NoSQL

COMP9311 24T2; Week 9

By Zhengyi Yang, UNSW

Notice

- Additional consultation will be scheduled before the final exam
- Project 1: marks and sample solution released
- Assignment 2 is due at 10pm this Sunday

MyExperience Survey

- The UNSW MyExperience survey is open, participation is highly encouraged.
- *“Please participate in the myExperience Survey and take the opportunity to share your constructive thoughts on your learning experience. Your contributions help your teachers and shape the future of education at UNSW.”*
- You can access the survey by logging into Moodle or accessing https://myexperience.unsw.edu.au directly.
- More information: https://www.student.unsw.edu.au/myexperience

Guest Lecture Next Week

- We have an exciting guest lecture scheduled for next Tuesday.
- Speaker: Google Cloud
- Free pizza and drinks will be provided during the break

Acknowledgements

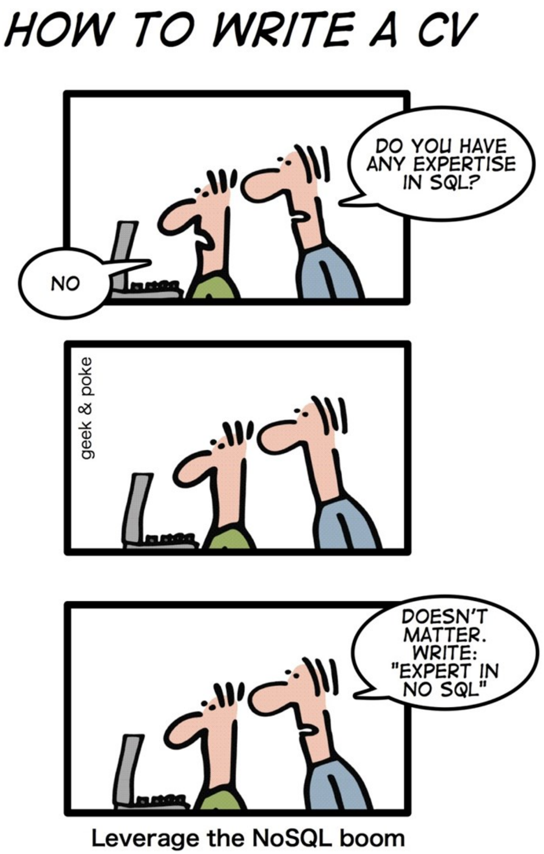
Some parts of this slides are adopted from

- “Database System Concepts” - 7th Edition
- Slides by Prof. George Kollios (Boston University)
- Slides by Asst Prof. Risa B. Myers (Rice University)
- Slides by Dr. David Novak (Masaryk University)
- Slides by Prof. Ying Zhang (UTS)
- Slides by Dr. Longbin Lai (UNSW)
- Neo4j Educator Resources
- Slides by myself at Rust Meetup Sydeny 2020

NoSQL is Hot!

NoSQL stands for “**not only SQL**”:

- ➢ Non-tabular databases and store data differently than relational tables
- ➢ Firstly proposed in 2009

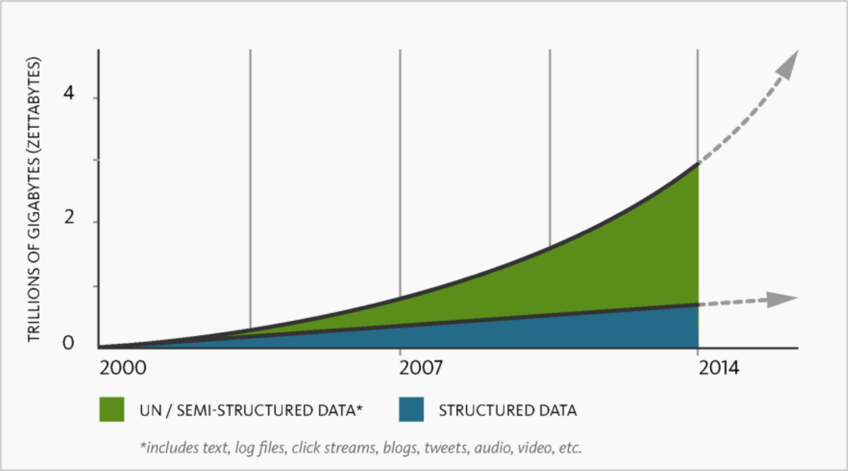


Big Data

- Very large volumes of data being collected
  - Driven by growth of web, social media, and more recently internet-of-things
  - Web logs were an early source of data
    - Analytics on web logs has great value for advertisements, web site structuring, what posts to show to a user, etc
- Big Data: differentiated from data handled by earlier generation databases
  - **Volume**: much larger amounts of data stored
  - **Velocity**: much higher rates of insertions
  - **Variety**: many types of data, beyond relational data

Some Old Numbers

- **Facebook:**
  - 130TB/day: user logs
  - 200-400TB/day: 83 million pictures
- **Google: > 25 PB/day processed data**
- **Gene sequencing: 100M kilobases per day per machine**
  - Sequence 1 human cell costs Illumina $1k
  - Sequence 1 cell for every infant by 2015?
  - 10 trillion cells / human body
- **Total data created in 2010: 1 ZettaByte (1,000,000 PB)/year**
  - ~60% increase every year



Big Data is not only Databases

Big data is more about data analytics and on-line querying

Many components:

- Storage systems
- **Database systems**
- Data mining and statistical algorithms
- Visualization

Features of RDBMS

- Data stored in columns and tables
- Relationships represented by data
- Data Manipulation Language
- Data Definition Language
- Transactions (ACID)
- Abstraction from physical layer
- Applications specify what, not how
- Physical layer can change without modifying applications

The Value of Relational Databases

- A (mostly) **standard** data model
- Many well **developed** technologies
  - ➢ physical organization of the data, search indexes, query optimization, search operator implementations
- Good **concurrency** control (ACID)
  - ➢ transactions: atomicity, consistency, isolation, durability
- Many reliable **integration** mechanisms
  - ➢ "shared database integration" of applications
- Well-**established**: familiar, mature, support,...

Data Management: Trends & Requirements

Trends

- **Volume** of data
- **Cloud** comp. (IaaS)
- **Velocity** of data
- **Big** users
- **Variety** of data

Requirements

- Real database **scalability** massive
  - ➢ database distribution
  - ➢ dynamic resource management
  - ➢ horizontally scaling systems
- Frequent **update** operations
- Massive **read** throughput
- **Flexible** database schema
  - ➢ semi-structured data

RDBMS for Big Data

- relational schema
  - data in tuples
  - a priori known schema
- schema normalization
  - data split into tables (3NF)
  - queries merge the data
- transaction support
  - trans. management with ACID
  - Atomicity, Consistency, Isolation, Durability
  - safety first

- but current data are naturally flexible

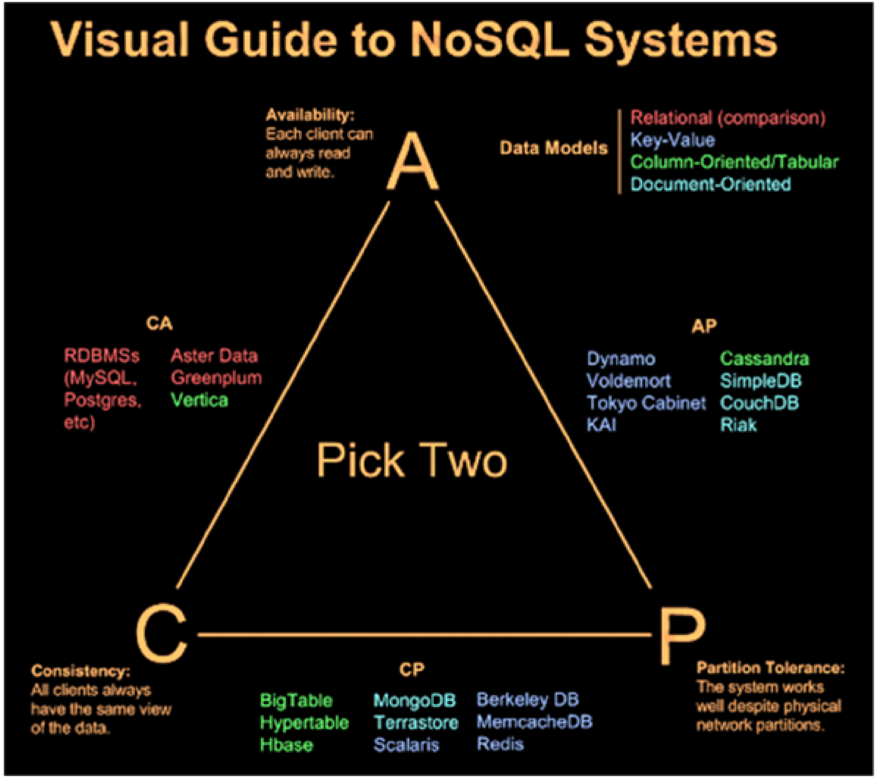
- inefficient for large data
- slow in distributed environment

- full transactions very inefficient in distributed enviroment.

