# Une classification expérimentale multi-critères des évaluateurs SPARQL répartis

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# General Context & Goal

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- Large amounts of available RDF data
- Several SPARQL evaluators
- Distributed context

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## Goal

How to choose an efficient SPARQL evaluator in a distributed context?

Section 1

# Background

# Resource Description Framework [HM04]

**RDF standard has been designed to:**

- Present a simple way of representing data
- Have a formal semantics to offer basis for reasoning
- Have an extensible vocabulary
- Provide, share and exchange datasets between applications.
- Allow anyone to make statements about any resource.

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## RDF essentials

- RDF is a W3C standard
- An RDF graph is a set of RDF triples
- An RDF triple has three components:
  - a subject (s)
  - a predicate (p)
  - a object (o)

# SPARQL Protocol and RDF Query Language [G+13]

## Syntax in a nutshell

- SPARQL is an RDF query language
- SPARQL is a W3C standard
- 4 types: `SELECT` `ASK` `CONSTRUCT` `DESCRIBE`
- SQL-like syntax: `SELECT Var List WHERE { Pattern }`
-

$$
\begin{array}{lcl}
\texttt{Pattern}\ (\mathsf{P}) & := & \mathsf{P}\ .\ \mathsf{P} \\
 & | & (\text{subject}|\text{var})\ (\text{predicate}|\text{var})\ (\text{object}|\text{var}) \\
 & | & \{\mathsf{P}\}\ \texttt{UNION}\ \{\mathsf{P}\} \\
 & | & \mathsf{P}\ \texttt{OPTIONAL}\ \{\mathsf{P}\} \\
 & | & \texttt{FILTER}\ \text{Constraint}
\end{array}
$$

Section 2

# SPARQL Evaluators

# Jumble of Evaluators

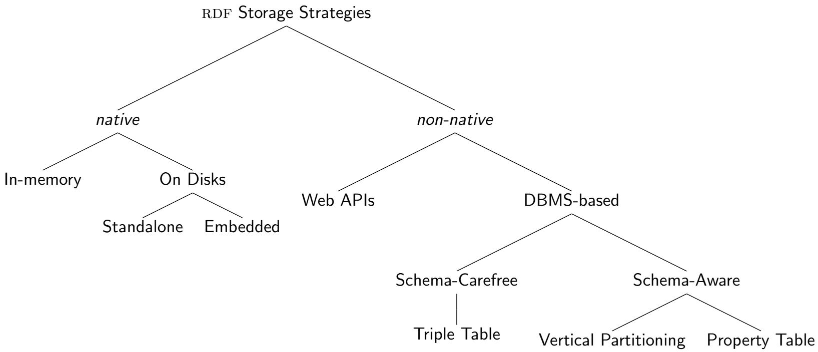
4store
CouchBaseRDF
BitMat
YARS
Hexastore
CliqueSquare
RYA
Parliament
Virtuoso
RDF-3X
...

# Jumble of Evaluators

## ... Some Previous Surveys

| When? | Who? | What? |
|---|---|---|
| 2001 | Barstow [Bar01] | Focuses on open-source solutions; and looks at some of their specificities |
| 2002 | Beckett [Bec02] | Updates |
| 2003 | Beckett [BG03] | Focuses on the use of relational database management systems to store RDF datasets |
| 2004 | Lee [Lee04] | Updates |
| 2012 | Faye [FCB12] | Lists the various RDF storage approaches mainly used by single-node systems |
| 2015 | Kaoudi [KM15] | Presents a survey focusing only on RDF in the clouds |

