Advanced Data Management

Thomas Heinis

EPFL

Imperial College London

Some Data Management History…

The Database

What about…

Reliability?

Security?

Consistency?

Response time?

Scalability?

Relational Databases

- Structured, schema-based organization of data
- Data decomposed into tables, ex. customer data:

Customer		
Name	**Date**	**City**
Dustin	12.1.1971	London
Jack	8.19.1965	Leicester

City	
City	**Country**
London	UK
Leicester	UK

- SQL - General-purpose query language
- Join tables to retrieve all data: e.g., SELECT * FROM Customer, City WHERE City.City = Customer.City
- Focused on strong consistency (ACID)

Transactions – Data Integrity

Why Concurrent Access to Data must be managed?

John and Jane withdraw $50 and $100 from a common account…

John:
1. get balance
2. if balance > $50
3. balance = balance - $50
4. update balance

Jane:
1. get balance
2. if balance > $100
3. balance = balance - $100
4. update balance

Initial balance $300. Final balance=?

It depends…

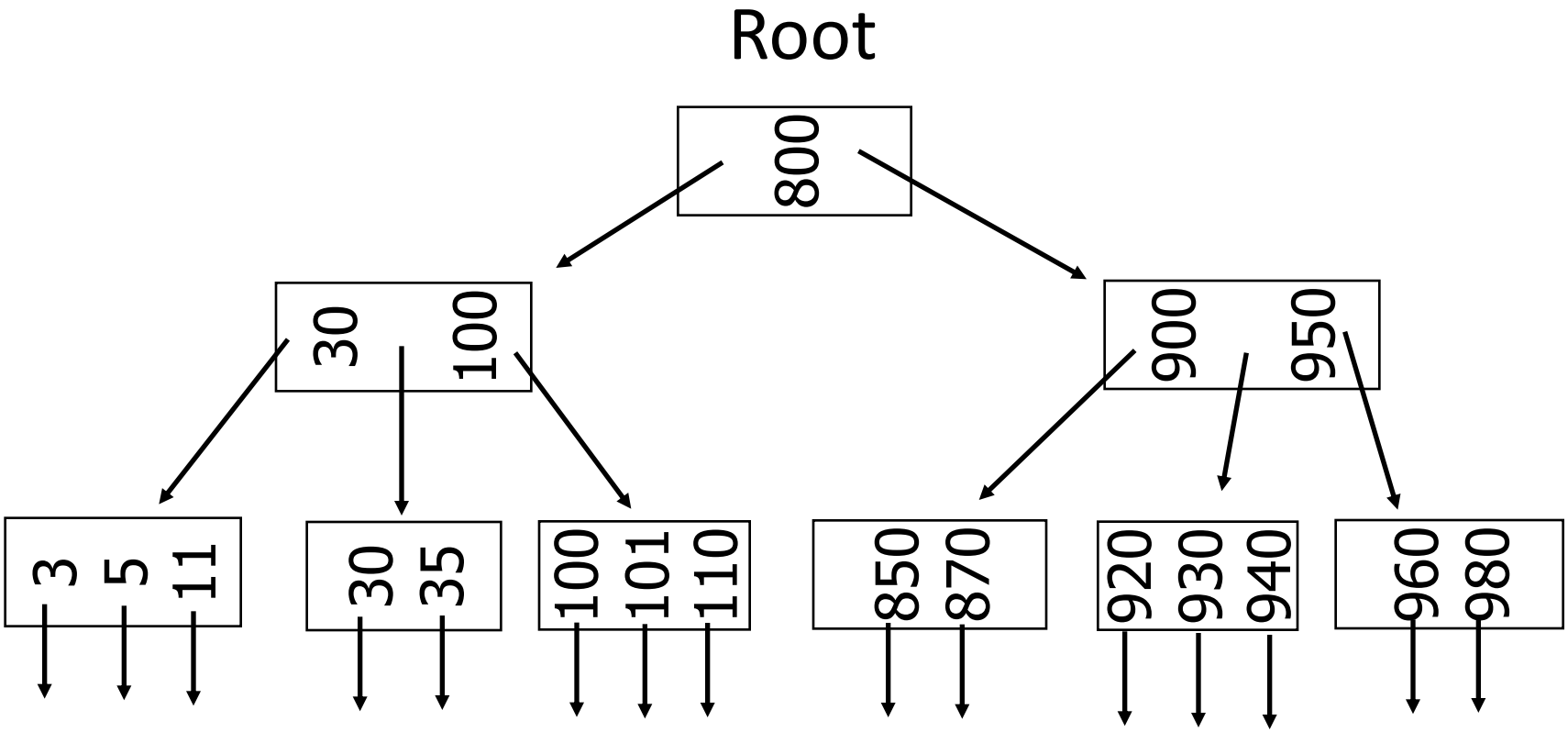
Need to order operations ➔ transactions!

