MDK: **Modern Database Concepts**

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

Lecture 6

RDF Stores: SPARQL

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24. 4. 2020

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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

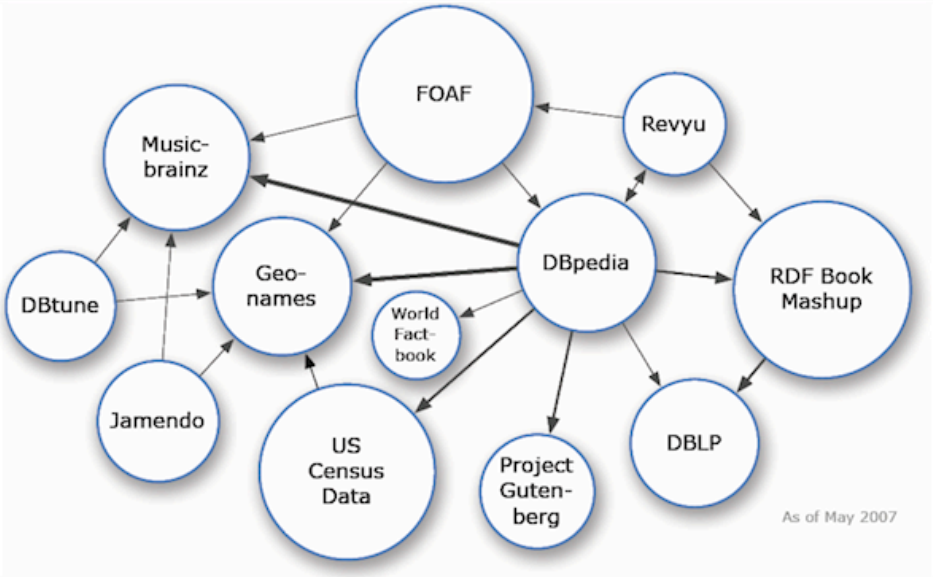
Principles of Linked Open Data

- **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

- 12 datasets



October 2007

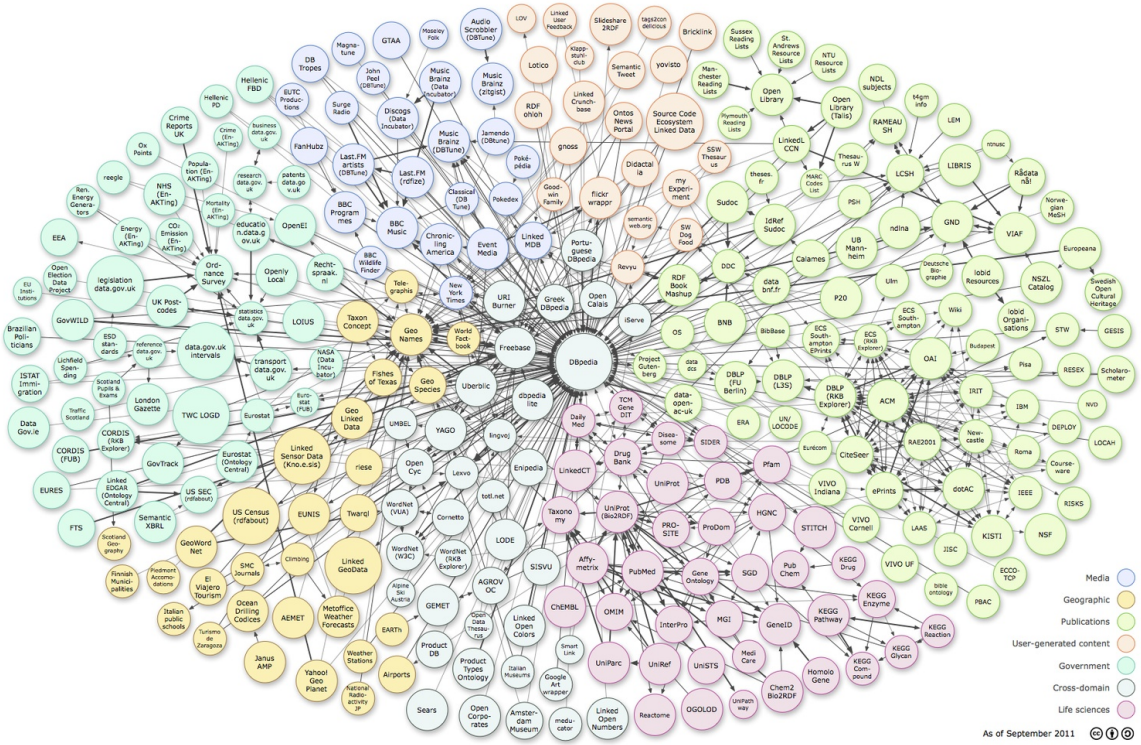
- 25 datasets, 2 billion triples, 2 million links