# RDF Storage Strategies [FCB12]



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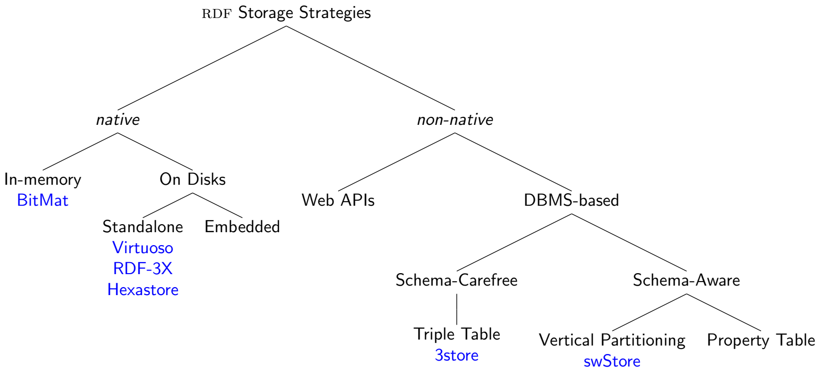
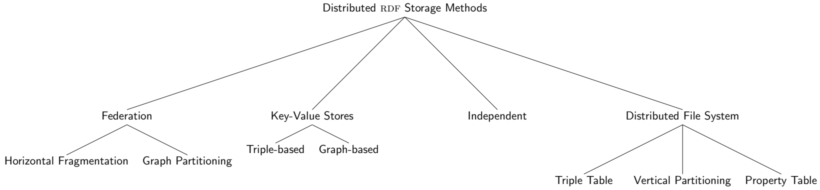


# Distributed Evaluation Methods [KM15]



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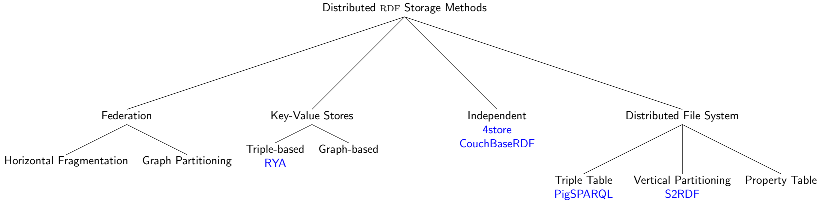

# Distributed SPARQL Evaluator State-of-the-art Summary

## Observations

1. Multiple RDF storage strategies
2. Various methods to distribute data and to compute queries

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## How to pick an efficient evaluator?

Experimental Evaluation!

Section 3

# Running an Experimental Study

# Experimental Studies

| When? | Who? | What? |
|---|---|---|
| 2002 | Magkanaraki [MKA+02] | Reviews solutions dealing with ontologies |
| 2009 | Stegmaier [SGD+09] | Reviews solutions according to several parameters such as their licenses, their architectures and compares them using a scalable test dataset |
| 2013 | Cudré-Mauroux [CMEF+13] | Realizes an empirical study of distributed SPARQL evaluators (native RDF stores and several NoSQL solutions they adapted) |

# Popular Benchmarks

| Name | SPARQL Fragment |
|---|---|
| LUBM [GPH05] | BGP |
| WatDiv [AHÖD14] | BGP |
| $SP^2$Bench [SHLP09] | BGP + `FILTER UNION OPTIONAL` + Solution Modifiers + `ASK` |
| BolowgnaB [DEW+11] | BGP + aggregator (*e.g.* `COUNT`) |
| BSBM [BS09] | BGP + `FILTER UNION OPTIONAL` + Solution Modifiers + Logical negation + `CONSTRUCT` |
| DBPSB [MLAN11] | Use actually posed queries against dbpedia |
| RBench [QÖ15] | Generate queries according to considered datasets |

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# Considered Benchmarks

## LUBM

- deterministically generated datasets
- 14 predefined queries (Q1-Q14)

## WatDiv

- deterministically generated datasets (richer than the LUBM one)
- 20 generated queries according to templates

