CPT-S 415

Big Data

Yinghui Wu

EME B45

CPT-S 415
Big Data

Beyond Relational Data

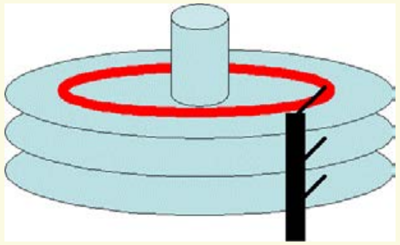
noSQL databases

- ✓ Column store
- ✓ Document DBs
  - MongoDB
- ✓ Graph databases
  - Neo4j

Column store

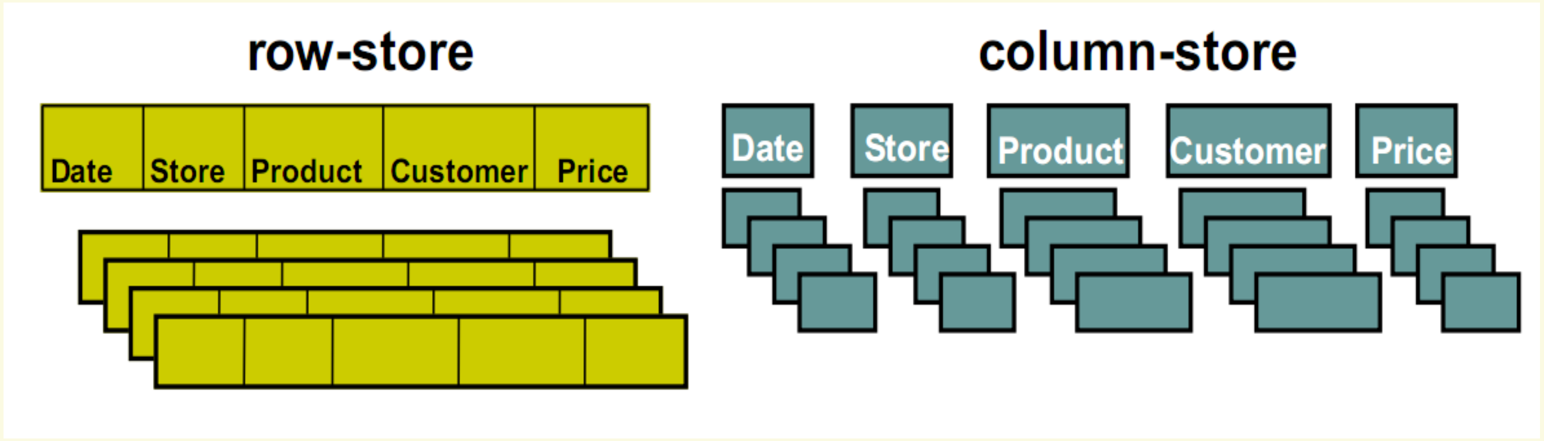
Row Store and Column Store

- ✓ Most of the queries does not process all the attributes of a particular relation.
- ✓ For example the query
  - ✓ Select c.name and c.address
  - ✓ From CUSTOMER as c
  - ✓ Where c.region=Pullman;



- ✓ Only process three attributes of the relation CUSTOMER. But the customer relation can have more than three attributes.
- ✓ more I/O efficient for read-only queries as they read, only those attributes which are accessed by a query.

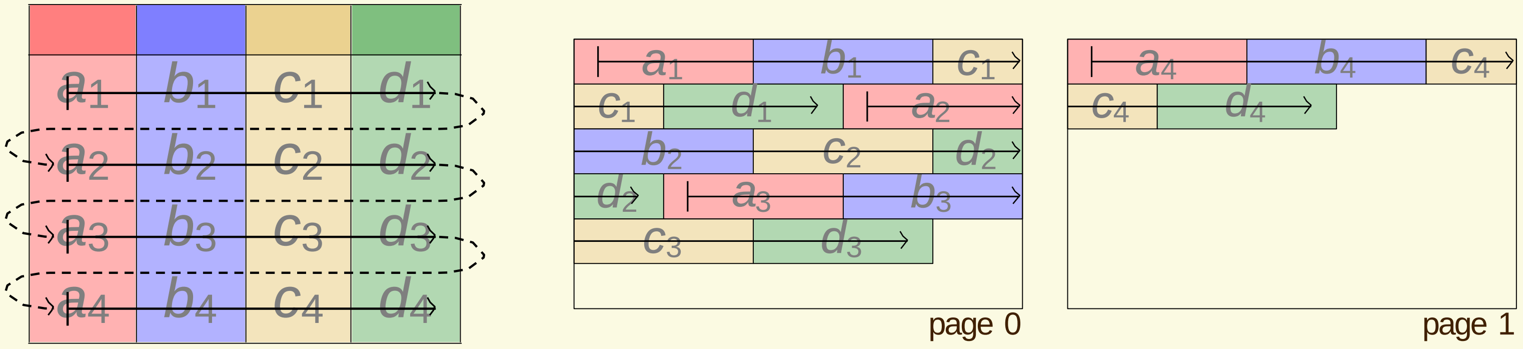
Row Store and Column Store



- ✓ In row store data are stored in the disk tuple by tuple.
- ✓ Where in column store data are stored in the disk column by column

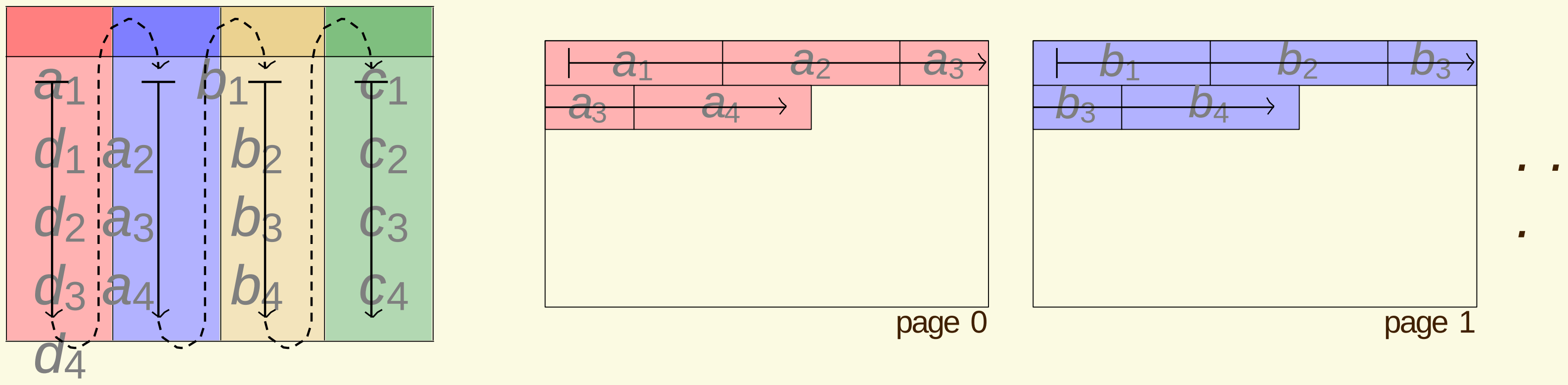
Row-stores

In a row-store, a.k.a. row-wise storage or n-ary storage model, NSM:
all rows of a table are stored sequentially on a database page.



Column-stores

a.k.a. column-wise storage or decomposition storage model, DSM:



a_1 d_1 d_2 d_3 d_4
a_2 a_3 a_4
b_1 b_2 b_3 b_4
c_1 c_2 c_3 c_4
a_1 a_2 a_3 a_3 a_4
page 0
b_1 b_2 b_3 b_3 b_4
page 1

The effect on query processing

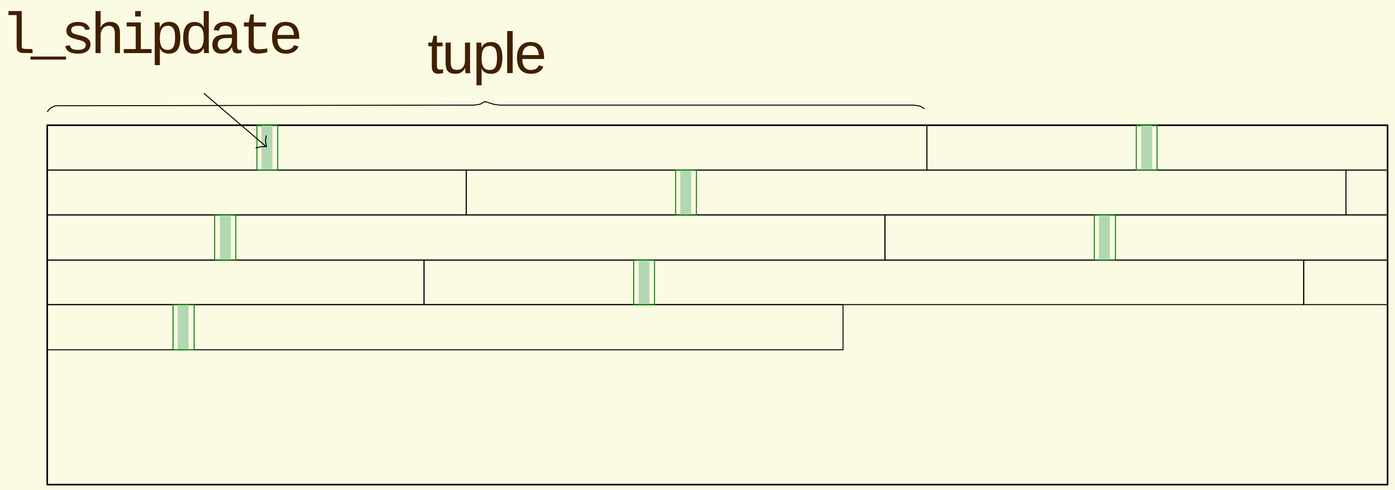
Consider, e.g., a selection query:

```
SELECT COUNT(*)
FROM lineitem
WHERE l_shipdate = "2017-10-19"
```

This query typically involves a full table scan.

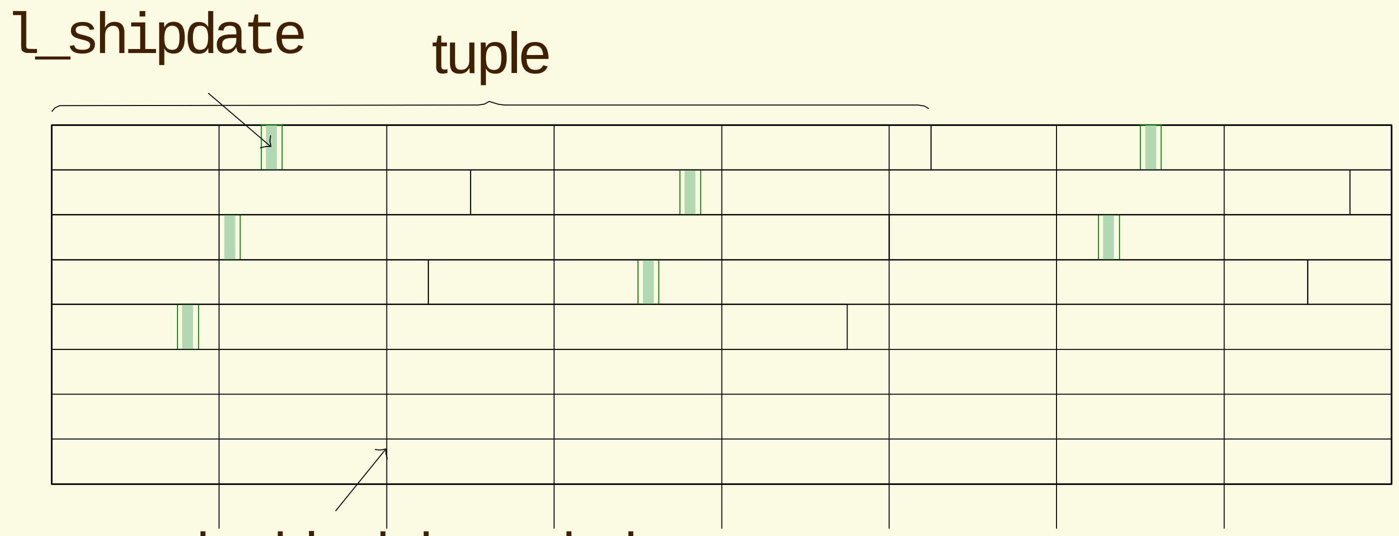
A full table scan in a row-store

In a row-store, all rows of a table are stored sequentially on a database page.



A full table scan in a row-store

In a row-store, all rows of a table are stored sequentially on a database page.



