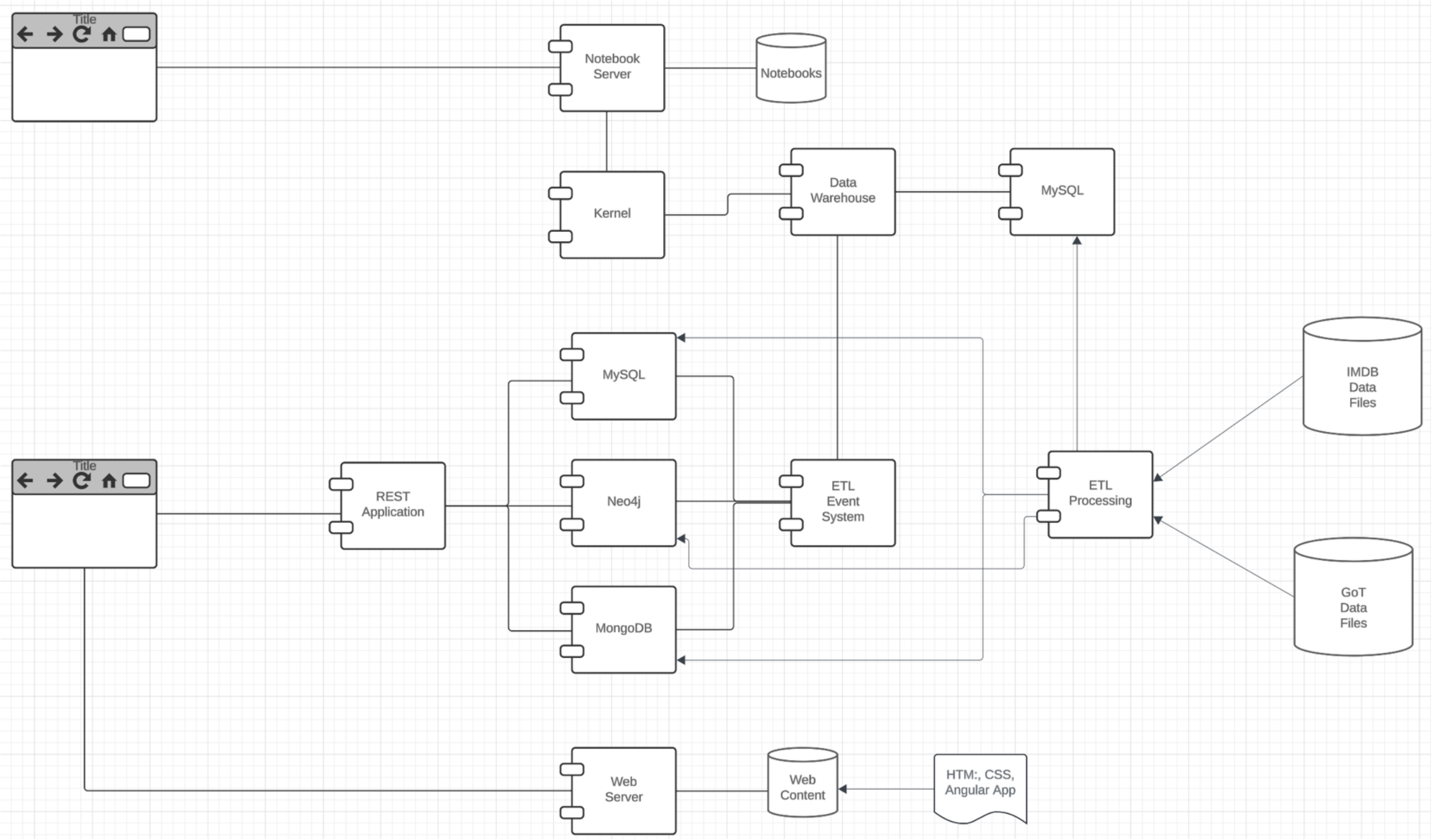
W4111 – Introduction to Databases
Module II (1), NoSQL (1)

COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

Update on Project

Vision



Title
Notebook Server
Notebooks
Kernel
Data Warehouse
MySQL
MySQL
IMDB Data Files
Title
REST Application
Neo4j
ETL Event System
ETL Processing
GoT Data Files
MongoDB
Web Server
Web Content
HTM:, CSS, Angular App

Module II Kickoff

Course Modules – Reminder

Course Overview

Each section of W4111 is slightly different based on student interest and professor's focus. There is a common, core syllabus. Professors cover topics in different orders and grouping based on teaching style.

This section of W4111 has four modules:

- **Foundational concepts (50% of semester):** This module covers concepts like data models, relational model, relational databases and applications, schema, normalization, ... The module focuses on the relational model and relational databases. The concepts are critical and foundational for all types of databases and data centric applications.
- **Database management system architecture and implementation (10%):** This module covers the software architecture, algorithms and implementation techniques that allow databases management systems to deliver functions. Topics include memory hierarchy, storage systems, caching/buffer pools, indexes, query processing, query optimization, transaction processing, isolation and concurrency control.
- **NoSQL – "Not Only SQL" databases (20%):** This module provides motivation for "NoSQL" data models and databases, and covers examples and use cases. The module also includes cloud databases and databases-as-a-service.
- **Data Enabled Decision Support (20%):** This module covers data warehouses, data import and cleanse, OLAP, Pivot Tables, Star Schema, reporting and visualization, and provides and overview of analysis techniques, e.g. clustering, classification, analysis, mining.

Module II – DBMS Architecture and Implementation Overview and Reminder

What is a database? In essence a database is nothing more than a collection of information that exists over a long period of time, often many years. In common parlance, the term *database* refers to a collection of data that is managed by a DBMS. The DBMS is expected to:

1. Allow users to create new databases and specify their *schemas* (logical structure of the data), using a specialized *data-definition language*.

Covered for the relational model.

Database Systems: The Complete Book (2nd Edition)
by Hector Garcia-Molina (Author), Jeffrey D. Ullman (Author), Jennifer Widom (Author)

Module II – DBMS Architecture and

2. Give users the ability to *query* the data (a "query" is database lingo for a question about the data) and modify the data, using an appropriate language, often called a *query language* or *data-manipulation language*.

3. Support the storage of very large amounts of data — many terabytes or more — over a long period of time, allowing efficient access to the data for queries and database modifications.

4. Enable *durability*, the recovery of the database in the face of failures, errors of many kinds, or intentional misuse.

5. Control access to data from many users at once, without allowing unexpected interactions among users (called *isolation*) and without actions on the data to be performed partially but not completely (called *atomicity*).

Database Systems: The Complete Book (2nd Edition)
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Purpose of Database Systems

In the early days, database applications were built directly on top of file systems, which leads to:

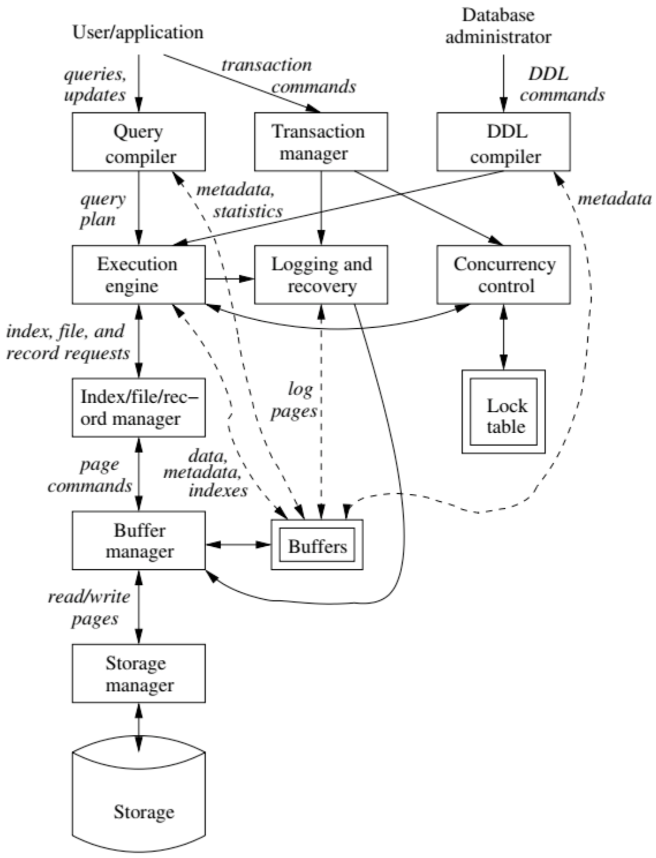
- Data redundancy and inconsistency: data is stored in multiple file formats resulting induplication of information in different files
- Difficulty in accessing data
  - Need to write a new program to carry out each new task
- Data isolation
  - Multiple files and formats
- Integrity problems
  - Integrity constraints (e.g., account balance > 0) become “buried” in program code rather than being stated explicitly
  - Hard to add new constraints or change existing ones

Purpose of Database Systems (Cont.)

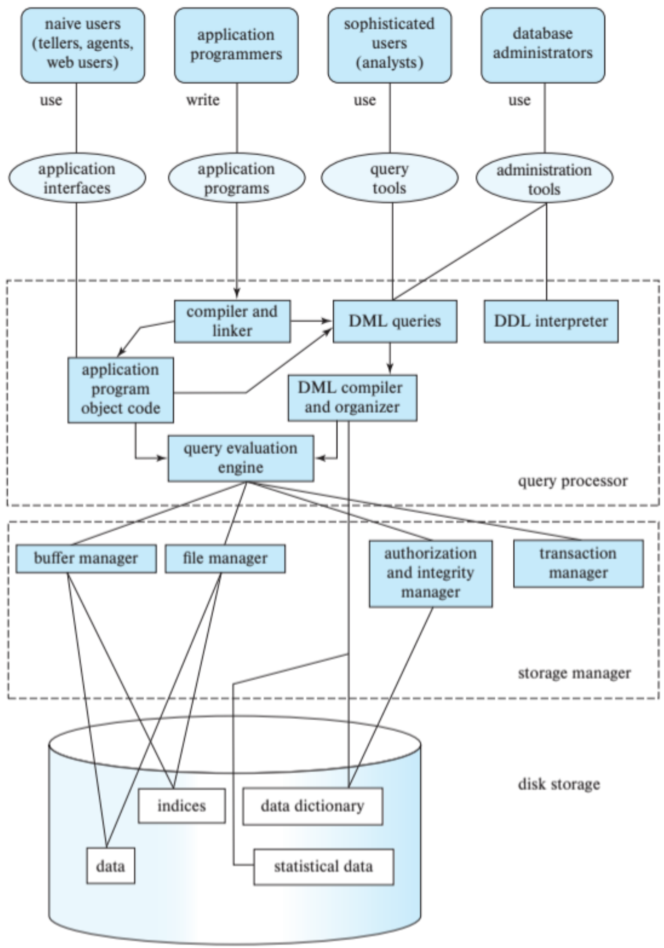
- Atomicity of updates
  - Failures may leave database in an inconsistent state with partial updates carried out
  - Example: Transfer of funds from one account to another should either complete or not happen at all
- Concurrent access by multiple users
  - Concurrent access needed for performance
  - Uncontrolled concurrent accesses can lead to inconsistencies
    - Ex: Two people reading a balance (say 100) and updating it by withdrawing money (say 50 each) at the same time
- Security problems
  - Hard to provide user access to some, but not all, data

Database systems offer solutions to all the above problems

DBMS Arch.

