NIE-PDB: **Advanced Database Systems**

http://www.ksi.mff.cuni.cz/~svoboda/courses/221-NIE-PDB/

Lecture 10

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**
- **Subgraph** queries or **super-graph** queries
- Similarity based queries (approximate matching)

Neo4j Graph Database

Neo4j

Graph database

- https://neo4j.com/
- Features
  - Open source, massive scalability, high availability, fault-tolerant, **master-slave replication**, **ACID transactions**, …
- Developed by **Neo Technology**
- Implemented in **Java**
- Operating systems: cross-platform
- Initial release in 2007
  - Version we cover is 4.4.10 (August 2022)

Data Model

Dataspace structure

$$\boxed{\text{Instance } (\rightarrow \textbf{database}) \rightarrow \text{single } \textbf{graph}}$$

Property graph = **directed labeled multigraph**

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

Node

- Unique **identity**
  - Internal, should not be used directly
- **Set of labels** (zero or more)
  - Allow for node categorization via user-defined types
  - E.g.: `ACTOR`, `MOVIE`, …
- **Property map** = set of individual **properties**
  - Allow to associate a given node with additional data

Data Model

Relationship

- Unique **identity**
  - Once again, internal only
- **Direction** (immutable and compulsory)
  - Relationships are **traversable in both directions**
    - There is no impact on efficiency
    - Directions can also be entirely ignored when querying
- **Start node** and **end node**
  - Can be the same, i.e., loops are allowed as well
- **Exactly one type** (immutable)
  - E.g.: `PLAY`, …
- **Property map**

Data Types

Structural types

- **Node**, **Relationship**
- **Path** = sequence of **interleaved nodes and relationships**

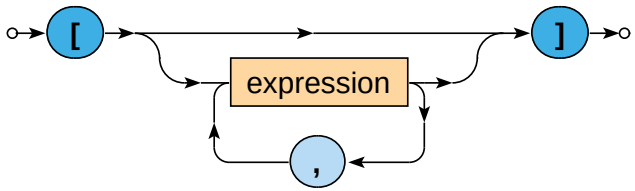
Property types

- **String** (e.g., `"Samotáři"`)
  - Sequence of Unicode characters
    - Enclosed preferably by **double quotes**
    - Standard **backslash escaping** (`\"`, `\n`, `\\`, …)
- **Integer** (e.g., `165`, `0xA5`, `0o245`)
- **Float**
- **Boolean** (literals `true` and `false`)
- …

Data Types

Composite types

- List = **ordered collection of values**
  - Values can be anything
    - I.e., all types are permitted (property, structural, composite)
    - And so lists can contain other embedded lists, maps, …
  - Lists can be heterogeneous

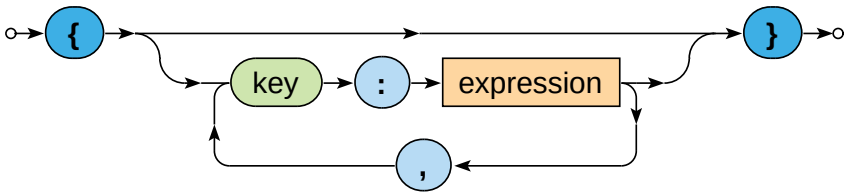


  - E.g.: `[ 2015, "Samotáři", [ 2020 ], 2015 ]`

Data Types

Composite types (cont'd)

- **Map** = **unordered collection of key-value pairs**
  - **Key** is a string, unique in a given map
  - **Value** can be anything, again
  - Maps can be heterogeneous, too



  - E.g.: `{ title: "Samotáři", genres: [ "comedy" ] }`

Property map = restricted version of a general map

- Used for **node and relationship property maps**
  - Only **atomic values** or homogeneous **arrays of atomic values** of any property type are permitted for **top-level properties**

Sample Data

Sample graph with **movies and actors**

```
CREATE
  // Movies
  (m1:MOVIE { id: "vratnelahve", title: "Vratné lahve", year: 2006,
              rating: 76, language: "cs", genres: [ "comedy" ] }),
  (m2:MOVIE { id: "samotari", title: "Samotáři", year: 2000,
              rating: 84, language: "cs", genres: [ "comedy", "drama" ] }),
  (m3:MOVIE { id: "medvidek", title: "Medvídek", year: 2007,
              rating: 53, language: "cs", genres: [ "comedy", "drama" ] }),
  (m4:MOVIE { id: "stesti", title: "Štěstí", year: 2005,
              rating: 72, language: "cs", genres: [ "drama" ] }),
  // Actors
  (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 }),
  (a5:ACTOR { id: "vilhelmova", name: "Tatiana Vilhelmová", year: 1978 }),
  ...
```

Sample Data

Sample graph with **movies and actors** (cont'd)

```
...
// Vratné lahve --> Jiří Macháček
(m1)-[p1:PLAY { role: "Robert Landa" }]->(a2),
// Vratné lahve --> Zdeněk Svěrák
(m1)-[p2:PLAY { role: "Josef Tkaloun" }]->(a4),
// Samotáři --> Ivan Trojan
(m2)-[p3:PLAY { role: "Ondřej" }]->(a1),
// Samotáři --> Jiří Macháček
(m2)-[p4:PLAY { role: "Jakub" }]->(a2),
// Samotáři --> Jitka Schneiderová
(m2)-[p5:PLAY { role: "Hanka" }]->(a3),
// Medvídek --> Ivan Trojan
(m3)-[p6:PLAY { role: "Ivan" }]->(a1),
// Medvídek --> Jiří Macháček
(m3)-[p7:PLAY { role: "Jirka" }]->(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, …

Cypher shell

- Interactive command-line tool

Query patterns

- **Cypher** 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
```

Cypher

Cypher

Cypher

- Declarative **graph query language**
  - Allows for expressive and efficient querying and updates
- Based on **sub-graph pattern matching**, similarly as SPARQL
  - Patterns are expressed using **ASCII-Art inspired syntax**
    - **Circles** `()` for nodes
    - **Arrows** `<--`, `--`, `-->` for relationships
- Each query is evaluated to a **solution sequence** (table)
  - Ordered collection of individual solutions (matching subgraphs)

Chaining of clauses

- Not only individual clauses can be used repeatedly…
- … they can also be (almost arbitrarily) **chained together**
  - Intermediate result of one clause is passed to the following one

Sample Query

Names of actors who played in *Medvídek* movie

```
MATCH (m:MOVIE)-[:PLAY]->(a:ACTOR)
  WHERE m.title = "Medvídek"
RETURN a.name, a.year
  ORDER BY a.year
```

m	a
(medvidek)	(trojan)
(medvidek)	(machacek)