Indexing – Efficient Data Retrieval

- How can we answer the query: “Find the account with the balance of 920.-” efficient?

- One approach is to scan the entire customer table, check every customer, return the one with balance = 920 … very slow for large databases

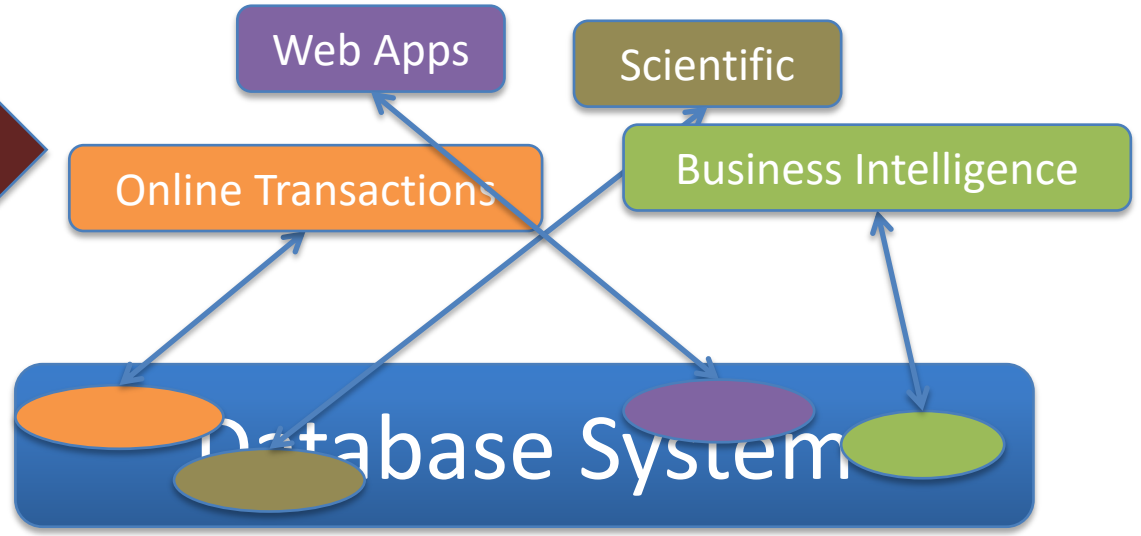
Example Index (B-Tree)



NOSQL DATABASES

Database Systems Today

New applications, more requirements!



Rapidly changing hardware, new performance hurdles!

Relational Databases: One Size Does Not Fit All…

New applications challenge relational databases:

1. Strong consistency (ACID) limits scalability
2. Schema evolution is challenging
3. Little optimization for novel hardware
4. Cumbersome language
5. Limited data types

NoSQL

"Not Only SQL" or "Not Relational".
Six key features:

1. Scale horizontally "simple operations"
2. Replicate/distribute data over many servers
3. Simple call level interface (contrast w/ SQL)
4. Weaker concurrency model than ACID
5. Efficient use of distributed indexes and main memory
6. Flexible schema

Key-value Stores

- Operate on key-value pairs
- Single key to store (or retrieve) data value
- Think “file system” more than “database”
- Consistent hashing (DHT)
- Only primary index: lookup by key
- No secondary indexes

Key-Value Store – Basic Idea

Table T:

key	value
k1	v1
k2	v2
k3	v3
k4	v4

- No query language!
- API with simple operations:
  - lookup(key) → value
  - lookup(key range) → values
  - getNext → value
  - insert(key, value)
  - delete(key)
- Each row has timestamp
- No multi-key transactions

Document Stores

- A "document" = a pointerless object = e.g. JSON = nested or not = schema-less
- In addition to KV stores, may have secondary indexes
- SimpleDB, CouchDB, MongoDB, Terrastore
- Scalability:
  - Replication (e.g. SimpleDB, CounchDB – means entire db is replicated),
  - Sharding (MongoDB);
  - Both

Document Store (MongoDB)

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

```
> db.user.find ({"first" : "John"})
{
      "_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/
})
```

Scalable Relational Systems (NewSQL)

- Means relational databases that offer sharding
- **Key difference to NoSQL**:
  - NoSQL difficult or impossible to perform large-scope operations and transactions
  - NewSQL systems do not **preclude** these operations, but users pay a price only when they need them.
- MySQL Cluster, VoltDB, Clusterix, ScaleDB, Megastore (the new BigTable)
- Many more **NewSQL** systems coming online…