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

Linked Open Data Cloud

September 2011

- 295 datasets, 31 billion triples, 504 million links

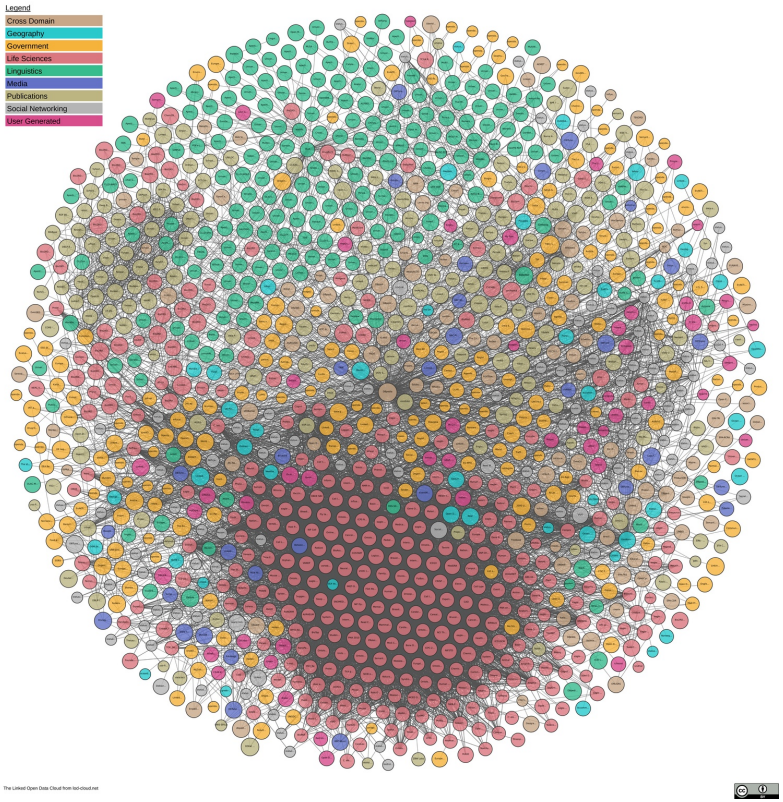


Source: http://lod-cloud.net/

Linked Open Data Cloud

March 2019

- 1239 datasets, 16 thousand dataset links



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

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 pats: 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 .
```

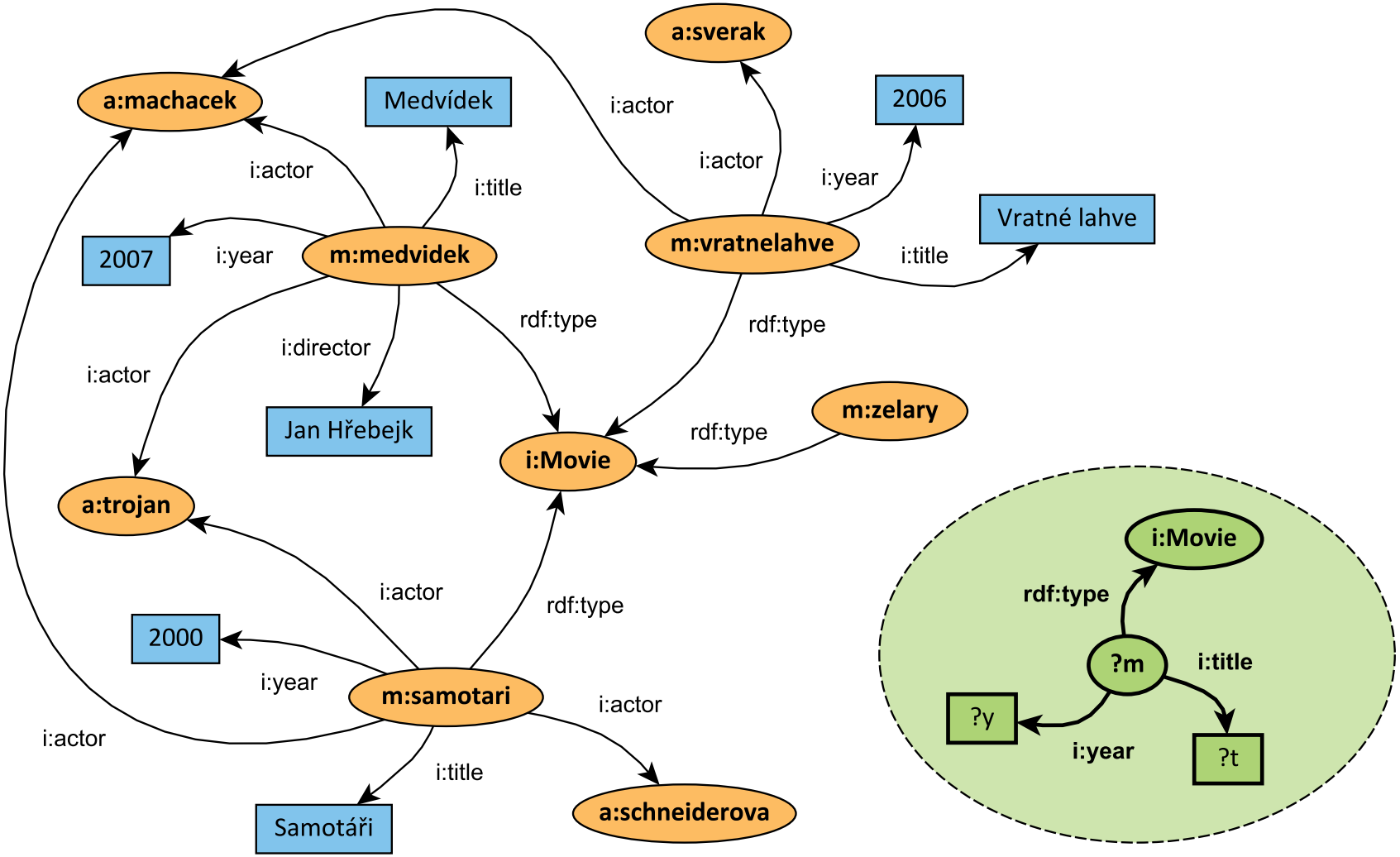
Sample Query

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

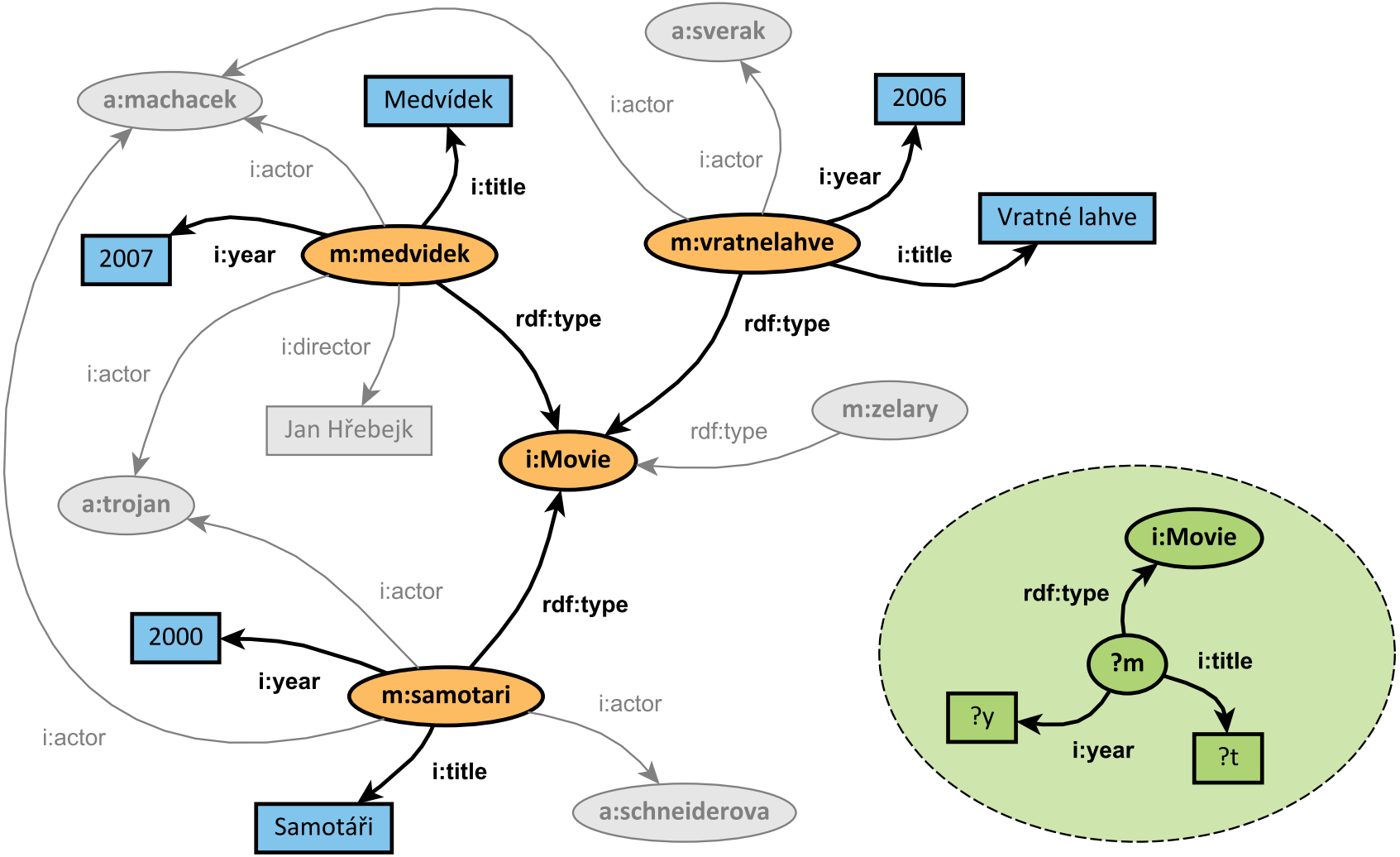
```
PREFIX i: <http://db.cz/terms#>
SELECT ?t ?y
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t ;
       i:year ?y .
  }
ORDER BY ?y
```

?t	?y
Samotáři	2000
Vratné lahve	2006
Medvídek	2007

Sample Query



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

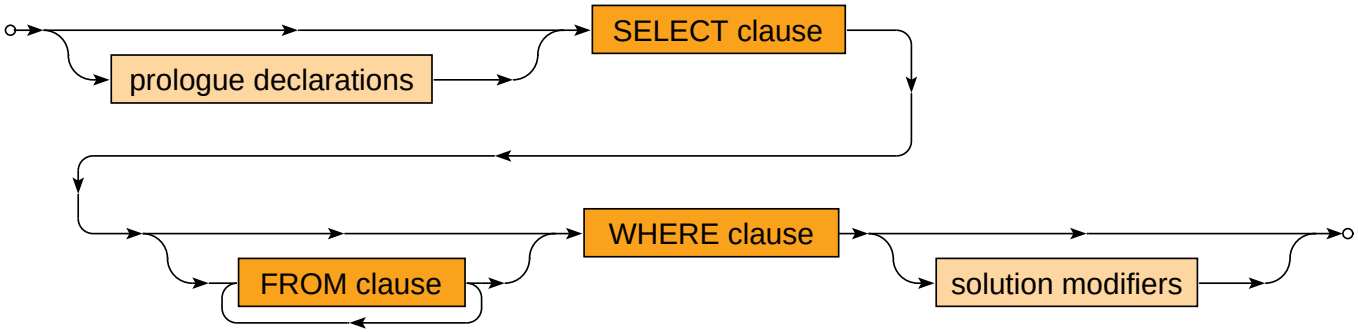
- Two solutions are mutually compatible if and only if all the variables they share are pairwise bound to identical values

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

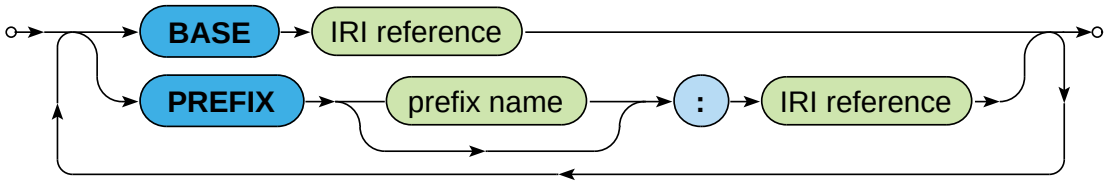