→

a.name	a.year
Ivan Trojan	1964
Jiří Macháček	1966

Clauses and Subclauses

Read clauses

- `MATCH` – describes graph pattern to be searched for
  - `WHERE` – adds additional filtering constraints

Write clauses

- `CREATE`, `DELETE`, `SET`, `REMOVE`
  - Creates / deletes nodes / relationships / labels / properties

General clauses

- `RETURN` – defines what the query result should contain
  - `ORDER BY`, `SKIP`, and `LIMIT` subclauses
- `WITH` – constructs auxiliary intermediate query result
  - `ORDER BY`, `SKIP`, `LIMIT`, and also `WHERE`

Path Patterns

Path Patterns

Node pattern

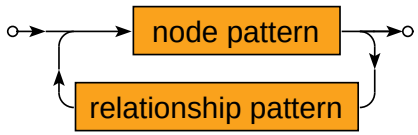
- Describes one data **node** and conditions it must satisfy
  - E.g.: `()`, `(:ACTOR { name: "Ivan Trojan" })`, …

Relationship pattern

- Describes one data **relationship** and conditions it must satisfy
  - E.g.: `()--()`, `(:MOVIE)-[:PLAY]->(:ACTOR)`, …

Path pattern

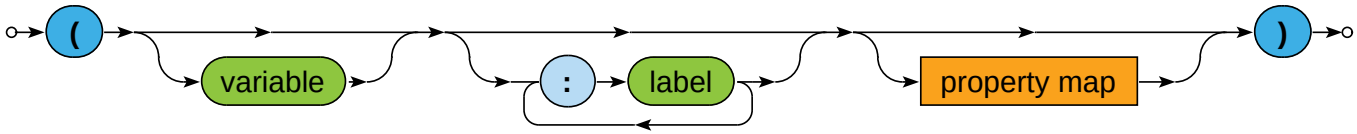
- Describes one data **path** to be found
  - Via a sequence of interleaved node and relationship patterns



Node Patterns

Node pattern

- Describes **one data node** to be matched
  - When inner conditions are provided, they must all be satisfied



- **Variable**
  - **Makes a given node accessible** in subsequent query fragments
    - I.e., for selection in `WHERE` conditions, projection in `RETURN` clauses, alignment with other node patterns, …
    - Such a thing would otherwise be impossible
  - E.g.: `(m)`

Node Patterns

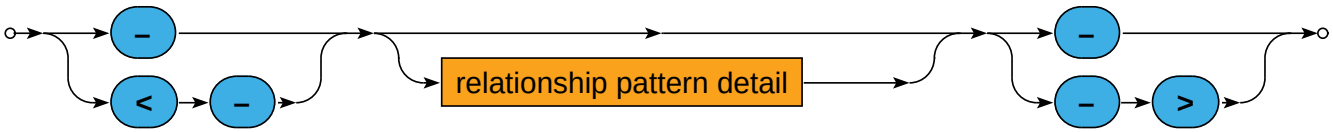
Node **pattern** (cont'd)

- **Labels condition**
  - Set of zero or more labels can be provided
  - Data node to be matched then…
    - Must have at least **all the specified labels**
    - I.e., there may also be other, but these are compulsory
  - E.g.: `(m:MOVIE)`
- **Property map condition**
  - Data node to be matched…
    - Must have at least **all the specified properties**
    - I.e., they are present and have **identical values**
    - Note that mutual order of such properties is unimportant
  - E.g.: `(m:MOVIE { title: "Medvídek", year: 2007 })`

Relationship Patterns

Relationship pattern

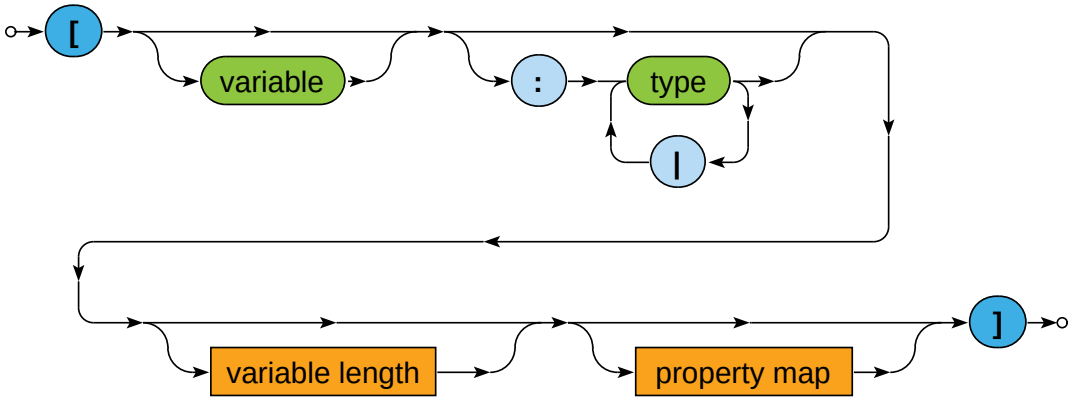
- Describes **one data relationship** to be matched
  - When the direction condition is provided, it must be satisfied
  - When inner conditions are given, they must also be satisfied



- **Direction condition**
  - Data relationship to be matched…
    - Must have **the same direction**
    - I.e., `-->` for outgoing direction or `<--` for incoming
    - When `--` is used, direction is ignored

Relationship Patterns

Relationship **pattern** (cont'd)



- **Variable**
  - Allows us to access a given relationship later on
  - E.g.: `()-[r]->()`

Relationship Patterns

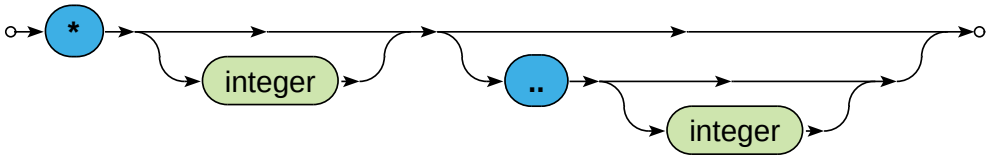
Relationship pattern (cont'd)

- **Type condition**
  - Set of zero or more types can be provided
  - Data relationship to be matched then…
    - Must have **one of the enumerated types**
  - E.g.: `()-[r:PLAY]->()`
- **Property map condition**
  - Data relationship to be matched…
    - Must have at least **all the specified properties**
  - E.g.: `()-[r:PLAY { role: "Jakub" }]->()`