CAP Theorem

At most two of the following three can be maximized at one time

- **Consistency**
  - Each client has the same view of the data
- **Availability**
  - Each client can always read and write
- **Partition Tolerance**
  - System works well across distributed physical networks



Summary: Querying Big Data

- Transaction processing systems that need very high scalability
  - Many applications willing to sacrifice ACID properties and other database features, if they can get very high scalability
- Query processing systems that
  - Need very high scalability, and
  - Need to support non-relation data

Processing Data - Terms

- **OLTP**: Online Transaction Processing (DBMSs)
  - Database applications
  - Storing, querying, multi-user access
- **OLAP**: Online Analytical Processing (Warehousing)
  - Answer multi-dimensional analytical queries
  - Financial/marketing reporting, budgeting, forecasting, …
- **HTAP**: Hybrid Transaction/Analytical Processing

NoSQL Databases

- NoSQL: Database technologies that are (mostly):
  - Not using the relational model (nor the SQL language)
  - Designed to run on large clusters (horizontally scalable)
  - No schema - fields can be freely added to any record
  - Open source
  - Based on the needs of the current big data era
- Other characteristics (often true):
  - easy replication support (fault-tolerance, query efficiency)
  - Simple API
  - Eventually consistent (not ACID)

Just Another Temporary Trend?

- There have been other trends here before
  - object databases, XML databases, etc.
- But NoSQL databases:
  - are answer to real practical problems big companies have
  - are often developed by the biggest players
  - outside academia but based on solid theoretical results
    - e.g. old results on distributed processing
  - widely used

The End of RDBMS?

- Relational databases are not going away
    - are ideal for a lot of structured data, reliable, mature, etc.
- RDBMS became one option for data storage

Using different data stores in different circumstances

Two trends:

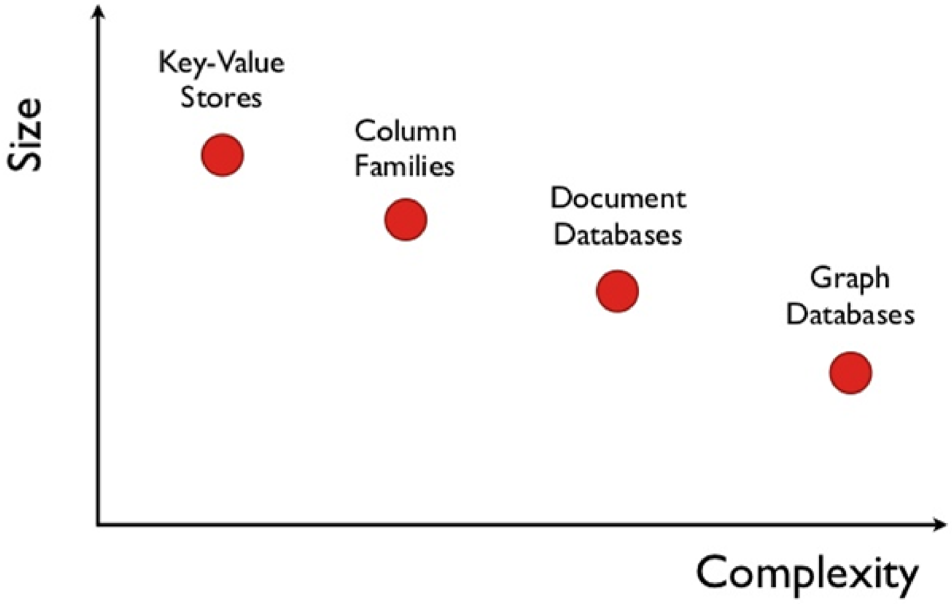
1. NoSQL databases implement standard RDBMS features
2. RDBMS are adopting NoSQL principles

NoSQL Properties

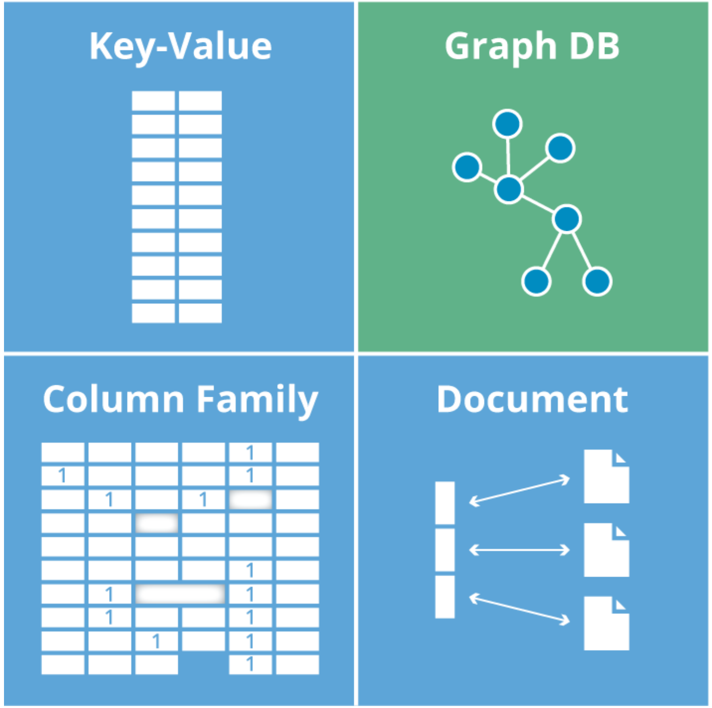
1. Flexible scalability
   - horizontal scalability instead of vertical
2. Dynamic schema of data
   - different levels of flexibility for different types of DB
3. Efficient reading
   - spend more time storing the data, but read fast
   - keep relevant information together
4. Cost saving
   - designed to run on commodity hardware
   - typically open-source (with a support from a company)

NoSQL Databases

- Key-value stores
- Document databases
- Column-family stores
- Graph databases



NoSQL Databases by Data Models



Key-Value Stores

- Come from a research paper by Amazon (Dynamo)
  - Global Distributed Hash Table (Key-Value Stores)
- A simple hash table (map), primarily used when all accesses to the database are via primary key
  - key-value mapping
- In RDBMS world: A table with two columns:
  - ID column (primary key)
  - DATA column storing the value (unstructured binary large object)

Key-Value Stores - Operations

- Key-value stores support
  - ***put***(key, value): used to store values with an associated key,
  - ***get***(key): which retrieves the stored value associated with the specified key
  - ***delete***(key): remove the key and its associated value
  - ***scan***(from, to): range scan
- Some systems also support ***range queries*** on key values

Key-Value Stores - Architecture

1. Embedded systems
   a. the system is a library and the DB runs within your system
2. Large-scale Distributed stores
   a. distributed hash table (DHT)

Key-Value Stores

- Why?
  - Simple Data Model: Hash Table is well-studied
  - Good Scalability: Small System Cost, via good look-up locality and caching
- Why not?
  - Poor to complex (interconnected) data

Key-Value Stores - Vendors

amazon DynamoDB

riak

levelDB

Infinispan

redis

ORACLE BERKELEY DB 12c

RocksDB

Project Voldemort

MEMCACHED

MapDB

hazelcast

EHCACHE

Ranked list: http://db-engines.com/en/ranking/key-value+store

Document Stores

- Basic concept of data: ***Document***
- Documents are self-describing pieces of data
  - Hierarchical tree data structures
  - Nested associative arrays (maps), collections, scalars
  - XML, JSON (JavaScript Object Notation), BSON, …
- Documents in a collection should be “similar”
  - Their schema can differ
- Documents stored in the value part of key-value
  - Key-value stores where the values are examinable
  - Building search indexes on various keys/fields

Document Stores - Example

```
key=3 ->  { "personID": 3,
            "firstname": "Martin",
            "likes": [ "Biking","Photography" ],
            "lastcity": "Boston",
            "visited": [ "NYC", "Paris" ] }

key=5 ->  { "personID": 5,
            "firstname": "Pramod",
            "citiesvisited": [ "Chicago", "London","NYC" ],
            "addresses": [
               { "state": "AK",
                 "city": "DILLINGHAM" },
               { "state": "MH",
                 "city": "PUNE" }  ],
            "lastcity": "Chicago" }
```