- **Prologue declarations** – `PREFIX`, `BASE`
- Main clauses
  - `SELECT` – **variables to be projected**
  - `FROM` – **data graphs to be queried**
  - `WHERE` – **graph patterns to be matched**
- **Solution modifiers** – `ORDER BY`, …

Prologue Declarations

Prologue declarations

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



BASE clause

- At most **one base IRI** can be 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
  - These names must be distinct, one of them can be empty
- All **prefixed names** are then related to the respective base IRIs

Prologue Declarations

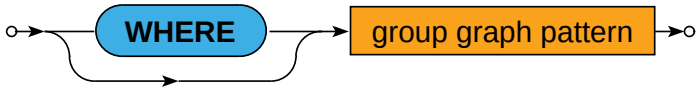
Examples

- 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

- Describes 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

Basic Graph Pattern

Basic graph pattern (block of triples)

One or more triple patterns to be all matched

- Ordinary **triples** separated by `.`
  - E.g. `s p1 o1 . s p1 o2 . s p2 o3 .`
- May contain variables
  - E.g. `?var` or `$var`
- Turtle abbreviations also permitted
  - **Object lists** using `,` or **predicate-object lists** using `;`
    - E.g. `s p1 o1 , o2 ; p2 o3 .`
  - **Blank nodes** using `[]`
    - Act as non-selectable variables
