THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

# 9. DBMS Internals

## CSCI 2541 Database Systems & Team Projects

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# Library Usage

For your project you **may** use…

- Anything in the standard python library
- Form helper libraries like Flask-WTF
- Login libraries like Flask-login
- CSS/HTML libraries like Bootstrap
- Javascript libraries like jquery

You may not use…

- Libraries which fully abstract away database operations (e.g., object relational mapping / ORM libraries)
- A framework other than Flask

If you aren't sure, ask me!

# DBMS Internals

# DBMS

A database management system provides efficient, convenient, and safe multi-user storage and access to massive amounts of persistent data.

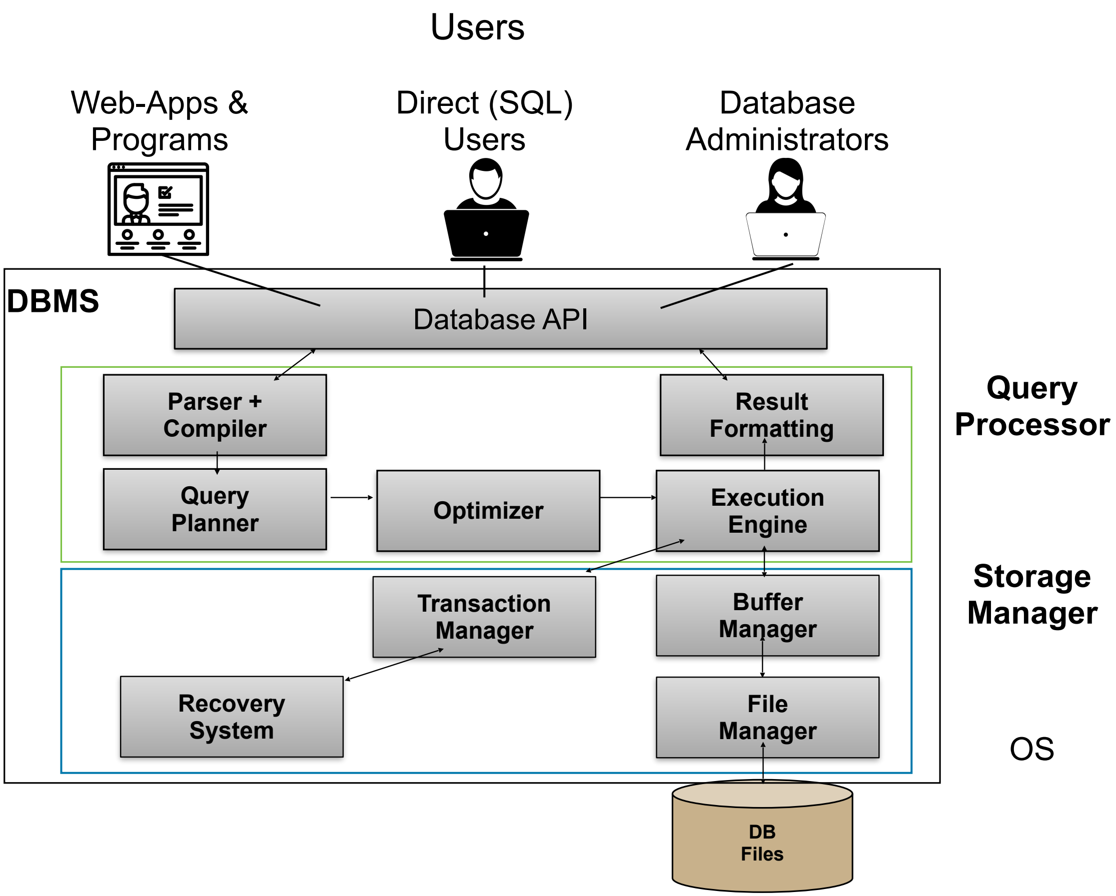
- **Efficient** - Able to handle large data sets and complex queries without searching all files and data items.
- **Convenient** - Easy to write queries to retrieve data.
- **Safe** - Protects data from system failures and hackers.
- **Massive** - Database sizes in gigabytes/terabytes/petabytes.
- **Persistent** - Data exists after program execution completes.
- **Multi-user** - More than one user can access and update data at the same time while preserving consistency…. concept of **transactions**

# Components of a DBMS

A DBMS is a complicated software system containing many components:

- **Query processor** - translates user/application queries into low-level data manipulations
  - Sub-components: query parser, query optimizer
- **Storage manager** - maintains storage information including memory allocation, buffer management, and file storage
  - Sub-components: buffer manager, file manager
- **Transaction manager** - performs scheduling of operations and implements concurrency control algorithms
  - You will learn more about storage management and concurrency in the Operating Systems course… enjoy!

