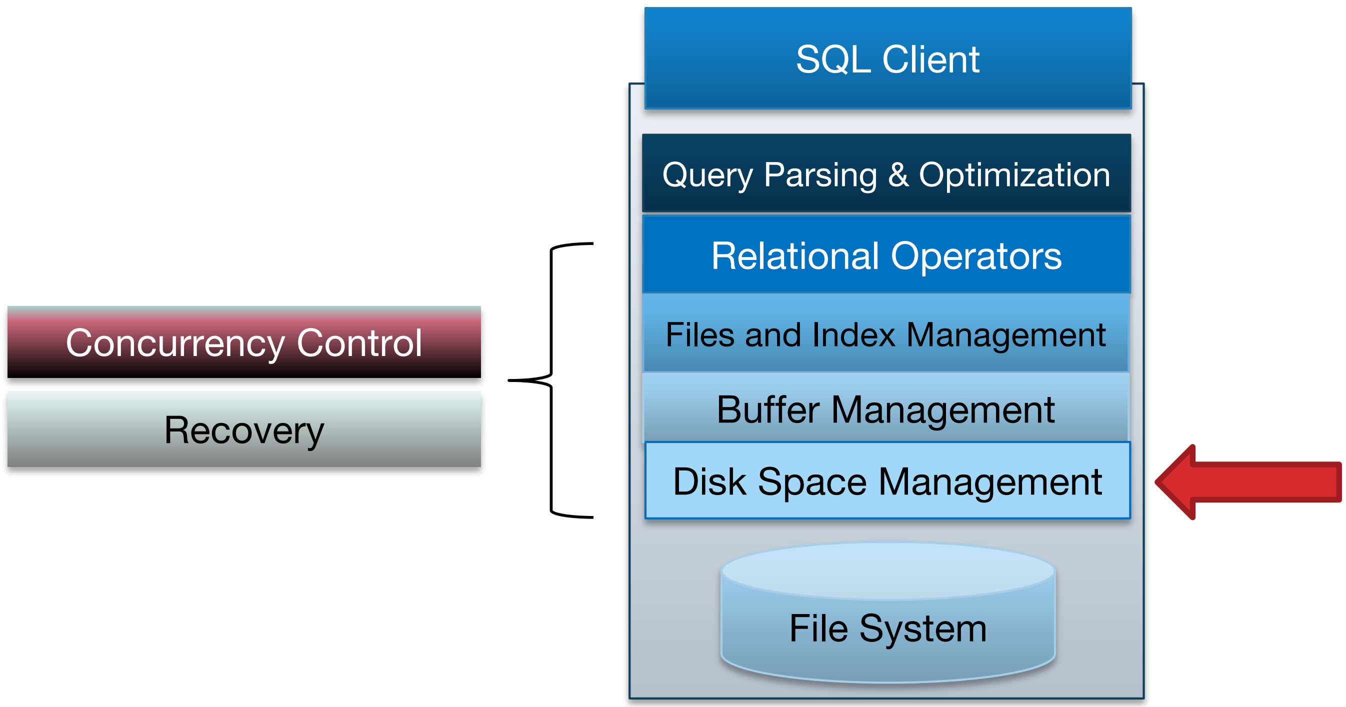
- Organized in layers
- Each layer abstracts the layer below
  - Manage complexity
  - Performance assumptions
- Example of good systems design

- Many non-relational DBMSs are structured similarly



DBMS: Concurrency & Recovery

Two cross-cutting issues related to storage and memory management:



STORAGE MEDIA

Disks

- Most database systems were originally designed for magnetic “spinning” disks
  - Disk are a mechanical anachronism!
  - Instilled design ideas that apply to using solid state disks as well

- Major implications:
  - Disk API:
    - READ: transfer “page” of data from disk to RAM.
    - WRITE: transfer “page” of data from RAM to disk.
    - No random reads / writes!!
  - Both API calls are very**, very slow!**
    - Plan carefully!