Relationship Patterns

Relationship **pattern** (cont'd)

- **Variable length mode**
  - When activated, **paths of arbitrary lengths** can be found
    - Otherwise (i.e., by default), one relationship pattern will be matched by exactly one data relationship
  - **Length condition** ranges: `*`, `*4`, `*2..6`, `*..6`, `*2..`



  - Each data relationship on the path must…
    - **Satisfy all the involved conditions** (direction, type, properties)
  - E.g.: `()-[r:FRIEND *..2]-()`
    - If **variable** is introduced, it then references the whole path

Graph Patterns

Relationship uniqueness requirement

- **One data node** may match **multiple node patterns** at once
  - E.g.: `(a)-[:FRIEND]-()-[:FRIEND]-(b)`
    - It may happen that both `a` and `b` will actually be the same node
    - However, only when **distinct data relationships** were used…
- I.e., **one data relationship** cannot be matched repeatedly

Node pattern alignment

- Intentional alignment of nodes (not relationships) is possible
  - Simply by using the same **shared variables**
- E.g.: `(a)-[:FRIEND]-()-[:FRIEND]-(a)`

General graph pattern

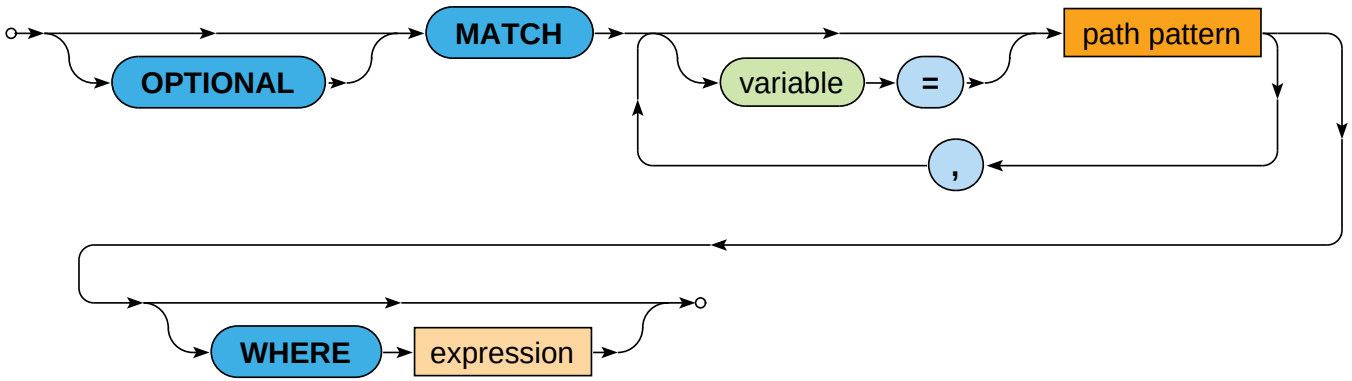
- Graphs can be decomposed into individual path patterns
  - Uniqueness requirement / shared variables work the same way

Read Clauses

Match Clause

`MATCH` **clause**

- Allows to search for **sub-graphs of the data graph** that **match** the provided **graph pattern**
  - Solution sequence is produced, each variable has to be bound
- **Natural join** is used on the previous result when chaining



- `WHERE` **condition**
  - Only solutions satisfying a given condition are preserved

Match Clause: Example

Names of actors who played with *Ivan Trojan* in any movie

- Notice that *Ivan Trojan* himself is not included in the result
  - Because of the **uniqueness requirement**

```
MATCH (i:ACTOR)<-[:PLAY]-(m:MOVIE)-[:PLAY]->(a:ACTOR)
  WHERE (i.name = "Ivan Trojan")
RETURN a.name
```

```
MATCH (i:ACTOR { name: "Ivan Trojan" })
        <-[:PLAY]-(m:MOVIE)-[:PLAY]->
      (a:ACTOR)
RETURN a.name
```

i	m	a
(trojan)	(samotari)	(machacek)
(trojan)	(samotari)	(schneiderova)
(trojan)	(medvidek)	(machacek)

→

a.name
"Jiří Macháček"
"Jitka Schneiderová"
"Jiří Macháček"

Match Clause: Example

Names of actors who played with *Ivan Trojan* in any movie (cont'd)

- **Uniqueness requirement** is not applied **across clauses**
  - And so internal identities must be used to exclude *Ivan Trojan*

```
MATCH (i:ACTOR { name: "Ivan Trojan" })<-[:PLAY]-(m:MOVIE)
MATCH (m:MOVIE)-[:PLAY]->(a:ACTOR)
  WHERE (i <> a)
RETURN a.name
```

i	m
(trojan)	(samotari)
(trojan)	(medvidek)

⋈

m	i
(vratnelahve)	(machacek)
(vratnelahve)	(sverak)
(samotari)	(trojan)
(samotari)	(machacek)
(samotari)	(schneiderova)
(medvidek)	(trojan)
(medvidek)	(machacek)

Search Conditions

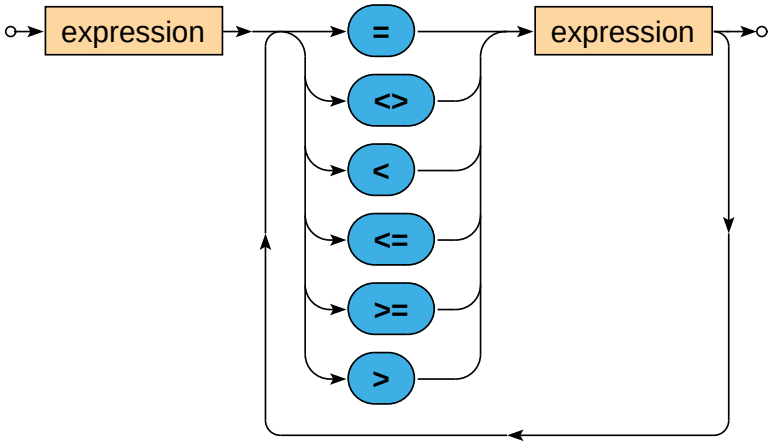
`WHERE` **subclause conditions**

- Only solutions satisfying a given condition are preserved
  - Evaluated directly during the matching phase (not after it)
- Possible conditions
  - **Comparisons**
  - NULL testing predicate
  - IN predicate
  - **Path patterns**
  - Existential subqueries
  - **Quantifiers**
  - **Boolean expressions**
  - …

Search Conditions

Comparison conditions

- Traditional comparison operators are available
  - **Chained comparisons** can be created, too