# DBMS Architecture: Complete Picture




**Structure** that is **independent** of the underlying file formats

**Queries** to flexibly read, update, and delete information

**Transactions** that provide **multi-user consistency**

# Storage and Organization: Overview

A database system relies on the operating system to store data on storage devices.

Database performance depends on:

- Properties of storage devices
- How devices are used and accessed via the operating system

Quick look into techniques for storing and representing data

- These apply for SQL as well as NoSQL systems
- Key in efficient storage and retrieval systems
  - Including search engines and big data analytics

# Review (?) from architecture: Memory Definitions

What is **Temporary Memory**?

What is **Permanent Memory**?

What is **Cache Memory**?

# Review (?) from architecture: Memory Definitions

**Temporary memory** retains data only while the power is on.

- Also referred to as **volatile** storage.
- e.g. dynamic random-access memory (DRAM) (main memory)

**Permanent memory** stores data even after the power is off.

- Also referred to as non-volatile storage or secondary storage
- e.g. flash memory, SSD, hard drive, DVD, tape drives

**Cache** is faster memory used to store a subset of a larger, slower memory for performance.

- processor cache (Level 1 & 2), disk cache, network cache

# Physical Storage: Memory Hierarchy

Primary Storage: cache & main memory

- Can be directly accessed by CPU
- Currently used data

Secondary Storage: flash, SSD, magnetic disks, optical disks, tapes

- Larger capacity, low cost, slow access
- Cannot be directly processed by CPU

DB stores large amount, persist over time

- Data is stored in secondary storage
- Contrast with run-time data structures

**Time taken to fetch data depends on how data is organized on disk/file**

# DBMS storage

Why not store everything in Main Memory (DRAM)?

# DBMS storage

**Why not store everything in Main Memory (DRAM)?**

Costs too much.

Main memory is volatile.

- We want data to be saved between runs. (Obviously!)
- Situations that cause permanent loss of data occur less frequently in disks than primary memory
- Disk/Flash storage is non-volatile

# Magnetic Hard Disks

Secondary storage device of choice for BIG data.

Main advantage over tapes: *random access* vs. *sequential*.

Data is stored and retrieved in units called *disk blocks* or *pages*.

Unlike RAM, time to retrieve a disk page varies depending upon location on disk.

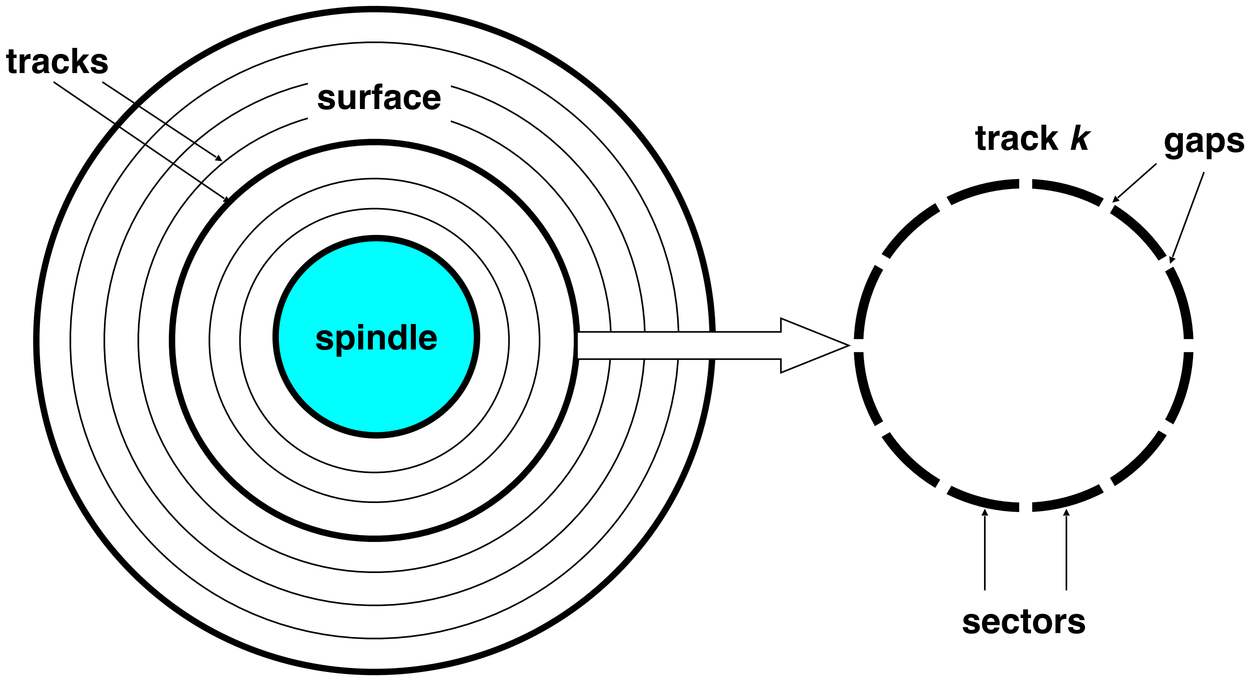
- Therefore, relative placement of pages on disk has major impact on DBMS performance!

