max planck institut
informatik

# RDF-3X: a RISC-style Engine for RDF

Thomas Neumann Gerhard Weikum

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# Motivation

RDF is increasingly popular...

- Semantic Web
- Life-Sciences
- seems natural for Social-Networks

... but RDF indexing and query processing is non-trivial:

- no schema, very fine grained data items
- workloads hard to predict and characterize
- physical design difficult

Our solution: RDF-3X

- RISC-style execution engine
- exhaustive compressed indexes
- query optimization techniques

# Overview

1. Short Introduction to RDF and SPARQL
2. Storage of RDF data
3. Retrieval for SPARQL queries
4. Evaluation
5. Conclusion

# Short Introduction to RDF and SPARQL

RDF: Resource Description Framework

- conceptually a labeled graph
- each edge represents a fact (triple in RDF notation)
- triples have the form *(subject, predicate, object)*

Examples:

- ($id_1$, <hasTitle>, "Sweeney Todd"),
- ($id_1$, <directedBy>, <Tim_Burton>),
- ($id_1$, <hasCasting>, $id_2$)
- ($id_2$, <Actor>, $id_{11}$)
- ($id_{11}$, <hasName>, "Johnny Depp")

RDF data can be seen as a (potentially huge) set of triples.

# Short Introduction to RDF and SPARQL (2)

## SPARQL: SPARQL Protocol and RDF Query Language

```
SELECT ?title
WHERE  {
   ?m  <hasTitle> ?title;
       <hasCasting> ?c.
   ?c  <Actor> ?a.
   ?a  <hasName> "Johnny Depp"
}
```

- queries RDF data by matching patterns in the graph
- query-by-example style, joins are implicit
- set of triple patterns, shortcuts to avoid typing

Note: must produce all valid bindings (might create duplicates)

# Storage of RDF data

Raw RDF input: triples

| Facts | | |
|---|---|---|
| Subject | Predicate | Object |
| object214 | hasColor | blue |
| object214 | belongsTo | object352 |
| ... | ... | ... |

Literals can be very large, contains a lot of redundancy.

First step to reduce the data: dictionary compression

| Facts | | |
|---|---|---|
| Subject | Predicate | Object |
| 0 | 1 | 2 |
| 0 | 3 | 4 |
| ... | ... | ... |

| Strings | |
|---|---|
| ID | Value |
| 0 | object214 |
| 1 | hasColor |
| ... | ... |

# Storage of RDF data - RDF-3X

Our approach: Store everything in a clustered $B^+$-Tree

- triples sorted in lexicographical order
- can be **compressed** well (delta encoding)
- efficient scan, fast lookup if prefix is known

Which sort order to choose?

- index is compressed, we can afford redundancy
- 6 possible orderings, store all of them
- will make merge joins very convenient

**Observation**: Each SPARQL triple pattern can be answered by a single range scan.

# Storage of RDF data - Aggregated Indices

Sometimes we do not need the full triple:

- is there a connection between $object_4$ and $object_{13}$?
- how many *author* annotations does $object_{14}$ have?

Therefore maintain **aggregated indexes** with $(value_1, value_2, count)$

- *count* is required for SPARQL duplicate semantic
- compressed, too
- much smaller than the full index

We can afford another 6 indexes. And three for $(value_1, count)$.

- smaller index $\Rightarrow$ faster scan
- improves query performance significantly

# Retrieval of RDF data

- each SPARQL triple pattern becomes an index scan
- patterns with common variables induce joins
- indexes for all orderings, which makes merge joins very attractive

**basic strategy**: merge joins if possible, hash joins afterwards

- decision cost based, dynamic programming strategy
- order optimization required to infer orderings

A bit different from standard join ordering, though:

- one big "relation", no schema
- selectivity estimates are hard

# Retrieval of RDF data - Selectivity Estimates

Standard single attribute synopses are not very useful:

- only three attributes
- one big "relation"
- but `(?a,?b,"Auckland")` and `(?a,?b,"1900-01-01")` produce vastly different values for `?a` and `?b`

Instead: Another six indexes

- aggregate indexes until they fit into one page
- merge smallest buckets ($\approx$ equi-depth)
- for each bucket (i.e., triple range) compute statistics
- 6 indexes, pick the best for each triple pattern

# Retrieval of RDF data - Selectivity Estimates (2)

Example: bucket with (subject,predicate,object) statistics

| range | (10,2,30) - (10,5,12000) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| # prefixes of length | 1 | 3 | 3000 |
| | subject | predicate | object |
| # subject joins with | 4000 | 0 | 200 |
| # predicate joins with | 50 | 400000 | 200 |
| # object joins with | 6000 | 0 | 9000 |

Estimations:

- `(10,4,?a)` $\Rightarrow$ 1000 triples
- {`(10,4,?a)`,`(?a,?b,?c)`} $\Rightarrow$ 2000 triples

