NOSQL
EECS4415 – Big Data Systems
How to leverage the NoSQL boom?

DO YOU HAVE ANY EXPERTISE IN SQL?

NO

**Leverage the NoSQL boom**

**DOESN'T MATTER. WRITE: “EXPERT IN NO SQL”**
Overview

• Part I: Structured, unstructured, semi-structured data
• Part II: What is NOSQL?
• Part III: NOSQL taxonomy

Thanks to Suprio Ray for some material in these slides
Part I: Structured, Unstructured and Semi-structured Data
Structured vs. unstructured data

- Databases are highly structured
  - Well-known data format: relations and tuples
  - Every tuple conforms to a known schema
  - Data independence? Woe unto you if you lose the schema
- Plain text is unstructured
  - Cannot assume any predefined format
  - Apparent organization makes no guarantees
  - Self-describing: little external knowledge needed
    ... but have to infer what the data means
Structured vs. unstructured data (examples)

**Data Format**

**Structured**
- **Human-Generated**
  - Survey ratings
  - Aptitude testing
  - Machine-Generated
  - Web metrics from Web logs
  - Product purchase from sales records
  - Process control measures

**Unstructured**
- **Human-Generated**
  - Emails, letters, text messages
  - Audio transcripts
  - Customer comments
  - Voicemails
  - Corporate video/communications
  - Pictures, illustrations
  - Employee reviews

**Data Source**

**Internal**
- Human-Generated
  - Number of Retweets, Facebook likes, Google Plus +1s
  - Ratings on Yelp
  - Patient ratings ratings

**External**
- Human-Generated
  - YouTube
  - Facebook
  - Yelp
  - Data.gov
  - Flickr
  - GPS for tweets
  - Time of tweet/uploads/postings

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Structured vs unstructured data

Structured Data vs Unstructured Data

- Can be displayed in rows, columns and relational databases
- Numbers, dates and strings
- Estimated 20% of enterprise data (Gartner)
- Requires less storage
- Easier to manage and protect with legacy solutions

Unstructured Data

- Cannot be displayed in rows, columns and relational databases
- Images, audio, video, word processing files, e-mails, spreadsheets
- Estimated 80% of enterprise data (Gartner)
- Requires more storage
- More difficult to manage and protect with legacy solutions

source: https://www.igneous.io/blog/structured-data-vs-unstructured-data
Semi-structured data

• Observation: most data has some structure
  – Text: sentences, paragraphs, sections, ...
  – Books: chapters
  – Web pages: HTML

• Idea of semistructured data:
  – Enforce “well-formatted” data
    => Always know how to read/parse/manipulate it
  – Optionally, enforce “well-structured” data also
    => Adheres to a less-strict schema
    => Might help us interpret the data, too

Pro: highly portable    Con: verbose/redundant
Semi-structured data: JSON

Describing a menu:

```json
{"menu": {
    "id": "file",
    "value": "File",
    "popup": {
        "menuitem": [
            {"value": "New", "onclick": "CreateNewDoc()"},
            {"value": "Open", "onclick": "OpenDoc()"},
            {"value": "Close", "onclick": "CloseDoc()"}
        ]
    }
}}
```
Semi-structured data: XML

Describing a menu:

```xml
<menu id="file" value="File">
  <popup>
    <menuitem value="New" onclick="CreateNewDoc()" />
    <menuitem value="Open" onclick="OpenDoc()" />
    <menuitem value="Close" onclick="CloseDoc()" />
  </popup>
</menu>
```
Part II: What is NOSQL?
NoSQL

A history of databases in No-tation

1970: NoSQL = We have no SQL
1980: NoSQL = Know SQL
2000: NoSQL = No SQL!
2005: NoSQL = Not only SQL
2013: NoSQL = No, SQL!