# Disk Geometry

Disks consist of **platters**, each with two **surfaces**.

Each **surface** consists of concentric rings called **tracks**.

Each **track** consists of **sectors** separated by **gaps**.



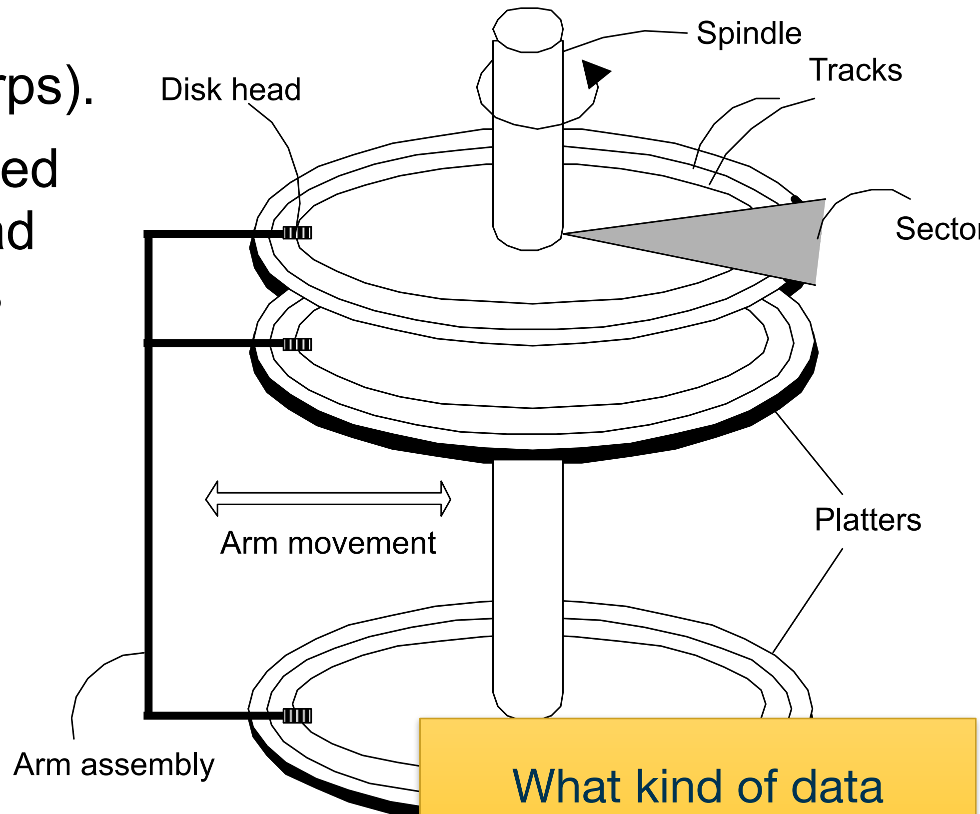
# Components of a Disk

The platters spin (say, 90rps).

The arm assembly is moved in or out to position a head on a desired track. Tracks under heads make a *cylinder*

Only **one** head reads/writes at any one time.

*Block size* is a multiple of *sector size* (which is fixed).