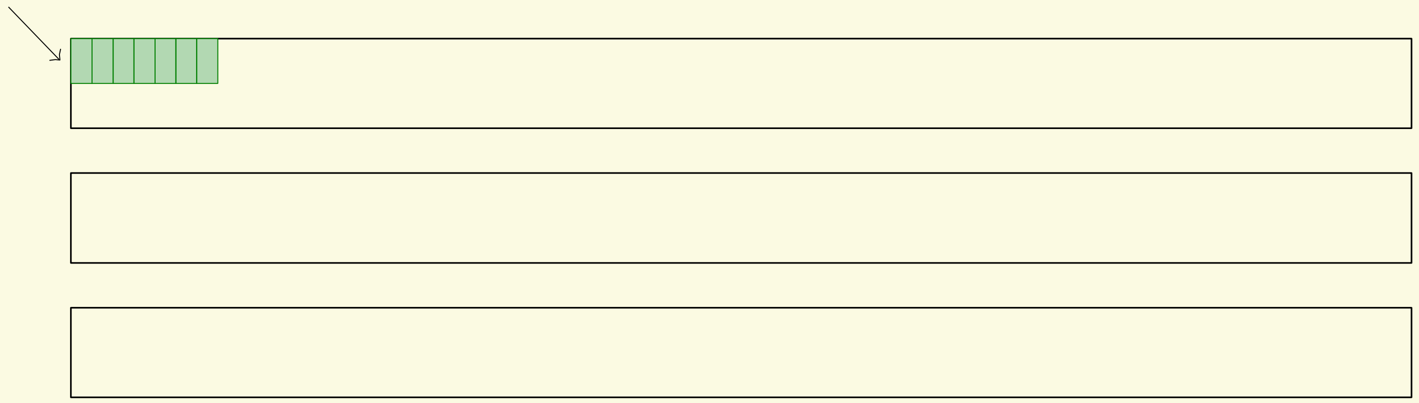
cache block boundaries

With every access to a l_shipdate field, load a large amount of irrelevant information into the cache.

A ”full table scan” on a column-store

In a column-store, all values of one column are stored sequentially on a database page.

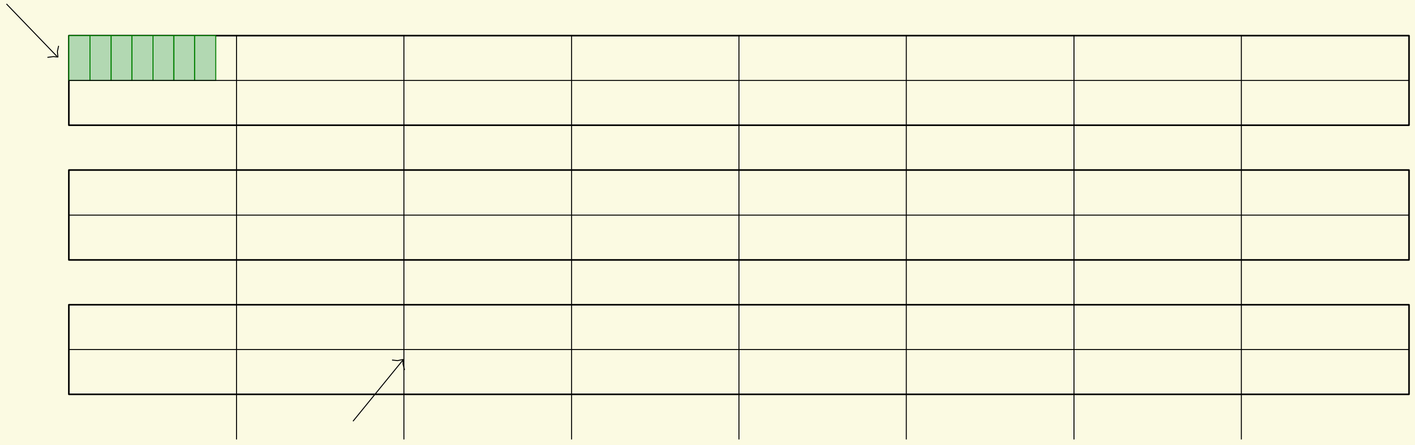
`l_shipdate(s)`



A "full table scan" on a column-store

In a column-store, all values of one column are stored sequentially on a database page.

`l_shipdate(s)`



cache block boundaries

All data loaded into caches by a "`l_shipdate` scan" is now actually **relevant** for the query.

Column-store advantages

- ✓ Less data has to be fetched from memory.
- ✓ Amortize cost for fetch over more tuples.
- The same arguments hold also for in-memory based systems (we will see soon).
- Additional benefit: Data compression might work better.

Why Column Stores?

- ✓ Can be significantly faster than row stores for some applications
  - Fetch only required columns for a query
  - Better cache effects
  - Better compression (similar attribute values within a column)
- ✓ But can be slower for other applications
  - OLTP with many row inserts, ..
- ✓ Long war between the column store and row store camps :-)

Row Store and Column Store

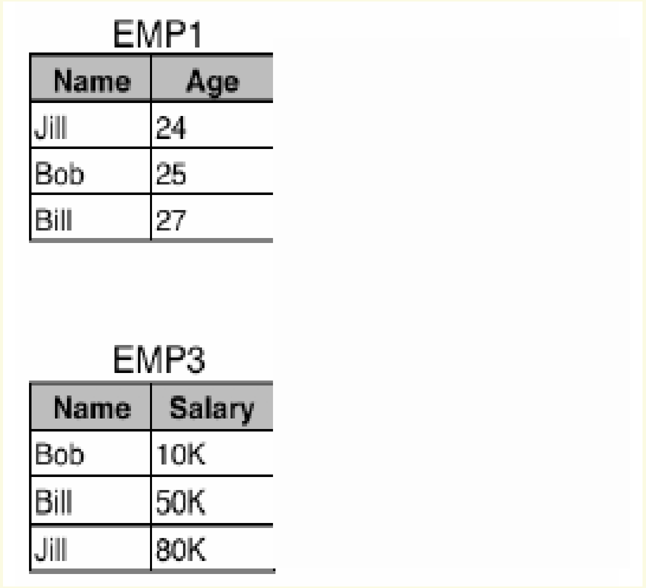
Row Store	Column Store
(+) Easy to add/modify a record	(+) Only need to read in relevant data
(-) Might read in unnecessary data	(-) Tuple writes require multiple accesses

- ✓ Column stores are suitable for read-mostly, read-intensive, large data repositories

Column store noSQL system

Column Stores - Data Model

- ✓ Standard relational logical data model
  - – EMP(name, age, salary, dept)
  - – DEPT(dname, floor)
- ✓ Table – collection of projections
- ✓ Projection – set of columns
- ✓ Horizontally partitioned into segments with segment identifier



EMP1

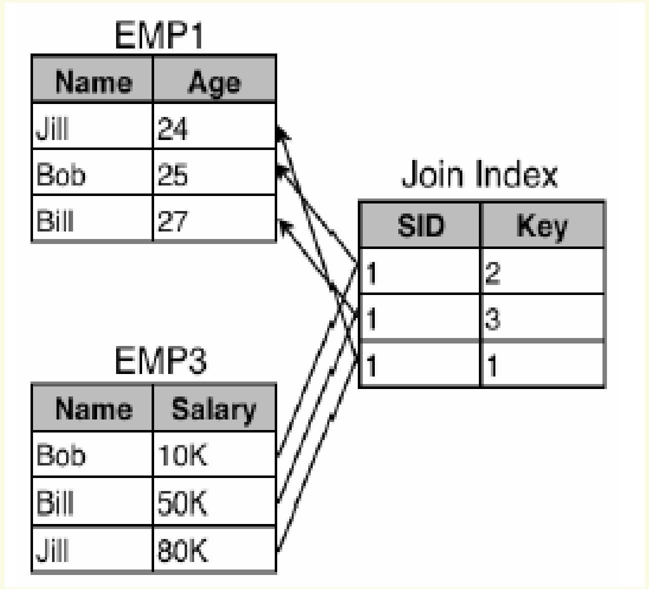
Name	Age
Jill	24
Bob	25
Bill	27

EMP3

Name	Salary
Bob	10K
Bill	50K
Jill	80K

Column Stores - Data Model

- ✓ To answer queries, projections are joined using Storage keys and join indexes
- ✓ Storage Keys:
  - – Within a segment, every data value of every column is associated with a unique Skey
  - – Values from different columns with matching Skey belong to the same logical row



EMP1

Name	Age
Jill	24
Bob	25
Bill	27

Join Index

SID	Key
1	2
1	3
1	1

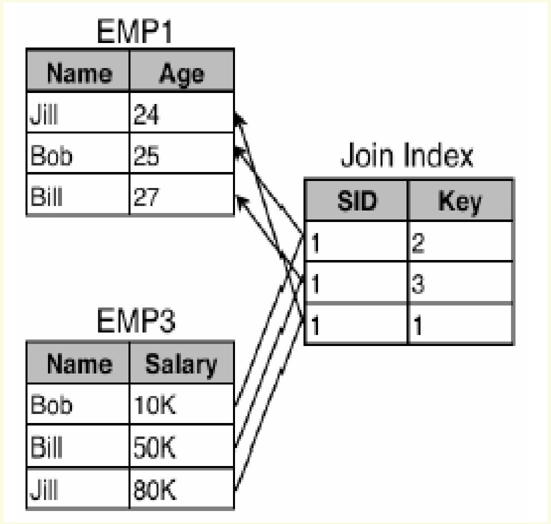
EMP3

Name	Salary
Bob	10K
Bill	50K
Jill	80K

Column Stores – Data Model

- ✓ Join Indexes
  - T1 and T2 are projections on T
  - M segments in T1 and N segments in T2
  - Join Index from T1 to T2 is a table of the form:
    - (s: Segment ID in T2, k: Storage key in Segment s)
    - Each row in join index matches corresponding row in T1
  - Join indexes are built such that T could be efficiently reconstructed from T1 and T2

Construct EMP(name, age, salary) from EMP1 and EMP3 using join index on EMP3



EMP1

Name	Age
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EMP3

Name	Salary
Bob	10K
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Join Index

SID	Key
1	2
1	3
1	1

Query Execution - Operators

- **Select:** Same as relational algebra, but produces a bit string
- **Project:** Same as relational algebra
- **Join:** Joins projections according to predicates

- **Aggregation:** SQL like aggregates
- **Sort:** Sort all columns of a projection
- **Decompress:** Converts compressed column to uncompressed representation
- **Mask**(Bitstring B, Projection Cs) => emit only those values whose corresponding bits are 1
- **Concat:** Combines one or more projections sorted in the same order into a single projection
- **Permute:** Permutes a projection according to the ordering defined by a join index
- **Bitstring operators:** Band – Bitwise AND, Bor – Bitwise OR, Bnot – complement

Row Store Vs Column Store

- ✓ One can obtain the performance benefits of a column-store using a row-store by making some changes to the physical structure of the row store.

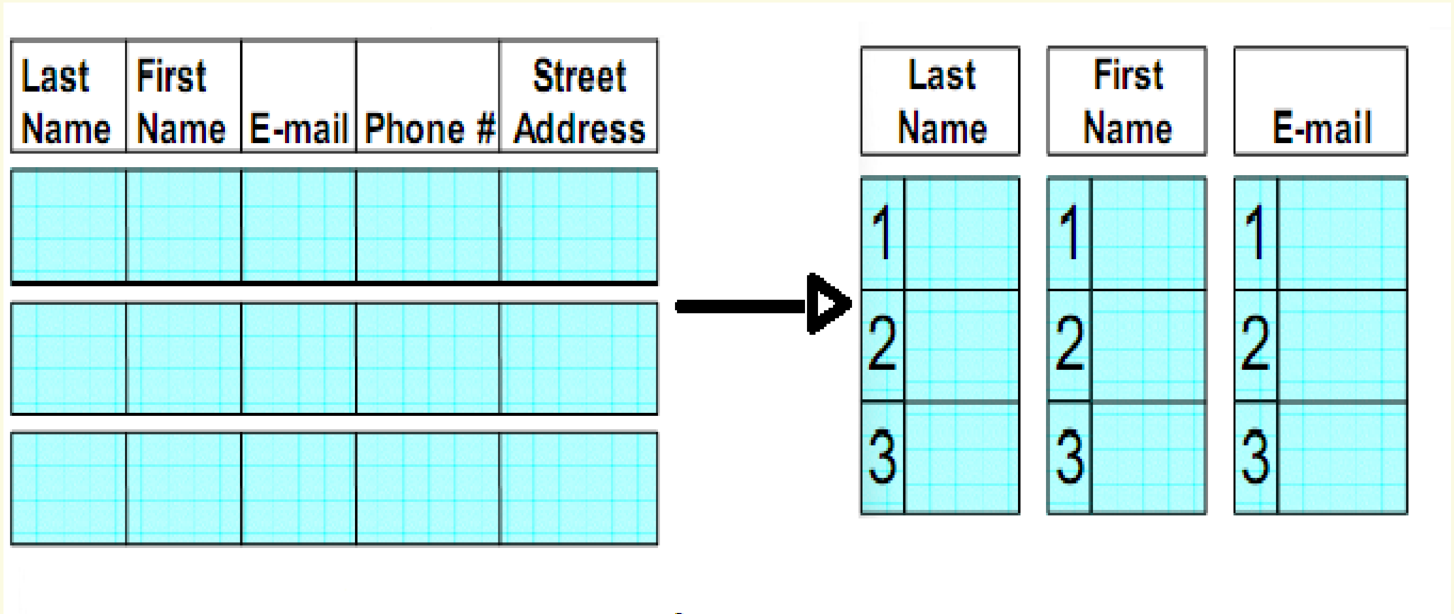
  - Vertically partitioning
  - Using index-only plans
  - Using materialized views

