FAKULTA ELEKTROTECHNICKÁ

České vysoké učení technické v Praze

B4M36DS2 – Database Systems 2

Lecture 2 – Types of NoSQL Databases

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Yuliia Prokop

prokoyul@fel.cvut.cz

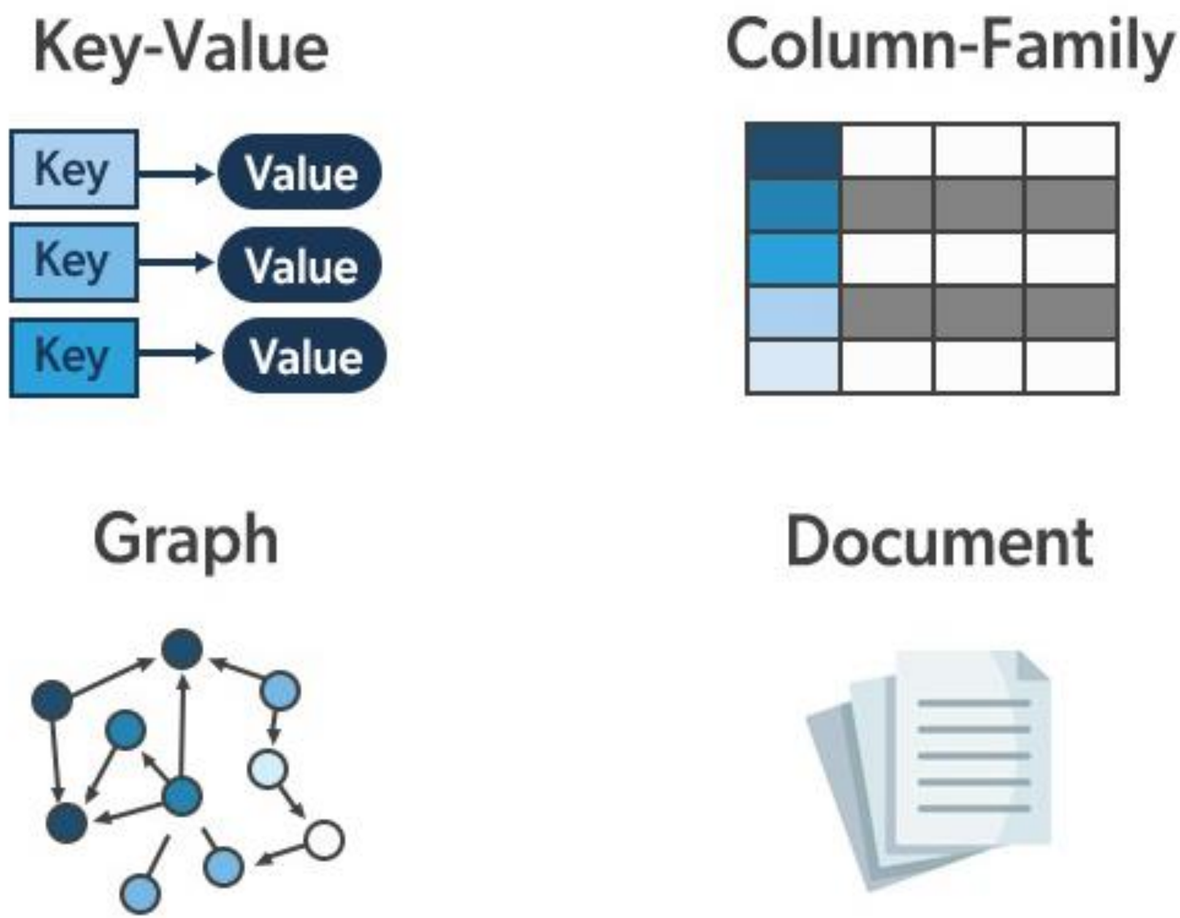
Based on **Martin Svoboda**'s materials (https://www.ksi.mff.cuni.cz/~svoboda/courses/211-B4M36DS2/)