MongoDB

- hu**mongo**us => Mongo
- Data are organized in **collections.** A collection stores a set of **documents**.
- Collection like table and document like record
  - but: each document can have a different set of attributes even in the same collection
  - **Semi-structured** schema!
- Only requirement: every document should have an **"_id"** field

Example MongoDB

```
{     "_id”:ObjectId("4efa8d2b7d284dad101e4bc9"),
       "Last Name": ” Cousteau",
       "First Name": ” Jacques-Yves",
       "Date of Birth": ”06-1-1910" },

{     "_id": ObjectId("4efa8d2b7d284dad101e4bc7"),
       "Last Name": "PELLERIN",
       "First Name": "Franck",
       "Date of Birth": "09-19-1983",
       "Address": "1 chemin des Loges",
       "City": "VERSAILLES" }
```

MongoDB - Features

- **JSON**-style documents
  - actually uses BSON (JSON's binary format)
- replication for high availability
- auto-sharding for scalability
- document-based queries
- can create an index on any attribute
- for faster reads

MongoDB vs RDBMS

RDBMS	MongoDB Equivalent
database	database
table	collection
row	document
attributes	fields (field-name:value pairs)
primary key	the ‘_*id*’ field, which is the key associated with the document

Relationships in MongoDB

Two options:

1. store references to other documents using their _id values
2. embed documents within other documents

Example

Here is an example of embedded relationship:

```
{
  "_id":ObjectId("52ffc33cd85242f436000001"),
  "contact": "987654321",
  "dob": "01-01-1991",
  "name": "Tom Benzamin",
  "address": [
    {
      "building": "22 A, Indiana Apt",
      "pincode": 123456,
      "city": "Los Angeles",
      "state": "California"
    },
    {
      "building": "170 A, Acropolis Apt",
      "pincode": 456789,
      "city": "Chicago",
      "state": "Illinois"
    }
  ]
}
```

And here an example of reference based

```
{
  "_id":ObjectId("52ffc33cd85242f436000001"),
  "contact": "987654321",
  "dob": "01-01-1991",
  "name": "Tom Benzamin",
  "address_ids": [
    ObjectId("52ffc4a5d85242602e000000"),
    ObjectId("52ffc4a5d85242602e000001")
  ]
}
```

MongoDB - Queries

- Query language expressed via JSON
- clauses: where, sort, count, sum, etc.

SQL: `SELECT * FROM users`
MongoDB: `db.users.find()`

- `SELECT * FROM users WHERE personID = 3`
- `db.users.find( { "personID": 3 } )`

- `SELECT firstname, lastcity FROM users WHERE personID = 5`
- `db.users.find( { "personID": 5}, {firstname:1, lastcity:1} )`

Document Stores - Vendors

mongoDB

Apache CouchDB relax

OrientDB

RAVENDB

terrastore

amazon DynamoDB

MS Azure DocumentDB

Ranked list: http://db-engines.com/en/ranking/document+store

Column-Family Stores

- Origin from Google's BigTable
- Also known as *wide-column* or *columnar*
- Data model: **rows** that have **many columns** associated with a **row key**
- Column families are groups of related data (columns) that are often **accessed together**

Column-Family Stores - Main Idea

- Each table tends to have many attributes (from thousands ~ millions)
- In most applications (in OLAP) we are only interested in a **few** attributes
- Traditional raw-based
  - Store each record in a sequential file
  - We need to read the **whole** record to access only one attribute
- Column-based
  - Store the data by putting the same attribute in a sequential file
  - Faster access and better compression

Column-Family Stores - Example 1

Column-oriented vs. row-oriented databases

ID NUMBER	LAST NAME	FIRST NAME	BONUS
513001	Jones	Joanna	8000
502333	Smith	Jamie	4000
455332	Beck	Samuel	1000

Row-oriented database

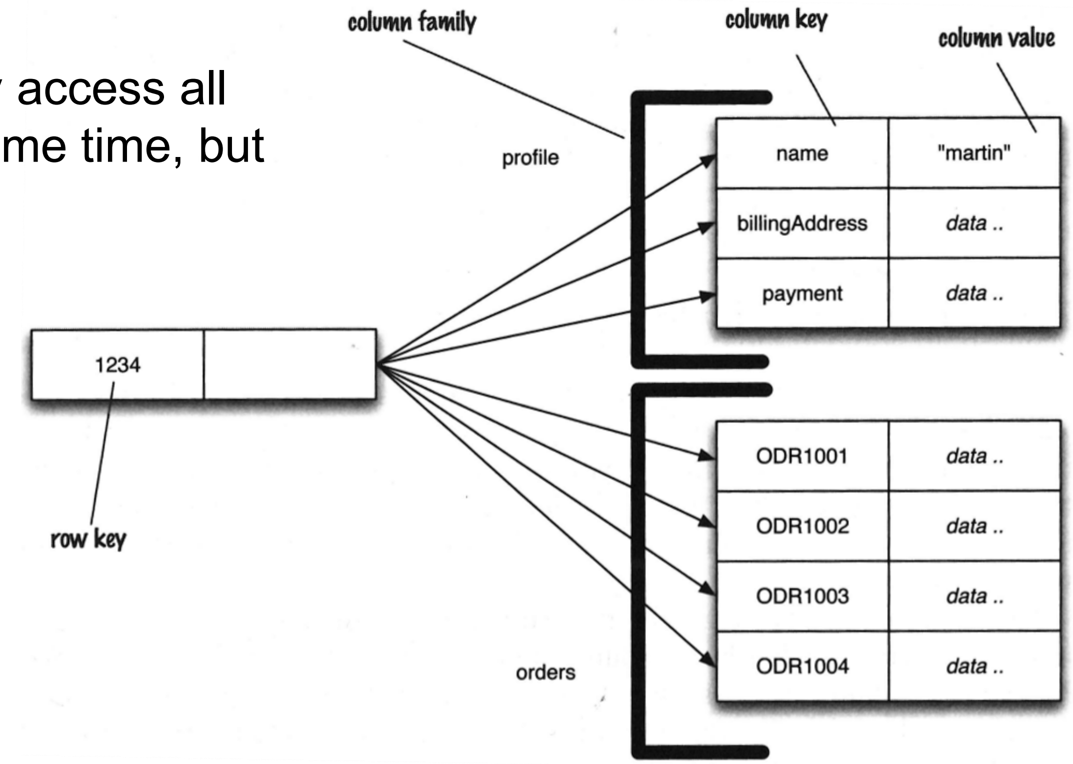
513001	Jones	Joanna	8000
502333	Smith	Jamie	4000
455332	Beck	Samuel	1000

Column-oriented database

513001	502333	455332
Jones	Smith	Beck
Joanna	Jamie	Samuel
8000	4000	1000

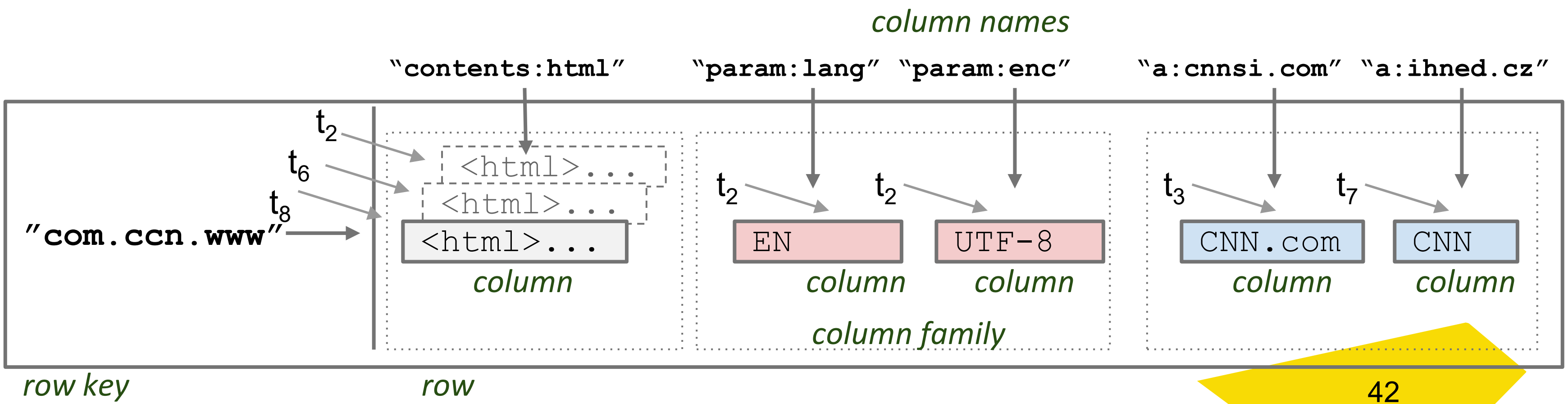
Column-Family Stores - Example 2

For a customer we typically access all profile information at the same time, but not customer’s orders.