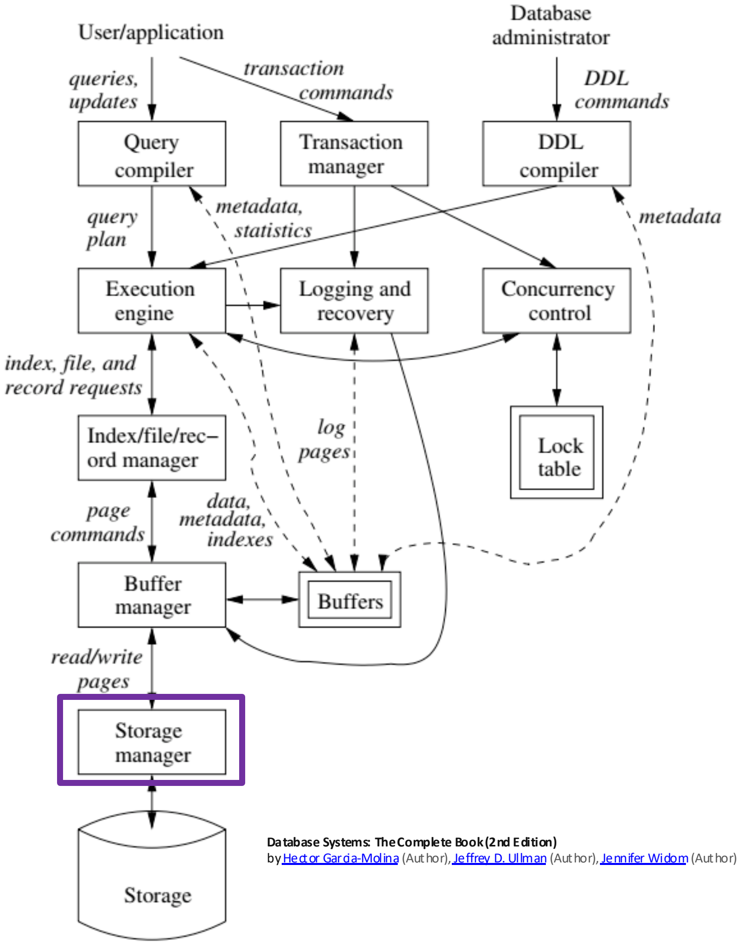


User/application
Database administrator
queries, updates
transaction commands
DDL commands
Query compiler
Transaction manager
DDL compiler
query plan
metadata, statistics
metadata
Execution engine
Logging and recovery
Concurrency control
index, file, and record requests
Index/file/record manager
log pages
Lock table
page commands
data, metadata, indexes
Buffer manager
Buffers
read/write pages
Storage manager
Storage



naive users (tellers, agents, web users)
application programmers
sophisticated users (analysts)
database administrators
use
write
use
use
application interfaces
application programs
query tools
administration tools
compiler and linker
DML queries
DDL interpreter
application program object code
DML compiler and organizer
query evaluation engine
query processor
buffer manager
file manager
authorization and integrity manager
transaction manager
storage manager
indices
data dictionary
data
statistical data
disk storage

Data Management



Today

- Load/save things quickly.

Database Systems: The Complete Book (2nd Edition)
by Hector Garcia-Molina (Author), Jeffrey D. Ullman (Author), Jennifer Widom (Author)

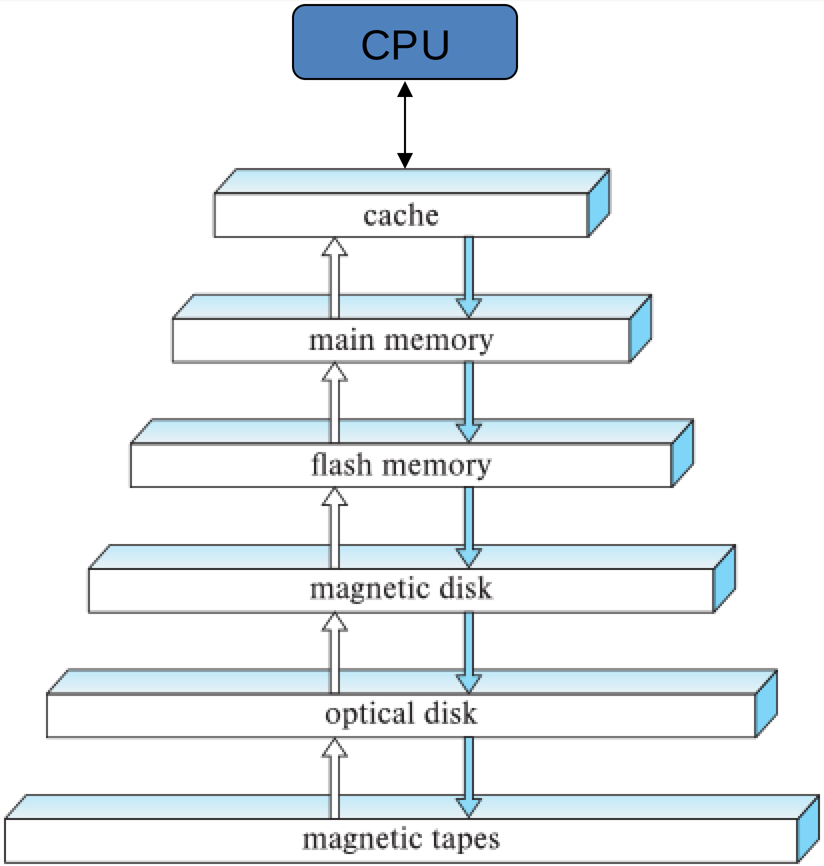
Disks
Input/Output (IO)

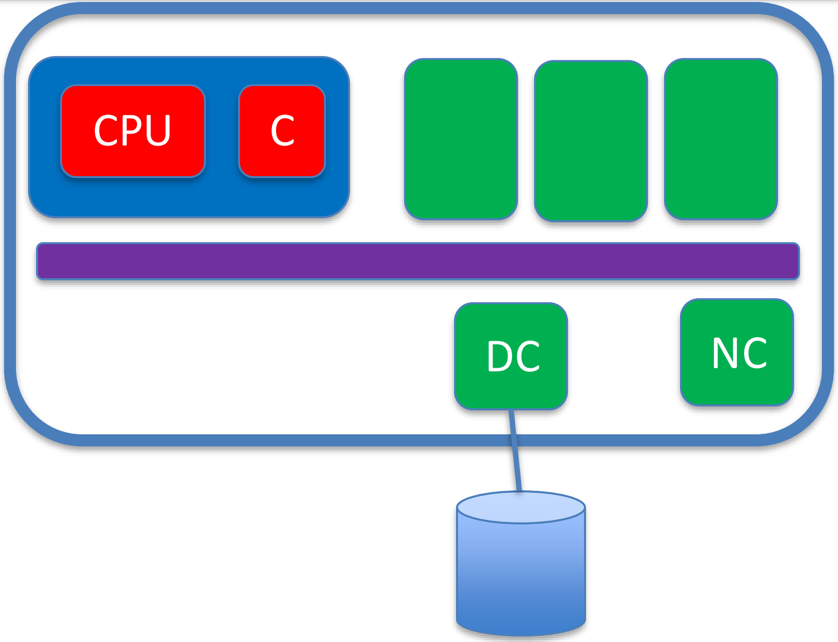
Disks as Far as the Eye can See

Classification of Physical Storage Media

- Can differentiate storage into:
  - **volatile storage:** loses contents when power is switched off
  - **non-volatile storage**:
    - Contents persist even when power is switched off.
    - Includes secondary and tertiary storage, as well as batter-backed up main-memory.
- Factors affecting choice of storage media include
  - Speed with which data can be accessed
  - Cost per unit of data
  - Reliability

Storage Hierarchy





From: Database System Concepts, 7th Ed.

Memory Hierarchy

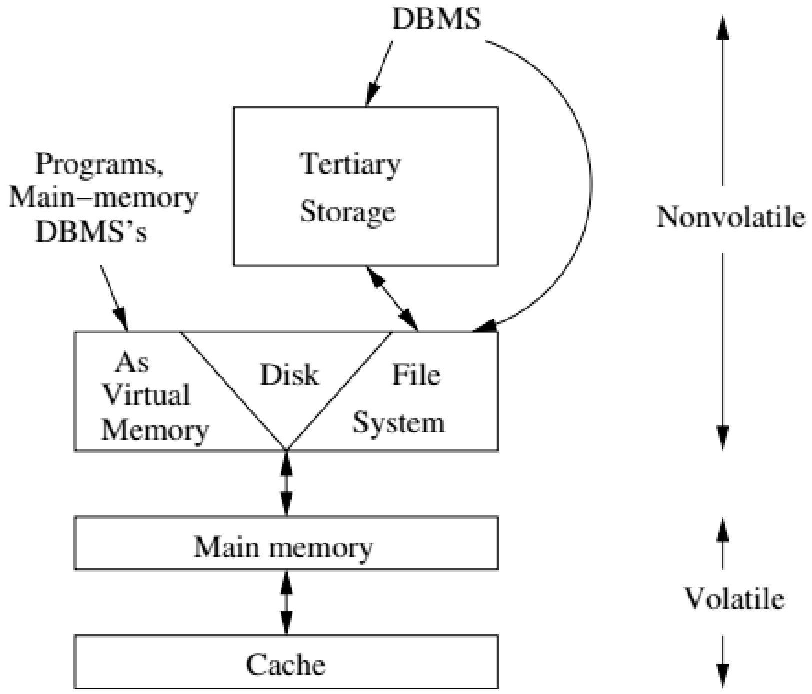


Figure 13.1: The memory hierarchy

Slower

Cheaper

Unlimited

Faster

More expensive

Limited

From: Database System Concepts, 7th Ed.

