Matrix “Bit” loaded: A Scalable Lightweight Join Query Processor for RDF Data

Hot Topics in Information Retrieval

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Outline

1. Introduction
2. BitMat method overview
3. BitMat construction
4. Join processing algorithm
5. Evaluation
6. Conclusions and further work

Introduction

- RDF (Resource Description Framework) for representing any information

Subject	Predicate	Object
:the_matrix	:releasedIn	"1999"
:the_thirteenth_floor	:releasedIn	"1999"
:the_matrix	:similar_to	:the_matrix_reloaded
:the_thirteenth_floor	:similar_to	:the_matrix
:the_matrix	rdf:type	:movie
:the_thirteenth_floor	rdf:type	:movie

Introduction - SPARQL

SPARQL join query	**Equivalent SQL join query**

SELECT *
 	
 WHERE {
 B - ?m rdf:type :movie
 C - ?n rdf:type :movie
 A - ?m :similar_to ?n
 }
	SELECT * FROM
	 tripletable AS A, tripletable AS B,
	 tripletable AS C
	 WHERE A.subject = B. subject
	 AND A.object = C. subject
	 AND A.predicate = ":similar_to"
	 AND B.predicate = "rdf:type"
	 AND C.object = ":movie"
	 AND B.object = ":movie"
	 AND C. predicate = "rdf:type"

Introduction

- Database systems used for querying and storage of RDF data:

  RDF-3X

  - generic solution for storing and indexing RDF triples
  - query processor that leverages fast merge joins
  - a query optimizer for choosing optimal join orders using a cost model based on statistical synopses for entire join path

Introduction

- MonetDB
  - storage model based on vertical fragmentation
  - a modern CPU-tuned query execution architecture
  - automatic and self-tuning indexes
- Jena-TDB
- Hexastore

Introduction

Join queries classification:

1. Highly selective triple patterns

(?s :residesInUSA)(?s :hasSSN "123-56-6789")

2. Low-selectivity triple patterns, but highly selective join results

(?s :residesIn India)(?s :worksFor BigOrg)

3. Low-selectivity triple patterns and low-selectivity join results

(?s :residesIn USA)(?s :hasSSN ?y)

Introduction

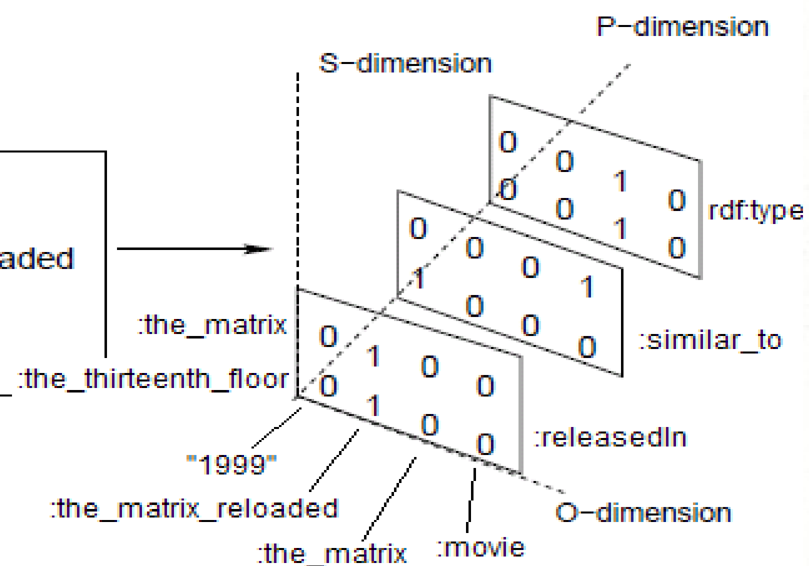
BitMat method overview

- compressed bit-matrix structure for storing huge RDF graphs
- novel, lightweight, SPARQL query processing method
- no intermediate join tables
- works directly on compressed data