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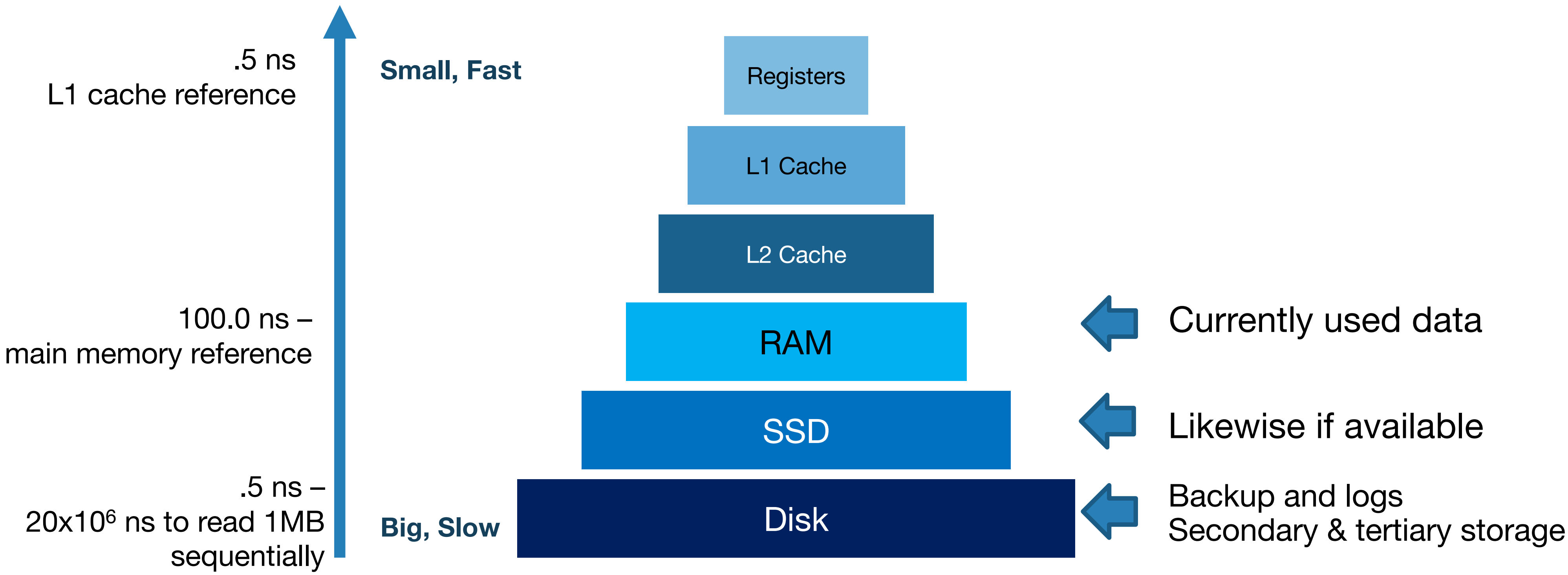
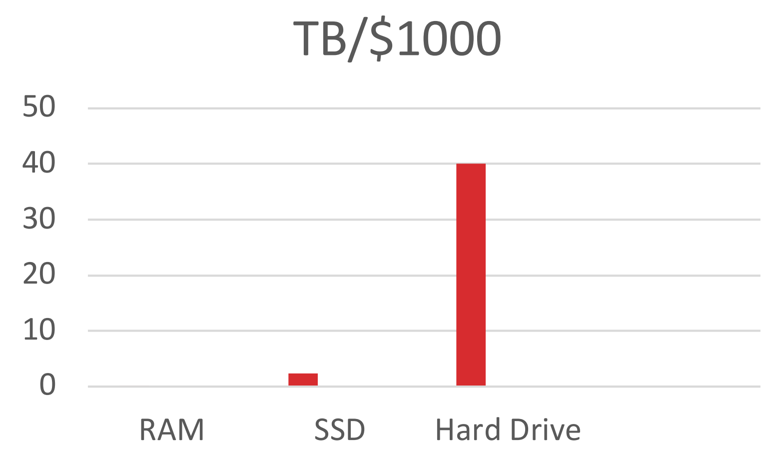
Storage Hierarchy