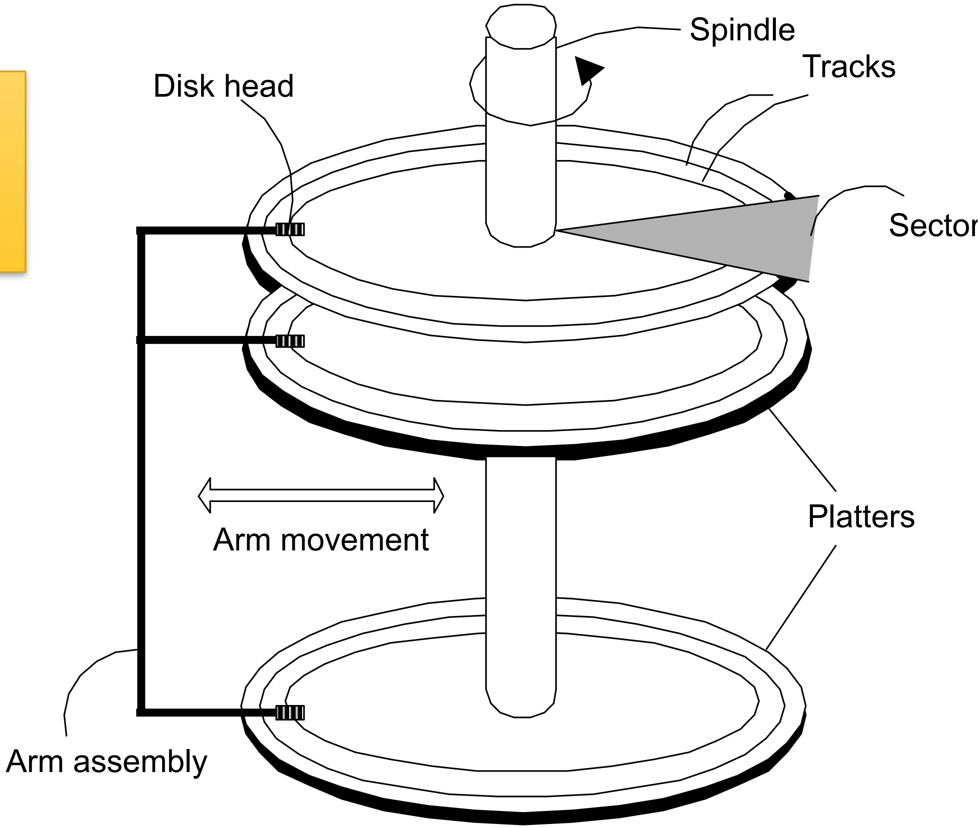



What kind of data accesses will be fastest?

# Accessing a Disk Page

Time to access (read/write) a disk block:

What physically must happen to read?