# Selected SPARQL Evaluators

## Criteria

- OpenSource
- Popular
- Recent
- Distributed
- At least BGP SPARQL Fragment

# Selected SPARQL Evaluators

| 10 Systems | Framework | Back-End | Layout |
|---|---|---|---|
| 4store | — | Data Fragments | Indexes |
| CumulusRDF | Cassandra | Key-Value | Hash-Sorted Indexes |
| CouchBaseRDF | CouchBase | Buckets | 3 views |
| RYA | Accumulo | Key-Value on HDFS | 3 Sorted indexes |
| SPARQLGX | Spark | Files on HDFS | Vertical Partition |
| S2RDF | SparkSQL | Tables on HDFS | Ext. Vertical Partition |
| CliqueSquare | Hadoop | Files on HDFS | Indexes |
| PigSPARQL | PigLatin | Files on HDFS | N-Triples Files |
| RDFHive | Hive | Tables on HDFS | Three-column Table |
| SDE | Spark | Files on HDFS | N-Triples Files |

# Cluster Specifications

- Cluster composed of 10 Virtual Machines hosted on two servers.
- Each VM has:
  - dedicated 2 physical cores (thus 4 logical cores)
  - 17 GB of RAM
  - 6 TeraBytes (TB) of disk.
- The network allows two VMs to communicate at 125MB/s

# Obtained Results

## We learned:

1. Considering the same dataset, loading times are spread over several magnitude orders

# Obtained Results

## With the following RDF datasets:

| Dataset | Number of Triples | Original File Size |
|---|---|---|
| WatDiv1k | 109 million | 15 GB |
| Lubm1k | 134 million | 23 GB |
| Lubm10k | 1.38 billion | 232 GB |

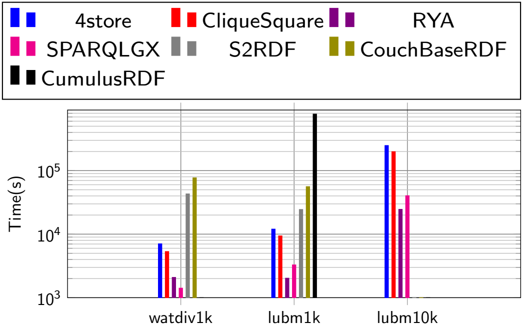


Figure : Preprocessing Time.

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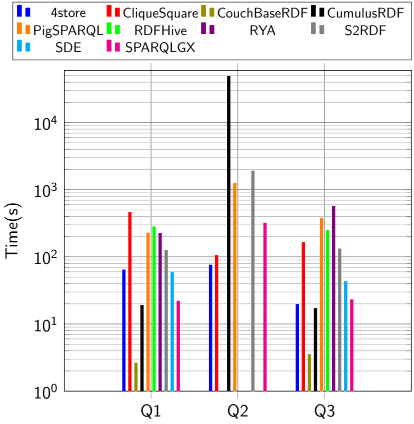


Figure : Query Response Time with Lubm1k (134 million triples).

**Q1**

```
SELECT ?X WHERE {
 ?X rdf:type ub:GraduateStudent .
 ?X ub:takesCourse GraduateCourse0

}
```

**Q2**

```
SELECT ?X ?Y ?Z WHERE {
 ?X rdf:type ub:GraduateStudent .
 ?Y rdf:type ub:University .
 ?Z rdf:type ub:Department .
 ?X ub:memberOf ?Z .
 ?Z ub:subOrganizationOf ?Y .
 ?X ub:undergraduateDegreeFrom ?Y

}
```

**Q3**

```
SELECT ?X WHERE {
 ?X rdf:type ub:Publication .
 ?X ub:publicationAuthor AssistantProfessor0

}
```

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3. Even with large datasets, most queries are not harmful *per se*, *i.e.* queries that incurr long running times with some implementations still remain in the "comfort zone" for other implementations