    - I.e. do not enforce to be matched only by blank nodes in data!

Basic Graph Pattern

Interpretation

- **All the involved triples 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 all the variables need to be bound
  - I.e. if any of the involved variables cannot be bound at all, then the entire basic graph pattern cannot be matched!

Basic Graph Pattern: Example

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

Basic Graph Pattern: Example

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

?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

Equality of Terms

IRIs

Literals

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

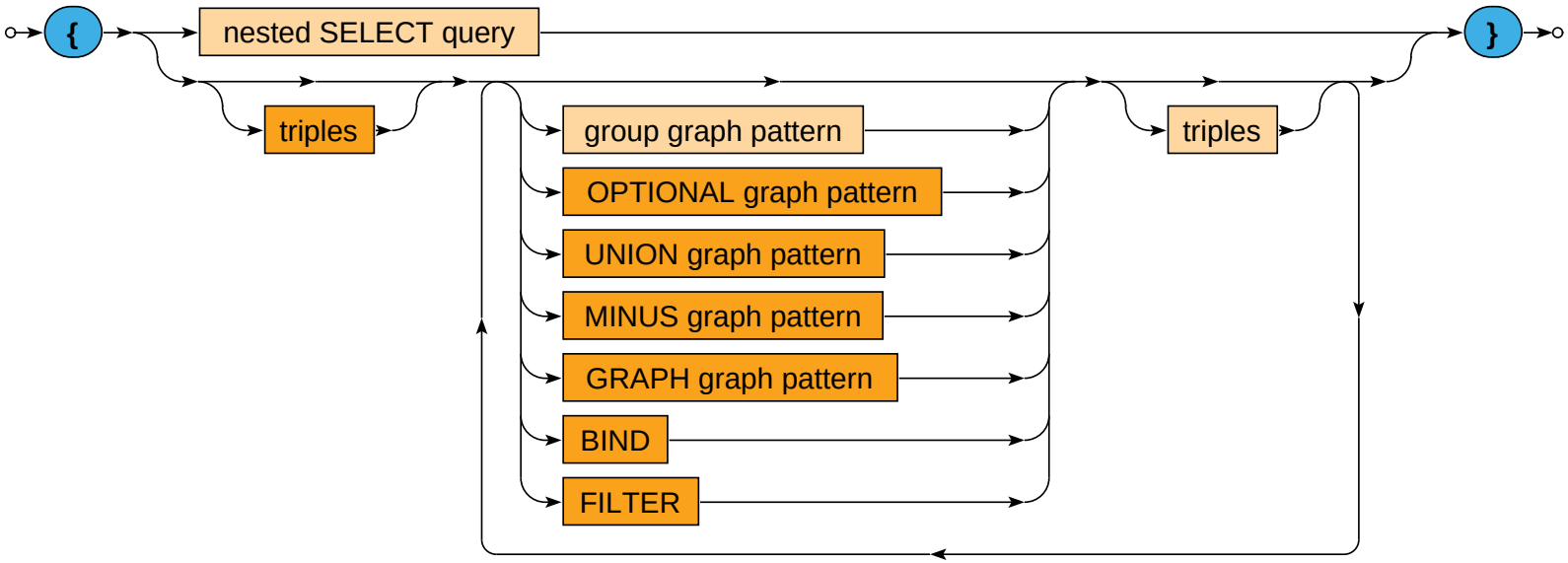
Blank nodes

- 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

Group Graph Pattern

Group graph pattern

Set of graph patterns to be all matched



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

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

Optional Graph Pattern: Example

Movies together with their directors when possible

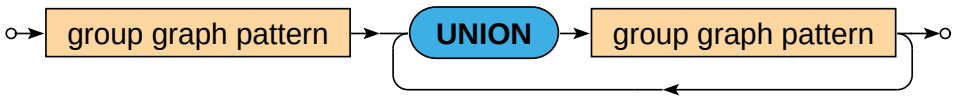
```
PREFIX i: <http://db.cz/terms#>
SELECT ?t ?y ?d