Vertical Partitioning

- ✓ Process:
  - – Full Vertical partitioning of each relation
    - • Each column =1 Physical table
      - – by adding integer position column to every table
  - – Join on Position for multi column fetch

- ✓ Problems:
  - – “Position” - Space and disk bandwidth
  - – Header for every tuple – further space wastage
    - • e.g. 24 byte overhead in PostgreSQL

Vertical Partitioning: Example



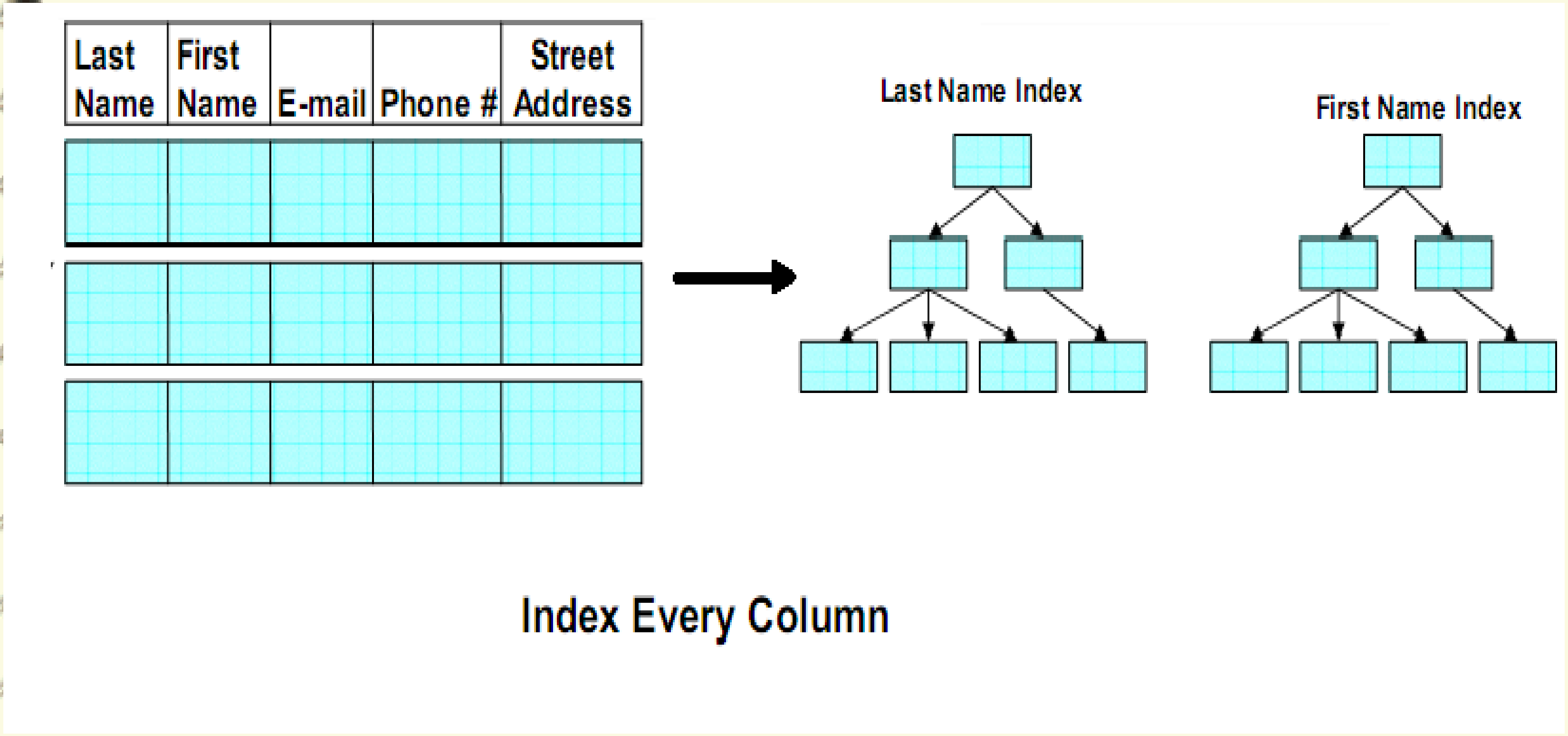
Vertical Partitioning

Index-only plans

- ✓ Process:
  - Add B+Tree index for every Table.column
  - Plans never access the actual tuples on disk
  - Headers are not stored, so per tuple overhead is less

- ✓ Problem:
  - Separate indices may require full index scan, which is slower
  - Eg:
    ```
    SELECT AVG(salary)
    FROM emp
    WHERE age > 40
    ```
  - Composite index with (age, salary) key helps.

Index-only plans: Example



Materialized Views

- ✓ Process:
  - – Create ‘optimal' set of MVs for given query workload
  - – Objective:
    - Provide just the required data
    - Avoid overheads
    - Performs better
- ✓ Expected to perform better than other two approach

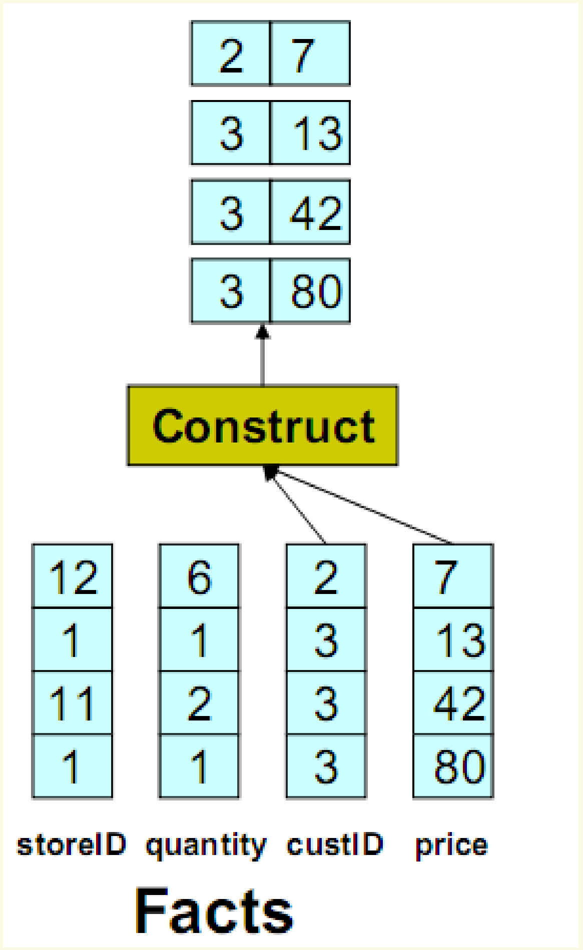
- ✓ Problems:
  - – Practical only in limited situation
  - – Require knowledge of query workloads in advance

Materialized Views: Example

- ✓ Select F.custID

  from Facts as F

  where F.price>20

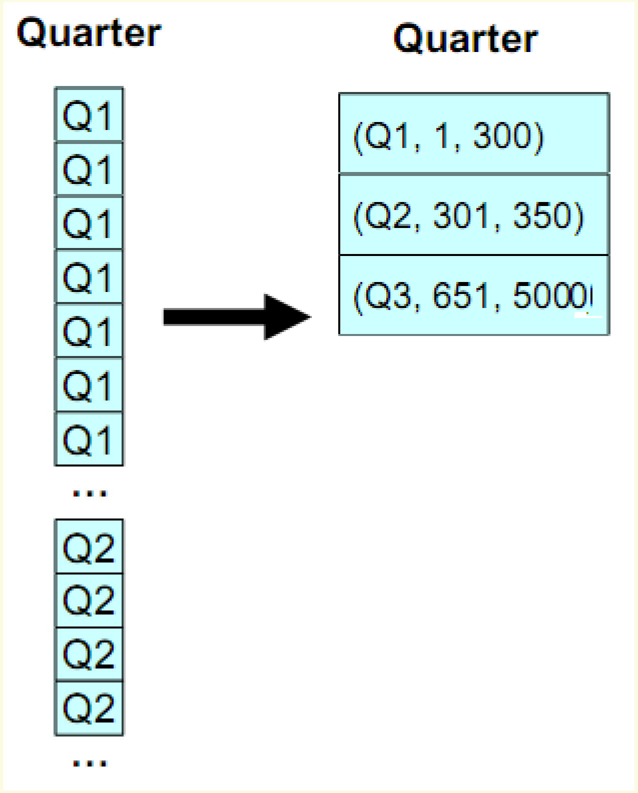


Optimizing Column oriented Execution

- ✓ Different optimization for column oriented database
  - Compression
  - Late Materialization
  - Block Iteration

Compression

- ✓ column can be super-compressible
- ✓ eg. Run length encoding



Compression

- ✓ Low information entropy (high data value locality) leads to High compression ratio
- ✓ Advantage
  - Disk Space is saved
  - Less I/O
  - CPU cost decrease if we can perform operation without decompressing
- ✓ Light weight compression schemes do better

Late Materialization

- ✓ Most query results entity-at-a-time not column-at-a-time

- Idea: Delay Tuple Construction
- Might avoid constructing it altogether
- Intermediate position lists might need to be constructed
- Eg: SELECT R.a FROM R WHERE R.c = 5 AND R.b = 10
  - Output of each predicate is a bit string
  - Perform Bitwise AND
  - Use final position list to extract R.a

Advantages: Unnecessary construction of tuple is avoided
Direct operation on compressed data
Cache performance is improved

Block Iteration

- ✓ Operators operate on blocks of tuples at once
- ✓ Iterate over blocks rather than tuples
- ✓ If column is fixed width, it can be operated as an array
- ✓ Minimizes per-tuple overhead
- ✓ Exploits potential for parallelism
- ✓ Can be applied even in Row stores – IBM DB2 implements it

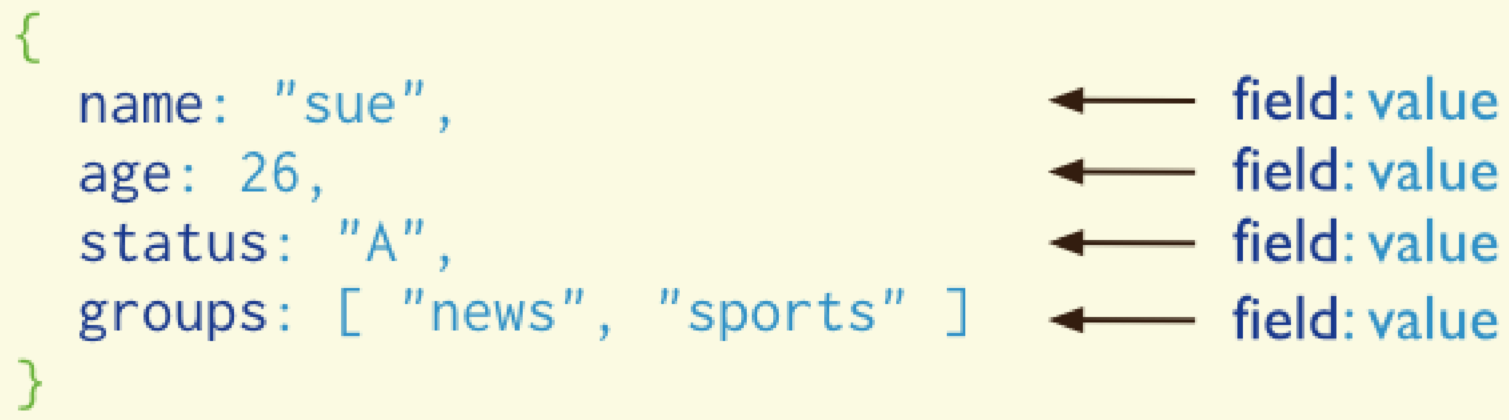
Document DB

Document DB

- Documents are the main concept.
- A Document-oriented database stores and retrieves documents (XML, JSON, BSON and so on).
- Documents are:
  - Self-describing
  - Hierarchical tree data structures (maps, collection and scalar values)

What is a Document DB?