ČVUT FEL CourseWare Wiki **https://cw.fel.cvut.cz/b241/courses/b4m36ds2/start**

Lecture Outline

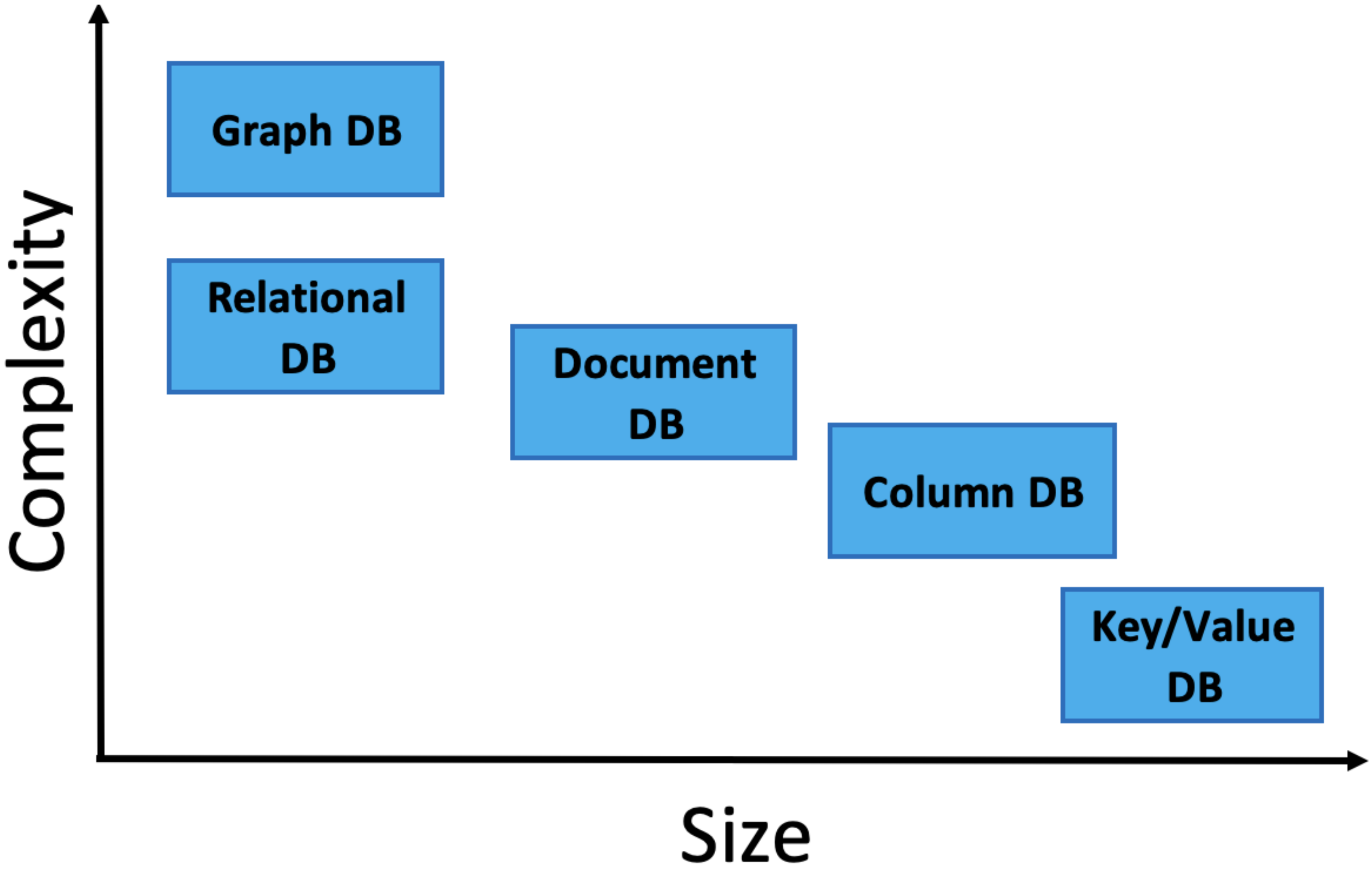
- ✓ Types of data stores
  - Key-value
  - Document
  - Wide column
  - Graph
- ✓ Polyglot Persistence