Memory Hierarchy (Very Old Numbers – Still Directionally Valid)

Storage Technology

Price, Performance & Capacity

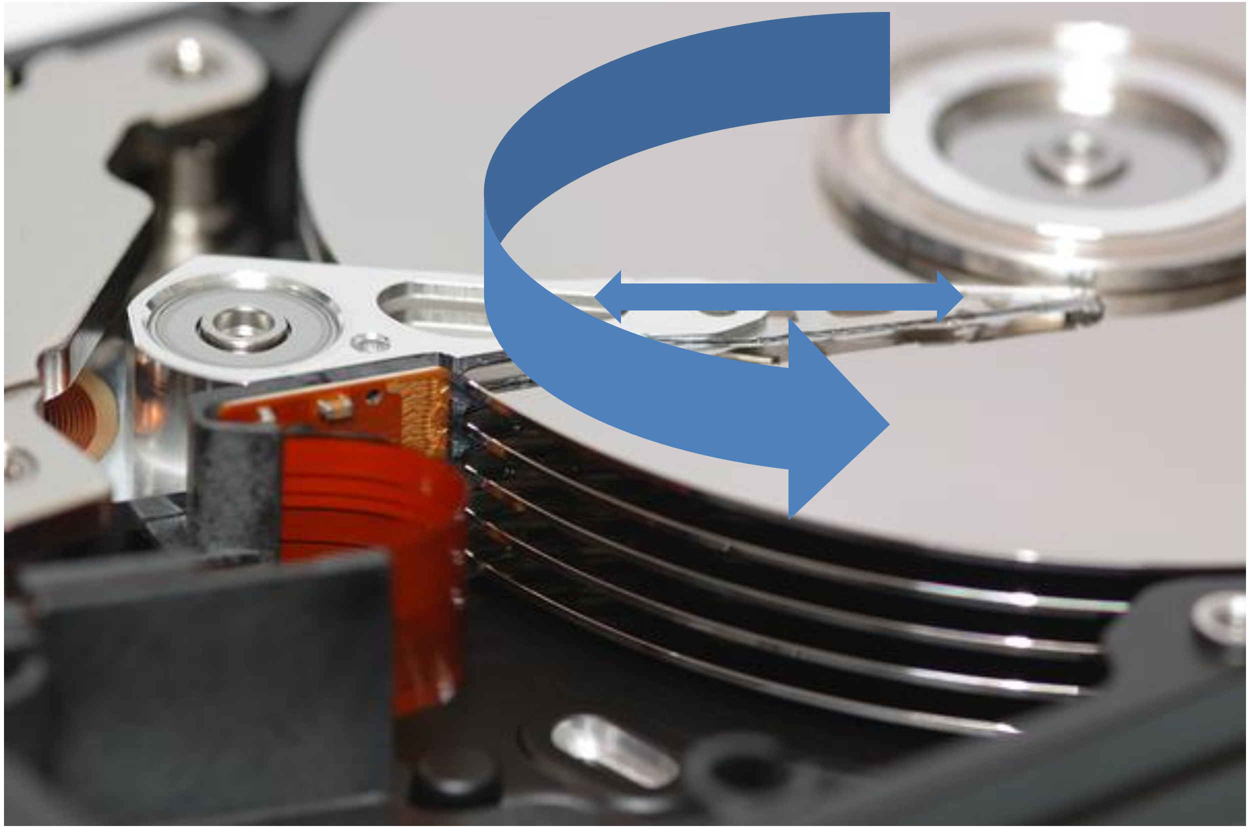
Technologies	Capacity (GB)	Latency (microS)	IOPs	Cost/IOPS ($)	Cost/GB ($)
Cloud Storage	*Unlimited*	*60,000*	*20*	*17c/GB*	*0.15/month*
Capacity HDDs	*2,500*	*12,000*	*250*	*1.67*	*0.15*
Performance HDDs	*300*	*7,000*	*500*	*1.52*	*1.30*
SSDs (write)	*64*	*300*	*5000*	*0.20*	*13*
SSDs (read only)	*64*	*45*	*30,000*	*0.03*	*13*
DRAM	*8*	*0.005*	*500,000*	*0.001*	*52*

- These numbers are ancient.
- Looking for more modern numbers.
- But, does give an idea of
  - Price
  - Performance
- The general observation is that
  - Performance goes up 10X/level.
  - Price goes up 10x per level.
- Note: One major change is improved price performance of SDD relative to HDD for large data.

Storage Hierarchy (Cont.)

- **primary storage:** Fastest media but volatile (cache, main memory).
- **secondary storage:** next level in hierarchy, non-volatile, moderately fast access time
  - Also called **on-line storage**
  - E.g., flash memory, magnetic disks
- **tertiary storage:** lowest level in hierarchy, non-volatile, slow access time
  - also called **off-line storage** and used for **archival storage**
  - e.g., magnetic tape, optical storage
  - Magnetic tape
    - Sequential access, 1 to 12 TB capacity
    - A few drives with many tapes
    - Juke boxes with petabytes (1000’s of TB) of storage

Hard Disk Drive



Disk Configuration

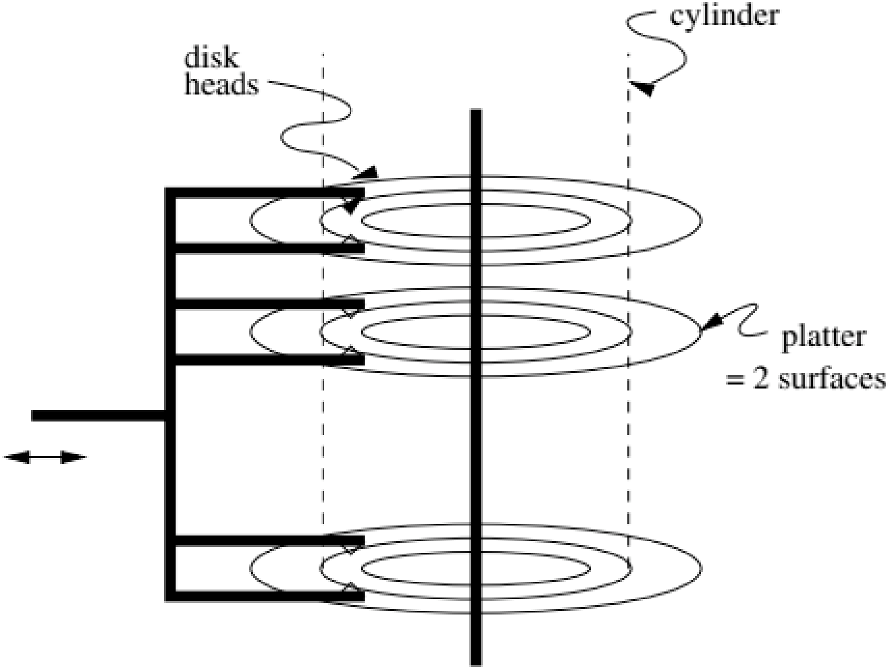


Figure 13.2: A typical disk

Components of disk I/O delay

- Seek: Move head to cylinder/track.
- Rotation: Wait for sector to get under head
- Transfer: Move data from disk to memory.

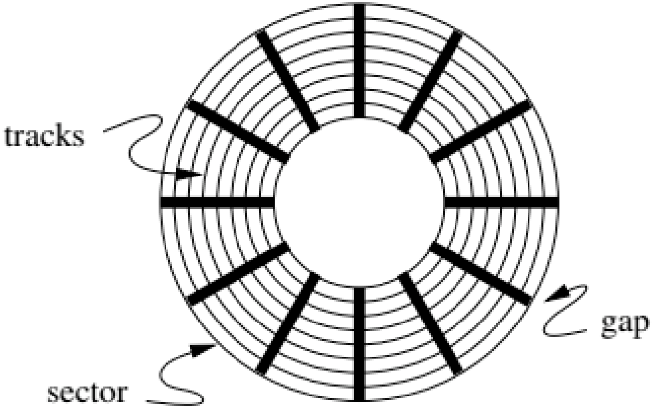


Figure 13.3: Top view of a disk surface

Database Systems: The Complete Book (2nd Edition)
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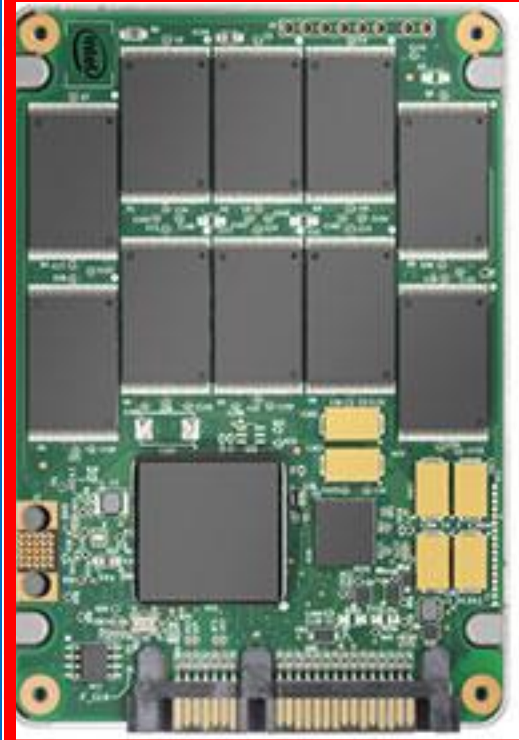
Hard Disk versus Solid State Disk

Hard
Disk
Drive



Solid
State
Drive

Flash Storage

- NOR flash vs NAND flash
- NAND flash
  - used widely for storage, cheaper than NOR flash
  - requires page-at-a-time read (page: 512 bytes to 4 KB)
    - 20 to 100 microseconds for a page read
    - Not much difference between sequential and random read
  - Page can only be written once
    - Must be erased to allow rewrite
- **Solid state disks**
  - Use standard block-oriented disk interfaces, but store data on multiple flash storage devices internally
  - Transfer rate of up to 500 MB/sec using SATA, and up to 3 GB/sec using NVMe PCIe

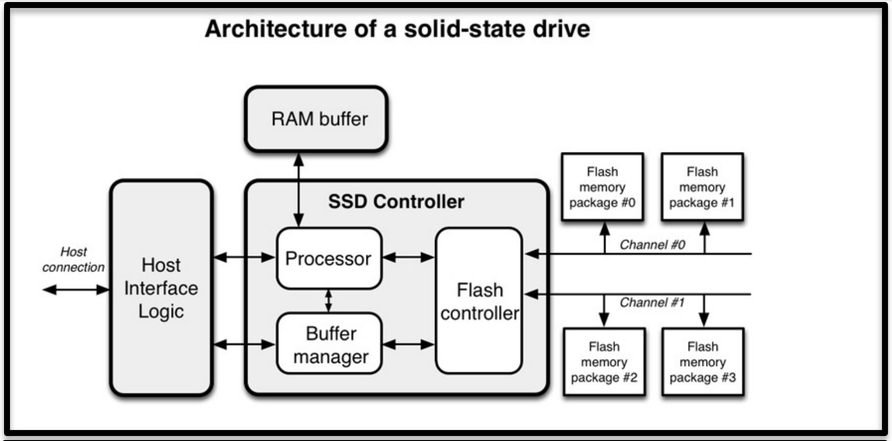
Logical Block Addressing

- Concept:
  - The *unit of transfer* from a "disk" to the computers memory is a "block. Blocks are usually relatively large, e.g. 16 KB, 32 KB, ...
  - A program that reads or write a single byte, requires the database engine (or file system) to read/write the entire block.
- The address of a block in the entire space of blocks is:
  - (Device ID, Block ID)
  - Block ID is simple 0, 1, 2, ...
- The disk controller and disk implementation translate the *logical block address* into the *physical address of blocks.*
- The physical address changes over time for various reasons, e.g. performance optimization, internal HW failure, etc.

Logical/Physical Block Addressing

The mapping from LBA to physical block address can change over time.

