NDBI040: **Big Data Management and NoSQL Databases**

http://www.ksi.mff.cuni.cz/~svoboda/courses/171-NDBI040/

Lecture 4

RDF Stores: SPARQL

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Lecture Outline

RDF stores

- Introduction
- Linked Data

SPARQL query language

- Graph patterns
- Filter constraints
- Solution modifiers
- Aggregation
- Query forms

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**

Linked Data

Linked Data

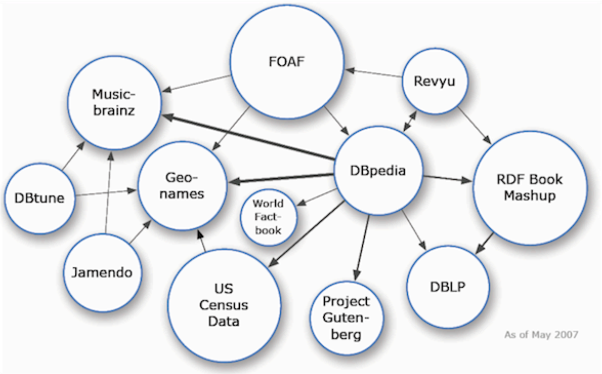
- Method of **publishing structured and interlinked data** in a way that allows for an **automated processing by programs** rather than browsing by human readers

Principles of Linked Open Data

- **Identify resources** using URIs or even better using **URLs**
- **Publish data** about resources in standard formats via **HTTP**
- Mutually **interlink resources** to form Web of Data
- Release the data under an **open licence**

Linked Open Data Cloud

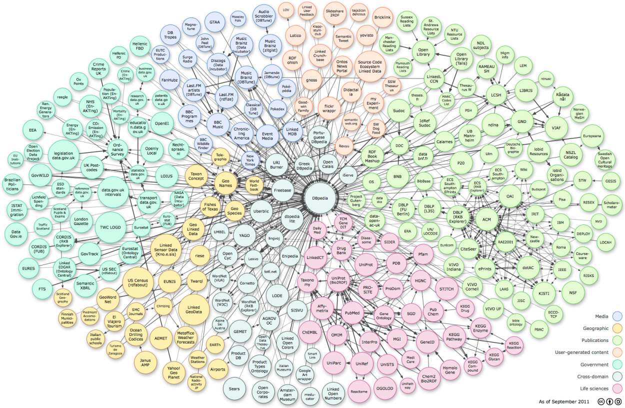
May 2007



Source: http://lod-cloud.net/

Linked Open Data Cloud

September 2011



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Linked Open Data Cloud

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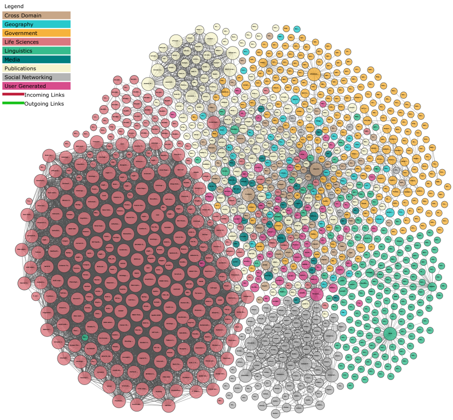


Source: http://lod-cloud.net/

Linked Data

Statistics

- October 2007
  - 25 datasets
  - 2 billion triples, 2 million links
- September 2011
  - 295 datasets
  - 31 billion triples, 504 million links
- August 2017
  - 1163 datasets

SPARQL Query Language

SPARQL

SPARQL Query Language

- Query language for RDF data
  - **Graph patterns**, optional graph patterns, **subqueries**, negation, **aggregation**, value constructors, …
- Versions: 1.0 (2008), **1.1** (2013)
- W3C recommendations
  - https://www.w3.org/TR/sparql11-query/
  - Altogether 11 recommendations: query language, update facility, federated queries, protocol, result formats, …