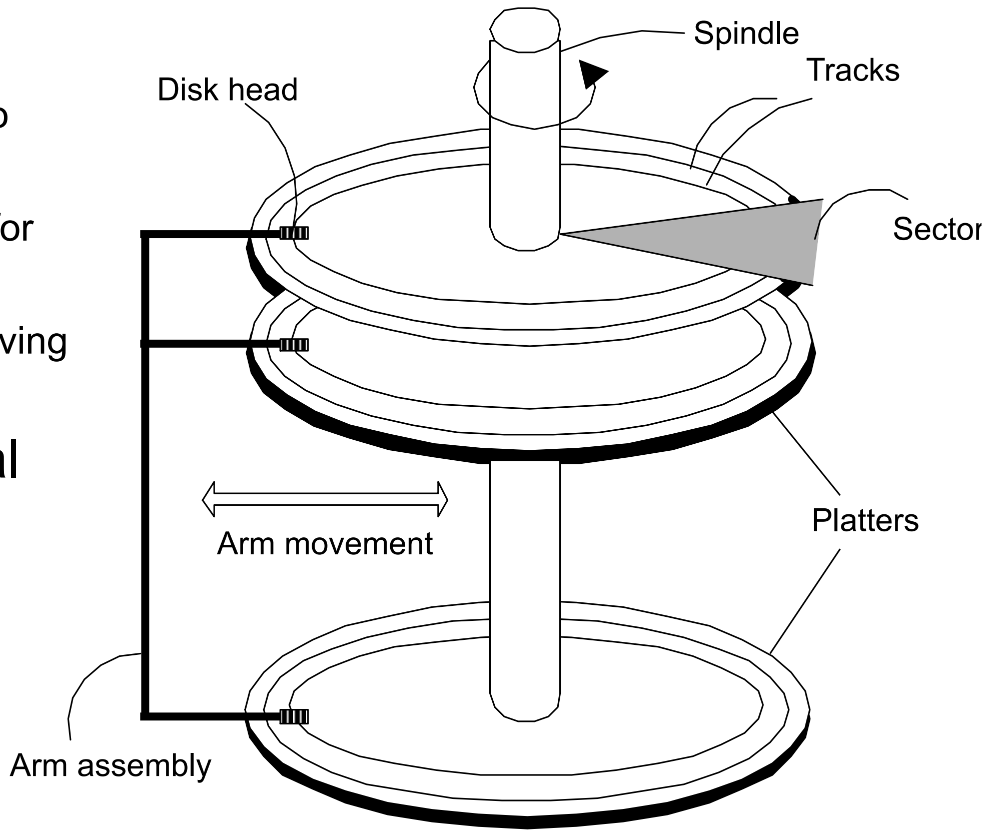
# Accessing a Disk Page

Time to access (read/ write) a disk block:

- *seek time* (moving arms to position disk head on track)
- *rotational delay* (waiting for block to rotate under head)
- *transfer time* (actually moving data to/from disk surface)

Seek time and rotational delay dominate.

Key to lower I/O cost: reduce seek/rotation delays!



# Disk Access Times

Average time to access a target sector approximated by :

$$T_{access} = T_{avg}\ \text{seek} + T_{avg}\ \text{rotation} + T_{avg}\ \text{transfer}$$

**Seek time** (Tavg seek)

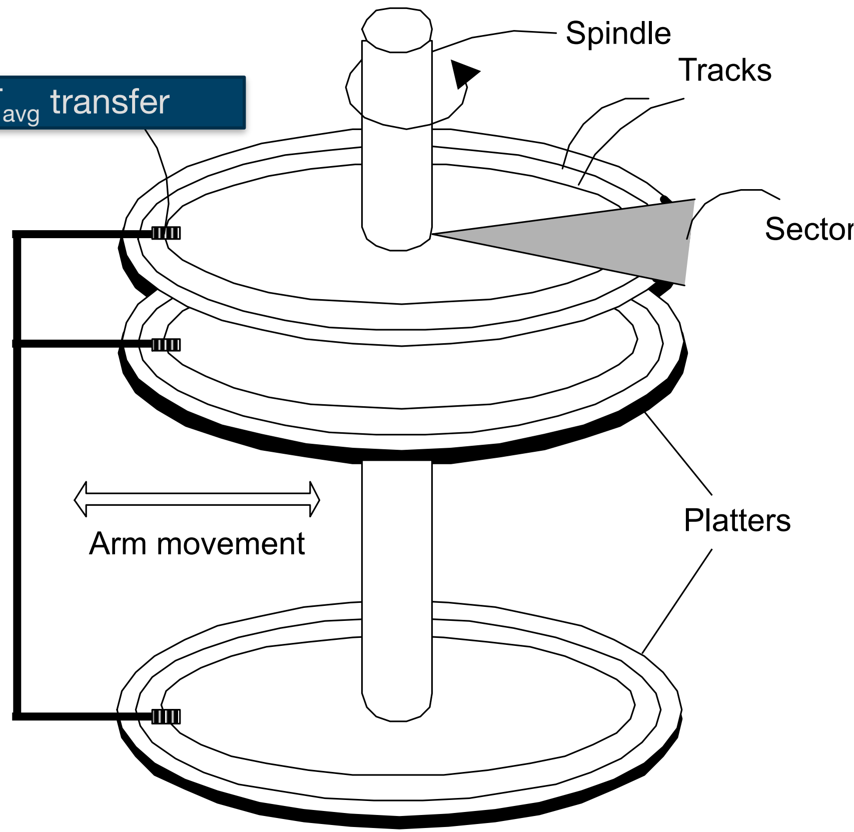
- Time to position heads over cylinder containing target sector.
- Typical Tavg seek = 9 ms

**Rotational latency** (Tavg rotation)

- Time waiting for first bit of target sector to pass under r/w head.
- Tavg rotation = 1/2 x 1/RPMs x 60 sec/ 1 min = 6 ms

**Transfer time** (Tavg transfer)

- Time to read the bits in the target sector.
- Tavg transfer = 1/RPM x 1/(avg # sectors/track) x 60 secs/1 min. = ~200 MB/sec



# Accessing Data

```
SELECT * FROM EMP;
```

Need to scan entire file

- Read all records

Access all blocks/pages of the file on the disk

- Assume N pages

$$T_{access} = T_{avg} \text{ seek} + T_{avg} \text{ rotation} + T_{avg} \text{ transfer}$$

How long does this take ?