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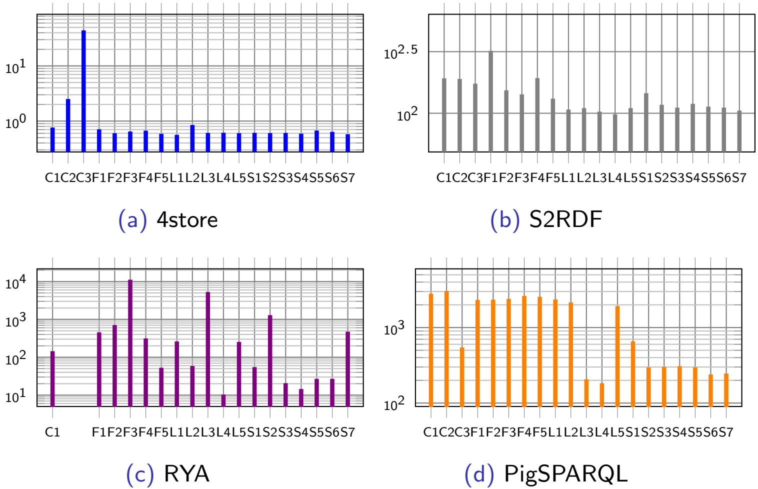


Figure : Obtained results with WatDiv1k.

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## Ok, but...

...how to rank evaluators? ☹

Section 4

# Multi-Criteria Experimental Ranking

# An extended set of metrics

**Usual metrics:**

- Time *always*
- Disk Footprint *only sometimes*

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**Usual metrics:**

- Time — *always*
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**Our additions:**

- Disk Activity — *new*
- Network Traffic — *new*
- Resources: CPU, RAM, SWAP — *new*

# Multi-Criteria Reading Grid

## Criteria List

- **Velocity**: the fastest possible answers

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- **Dynamicity**: dealing with dynamic data

  *Preprocessing Time & Disk Activity*

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  *Footprint*

- **Immediacy**: evaluating some SPARQL queries only once

  *Preprocessing Time*

- **Dynamicity**: dealing with dynamic data

  *Preprocessing Time & Disk Activity*

- **Parsimony**: minimizing some of the resources

  *CPU, RAM, . . .*

# Immediacy

## Trade-off between querying and preprocessing

The preprocessing time required before querying can be seen as an investment *i.e.* taking time to preprocess data (load/index) should imply faster query response time, offseting the time spent in preprocessing.

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## To highlight the trade-off of a query Q, we draw

- with logarithmic scale
- the affine line $y = ax + b$
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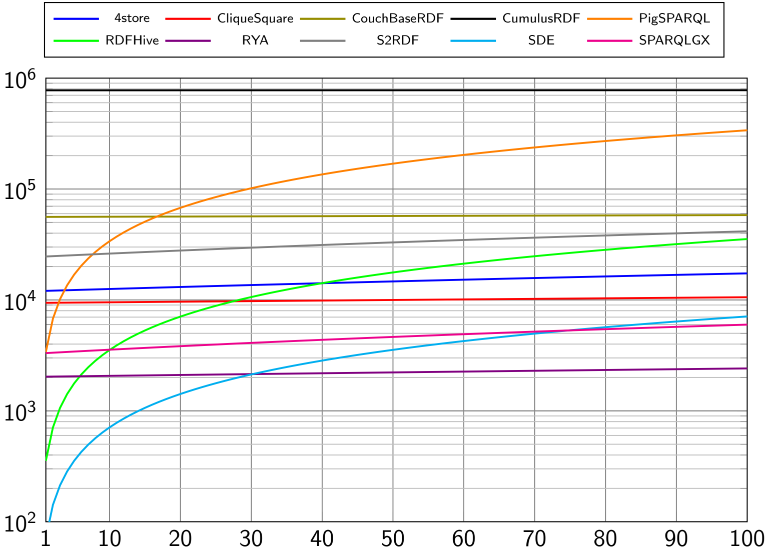


Trade-off for Q8 with Lubm1k.

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## To quickly answer to a single query once:

SDE should be selected.