Sample Data

Graph of **movies** `<http://db.cz/movies>`

```
@prefix i: <http://db.cz/terms#> .
@prefix m: <http://db.cz/movies/> .
@prefix a: <http://db.cz/actors/> .
m:vratnelahve
  rdf:type i:Movie ; i:title "Vratné lahve" ;
  i:year "2006" ;
  i:actor a:sverak , a:machacek .
m:samotari
  rdf:type i:Movie ; i:title "Samotáři" ;
  i:year "2000" ;
  i:actor a:schneiderova , a:trojan , a:machacek .
m:medvidek
  rdf:type i:Movie ; i:title "Medvídek" ;
  i:year "2007" ;
  i:actor a:machacek , a:trojan ;
  i:director "Jan Hřebejk" .
m:zelary
  rdf:type i:Movie .
```

Sample Data

Graph of **actors** `<http://db.cz/actors>`

```
@prefix i: <http://db.cz/terms#> .
@prefix a: <http://db.cz/actors/> .
a:trojan
  rdf:type i:Actor ;
  i:firstname "Ivan" ; i:lastname "Trojan" ;
  i:year "1964" .
a:machacek
  rdf:type i:Actor ;
  i:firstname "Jiří" ; i:lastname "Macháček" ;
  i:year "1966" .
a:schneiderova
  rdf:type i:Actor ;
  i:firstname "Jitka" ; i:lastname "Schneiderová" ;
  i:year "1973" .
a:sverak
  rdf:type i:Actor ;
  i:firstname "Zdeněk" ; i:lastname "Svěrák" ;
  i:year "1936" .
```

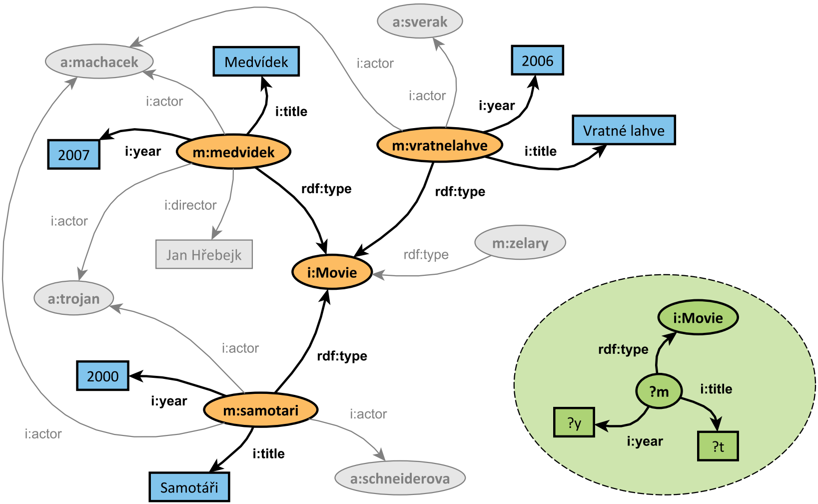
Sample Query

Find all movies, return their titles and years they were filmed

```
PREFIX i: <http://db.cz/terms#>
SELECT ?t ?y
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t ;
       i:year ?y .
  }
ORDER BY ?y
```

?t	?y
Samotáři	2000
Vratné lahve	2006
Medvídek	2007

Sample Query



Graph Pattern Matching

Graph patterns

- **Basic graph pattern**
  - Based on ordinary **triples with variables**
    - `?variable` or `$variable`
- More complicated graph patterns
  - E.g. group, optional, minus, …

Graph pattern matching

- Our goal is to find all **subgraphs of the data graph that are matched by the query graph pattern**
  - I.e. subgraphs of the data graph that are identical to the query graph pattern with variables substituted by particular terms
- One matching subgraph = one solution = one row of a table