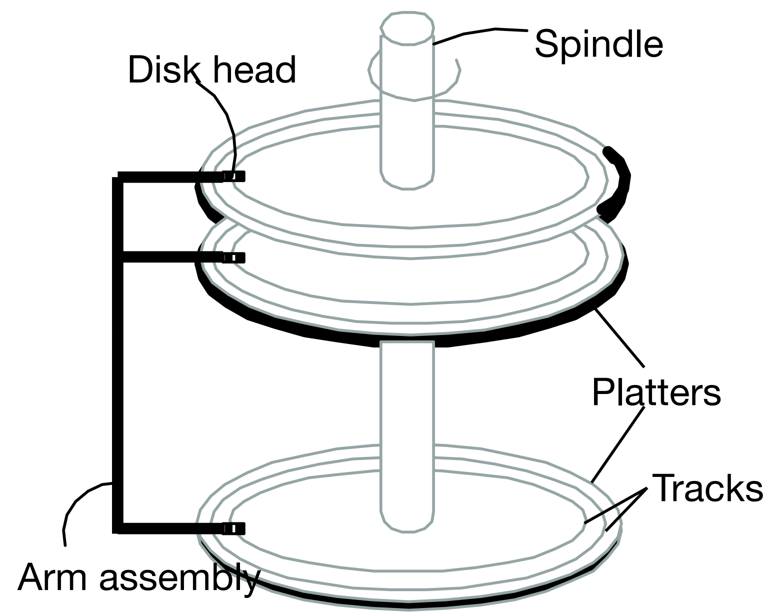
Economics

- $1000 at NewEgg 2018:
  - Mag Disk: ~40TB for $1000
  - SSD: ~2.3TB for $1000
  - RAM: 80GB for $1000



Components of a Disk

- **Platters** spin (say 15000 rpm)
- **Arm assembly** moved in or out to position a **head** on a desired **track**
  - Tracks under heads make a “cylinder”



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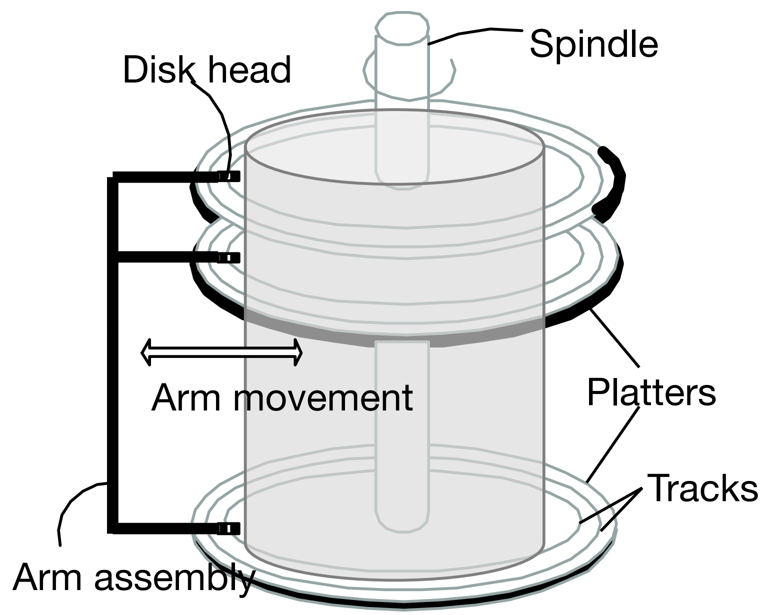