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## Resiliency

- *Data Resiliency*

# Dynamicity & Resiliency

| Systems | Lubm1k (GB) | WatDiv1k (GB) |
|---|---|---|
| S2RDF | **13.057** | 15.150 |
| RYA | 16.275 | **11.027** |
| CumulusRDF | 20.325 | – |
| 4store | 20.551 | 14.390 |
| CouchBaseRDF | 37.941 | 20.559 |
| SPARQLGX | 39.057 | 23.629 |
| CliqueSquare | 55.753 | 90.608 |
| PigSPARQL | 72.044 | 46.797 |
| RDFHive | 72.044 | 46.797 |
| SDE | 72.044 | 46.797 |

Without replication: Lubm1k 23GB and WatDiv1k 15GB

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  1. Failure: 4store, CumulusRDF

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  1. Failure: 4store, CumulusRDF
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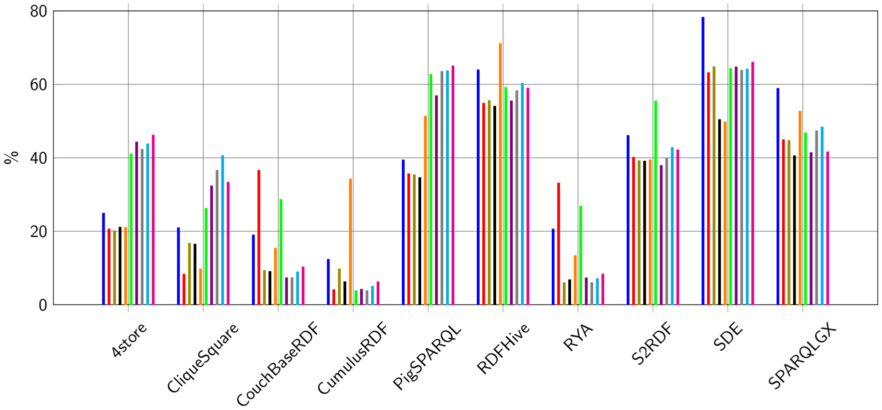
     - A predefined number of minutes: CouchBaseRDF
     - For ever: PigSPARQL
  3. Succeeding: RDFHive, SPARQLGX, RYA, SDE, CliqueSquare, S2RDF

# Parsimony

## Some observations:

1. CPU-consumption observation allows to see storage model.

# Parsimony




Average CPU during Lubm1k query phase.

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1. CPU-consumption observation allows to see storage model.
2. Spark-based evaluators are RAM-selfish unlike 4store or CliqueSquare.

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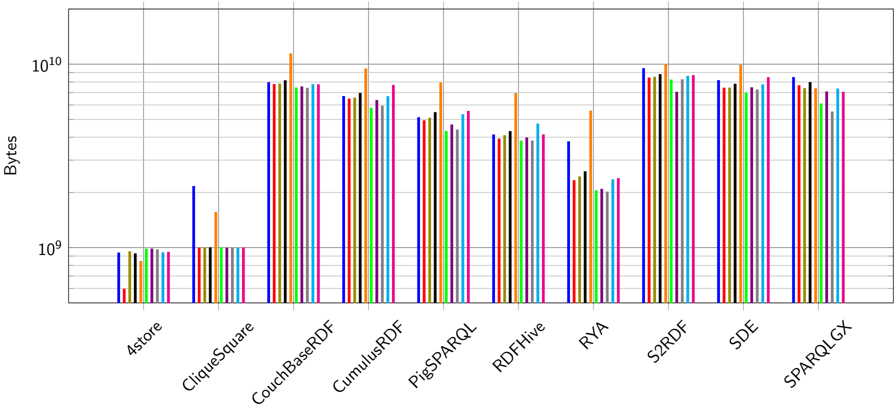


Maximum allocated RAM during Lubm1k query phase.

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3. Master nodes show their role looking at network traffic.