Types of NoSQL Databases



Source: https://www.geeksforgeeks.org/types-of-nosql-databases/

Size / Complexity of data stores



Database ranking 2024 & NoSQL DBS in the course

- **Document** stores (**MongoDB**)
- **Key-value** stores (**Redis**)
- **Wide column** stores (**Cassandra**)
- **Grapf** DBMS (**Neo4j**)

- **Search** engines (**Elasticsearch**)

- Hybrid systems (**HADOOP, Mapreduce**)

Types of NoSQL Databases

Core types

- **Key-value** stores
- **Wide column** (column family, column-oriented, …) stores
- **Document** stores
- **Graph** databases

Non-core types

- **Object** databases
- Native **XML** databases
- **RDF** stores…

Types of NoSQL Databases: Key-Value Stores

Data model

- The most simple NoSQL database type
  - Works as a simple hash table (mapping)
- **Key-value pairs**
  - Key (id, identifier, primary key)
  - Value: binary object, black box for the database system

Query patterns

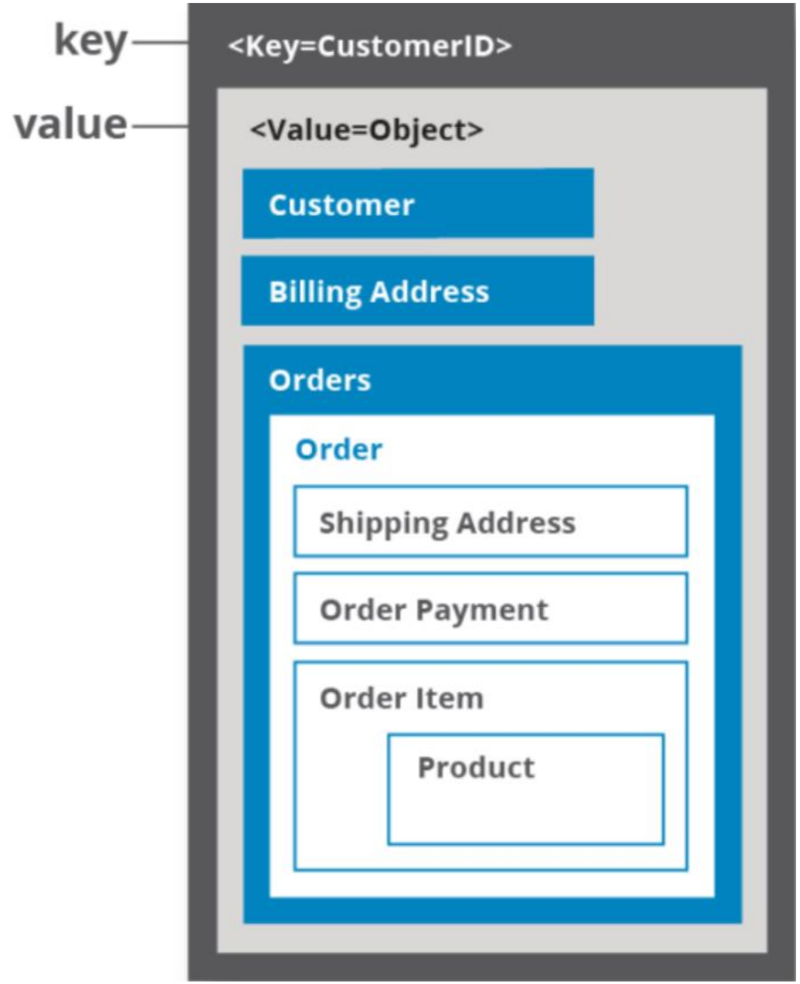
- Create, update or remove value for a given key
- **Get value** for a given key