# Accessing Data

```
SELECT * FROM EMP;
```

Need to scan entire file

- Read all records

Access all blocks/pages of the file on the disk

- Assume N pages

How long does this take ?

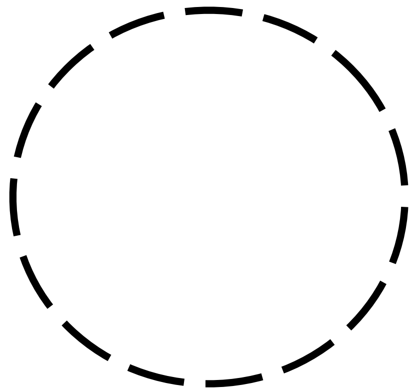
How could we make this more efficient?

Simple approach: N* Taccess

- Taccess = Tavg seek + Tavg rotation + Tavg transfer
- **May need to seek and rotate for every block!**

# Impact of Disk Layout

If we can keep the data from a DB in a contiguous region on disk we can eliminate seeks and rotation!



First Block: = Taccess = $T_{avg}$ seek + $T_{avg}$ rotation + $T_{avg}$ transfer

Second Block = $T_{avg}$ transfer

Third block = $T_{avg}$ transfer

…

# But…

Unfortunately we don't usually have very much control over exactly where data is located on disk

- When you call write you don't need to specify what platter and track! That would be a pain

Often DBMS just reserve large files to store tables in

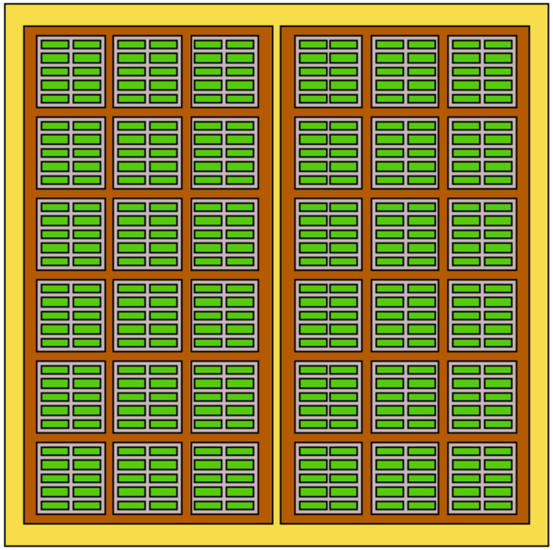
- Assume that the OS File System will lay out those files in contiguous regions
- For really high performance environments, can co-design file system and DBMS!

# New(-ish) Technology: SSDs

Solid State Drives (SSDs) use different technology to store data - flash memory instead of spinning disks

- Data stored in grid of blocks
- Can access blocks directly (no moving parts)
- Similar interface to HDDs: block-level access
- Higher cost and lower capacity
    - HDD: 8TB for $150
    - SDD: 1TB for $250