Graph Pattern Matching

Query result = **solution sequence** = ordered multiset of solutions

?t	?y
Samotáři	2000
Vratné lahve	2006
Medvídek	2007

```
{
  { (?t, "Samotáři"), (?y, "2000") },
  { (?t, "Vratné lahve"), (?y, "2006") },
  { (?t, "Medvídek"), (?y, "2007") }
}
```

Solution = set of variable bindings

?t	?y
Samotáři	2000

```
{ (?t, "Samotáři"), (?y, "2000") }
```

Variable binding = pair of a variable name and a value it is assigned

?t
Samotáři

```
(?t, "Samotáři")
```

Graph Pattern Matching

Compatibility of solutions

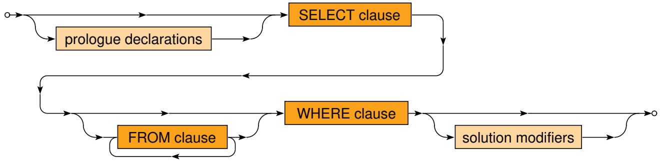
- Two solutions are mutually compatible if and only if all the variables they share are pairwise bound to identical values

Examples

- Compatible solutions
  - `{ (?m, m:samotari), (?t, "Samotáři") }`
    `{ (?m, m:samotari), (?y, "2000") }`
- Incompatible solutions
  - `{ (?m, m:samotari), (?t, "Samotáři") }`
    `{ (?m, m:medvidek), (?y, "2007") }`

Select Queries

SELECT queries

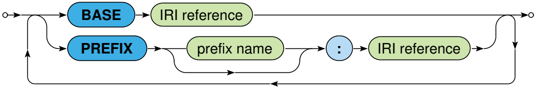


- **Prologue declarations** – `PREFIX`, `BASE`
- Main clauses
  - `SELECT` – **variables to be projected**
  - `FROM` – **data graphs to be queried**
  - `WHERE` – **graph patterns to be matched**
- **Solution modifiers** – `ORDER BY`, ...

Prologue Declarations

Prologue declarations

- Allow to simplify IRI references by declaring **base IRIs**



BASE clause

- One **single base IRI** is defined
  all **relative IRI references** are then related to this base IRI

PREFIX clause

- **Several base IRIs** are defined, each is associated with a name
  all **prefixed names** are then related to the respective base IRI

Prologue Declarations

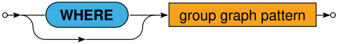
Examples

- When `BASE <http://db.cz/>` is defined,
  then a relative IRI reference `terms#Movie`
  is interpreted as `http://db.cz/terms#Movie`
- When `PREFIX i: <http://db.cz/>` is defined,
  then a prefixed name `i:terms#Movie`
  is interpreted as `http://db.cz/terms#Movie`

Where Clause

WHERE clause

- Prescribes one **group graph pattern**



Types of **graph patterns**

- **Basic** – triple patterns to be matched
- **Group** – set of graph patterns to be matched
- **Optional** – graph pattern to be matched only if possible
- **Alternative** – two or more alternative graph patterns
- …

Graph patterns can be inductively combined into complex ones

Graph Patterns

Basic Graph Pattern

Basic graph pattern (triple block)

One or more triple patterns to be all matched

- Ordinary **triples** separated by `.`
- … or their abbreviated forms inspired by Turtle notation
  - **Object lists** using `,`
  - **Predicate-object lists** using `;`
  - **Blank nodes** using `[]`

Examples

- `s p1 o1 . s p1 o2 . s p2 o3 .`
- `s p1 o1 , o2 ; p2 o3 .`

Graph Patterns

Basic Graph Pattern

Interpretation

- **All the involved triple patterns must be matched**
  - I.e. we combine them as if they were in conjunction
  - More precisely…
    - **Each triple pattern is evaluated to its solution sequence**
    - **All combinations of compatible solutions are then found**
- Note that <u>all the variables need to be bound</u>
  - I.e. if any of the involved variables cannot be bound at all, then the entire basic graph pattern cannot be matched!