Characteristics

- Simple model ⇒ **great performance, easily scaled, …**
- Simple model ⇒ **not for complex queries nor complex data**

Types of NoSQL Databases: Key-Value Stores

key	value
123	123 Main St.
126	(805) 477-3900



Source: https://hazelcast.com

Key-Value – Benefits & Downsides

Benefits (+):

- Can store anything
  - Value is essentially just a byte array
- Fastest possible method of writing and reading data from/to memory or disk
  - No format or model associated with values
- Easy adoption of new data sources with a different format

Downsides (-):

- Lowest common denominator
  - The application needs to know the format of all the values it reads
- Complex to analyze
  - Analytics need to be written in the app tier
  - No easy means to filter or aggregate on the data tier

Key-Value – Usages

When to use:

- Fastest possible read/write performance of a value
- There are no restrictions on what you can store
- New data source formats aren't known
- Examples: IoT, caches, very fast lookups of individual values

When not to use:

- Sophisticated analytics
- The format is well known and/or repetitive & fastest possible performance is of no concern.
- Relationships among entities
- Queries requiring access to the content of the value part
- Set operations involving multiple key-value pairs

Types of NoSQL Databases: Key-Value Stores

Suitable use cases

- Session data, user profiles, user preferences, shopping carts, …

  I.e. **when values are only accessed via keys**

Representatives

- **Redis**, **MemcachedDB**, **Riak KV**, Hazelcast, Ehcache, Amazon SimpleDB, Berkeley DB, Oracle NoSQL, Infinispan, LevelDB, Ignite, Project Voldemort
- *Multi-model*: OrientDB, ArangoDB

Types of NoSQL Databases: Document Stores

Data model

- **Documents**
  - Self-describing
  - **Hierarchical tree structures** (**JSON**, **XML**, …)
    - Scalar values, maps, lists, sets, nested documents, …
  - Identified by a **unique identifier** (key, …)
- Documents are **organized into collections**

Query patterns

- Create, update or remove a document
- **Retrieve documents according to complex query conditions**

Observation

- Extended key-value stores where the value part is examinable!

Types of NoSQL Databases: Document Stores

```
[
 {
  "Employee_ID": 2365,
  "Employee_Name": "Jiří Novák",
  "Department": "Finance",
  "Phone": "666555444",
  "Address": {
      "Street": "Václavské náměstí 123",
      "City": "Praha",
  },
  "Skills": [
   "Účetnictví", "Finanční analýza", "Rozpočtování"
  ]
 },
 {
  "Employee_ID": 3398,
  "Employee_Name": "Kateřina Svobodová",
  "Department": "Admin",
  "Projects": [
   {
    "Name": "Renovace kanceláří",
    "Duration": "6 měsíců"
   },
   {
    "Name": "Aktualizace HR systému",
    "Duration": "3 měsíce"
   }
  ]
 }
]
```

Document – Benefits & Downsides

Benefits (+):

- Self-contained
  - Data & Metadata stored together
  - Self describing
- Flexible schema
  - Schema-on-read
  - Document structure can look different between documents
- Human & Machine readable (?)

Downsides (-):

- Self-contained
  - Data and metadata is duplicated
  - Changes in data or metadata require scanning for all documents
- Flexible schema
  - Analytic workloads need to reason about the schema every time
  - Risk of becoming a "dumping ground"

Document – Usages

When to use:

- Data transfer
- Stateless communication
- Relatively static data
- Natural aggregates
- Examples: REST, product catalog, etc.