- Internal HW failure.
- SSD writes in a funny way.
  - You have to erase before writing.
  - So, the SSD (for performance)
    - Writes to an empty block.
    - Erase the original block.
- Performance optimization on HDD
  - Based on block access patterns.
  - Place blocks on cylinder/sector/head in a way to minimize:
    - Seek
    - Rotate



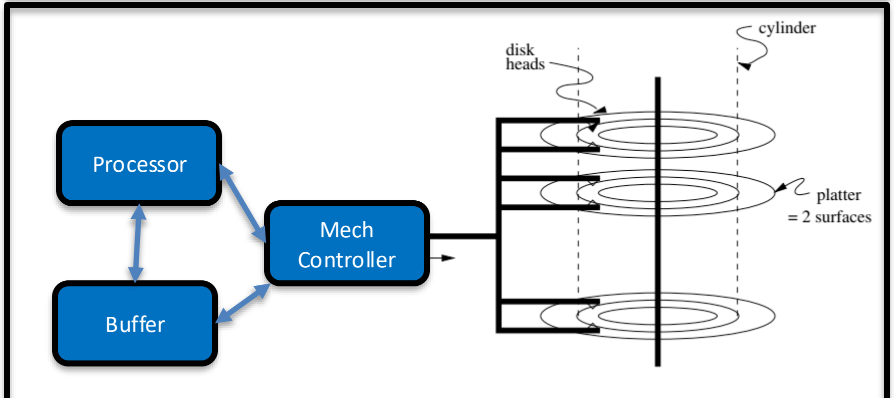
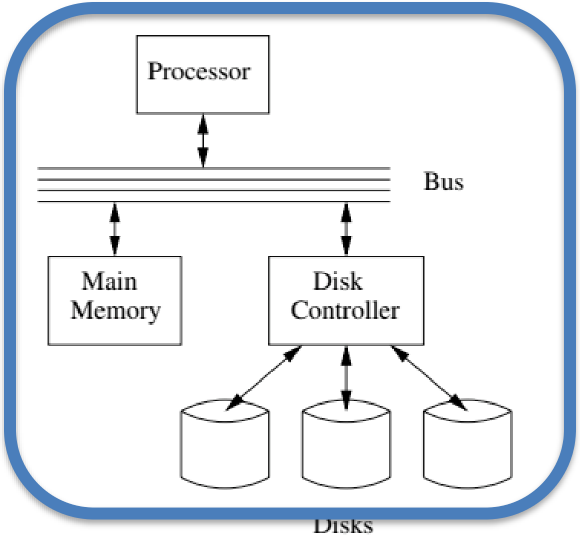
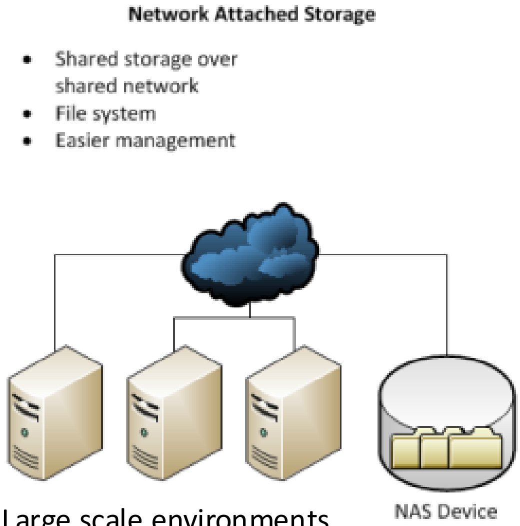


Figure 13.2: A typical disk

I/O Architecture

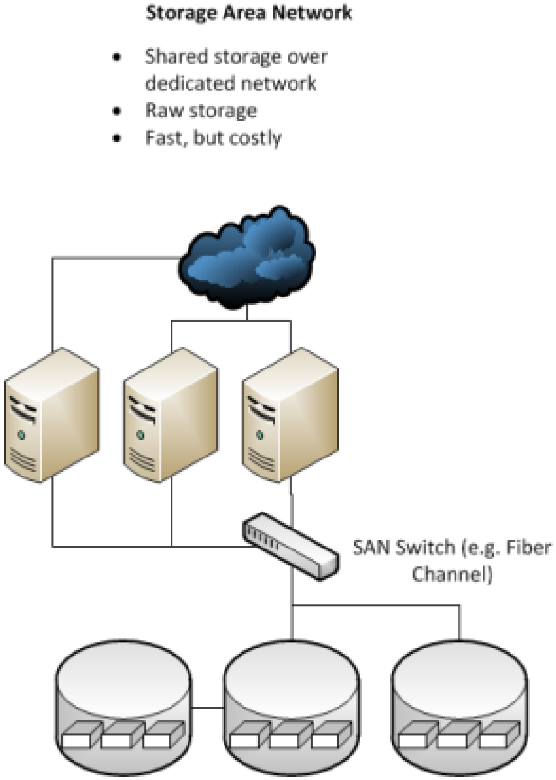


How we normally think of disks and I/O.



Large scale environments

- The bus-controller connection is over some kind of network.
- <u>The disk controller is at the disks, and basically a "computer" with SW.</u>
- Network is either
  - Standard communication network, or
  - Highly optimized I/O network.



Magnetic Disks

- **Read-write head**
- Surface of platter divided into circular **tracks**
  - Over 50K-100K tracks per platter on typical hard disks
- Each track is divided into **sectors.**
  - A sector is the smallest unit of data that can be read or written.
  - Sector size typically 512 bytes
  - Typical sectors per track: 500 to 1000 (on inner tracks) to 1000 to 2000 (on outer tracks)
- To read/write a sector
  - disk arm swings to position head on right track
  - platter spins continually; data is read/written as sector passes under head
- Head-disk assemblies
  - multiple disk platters on a single spindle (1 to 5 usually)
  - one head per platter, mounted on a common arm.
- **Cylinder** *i* consists of i^{th} track of all the platters

Magnetic Disks (Cont.)

- **Disk controller** – interfaces between the computer system and the disk drive hardware.
  - accepts high-level commands to read or write a sector
  - initiates actions such as moving the disk arm to the right track and actually reading or writing the data
  - Computes and attaches **checksums** to each sector to verify that data is read back correctly
    - If data is corrupted, with very high probability stored checksum won't match recomputed checksum
  - Ensures successful writing by reading back sector after writing it
  - Performs **remapping of bad sectors**

Performance Measures of Disks

- **Access time** – the time it takes from when a read or write request is issued to when data transfer begins. Consists of:
  - **Seek time** – time it takes to reposition the arm over the correct track.
    - Average seek time is 1/2 the worst case seek time.
      - Would be 1/3 if all tracks had the same number of sectors, and we ignore the time to start and stop arm movement
    - 4 to 10 milliseconds on typical disks
  - **Rotational latency** – time it takes for the sector to be accessed to appear under the head.
    - 4 to 11 milliseconds on typical disks (5400 to 15000 r.p.m.)
    - Average latency is 1/2 of the above latency.
  - Overall latency is 5 to 20 msec depending on disk model
- **Data-transfer rate** – the rate at which data can be retrieved from or stored to the disk.
  - 25 to 200 MB per second max rate, lower for inner tracks

Performance Measures (Cont.)

- **Disk block** is a logical unit for storage allocation and retrieval
  - 4 to 16 kilobytes typically
    - Smaller blocks: more transfers from disk
    - Larger blocks: more space wasted due to partially filled blocks
- **Sequential access pattern**
  - Successive requests are for successive disk blocks
  - Disk seek required only for first block
- **Random access pattern**
  - Successive requests are for blocks that can be anywhere on disk
  - Each access requires a seek
  - Transfer rates are low since a lot of time is wasted in seeks
- **I/O operations per second (IOPS)**
  - Number of random block reads that a disk can support per second
  - 50 to 200 IOPS on current generation magnetic disks

Performance Measures (Cont.)

- **Mean time to failure (MTTF)** – the average time the disk is expected to run continuously without any failure.
  - Typically 3 to 5 years
  - Probability of failure of new disks is quite low, corresponding to a "theoretical MTTF" of 500,000 to 1,200,000 hours for a new disk
    - E.g., an MTTF of 1,200,000 hours for a new disk means that given 1000 relatively new disks, on an average one will fail every 1200 hours
  - MTTF decreases as disk ages

Performance Measures of Disks

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From: Database System Concepts, 7th Ed.

Logical Block Addressing (https://gerardnico.com/wiki/data_storage/lba)

3 - The LBA scheme

LBA	C	H	S
0	0	0	0
1	0	0	1
2	0	0	2
3	0	0	3
4	0	0	4
5	0	0	5
6	0	0	6
7	0	0	7
8	0	0	8
9	0	0	9
10	0	1	0
11	0	1	1
12	0	1	2
13	0	1	3
14	0	1	4
15	0	1	5
16	0	1	6
17	0	1	7
18	0	1	8
19	0	1	9
Cylinder 0			

LBA	C	H	S
20	1	0	0
21	1	0	1
22	1	0	2
23	1	0	3
24	1	0	4
25	1	0	5
26	1	0	6
27	1	0	7
28	1	0	8
29	1	0	9
30	1	1	0
31	1	1	1
32	1	1	2
33	1	1	3
34	1	1	4
35	1	1	5
36	1	1	6
37	1	1	7
38	1	1	8
39	1	1	9
Cylinder 1			

CHS addresses can be converted to LBA addresses using the following formula:

LBA = ((C x HPC) + H) x SPT + S – 1

where,

- C, H and S are the cylinder number, the head number, and the sector number
- LBA is the logical block address
- HPC is the number of heads per cylinder
- SPT is the number of sectors per track

Devices have configuration and metadata

APIs that allow storage manager to

- Map between LBA and CHS
- To optimize block placement
- Based on access patterns, statistics, data schema, etc.

I/O Architecture

Redundant
Array
of
Independent
Disks

(RAID)

RAID (https://en.wikipedia.org/wiki/RAID)

"**RAID** (**redundant array of independent disks**) is a data storage virtualization technology that combines multiple physical disk drive components into a single logical unit for the purposes of data redundancy, performance improvement, or both. (…)

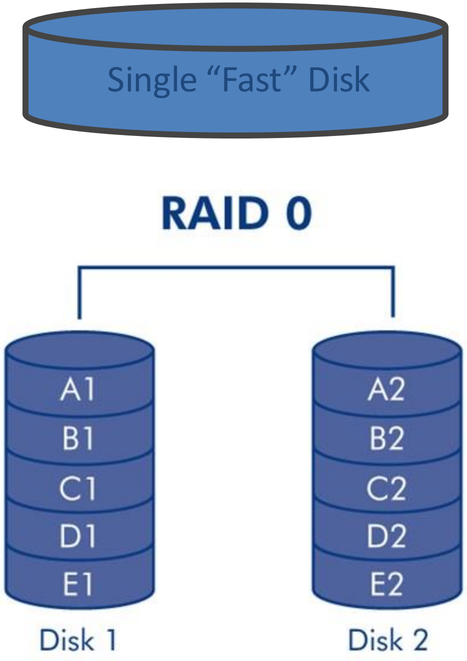
RAID 0 consists of striping, without mirroring or parity. (…)
RAID 1 consists of data mirroring, without parity or striping. (…)
RAID 2 consists of bit-level striping with dedicated Hamming-code parity. (…)
RAID 3 consists of byte-level striping with dedicated parity. (…)
RAID 4 consists of block-level striping with dedicated parity. (…)
RAID 5 consists of block-level striping with distributed parity. (…)
RAID 6 consists of block-level striping with double distributed parity. (…)