Graph Patterns: Example

Basic Graph Pattern

Titles and years of all movies

```
PREFIX i: <http://db.cz/terms#>
SELECT ?t ?y
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie .  # triple 1
    ?m i:title ?t .        # triple 2
    ?m i:year ?y .         # triple 3
  }
```

?t	?y
Vratné lahve	2006
Samotáři	2000
Medvídek	2007

Graph Patterns: Example

Basic Graph Pattern

$[\![t_1]\!] =$

?m
m:vratnelahve
m:samotari
m:medvidek
m:zelary

$[\![t_2]\!] =$

?m	?t
m:vratnelahve	Vratné lahve
m:samotari	Samotáři
m:medvidek	Medvídek

$[\![t_3]\!] =$

?m	?y
m:vratnelahve	2006
m:samotari	2000
m:medvidek	2007

?t	?y
Vratné lahve	2006
Samotáři	2000
Medvídek	2007

Graph Patterns

Basic Graph Pattern

Equivalence of **literals**

- Values must be identical
- And when **types** / **language tags** are specified, these must be identical as well
  - E.g.: `"Medvídek"@cs != "Medvídek"`

Equivalence of **blank nodes**

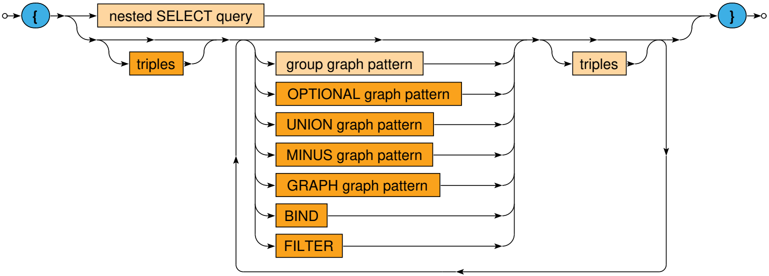
- Blank nodes in query patterns act as **non-selectable variables**
- **Labels of blank nodes** in data graphs / query graph patterns / query results **may not refer to the same nodes despite being the same**
  - I.e. the scope of validity is always local only

Graph Patterns

Group Graph Pattern

Group graph pattern

Set of graph patterns to be all matched



Graph Patterns

Group Graph Pattern

Two modes

- **Nested SELECT query**
  - Only with SELECT and WHERE clauses and solution modifiers i.e. without FROM clause
- **Set of graph patterns** interleaved by **triple blocks**

Interpretation

- **All the involved graph patterns must be matched**
  - I.e. we combine them as if they were in conjunction

Notes

- Empty group patterns {} are also allowed

Graph Patterns

Optional Graph Pattern

OPTIONAL graph pattern

One group graph pattern is tried to be matched

Interpretation

- **When the optional part does not match, it creates no bindings but does not eliminate the solution**

Graph Patterns: Example

Optional Graph Pattern

Movies together with their directors when possible

```
PREFIX i: <http://db.cz/terms#>
SELECT ?t ?y ?d
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t ;
       i:year ?y .
    OPTIONAL { ?m i:director ?d . }
  }
```

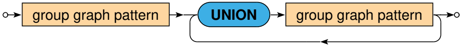
?t	?y	?d
Vratné lahve	2006	
Samotáři	2000	
Medvídek	2007	Jan Hřebejk

Graph Patterns

Alternative Graph Pattern

UNION graph pattern

Two or more group graph patterns are tried to be matched



Interpretation

- Standard set **union** of the involved query results

Graph Patterns

Minus Graph Pattern

MINUS graph pattern

One group graph pattern removing compatible solutions

Interpretation

- **Solutions of the first pattern are preserved if and only if they are not compatible with any solution of the second pattern**
  - I.e. minus graph pattern does not correspond to the standard set minus operation!