(R)DB(MS)

source: Mark Madsen
NoSQL Definition

From www.nosql-database.org:

Next generation databases mostly addressing some of the points: being non-relational, distributed, open-source and horizontal scalable. The original intention has been modern web-scale databases. The movement began early 2009 and is growing rapidly. Often more characteristics apply as: schema-free, easy replication support, simple API, eventually consistent / BASE (not ACID), a huge data amount, and more.
Motivation: avoid RDBMS/SQL limitations

- Harder to scale - **expensive**
- Joins across multiple nodes - **hard**
- How does RDBMS handle data growth - **hard**
- Rigid schema design - **not manageable**
- Need for a DBA - **expensive**
NoSQL Distinguishing Characteristics

- Can handle large data volumes
  - “big data”
- Scalable replication and distribution
  - Thousands of machines distributed around the world
  - “Queries” can return answers quickly
- Schema-less (schema-at-read vs schema-at-write)
- ACID transaction properties are not needed – BASE
- CAP Theorem
Scaling vertically vs. horizontally

**Vertical Scaling / Scale Up**
- Upgrade to more powerful hardware
- Issues:
  - additional investment
  - single point of failure (SPOF)

**Horizontal Scaling / Scale Out**
- Add extra identical boxes to server
- Issues
  - network communication
  - workload balancing
  - additional Investment
Network partition

To scale out, you need a **distributed** store (cluster of servers)

=> can lead to network partition

=> refers to failures of network that causes communication interruptions

AWS data centers with worldwide underwater cables

(src: http://turnkeylinux.github.io/aws-datacenters/)
CAP Theorem

It is impossible for a distributed data store to simultaneously provide more than two out of the following three guarantees:

**Consistency**: Every read receives the most recent write or an error

**Availability**: Every request receives a (non-error) response – without guarantee that it contains the most recent write

**Partition Tolerance**: The system continues to operate despite an arbitrary number of messages being dropped (or delayed) by the network between nodes
CAP Theorem & example data stores

- **Availability**: Each client can always read and write.
- **Partition Tolerance**: The system works well despite physical network partitions.
- **Consistency**: All clients always have the same view of the data.

**Data Models**
- Relational (Comparison)
- Key-value
- Column-oriented/Tabular
- Document oriented

**Examples**

- **CA**
  - RDBMSs (MySQL, Postgres, etc)
  - Aster Data
  - Greenplum
  - Vertica

- **CP**
  - BigTable
  - HyperTable
  - HBase

- **AP**
  - Dynamo
  - Voldemort
  - Tokyo Cabinet
  - KAI
  - Cassandra
  - SimpleDB
  - CouchDB
  - Riak

**Pick 2**

- CA
- CP
CAP Theorem in real-life

Amazon shopping cart: adding to the shopping cart

- **Availability**
  - *always want to honor requests* to add items to a shopping cart

- **Consistency**
CAP Theorem in real-life

Amazon shopping cart: checkout process

- **Availability**
- **Consistency**
  - you favor consistency because several services are simultaneously accessing the data (credit card processing, shipping and handling, reporting)
ACID vs. BASE

Relational
- Atomicity
- Consistency
- Isolation
- Durability

NoSQL
- Basically
- Available (CP)
- Soft-state
- Eventually consistent (AP)

Pritchett, D.: BASE: An Acid Alternative (queue.acm.org/detail.cfm?id=1394128)
Recap: Transactions – ACID Properties

• **Atomic**: all of the work in a transaction completes (commit) or none of it completes
• **Consistent**: a transaction transforms the database from one consistent state to another consistent state; consistency is defined in terms of constraints
• **Isolated**: the results of any changes made during a transaction are not visible until the transaction has committed
• **Durable**: the results of a committed transaction survive failures
BASE Transactions

Acronym contrived to be the opposite of ACID

- **Basically Available**: system seems to work all the time - some parts of system remain available on failure
- **Soft state**: it does not have to be consistent all the time
- **Eventually Consistent**: as the data is written, the latest version is on at least one node. The data is then versioned/replicated to other nodes within the system. Eventually, the same version is on all nodes
BASE Transactions

• Characteristics
  – Availability first
  – Best effort
  – Weak consistency – stale data OK
  – Approximate answers OK
  – Simpler and faster
NoSQL 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
• Can scale up and down
• Doesn't require a schema
What am I giving up?