Nested RAID

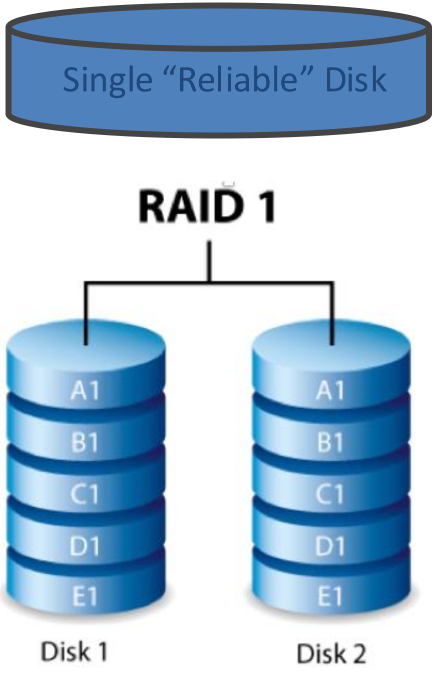
- RAID 0+1: creates two stripes and mirrors them. (…)
- RAID 1+0: creates a striped set from a series of mirrored drives. (…)
- **JBOD RAID N+N:** With JBOD (*just a bunch of disks*), (…)"

RAID-0 and RAID-1

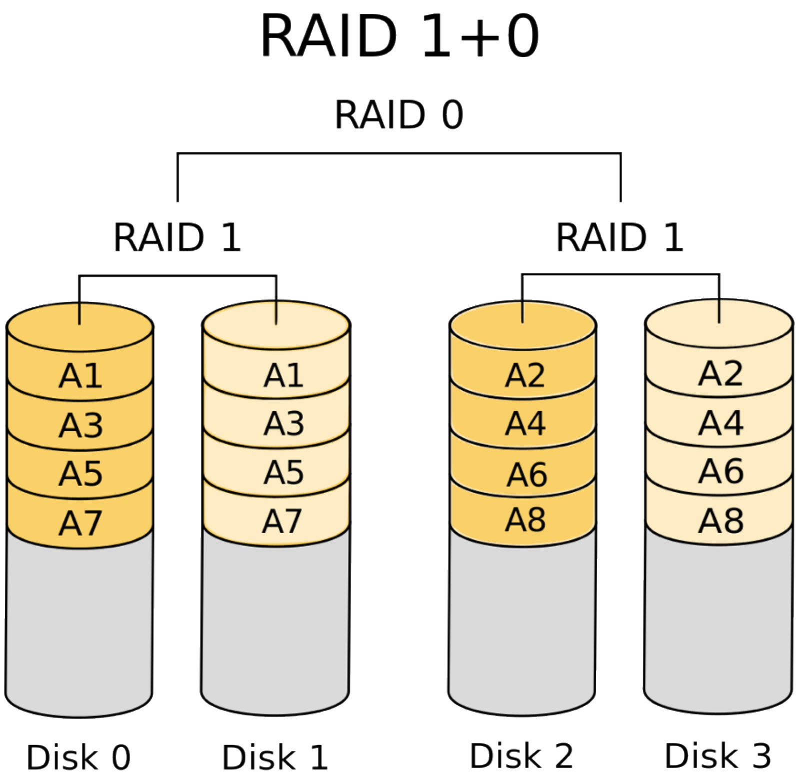
Two physical disks make
one single, logical **fast** disk



Two physical disks make
one single, logical **reliable** disk



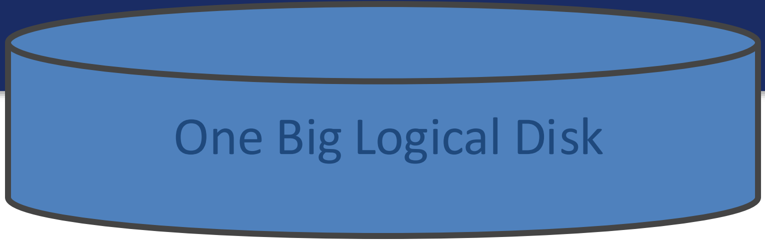
Mixed RAID Modes



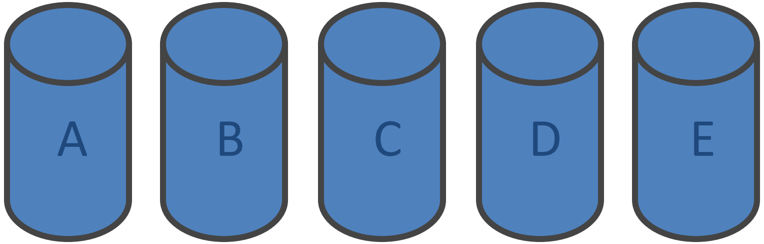
Stripe
And
Mirror

RAID-5

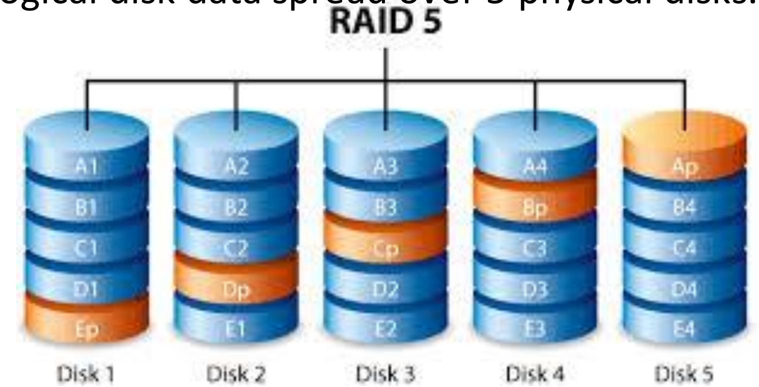
- Improved performance through parallelism
  - Rotation/seek
  - Transfer
- Availability uses *parity blocks*
  - Suppose I have 4 different data blocks on the logical drive A: A1, A2, A3, A4.
  - Parity function: **Ap** = P(A1,A2,A3,A4)
  - Recovery function: A2=R(**Ap**,A1,A3,A4)
- During normal operations:
  - Read processing simply retrieves block.
  - Write processing of A2 updates A2 and Ap
- If an individual disk fails, the RAID
  - Read
    - Continues to function for reads on non-missing blocks.
    - Implements read on missing block by recalculating value.
  - Write
    - Updates block and parity block for non-missing blocks.
    - Computes missing block, and calculates parity based on old and new value.
  - Over time
    - "Hot Swap" the failed disk.
    - Rebuild the missing data from values and parity.



Is actually 5 smaller "logical" disks.



Logical disk data spread over 5 physical disks.



Very Simple Parity Example

- Even-Odd Parity
  - b[i] is an array of bits (0 or 1)
  - P(b[i]) =
    - 0 is an even number of bits = 1. {P([0,1,1,0,1,1])= 0
    - 1 if an odd number of bits = 1. {P(0,0,1,0,1,1]= 1
  - Given an array with one missing bit and the parity bit, I can re-compute the missing bit.
    - Case 1: [0,?,1,0,1,1] has P=0. There must be an EVEN number of ones and ?=1.
    - Case 2: [0,?,1,0,1,1] has P=1. There must be an ODD number of ones and ?=0.
- Block Parity applies this to a set of blocks bitwise
  - A1=[0,1,0,0,1,1]
  - A2=[1,1,1,0,0,0]
  - A3=[0,0,0,1,0,1]
  - Pa=[1,0,1,1,1,0]

➔ If I am missing a block and have the parity block, I can re-compute the missing block bitwise from remaining blocks and parity block.

NoSQL

Concepts

Overview (I) (https://en.wikipedia.org/wiki/NoSQL)

A **NoSQL** (originally referring to "non SQL" or "non relational")[1] database provides a mechanism for storage and retrieval of data that is modeled in means other than the tabular relations used in relational databases. Such databases have existed since the late 1960s, but did not obtain the "NoSQL" moniker until a surge of popularity in the early twenty-first century,[2] triggered by the needs of Web 2.0 companies such as Facebook, Google, and Amazon.com.[3][4][5] NoSQL databases are increasingly used in big data and real-time web applications.[6] NoSQL systems are also sometimes called "Not only SQL" to emphasize that they may support SQL-like query languages.[7][8]

Motivations for this approach include: simplicity of design, simpler "horizontal" scaling to clusters of machines (which is a problem for relational databases),[2] and finer control over availability. The data structures used by NoSQL databases (e.g. key-value, wide column, graph, or document) are different from those used by default in relational databases, making some operations faster in NoSQL. The particular suitability of a given NoSQL database depends on the problem it must solve. Sometimes the data structures used by NoSQL databases are also viewed as "more flexible" than relational database tables.[9]

Overview (I) (https://en.wikipedia.org/wiki/NoSQL)

Many NoSQL stores compromise consistency (in the sense of the CAP theorem) in favor of availability, partition tolerance, and speed. Barriers to the greater adoption of NoSQL stores include the use of low-level query languages (instead of SQL, for instance the lack of ability to perform ad-hoc joins across tables), lack of standardized interfaces, and huge previous investments in existing relational databases.[10] Most NoSQL stores lack true ACID transactions, … …

Instead, most NoSQL databases offer a concept of "eventual consistency" in which database changes are propagated to all nodes "eventually" (typically within milliseconds) so queries for data might not return updated data immediately or might result in reading data that is not accurate, a problem known as stale reads.[11] Additionally, some NoSQL systems may exhibit lost writes and other forms of data loss.[12] Fortunately, some NoSQL systems provide concepts such as write-ahead logging to avoid data loss.[13] For distributed transaction processing across multiple databases, data consistency is an even bigger challenge that is difficult for both NoSQL and relational databases. Even current relational databases "do not allow referential integrity constraints to span databases."[14]