When not to use:

- Set operations involving multiple documents
- If data needs to be updated regularly
- The design of document structure is constantly changing
- Many downstream systems consuming the data
- No natural aggregates

Types of NoSQL Databases: Document Stores

Suitable use cases

- Event logging, content management systems, blogs, web analytics, e-commerce applications, …
  - I.e. **for structured documents with similar schema**

Representatives

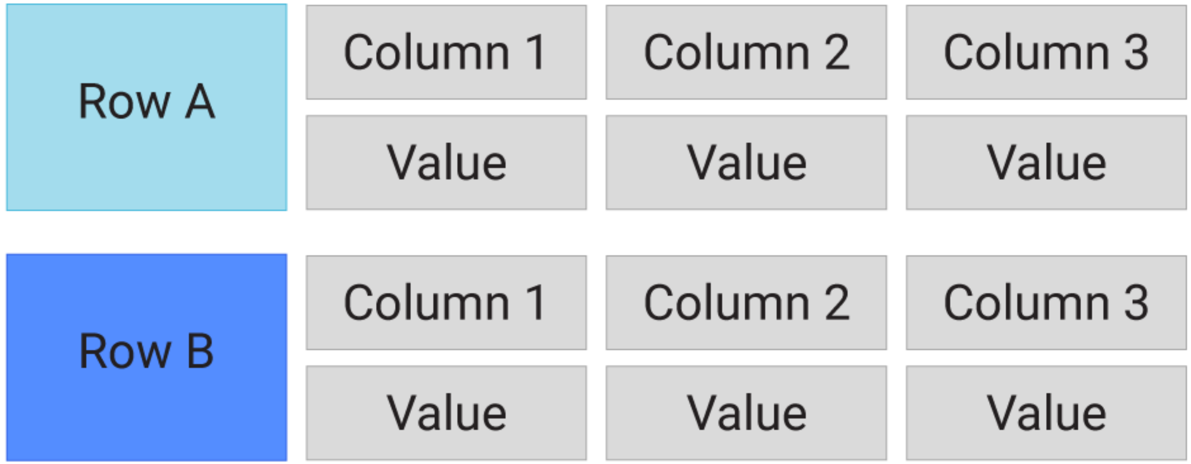
- <u>**MongoDB**</u>, **Couchbase**, Amazon **DynamoDB**, **CouchDB**, RethinkDB, RavenDB, Terrastore
- *Multi-model*: **MarkLogic**, **OrientDB**, OpenLink Virtuoso, ArangoDB

Types of NoSQL Databases: Wide Column Stores

Data model

- **Column family** (table)
  - Table is a collection of **similar rows** (not necessarily identical)
- **Row**
  - Row is a collection of **columns**
    - Should encompass a group of data that is accessed together
  - Associated with a unique **row key**
- **Column**
  - Column consists of a **column name** and **column value** (and possibly other metadata records)
  - Scalar values, but also **flat sets, lists or maps** may be allowed

Types of NoSQL Databases: Wide Column Stores



Query patterns

- Create, update or remove a row within a given column family
- **Select rows according to a row key or <u>simple</u> conditions**

Warning

- Wide column stores are <u>not just a special kind of RDBMSs</u> with a variable set of columns!

Document – Benefits & Downsides

Benefits (+):

- Can handle massive amounts of data across distributed systems
- Optimized for fast write operations
- Flexible schema
- Can handle sparse data efficiently
- Fast retrieval when column keys are known
- Often designed with built-in replication and fault tolerance
- Many wide-column stores offer adjustable consistency levels

Downsides (-):

- Limited support for complex queries
- Different data model compared to traditional relational databases
- Limited ACID transactions
- Not ideal for small datasets
- Potential for data duplication
- Requires careful planning to optimize for specific query patterns

Document – Usages

When to use:

- Big data applications with high write volumes
- Time-series data storage
- Content management systems with varying attributes
- Systems requiring high scalability and availability
- Applications with known query patterns

When not to use:

- Small-scale applications with simple data structures
- Systems requiring complex joins and relational data models
- Applications needing strong ACID guarantees across multiple rows or tables
- Scenarios requiring frequent, unpredictable analytical queries

Types of NoSQL Databases: Wide Column Stores

Suitable use cases

- Event logging, content management systems, blogs, …
  - I.e. **for structured flat data with similar schema**