- ✓ Document databases store documents in the value part of the key-value store



```
{
   name: "sue",
   age: 26,
   status: "A",
   groups: [ "news", "sports" ]
}
```

  - ✓ Documents may have different attributes
  - ✓ Different from relational databases where columns stores the same type of values or null

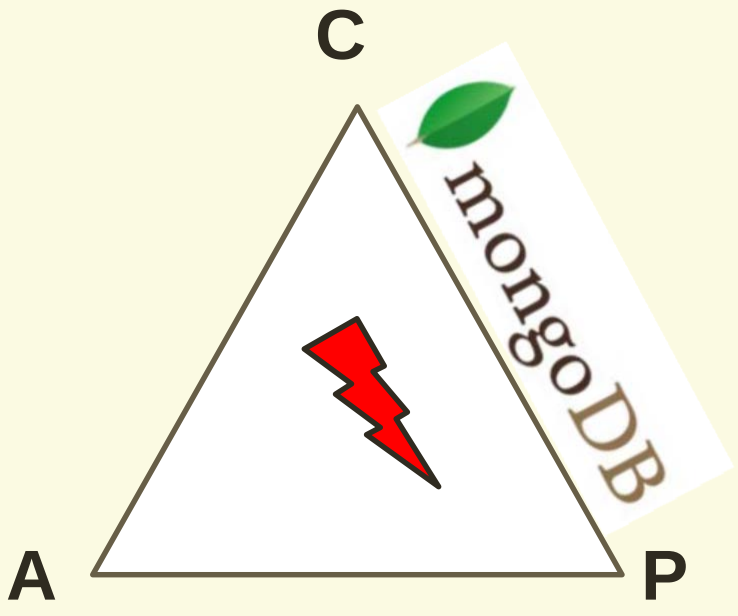
MongoDB

- MongoDB Features
  - Document-Oriented storage
  - Index Support
  - Replication & Availability
  - Auto-Sharding
  - Ad-hoc Querying
  - Fast In-Place Updates
  - Map/Reduce functionality

MongoDB: CAP approach

Focus on Consistency and Partition tolerance

- Consistency
  - all replicas contain the same version of the data
- Availability
  - system remains operational on failing nodes
- Partition tolarence
  - multiple entry points
  - system remains operational on system split

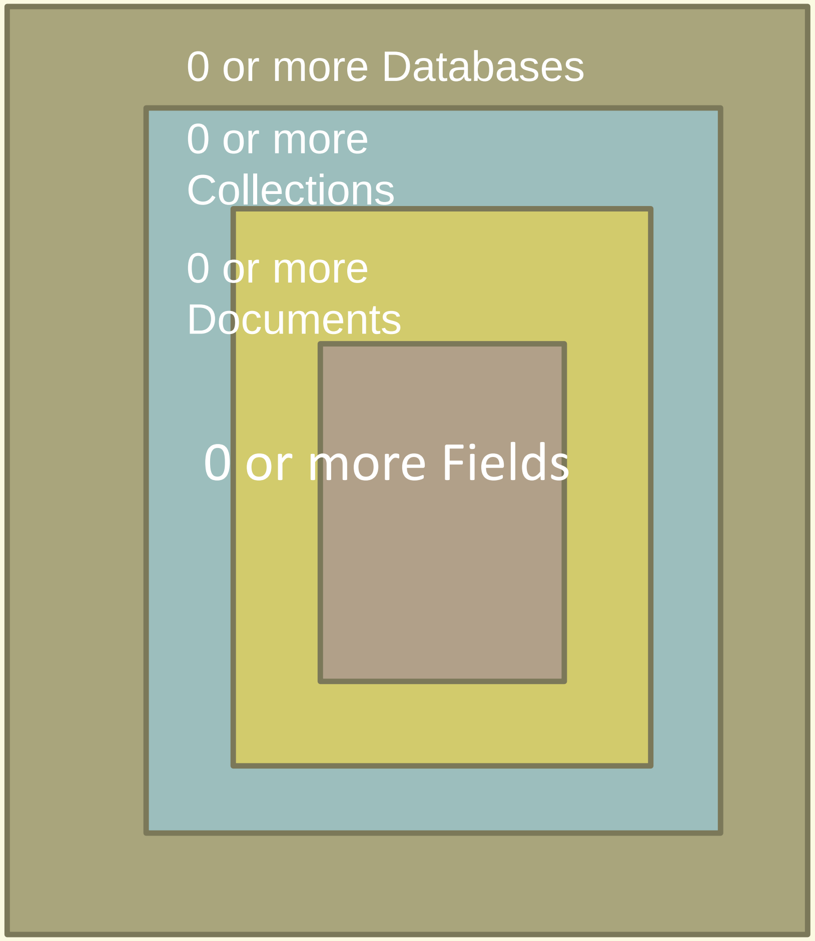


CAP Theorem:
satisfying all three at the same time is impossible

Document DB: Data model

MongoDB: Hierarchical Objects

- A MongoDB instance may have zero or more 'databases'
- A database may have zero or more 'collections'.
- A collection may have zero or more 'documents'.
- A document may have one or more 'fields'.
- MongoDB 'Indexes' function much like their RDBMS counterparts.



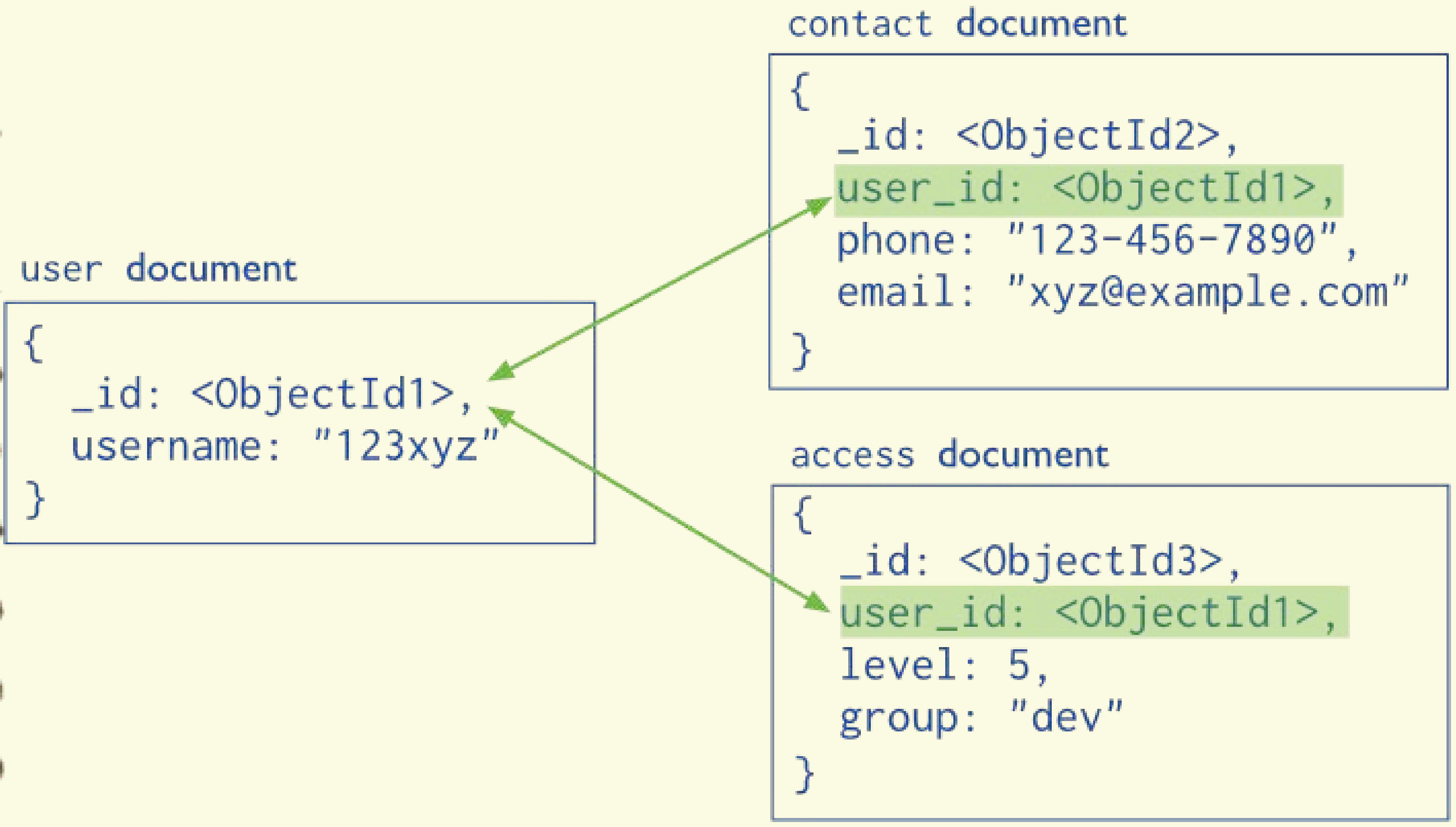
The _id Field

- By default, each document contains an _id field. This field has a number of special characteristics:
  - Value serves as primary key for collection.
  - Value is unique, immutable, and may be any non-array type.
  - Default data type is ObjectId, which is “small, likely unique, fast to generate, and ordered.”

```
{ "_id" :   "37010"
"city" :    "ADAMS",
"pop" :     2660,
"state" :   "TN",}
```

http://docs.mongodb.org/manual/reference/bson-types/

Documents: Structure References



contact document

```
{
  _id: <ObjectId2>,
  user_id: <ObjectId1>,
  phone: "123-456-7890",
  email: "xyz@example.com"
}
```

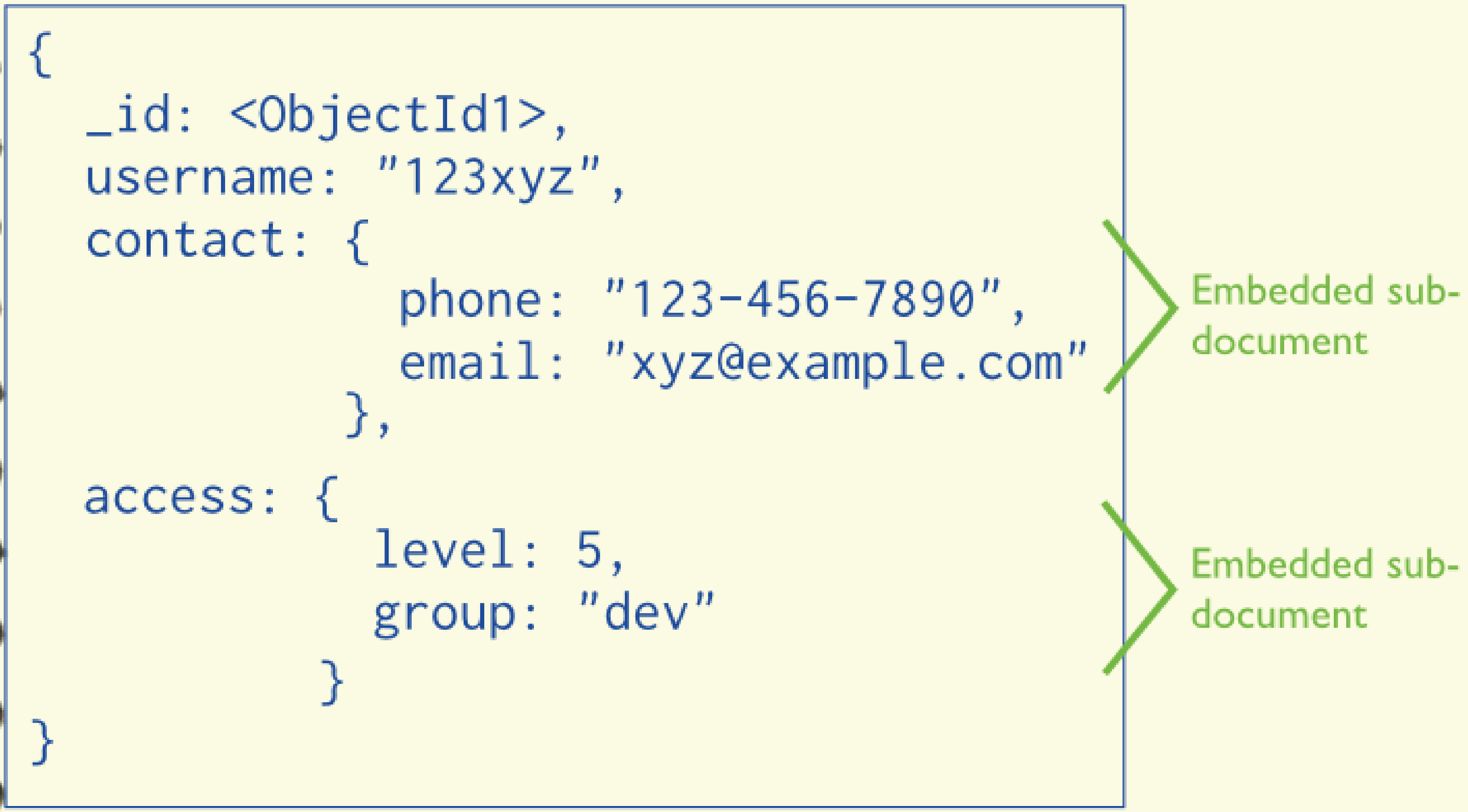
user document

```
{
  _id: <ObjectId1>,
  username: "123xyz"
}
```

access document

```
{
  _id: <ObjectId3>,
  user_id: <ObjectId1>,
  level: 5,
  group: "dev"
}
```