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t ;
       i:year ?y .
    OPTIONAL { ?m i:director ?d . }
  }
```

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

Alternative Graph Pattern

UNION graph pattern

Two or more group graph patterns are to be matched



Interpretation

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

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!

Minus Graph Pattern: Example

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

Minus Graph Pattern: Example

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

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

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

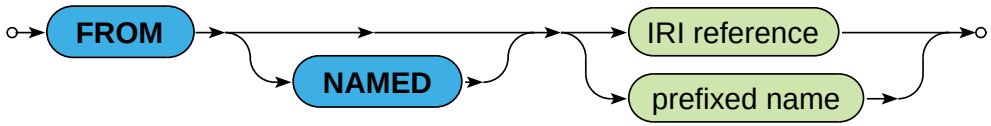
?m	?d
m:medvidek	Jan Hřebejk

?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

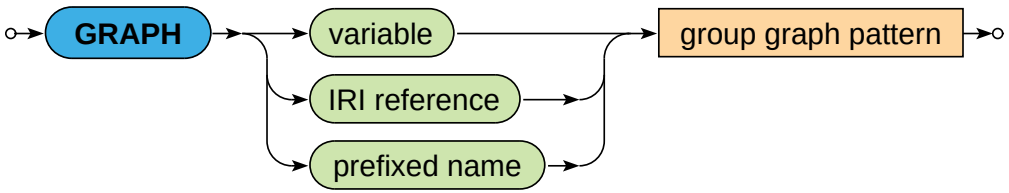
```
PREFIX i: <http://db.cz/terms#>
PREFIX m: <http://db.cz/movies/>
SELECT ?f ?l
FROM <http://db.cz/movies>
FROM <http://db.cz/actors>
WHERE
  {
    m:medvidek i:actor ?a .
    ?a i:firstname ?f ; i:lastname ?l .
  }
```

?f	?l
Jiří	Macháček
Ivan	Trojan

Graph 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 Graph Pattern: Example