When not to use

- **ACID transactions** are required
- **Complex queries**: aggregation (SUM, AVG, …), joining, …
- Early prototypes: i.e. when **database design may change**

Representatives

- Apache **Cassandra**, Apache **HBase**, Apache Accumulo, Hypertable, **Google Bigtable**

Types of NoSQL Databases: Graph Databases

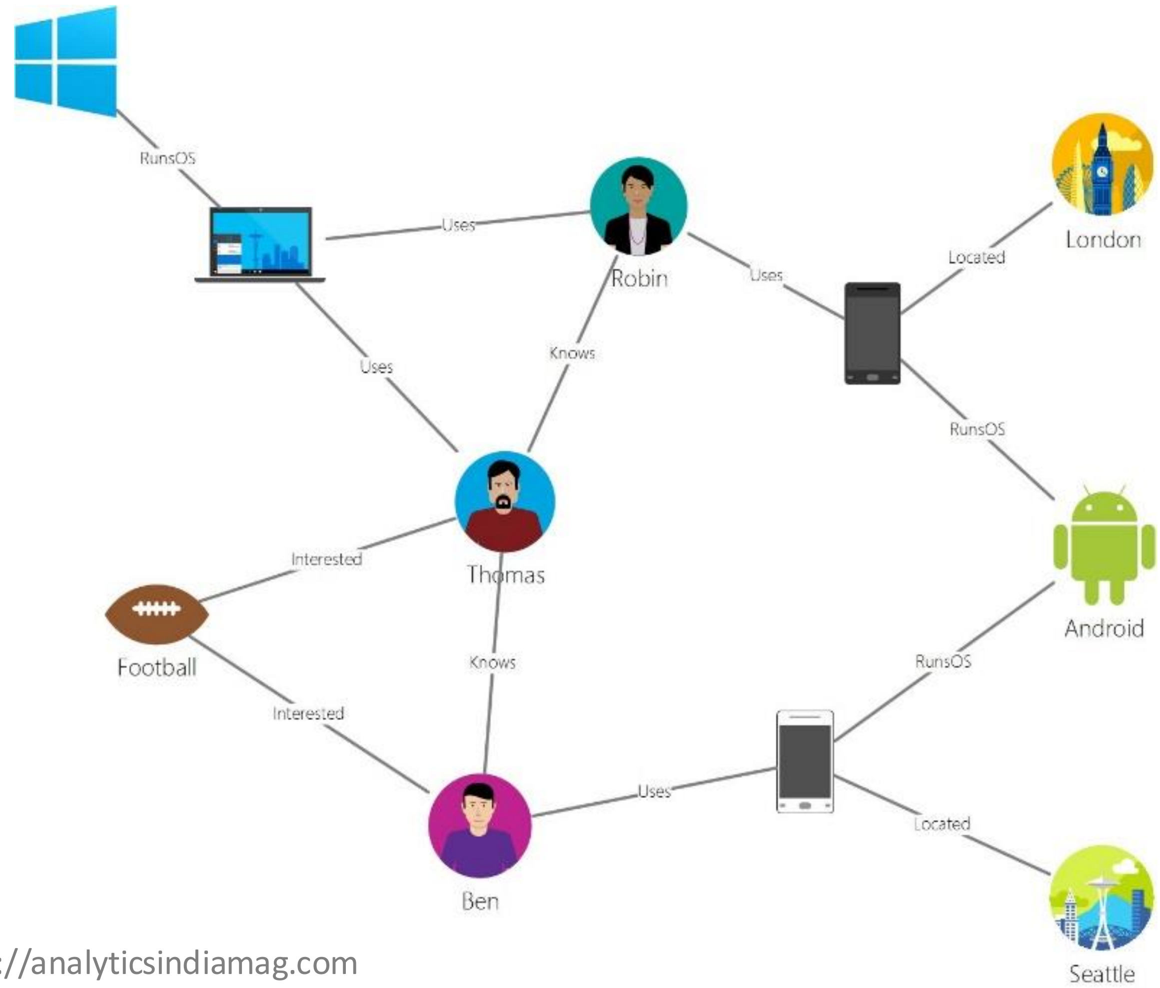
Data model

- Property graphs
  - **Directed / undirected graphs**, i.e. collections of …
    - nodes (vertices) for real-world entities, and
    - relationships (edges) between these nodes
  - Both the nodes and relationships can be associated with additional properties