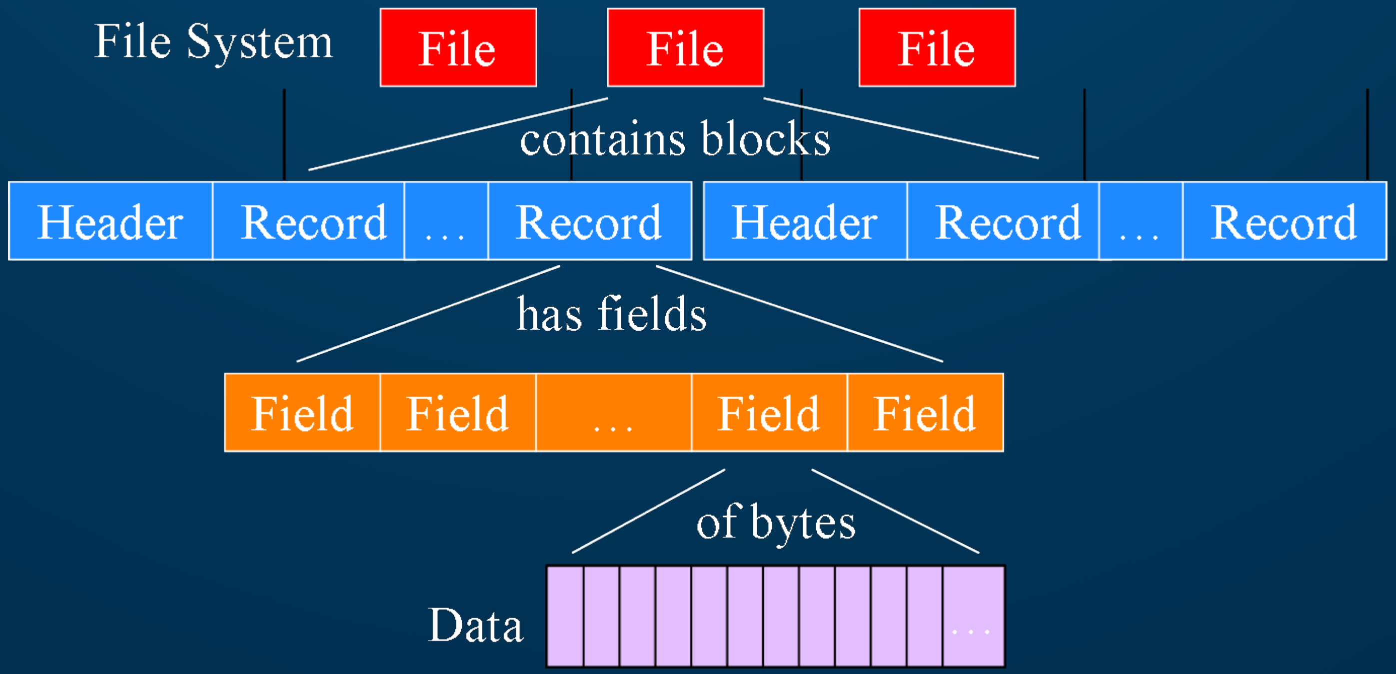
How will this affect DBMS performance?



# Representing Data in Databases

A **database** is made up of one or more files.

- Each **file** contains one or more blocks.
- Each **block** has a header and contains one or more records.
- Each **record** contains one or more fields.
- Each **field** is a representation of a data item in a record.




File = Relation; Record = row/tuple; Field = column/attribute

# Organization of Records

Record is collection of related information

- Each tuple/row is a record
- each value is one or more bytes, corresponds to a particular field of record
- each field specifies some attribute
- collection of field definitions and their types constitutes record type or format
  - data type associated with each field
- blocks are fixed size, but record sizes vary

Two main types of records:

- Variable length: size of record varies
- Fixed length: all records have fixed length

# Fixed Length Records

| **<u>Customer ID</u>** | **First Name** | **Surname** | **Birthday** | **Age** | **Fav Color** |
|---|---|---|---|---|---|
| 123 | Pooja | Singh | 1/4/1984 | 37 | Blue |
| 456 | San | Zhang | 3/15/2001 | 19 | Blue |
| 789 | John | Zhang | 11/12/2006 | 14 | Buff |

How should we store a fixed length record?

# Fixed Length Records

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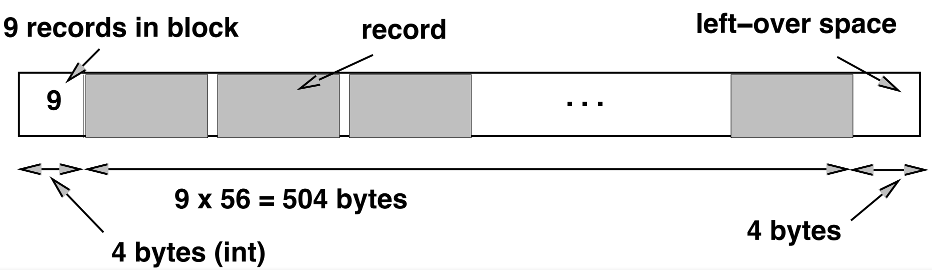
Need a fixed size for each field/attribute

Store the offset from start of record to each field

- Will be the same for all records in a table



# Variable Length Records

| <u>**Customer ID**</u> | **First Name** | **Surname** | **Birthday** | **Age** | **Fav Quote** |
|---|---|---|---|---|---|
| 123 | Pooja | Singh | 1/4/1984 | 37 | Carpe Diem |
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# Variable Length Records

