Towards Fast Processing of SPARQL Queries on RDF Quads

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Comprehensive Exam

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Committee

- Dr. Praveen Rao, Advisor and Chair
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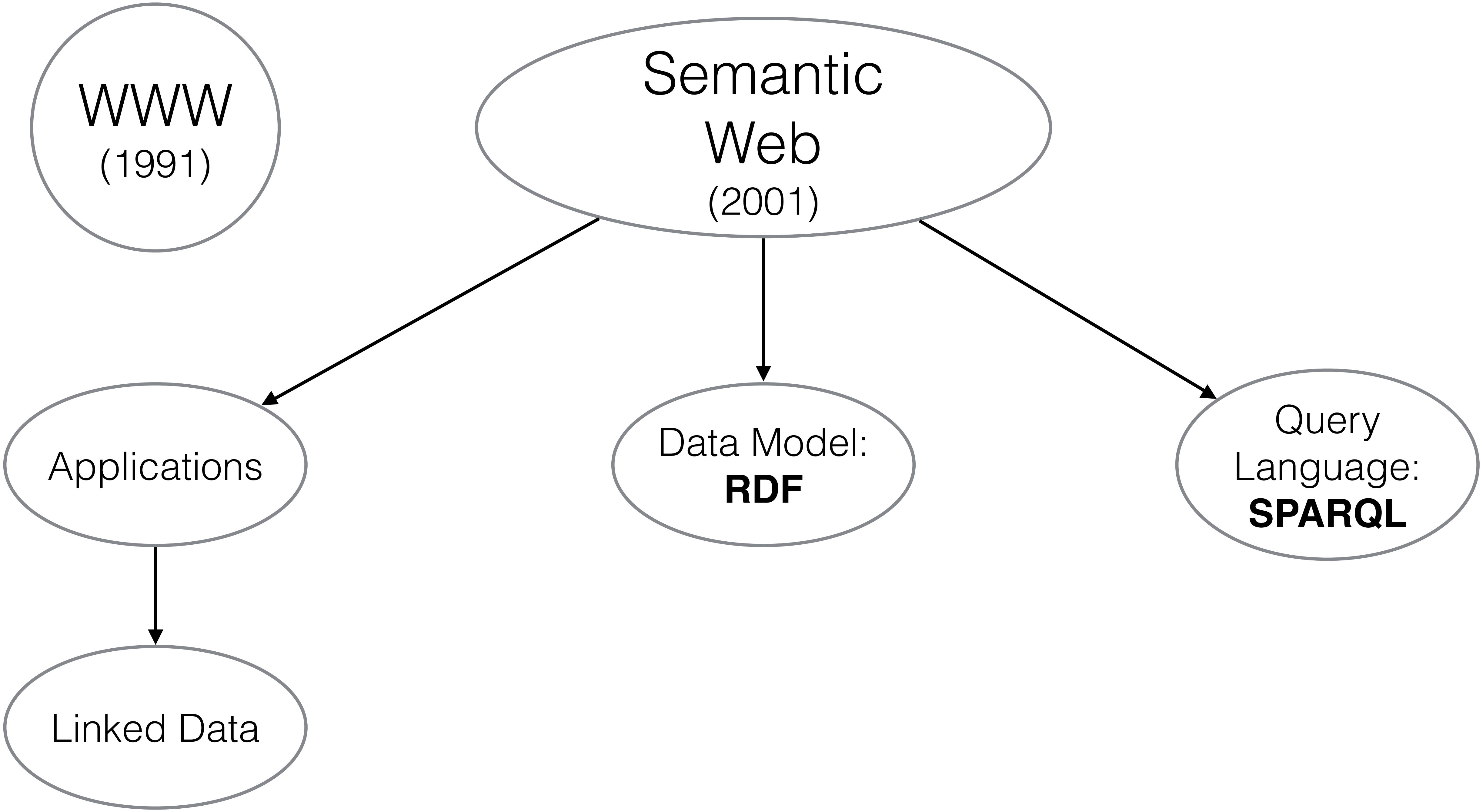
Outline

- Semantic Web, RDF, SPARQL, applications
- Related work
    - Indexing & query processing
- Our approach
    - The design of RIQ
- Performance evaluation of RIQ
- Future direction

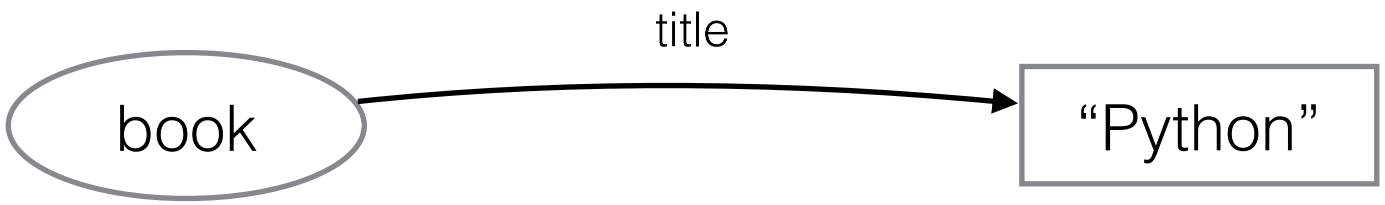
Semantic Web



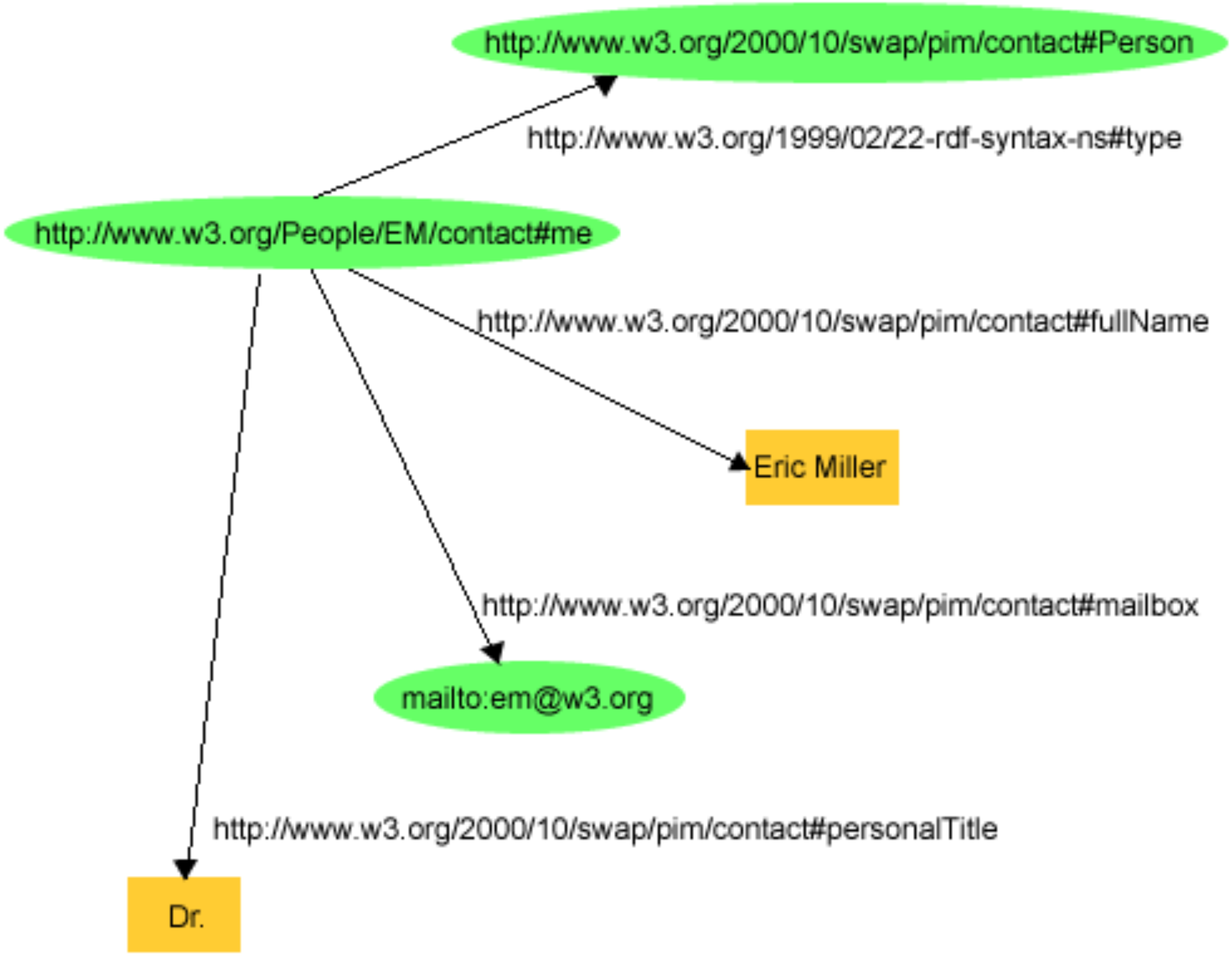
RDF

- Data model, W3C specification
- Directed, labeled graph
- Triples:

```
<subject> <predicate> <object> .
```



RDF graph


http://www.w3.org/2000/10/swap/pim/contact#Person
http://www.w3.org/1999/02/22-rdf-syntax-ns#type
http://www.w3.org/People/EM/contact#me
http://www.w3.org/2000/10/swap/pim/contact#fullName
Eric Miller
http://www.w3.org/2000/10/swap/pim/contact#mailbox
mailto:em@w3.org
http://www.w3.org/2000/10/swap/pim/contact#personalTitle
Dr.

[http://en.wikipedia.org/wiki/Resource_Description_Framework]