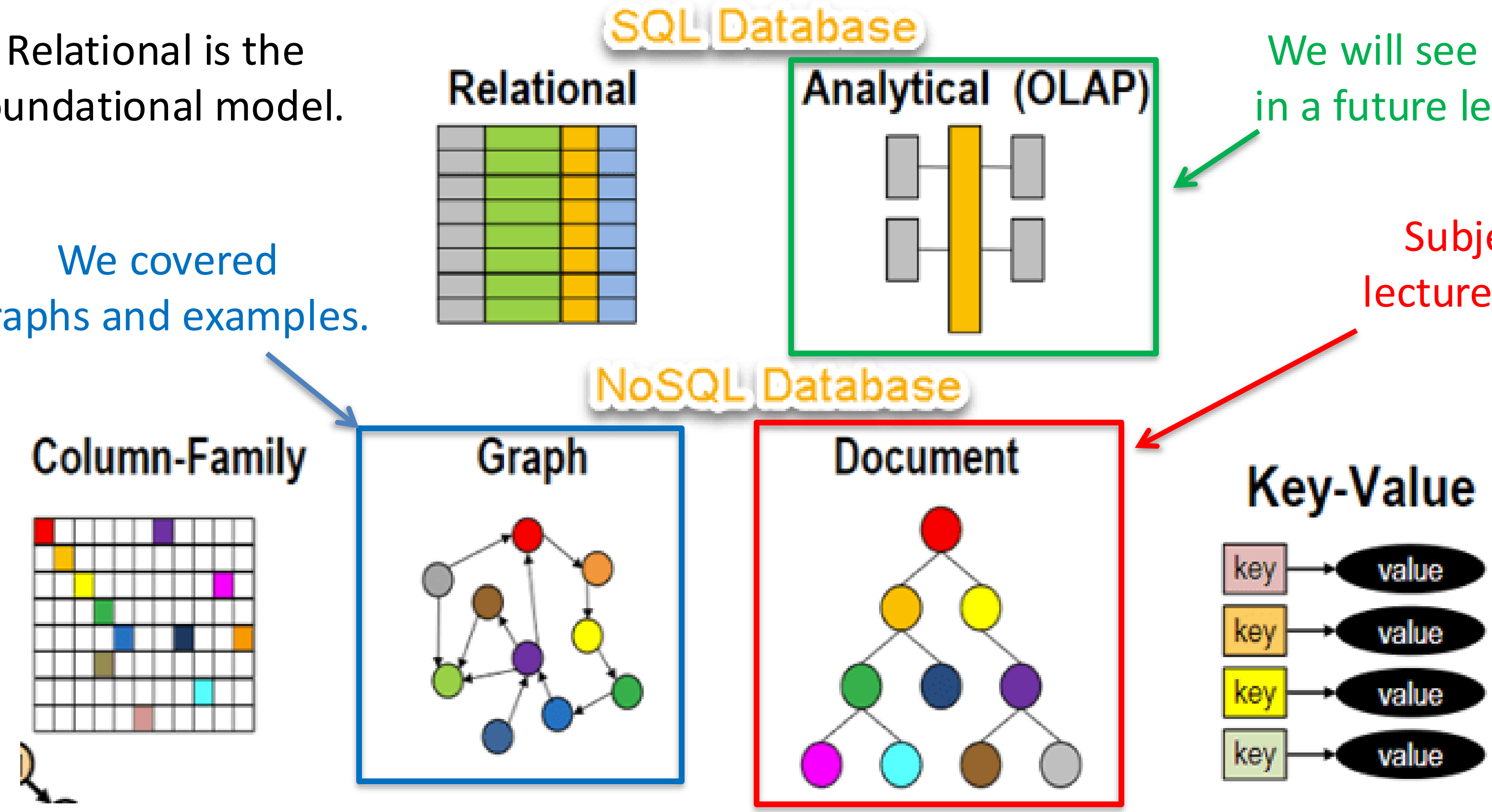
Simplistic Classification (https://medium.com/swlh/4-types-of-nosql-databases-d88ad21f7d3b)

Relational is the foundational model.

We will see OLAP in a future lecture.

We covered graphs and examples.

Subject of this lecture and part of HW3



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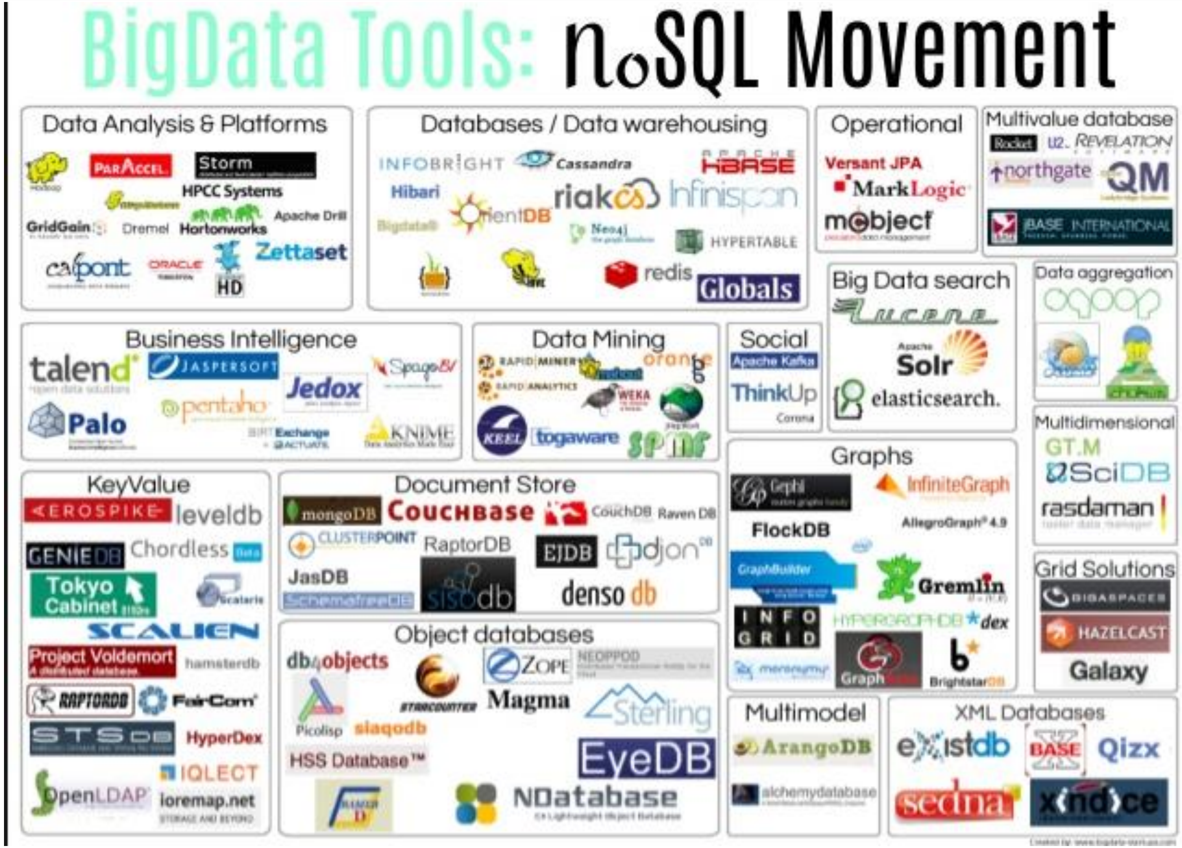
One Taxonomy

Document Database	Graph Databases
Couchbase, MarkLogic, mongoDB	Neo4j, InfiniteGraph The Distributed Graph Database

Wide Column Stores	Key-Value Databases
redis, amazon DynamoDB, AEROSPIKE, riak	accumulo, HYPERTABLE INC, Cassandra, APACHE HBASE, Amazon SimpleDB

Another Taxonomy



Use Cases

Motivations

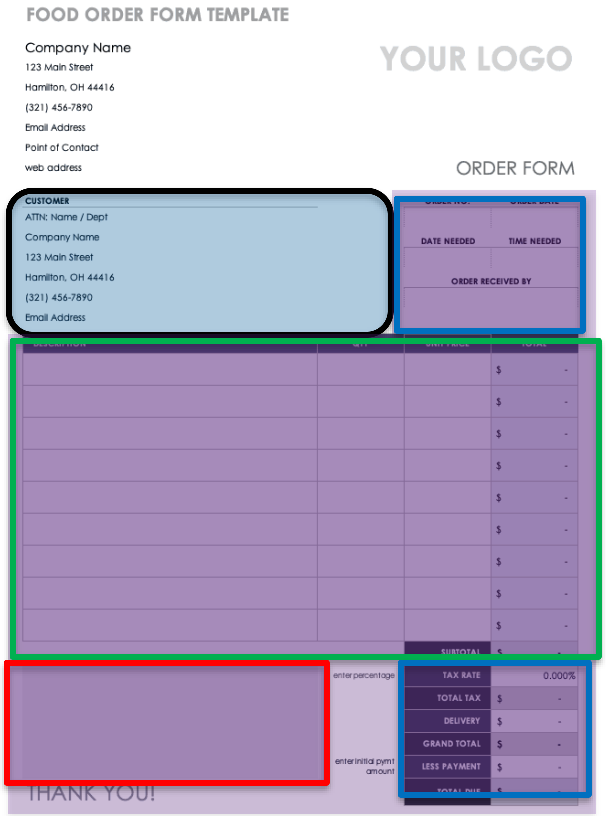
- Massive write performance.
- Fast key value look ups.
- Flexible schema and data types.
- No single point of failure.
- Fast prototyping and development.
- Out of the box scalability.
- Easy maintenance.

What is wrong with SQL/Relational?

- Nothing. One size fits all? Not really.
- Impedance mismatch. – Object Relational Mapping doesn't work quite well.
- Rigid schema design.
- Harder to scale.
- Replication.
- Joins across multiple nodes? Hard.
- How does RDMS handle data growth? Hard.
- Need for a DBA.
- Many programmers are already familiar with it.
- Transactions and ACID make development easy.
- Lots of tools to use.

Documents

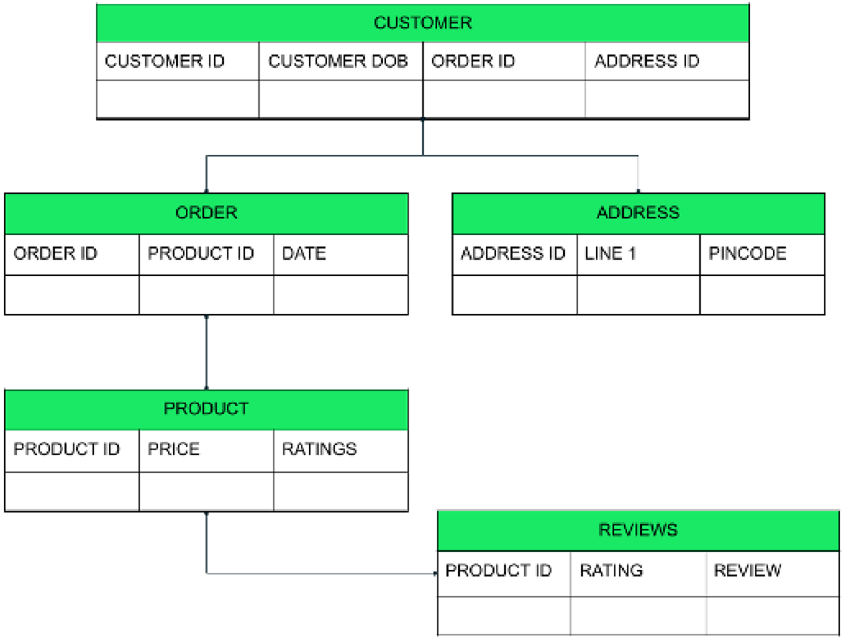
Example Document – An Order



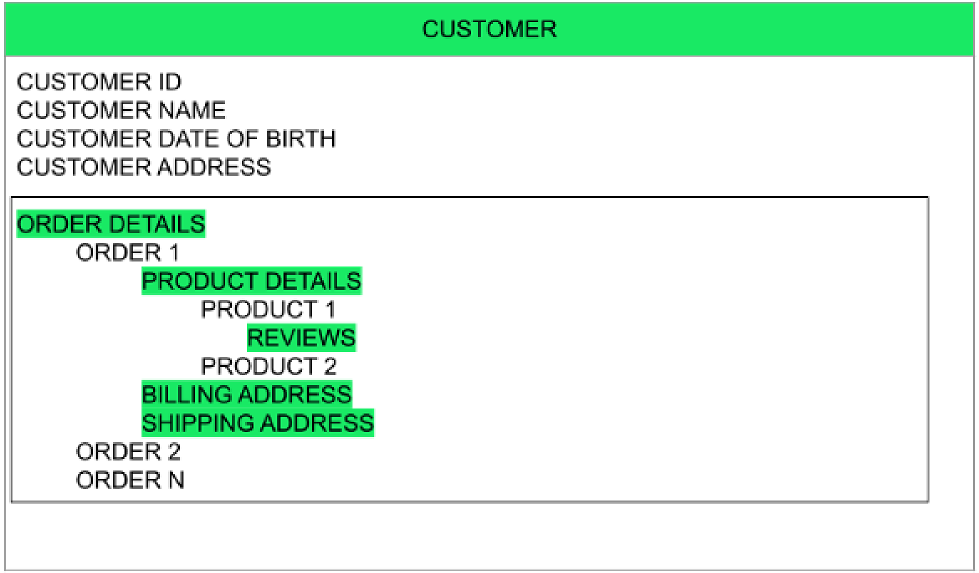
- There are 5 entity types on the form:
  - A “copy of” customer information.
  - Links (via productCode) to products
  - Order
  - OrderDetails
  - Comments
- *But OrderDetails and Comments are somehow different from the others.*
  - *These are arrays of objects*
  - *That are sort of “inside” the order.*
- These are weak entities, but relational does not always handle these well.