Names of actors who played in *Medvídek* movie

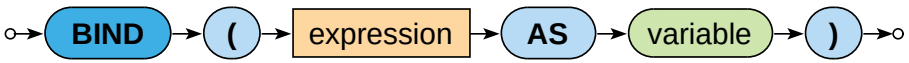
```
PREFIX i: <http://db.cz/terms#>
PREFIX m: <http://db.cz/movies/>
SELECT ?f ?l
FROM <http://db.cz/movies>
FROM NAMED <http://db.cz/actors>
WHERE
  {
    m:medvidek i:actor ?a .
    GRAPH <http://db.cz/actors> {
      ?a i:firstname ?f ; i:lastname ?l .
    }
  }
```

?f	?l
Jiří	Macháček
Ivan	Trojan

Variable Assignments

BIND *graph pattern*

Explicitly assigns a value to a given variable

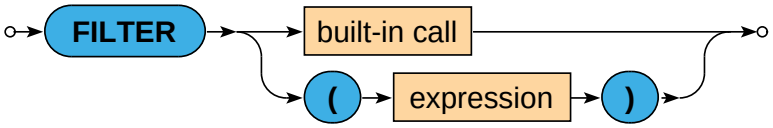


- This variable must not yet be bound!

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

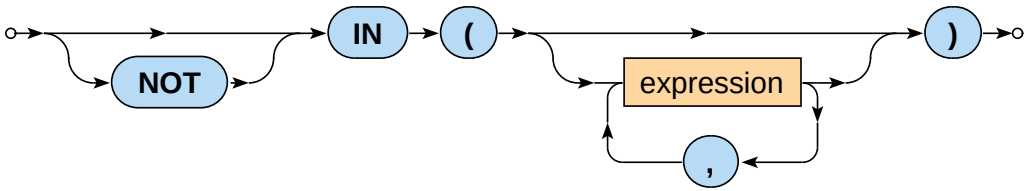
```
PREFIX i: <http://db.cz/terms#>
PREFIX a: <http://db.cz/actors/>
SELECT ?t ?y
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t ;
       i:year ?y .
    FILTER (
      (?y >= 2005) &&
      EXISTS { ?m i:actor a:trojan . }
    )
  }
```

?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

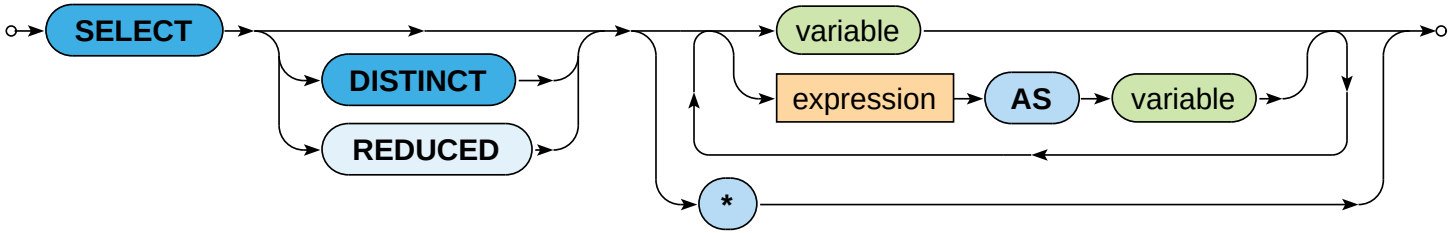
Built-in calls

- **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

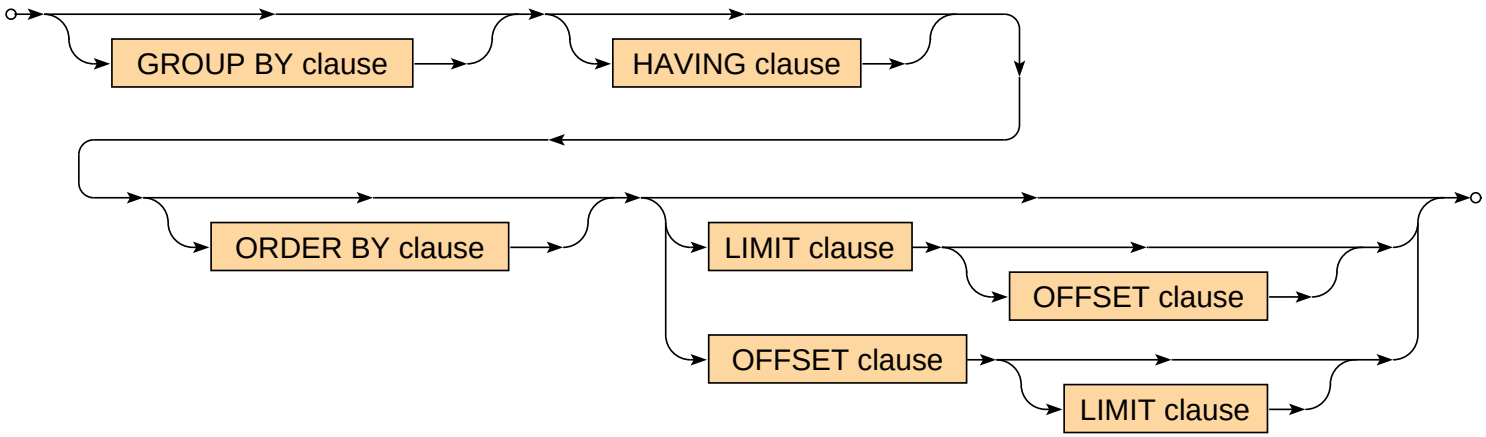
Solution modifiers

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