BigTable

- Google's BigTable
  - Drives MapReduce, and the following: Apache Hadoop, Hadoop File System (HDFS), HBase, Apache Cassandra
- 2008: Google published the Bigtable Paper
  - "BigTable = sparse, distributed, persistent, multi-dimensional sorted map indexed by (row_key, column_key, timestamp)"



Column-Family Stores

- Why?
  - Optimized for OLAP
  - Semi-Structured Data: Each column can define its own schema
- Why not?
  - Not good for
    - OLTP
    - Incremental Data Loading
    - Row-specific Queries

Column-Family Stores - Vendors

Cassandra

Google BigTable

HBASE

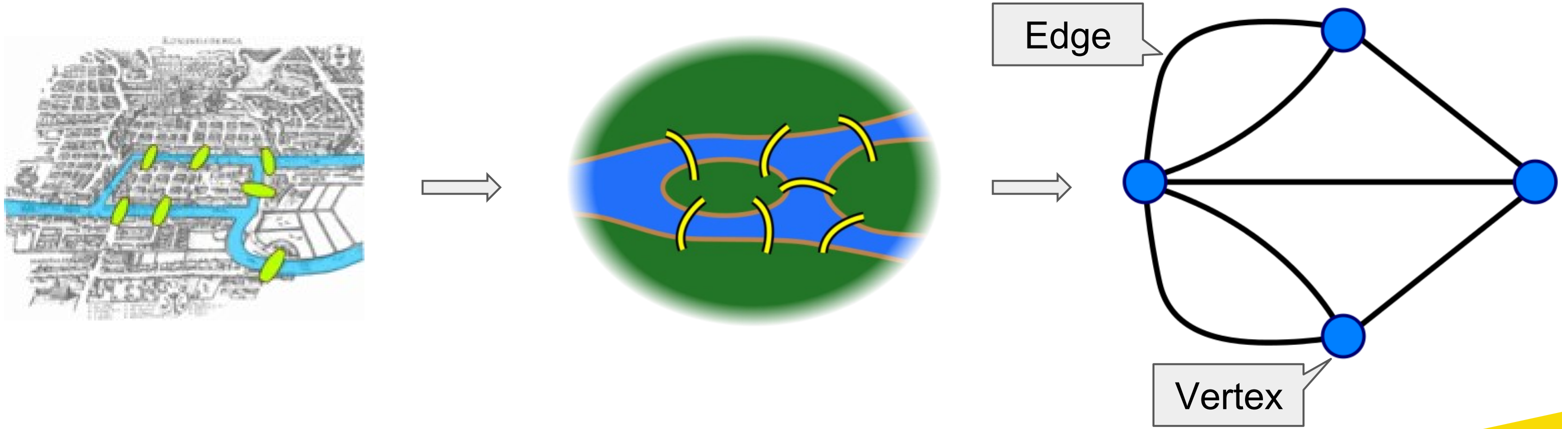
HYPERTABLE

accumulo™

Ranked list: http://db-engines.com/en/ranking/wide+column+store

Graph Data Structure

- A ***graph*** is a structure in mathematics (graph theory)
- Famous problem: Seven Bridges of Königsberg
- Optimised for handling highly connected data

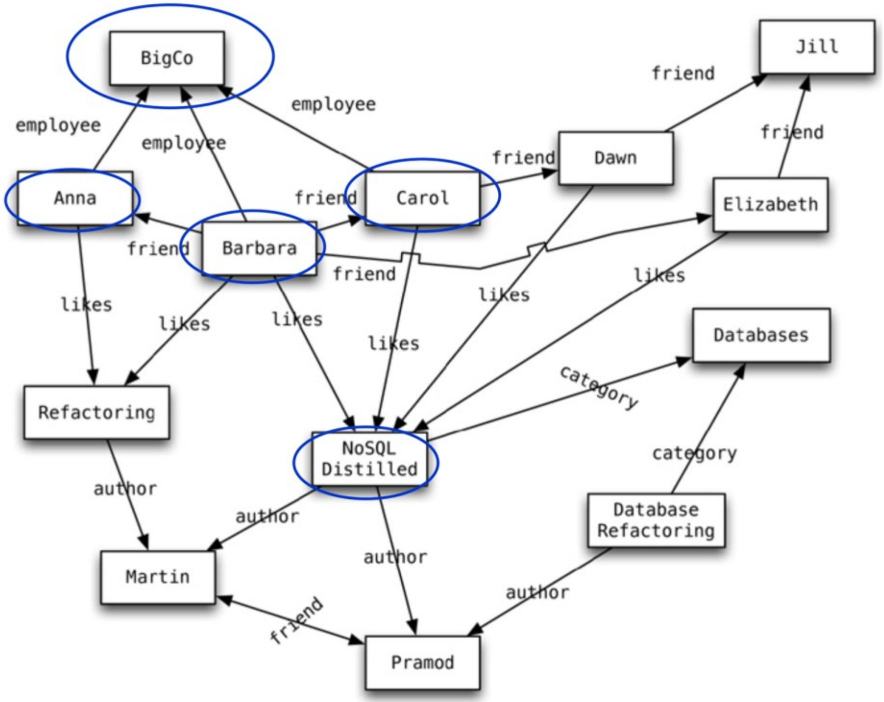


Graph Database

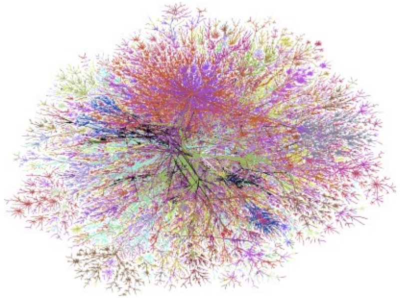
Data Model

- Vertices (Nodes) -> Entities
- Edges -> Relations

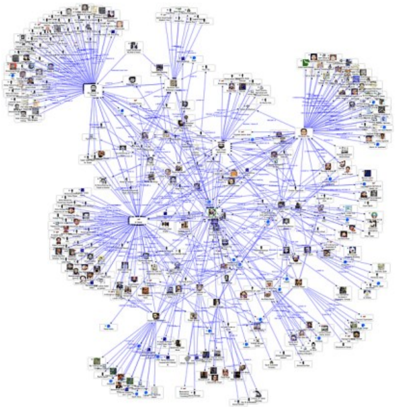
Are we going to learn ER model again?



Graphs are Everywhere!

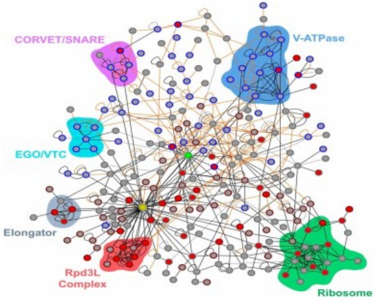


Internet

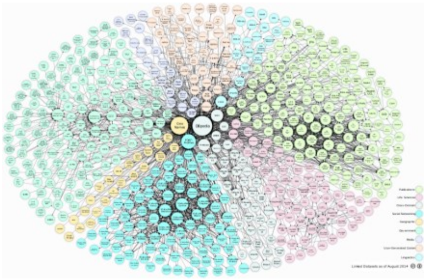


Social Networks

Road Networks



Biological Networks



Knowledge Graphs

Graphs are Large!