Scalable Data Processing

- Parallel execution achieves greater efficiency
- But, parallel programming is hard
  - Parallelization
  - Fault Tolerance
  - Data Distribution
  - Load Balancing

MapReduce (Hadoop and others)

- "*MapReduce is a programming model and an associated implementation for processing and generating large data sets*"
- Programming model
  - Abstractions to express simple computations
- Library
  - Takes care of the gory stuff: Parallelization, Fault Tolerance, Data Distribution and Load Balancing

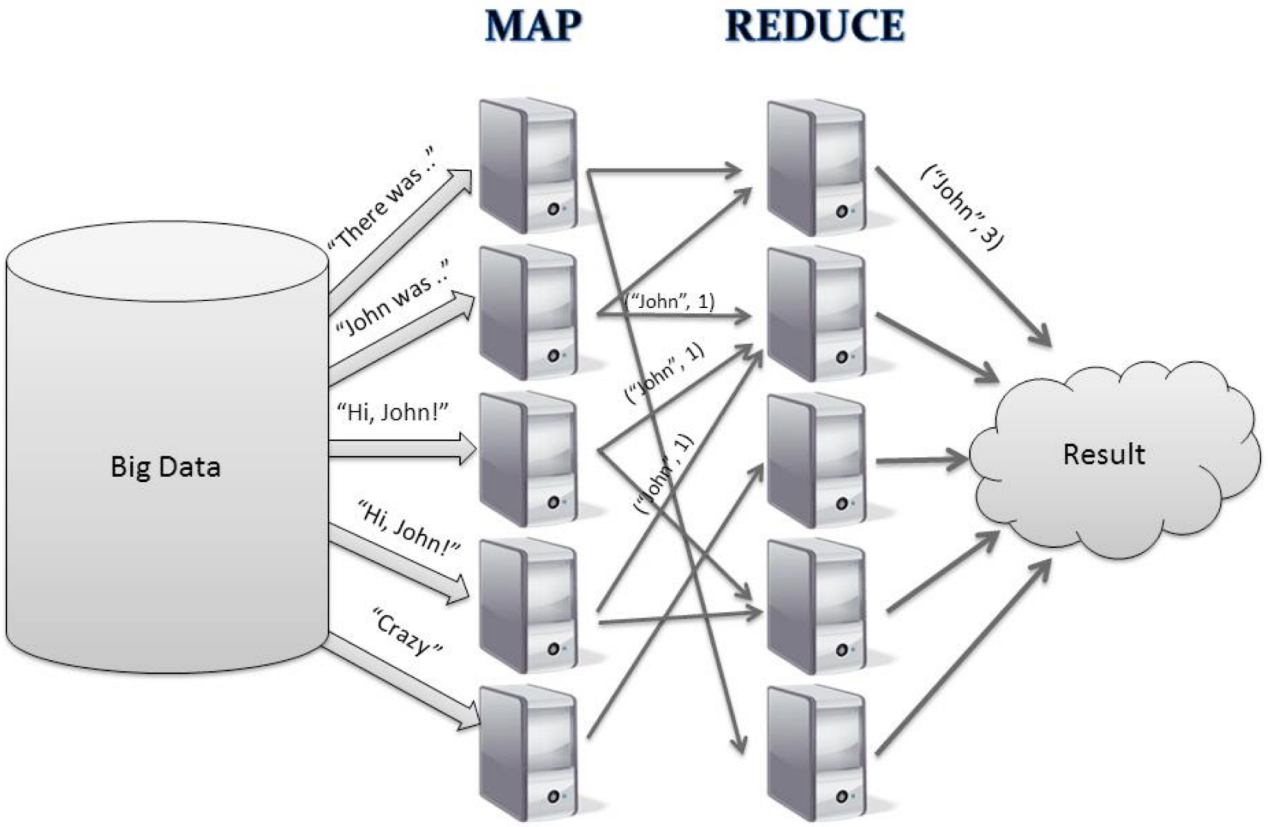
Programming Model

- To generate a set of output key-value pairs from a set of input key-value pairs
  - $\{ < k_i, v_i > \} \rightarrow \{ < k_o, v_o > \}$
- Expressed using two abstractions:
  - Map task

    $< k_i, v_i > \rightarrow \{ < k_{int}, v_{int} > \}$
  - Reduce task

    $< k_{int}, \{v_{int}\} > \rightarrow < k_o, v_o >$
- Library
  - aggregates all the all intermediate values associated with the same intermediate key
  - passes the intermediate key-value pairs to ***reduce*** function