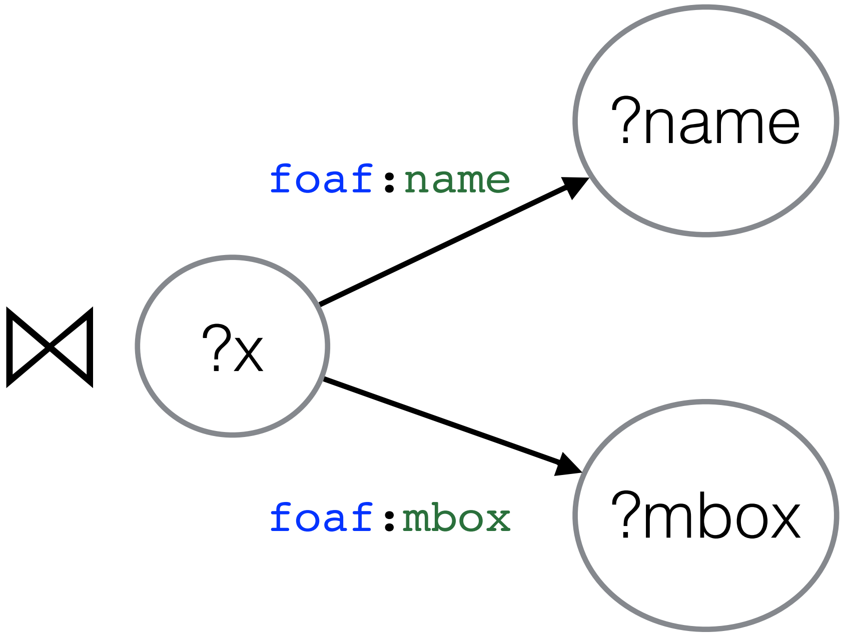
SPARQL

- Query language
- Basic Graph Pattern (BGP) matching

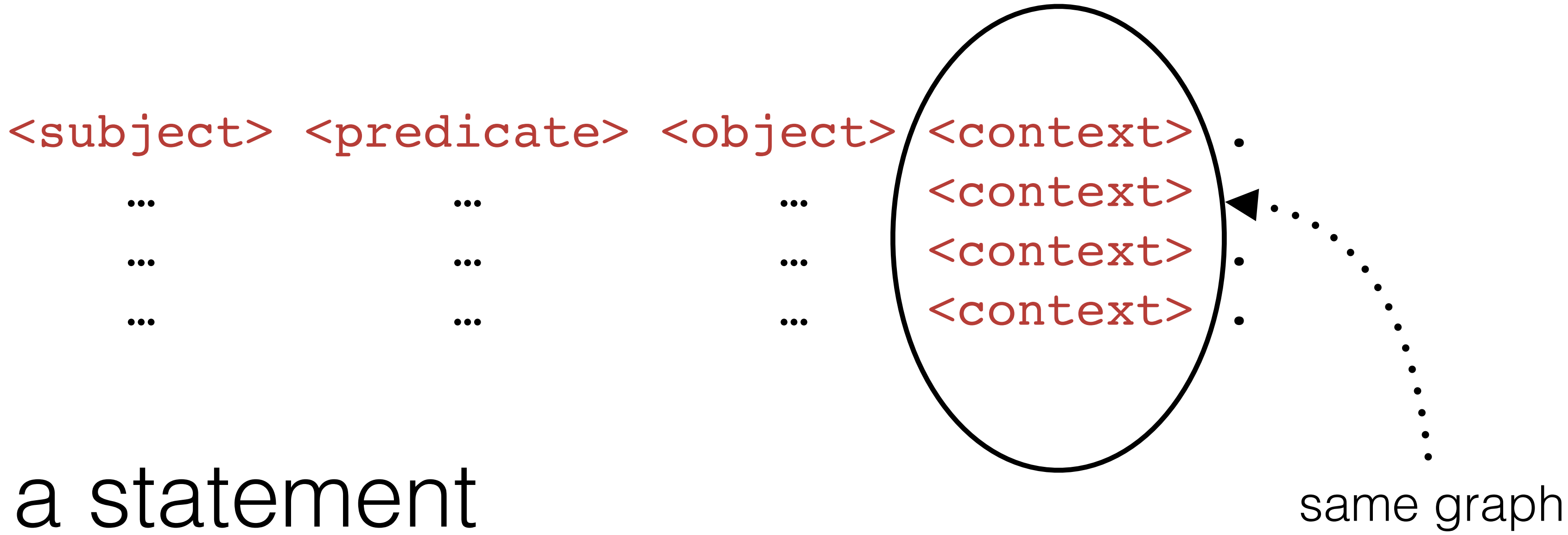
```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>

SELECT ?name ?mbox WHERE {
  ?x foaf:name ?name .
  ?x foaf:mbox ?mbox .
}
```

triple pattern



Quads



- Origin of a statement

```
foaf:me foaf:name "Alice" <http://ex.org/alice/foaf.rdf> .
foaf:me foaf:name "Bob" <http://ex.org/bob/foaf.rdf> .
```

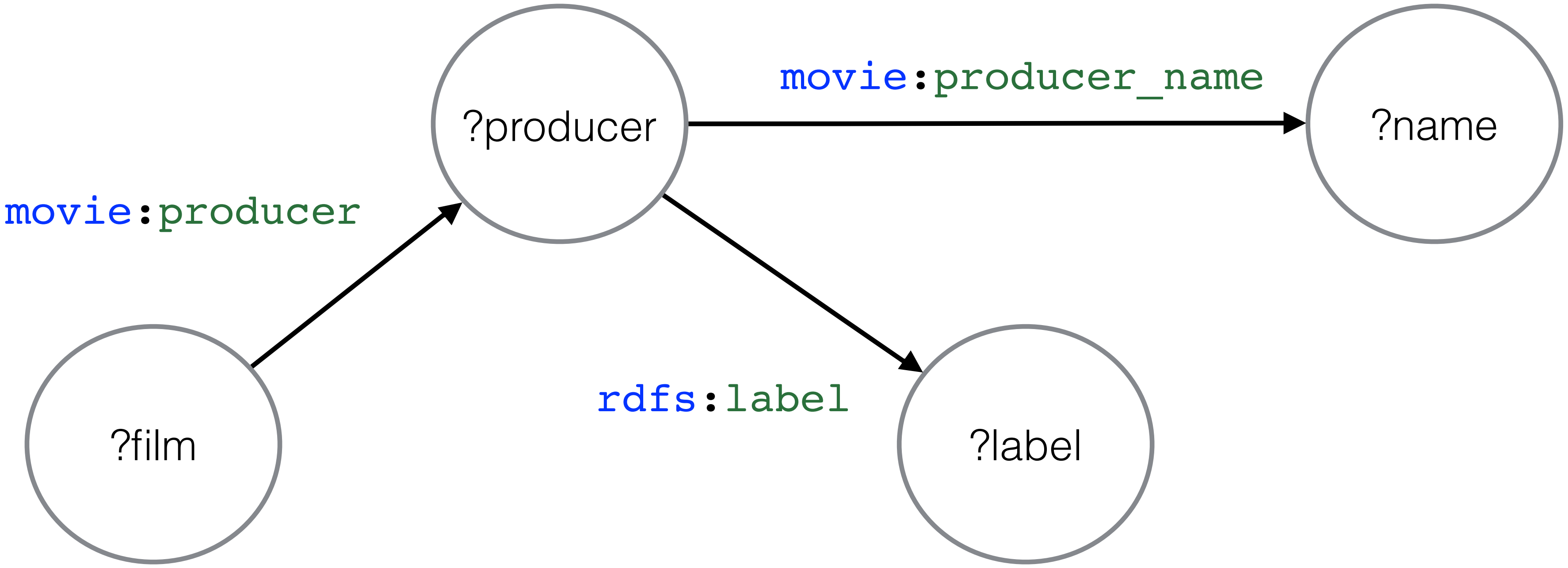
- Differentiate b/w identical statements

```
foaf:alice foaf:knows foaf:bob <http://ex.org/graphs/john> .
foaf:alice foaf:knows foaf:bob <http://ex.org/graphs/james> .
```

GRAPH query

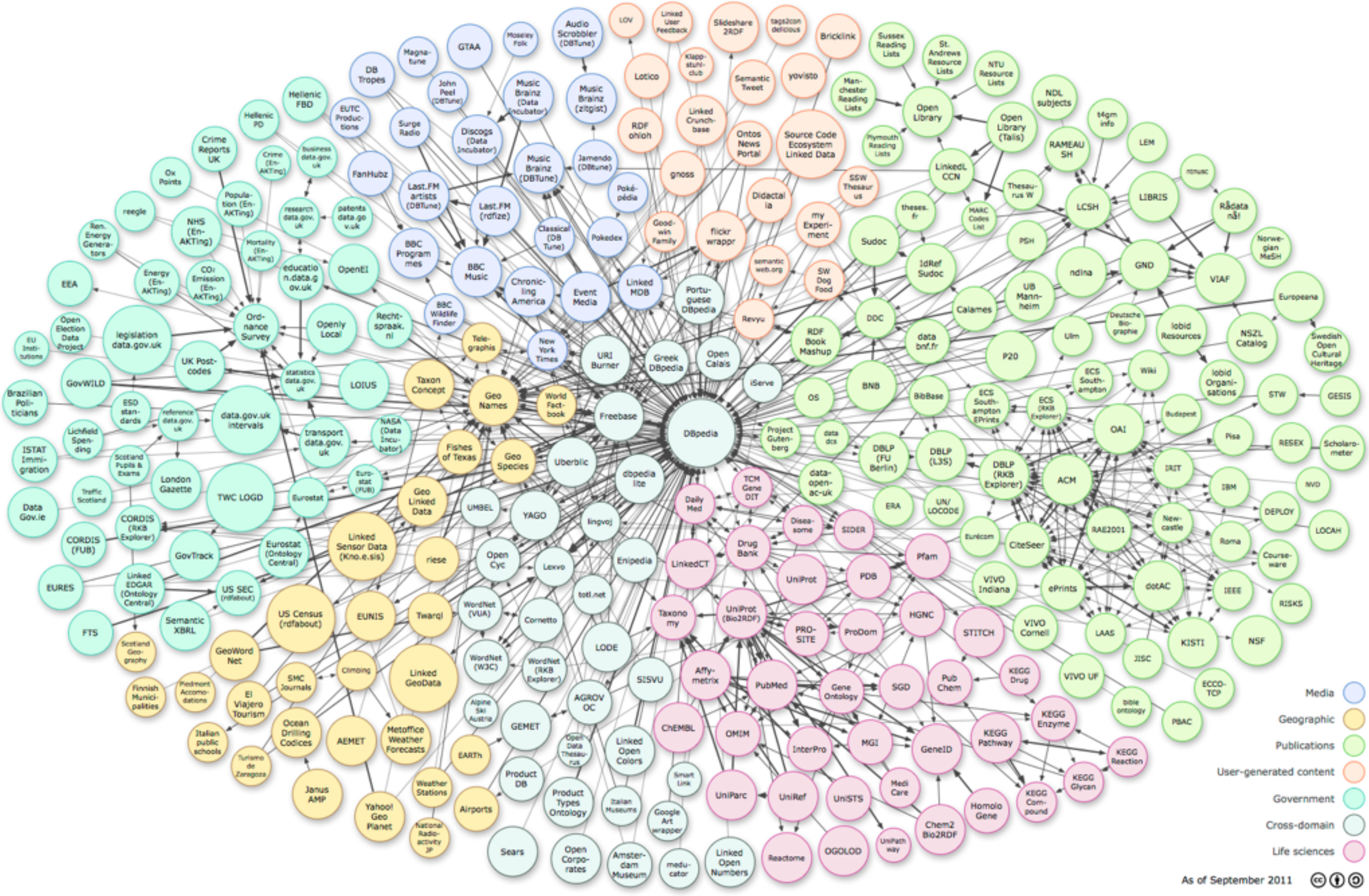
```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX movie: <http://data.linkedmdb.org/resource/movie/>

SELECT ?g ?producer ?name ?label ?page ?film WHERE {
    GRAPH ?g {
       ?producer movie:producer_name ?name .
       ?producer rdfs:label ?label .
       ?film movie:producer ?producer .
    }
}
```



Who is using SW and LD?