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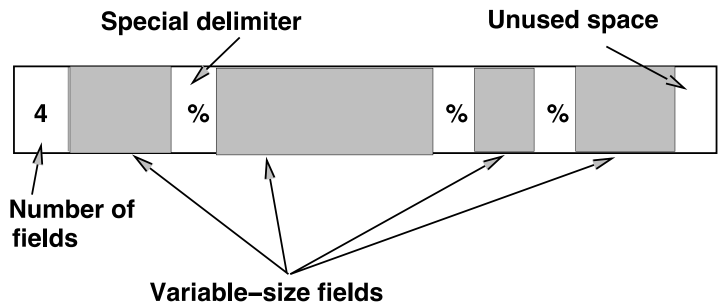
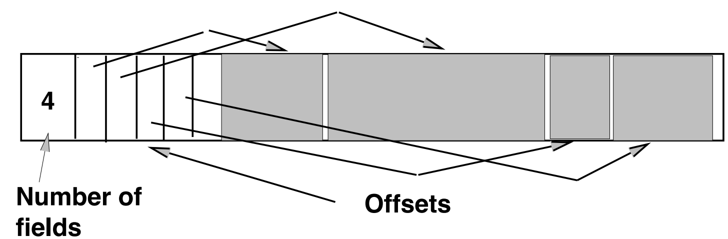
1) Use a delimiter between each field




2) Store an offset to each field within a record



# Record Types

**Fixed length** vs **Variable length** records

- fixed is easier to implement
- fixed wastes space when block size not multiple of record size

**Spanned** vs **Unspanned**

- when parts of a record can be placed onto a block, need pointers to next block where remainder of record is placed

# Record Layout

How should we store records in a file?

| Customer ID | First Name | Surname | Birthday | Age | Fav Quote |
|---|---|---|---|---|---|
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| … | … | … | … | … | … |

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| … | … | … | … | … | … |

Heap File: dump all records together in a heap, keep adding new records to the end of the file

- Fast insertion!
- Slow lookups!

Sorted File: carefully store all records in sorted order

- Slow insertion!
- Fast lookups!

# DBMS Operations

Queries will require operations on disk

- **Insert** a record
- **Delete** a record
- **Modify** a record
- **Scan** all records
- **Search** for records that satisfy a condition
  - Range Search
  - Equality Search
- **Reorganize** to clean up deleted records
  - Garbage collection

# Heap Files

Record are unordered

Insertion?

Deletion?

Search?

# Sorted Files

Sort records based on a particular field (primary key?)

Insertion?

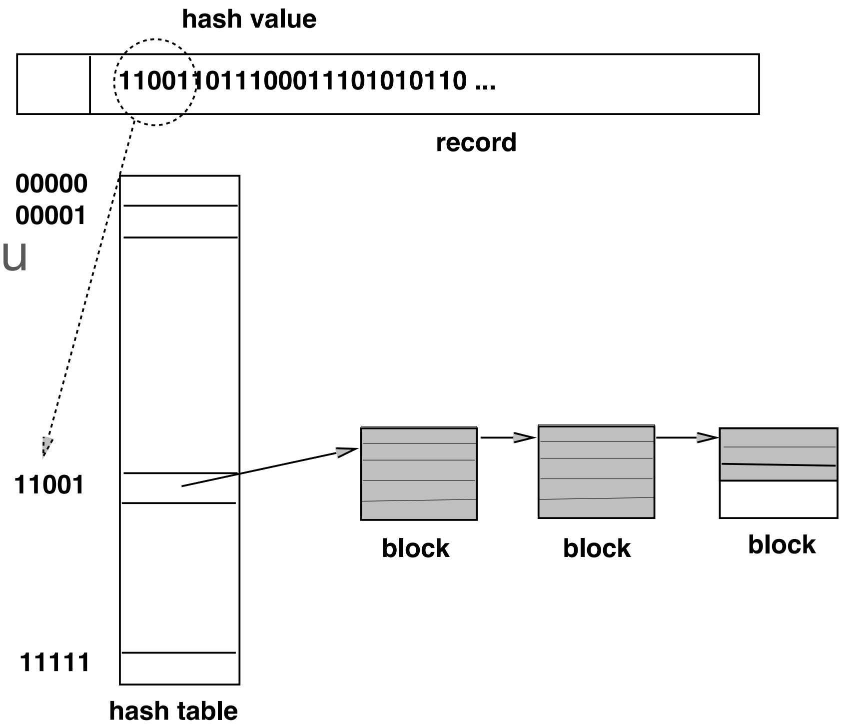
Deletion?

Search?

# Hashed Files

Distribute records among buckets based on a hash key

- Use hash key to find a bucket of similar records
- Keep adding blocks as you get more records in that bucket




What kind of search can this help with?

- Range search?
- Equality search?