Assumes uniformity, independence, etc., but works quite well

# Retrieval of RDF data - Selectivity Estimates (3)

Still issues with (common) large correlated join patterns:

- navigation: {(?a,[],?b),(?b,[],?c),(?c,[],?d)} (chain)
- selection: {(?a,[],?b),(?a,[],?c),(?a,[],?d)} (star)

Capture common correlations:

- mine the most frequent paths (chains and stars) and count
- exact prediction for these paths, otherwise upper bound

Not as easily applicable as histograms, but very accurate

# Evaluation

We compare RDF-3X with different competitors:

- MonetDB (column store approach, similar to Abadi et al., VLDB07)
- PostgreSQL (triple store approach, similar to Sesame)
- other approaches performed much worse (see the paper)

Three different data sets:

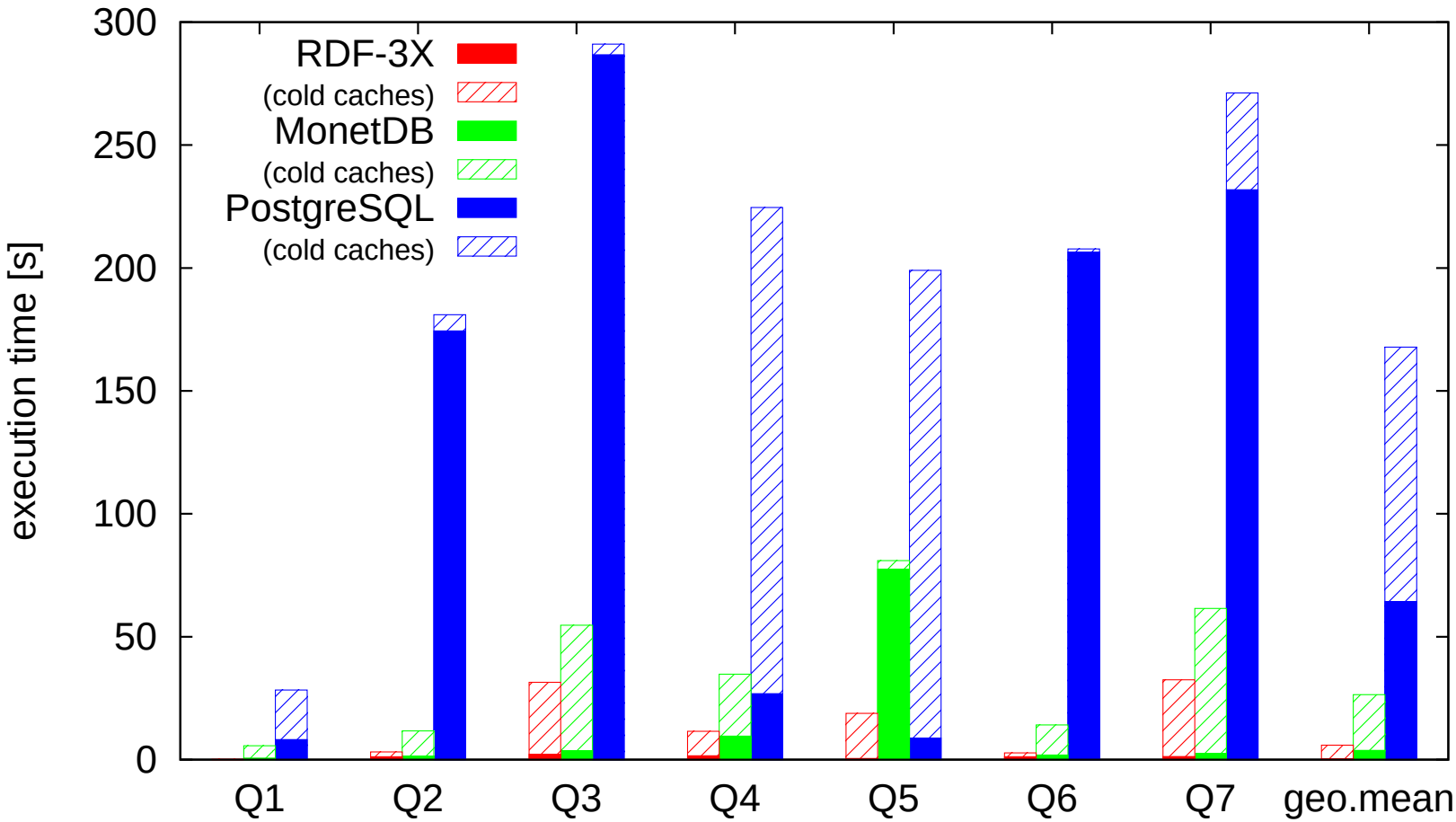
- Barton (same as the VLDB07 paper), library data
- Yago, Wikipedia-based ontology
- LibraryThing (partial crawl), users tag books