Types of databases

- **Non-transactional** = small number of very large graphs
- **Transactional** = large number of small graphs

Types of NoSQL Databases: Graph Databases



Source: https://analyticsindiamag.com

Document – Benefits & Downsides

Benefits (+):

- Easy analytics for finding relationships between entities
  - Walking the graph
- Great for finding "hidden" relationships between entities
  - Visualizing the graph

Downsides (-):

- Anything not to do with finding relationships between entities
  - It is much more cumbersome and/or impractical to model anything that isn't to do with relationships between nodes

Document – Usages

When to use:

- LinkedIn – who knows who
- Facebook – friends of friends
- Recommendation engines – people who bought, etc.
- Fraud detection
- etc.

When not to use:

- Anything not to do with finding relationships between entities

Types of NoSQL Databases: Graph Databases

Query patterns

- Create, update or remove a node / relationship in a graph
- **Graph algorithms** (shortest paths, spanning trees, …)
- General **graph traversals**
- **Sub-graph** queries or **super-graph** queries
- Similarity based queries (approximate matching)

Representatives

- <u>**Neo4j**</u>, **Titan**, Apache Giraph, InfiniteGraph, FlockDB
- *Multi-model*: **OrientDB**, OpenLink **Virtuoso**, **ArangoDB**

Types of NoSQL Databases: Graph Databases

Suitable use cases

- Social networks, routing, dispatch, and location-based services, recommendation engines, chemical compounds, biological pathways, linguistic trees, ...
    - I.e. simply **for graph structures**

When not to use

- **Extensive batch operations** are required
    - Multiple nodes / relationships are to be affected
- **Only too large graphs** to be stored
    - Graph distribution is difficult or impossible at all

Types of NoSQL Databases: Native XML Databases

Data model

- **XML documents**
  - Tree structure with nested elements, attributes, and text values (beside other less important constructs)
  - Documents are organized into collections

Query languages

- **XPath**: *XML Path Language* (navigation)
- **XQuery**: *XML Query Language* (querying)
- **XSLT**: *XSL Transformations* (transformation) Representatives
- **Sedna**, **Tamino**, BaseX, eXist-db
- *Multi-model*: **MarkLogic**, OpenLink **Virtuoso**

Types of NoSQL Databases: Native XML Databases

```xml
<?xml version = "1.0"?>
<contact-info>
   <contact1>
      <name>Tanmay Patil</name>
      <company>TutorialsPoint</company>
      <phone>(011) 123-4567</phone>
   </contact1>

   <contact2>
      <name>Manisha Patil</name>
      <company>TutorialsPoint</company>
      <phone>(011) 789-4567</phone>
   </contact2>
</contact-info>
```

https://www.tutorialspoint.com

Types of NoSQL Databases: RDF Stores

Data model

- **RDF triples**
  - Components: **subject**, **predicate**, and **object**
  - Each triple represents a statement about a real-world entity
- Triples can be viewed as **graphs**
  - **Vertices** for subjects and objects
  - **Edges** directly correspond to individual statements