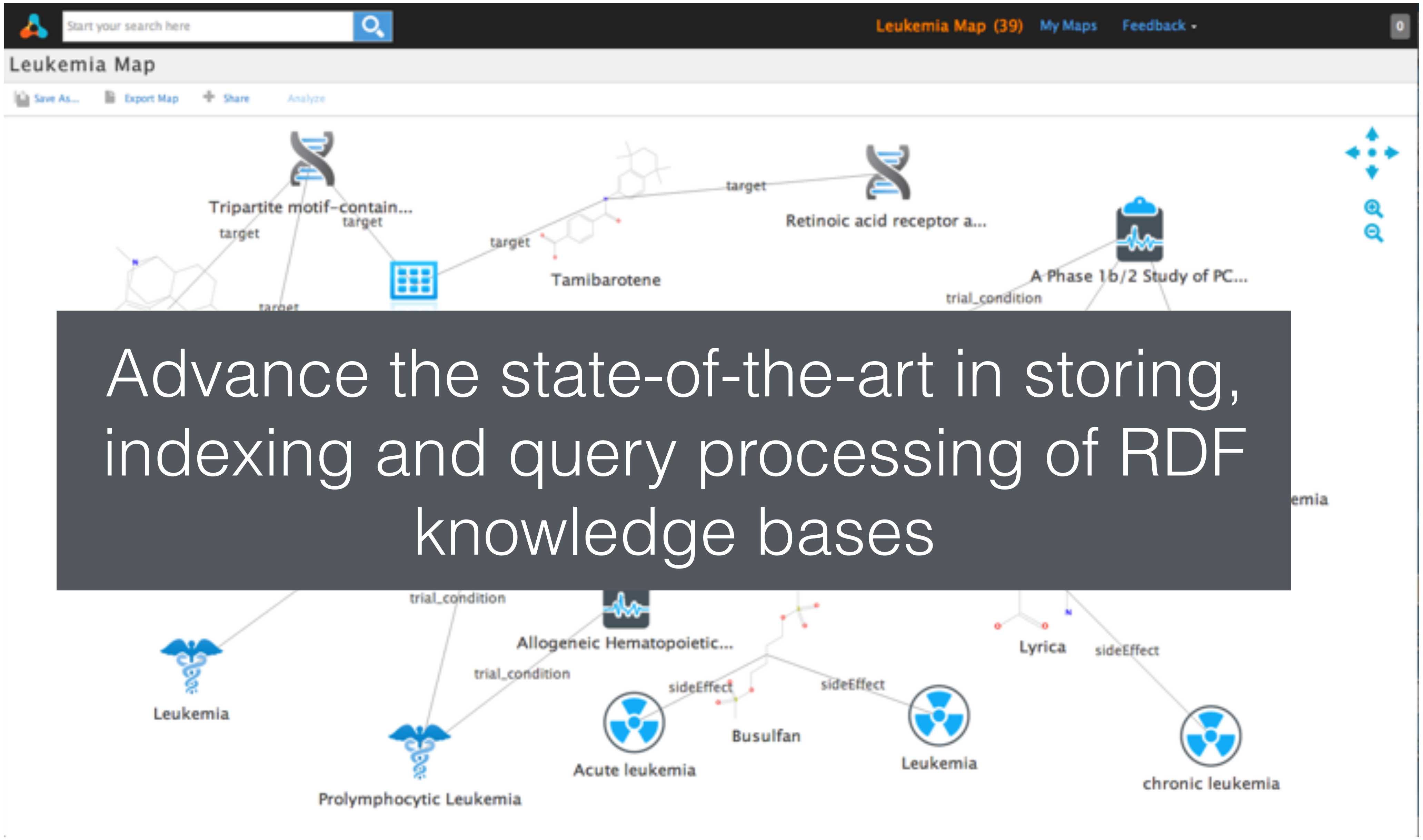
- Governments: US, UK (LOGD, Data.gov)
- BBC
- New York Times
- Pfizer (LODD)
- Best Buy



“Linking Open Data cloud diagram, by Richard Cyganiak and Anja Jentzsch. http://lod-cloud.net/”

Problem Statement

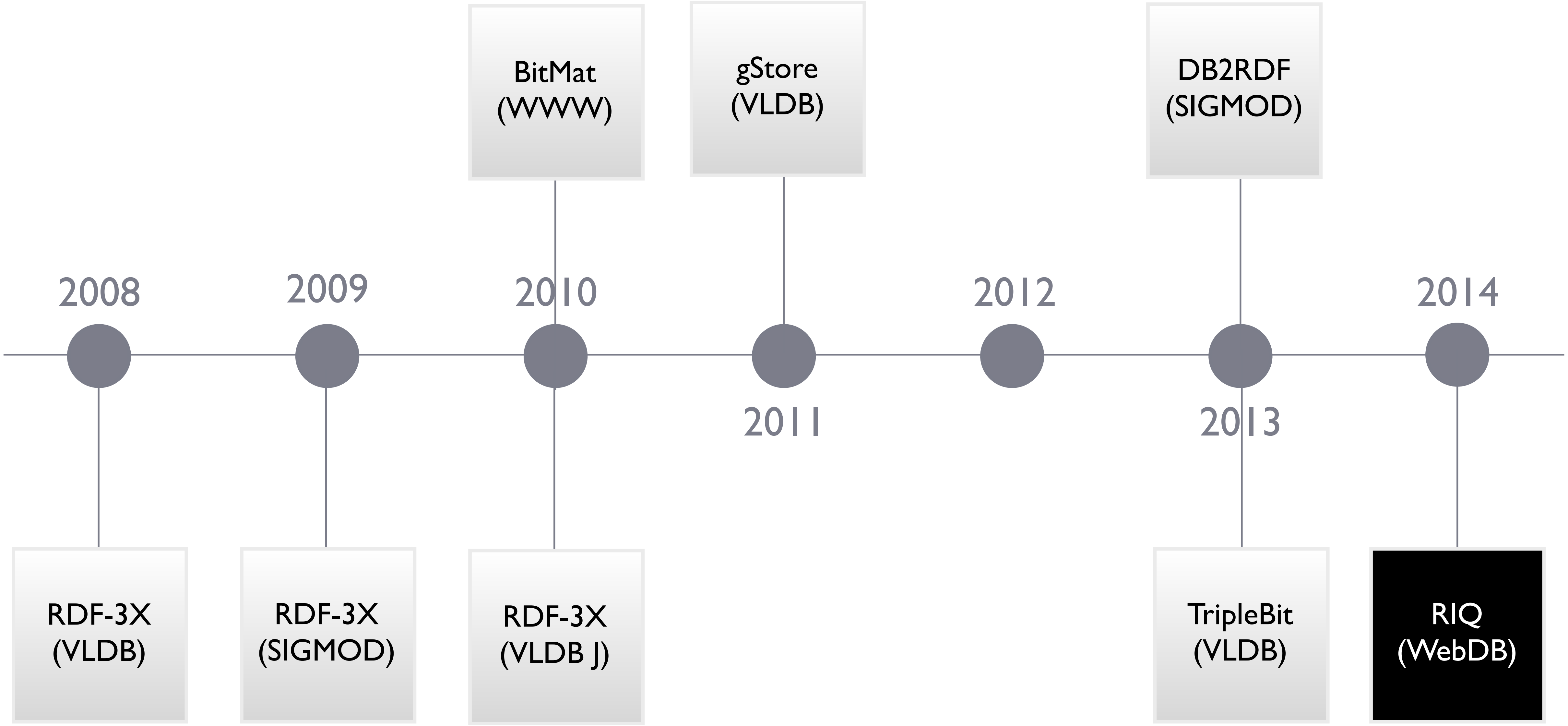
TripleMap



Advance the state-of-the-art in storing, indexing and query processing of RDF knowledge bases

[http://www.triplemap.com/]

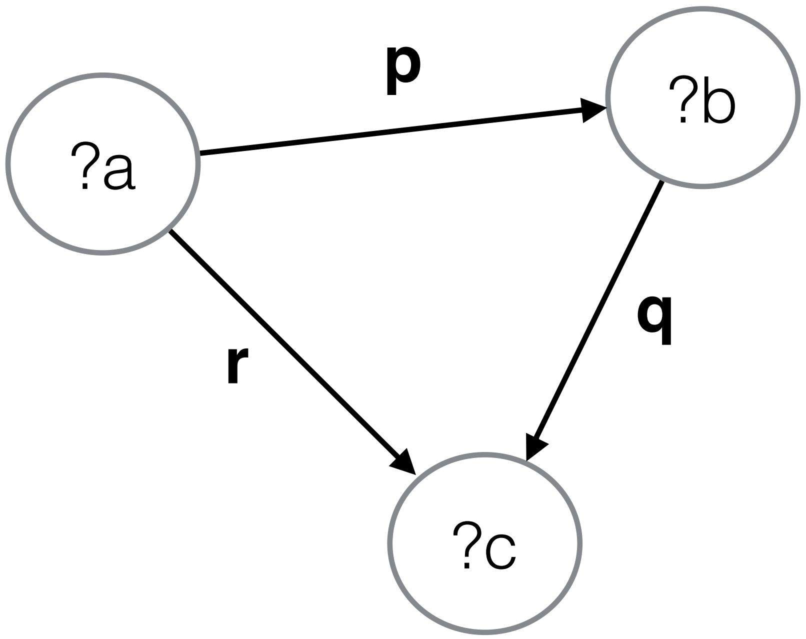
Related work



What's missing in them?

1. No support for quads
2. No large BGP queries (over 8 triple patterns)
3. No complex BGP queries (undirected cycles):

```
SELECT * WHERE {
  ?a p ?b .
  ?b q ?c .
  ?a r ?c .
}
```



Why not use triple stores for quads?

INCORRECT RESULTS

Triple vs. Quad

Data

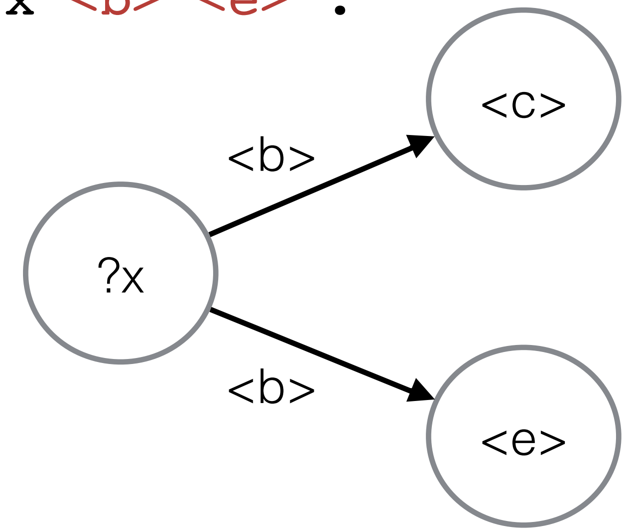
```
<a> <b> <c> <g1> .
<a> <b> <e> <g2> .
```

Triple store results

```
<a>
```

Query

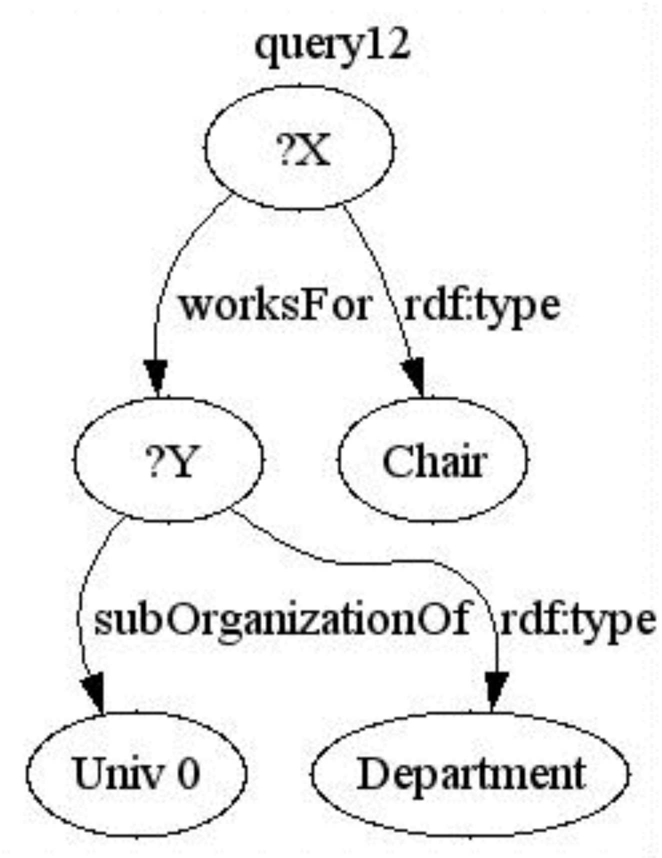
```
SELECT ?x WHERE {
  GRAPH ?g {
    ?x <b> <c> .
    ?x <b> <e> .
  }
}
```