Graph Patterns: Example

Minus Graph Pattern

Titles of movies that have no director

```
PREFIX i: <http://db.cz/terms#>
SELECT ?t
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t .                                 # pattern 1
    MINUS { ?m rdf:type i:Movie ; i:director ?d . } # pattern 2
  }
```

?t
Vratné lahve
Samotáři

Graph Patterns: Example

Minus Graph Pattern

$[\![p_1]\!] =$

?m	?t
m:vratnelahve	Vratné lahve
m:samotari	Samotáři
m:medvidek	Medvídek

$[\![p_2]\!] =$

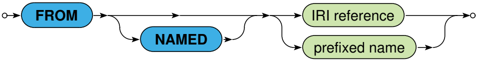
?m	?d
m:medvidek	Jan Hřebejk

?t
Vratné lahve
Samotáři

From Clause

FROM clause

- Defines data graphs to be queried



Dataset = **collection of graphs to be queried**

- One default graph
  - Merge of all the declared graphs from unnamed FROM clauses
  - Empty when no unnamed FROM clause is provided
- Zero or more named graphs

Active graph = used for the evaluation of graph patterns

- The default graph unless changed using GRAPH graph pattern

From Clause: Example

Names of actors who played in *Medvídek* movie

```
PREFIX i: <http://db.cz/terms#>
PREFIX m: <http://db.cz/movies/>
SELECT ?f ?l
FROM <http://db.cz/movies>
FROM <http://db.cz/actors>
WHERE
  {
    m:medvidek i:actor ?a .
    ?a i:firstname ?f ; i:lastname ?l .
  }
```

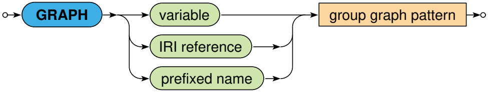
?f	?l
Jiří	Macháček
Ivan	Trojan

Graph Patterns

Graph Graph Pattern

GRAPH graph pattern

Pattern evaluated with respect to a particular named graph



- **Changes the active graph** for a given group graph pattern
  - `GRAPH <http://db.cz/actors> { … }`
- We can also consider all the named graphs
  - `GRAPH ?g { … }`

Graph Patterns: Example

Graph Graph Pattern

Names of actors who played in *Medvídek* movie

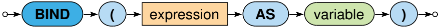
```
PREFIX i: <http://db.cz/terms#>
PREFIX m: <http://db.cz/movies/>
SELECT ?f ?l
FROM <http://db.cz/movies>
FROM NAMED <http://db.cz/actors>
WHERE
  {
    m:medvidek i:actor ?a .
    GRAPH <http://db.cz/actors> {
      ?a i:firstname ?f ; i:lastname ?l .
    }
  }
```

?f	?l
Jiří	Macháček
Ivan	Trojan

Variable Assignments

BIND *graph pattern*

Explicitly assigns a value to a given variable

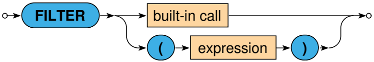


- This variable must not yet be bound!

Filter Constraints

FILTER constraints

Impose constraints on variables and their values



- **Only solutions satisfying the given condition are preserved**
- Does not create any new variable bindings!
- Always applied on the entire group graph pattern
  i.e. evaluated at the very end

Filter Constraints: Example

Movies filmed in 2005 or later where *Ivan Trojan* played

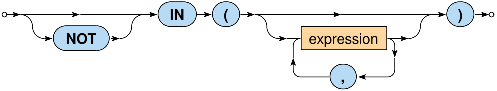
```
PREFIX i: <http://db.cz/terms#>
PREFIX a: <http://db.cz/actors/>
SELECT ?t ?y
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t ;
       i:year ?y .
    FILTER (
      (?y >= 2005) &&
      EXISTS { ?m i:actor a:trojan . }
    )
  }
```