Query language

- **SPARQL**: *SPARQL Protocol and RDF Query Language*

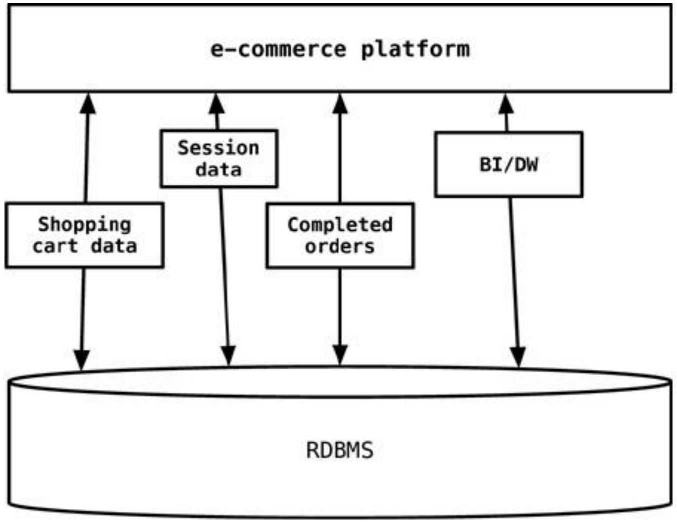
Representatives

- Apache **Jena**, **rdf4j** (Sesame), Algebraix
- *Multi-model*: **MarkLogic**, OpenLink **Virtuoso**

Polyglot Persistence

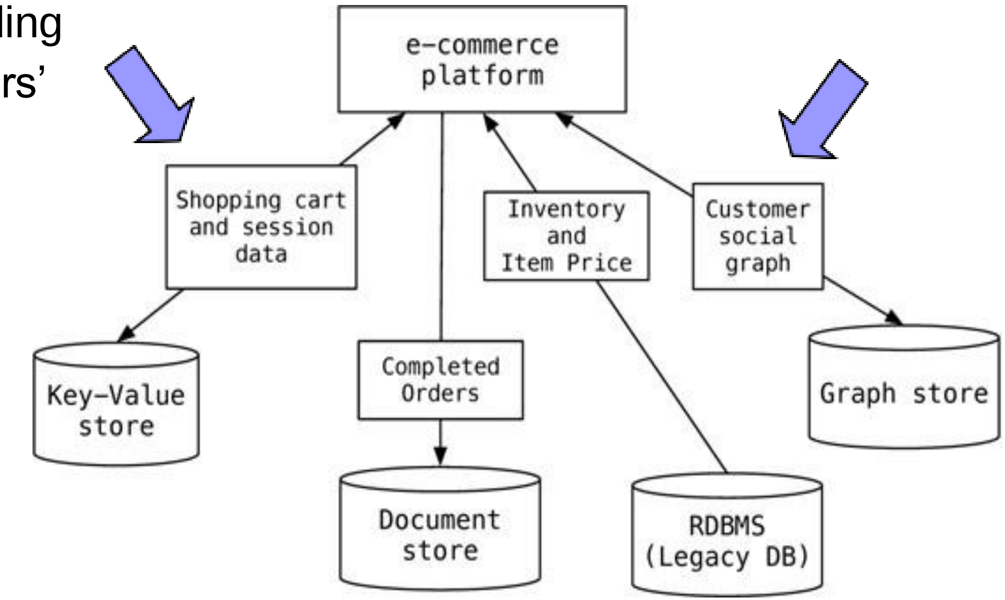
Polyglot Persistence

- Different databases are designed to solve different kinds of problems
- Using a single database engine for all of the requirements usually leads to partially non-performant solutions
- Example: e-commerce
  - Many types of data
    - Business transactions, session management data, reporting, data warehousing, logging information, …
  - Do not need the same properties of availability, consistency, or backup requirements



Polyglot Persistence

- Polyglot programming (2006)
  - Applications should be written in a mix of languages
  - Different languages are suitable for tackling different problems
- Polyglot persistence
  - Hybrid approach to persistence
  - e.g., a data store for the shopping cart, which is highly available vs. finding products bought by the customers' friends



Polyglot Persistence

- There may be other applications in the enterprise
  - e.g., the graph data store can serve data to applications that need to understand which products are being bought by a certain segment of the customer base

$\Rightarrow$ Instead of each application talking independently to the graph database, we can wrap the graph database into a service

- Assumption:
  - Nodes can be saved in one place
  - Queried by all the applications
- Allows for the databases inside the services to evolve without having to change the dependent applications

Polyglot Persistence