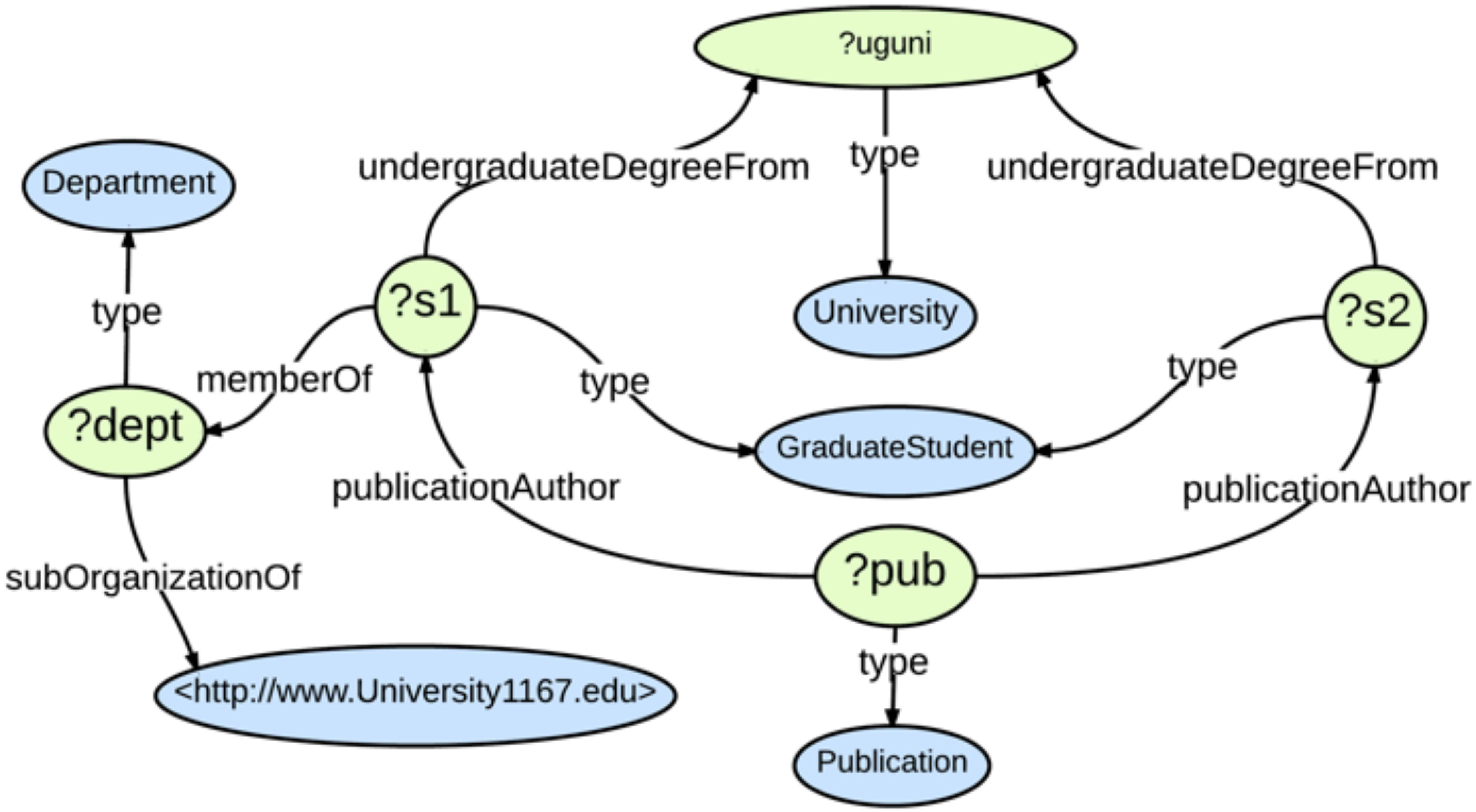
Quad store results

```
<empty>
```

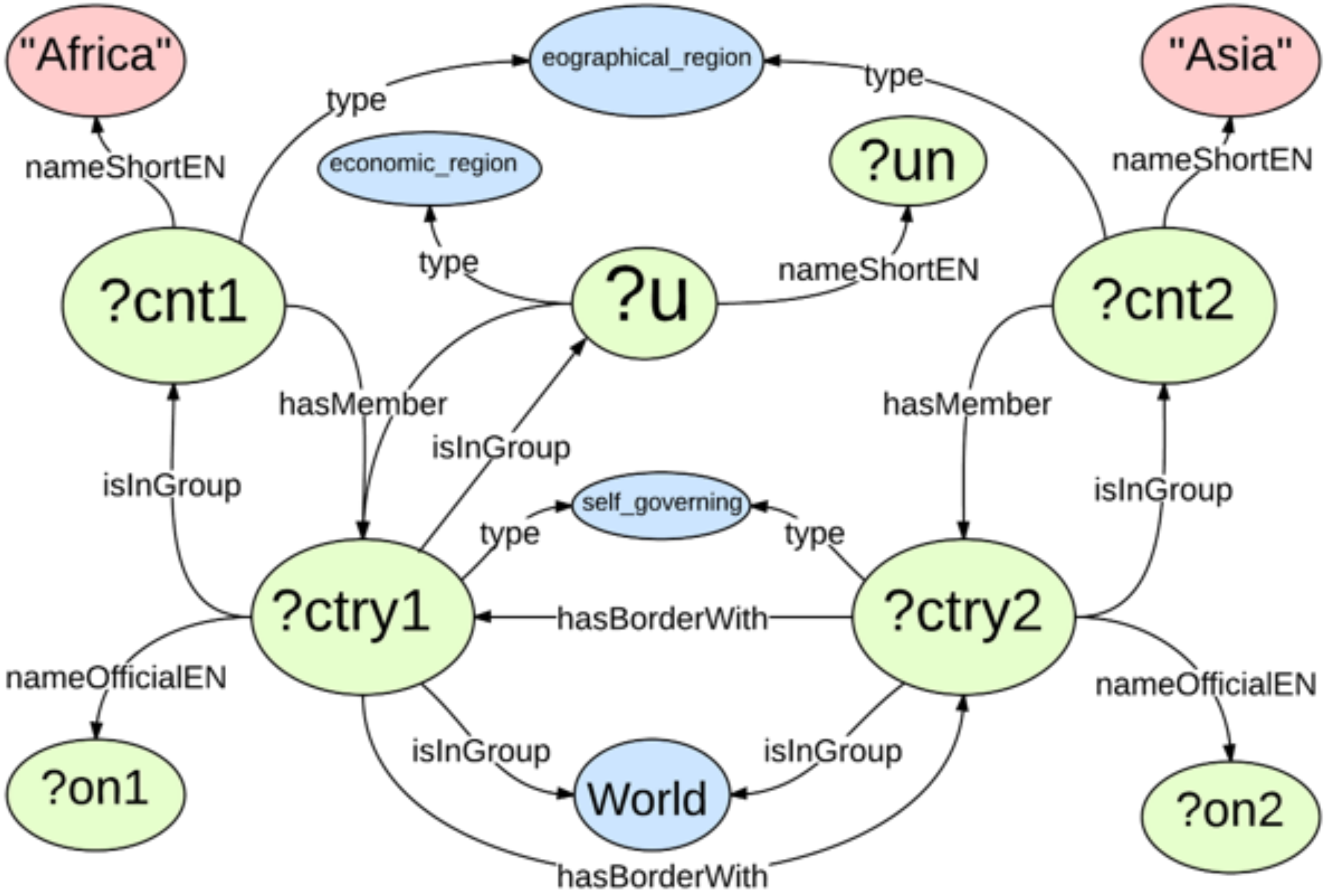
State-of-the-art technologies are… fast



State-of-the-art technologies are… slow



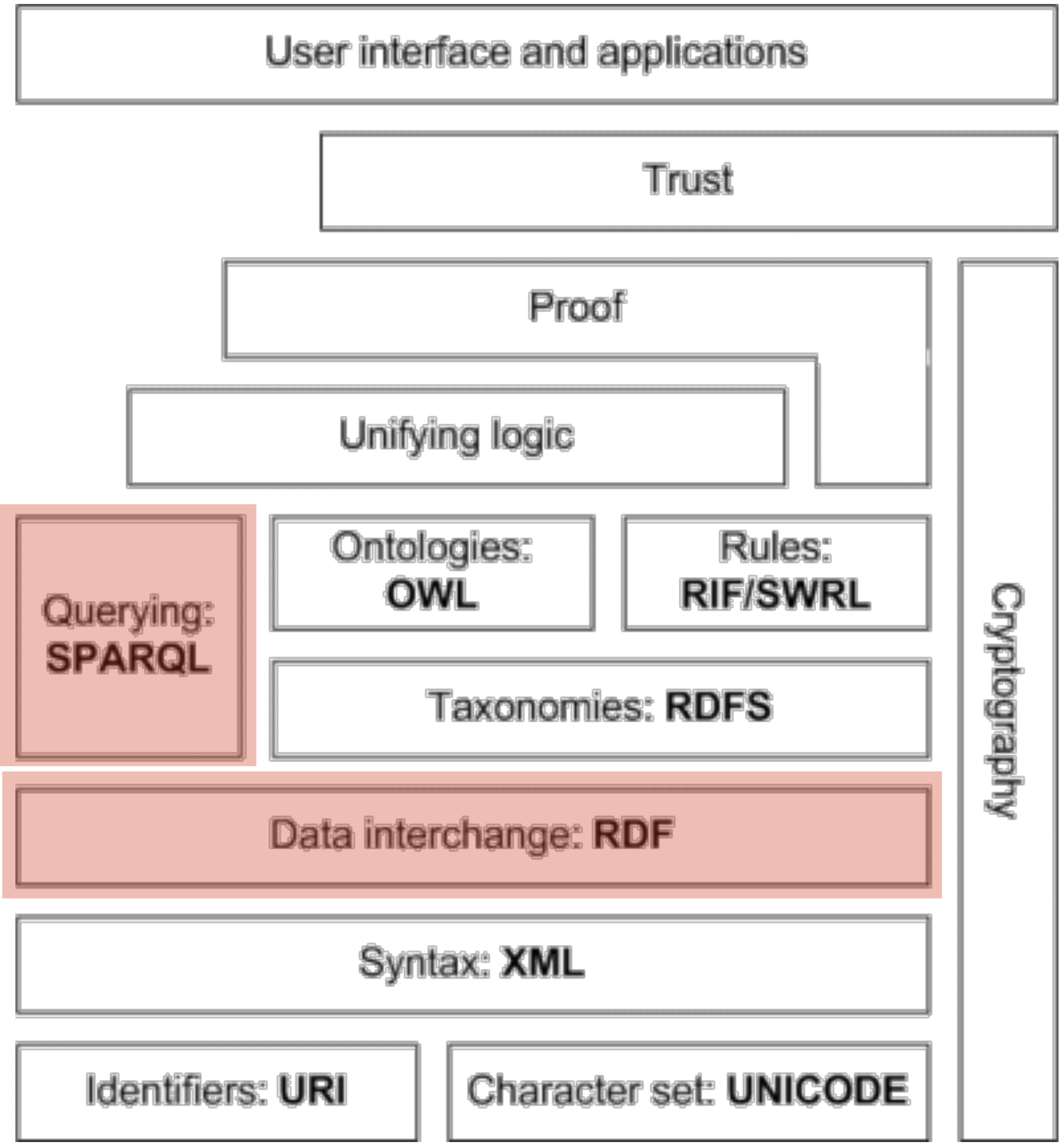
State-of-the-art technologies are… really slow



Comparison

	quads	**max triples/ quads**	**max triple patterns**
RIQ	yes	1.38B	22
RDF-3X	no	845M	13
BitMat	no	1.33B	8
Jena TDB	yes	333M	6
DB2RDF	no	333M	6
TripleBit	no	2.95B	12

