MDK: **Modern Database Concepts**

http://www.ksi.mff.cuni.cz/~svoboda/courses/192-MDK/

Lecture 11

Graph Databases: Neo4j

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Lecture Outline

Graph databases

- Introduction

Neo4j

- Data model: **property graphs**
- **Traversal framework**
- **Cypher** query language
  - Read, write, and general clauses

Graph Databases

Data model

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

Types of databases

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

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)

Neo4j Graph Database

Neo4j

Graph database

- https://neo4j.com/
- Features
  - Open source, massive scalability (billions of nodes), high availability, fault-tolerant, master-slave replication, **ACID transactions**, embeddable, …
  - Expressive graph query language (**Cypher**), **traversal framework**
- Developed by **Neo Technology**
- Implemented in Java
- Operating systems: cross-platform
- Initial release in 2007

Data Model

Database system structure

Instance $\rightarrow$ single **graph**

Property graph = directed labeled multigraph

- Collection of vertices (nodes) and edges (relationships)

Graph **node**

- Has a unique (internal) **identifier**
- Can be associated with a **set of labels**
  - Allow us to categorize nodes
- Can also be associated with a **set of properties**
  - Allow us to store additional data together with nodes

Data Model

Graph **relationship**

- Has a unique (internal) **identifier**
- Has a **direction**
  - Relationships are equally well traversed in either direction!
  - Directions can even be ignored when querying at all
- Always has a **start** and **end node**
  - Can be recursive (i.e. loops are allowed as well)
- Is associated with **exactly one type**
- Can also be associated with a **set of properties**

Data Model

Node and relationship **property**

- **Key-value pair**
  - Key is a string
  - Value is an **atomic value** of any primitive data type, or an **array of atomic values** of one primitive data type

Primitive **data types**

- `boolean` – **boolean** values `true` and `false`
- `byte`, `short`, `int`, `long` – **integers** (1B, 2B, 4B, 8B)
- `float`, `double` – **floating-point numbers** (4B, 8B)
- `char` – one Unicode character
- `String` – sequence of **Unicode characters**

Sample Data

Sample graph with **movies and actors**

```
(m1:MOVIE { id: "vratnelahve", title: "Vratné lahve", year: 2006 })
(m2:MOVIE { id: "samotari", title: "Samotáři", year: 2000 })
(m3:MOVIE { id: "medvidek", title: "Medvídek", year: 2007 })
(m4:MOVIE { id: "stesti", title: "Štěstí", year: 2005 })

(a1:ACTOR { id: "trojan", name: "Ivan Trojan", year: 1964 })
(a2:ACTOR { id: "machacek", name: "Jiří Macháček", year: 1966 })
(a3:ACTOR { id: "schneiderova", name: "Jitka Schneiderová", year: 1973 })
(a4:ACTOR { id: "sverak", name: "Zdeněk Svěrák", year: 1936 })

(m1)-[c1:PLAY { role: "Robert Landa" }]->(a2)
(m1)-[c2:PLAY { role: "Josef Tkaloun" }]->(a4)
(m2)-[c3:PLAY { role: "Ondřej" }]->(a1)
(m2)-[c4:PLAY { role: "Jakub" }]->(a2)
(m2)-[c5:PLAY { role: "Hanka" }]->(a3)
(m3)-[c6:PLAY { role: "Ivan" }]->(a1)
(m3)-[c7:PLAY { role: "Jirka", award: "Czech Lion" }]->(a2)
```

Neo4j Interfaces

Database architecture

- Client-server
- **Embedded database**
  - Directly integrated within your application

Neo4j drivers

- Official: Java, .NET, JavaScript, Python
- Community: C, C++, PHP, Ruby, Perl, R, …

Neo4j shell

- Interactive command-line tool

Query patterns

- **Cypher** – declarative graph query language
- **Traversal framework**

Traversal Framework

Traversal Framework

Traversal framework

- Allows us to express and execute graph traversal queries
- Based on callbacks, executed lazily

Traversal description

- **Defines rules and other characteristics of a traversal**

Traverser

- Initiates and **manages a particular graph traversal** according to…
  - the provided traversal description, and
  - graph node / set of nodes where the traversal starts
- Allows for the **iteration over the matching paths**, one by one

Traversal Framework: Example

Find actors who played in *Medvídek* movie

```
TraversalDescription td = db.traversalDescription()
  .breadthFirst()
  .relationships(Types.PLAY, Direction.OUTGOING)
  .evaluator(Evaluators.atDepth(1));

Node s = db.findNode(Label.label("MOVIE"), "id", "medvidek");
Traverser t = td.traverse(s);

for (Path p : t) {
  Node n = p.endNode();
  System.out.println(
    n.getProperty("name")
  );
}
```

```
Ivan Trojan
Jiří Macháček
```

Traversal Description

Components of a **traversal description**

- **Order**
  - Which graph traversal algorithm should be used
- **Expanders**
  - What relationships should be considered
- **Uniqueness**
  - Whether nodes / relationships can be visited repeatedly
- **Evaluators**
  - When the traversal should be terminated
  - What should be included in the query result

Traversal Description: Order

Order

Which graph traversal algorithm should be used?