#Vetices	Ratio
<10K	17.3%
10K-100K	17.3%
100K-1M	15.0%
1M-10M	13.4%
10M-100M	15.7%
>100M	21.3%

#Edges	Ratio
<10K	17.8%
10K-100K	17.1%
100K-1M	10.1%
1M-10M	6.9%
10M-100M	16.3%
100M-1B	16.3%
>1B	15.5%

#Bytes	Ratio
<100MB	19.0%
100MB-1G	15.7%
1G-10G	20.7%
10G-100G	14.1%
100G-1T	16.5%
>1T	14.0%

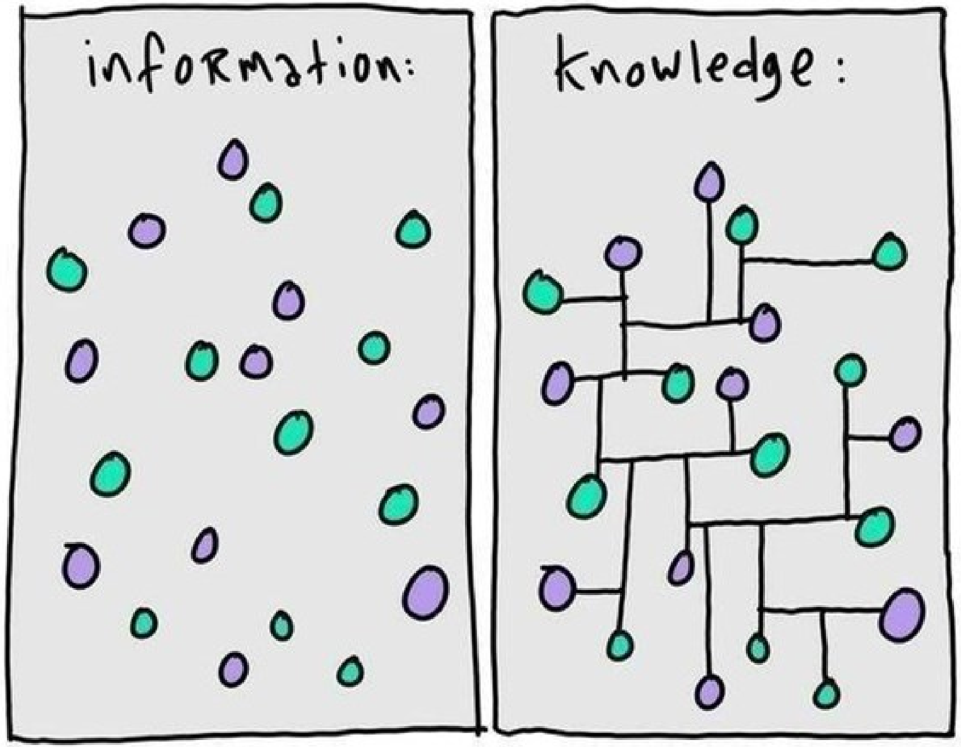
Small to medium sized companies

>1 trillion connections

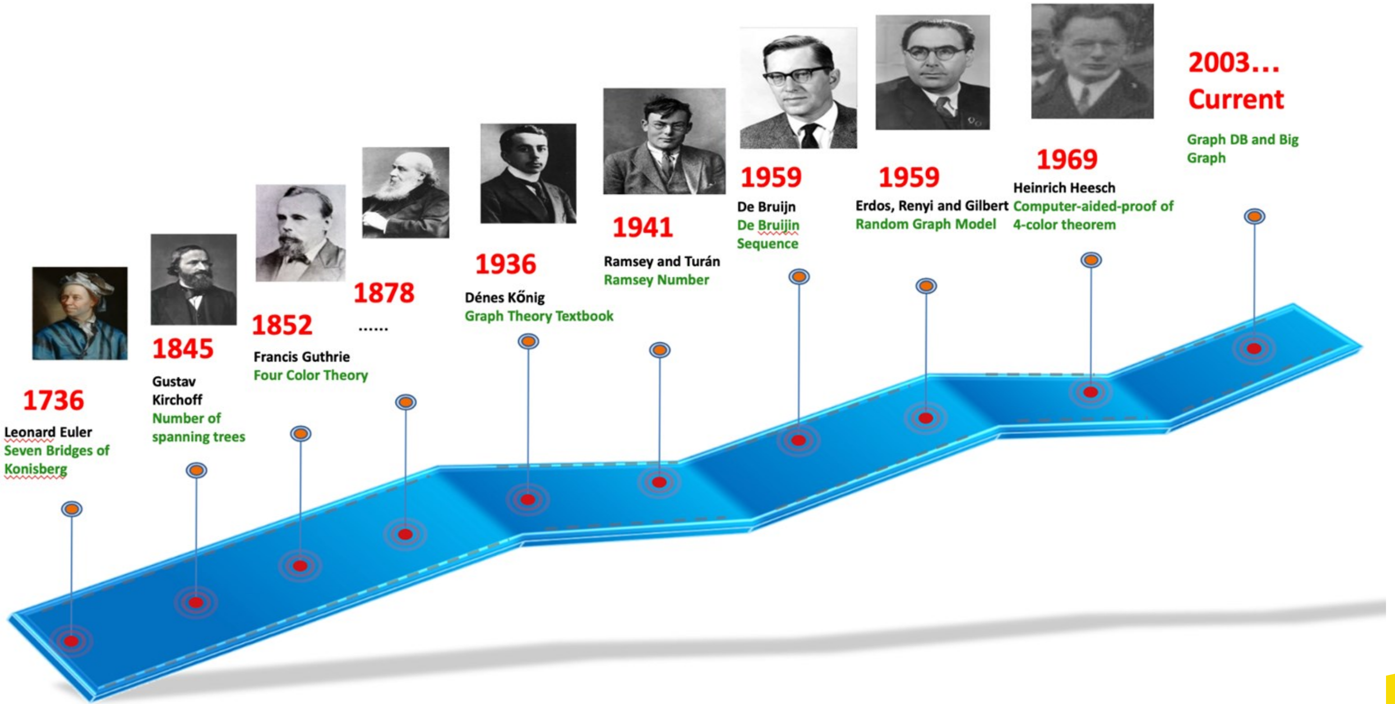
>60 trillion URLs

>60 billion edges every 30 days

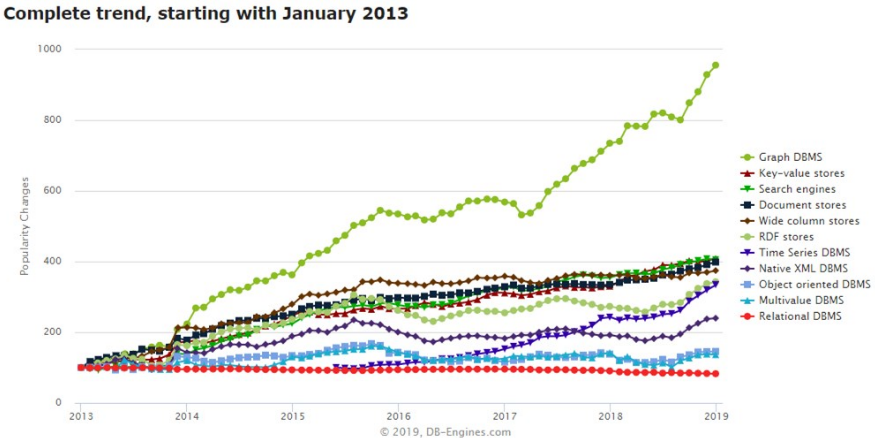
Information vs Knowledge



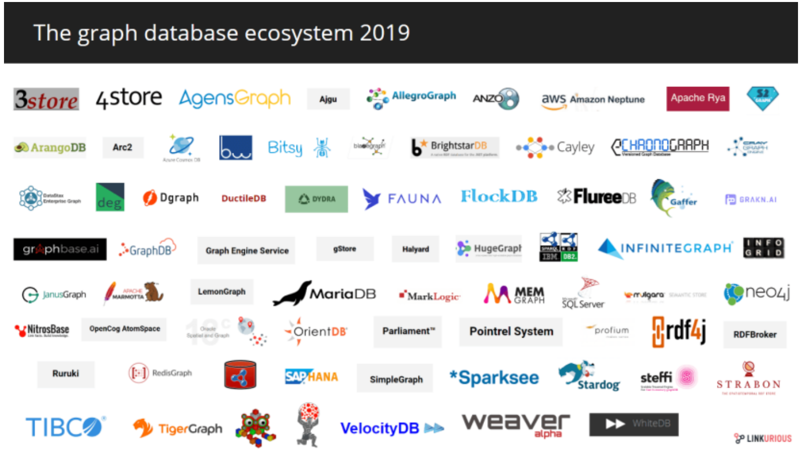
History


1736
Leonard Euler
Seven Bridges of Konisberg
1845
Gustav Kirchoff
Number of spanning trees
1852
Francis Guthrie
Four Color Theory
1878
......
1936
Dénes Kőnig
Graph Theory Textbook
1941
Ramsey and Turán
Ramsey Number
1959
De Bruijn
De Bruijin Sequence
1959
Erdos, Renyi and Gilbert
Random Graph Model
1969
Heinrich Heesch
Computer-aided-proof of 4-color theorem
2003…
Current
Graph DB and Big Graph