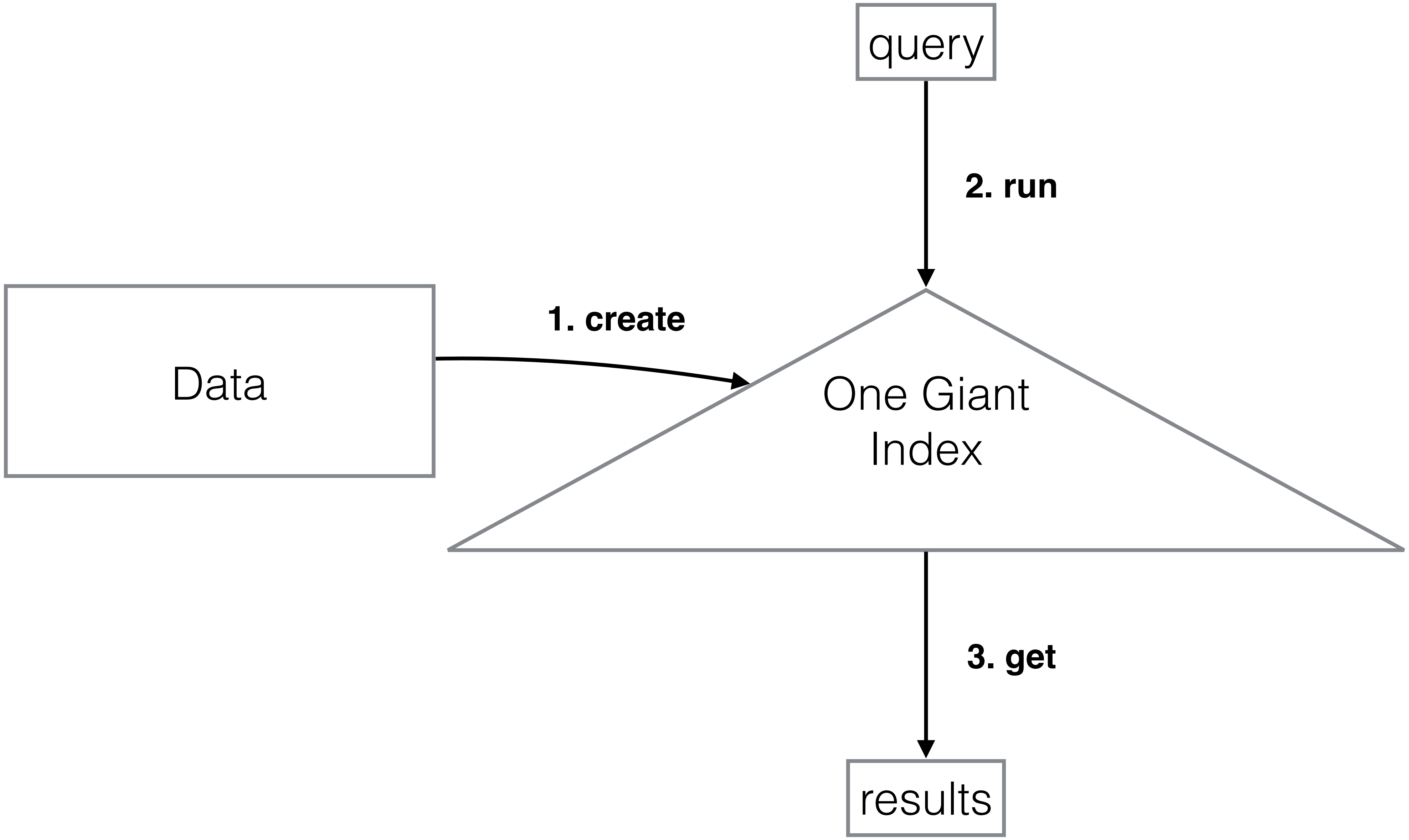
Semantic Web stack



[http://en.wikipedia.org/wiki/Semantic_Web_Stack]

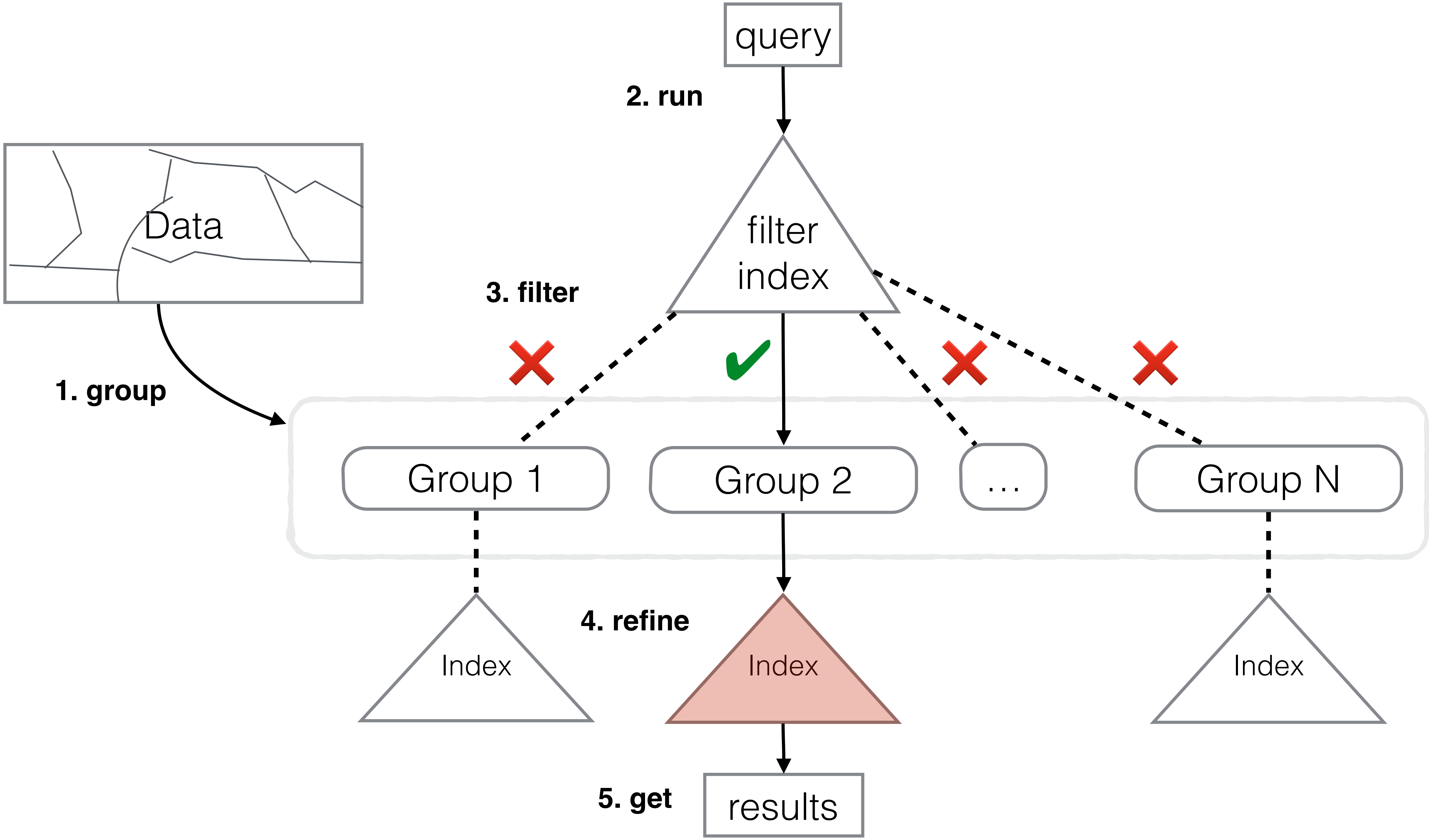
Query processing

(traditional)



Query processing

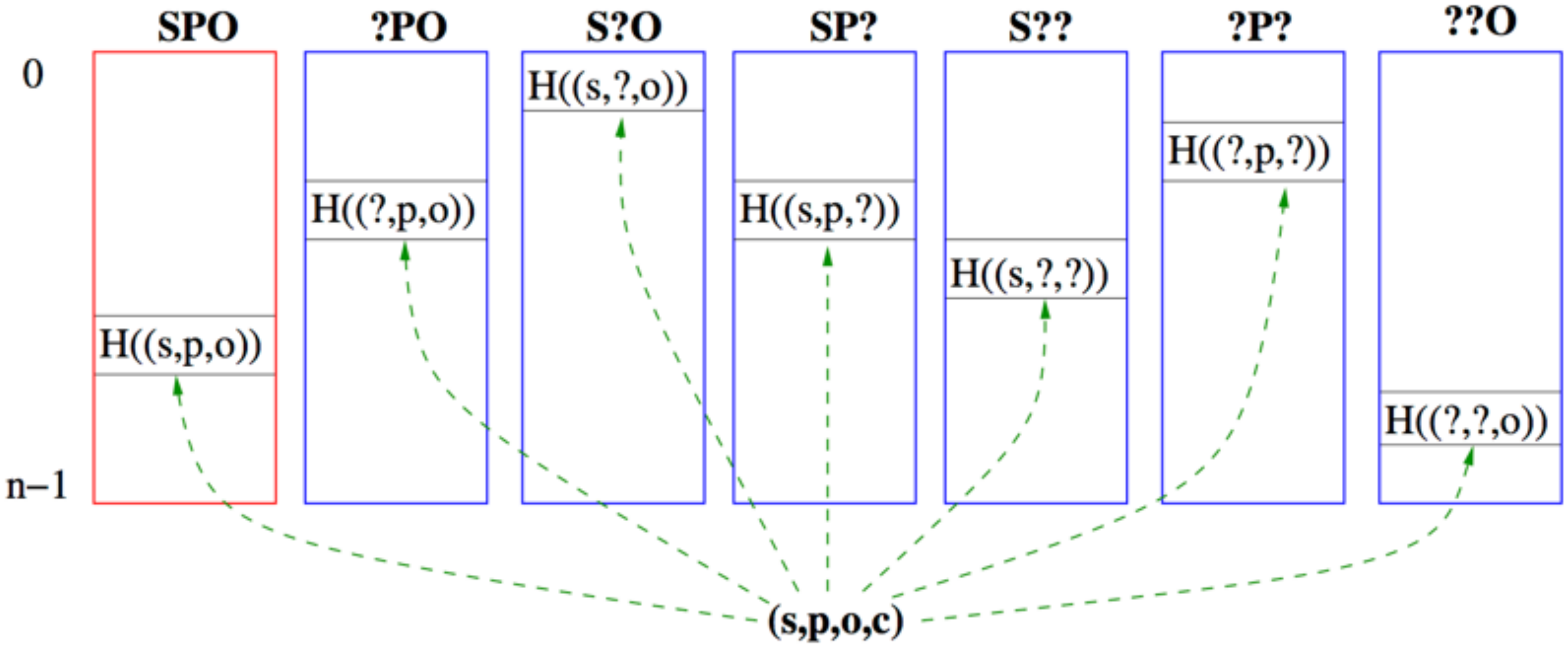
(our approach)



Contributions

- New vector representation
    - RDF graphs
    - Graph patterns in SPARQL queries
- Novel filtering index
- *Decrease-and-conquer* approach for SPARQL query processing

Pattern Vectors (PVs)



$\mathbb{H} : B \rightarrow \mathbb{Z}^*$

$\mathbb{P} = \{SPO, SP?, S?O, ?PO, S??, ?P?, ??O\}$

Filter Index construction

Steps:

1. Create groups of similar PVs

   Locality Sensitive Hashing

2. Compactly store Filter Index

   Bloom Filters and Counting Bloom Filters

Locality Sensitive Hashing

- Indyk and Motwani [STOC '98]
- LSH on sets using Jaccard index [WWW '02, WWW '05]:

$LSH_{k,l}(S)$

$k \times l$ functions: $h(x) = (ax + b)\ mod\ p$

$$g(S) = min\{h(x)\}$$

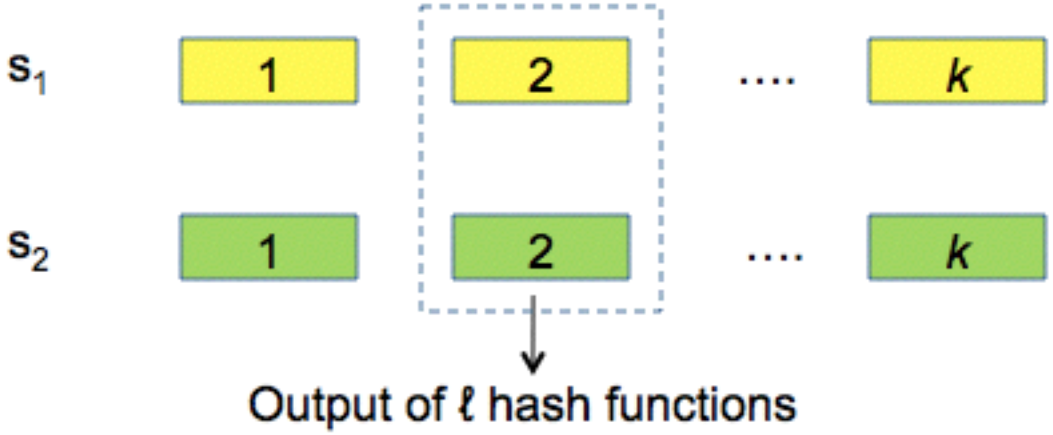
Two sets S_1 and S_2

$$Pr[g(S_1) = g(S_2)] = \frac{|S_1 \cap S_2|}{|S_1 \cup S_2|}$$

Jaccard index

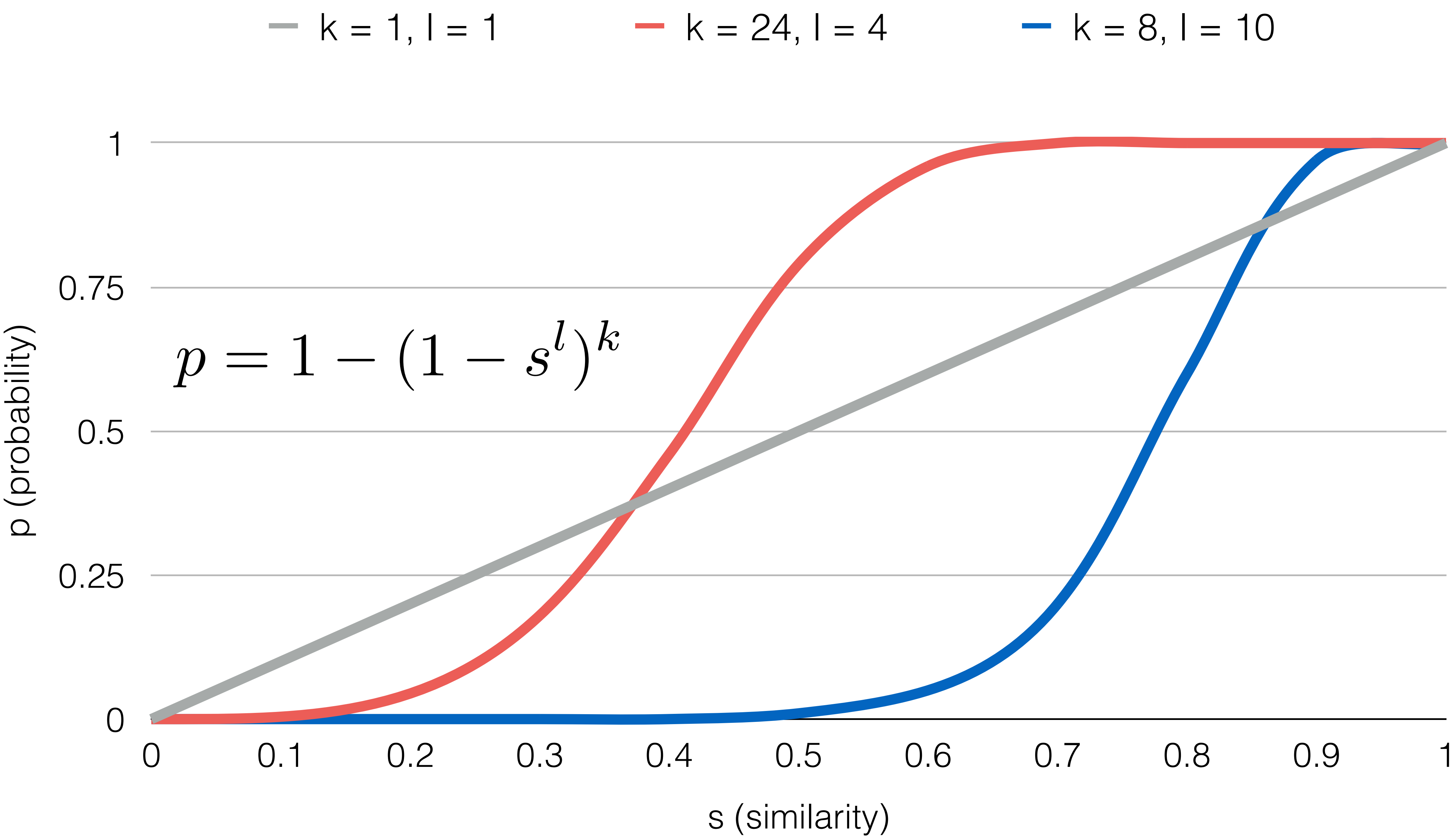
LSH example

$$sim = \frac{|s_1 \cap s_2|}{|s_1 \cup s_2|}$$



Pr[at least one pair of yellow and green is identical] = $1 - (1 - sim^l)^k$

LSH parameters



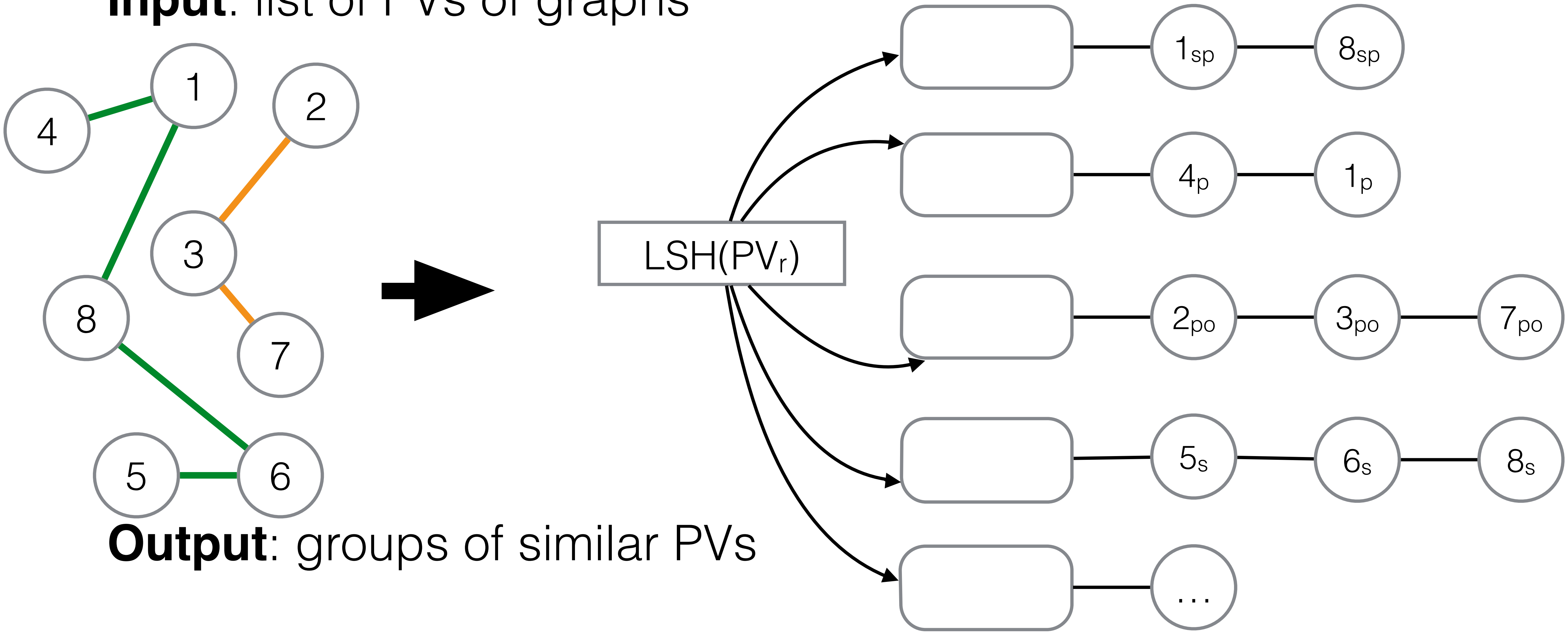
$$p = 1 - (1 - s^l)^k$$

Bloom Filters

- Operations
    - Test
    - Add
- N-bit counters for multisets
- Capacity: # of inserts
- False positive rate

Grouping PVs

Input: list of PVs of graphs



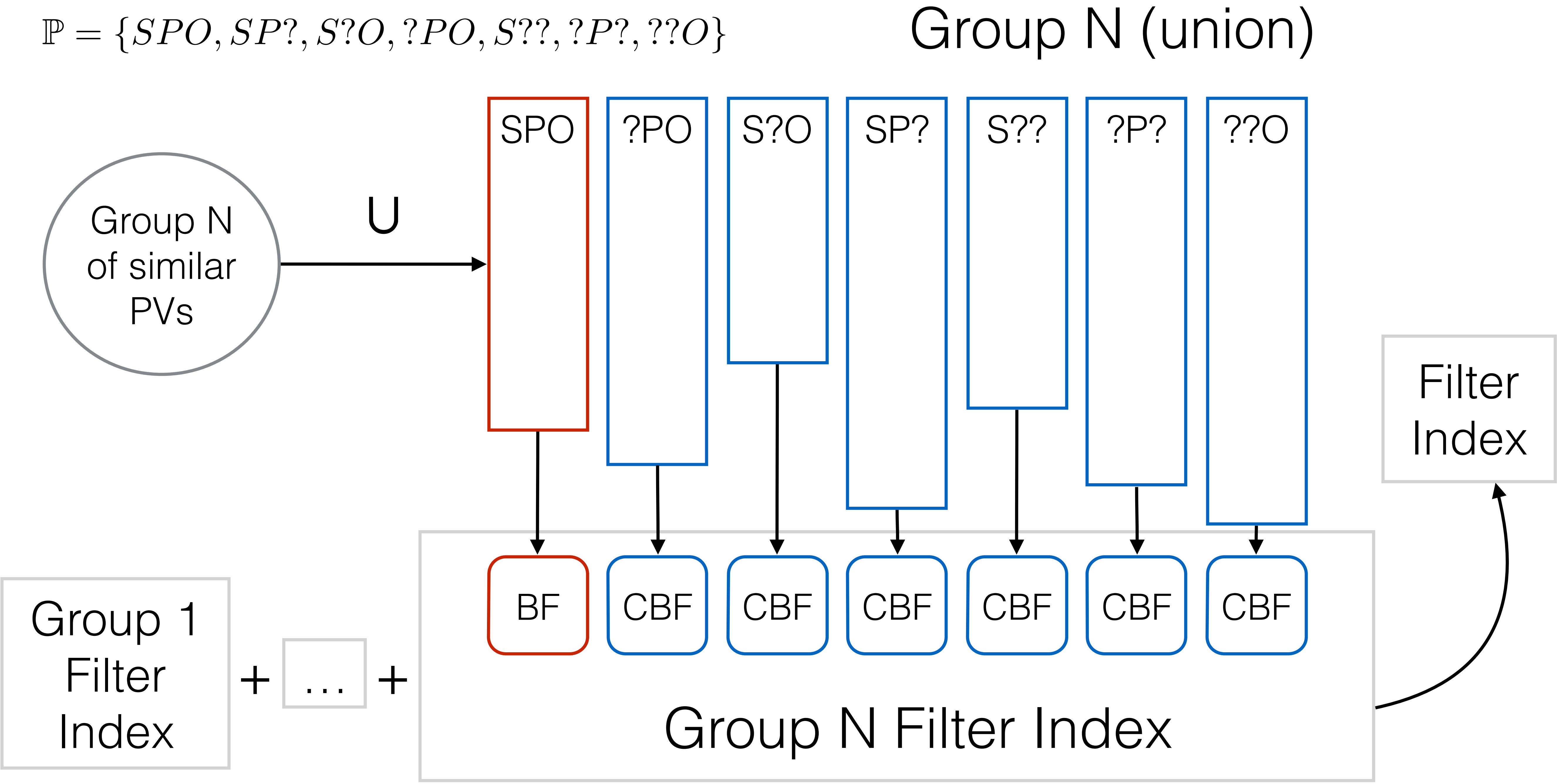
Output: groups of similar PVs

$$sim(PV_a, PV_b) = \max_{r\in\mathbb{P}} \frac{|PV_{a,r} \cap PV_{b,r}|}{|PV_{a,r} \cup PV_{b,r}|} \qquad \mathbb{P} = \{SPO, SP?, S?O, ?PO, S??, ?P?, ??O\}$$