Solution Modifiers

Solution modifiers – modify the entire solution sequence

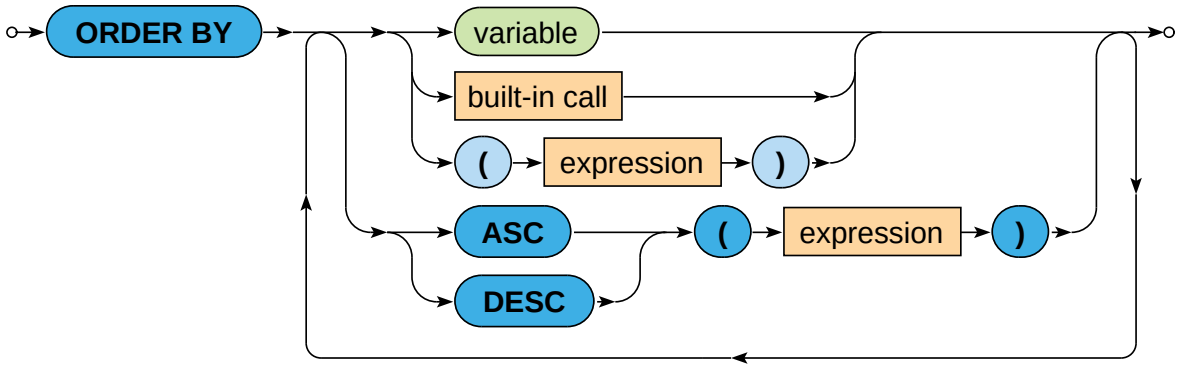
- Aggregation
  - `GROUP BY` and `HAVING`
- Ordering
  - `ORDER BY`
  - `LIMIT` and `OFFSET`



Solution Modifiers

ORDER BY clause

- Defines the order of solutions within the query result

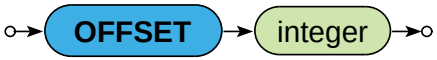


- `ASC(…)` = **ascending** (default)
- `DESC(…)` = **descending**

Solution Modifiers

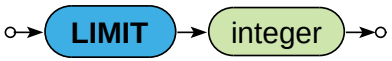
OFFSET clause

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



LIMIT clause

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



Solution Modifiers: Example

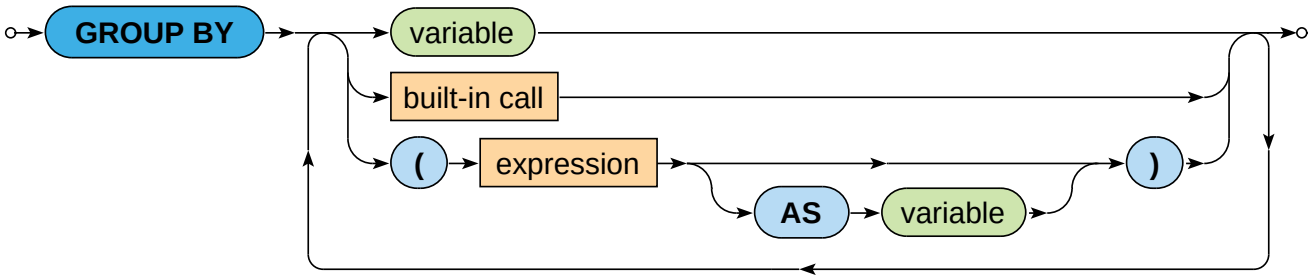
```
PREFIX i: <http://db.cz/terms#>
SELECT ?t ?y
FROM <http://db.cz/movies>
WHERE
  {
    ?m rdf:type i:Movie ;
       i:title ?t ;
       i:year ?y .
  }
ORDER BY DESC(?y) ASC(?t)
OFFSET 1
LIMIT 5
```

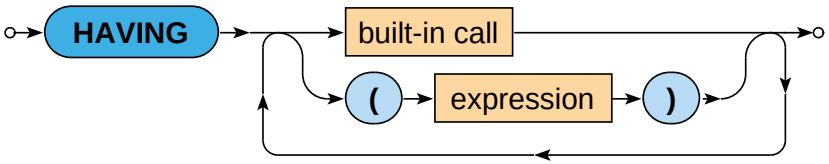
?t	?y
Vratné lahve	2006
Samotáři	2000

Aggregation

GROUP BY + **HAVING** clauses

- Standard aggregation over a solution sequence





Aggregation: Example

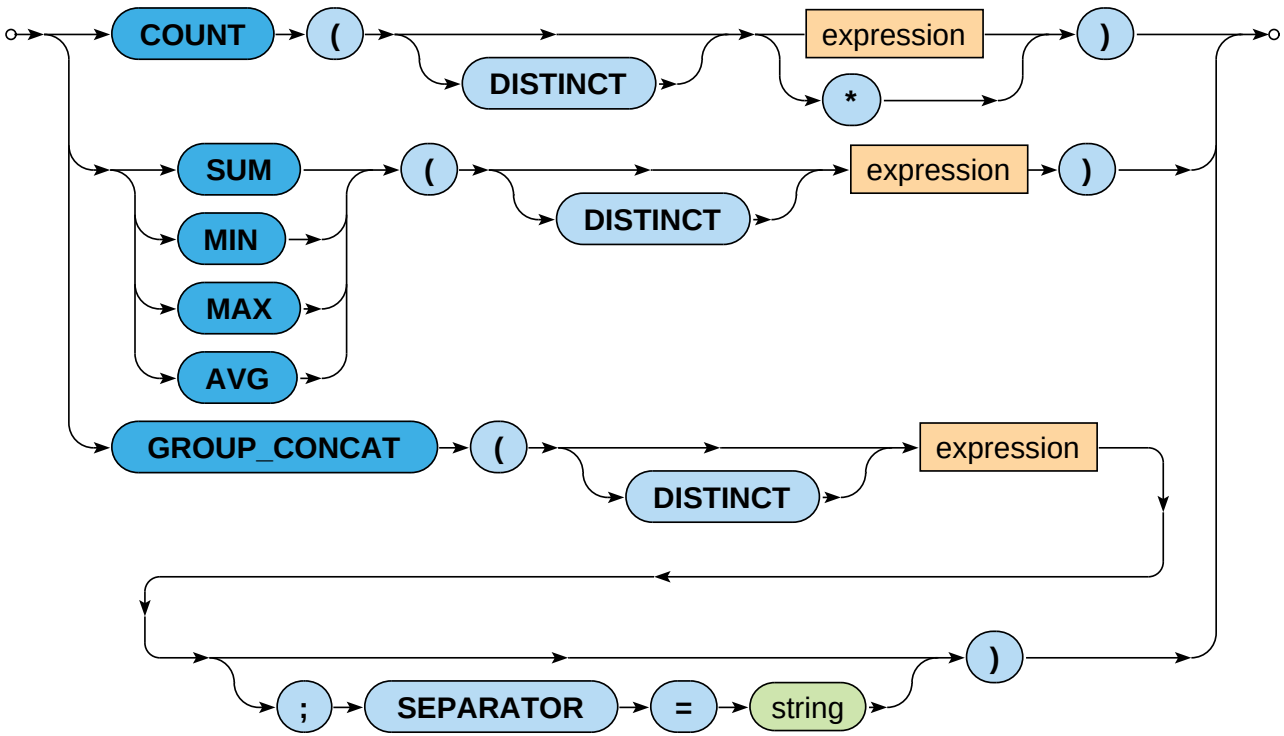
Numbers of actors in movies with at most 2 actors