Graph DBMS Landscape



DBMS popularity trend by database model between 2013 and 2019 – DB-Engine



The graph database landscape in 2019

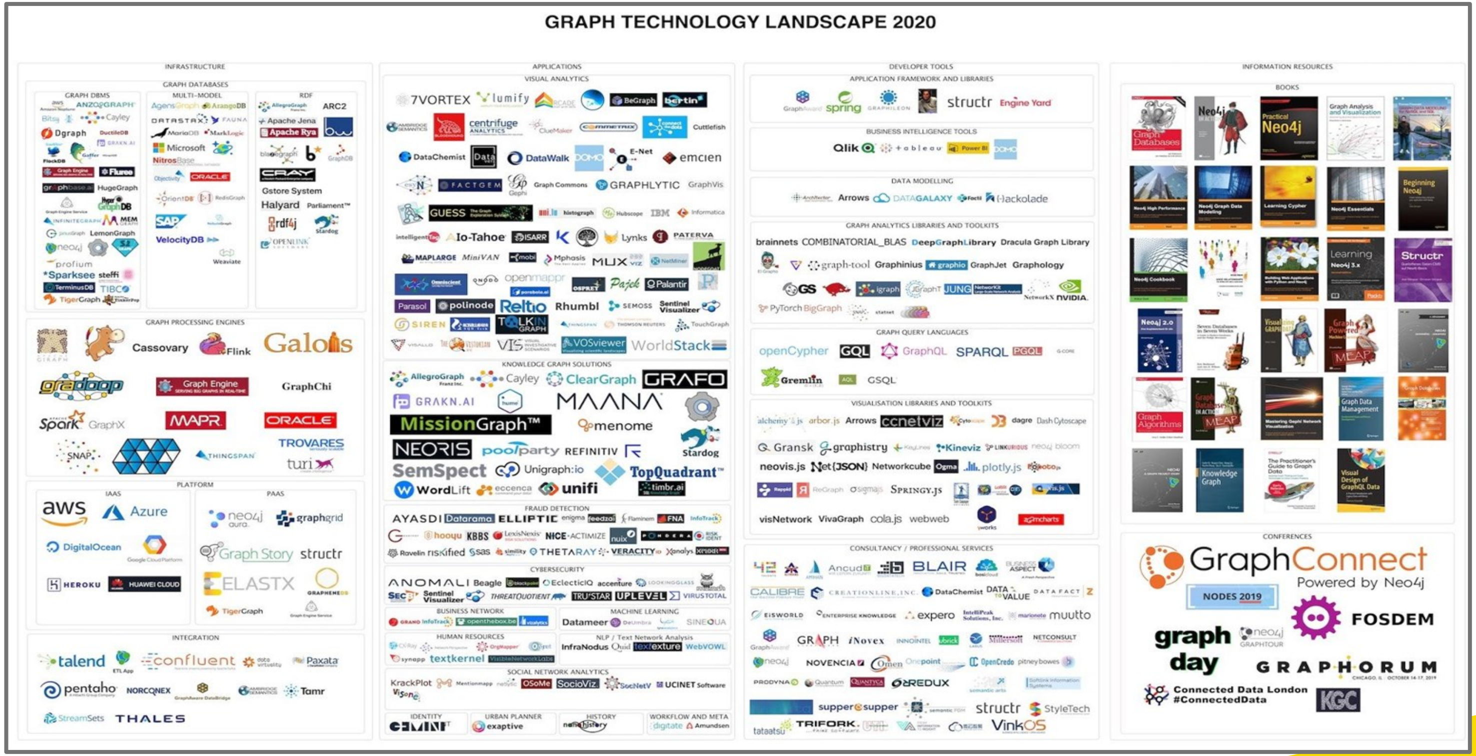
Advantages

- **Performance**
  - ❑ Traditional Joins are inefficient
  - ❑ Billion-scale data are common, e.g., Facebook social network , Google web graph
- **Flexibility**
  - ❑ Real-world entities may not have a fixed schema. It is not feasible to design 1000 attributes for a table.
  - ❑ Relationships among entities can be arbitrary. It is not feasible to use 1000 tables to model 1000 types of relationships.
- **Agility**
  - ❑ Business requirements changes over time
  - ❑ Today’s development practices are agile, test-driven

Applications

- **Social Network**: Facebook, Twitter, LinkedIn …
- **E-commerce**: eBay, Amazon, Alibaba …
- **Banking**: JPMorgan, Citi, UBS …
- **Telecom**: Verizon, Orange, AT&T …
- **IoT**: nest
- **Search Engine**: Google
- **Navigation**: Google Maps
- **Bioinformatics**: DNAnexue
- …

Graph Technology Landspace

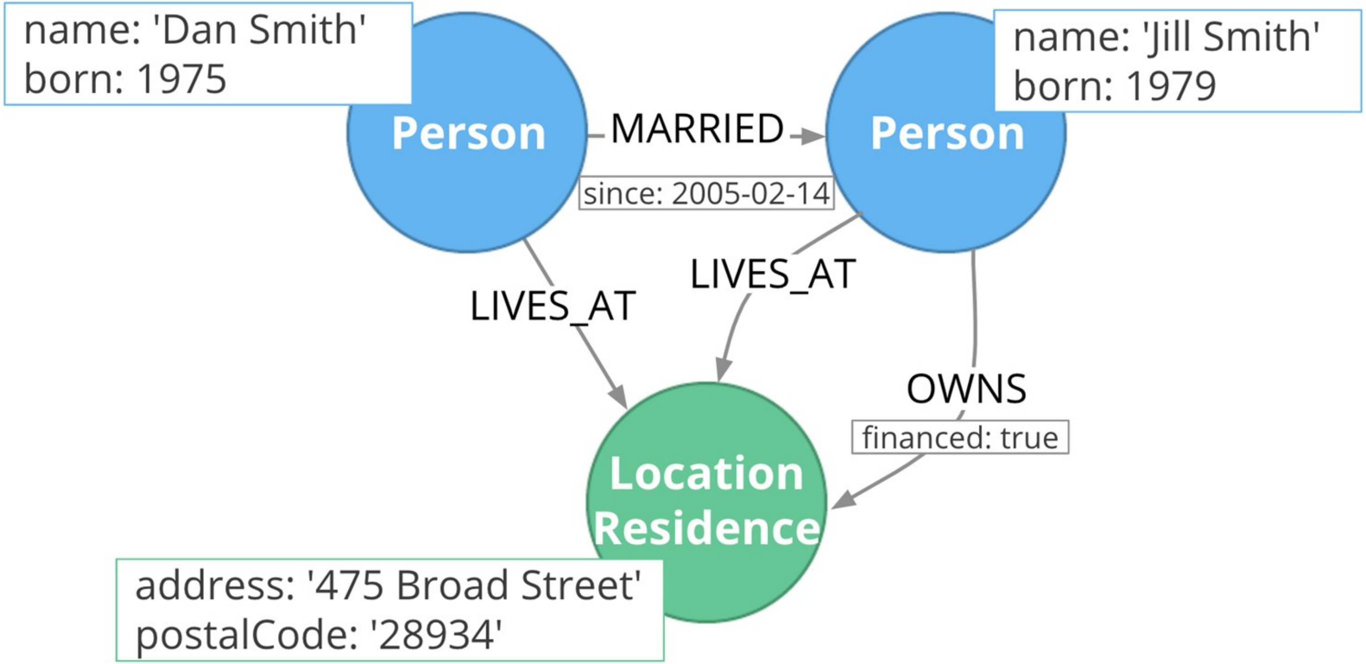


Neo4j

- The most popular Graph Database at present
- *Cypher* query language
- Developed in Java and open-source
- Resources:
    - Neo4j Cypher Manual
    - Neo4j Developer Resources

Property Graph Model

- Nodes
  (Entities)
- Relationships
- Properties
- Labels



Graph DB Data Modeling

- Flexible & adaptive schema compared to RDBMs

- What you sketch = what you store in the database

Neo4j vs Relational Model

- Retains ACID transaction properties

- Foreign keys not necessary as they are represented as relationships

- Relationships are stored/represented per relational record/row instead of per table