• Joins (in many cases)
• ACID transactions
• SQL, as a sometimes frustrating, but still powerful query language
• Easy integration with other SQL-based applications
Part III: NOSQL Taxonomy
NoSQL Taxonomy

Document store

- Key
- Document (collection of key-values)

Column store

- Key
- CF1: C1, CF1: C2, CF2: C1, CF3: C1

Key-value store

- Key
- Binary Data

Graph store

- Node 1
  - Key
  - Properties
  - Relationship 1
    - Key
    - Properties
  - Node 2
    - Key
    - Properties
## NoSQL Taxonomy - example data stores

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<td><img src="https://example.com/couchdb" alt="CouchDB" /> <img src="https://example.com/mongodb" alt="mongoDB" /></td>
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<tr>
<td>Column store</td>
<td><img src="https://example.com/cassandra" alt="Cassandra" /> <img src="https://example.com/hbase" alt="HBase" /></td>
</tr>
<tr>
<td>Key-value store</td>
<td><img src="https://example.com/redis" alt="redis" /> <img src="https://example.com/riak" alt="riak" /></td>
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<td><img src="https://example.com/infinitegraph" alt="InfiniteGraph" /> <img src="https://example.com/neo4j" alt="Neo4j" /></td>
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Complexity vs size

- Key-Value Stores
- Column Families
- Document Databases
- Graph Databases
# Key-Value store

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Key-Value stores

• Very simple interface
  – Data model: (key, value) pairs
  – Operations:
    ▪ put(key, value)
    ▪ value = get(key)

• Implementation: efficiency, scalability, fault-tolerance
  – Records distributed to nodes based on key
  – Replication: scalability and fault-tolerance

• Examples
  – Redis, Memcached, Riak
Redis

• History
  − Started in early 2009 - Salvatore Sanfilippo, an Italian developer
  − He was working on a real-time web analytics solution and realized that MySQL could not provide necessary performance

• Distributed data structure server
• Simple API
• **Automatic data partitioning** across multiple nodes
Distributed data structure

- Distributed hash table (DHT)
  - Decentralized hash lookup service
  - (key, value) pairs are stored in DHT and any participating node can retrieve the value given a key
  - The key-space is spread across many buckets on the network
  - Each bucket is replicated (for fault-tolerance)
Logical data model

• Key
  – Printable ASCII

• Value
  – Primitives
    ▪ Strings
  – Containers (of strings)
    ▪ Hashes
    ▪ Lists
    ▪ Sets
    ▪ Sorted Sets
Logical data model

• Key
  − Printable ASCII

• Value
  − Primitives
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Logical data model

• Key
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    ▪ Sorted Sets
Logical data model

- **Key**
  - Printable ASCII

- **Value**
  - Primitives
    - Strings
  - Containers (of strings)
    - Hashes
    - **Lists**
    - Sets
    - Sorted Sets
Logical data model

- **Key**
  - Printable ASCII

- **Value**
  - Primitives
    - Strings
  - Containers (of strings)
    - Hashes
    - Lists
    - **Sets**
    - Sorted Sets
Redis-cli

- **API: primitive**
  - SET foo bar
  - GET foo
    => bar

- **API: list**
  - LPUSH mylist a  // now mylist holds 'a'
  - LPUSH mylist b  // now mylist holds 'b','a'
  - LPUSH mylist c  // now mylist holds 'c','b','a'
  - LRANGE mylist 0 1
    => c,b
Redis-cli

- **API: hash**
  - `HMSET myuser name Salvatore surname Filippo country Italy`
  - `HGET myuser surname`  
    => Filippo

- **API: set**
  - `SADD myset a`
  - `SADD myset b`
  - `SADD myset foo`
  - `SADD myset bar`
  - `SMEMBERS myset`  
    => bar,a,foo,b
# Column stores

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Column family store

- Not to be confused with the relational-db version of it
  - Sybase-IQ, etc.
- Multi-dimensional map
- Sparsely populated table whose rows can contain arbitrary columns → Column families
- Examples
  - Cassandra
  - Hbase
  - Amazon SimpleDB
Some statistics

• Facebook Search
• MySQL > 50 GB Data
  – Writes Average : ~300 ms
  – Reads Average : ~350 ms
• Rewritten with Cassandra > 50 GB Data
  – Writes Average : 0.12 ms
  – Reads Average : 15 ms
## Document stores

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Document store

• Key-document store
  – the document can be seen as a value so you can consider this is a super-set of key-value