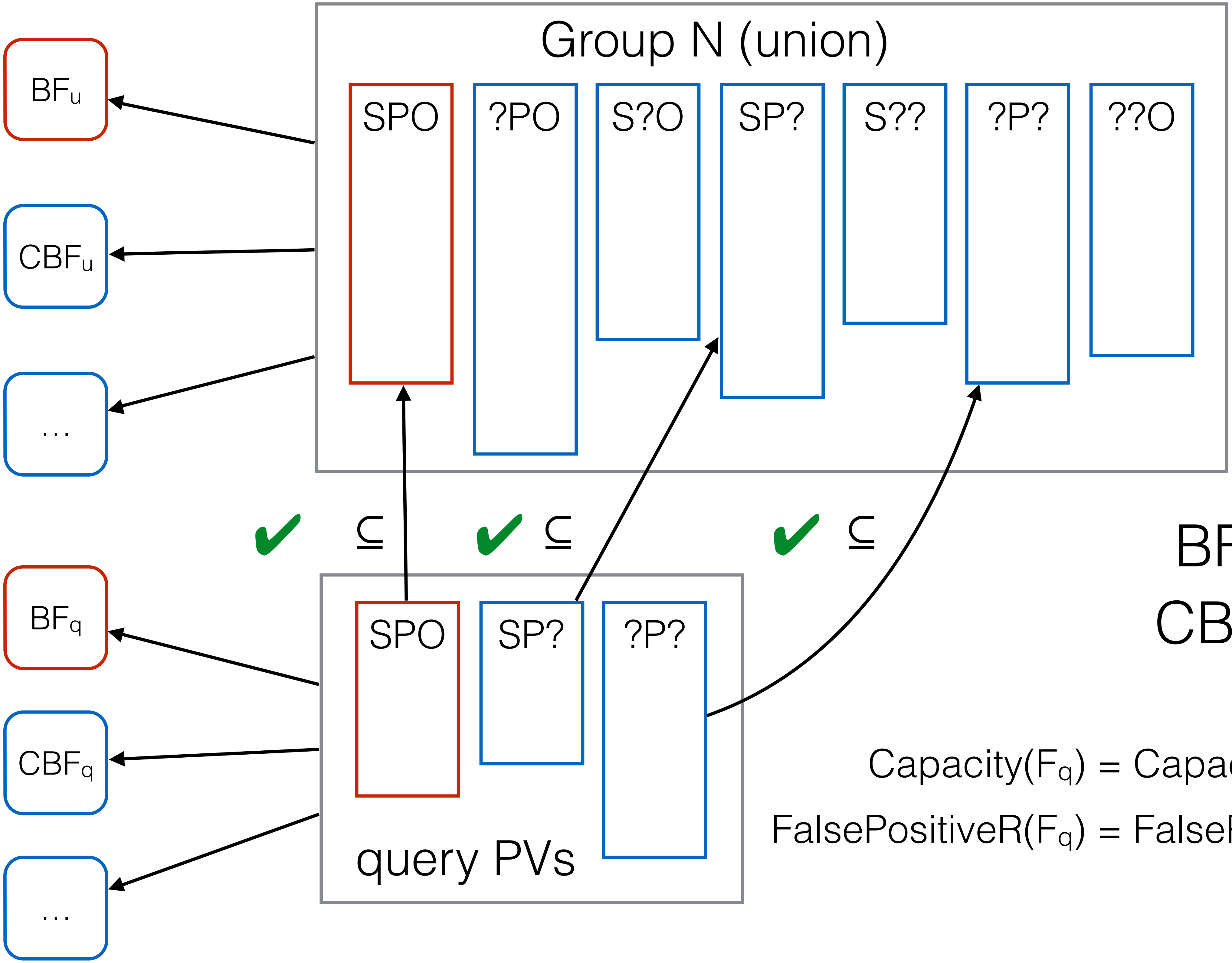
Filter Index

$PV_{c,r} \leftarrow PV_{a,r} \cup PV_{b,r} \; and \; r \in \mathbb{P}$

$\mathbb{P} = \{SPO, SP?, S?O, ?PO, S??, ?P?, ??O\}$



Query execution



$$BF_q[i] == BF_u[i]$$

$$CBF_q[i] \leq CBF_u[i]$$

$\text{Capacity}(F_q) = \text{Capacity}(F_u)$

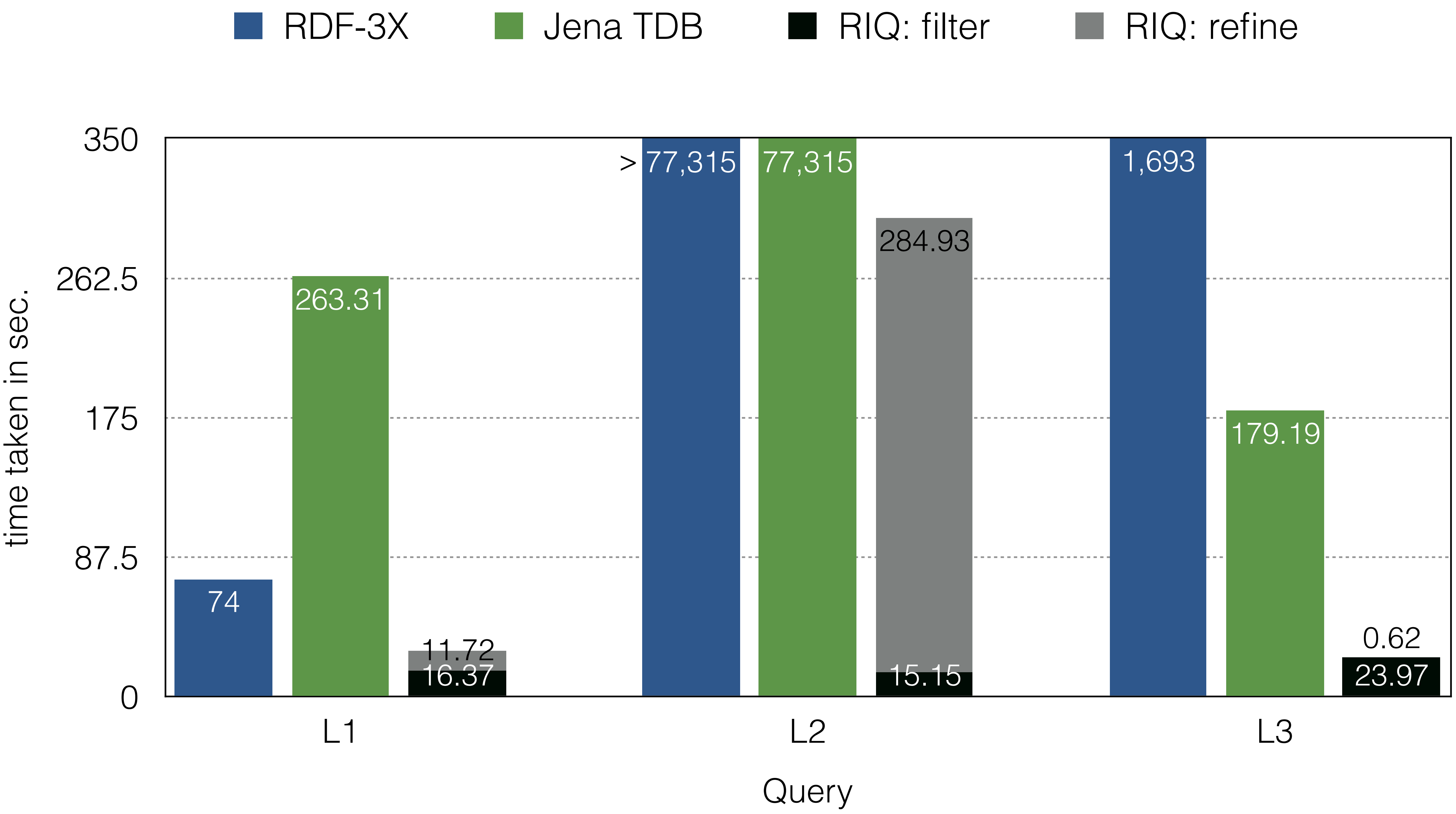
$\text{FalsePositiveR}(F_q) = \text{FalsePositiveR}(F_u)$

Initial performance evaluation

- Datasets
  - Synthetic: LUBM, 1.38 billion triples
  - Real: BTC-2012, 1.36 billion quads
- Queries
  - Large: up to 22 patterns
  - Small: up to 8 patterns

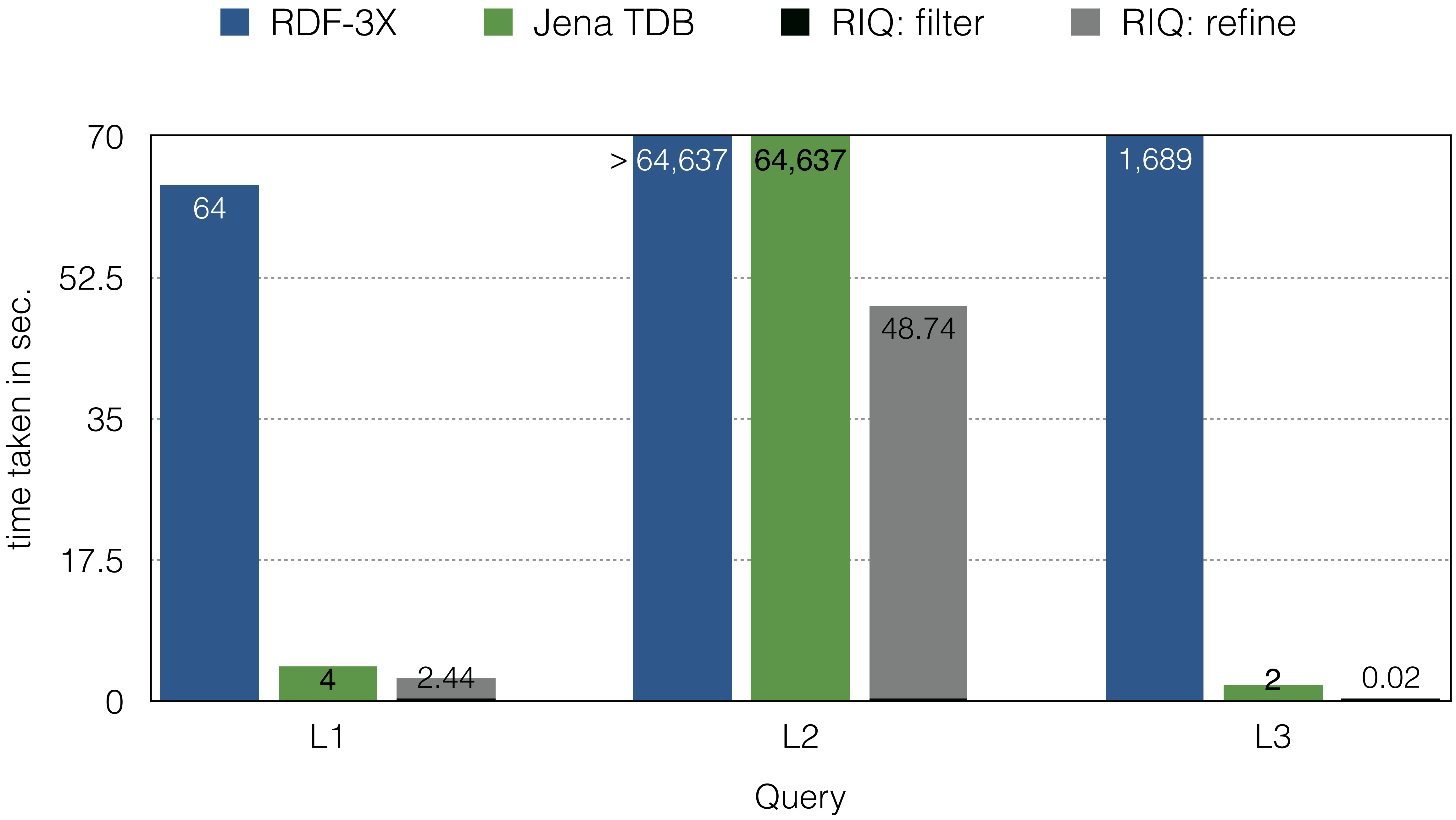
Large BGPs

(LUBM, cold cache)