Neo4j vs Relational Model - Example

Student

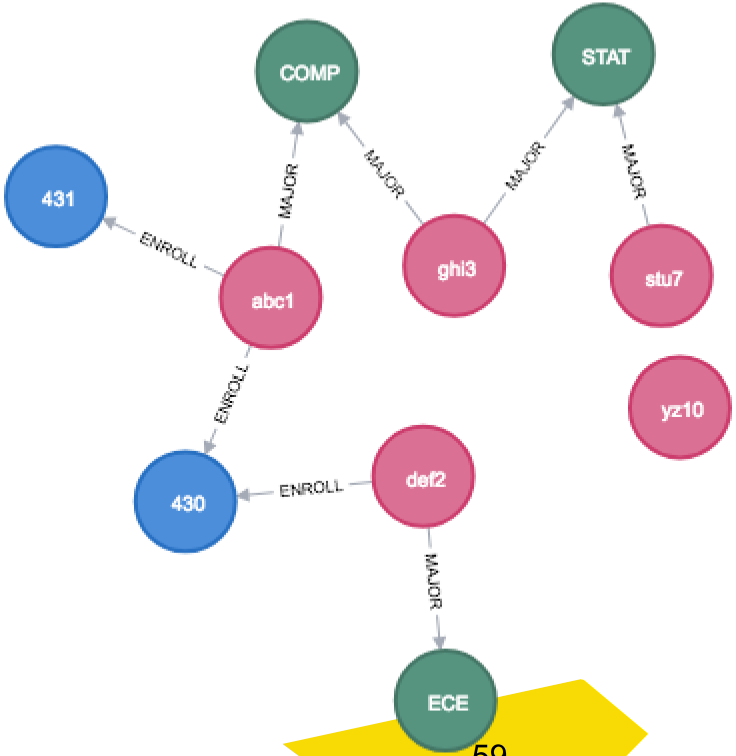
netId	FirstName
abc1	Albert
def2	Danielle
ghi3	Gary
stu7	Sandeep
yz10	Yusin

Enrolls

netId	Course
abc1	COMP 430
def2	COMP 430
abc1	COMP 431

Majors

netId	Major
ghi3	STAT
ghi3	COMP
abc1	COMP
def2	ECE
stu7	STAT



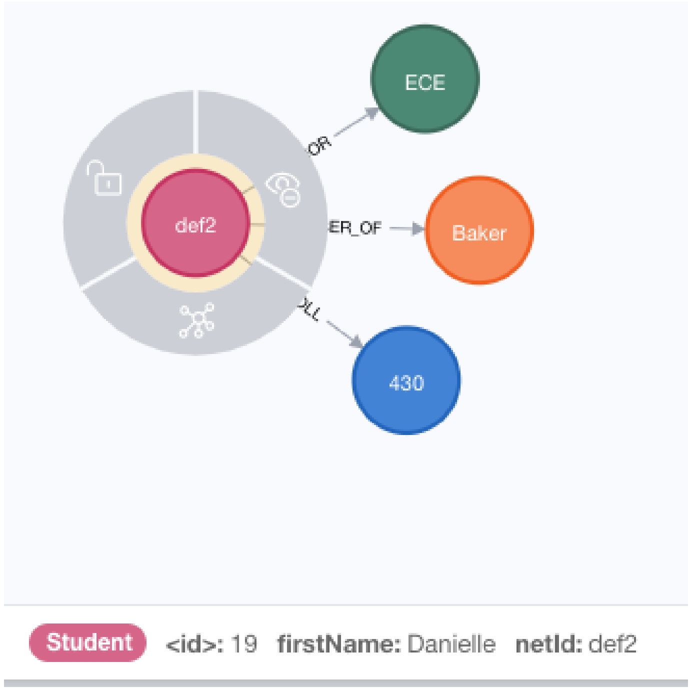
Property or Node?

- **Dept** for a course could be a property of course or a node
- How to decide? It depends
  - Standardization of terms
    - How often will it be updated?
  - Searchability
  - Readability
  - Reusability

MongoDB vs Neo4j

```
Student
{
    "_id": 5,
    netId: "def2",
    firstName: "Danielle",
    college: "Baker",
    major: "ECE",
    enrolls: "COMP 430"
}

Course
{
    "id": 12198,
    num: "430",
    dept: "COMP",
    title: "Intro to Database Systems"
}
```



Choosing a DBMS

- Efficient data storage
  - Structure (e.g. networks)
  - Sparsity
- Performance
  - Types of queries / analysis
  - Need for visualization
  - Built in algorithms or tools
  - Reads vs. Writes
  - Quantity of data
- Importance
  - Objects
  - Relationships

When to use a graph database?

- If…
  - Your data has many M-M relationships

Relational (A)	☺	Graph (B)	☺

  - Care about referential integrity

Relational	☺	Graph	

  - You highly value the relationships of the data

    (especially when you may consider the relationship to be more important than the elements themselves)

Relational		Graph	☺

  - …case by case question

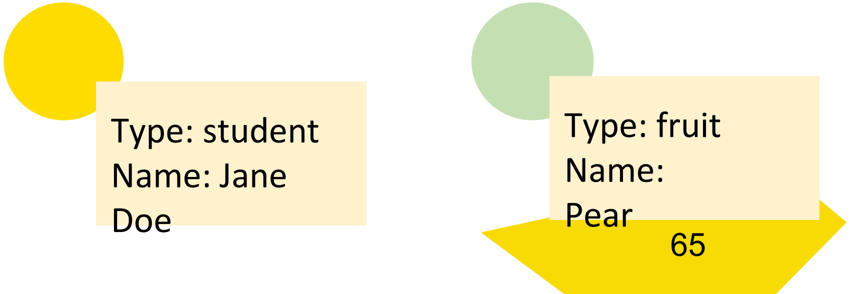
Which to use?

1. …if you were given a set of well-structured data
2. …if you are scraping data from the Internet
3. …if you are storing tax info
4. …if the dataset is extremely large
5. …if you are trying to build a friend network

A	Relational
B	NoSQL - Mongo
C	NoSQL – Neo4j
D	It depends

Nodes and Properties

- Node
  - Typically used to represent entities
  - Has zero or more relationships
  - Each node is an instance of an entity
- Property
  - Key/value pairs
  - Belong to nodes and relationships

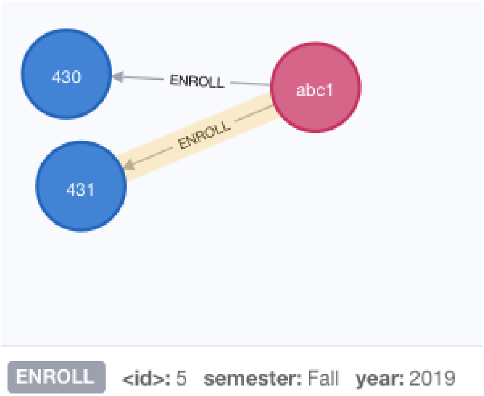


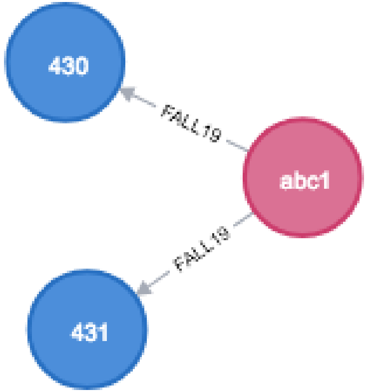
Property Types

- **Number** (*Integer* and *Float* specifically)
- **String**
- **Boolean**
- **Temporal type** - *Date, Time, LocalTime, DateTime, LocalDateTime* and *Duration*

Relationships

- Edge that connects nodes
- Relationships must have a **direction** and a **type**
- Can have properties





Questions

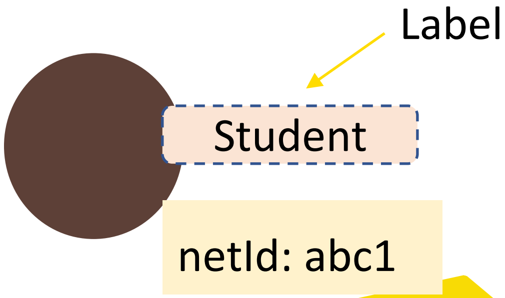
1. What are some examples of relationships that are directional?
2. What are some examples of relationships that are non-directional?