Documents: Structure Embedded



```
{
  _id: <ObjectId1>,
  username: "123xyz",
  contact: {
              phone: "123-456-7890",
              email: "xyz@example.com"
            },
  access: {
             level: 5,
             group: "dev"
           }
}
```

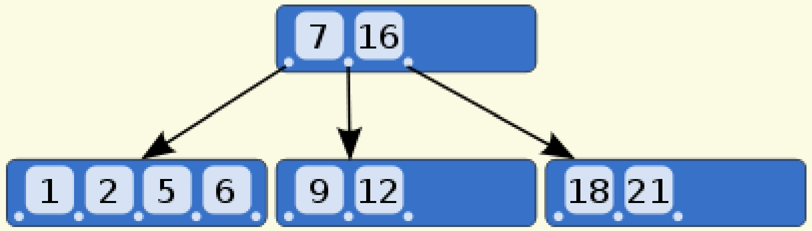
RDB Concepts to Document DB

RDBMS		MongoDB
Database	⇨	Database
Table, View	⇨	Collection
Row	⇨	Document (BSON)
Column	⇨	Field
Index	⇨	Index
Join	⇨	Embedded Document
Foreign Key	⇨	Reference
Partition	⇨	Shard

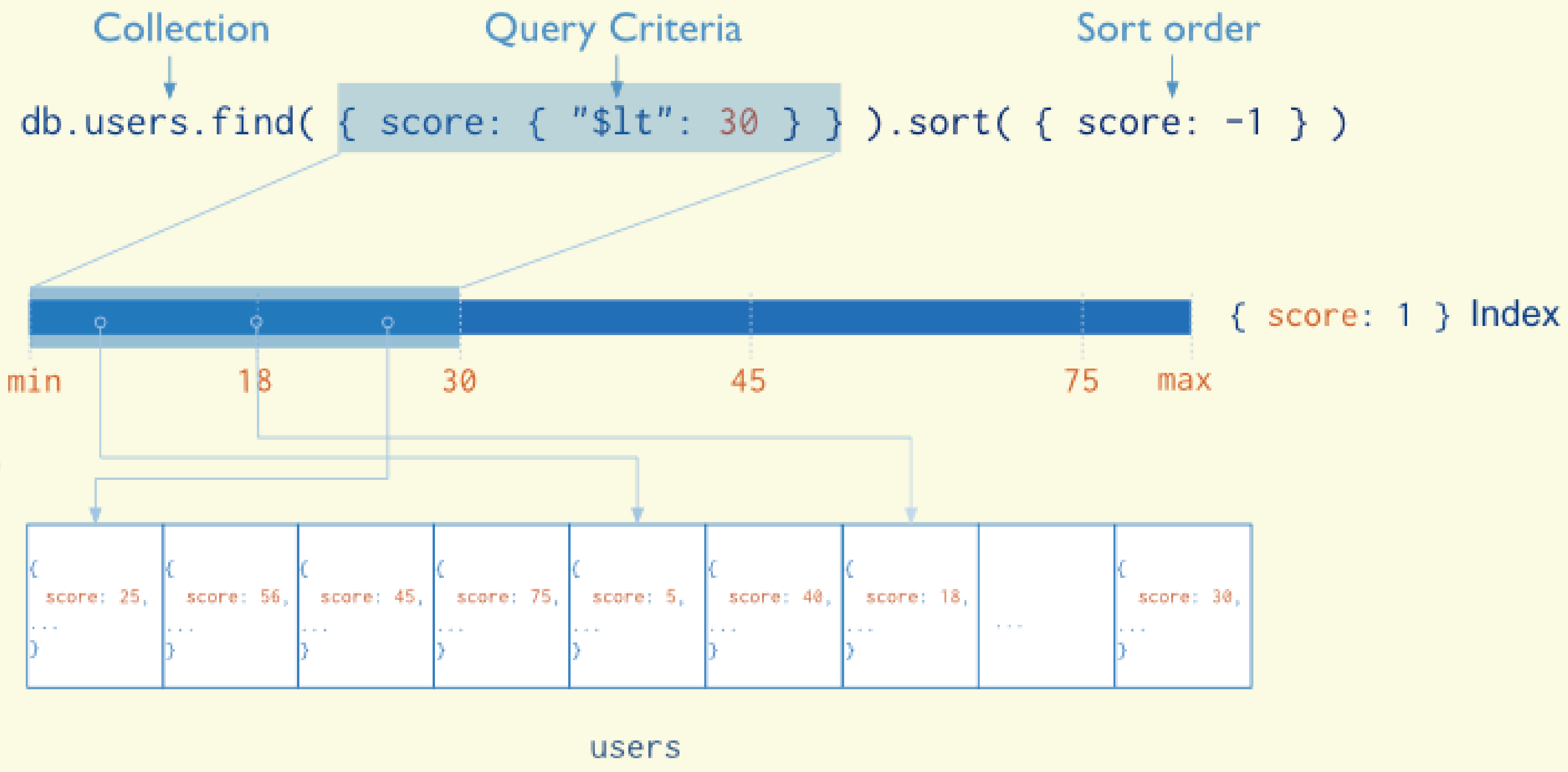
Documents: Indexing

- ✓ Indexes allows efficient queries on MongoDB.
- ✓ They are used to limit the number of documents to inspect (Otherwise, scan every document in a collection)
- ✓ By default MongoDB create indexes only on the _id field

- ✓ Indexes are created using B-tree and stores data of fields ordered by values.
- ✓ In addition, returns sorted results by using the index.



Documents: Indexing



```
db.users.find( { score: { "$lt": 30 } } ).sort( { score: -1 } )
```

Document DB: CRUD

CRUD

- ✓ Create
  - db.collection.insert(<document>)
  - db.collection.save(<document>)
  - db.collection.update(<query>, <update>, { upsert: true })
- ✓ Read
  - db.collection.find(<query>, <projection>)
  - db.collection.findOne(<query>, <projection>)
- ✓ Update
  - db.collection.update(<query>, <update>, <options>)
- ✓ Delete
  - db.collection.remove(<query>, <justOne>)

CRUD example

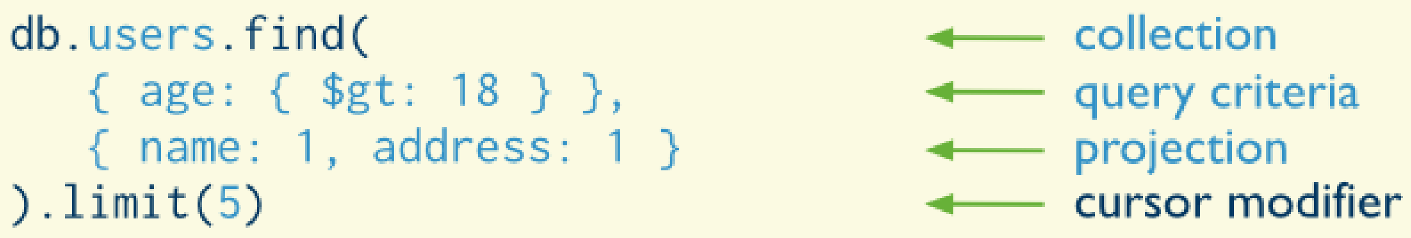
```
> db.user.insert({
      first: "John",
      last : "Doe",
      age: 39
})
```

```
> db.user.find ()
{
      "_id" : ObjectId("51…"),
      "first" : "John",
      "last" : "Doe",
      "age" : 39
}
```

```
> db.user.update(
      {"_id" :
ObjectId("51…")},
      { $set: {
            age: 40,
            salary: 7000}
      }
)
```

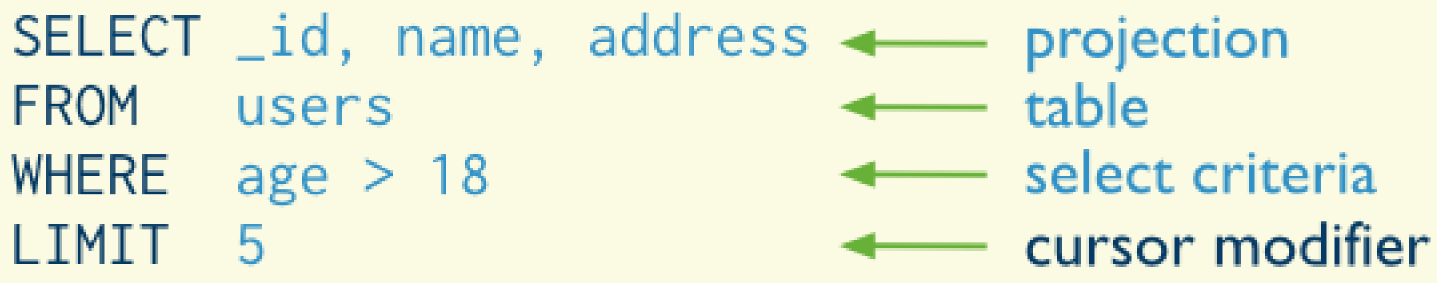
```
> db.user.remove({
      "first": /^J/
})
```

Query Interface



```
db.users.find(
   { age: { $gt: 18 } },
   { name: 1, address: 1 }
).limit(5)
```

The same query in SQL

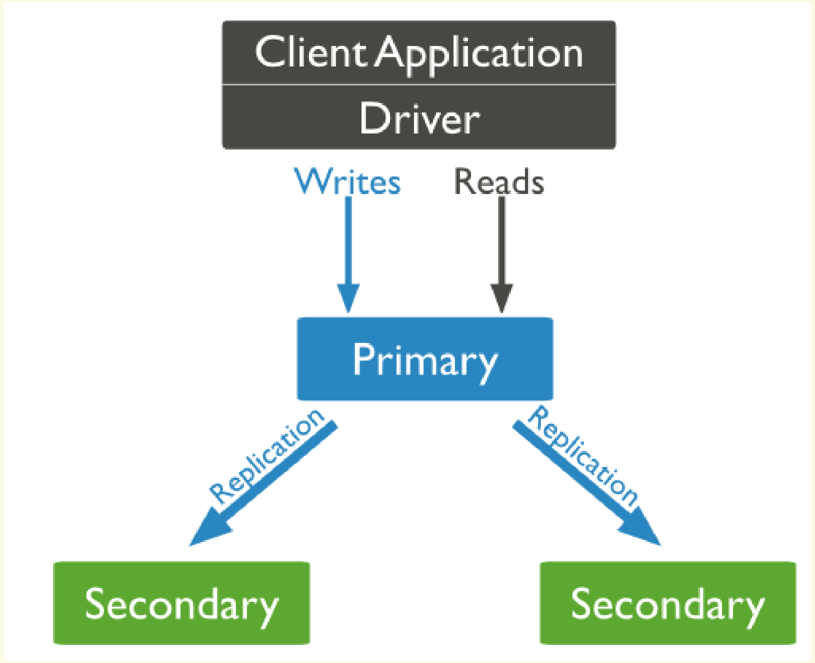


```
SELECT _id, name, address
FROM   users
WHERE  age > 18
LIMIT  5
```

Document DB: Scaling

Replication of data

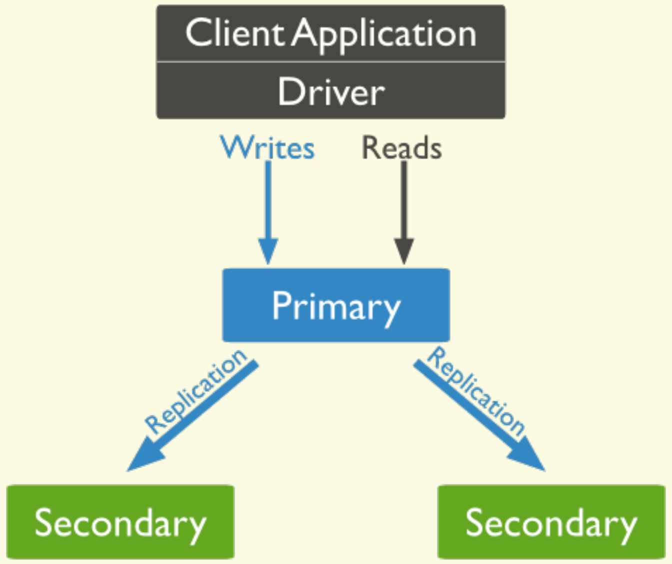
- Ensures redundancy, backup, and automatic failover
  - Recovery manager in the RDMS
- Replication through groups of servers known as replica sets
  - Primary set – set of servers that client tasks direct updates to
  - Secondary set – set of servers used for duplication of data
  - If the primary set fails the secondary sets ‘vote’ to elect the new primary set