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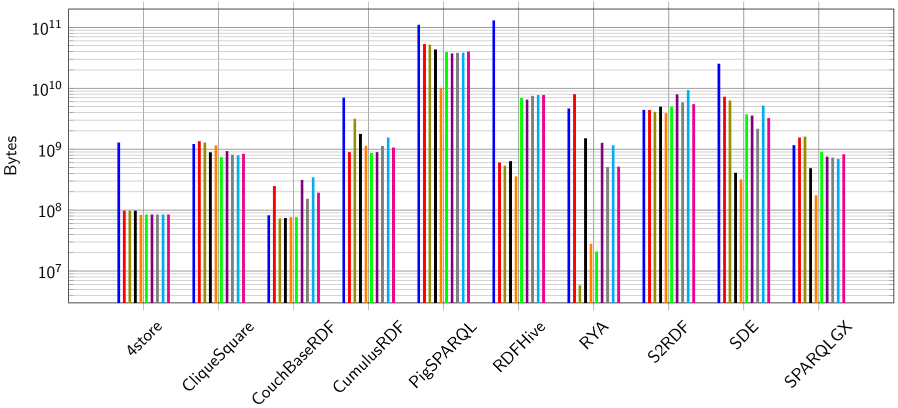


Total bytes sent during Lubm1k query phase.

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**When concurrent services are running...**

...4store and CliqueSquare should be selected.

# Estimated Cost

## Estimation Scenario

- MS-Azure cloud platform
- 10 “A4” instances (close to our vms in terms of ram)
- Each one costs \$0.480 an hour
- 10 $\times$ price $\times$ benchTime, where benchTime is the sum of preprocessing and successfully answered query times.

# Estimated Cost

| Systems | WatDiv1k | Lubm1k |
|---|---|---|
| 4store | \$9.48 | \$16.81 |
| CliqueSquare | \$7.81 | \$14.17 |
| CouchBaseRDF | \$106.29 | \$74.80 |
| CumulusRDF | – | \$1125.15 |
| PigSPARQL | \$36.44 | \$23.55 |
| RDFHive | \$7.72 | \$4.44 |
| RYA | \$29.40 | \$3.98 |
| S2RDF | \$61.17 | \$37.53 |
| SDE | **\$1.60** | **\$0.89** |
| SPARQLGX | \$2.69 | \$5.14 |

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## For a small number of queries...

...SDE seems to be the less expensive.

Section 5

# Conclusion & Perspectives

# Conclusion

**Summary:**

1. Update comparative Cudré-Mauroux *et al.* survey

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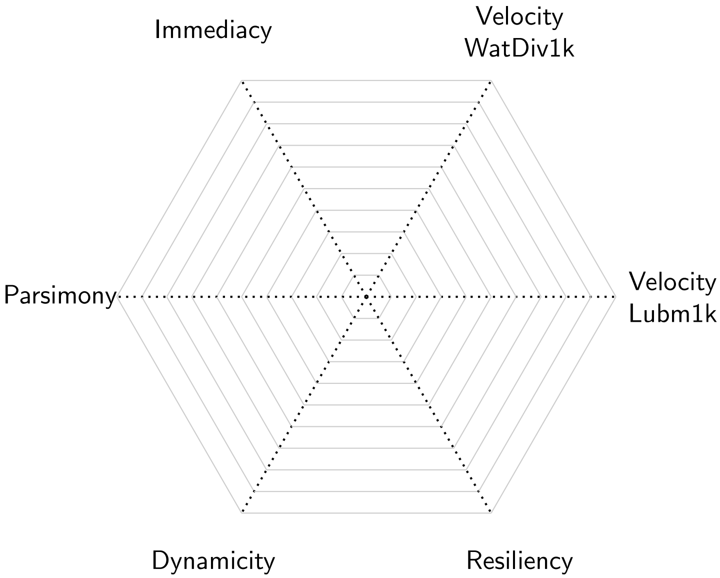
# Conclusion