?t	?y
Medvídek	2007

Filter Constraints

Relational expressions

- **Comparisons**
  - =, !=, <, <=, =>, >
  - Unbound variable < blank node < IRI < literal
- **Set membership tests**
  - `IN` and `NOT IN`



Numeric expressions

- Unary / binary **arithmetic operators** +, −, ∗, /

Filter Constraints

Primary expressions

- **Literals** – numeric, boolean, RDF triples
- **Variables**
- Built-in calls
- Parentheses

Boolean expressions

- Logical connectives
  - Conjunction `&&`, disjunction `||`, negation `!`
- **3-value logic** because of unbound variables (NULL values)
  - `true`, `false`, `error`

Filter Constraints

Built-in calls

- **Term accessors**
  - `STR` – lexical form of an IRI or literal
  - `LANG` – language tag of a literal
  - `DATATYPE` – data type of a literal
- **Variable tests**
  - `BOUND` – true when a variable is bound to a value
  - `isIRI`, `isBLANK`, `isLITERAL`

Filter Constraints

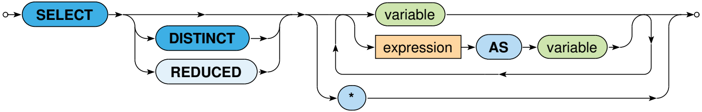
Built-in calls

- **Existence tests**
  - `EXISTS`
    - True when a provided group graph pattern is evaluated to at least one solution
  - `NOT EXISTS`

Select clause

SELECT clause

- Enumerates variables to be included in the query result



- Asterisk ∗ selects all the variables

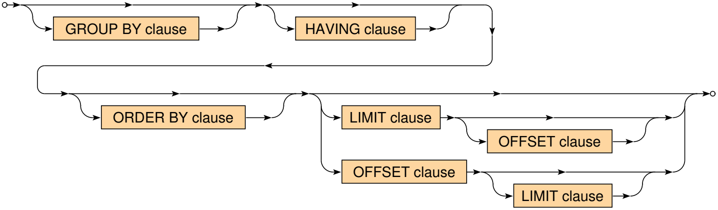
Solution modifiers

- `DISTINCT` – **duplicate solutions are removed**
- `REDUCED` – some duplicate solutions may be removed (implementation-dependent behavior)

Solution Modifiers

Solution modifiers – modify the entire solution sequence

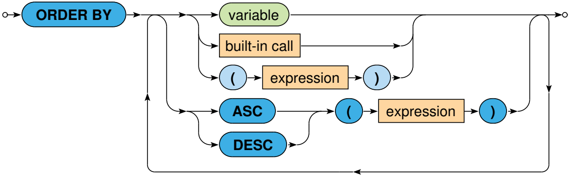
- Aggregation
  - `GROUP BY` and `HAVING`
- Ordering
  - `ORDER BY`
  - `LIMIT` and `OFFSET`



Solution Modifiers

ORDER BY clause

- Defines the order of solutions within the query result

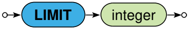


- `ASC(…)` = **ascending** (default)
- `DESC(…)` = **descending**

Solution Modifiers

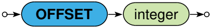
LIMIT clause

- **Limits the number of solutions** in the query result



OFFSET clause

- **Skips a certain number of solutions** in the query result



Solution Modifiers: Example

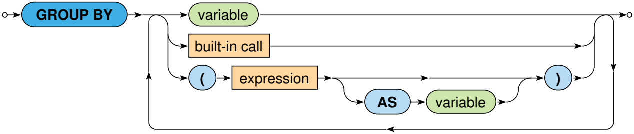
```
PREFIX i: <http://db.cz/terms#>
SELECT ?t ?y
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t ;
       i:year ?y .
  }
ORDER BY DESC(?y) ASC(?t)
OFFSET 1
LIMIT 5
```