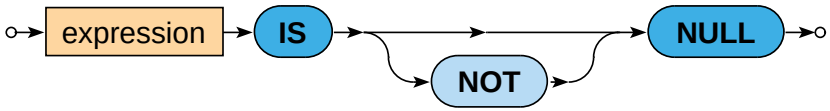


- E.g.: `2015 <= m.year < 2020`
  - Equivalent to `2015 <= m.year AND m.year < 2020`

Search Conditions

NULL testing conditions

- **Three-valued logic** is assumed
  - Traditional `true` and `false` values
    - But also `null` representing the third **unknown value**
- Indirect testing is thus necessary



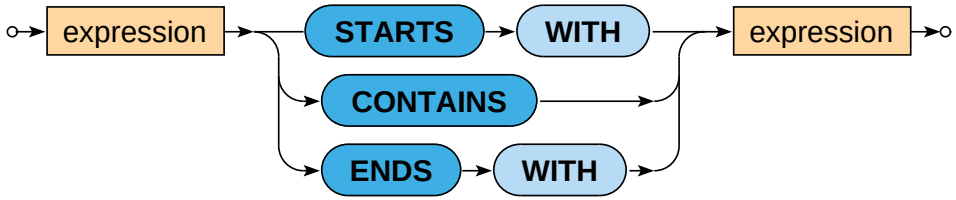
IN predicate conditions

- Allow for both **fixed enumerations** as well as **arbitrary lists**
- E.g.: `m.language IN [ "cs", "sk" ]`
- E.g.: `"comedy" IN m.genres`

Search Conditions

String matching conditions

- `STARTS WITH` / `CONTAINS` / `ENDS WITH` operators



- E.g.: `m.title ENDS WITH "Bobule"`
  - Matches `Bobule`, `2Bobule`, …

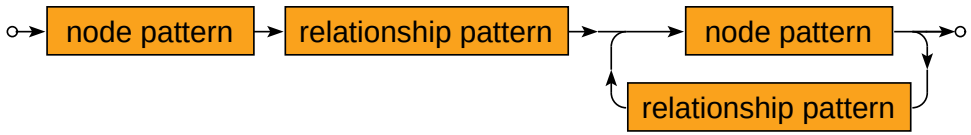
Regular expression conditions

- Special operator `=~` is used for this purpose
- E.g.: `m.title =~ ".*Bobule"`

Search Conditions

Path pattern predicate **conditions**

- **Path pattern** can directly be used as a condition
  - At least one relationship pattern is required, though

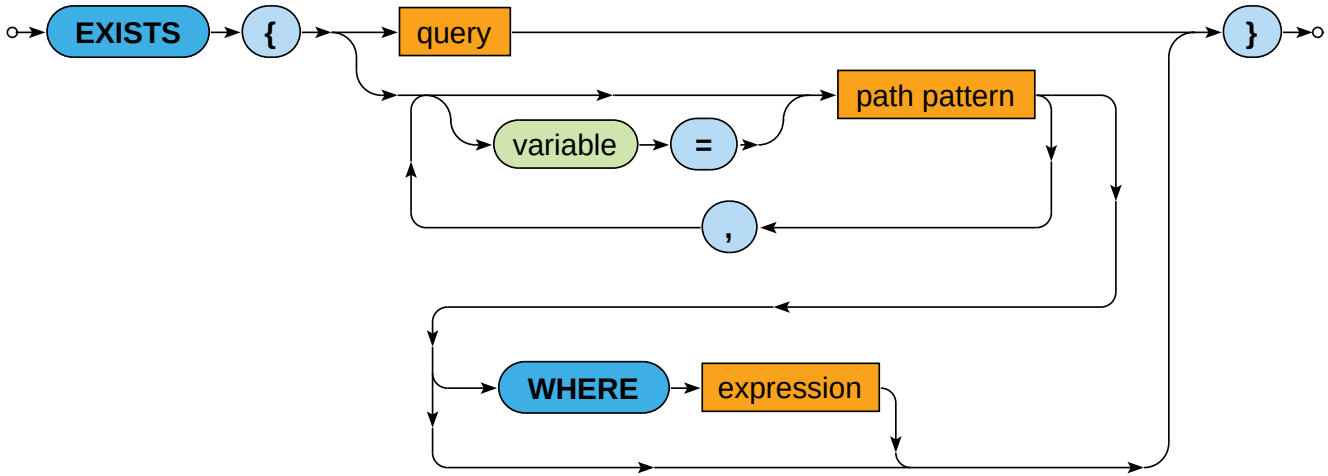


- Satisfied if and only if a **non-empty result** is yielded
- E.g.: `(m)-[:PLAY]->(:ACTOR)`
  - Ensures the existence of at least one actor for an already resolved movie node `m`

Search Conditions

Existential subquery conditions

- **Subquery** with **top-level query** expressive power
- Or standard **graph pattern** with optional filtering

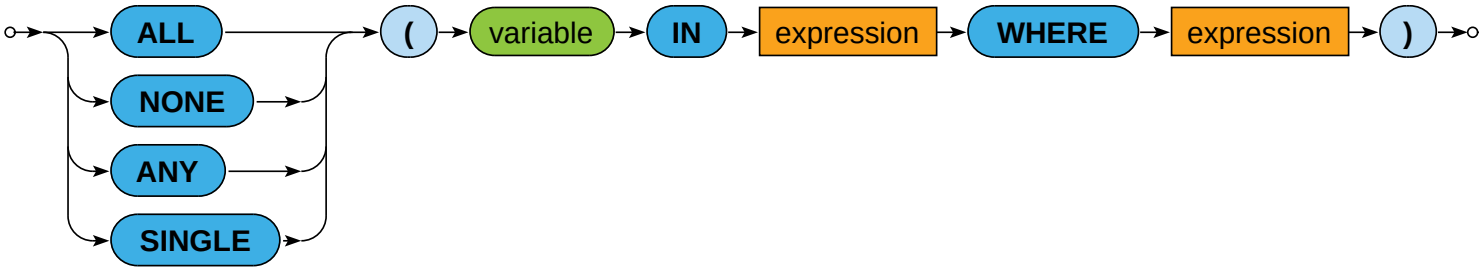


- Satisfied if and only if a **non-empty result** is yielded
- E.g.: `EXISTS { (m)-[:PLAY]->(a:ACTOR) WHERE a.name = "Ivan Trojan" }`