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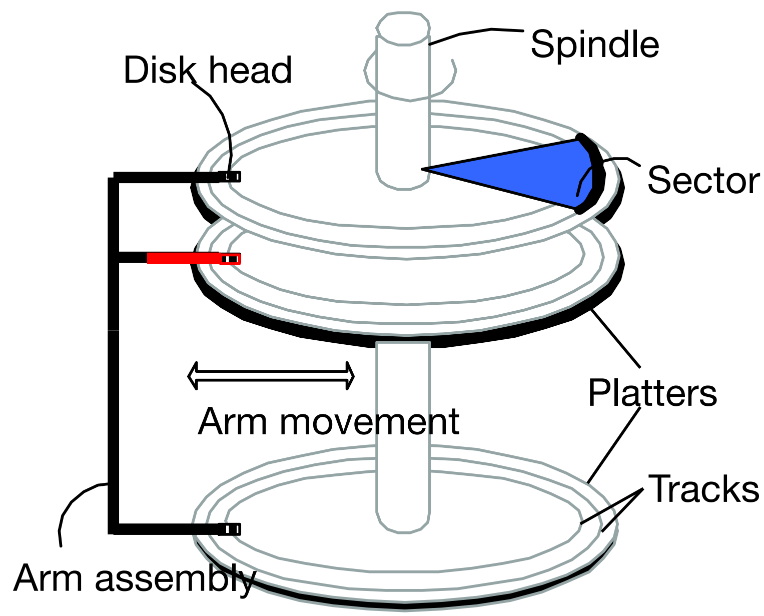


- Only one head reads/writes at any one time
- Block/page size is a multiple of (fixed) **sector** size

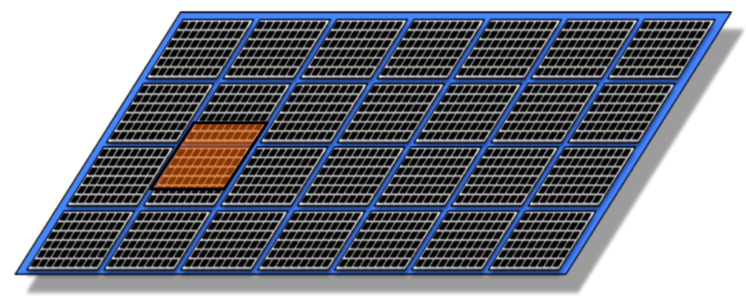
An Analogy

Accessing a Disk page

- Time to access (read/write) a disk block:
  - **seek time** (moving arms to position disk head on track)
    - ~2-3 ms on average
  - **rotational delay** (waiting for block to rotate under head)
    - ~0-4 ms (15000 RPM)
  - **transfer time** (actually moving data to/from disk surface)
    - ~0.25 ms per 64KB page
- Key to lower I/O cost: reduce seek/rotational delays

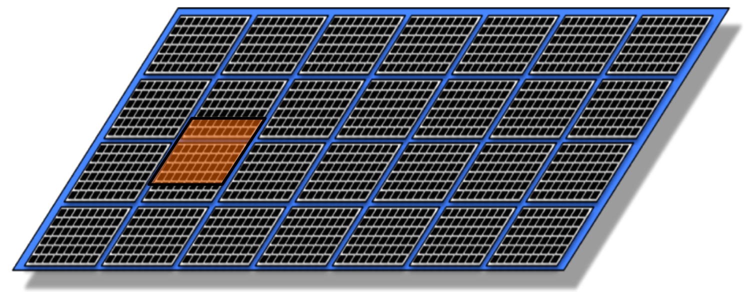
Flash (SSD)

- Organized into “cells”
- Current generation (NAND)
  - Random reads and writes, but:
  - Fine-grain reads (4-8K reads), coarse-grain writes (1-2MB writes)



Flash (SSD), Pt. 2

- So… read is fast and predictable
  - 4KB random reads: ~500MB/sec
- But write is not!
  - 4KB random writes: ~120 MB/sec
  - Why? Only 2k-3k erasures before failure
    - so keep moving write units around ("wear leveling")