**Summary:**

1. Update comparative Cudré-Mauroux *et al.* survey
2. Record a larger set of metrics
3. Provide a new reading grid

# Final Kiviat Chart



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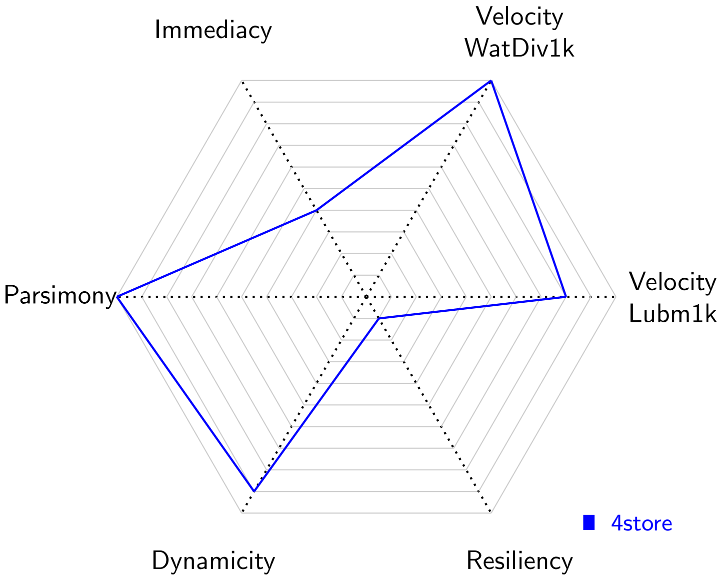

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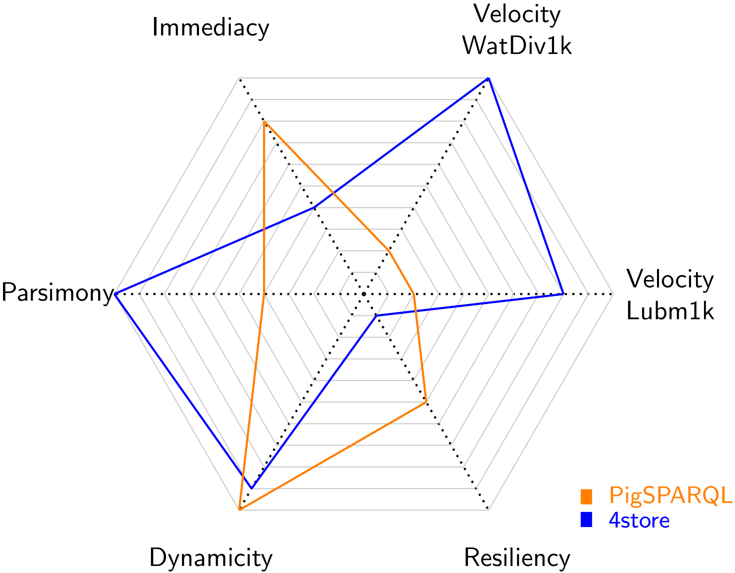

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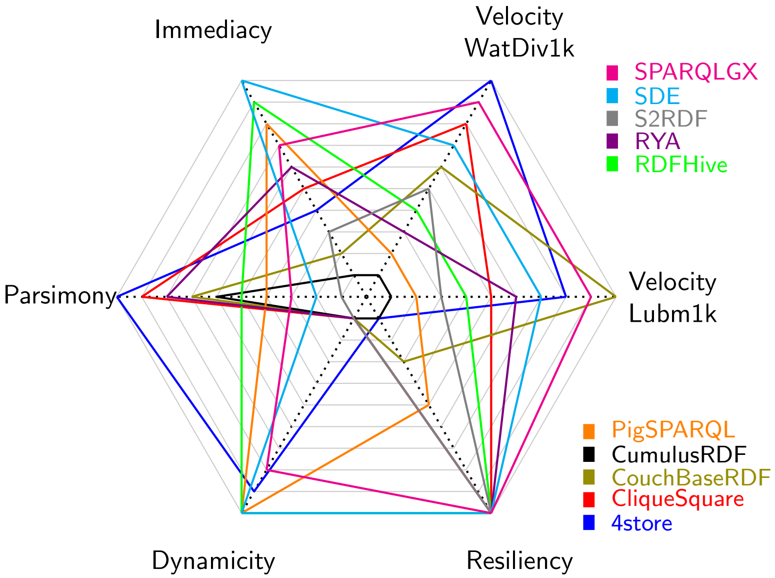

# Perspectives

**Evaluators**

Staying up-to-date in terms of SPARQL evaluators

**Infrastructures**

Testing with other clusters

**Comparison Methods**

Consider new benchmarks

**New criteria**

Extend to other criteria *e.g.* SPARQL covered fragment

Thanks for your attention!