- Standard **depth-first** or **breadth-first** methods can be selected
  or
  specific branch ordering policies can also be implemented
- Usage:
  td.`breadthFirst`()
  td.`depthFirst`()

Traversal Description: Expanders

Path expanders

Being at a given node…
what relationships should next be followed?

- **Expander specifies one allowed**…
  - relationship **type** and **direction**
    - `Direction.INCOMING`
    - `Direction.OUTGOING`
    - `Direction.BOTH`
- Multiple expanders can be specified at once
  - When none is provided,
    then all the relationships are permitted
- Usage:
  td.`relationships`(type, direction)

Traversal Description: Uniqueness

Uniqueness

Can particular nodes / relationships be revisited?

- Various **uniqueness levels** are provided
  - `Uniqueness.NONE` – no filter is applied
  - `Uniqueness.RELATIONSHIP_PATH`
    `Uniqueness.NODE_PATH`
    - Nodes / relationships within a current path must be distinct
  - `Uniqueness.RELATIONSHIP_GLOBAL`
    `Uniqueness.NODE_GLOBAL` (**default**)
    - No node / relationship may be visited more than once
- Usage:
  `td.uniqueness(level)`

Traversal Description: Evaluators

Evaluators

Considering a particular path…
should this path be included in the result?
should the traversal further continue?

- Available **evaluation actions**
  - `Evaluation.INCLUDE_AND_CONTINUE`
    `Evaluation.INCLUDE_AND_PRUNE`
    `Evaluation.EXCLUDE_AND_CONTINUE`
    `Evaluation.EXCLUDE_AND_PRUNE`
- Meaning of these actions
  - `INCLUDE` / `EXCLUDE` = whether to include the path in the result
  - `CONTINUE` / `PRUNE` = whether to continue the traversal

Traversal Description: Evaluators

Predefined evaluators

- `Evaluators.all()`
  - Never prunes, includes everything
- `Evaluators.excludeStartPosition()`
  - Never prunes, includes everything except the starting nodes
- `Evaluators.atDepth(depth)`
  `Evaluators.toDepth(maxDepth)`
  `Evaluators.fromDepth(minDepth)`
  `Evaluators.includingDepths(minDepth, maxDepth)`
  - Includes only positions within the specified interval of depths
- …

Traversal Description: Evaluators

Evaluators

- Usage:
  td.`evaluator`(evaluator)
- Note that evaluators are **applied even for the starting nodes**!
- When **multiple evaluators** are provided…
  - then they must all agree on both the questions
- When **no evaluator** is provided…
  - then the traversal never prunes and includes everything

Traverser

Traverser

- Allows us to perform a particular graph traversal
  - with respect to a given traversal description
  - starting at a given node / nodes
- Usage: t = td.`traverse`(node, ...)
  - `for (Path p : t) { ... }`
    - Iterates over all the paths
  - `for (Node n : t.nodes()) { ... }`
    - Iterates over all the paths, returns their end nodes
  - `for (Relationship r : t.relationships()) { ... }`
    - Iterates over all the paths, returns their last relationships

Path

- Well-formed **sequence of interleaved nodes and relationships**

Traversal Framework: Example

Find actors who played with *Zdeněk Svěrák*

```
TraversalDescription td = db.traversalDescription()
  .depthFirst()
  .uniqueness(Uniqueness.NODE_GLOBAL)
  .relationships(Types.PLAY)
  .evaluator(Evaluators.atDepth(2))
  .evaluator(Evaluators.excludeStartPosition());

Node s = db.findNode(Label.label("ACTOR"), "id", "sverak");
Traverser t = td.traverse(s);

for (Node n : t.nodes()) {
  System.out.println(
    n.getProperty("name")
  );
}
```

```
Jiří Macháček
```

Lecture Conclusion

Neo4j = graph database

- **Property graphs**
- **Traversal framework**
  - Path expanders, uniqueness, evaluators, traverser