DISK SPACE MANAGEMENT

Block Level Storage

- Read and Write **large chunks of sequential bytes**
- *Sequentially*: “Next” disk block is fastest
- Maximize usage of data per Read/Write
  - “Amortize” seek delays (HDDs) and writes (SSDs): *if you’re going all the way to Pluto, pack the spaceship full!*
- Predict future behavior
  - Cache popular blocks
  - Pre-fetch likely-to-be-accessed blocks
  - Buffer writes to sequential blocks
  - More on these as we go

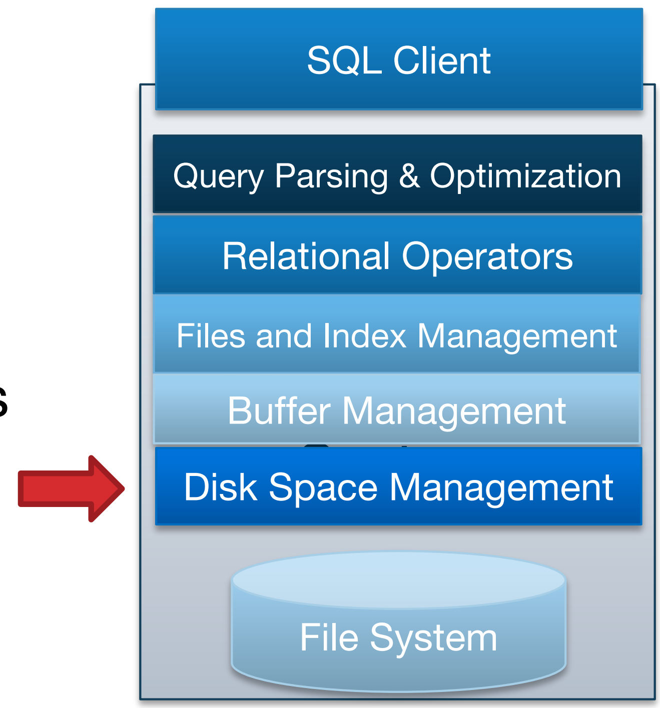
A Note on Terminology

- Block = Unit of transfer for disk read/write
  - 64KB – 128KB is a good number today
  - Book says 4KB
  - We'll use this unit for all storage devices
- Page: a common synonym for "block"
  - In some texts, "page" = a block-sized chunk of RAM

- We'll treat "block" and "page" as synonyms

Disk Space Management

- Lowest layer of DBMS, manages space on disk
- Purpose:
  - Map pages to locations on disk
  - Load pages from disk to memory
  - Save pages back to disk & ensuring writes
- Higher levels call upon this layer to:
  - Read/write a page
  - Allocate/de-allocate logical pages



Disk Space Management: Requesting Pages

- ```
  page = getFirstPage(“Sailors”);
  while (!done) {
    process(page);
    page = page.nextPage();
  }
  ```
- Physical details hidden from higher levels of system
- Higher levels may “safely” assume `nextPage` is fast
  - Hence sequential runs of pages are quick to scan
  ```

Disk Space Management: Implementation

- **Proposal 1:** Talk to the storage device directly
  - Could be very fast if you knew the device well
  - Hard to program when each device has its own API
  - What happens when devices change?

Disk Space Management: Implementation

- **Proposal 2**: Run our own over filesystem (FS)
  - Bypass the OS, allocate single large "contiguous" file on an empty disk
    - assume sequential/nearby byte access are fast
  - Most FS optimize disk layout for sequential access
    - Gives us more or less what we want if we start with an empty disk
  - DBMS "file" may span multiple FS files on multiple disks/machines

Disks and Files: Summary

- Magnetic (hard) disks and SSDs
  - Basic HDD and SSD mechanics
  - Concept of “near” pages and how it relates to cost of access

  - Relative cost of
    - Random vs. sequential disk access (10x)
    - Disk (Pluto) vs RAM (Sacramento) vs. registers (your head)
      - Big, big differences!

Files: Summary

- DB File storage
  - Typically over FS file(s)
- Disk space manager loads and stores pages
  - Block level reasoning
  - Abstracts device and file system; provides fast “next page”