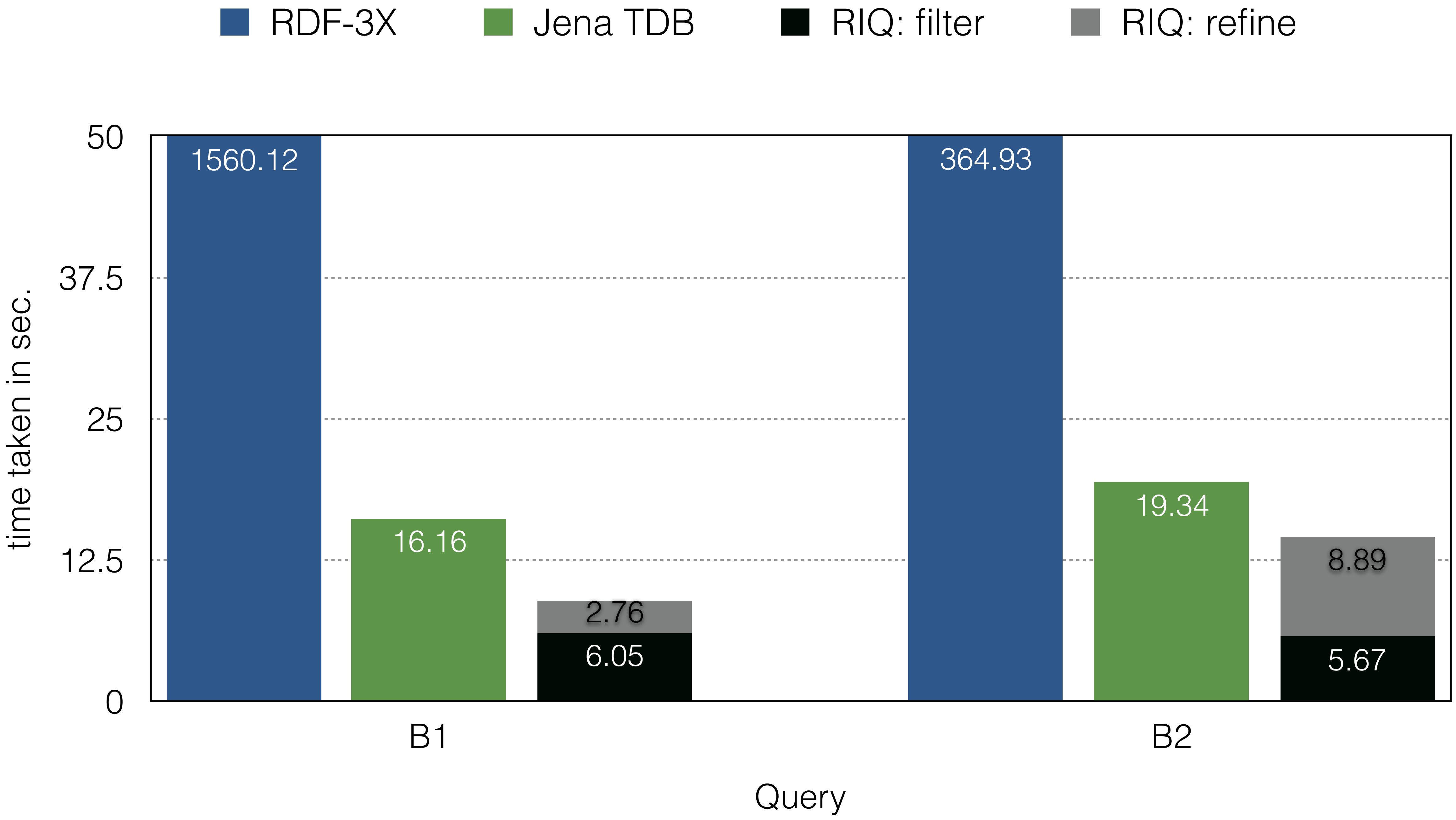
Large BGPs

(LUBM, warm cache)



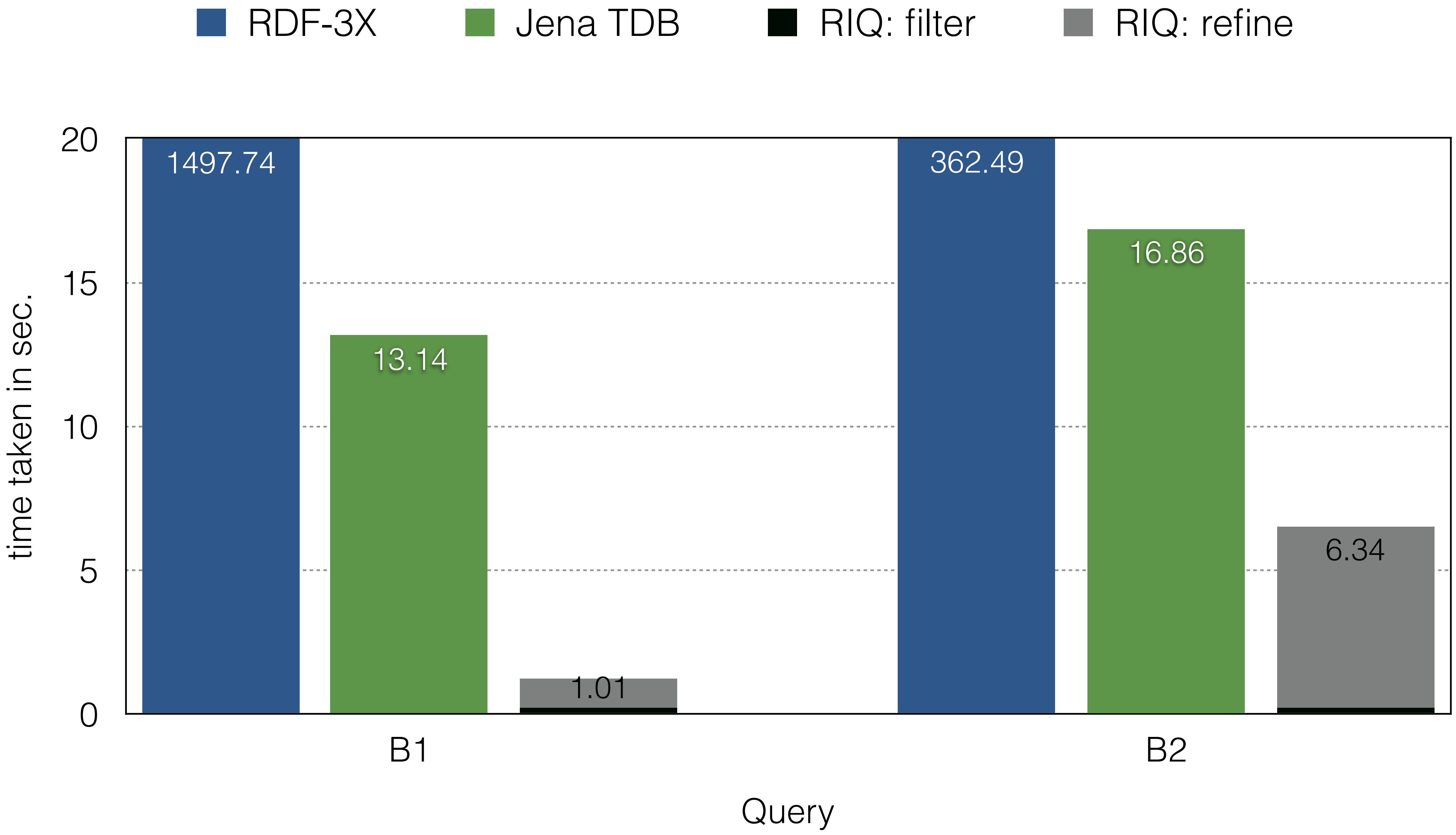
Large BGPs

(BTC-2012, cold cache)



Large BGPs

(BTC-2012, warm cache)



Small BGPs

(LUBM)

	Cold cache			Warm cache		
Query	**RIQ**	**RDF-3X**	**Jena TDB**	**RIQ**	**RDF-3X**	**Jena TDB**
L4	229.95	1986.21	698.08	27.46	1899.1	664.75
L5	576.96	995.26	1130.43	567.2	948.53	1127.37
L6	506.93	888.84	1119.31	489.36	847.59	1144.11
L7	892.7	1215.53	aborted	871.12	1153.31	aborted
L8	507.43	805.41	1346.17	497.69	70.35	1395.48
L9	538.99	979.79	1137.38	519.22	947.07	1142.73
L10	18.72	11.11	7.15	0.51	6.39	3.19
L11	12.19	1.98	5.79	0.41	0.25	1.13
L12	103.14	22.33	725.93	26.76	19.83	703.26
Geo. mean	**193.85**	**210.97**	**282.57**	**59.68**	**115.7**	**207.72**

Small BGPs

(BTC-2012)

	Cold cache			**Warm cache**		
Query	**RIQ**	**RDF-3X**	**Jena TDB**	**RIQ**	**RDF-3X**	**Jena TDB**
B3	41.01	56.42	373.59	1.83	0.82	20.13
B4	42.17	48.55	321.56	3.59	2.37	35.99
B5	70.15	74.86	3541.99	32.38	28.64	3540.28
B6	20.39	> 40,140	14.89	0.64	> 40,140	12.83
B7	221.86	210.37	1925.27	184.86	118.84	1817.85
Geo. mean	**55.96**	**280.34**	**414.25**	**7.59**	**48.4**	**143.01**

Future direction

- Query
  - optimization strategy
  - re-writing
  - SPARQL grammar: OPTIONAL, UNION, FILTER, etc.
- RIQ on other real datasets: LOGD, LODD

Publications

- Accepted at WebDB 2014

  Vasil Slavov, Anas Katib, Praveen Rao, Srivenu Paturi, Dinesh Barenkala. Fast Processing of SPARQL Queries on RDF Quadruples. 17th International Workshop on the Web and Databases (WebDB 2014), Snowbird, Utah, June 22, 2014.

- Future submissions
  - ICDE demo paper, September 2014
  - ACM Transactions on the Web Journal paper, December 2014

Q&A