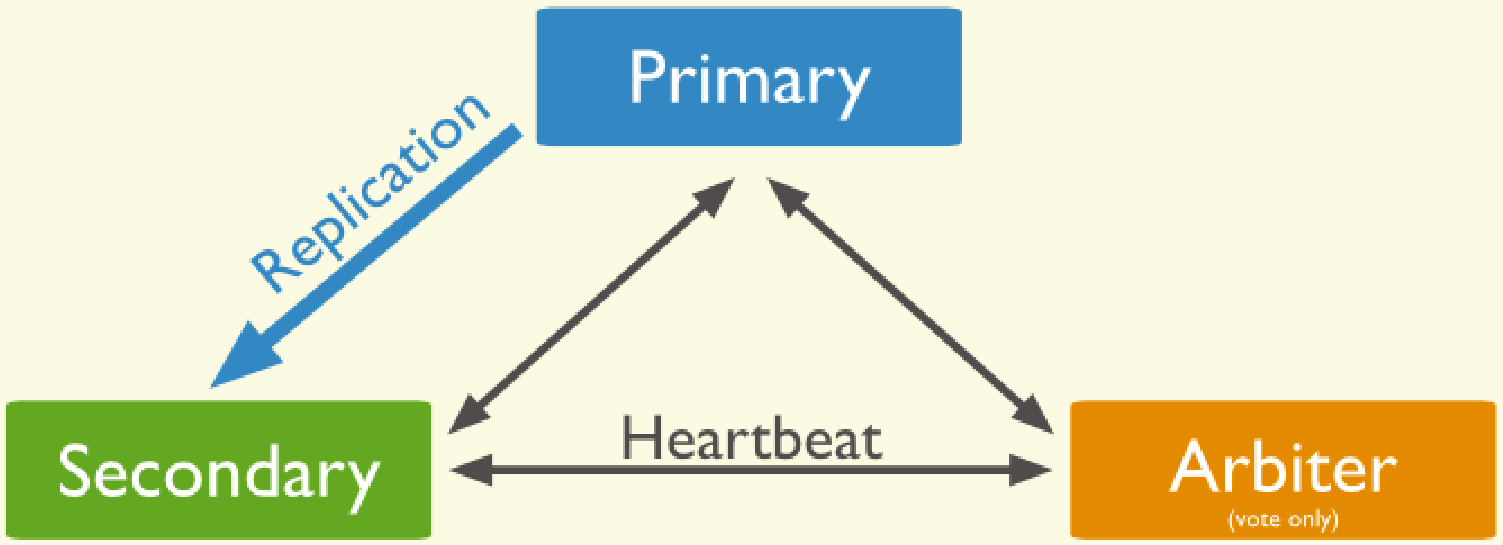
Scaling: Heavy Reads

- ✓ Scaling is achieved by adding more read slaves
- ✓ All the reads can be directed to the slaves.
- ✓ When a node is added it will sync with the other nodes -- no need to stop the cluster.

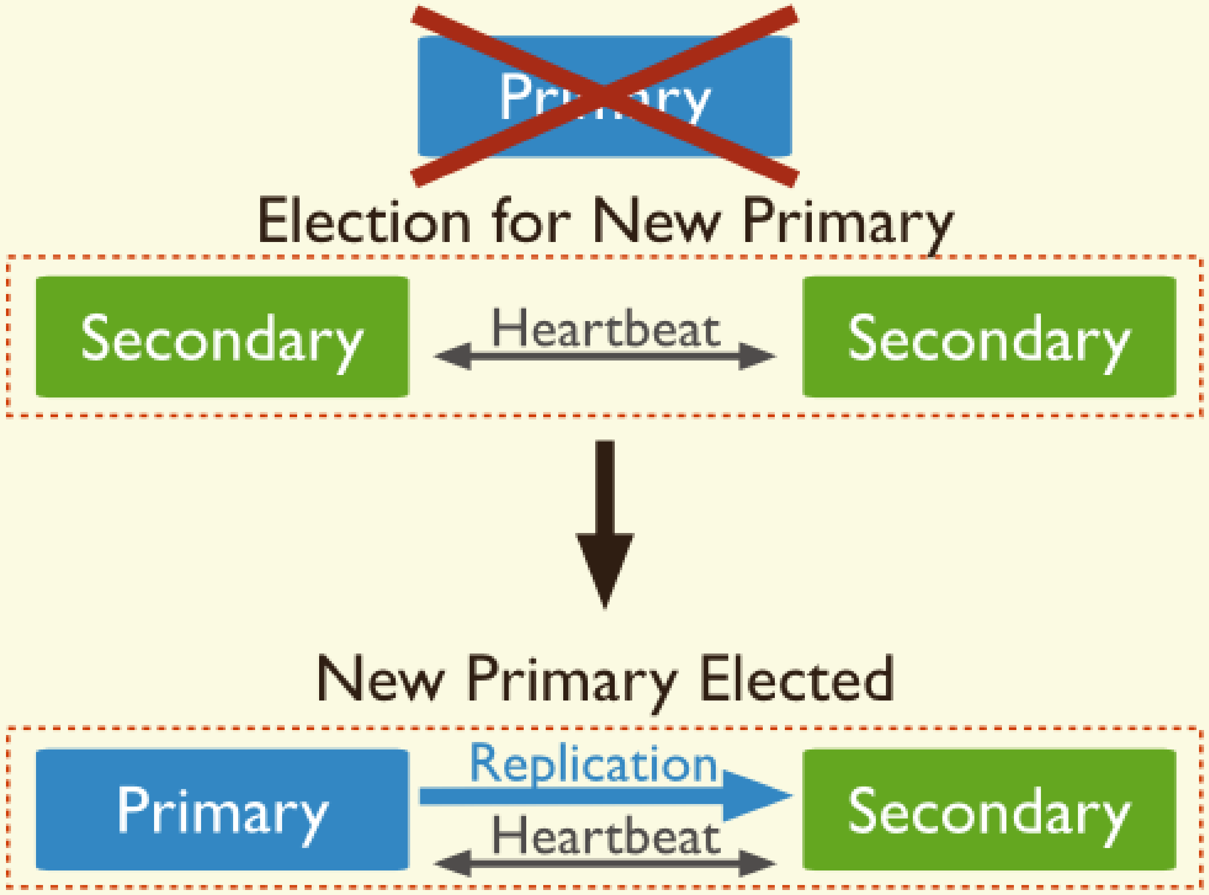
```
rs.add(“mongo_address:27017”)
```



Data Replication

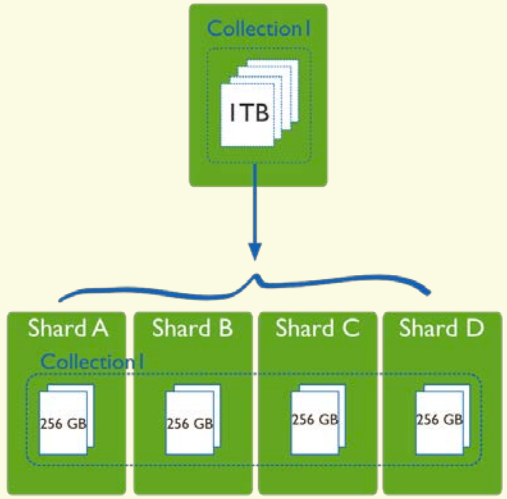


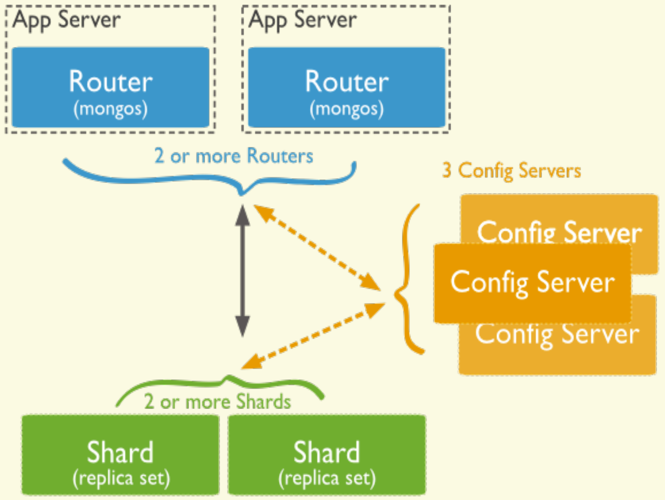
Automatic Failover



Sharding in MongoDB

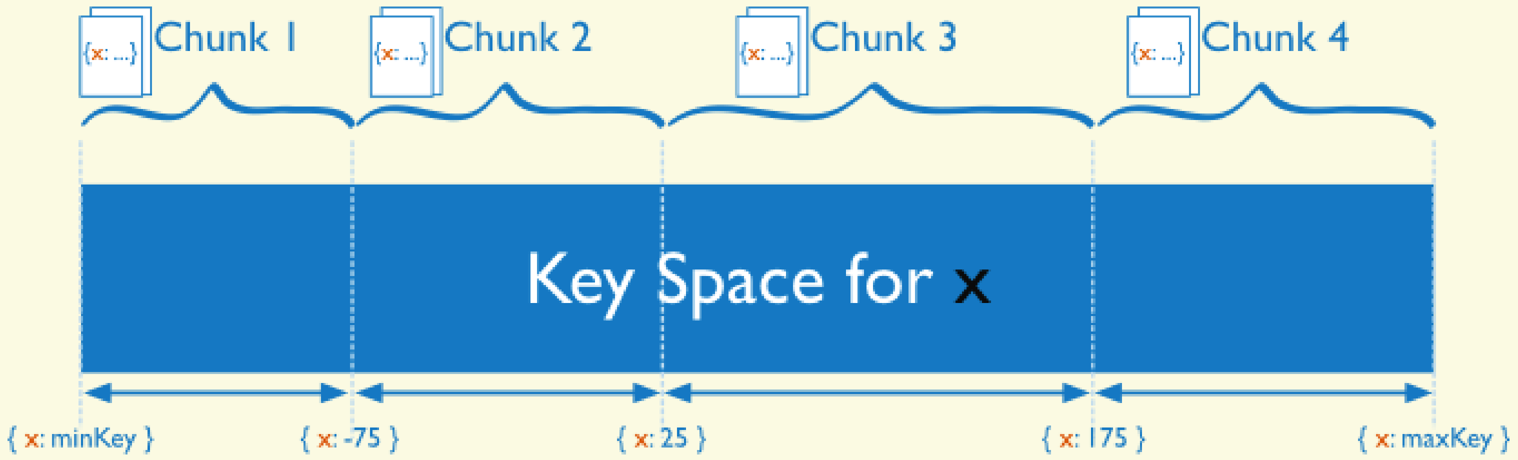
- ✓ Sharding, or horizontal scaling divides the data set and distributes the data over multiple servers.
- ✓ Each shard is an independent database, and collectively, the shards make up a single logical database.
- ✓ Query Routers: interface to client and direct queries
- ✓ Config Server: store cluster's metadata.





Range Based Sharding

✓ divides the data set into ranges determined by the shard key values to provide range based partitioning.

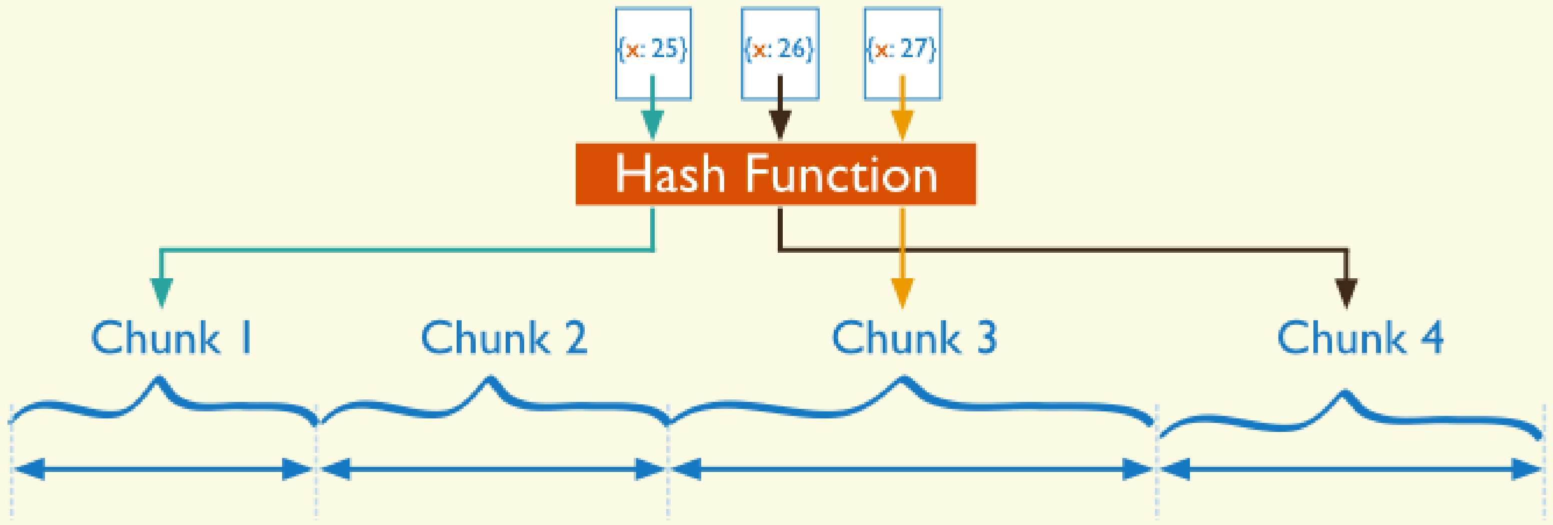


supports more efficient range queries

However, result in an uneven distribution of data.

