Revisiting compact RDF stores based on $k^2$-trees

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RDF and the Web of Data

- Web of Data
  - How to share structured knowledge on the Web?

- Resource Description Framework (RDF)
  - W3C Recommendation
  - Publish structured data
  - Graph-based data model for any kind of resource
RDF and SPARQL

RDF Triple

Subject → Predicate → Object

Resource Property Value

http://mylibrary/author18 foaf:name “W. Shakespeare”
## RDF and SPARQL

### Triple patterns

- $(s, ?p, ?o)$
  - $(http://mylibrary/book1, ?p, ?o)$
- $(s, p, o)$ $(s, p, ?o)$ $(s, ?p, o)$

### SPARQL

```sparql
SELECT ?name
WHERE{
  ?book dc:title "Hamlet".
  ?writer foaf:name ?name .
}
```

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<td><a href="http://mylibrary/author18">http://mylibrary/author18</a></td>
<td>foaf:name</td>
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RDF stores

- Compact representation of the RDF data

- Solutions
  - Relational databases
  - Custom solutions (multi-indexing structures)
  - Compact data structures: RDFCSA, $k^2$-triples

- Ability to answer SPARQL queries
  - Key element: triple patterns
The $k^2$-tree

\[ T = 11101101101001001000110100101001001010101100 \]
\[ L = 0011001100100010000100100100001010000101010 \]
The $k^2$-tree

$$T = 1110110110100100011010010101001010101100$$

$$L = 00110011001000100001001001000010100000101010$$

$$\text{Children}(p) = \text{rank}_1(T,p) \cdot k^2$$

$$L = 00110011001000100001001001000010100000101010$$
**k²-triples**

- **Vertical partitioning**
  - Generate a $k^2$-tree per predicate
  - Triple patterns are translated into cell/row/column/range queries
    - $(s,p,?) \rightarrow$ Find the ones in row $s$ in the $k^2$-tree for predicate $p$

- **k²-triples compression** overcomes other RDF stores

- **Performance suffers in some queries**

- **k²-triples+**
  - Vertical partitioning inefficient with a large number of predicates
  - Additional S-P and O-P indexes to speed up queries
Use $k^2$-trees to achieve good compression of the data

- Simple and efficient compression
- Queries should be translated into $k^2$-tree operations

Abandon vertical partitioning idea

- Look for other tradeoff opportunities
- Make the structure independent of the number of predicates
- Improve performance in queries with unbound predicate
BMatrix: dictionary encoding

(DCC20, held on, S. Lake City)
(S. Lake City, capital of, Utah)
(DCC20, has topic, Text comp.)
(DCC20, has topic, Video cod.)
(G. Navarro, attends, DCC20)
(G. Navarro, lives in, Chile)
(G. Navarro, expert in, Text comp.)
(T.Gagie, attends, DCC20)
(T.Gagie, lives in, Canada)
(T. Gagie, expert in, Text comp.)
(A. Bovik, attends, DCC20)
(A. Bovik, lives in, US)
(G. Sullivan, attends, DCC20)
(G. Sullivan, lives in, US)
BMatrix: data structure

- Sort triples in P-O-S order
  - Any P-based order can be applied

- Data structures:
  - ST: subject-triple matrix
  - OT: object-triple matrix
  - BP: bitmap marking predicate changes

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(4,6,4) (4,3,5)
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BMatrix: data structure

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**BP**

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**K^2-trees**

**Bitmap (rank/select)**
Find range of triples for p=3
Row query (row 4) in ST
  Limited to range of triples
    T6 = (4,3,?)
Check cell in (5,6) OT
    T6 = (4,3,5)
BMatrix: triple patterns

- (4,?p,?o)
  - Row query in ST
    - T2, T6, T12
  - For each result, column query in OT
    - T2: (4,?,1)
    - T6: (4,?,5)
    - T12: (4,?,4)
  - Find predicates in BP
    - rank₁(BP, p)
BMatrix: optimizations

- **Space improvements:**
  - Matrices have a single 1 per column
  - Custom compression of $k^2$-tree lower levels

- **Time improvements**
  - Optimized column queries
  - Custom solution for BP

- **Several alternatives for some queries**
  - Chained evaluation vs Query-and-merge
    
    $(s,?p,o)$
Experimental evaluation

- DBPedia dataset (v3.5.1)
  - 232 million triples
  - 40k predicates

- Baselines:
  - $k^2$-triples and $k^2$-triples+
    - Same configuration in K2-trees in both approaches
    - Custom compression of lower levels in our solution
  - RDFCSA
Experimental evaluation

- Bound predicate queries
  - BMatrix smallest solution
  - Performance varies:
    - Comparable in more complex patterns
    - Slower in simpler patterns
Experimental evaluation

- Unbound predicate queries
  - BMATRIX comparable to $k^2$-triples+ using 40% less space
  - $k^2$-triples very inefficient in most patterns
Conclusions

- New representation for RDF data
  - Designed for complex datasets → many predicates
  - Improves compression results of existing solutions

- Key features
  - Query times are relatively stable for all triple pattern queries
  - Space/time trade-off. Results depend on type of queries

- Future work
  - Support for joins and performance
  - Search for application-specific arrangements and tradeoffs
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