Search Conditions

Quantifier conditions

- Allow to simulate quantifiers and their derivatives



- Satisfied if and only if…
  - `ALL`: **all items** satisfy a given condition
  - `NONE`: **no item** satisfies a given condition
  - `ANY`: **at least one item** satisfies a given condition
  - `SINGLE`: **exactly one item** satisfies a given condition
- E.g.: `ANY (g IN m.genres WHERE g = "comedy")`

Search Conditions

Logical conditions

- Standard logical connectives are available
  - `AND` (**conjunction**)
  - `OR` (**disjunction**)
  - `NOT` (**negation**)

Match Clause

`OPTIONAL` **mode** of `MATCH` clauses

- **Optionally** attempts to find **matching data sub-graphs**…
  - When not possible, one solution with all variables bound to `null` is generated
- **Left outer natural join** is used when chaining

Match Clause: Example

Movies from *2005* or earlier, optionally their actors born after *1965*

```
MATCH (m:MOVIE)
  WHERE (m.year <= 2005)
OPTIONAL MATCH (m)-[:PLAY]->(a:ACTOR)
  WHERE (a.year > 1965)
RETURN m.title, a.name
```

m
(samotari)
(stesti)

⟕

m	i
(vratnelahve)	(machacek)
(samotari)	(machacek)
(samotari)	(schneiderova)
(medvidek)	(machacek)

=

m	a
(samotari)	(machacek)
(samotari)	(schneiderova)
(stesti)	null

→

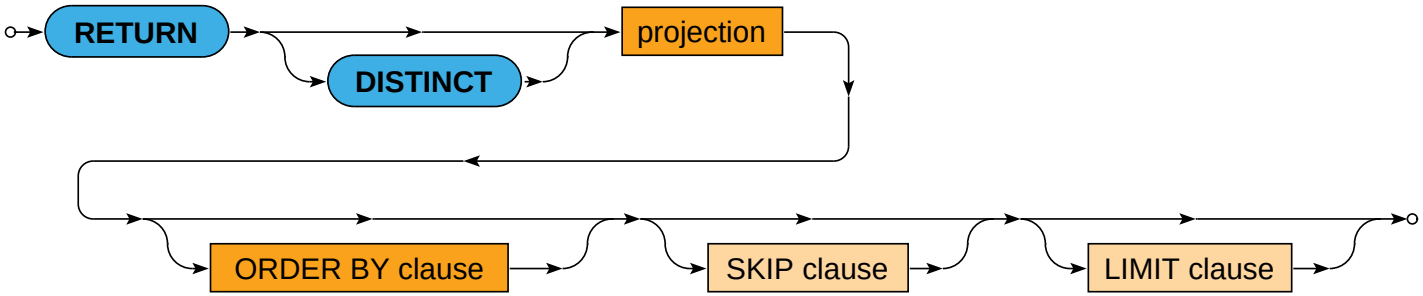
m.title	a.name
"Samotáři"	"Jiří Macháček"
"Samotáři"	"Jitka Schneiderová"
"Štěstí"	null

General Clauses

Return Clause

`RETURN` **clause**

- Defines the final **query result** to be **returned to the user**
  - Can only be provided as the **very last clause** in the chain

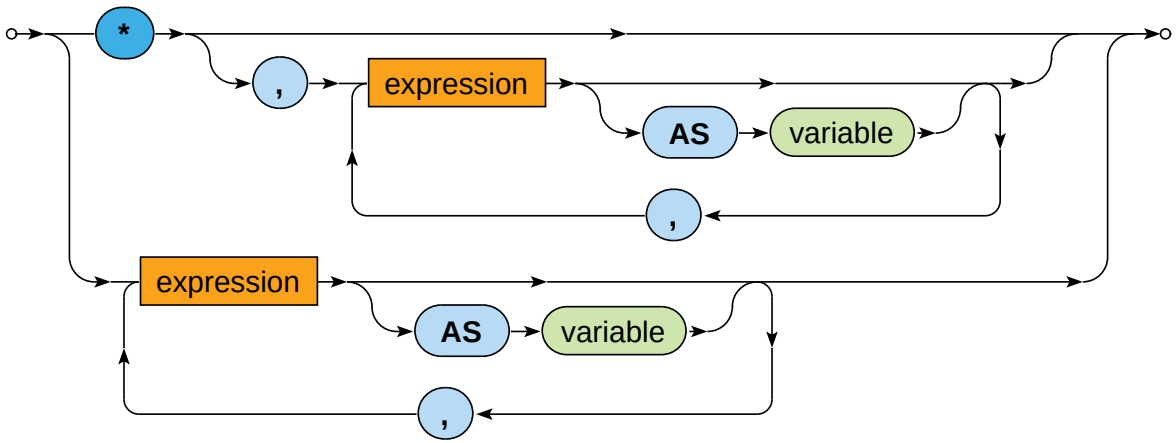


- `DISTINCT` **modifier**: removes **duplicate** solutions
- `ORDER BY` **subclause**
- `SKIP` and `LIMIT` **subclauses**: **pagination** of solutions

Return Clause

Projection

- **Enumeration of columns** to appear in the result
  - **Variables** for nodes, relationships, or even paths
  - **Properties** via the dot notation
  - Arithmetic expressions, **aggregate** functions, …
- **Wildcard** * = all the existing columns
  - Can only be specified as the very first item



Return Clause: Example

Actors born in *1965* or later and numbers of movies they played in

```
MATCH (a:ACTOR)
  WHERE (a.year >= 1965)
RETURN a.name, SIZE((a)<-[:PLAY]-(:MOVIE)) AS count
  ORDER BY count DESC
```

a
(schneiderova)
(machacek)
(vilhelmova)

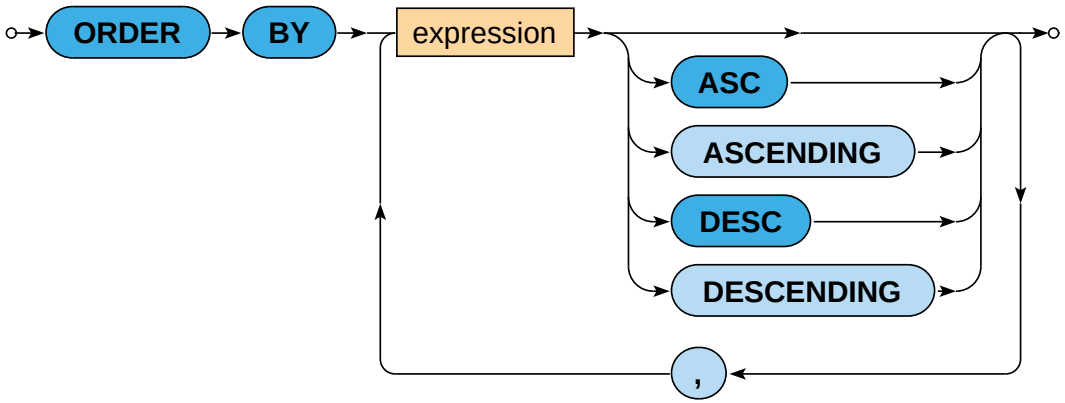
→

a.name	count
"Jiří Macháček"	3
"Jitka Schneiderová"	1
"Tatiana Vilhelmová"	0

Solution Modifiers

`ORDER BY` subclause

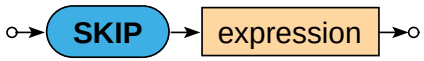
- Defines the **order of solutions** within the query result
  - Multiple criteria can be specified
    - Nodes, relationships, nor paths cannot be used for this purpose
  - The order is undefined unless explicitly defined
- **Default direction** is `ASC`