• Big difference with key-value store
  – that in document stores one can query also on the document, i.e. the document portion is structured (not just a blob of data)

• Examples
  – MongoDB
  – CouchDB
MongoDB

- A document-oriented database
  - documents encapsulate and encode data
- Uses BSON/JSON format
- Schema-less
  - No more configuring database columns with types
- No transactions
- No joins
MongoDB basics

• A MongoDB instance may have zero or more databases
• A database may have zero or more collections
  – Can be thought of as the relation (table) in RDBMS, but with differences
• A collection may have zero or more documents
  – Docs in the same collection don’t even need to have the same fields
  – Docs are the records in RDBMS
  – Docs can embed other documents
  – Documents are addressed in the database via a unique key
• A document may have one or more fields
• MongoDB Indexes is much like their RDBMS counterparts
# RDBMS vs MongoDB

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</tr>
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**JSON** is a human-readable format

**BSON** (Binary Structured Object Notation) is a serialization encoding format for **JSON** used for storing and accessing documents

Example JSON document

```json
{
  "_id": ObjectId("5114e0bd42..."),
  "first": "John",
  "last": "Doe",
  "age": 39,
  "interests": ["Mountain Biking"]
}
```
Collection example

```json
{
    "_id": ObjectId("5114e0bd42..."),
    "first": "John",
    "last": "Doe",
    "age": 39,
    "interests": ["Mountain Biking"]
},
{
    "_id": ObjectId("4a14e0f361...")
    "first": "Caroline",
    "last": "Smith",
    "age": 32,
    "interests": ["Reading", "Yoga"]
}
```

Obligatory, and automatically generated by MongoDB
DB Operations

- Inserting a record

```javascript
> db.comedy.insert({name:"Wayne's World", year:1992})
> db.comedy.insert({name:'The School of Rock', year:2003})
```

- Query (the whole collection)

```javascript
> db.comedy.find()
{ "_id" : ObjectId("4e9ebb318c02b838880ef412"), "name" : "Bill & Ted's Excellent Adventure" },
{ "_id" : ObjectId("4e9ebb478c02b838880ef413"), "name" : "Wayne's World" },
{ "_id" : ObjectId("4e9ebd5d8c02b838880ef414"), "name" : "The School of Rock" }
```

- Query (all titles released earlier than 1994)

```javascript
> db.comedy.find({year:{$lt:1994}})
{ "_id" : ObjectId("4e9ebb318c02b838880ef412"), "name" : "Bill & Ted's Excellent Adventure" },
{ "_id" : ObjectId("4e9ebb478c02b838880ef413"), "name" : "Wayne's World" },
```
# Graph stores

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Graph store

- Based on Graph Theory
- Scale vertically
- You can use graph algorithms easily
- Example, Neo4j
Relational vs. Graph: data model

Finding friends

- Person table:
  - ID: 1, Person: Alice
  - ID: 2, Person: Bob
  - ID: ..., Person: ...
  - ID: 99, Person: Zach

- PersonFriend table:
  - PersonID: 1, FriendID: 2
  - PersonID: 2, FriendID: 1
  - PersonID: 2, FriendID: 99
  - PersonID: ..., FriendID: ...
  - PersonID: 99, FriendID: 1
Relational vs. Graph: data model

Finding friends
• **Bob’s friends**

```sql
SELECT p1.Person
FROM Person p1
JOIN PersonFriend
ON PersonFriend.FriendID = p1.ID
JOIN Person p2
ON PersonFriend.PersonID = p2.ID
WHERE p2.Person = 'Bob'
```
Relational vs. Graph: data model

Finding friends
• Bob’s friends-of-friends

```
SELECT p1.Person AS PERSON, p2.Person AS FRIEND_OF_FRIEND
FROM PersonFriend pf1
JOIN Person p1
ON pf1.PersonID = p1.ID
JOIN PersonFriend pf2
ON pf2.PersonID = pf1.FriendID
JOIN Person p2
ON pf2.FriendID = p2.ID
WHERE p1.Person = 'Bob' AND pf2.FriendID <> p1.ID
```
Relational vs. Graph: data model