Hash Based Sharding

- ✓ computes a hash of a field's value, and then uses these hashes to create chunks



More likely to ensure even distribution of data at the expense of efficient range queries.

Document Store: Advantages

- ✓ Documents are independent units
- ✓ Application logic is easier to write. (JSON).
- ✓ Schema Free:
  - – Unstructured data can be stored easily, since a document contains whatever keys and values the application logic requires.
  - – In addition, costly migrations are avoided since the database does not need to know its information schema in advance.

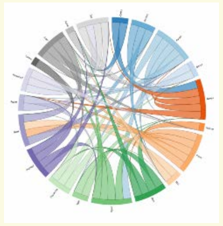
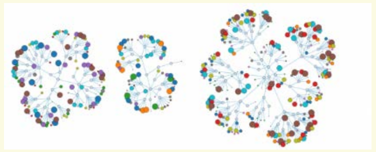
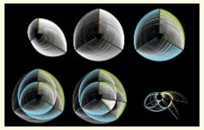
Suitable Use Cases

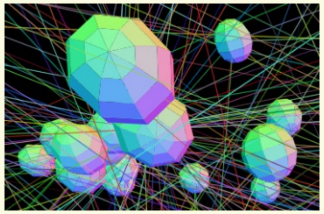
- ✓ **Event Logging:** where we need to store different types of event (order_processed, customer_logged).
- ✓ **Content Management System:** the schema-free approach is well suited
- ✓ **Web analytics or Real-Time Analytics:** useful to update counters, page views and metrics in general.

When Not to Use

- ✓ **Complex Transactions:** atomic cross-document operations
- ✓ **Queries against Varying Aggregate Structure:** i.e., when the structure of the aggregates vary because of continuous data evolutions

Graph databases



Motivations

- ✓ The necessity to represent, store and manipulate complex data make RDBMS somewhat obsolete

- ✓ Problem 1: Violations of the 1NF
  - Multi-valued attributes
  - Complex attributes

- ✓ Problem 2 : Accommodate Changes
  - acquiring data from autonomous dynamic sources or Web
  - RDBMS require schema renormalization

- ✓ Problem 3: Unified representation for:
  - Data
  - Knowledge (Schemas are a subset of this)
  - Queries [results + def]
  - Models (Concepts)

Existing Approaches

- ✓ RDBMS –need schema renormalization
- ✓ Approaches that try to fix the above mentioned problems:
  - OO Databases [P1], [P2] - graphs [but procedural]
  - XML Databases [P1] (somewhat [P3]) – trees
  - OORDBMS [P1] – graphs with foreign keys
  - RDF triple stores [P1, P2], somewhat [P3]
- ✓ Others
  - Datalog – more efficient fragment of Prolog
  - Network Models - graphs
  - Hierarchical Models – trees

What is a Graph Database?

- ✓ A database with an explicit graph structure: Each node knows its adjacent nodes
- ✓ As the number of nodes increases, the cost of a local step (or hop) remains the same; Plus an Index for lookups
- ✓ Express Queries as Traversals. Fast deep traversal instead of slow SQL queries that span many table joins.
- ✓ Very natural to express graph related problem with traversals (recommendation engine, find shortest path etc..)
- ✓ Seamless integration with various existing programming languages.
  - Two design principle: Declarativity & Change
- ✓ Distinguish between “Database for graph as object”!

Database Representation

- ✓ Sailors(sid:integer, sname:char(10), rating: integer, age:real)
- ✓ Boats(bid:integer, bname:char(10), color:char(10))
- ✓ Reserve(sid:integer, bid:integer, day:date)

Sailors

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

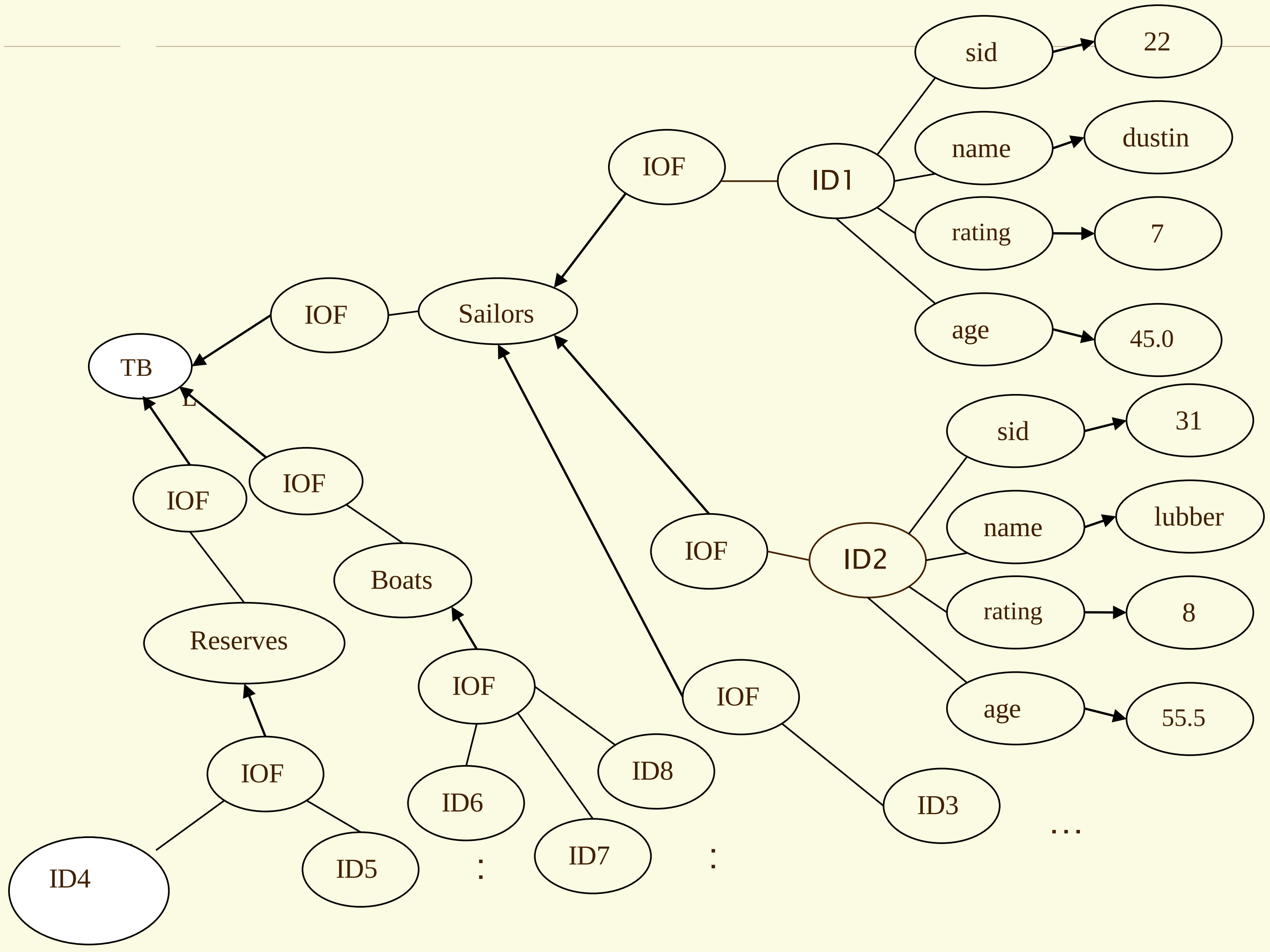
Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