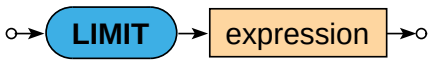
Solution Modifiers

Pagination

- `SKIP` **subclause**
  - Determines the **number of solutions to be skipped** in the query result



- `LIMIT` **subclause**
  - Determines the **number of solutions to be included** in the query result



Grouping and Aggregation

Traditional grouping is supported, too

- Works exactly as in the relational databases
  - However, there are no specific `GROUP BY` or `HAVING` clauses
- Happens **automatically**…
  - When **at least one aggregate function** is called in **projection**
- All columns are then divided into two disjoint types…
  - **Aggregating colums**
    - All the columns calling an **aggregate function**
    - E.g.: `COUNT`, `SUM`, `MIN`, `MAX`, `AVG`, `COLLECT`, …
  - **Grouping columns**
    - All the remaining ones
    - They all become the **classification columns**
    - And so they determine the individual **groups to be created**

Grouping and Aggregation: Example

Actors born in *1965* or later and movies they played in

```
MATCH (a:ACTOR)<-[:PLAY]-(m:MOVIE)
  WHERE (a.year >= 1965)
RETURN a.name, COUNT(m) AS count, COLLECT(m.title) AS movies
```

a	m
(machacek)	(vratnelahve)
(machacek)	(samotari)
(machacek)	(medvidek)
(schneiderova)	(samotari)

→

a.name	...
"Jiří Macháček"	...
"Jitka Schneiderová"	...

→

a.name	count	movies
"Jiří Macháček"	3	["Vratné lahve", "Samotáři", "Medvídek"]
"Jitka Schneiderová"	1	["Samotáři"]

- Note that *Tatiana Vilhelmová* will not be included
  - Since she did not play in any movie

Grouping and Aggregation: Example

Actors born in *1965* or later and movies they played in (cont'd)

```
MATCH (a:ACTOR)
  WHERE (a.year >= 1965)
OPTIONAL MATCH (a)<-[:PLAY]-(m:MOVIE)
RETURN a.name, COUNT(m) AS count, COLLECT(m.title) AS movies
```

a
(machacek)
(schneiderova)
(vilhelmova)

→

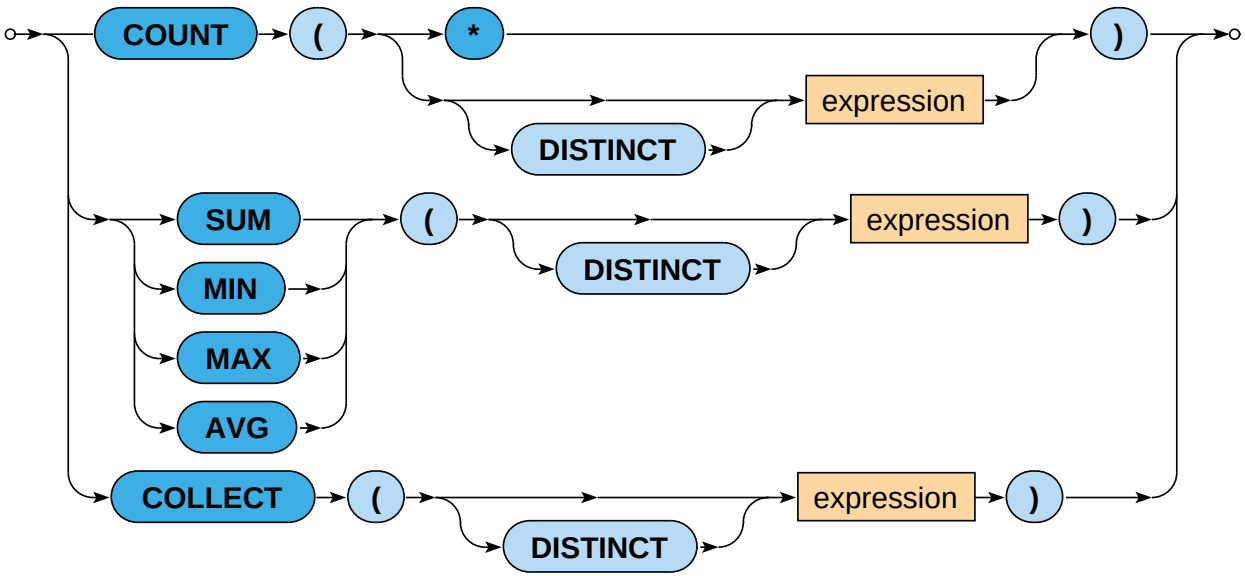
a	m
(machacek)	(vratnelahve)
(machacek)	(samotari)
(machacek)	(medvidek)
(schneiderova)	(samotari)
(vilhelmova)	null

→

a.name	count	movies
"Jiří Macháček"	3	["Vratné lahve", "Samotáři", "Medvídek"]
"Jitka Schneiderová"	1	["Samotáři"]
"Tatiana Vilhelmová"	0	[ ]