MapReduce Architecture



NoSQL Systems

- Key Value Stores

Key	Value
SW3 3TB	London
B18 4BJ	Birmingham

- Document Stores

- Scalable SQL Systems

- Data Processing Systems

NoSQL Challenges

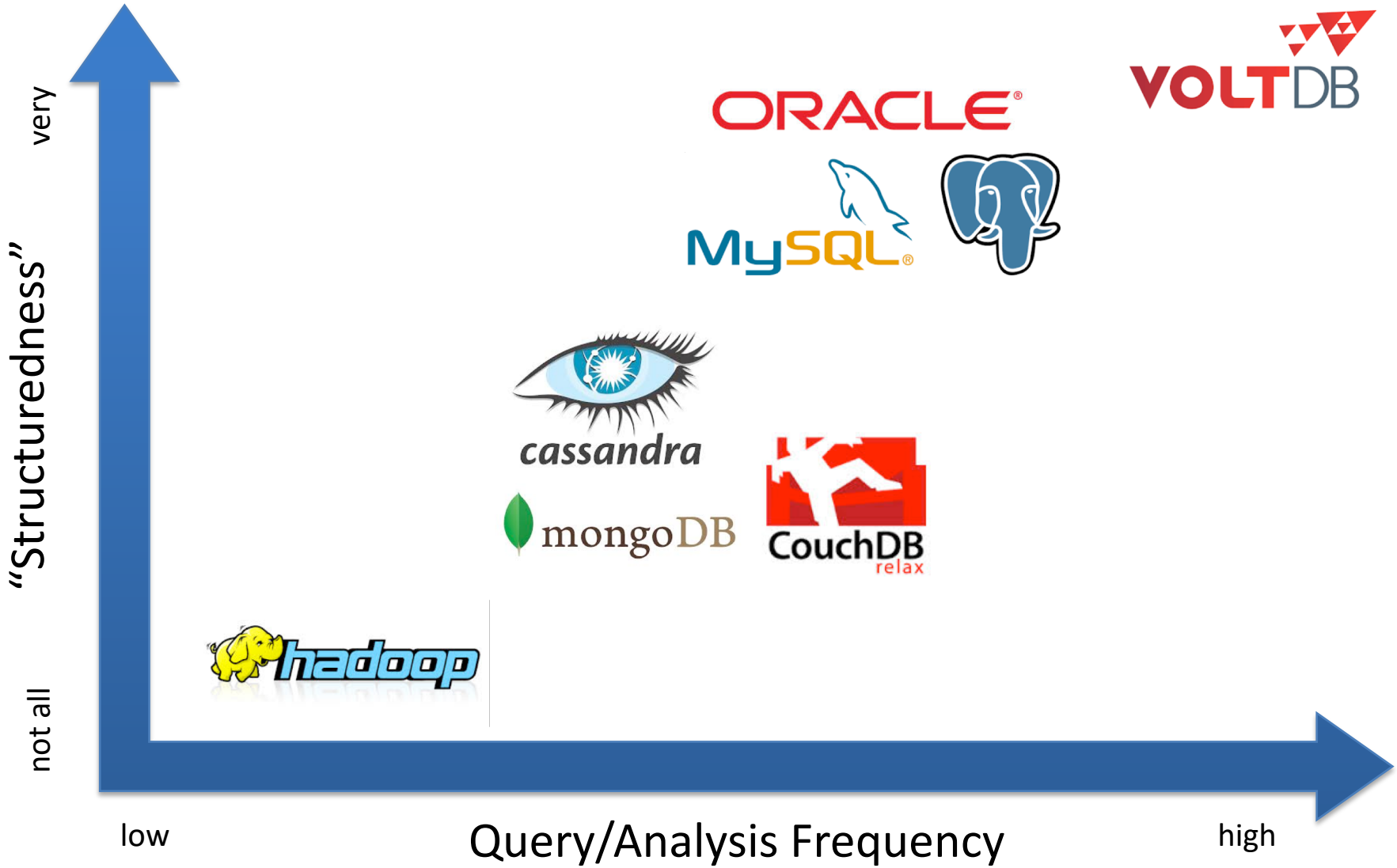
E.g., Flexible Schemas in MongoDB

```
db.inventory.insert(
  {
    category: ”vacuum",
    details: {
      model: "14Q3",
      manufacturer: "XYZ Company"
    },
    stock: [ { size: "S", qty: 25 }],
    category: "clothing"
  }
)
```

```
db.inventory.insert(
  {
    category: ”vacuum",
    details: {
      model: "14Q3",
      manufacturer: "XYZ Company"
    },
    color: ”blue"
  }
)
```

What fields does db.user.find ({”category" : ”vacuum”}) have?

Data Management Landscape*



* according to me