Relational vs Document

Relational



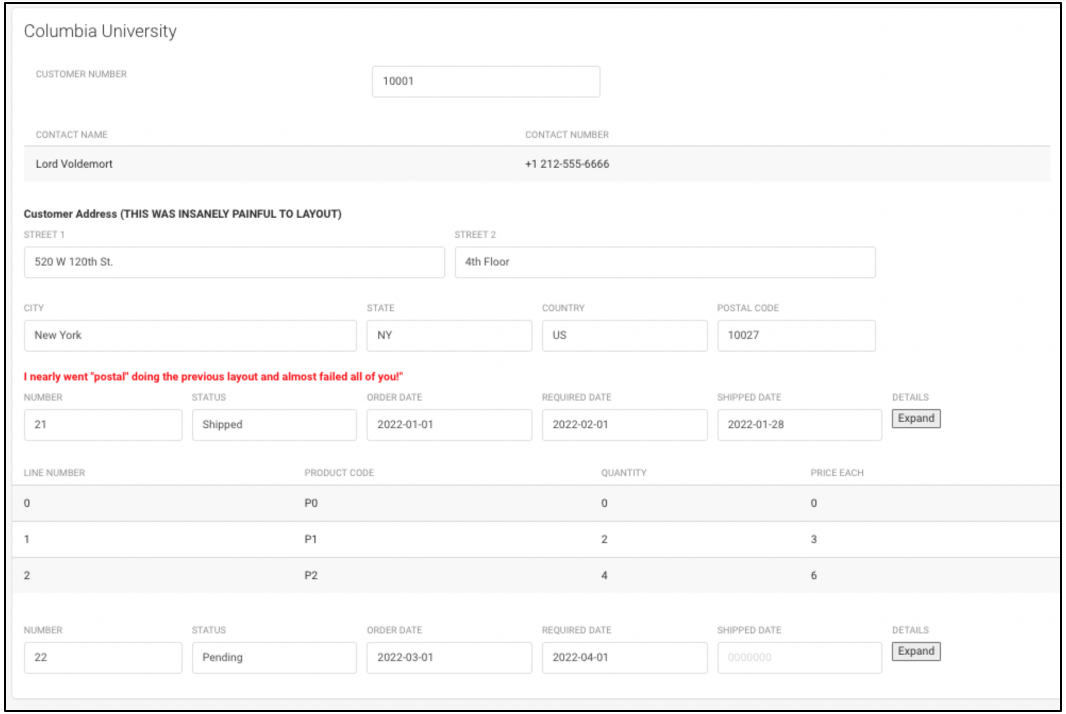
Document



The key difference?

- Relational DB attributes are atomic.
- Document DB attributes may be *multi-valued* and *complex.*

UI Interface and Logical Data Model




```
{
        customerName: “Columbia University”,
        contact: {
                name: “Lord Voldemort”,
                phone: “+1 212-555-6666”
        },
        address: {
                line1: “520 W 120th St.”
                line2: “Floor 4”,
                … …
        }
        orders: [
                {
                        number: …,
                        … …
                        details: [
                                … …
                        ]
                }
        ]
}
```

Note to DFF: Start

- ~/Dropbox/000/000-A-Current-Examples/W4111-FastAPI-IMDB-Solution
- ~/Dropbox/000/000-A-Current-Examples/current-dashboard

MongoDB

MongoDB Concepts

RDBMS	MongoDB
Database	Database
Table	Collection
Tuple/Row	Document
column	Field
Table Join	Embedded Documents
Primary Key	Primary Key (Default key _id provided by MongoDB itself)
Database Server, Client, Tools, Packages	
mysqld/Oracle	mongod
mysql/sqlplus	mongo
DataGrip	Compass
pymysql	pymongo

Core Operations

Basic Operations:

- Create database
- Create collection
- Create-Retrieve-Update-Delete (CRUD):
  - Create: insert()
  - Retrieve:
    - find()
    - find_one()
  - Update: update()
  - Delete: remove()

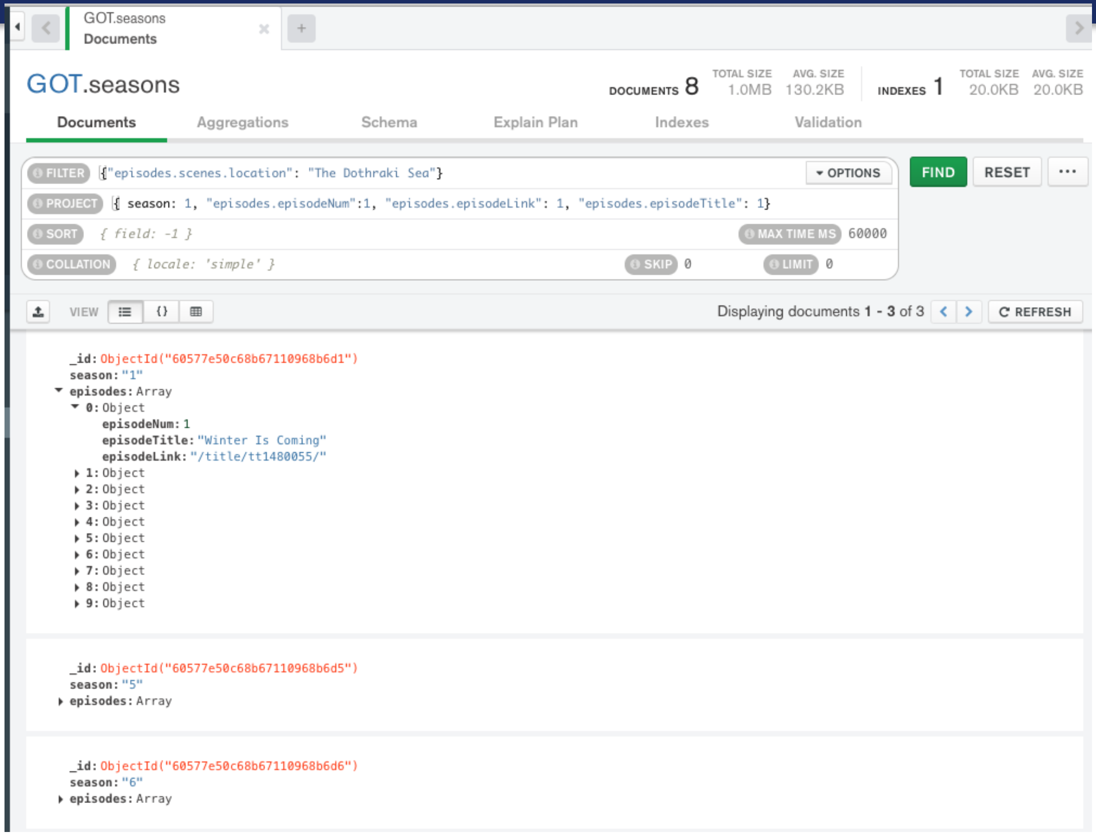
More Advanced Concepts:

- Limit
- Sort
- Aggregation Pipelines
  - Merge
  - Union
  - Lookup
  - Match
  - Merge
  - Sample
  - ... ...

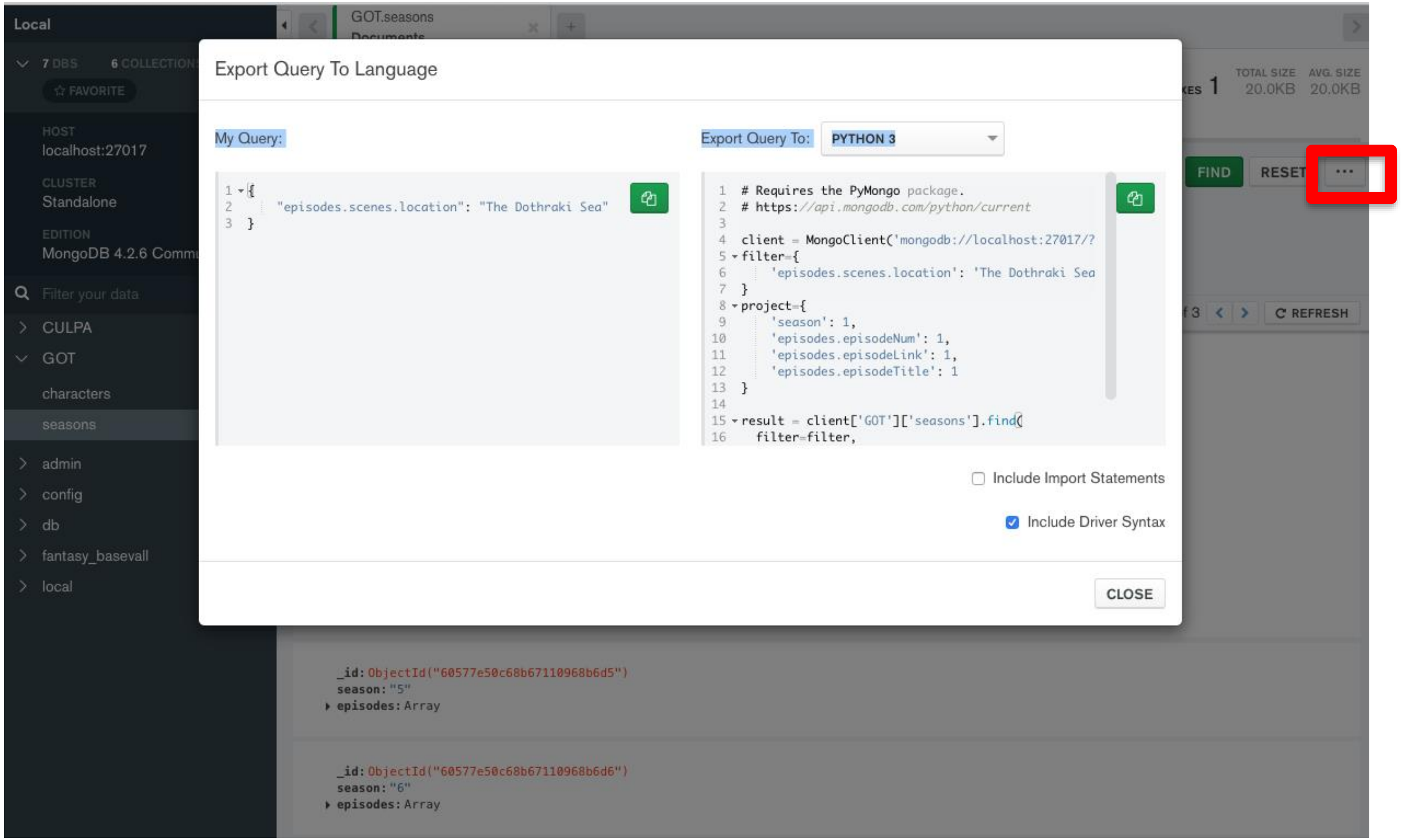
We will just cover the basics for now and may cover more things in HW or other lectures.

find()

- Note:
  - MongoDB uses a more pymysql approach, e.g. an API, than pure declarative languages like SQL.
  - The parameters for find() are where the declarative language appears.
- The basic forms of find() and find_one() have two parameters:
  - *filter expression*
  - *Project expression*
- You can use the Compass tool and screen captures for some HW and exam answers.
- What if I want the answer in a Jupyter Notebook?