Grouping and Aggregation

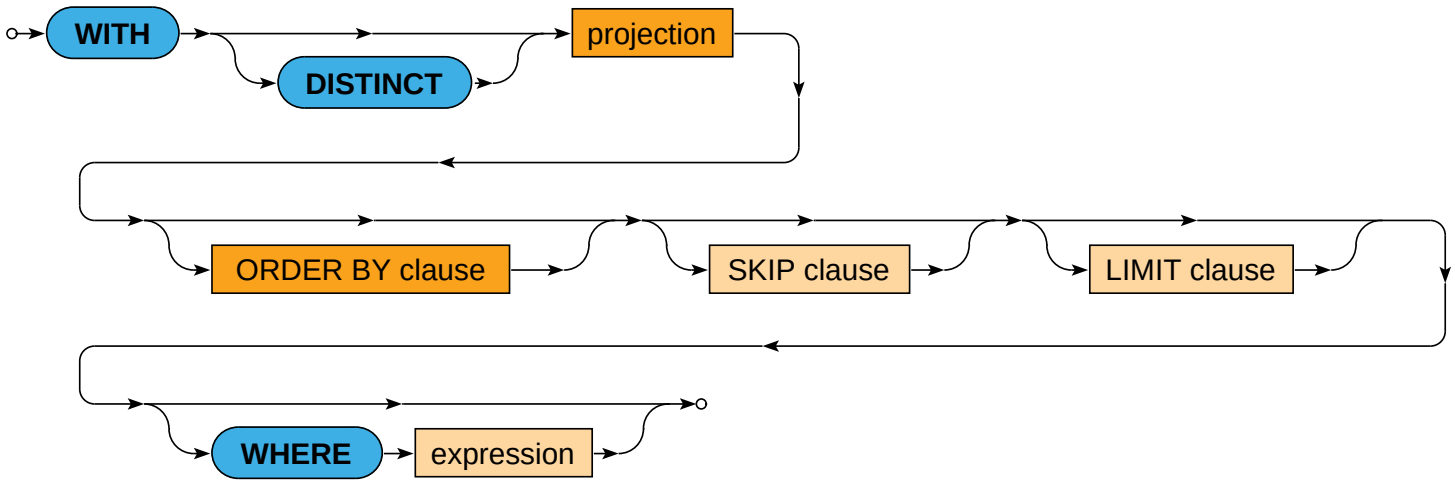
Aggregate functions



With Clause

`WITH` **clause**

- **Constructs** another **intermediate result** in the chain
  - Analogous behavior to the `RETURN` clause
    - Except that no output is sent to the user
  - Optional `WHERE` **subclause** can also be provided



With Clause: Example

Movies with above average number of actors and rating at least *75*

```
MATCH (m:MOVIE)
WITH m, SIZE((m)-[:PLAY]->(:ACTOR)) AS actors
WITH AVG(actors) AS average
MATCH (m:MOVIE)
  WHERE (SIZE((m)-[:PLAY]->(:ACTOR)) > average) AND (m.rating >= 75)
RETURN m.title, m.rating
```

m
(vratnelahve)
(samotari)
(medvidek)
(stesti)

→

m	actors
(vratnelahve)	2
(samotari)	3
(medvidek)	2
(stesti)	0

→

average
1.75

→

average	m
1.75	(vratnelahve)
1.75	(samotari)

→

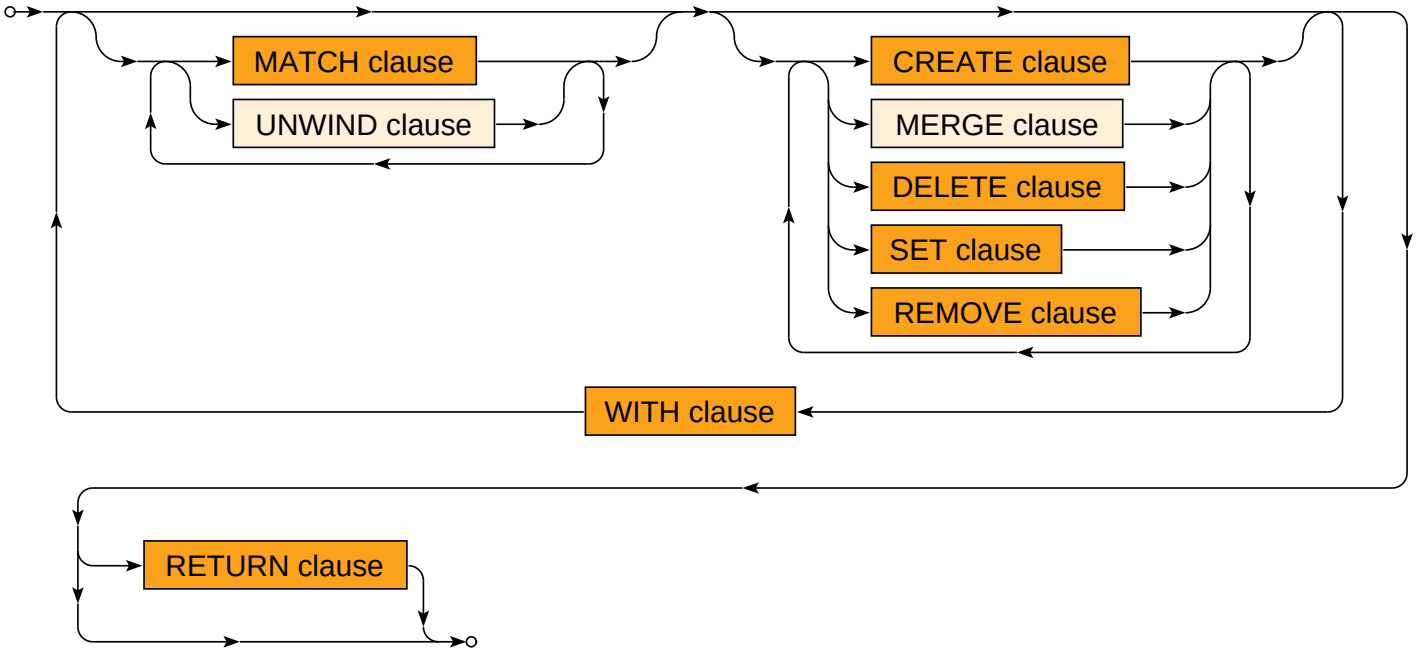
m.title	m.rating
"Vratné lahve"	76
"Samotáři"	84

Query Structure

Query Structure

Chaining of clauses

- Certain rules must be followed when chaining the clauses…



Query Structure

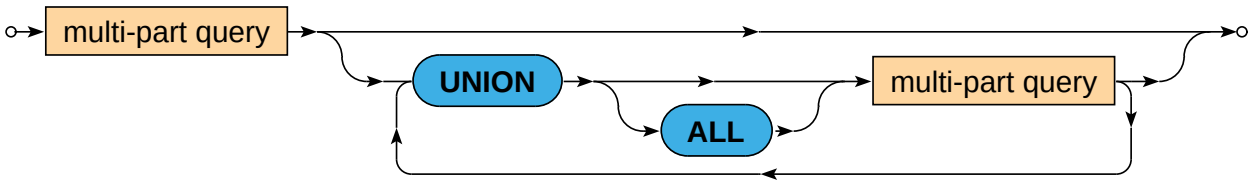
Query parts

- `WITH` **clauses** split the whole query into **query parts**
- Within each query part…
  - **Read clauses** (if any) **must precede write clauses** (if any)
    - Read clauses: `MATCH`, …
    - Write clauses: `CREATE`, `DELETE`, `SET`, `REMOVE`, …
- As for the very last query part…
  - It must be **terminated by** `RETURN` **clause**
    - Unless this part contains at least one write clause
    - I.e., read-only queries must return data