Questions

1. What are some examples of relationships that are directional?
   - Think of **Twitter**
2. What are some examples of relationships that are non-directional?
   - Thinks of **Facebook**

Labels

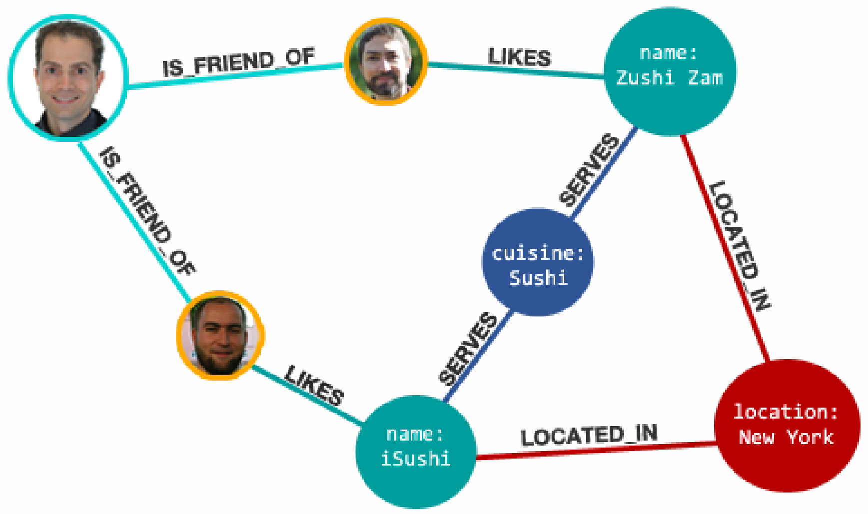
- Grouping mechanism for nodes
- Used to define constraints and/or indexes
- Faster lookup compared to checking a property



T/F Questions

1. There's a 1-1 mapping from the relational model to a graph database
2. Each node must have the same properties as all other nodes
3. Relationships cannot have properties

Cypher Query Language



An example of Cypher:
Find Sushi restaurants in New York that Philip's friends like

```
MATCH (person:Person)-[:IS_FRIEND_OF]->(friend),
      (friend)-[:LIKES]->(restaurant:Restaurant),
      (restaurant)-[:LOCATED_IN]->(loc:Location),
      (restaurant)-[:SERVES]->(type:Cuisine)

WHERE person.name = 'Philip'
  AND loc.location = 'New York'
  AND type.cuisine = 'Sushi'

RETURN restaurant.name, count(*) AS occurrence
ORDER BY occurrence DESC
LIMIT 5
```

Cypher Introduction

- Declarative graph query language
- Shares many keywords and query structures with SQL
- Comments can be added with “//” or "/* */"
- Case *insensitive* except for
  - Labels
  - Property keys
  - Relationship types

Cypher Patterns

- Used to describe the shape of what you are looking for
- Node: ( )
- Relationship: -, ->, <-
- Relationship identifier: [ ]
- Labels :<LabelName>
- Variables: n, node, foo
- Not only for querying, also for creating new nodes, relations etc.

Cypher Patterns 1

- Any directional relationship

```
MATCH (n:Student)-->(m:Student)
RETURN n,m;
```

Students with a relation with another Student

`n` and `m` are variables
`Student` is a label

"n.name"	"m.name"
"Gary"	"Danielle"
"Albert"	"Danielle"
"Albert"	"Gary"
"Danielle"	"Sandeep"
"Danielle"	"Yousef"

Cypher Patterns 2

- Specific relationships

```
MATCH (n:Student)-[:MENTORS]->(m:Student)
RETURN DISTINCT n.netId;
```

"n.netId"
"def2"
"abc1"

netIds of students who mentor other students

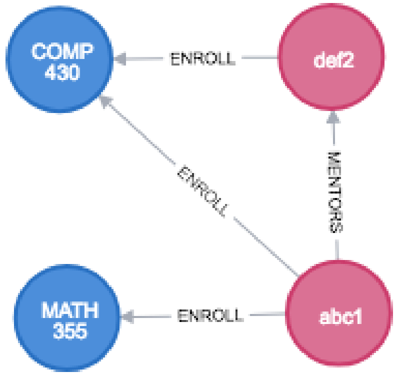
- Note the text output
- Can return properties

Cypher Patterns 3

- Nodes with different labels

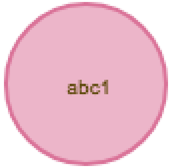
```
MATCH (n:Student)-[:ENROLL]->(m:Course)
RETURN n, m;
```

Students enrolled in courses



Cypher clauses – MATCH/WHERE

- Find pattern (MATCH), then filter results (WHERE)
  - WHERE is part of MATCH-WHERE clause
  - can be replaced with OPTIONAL MATCH, WITH for future constraints



- Find node with firstname ‘Albert’

```
MATCH (n {name: 'Albert'})
RETURN n;
```

- Also

```
MATCH (n)
WHERE n.name = 'Albert'
RETURN n;
```

```
{
  "name": "Albert",
  "netId": "abc1"
}
```

Cypher clauses – RETURN

- RETURN is equivalent to SELECT in SQL, it returns the specified nodes or properties
- RETURN netIds of students with relationships with other students

```
MATCH (a:Student)-->(otherNode:Student)
RETURN a.netId, otherNode.netId;
```

"a.netId"	"otherNode.netId"
"jkl4"	"def2"
"ghi3"	"def2"
"abc1"	"def2"
"abc1"	"ghi3"
"def2"	"stu7"
"def2"	"yz10"

Types of Graph Queries

- **Graph Pattern Matching**
  - Given a graph pattern, find **subgraphs** in the database graph that match the query.
  - Can be augmented with other (relational-like) features, such as *projection*.

```
MATCH (p:Person)-[:LIKES]->(:Language {name = "SQL"})
RETURN p.name
```

- **Graph Navigation**
  - A flexible querying mechanism to navigate the topology of the data.
  - Called **path queries**, since they require to navigate using paths (potentially variable length).

```
MATCH (p:Person)-[:KNOWS*1..2]->(:Person {name = "Alice"})
RETURN p.name
```

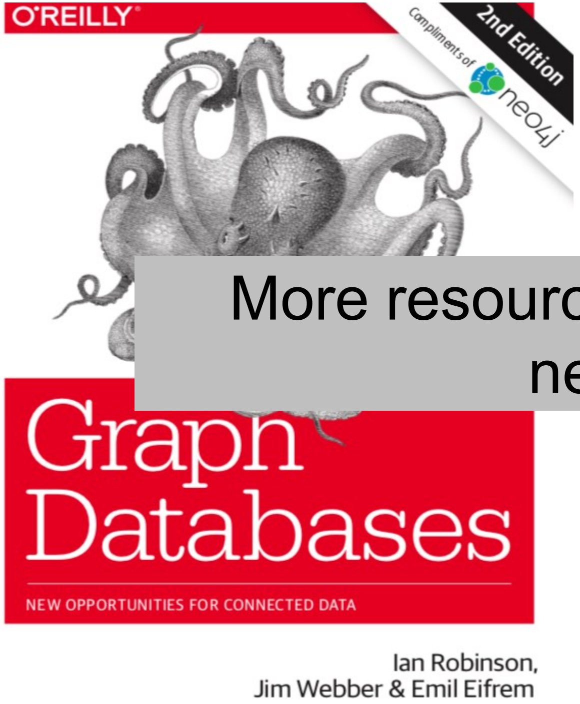
More Cypher clauses

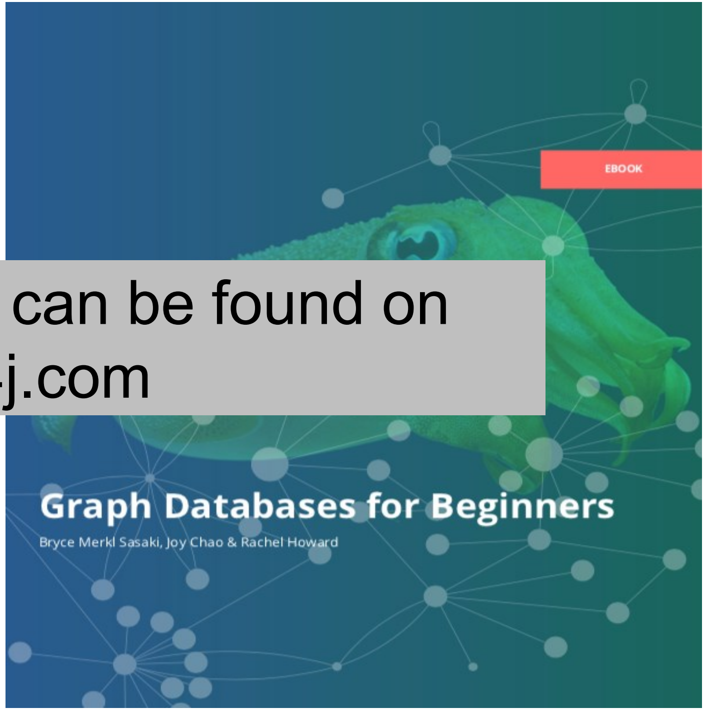
- CREATE
- DELETE
- SET
- ORDER BY
- LIMIT
- WITH
- Aggregations:
  - COUNT
  - COLLECT
  - SUM
  - …
- …

Graph Algorithms

- The real power of graph databases
- Can save huge amounts of programming effort
- Include
  - Centrality - node importance
  - Community detection – node connectivity and partitions
  - Path finding – routes through the network
  - Similarity – of nodes
  - Link prediction – closeness of nodes
- https://neo4j.com/docs/graph-data-science/current/

Neo4j





More resources can be found on neo4j.com

Related Courses at UNSW CSE

- COMP9312: Data Analytics for Graphs
- COMP9313: Big Data Management

Learning Outcome

- NoSQL vs RDBMS
- Data Models
    - Key-value
    - Document
    - Column-family
    - Graph