Same setup for all competitors:

- all competitors same preprocessing, same dictionary
- equivalent queries (SPARQL for RDF-3X, SQL for others)

# Evaluation - Barton Data Set [VLDB07]

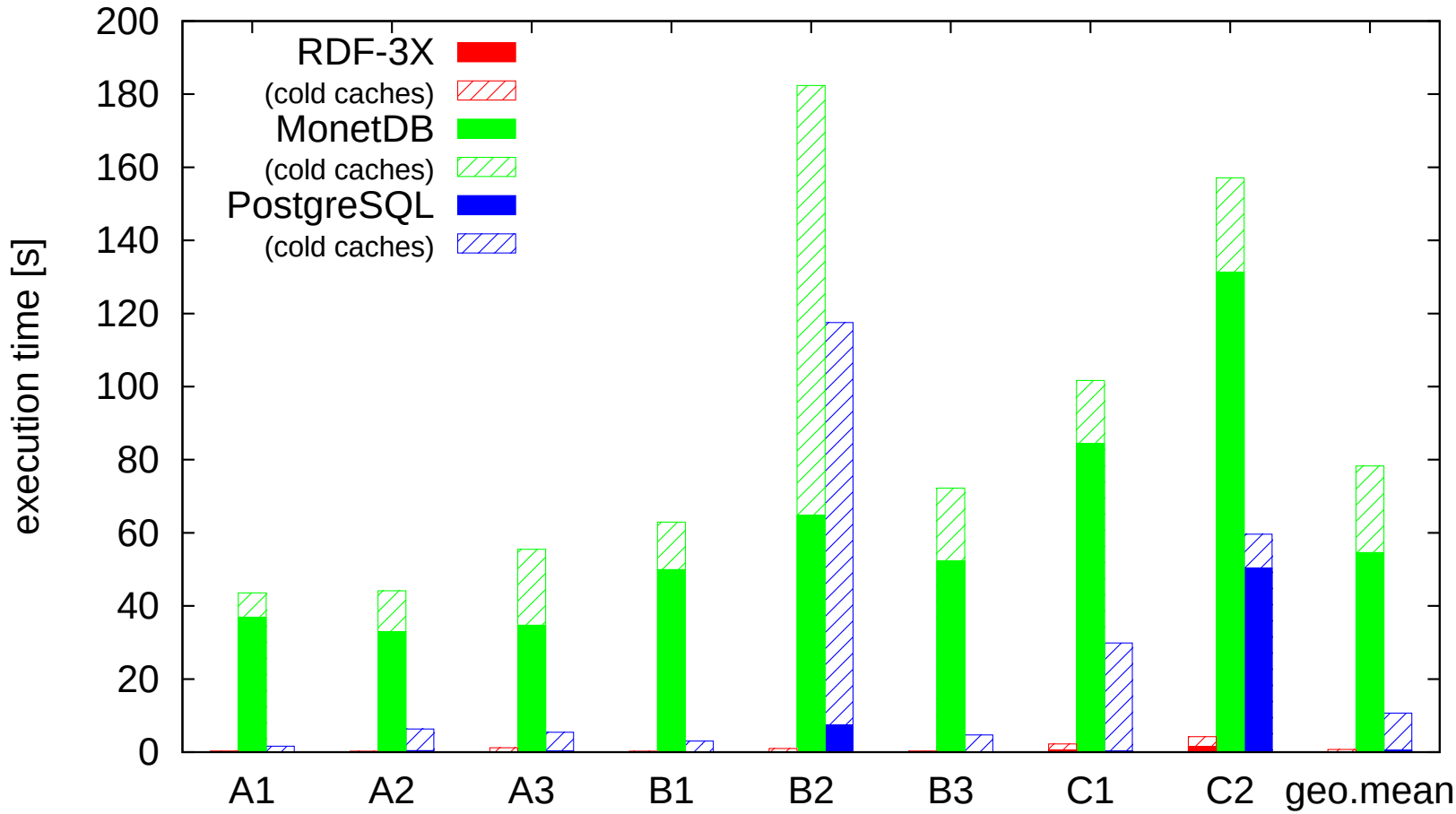
51M triples, 4.1GB original data, 2.8 GB in RDF-3X




sample query (Q5): select ?a ?c where { ?a <origin> <marcorg/DLC>. ?a <records> ?b. ?b <type >?c. filter (?c != <Text>) }