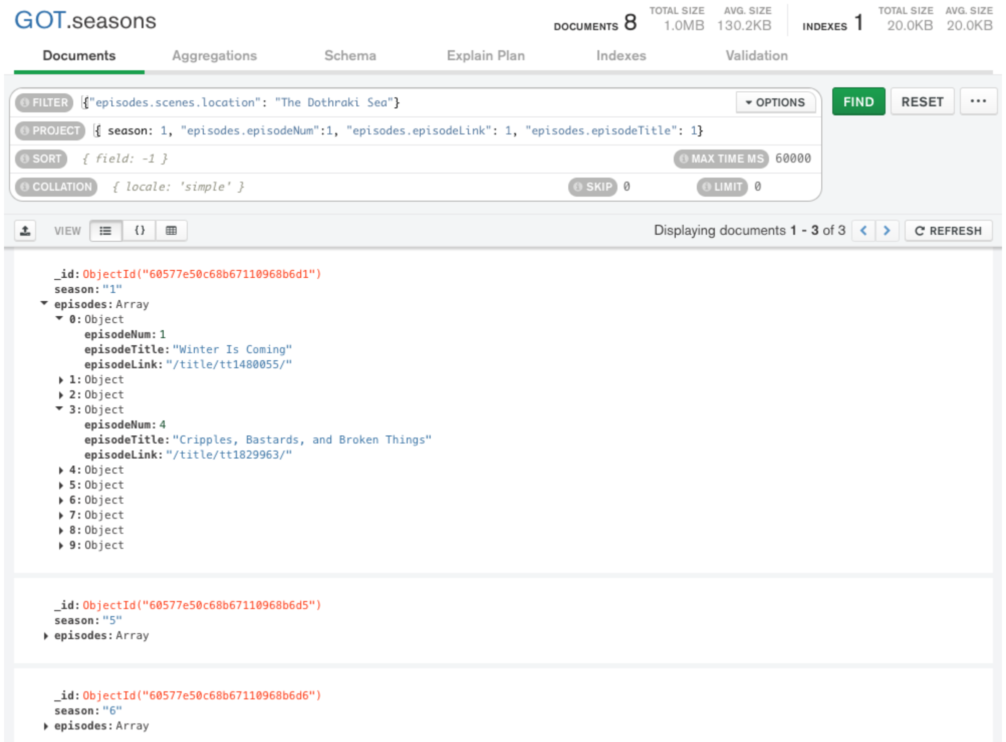
Generate Code



- Choose Export to Language.
- Copy into the notebook.
- The export has an option to include all the connection setup, choosing DB, … …

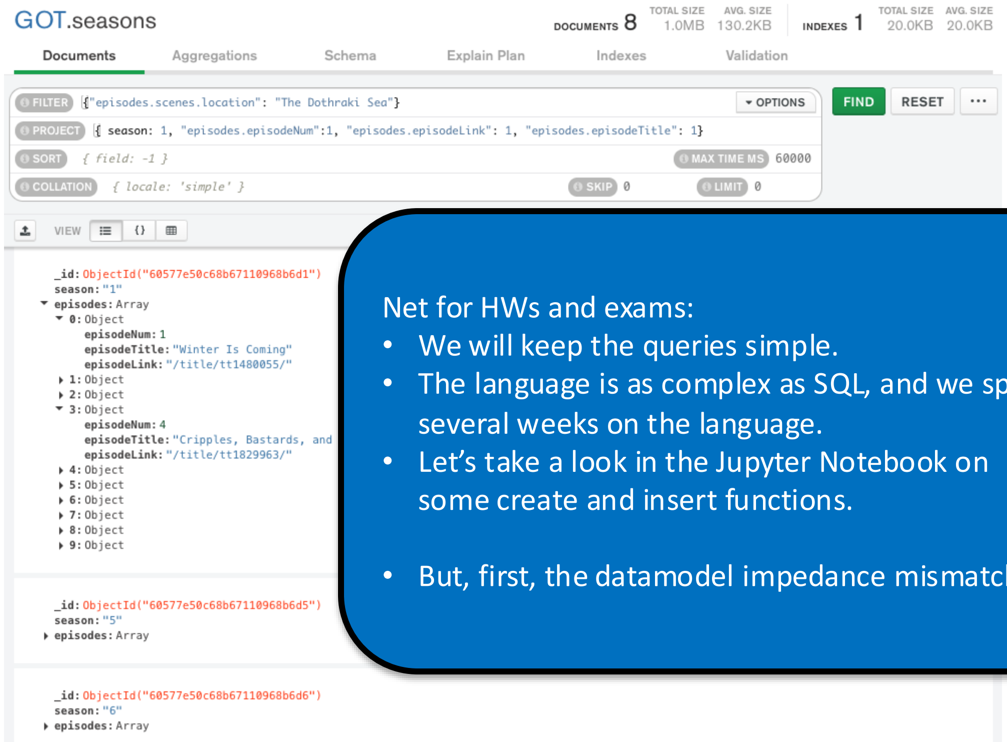
- Switch to Notebook

Result is not Quite You Expect



- The query returns documents that match.
  - The document is "Large" and has and episodes and seasons.
  - If you do a $project requesting episodes/episode content,
    - You get all episodes in the documents that match.
    - Not just the episodes with the scene/location.
    - Projecting array elements from arrays whose elements are arrays is complex and baffling.
- You also get back something (a cursor) that is iterable.

Result is not Quite You Expect



Net for HWs and exams:

- We will keep the queries simple.
- The language is as complex as SQL, and we spent several weeks on the language.
- Let's take a look in the Jupyter Notebook on some create and insert functions.
- But, first, the datamodel impedance mismatch concept.

- The query returns documents that match.
  - The document is "Large" and has ...l episodes and seasons.
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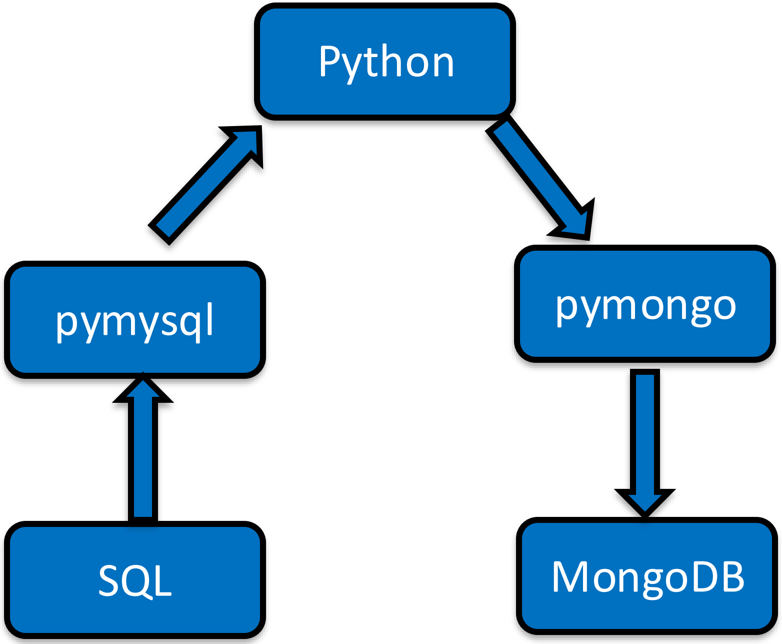
More Fun – Data Types

MongoDB supports many datatypes. Some of them are –

- **String** – This is the most commonly used datatype to store the data. String in MongoDB must be UTF-8 valid.
- **Integer** – This type is used to store a numerical value. Integer can be 32 bit or 64 bit depending upon your server.
- **Boolean** – This type is used to store a boolean (true/ false) value.
- **Double** – This type is used to store floating point values.
- **Min/ Max keys** – This type is used to compare a value against the lowest and highest BSON elements.
- **Arrays** – This type is used to store arrays or list or multiple values into one key.
- **Timestamp** – ctimestamp. This can be handy for recording when a document has been modified or added.
- **Object** – This datatype is used for embedded documents.
- **Null** – This type is used to store a Null value.
- **Symbol** – This datatype is used identically to a string; however, it's generally reserved for languages that use a specific symbol type.
- **Date** – This datatype is used to store the current date or time in UNIX time format. You can specify your own date time by creating object of Date and passing day, month, year into it.
- **Object ID** – This datatype is used to store the document's ID.
- **Binary data** – This datatype is used to store binary data.
- **Code** – This datatype is used to store JavaScript code into the document.
- **Regular expression** – This datatype is used to store regular expression.



(Some) MongoDB CRUD Operations

- Create:
  - db.collection.insertOne()
  - db.collection.insertMany()
- Retrieve:
  - db.collection.find()
  - db.collection.findOne()
  - db.collection.findOneAndUpdate()
  - … ..
- Update:
  - db.collection.updateOne()
  - db.collection.updateMany()
  - db.collection.replaceOne()
- Delete:
  - db.collection.deleteOne()
  - db.collection.deleteMany()

pymongo maps the camel case to _, e.g.

- findOne()
- find_one()

There are good online tutorials:

- https://www.tutorialspoint.com/python_data_access
- https://www.tutorialspoint.com/mongodb/index.htm

(Some) MongdoDB Pipeline Operators

https://www.slideshare.net/mongodb/s01-e04-analytics

Aggregation operators

- Pipeline and Expression operators

Pipeline	Expression	Arithmetic	Conditional
$match	$addToSet	$add	$cond
$sort	$first	$divide	$ifNull
$limit	$last	$mod	
$skip	$max	$multiply	
$project	$min	$subtract	
$unwind	$avg		**Variables**
$group	$push		
$geoNear	$sum		$let
$text			$map
$search			

Tip: Other operators for date, time, boolean and string manipulation

MongoDB Checkpoint

- You can see that MongoDB has powerful, sophisticated
  - Operators
  - Expressions
  - Pipelines
- We have only skimmed the surface. There is a lot more:
  - Indexes
  - Replication, Sharding
  - Embedded Map-Reduce support
  - … …
- We will explore a little more in subsequent lectures, homework, … …
- You will have to install MongoDB and Compass for HW4 and final exam.