Union Operation

`UNION` **operation**

- **Combines results** yielded by two or more **multi-part queries**
  - Standard union set operation is assumed



- **Schemas** of all involved results must be **identical**
  - I.e., the same number and the same names of columns
- **Duplicates** are automatically **removed**
  - Unless the `ALL` keyword is provided

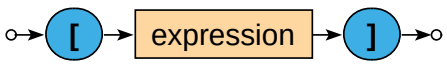
Map and List Operations

Property lookup operator

- Allows to access a particular property of a given map
  - **Static lookup**: `m.genres`
    - Dot notation is used, for fixed property keys only
  - **Dynamic lookup**: `m["genres"]`

List subscript operator

- Allows to access a particular list item based on its index
  - Position of the first item is `0`
  - **Negative values** are also permitted
    - For positions starting at the end and in the reverse direction

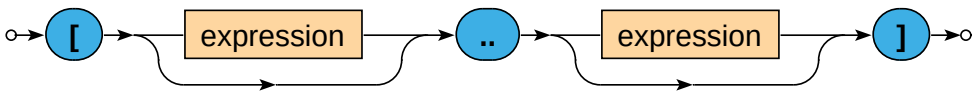


- E.g.: `m.genres[0]`, `m.genres[-1]` (the last genre)

List Operations

List slice **operator**

- Allows to retrieve an arbitrary range of a given list
  - Lower bound is inclusive, **upper bound is exclusive**
    - At least one bound needs to be specified
  - **Negative numbers** are allowed as well

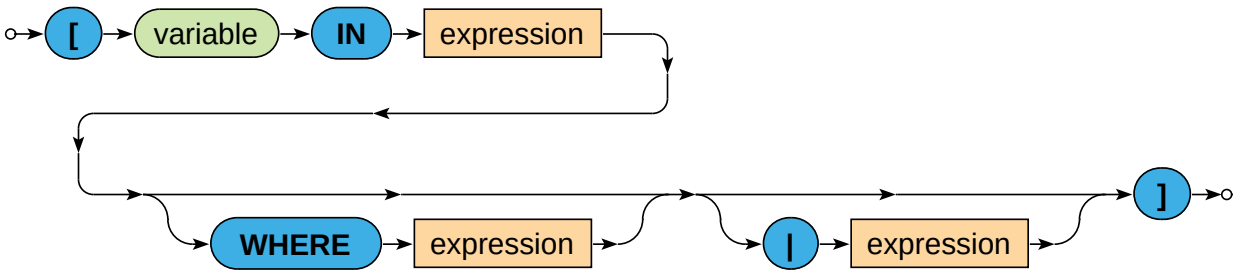


- Examples
  - `range(1, 5)` → `[1, 2, 3, 4, 5]`
  - `range(1, 5)[1..3]` → `[2, 3]`
  - `range(1, 5)[..3]` → `[1, 2, 3]`
  - `range(1, 5)[1..]` → `[2, 3, 4, 5]`
  - `range(1, 5)[-3..-1]` → `[3, 4]`
  - `range(1, 5)[3..-1]` → `[4]`

List Operations

List comprehension

- **Creates a new list based on items of an existing list**
  - Only items satisfying a given condition are considered
  - New output items can be constructed
    - Otherwise the original ones are returned intact

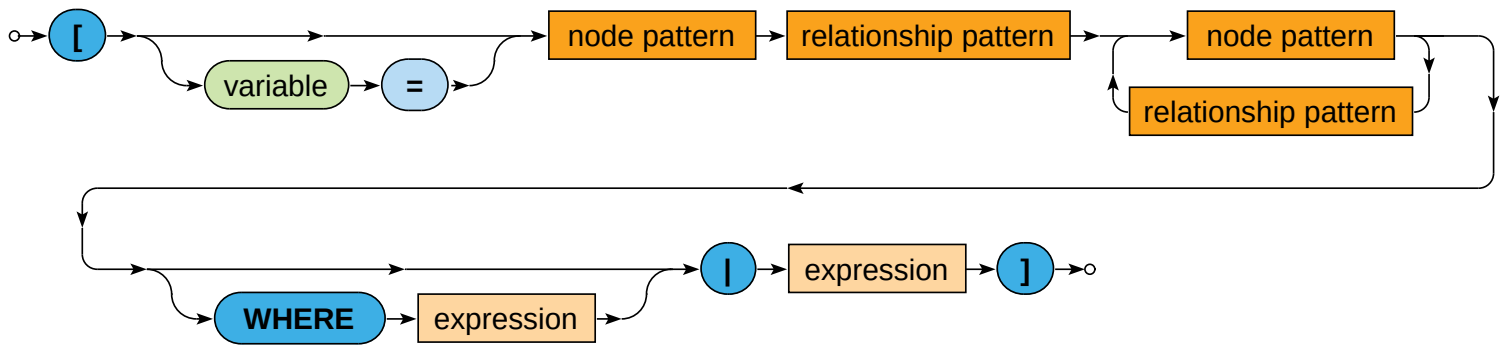


- Examples
  - `[ i IN range(1, 5) WHERE i % 2 = 0 ]` → `[2, 4]`
  - `[ i IN range(1, 5) WHERE i % 2 = 0 | i * 10 ]` → `[20, 40]`

List Operations

Pattern comprehension

- **Creates a new list based on solutions of a given path pattern**
  - Only solutions satisfying a given condition are considered



- Example
  - `[ (m:MOVIE)-[:PLAY]->(a:ACTOR) WHERE (m.year >= 2005) AND (a.name = "Jiří Macháček") | m.title ]`
    → `["Vratné lahve", "Medvídek"]`

Lecture Conclusion

Neo4j = graph database

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

Cypher = graph query language

- Read (sub-)clauses: `MATCH`, `WHERE`, …
- Write (sub-)clauses: `CREATE`, `DELETE`, `SET`, `REMOVE`, …
- General (sub-)clauses: `RETURN`, `WITH`, `ORDER BY`, `LIMIT`, …