# Evaluation - Yago

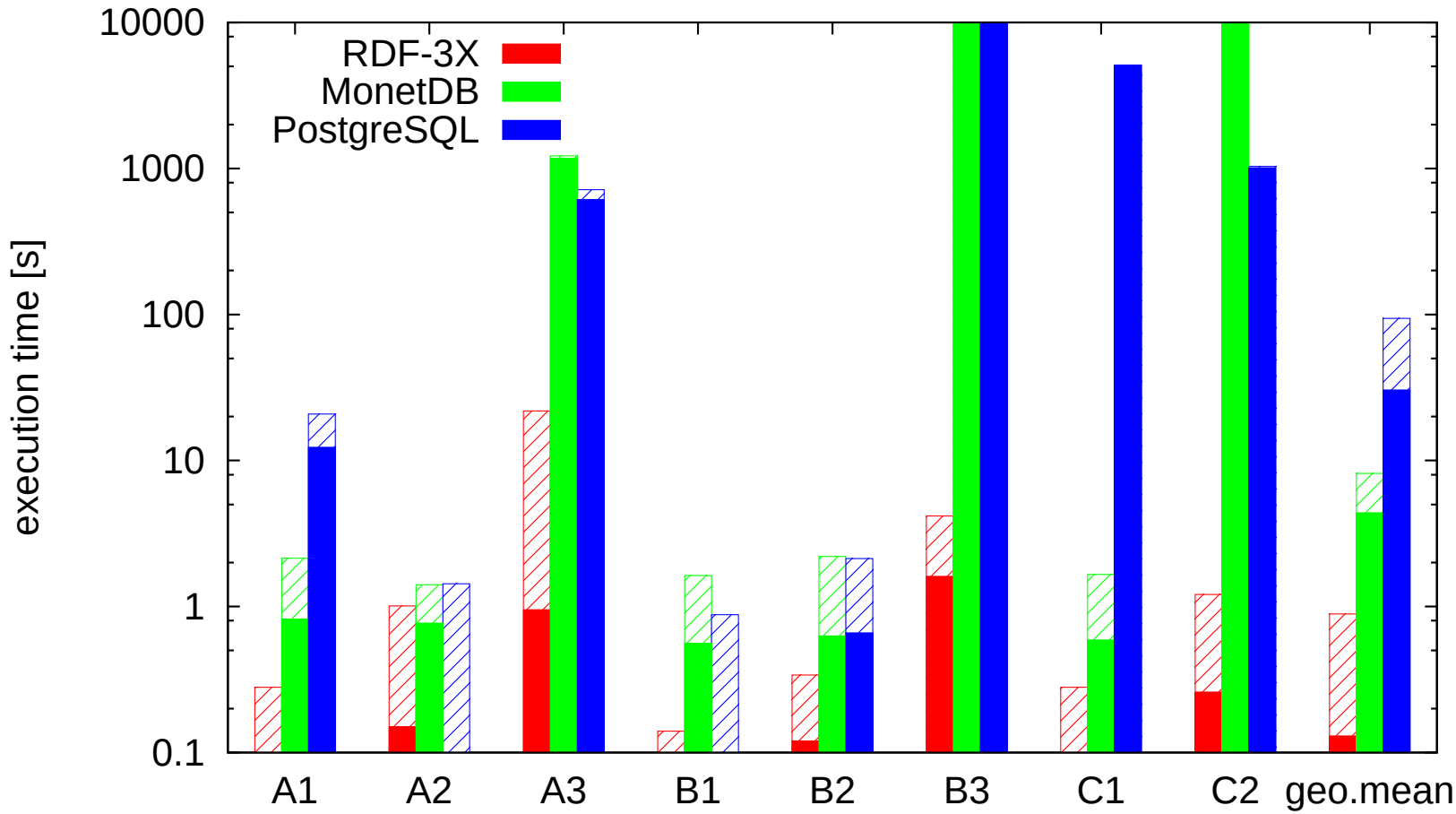
40M triples, 3.1GB original data, 2.7 GB in RDF-3X




sample query (B2): select ?n1 ?n2 where {
?p1 <isCalled> ?n1. ?p1 <bornInLocation> ?city. ?p1 <isMarriedTo> ?p2.
?p2 <isCalled> ?n2. ?p2 <bornInLocation> ?city. }

# Evaluation - LibraryThing

36M triples, 1.8GB original data, 1.6 GB in RDF-3X




sample query (B3): select distinct ?u where { ?u [] ?b1. ?u [] ?b2. ?u [] ?b3. [] <english> ?b1. [] <german> ?b2. [] <french> ?b3. }

# Conclusion

RDF-3X a fast and flexible RDF/SPARQL engine:

- exhaustive but very **space-efficient triple indexes**
- avoids physical design tuning, generic storage
- few assumptions about data and queries
- **fast runtime system**, exploits indexes for merge joins
- **query optimization** has a huge impact
- **accurate selectivity estimations** essential

RDF-3X is freely available, try it out:
`http://www.mpi-inf.mpg.de/~neumann/rdf3x`