Finding friends

- Bob’s friends-of-friends-of-....

```sql
SELECT p1.Person AS PERSON, p2.Person AS FRIEND_OF_FRIEND
FROM PersonFriend pf1
JOIN Person p1 ON pf1.PersonID = p1.ID
JOIN PersonFriend pf2 ON pf2.PersonID = pf1.FriendID
JOIN Person p2 ON pf2.FriendID = p2.ID
WHERE p1.Person = 'Bob' AND pf2.FriendID <> p1.ID
```

Join complexity increases with each additional depth
Relational model and connected data

- Relational model deals with connected data by means of join
- Join tables add **complexity**; they mix business data with foreign key metadata
- Foreign key constraints add additional development and maintenance overhead *just to make the database work*
- Things get more complex and more expensive the deeper we go into the network
Enter, property graph model...

- **Node**
  - contain properties

- **Relationship**
  - connect nodes
  - a start node and an end node
  - always has a direction
  - a label

- **Properties**
  - keys are strings and the values are arbitrary data types
Property graph model
Finding relations is easy!
Advantages of property graph model

• Flexibility
  − Allow us to add new nodes and new relationships without compromising the existing network or migrating data
  − Original data and its intent remain intact

• Expressive power
  − We can see who LOVES whom (and whether that love is requited!)
  − We can see who’s MARRIED_TO someone else
  − We can see who is a COLLEAGUE_OF of whom and who is BOSS_OF them all

• Performance
Relational vs. Graph: performance

- Finding friends-of-friends in a social network
  - Maximum depth 5
  - 1 million people, each with approximately 50 friends

<table>
<thead>
<tr>
<th>Depth</th>
<th>RDBMS execution time (s)</th>
<th>Neo4j execution time (s)</th>
<th>Records returned</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.016</td>
<td>0.01</td>
<td>~2500</td>
</tr>
<tr>
<td>3</td>
<td>30.267</td>
<td>0.168</td>
<td>~110,000</td>
</tr>
<tr>
<td>4</td>
<td>1543.505</td>
<td>1.359</td>
<td>~600,000</td>
</tr>
<tr>
<td>5</td>
<td>Unfinished</td>
<td>2.132</td>
<td>~800,000</td>
</tr>
</tbody>
</table>
Cypher: graph query language of NEO4J

• Declarative graph pattern matching language
  – “SQL for graphs”
  – Tabular results

• Cypher is evolving steadily
  – Syntax changes between releases

• Supports queries
  – Including aggregation, ordering and limits
  – Mutating operations in product roadmap
Two nodes, one relationship

(a) --> (b)
Two nodes, one relationship

START a=node(*)
MATCH (a)-->(b)
RETURN a, b;
Pattern matching

START a=node(*)
MATCH (a)-->(b)
RETURN a, b;
Two nodes, one relationship

START a=node(*)
MATCH (a)-[:ACTED_IN]->(m)
RETURN a.name, r.roles, m.title;
Paths

(a) --> (b) --> (c)
Pattern matching
Sort & Limit

START a=node(*)
MATCH (a)-[:ACTED_IN]-(m)<[:DIRECTED]-(d)
RETURN a.name, d.name, count(*) AS count
ORDER BY(count) DESC
LIMIT 5;
START tom=node:node_auto_index(name="Tom Hanks")
MATCH (tom)-[:ACTED_IN]->(movie)
WHERE movie.released < 1992
RETURN DISTINCT movie.title;

(Movies in which Tom Hanks acted, that were released before 1980)
Variable length paths

(a)-[*1..3]->(b)
Friends-of-Friends

START keanu=node:node_auto_index(name="Keanu Reeves")
MATCH (keanu)-[:KNOWS*2]->(fof)
RETURN DISTINCT fof.name;
NoSQL summary

• NoSQL databases reject:
  - Overhead of ACID transactions
  - “Complexity” of SQL
  - Burden of up-front schema design

• Programmer responsible for
  - Determining the consistency level
  - Navigating access path
Should I be using NoSQL Databases?

- NoSQL Data storage systems make sense for applications that need to deal with very large semi-structured data
  - log analysis
  - social networking feeds
- Most organizational databases are not that large and have low update/query rates
  - regular relational databases are the right solution for such environments
References

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- NoSQL Theory, Implementations, an introduction. Firat Atagun
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