```
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

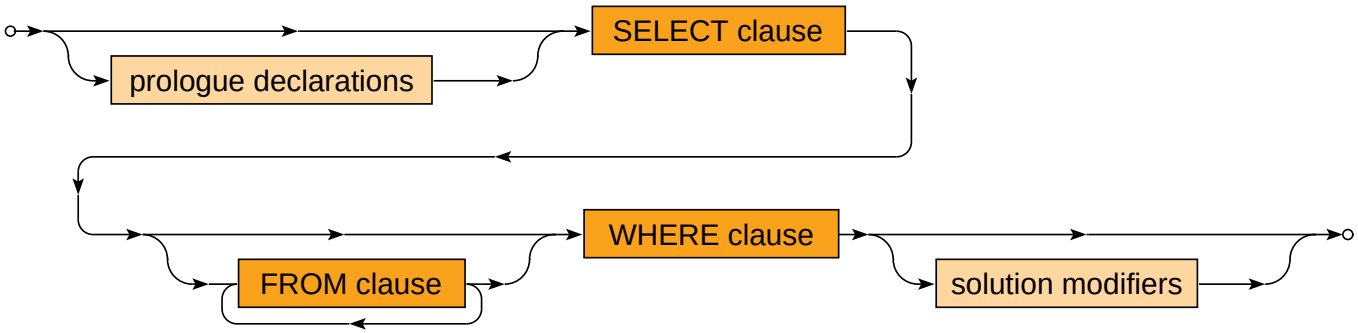
Query forms

- **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

Select Query Form

SELECT query form

Finds solutions matching a provided graph pattern



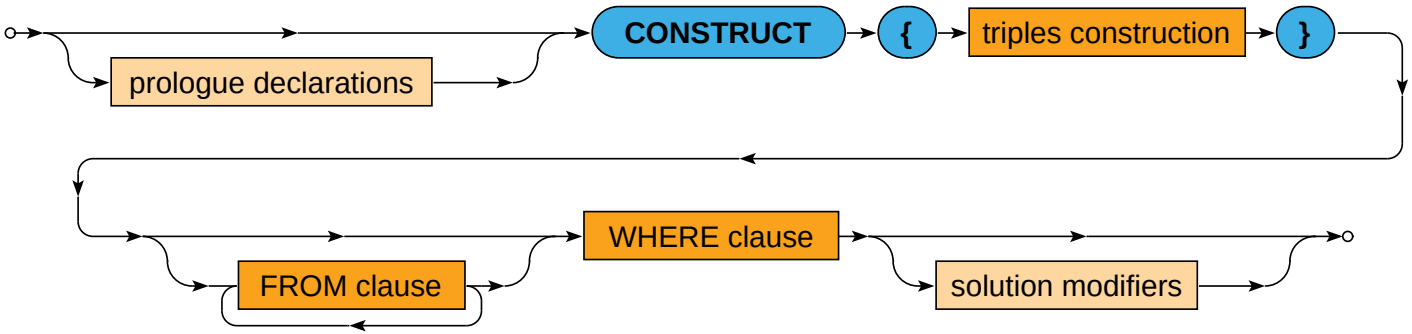
Result

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

Construct Query Form

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

Construct Query Form: Example

```
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`