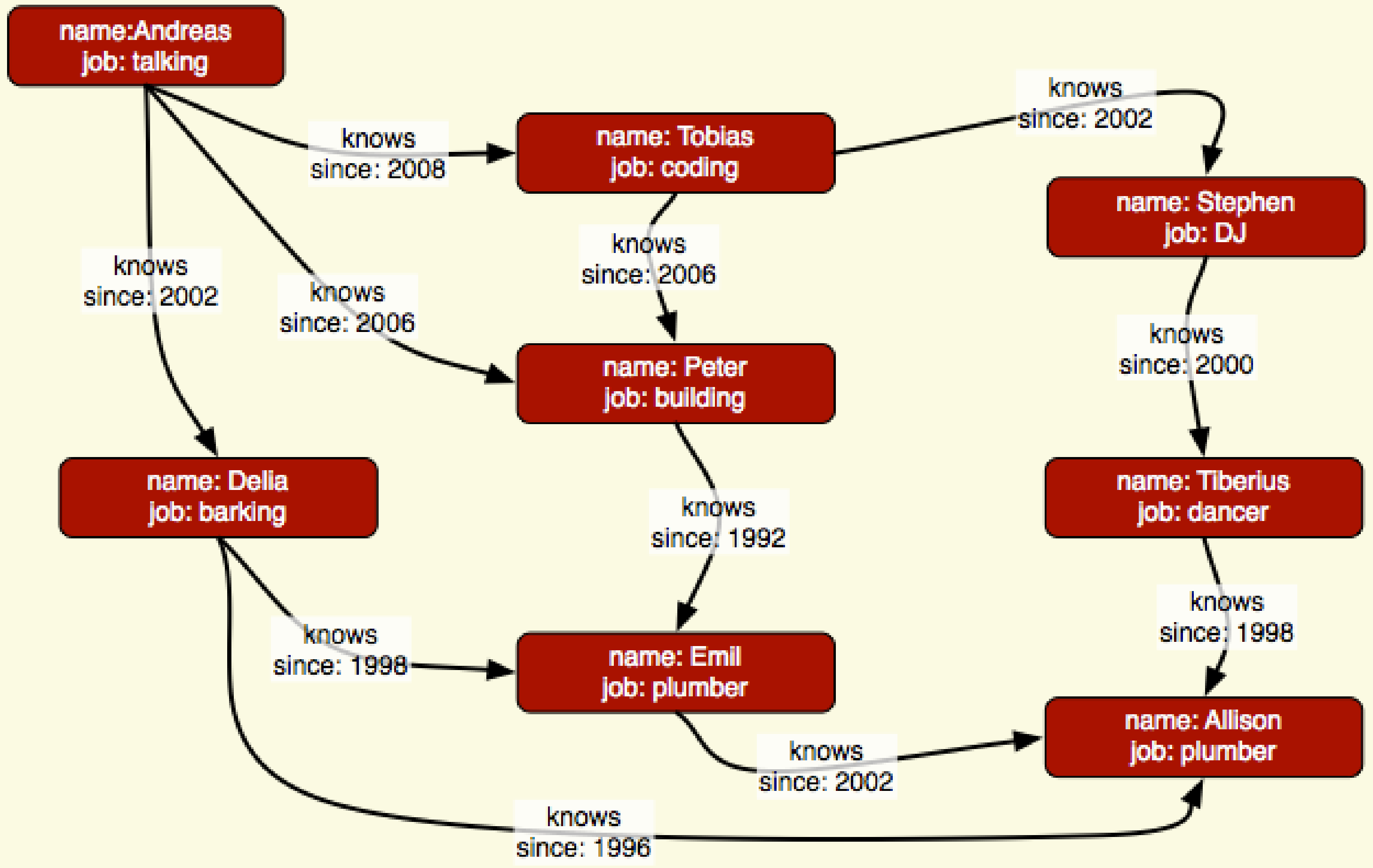
Boats

bid	bname	color
101	Interlake	red
102	Clipper	green
103	Marine	red

Graph Representation

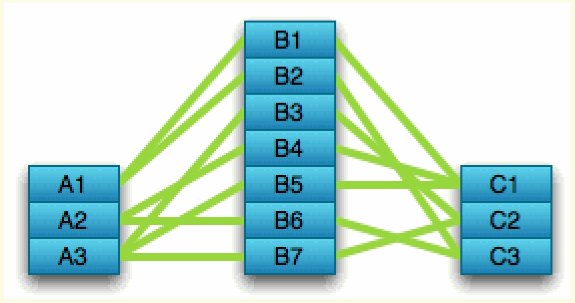


Property Graph

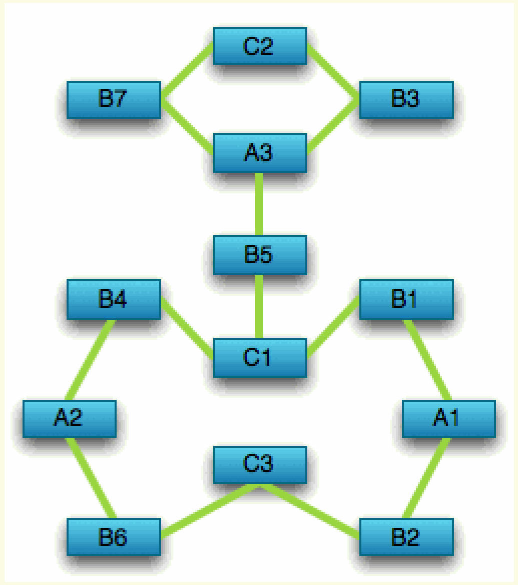


Compared to Relational Databases

Optimized for aggregation

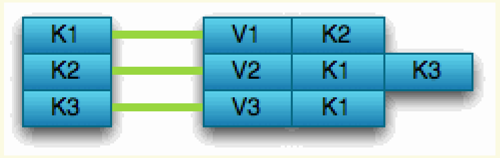


Optimized for connections

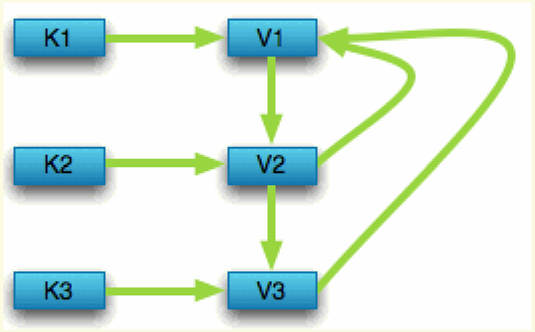


Compared to Key Value Stores

Optimized for
simple look-ups

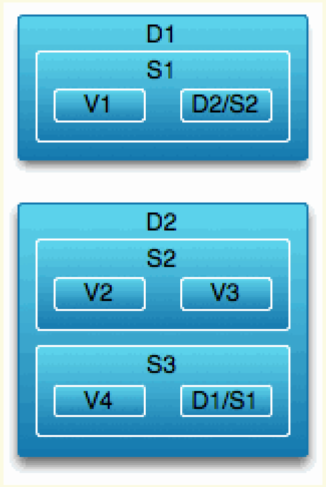


Optimized for
traversing connected data

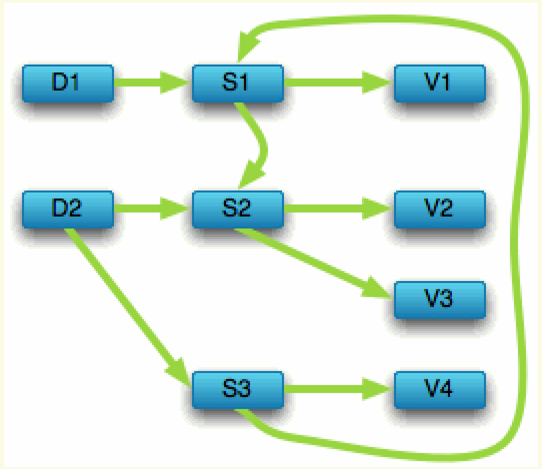


Compared to Document Stores

Optimized for "trees" of data



Optimized for seeing the forest and the trees, the branches, and the trunks



Social Network “path exists” Performance

- ✓ Experiment:
  - ~1k persons
  - Average 50 friends per person
  - `pathExists(a,b)` limited to depth 4

	# persons	query time
Relational database	1000	2000ms
Neo4j	1000	2ms
Neo4j	1000000	2ms

Neo4j?

- ✓ A Graph Database + Lucene Index
- ✓ Property Graph
- ✓ Full ACID (atomicity, consistency, isolation, durability) (?)
- ✓ High Availability (with Enterprise Edition)
- ✓ 32 Billion Nodes, 32 Billion Relationships, 64 Billion Properties
- ✓ Embedded Server
- ✓ REST API

Good For

- ✓ Highly connected data (social networks)
- ✓ Recommendations (e-commerce)
- ✓ Path Finding (how do I know you?)
- ✓ A* (Least Cost path)
- ✓ Data First Schema (bottom-up, but you still need to design)

Summary: noSQL systems

Summary

- ✓ SQL Databases
  - Predefined Schema
  - Standard definition and interface language
  - Tight consistency (ACID)
  - Well defined semantics

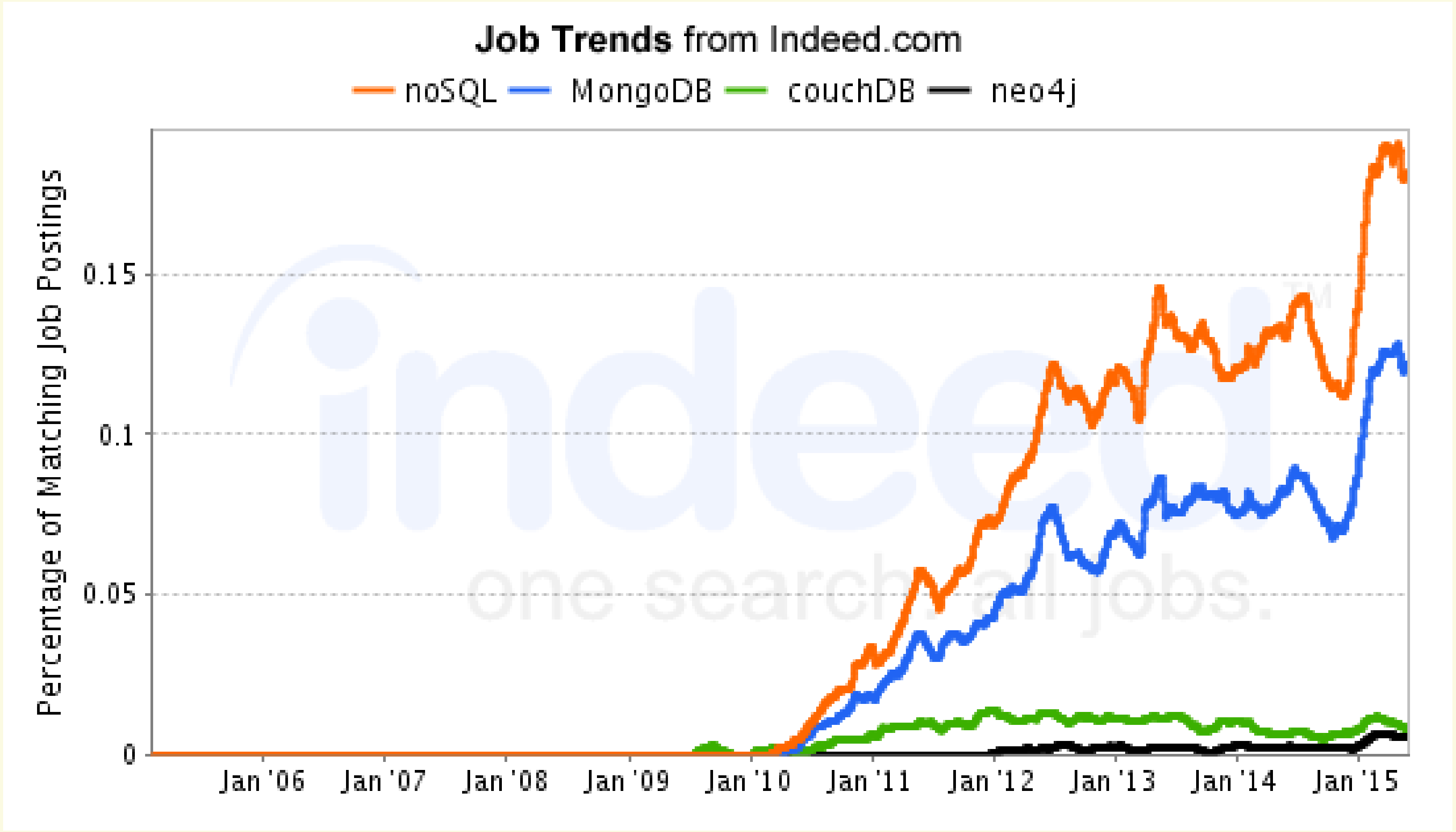
- ✓ NoSQL Database
  - No predefined Schema
  - Per-product definition and interface language
  - Getting an answer quickly is more important than getting a correct answer (BASE)

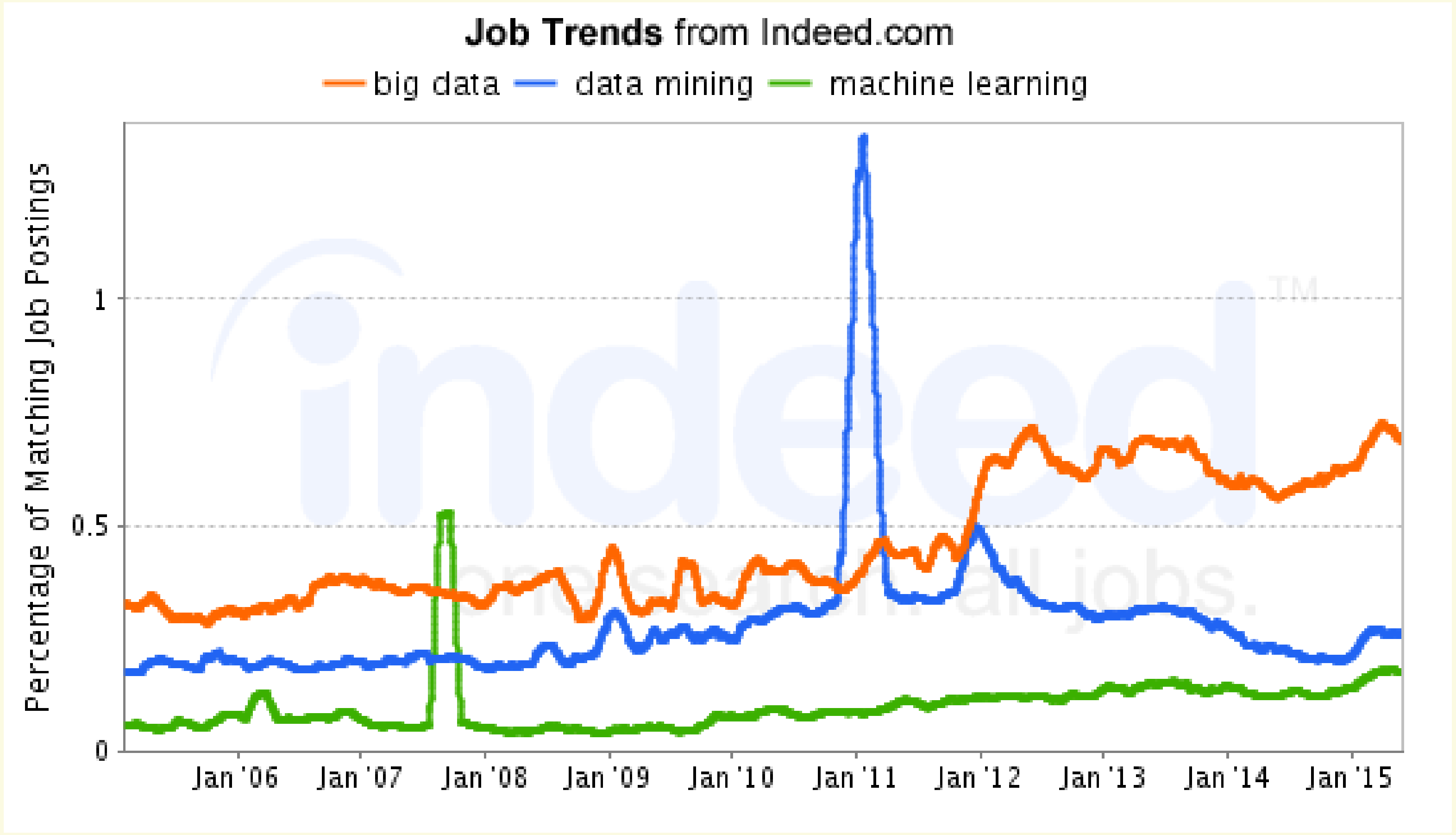
Summary: noSQL Common Advantages

- ✓ Cheap, easy to implement (open source)
- ✓ Data are replicated to multiple nodes (therefore identical and fault-tolerant) and can be partitioned
  - Down nodes easily replaced
  - No single point of failure
- ✓ Easy to distribute
- ✓ Don't require a schema
- ✓ Can scale up and down
- ✓ Relax the data consistency requirement (CAP)

Summary: What are we giving up?

- ✓ joins
- ✓ group by
- ✓ order by
- ✓ ACID transactions (none are strict ACID!)
- ✓ SQL as a sometimes frustrating but still powerful query language
- ✓ easy integration with other applications that support SQL


Job Trends from Indeed.com
noSQL
MongoDB
couchDB
neo4j
Percentage of Matching Job Postings
0.15
0.1
0.05
0
Jan '06
Jan '07
Jan '08
Jan '09
Jan '10
Jan '11
Jan '12
Jan '13
Jan '14
Jan '15
indeed
one search. all jobs.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