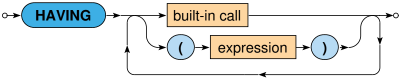
?t	?y
Vratné lahve	2006
Samotáři	2000

Aggregation

GROUP BY + **HAVING** clauses

- Standard aggregation over a solution sequence





Aggregation: Example

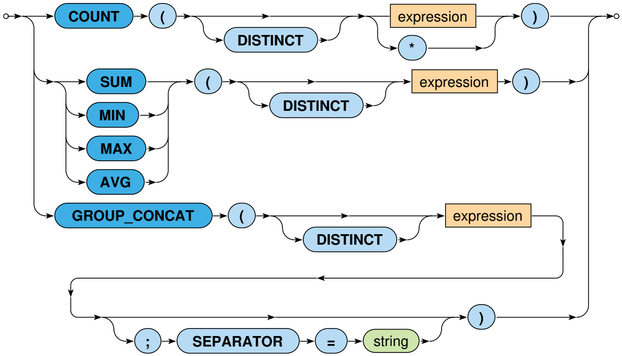
Numbers of actors in movies with at most 2 actors

```
PREFIX i: <http://db.cz/terms#>
SELECT ?t (COUNT(?a) AS ?c)
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t ;
       i:actor ?a .
  }
GROUP BY ?m ?t
HAVING (?c <= 2)
ORDER BY ?c ?t
```

?t	?c
Medvídek	2
Vratné lahve	2

Aggregation

Aggregate functions



Query Forms

Query forms

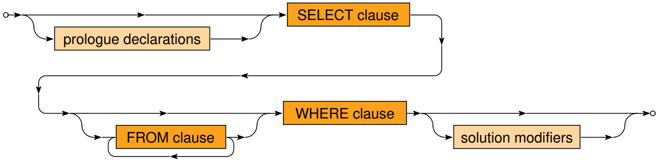
- **SELECT**
  - Finds solutions matching a provided graph pattern
- ASK
  - Checks whether at least one solution exists
- DESCRIBE
  - Retrieves a graph with data about selected resources
- **CONSTRUCT**
  - Creates a new graph according to a provided pattern

Query Forms

SELECT

SELECT query form

Finds solutions matching a provided graph pattern



Result

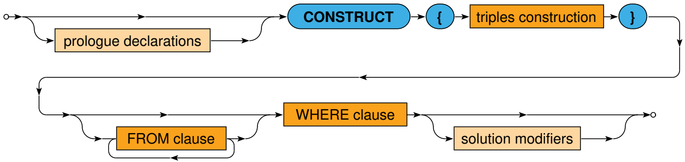
- **Solution sequence** = ordered multiset of solutions

Query Forms

CONSTRUCT

CONSTRUCT query form

Creates a new graph according to a provided pattern



Result

- **RDF graph** constructed according to a group graph pattern
    - Unbound or invalid triples are not involved

Query Forms: Example

CONSTRUCT

```
PREFIX i: <http://db.cz/terms#>
CONSTRUCT
  {
    ?a i:name concat(?f, " ", ?l) .
  }
FROM <http://db.cz/actors>
WHERE
  {
    ?a rdf:type i:Actor ;
       i:firstname ?f ;
       i:lastname ?l .
  }
```

```
<http://db.cz/actors/trojan> i:name "Ivan Trojan" .
<http://db.cz/actors/machacek> i:name "Jiří Macháček" .
<http://db.cz/actors/schneiderova> i:name "Jitka Schneiderová" .
<http://db.cz/actors/sverak> i:name "Zdeněk Svěrák" .
```

Lecture Conclusion

SPARQL

- **Query forms**
  - `SELECT`, `ASK`, `DESCRIBE`, `CONSTRUCT`
- **Graph patterns**
  - Basic, group, optional, alternative, minus
  - Variable assignments
  - Filters
- **Solution modifiers**
  - `DISTINCT`, `REDUCED`
  - `GROUP BY`, `HAVING`
  - `ORDER BY`, `LIMIT`, `OFFSET`