☺

# References

# References


Güneş Aluç, Olaf Hartig, M Tamer Özsu, and Khuzaima Daudjee.
Diversified stress testing of RDF data management systems.
In *ISWC*, pages 197–212. Springer, 2014.

A Barstow.
Survey of rdf/triple data stores.
*World Wide Web Consortium. Retrieved April*, 10:2003, 2001.

Dave Beckett.
Scalability and storage: Survey of free software/open source rdf storage systems.
*Latest version is available at http://www. w3. org/2001/sw/Europe/reports/rdf_ scalable_storage_report*, 2002.

Dave Beckett and Jan Grant.
Mapping semantic web data with RDBMSes.
*W3C Semantic Web Advanced Development for Europe (SWAD-Europe)*, 2003.

Christian Bizer and Andreas Schultz.
The berlin SPARQL benchmark.
*IJSWIS*, 2009.

Philippe Cudré-Mauroux, Iliya Enchev, Sever Fundatureanu, Paul Groth, Albert Haque, Andreas Harth, Felix Leif Keppmann, Daniel Miranker, Juan F Sequeda, and Marcin Wylot.
NoSQL databases for RDF: An empirical evaluation.
*ISWC*, pages 310–325, 2013.

Gianluca Demartini, Iliya Enchev, Marcin Wylot, Joël Gapany, and Philippe Cudré-Mauroux.
Bowlognabench – Benchmarking RDF Analytics.
In *International Symposium on Data-Driven Process Discovery and Analysis*, pages 82–102. Springer, 2011.

David C Faye, Olivier Curé, and Guillaume Blin.
A survey of RDF storage approaches.
*Arima Journal*, 15:11–35, 2012.

W3C SPARQL Working Group et al.
SPARQL 1.1 overview, 2013.
http://www.w3.org/TR/sparql11-overview/.

Yuanbo Guo, Zhengxiang Pan, and Jeff Heflin.
LUBM: A benchmark for OWL knowledge base systems.
*Web Semantics*, 2005.

# References


Patrick Hayes and Brian McBride.
RDF semantics.
*W3C recommendation*, 10, 2004.
www.w3.org/TR/rdf-concepts/.

Zoi Kaoudi and Ioana Manolescu.
RDF in the clouds: a survey.
*The VLDB Journal*, 24(1):67–91, 2015.

Ryan Lee.
Scalability report on triple store applications.
*Massachusetts institute of technology*, 2004.

Aimilia Magkanaraki, Grigoris Karvounarakis, Ta Tuan Anh, Vassilis Christophides, and Dimitris Plexousakis.
Ontology storage and querying.
*Ics-forth Technical Report*, 308, 2002.

Mohamed Morsey, Jens Lehmann, Sören Auer, and Axel-Cyrille Ngonga Ngomo.
DBpedia SPARQL Benchmark – Performance assessment with real queries on real data.
*ISWC*, pages 454–469, 2011.

Shi Qiao and Z Meral Özsoyoğlu.
Rbench: Application-specific RDF benchmarking.
In *SIGMOD*, pages 1825–1838. ACM, 2015.

Florian Stegmaier, Udo Gröbner, Mario Döller, Harald Kosch, and Gero Baese.
Evaluation of current rdf database solutions.
In *Proceedings of the 10th International Workshop on Semantic Multimedia Database Technologies (SeMuDaTe), 4th International Conference on Semantics And Digital Media Technologies (SAMT)*, pages 39–55. Citeseer, 2009.

Michael Schmidt, Thomas Hornung, Georg Lausen, and Christoph Pinkel.
SP$^2$Bench: a SPARQL performance benchmark.
*ICDE*, pages 222–233, 2009.