BitMat Construction

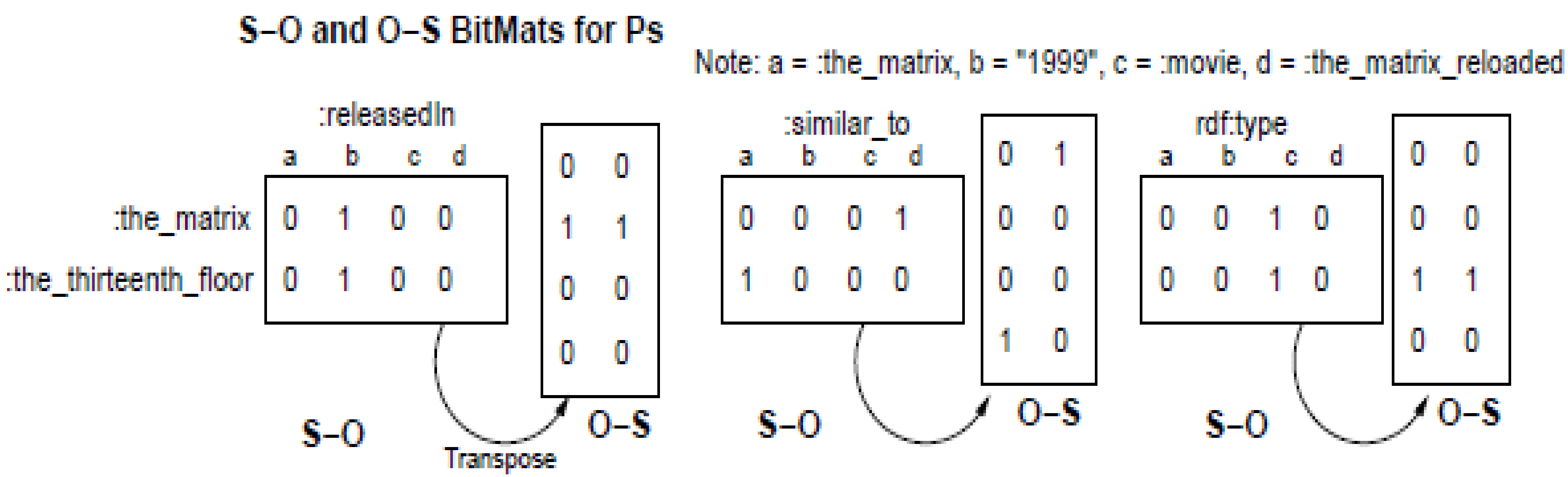
- V_S, V_P and V_O denote sets of distinct subjects, predicates and objects in the RDF data
- 3D bit cube with volume V_S x V_P x V_O

Subject	Predicate	Object
:the_matrix	:releasedIn	"1999"
:the_thirteenth_floor	:releasedIn	"1999"
:the_matrix	:similar_to	:the_matrix_reloaded
:the_thirteenth_floor	:similar_to	:the_matrix
:the_matrix	rdf:type	:movie
:the_thirteenth_floor	rdf:type	:movie



BitMatConstruction

- 3D bit-cube sliced along P-dimension to get 2D matrices
- Inverting an S-O BitMat gives an O-S BitMat
- S-O and O-S BitMats stored for each P value



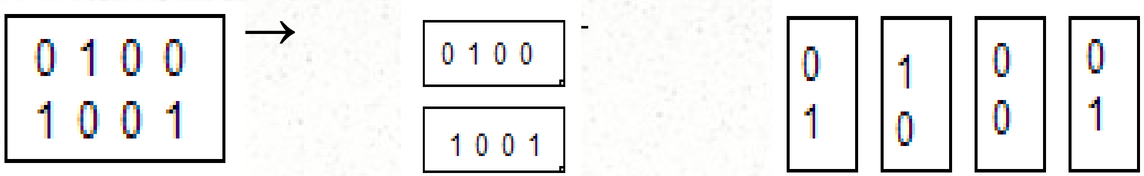
BitMat Construction

- $|V_S|$ x $|V_P|$ x $|V_O|$ possible triples
- RDF data contains much fewer number of triples

→ gap compression scheme

Example: 0011000 → [0] 2 2 3

- Store the number of triples in each compressed BitMat
- Store two bitarrays – row and column bitarray



- Store the compressed S-O, O-S, P-S, P-O BitMats

BitMat Operations

Fold

- *'fold(BitMat, retainDimension) returns bitArray'*
- *RetainDimension* can take the values “rows” or “columns”
- Folds the input BitMat by retaining the *retainDimension*
- Example:

0 0 0 1 OR
1 0 0 0
----
1 0 0 1

BitMat Operations

Unfold

- *'unfold(BitMat, MaskBitArray, RetainDimension)'*
- Unfolds the *MaskBitArray* on the BitMat
- Example: *unfold(BitMat, '011000', 'columns')*

```
0 1 0 1 0 0  AND          [0] 1 1 1 1 2 AND
0 1 1 0 0 0               [0] 1 2 3
---------------------------   -----------------------------
0 1 0 0 0 0               [0] 1 1 4
```

Join Processing Algorithm - Properties

Property 1

?x	p1	?n	p2	?y
x1		n1 n1		y1
x2		~~n4~~ ~~n5~~		y2
x3		n7 n7		y3

Property 2

?x	p	?y
x1		y1
x2		y2
x3		y3
x4		y4

?x	p	?y
x1		y1
x2		y2
~~x3~~		y3
x4		y4

→

?x	p	?y
x1		y1
x2		y2
~~x3~~		~~y3~~
x4		y4

Join Processing Algorithm - Properties

Property 3

?x	p1	?n
x1	p1	n1
x2	p1	n4
x3	p1	n7

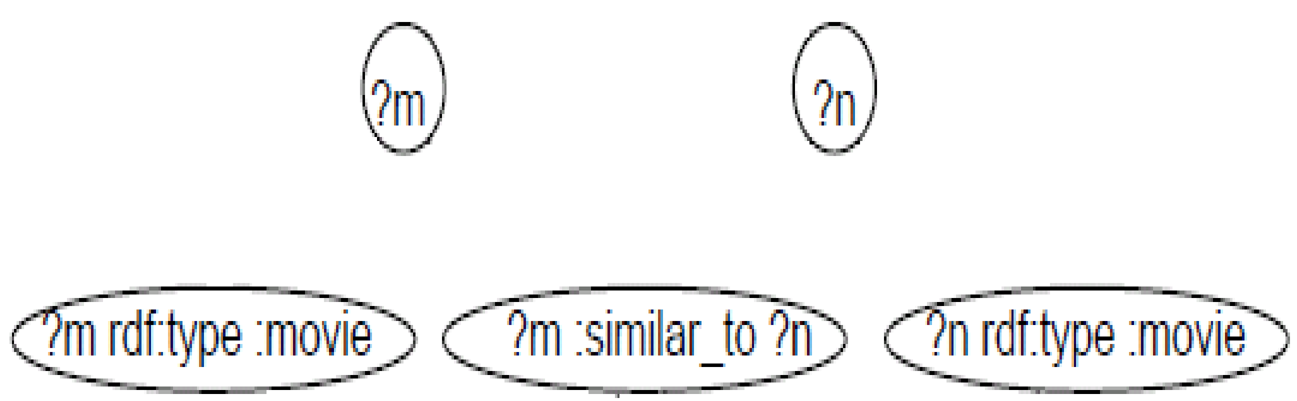
?n	p2	?y
n1	p2	y1
n5	p2	y2
n7	p2	y3

?x	p1	?n	p2	?y
x1		n1 n1		y1
~~x2~~		~~n4~~ ~~n5~~		~~y2~~
x3		n7 n7		y3

Constructing the Constraint Graph G

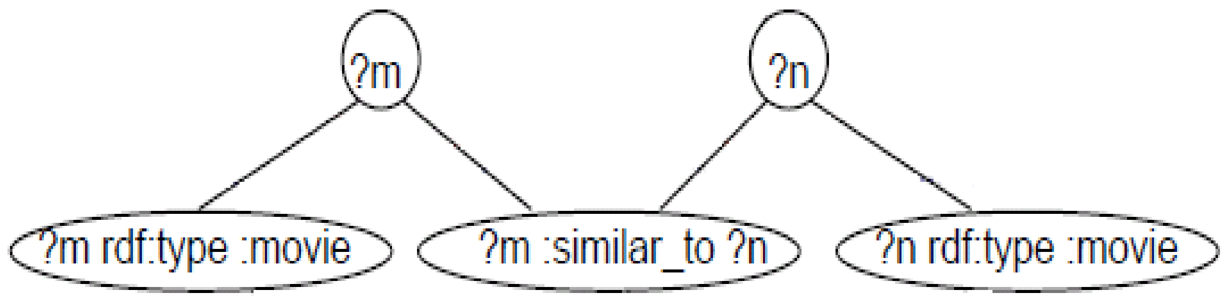
triple pattern = tp-node

join variable = jvar-node



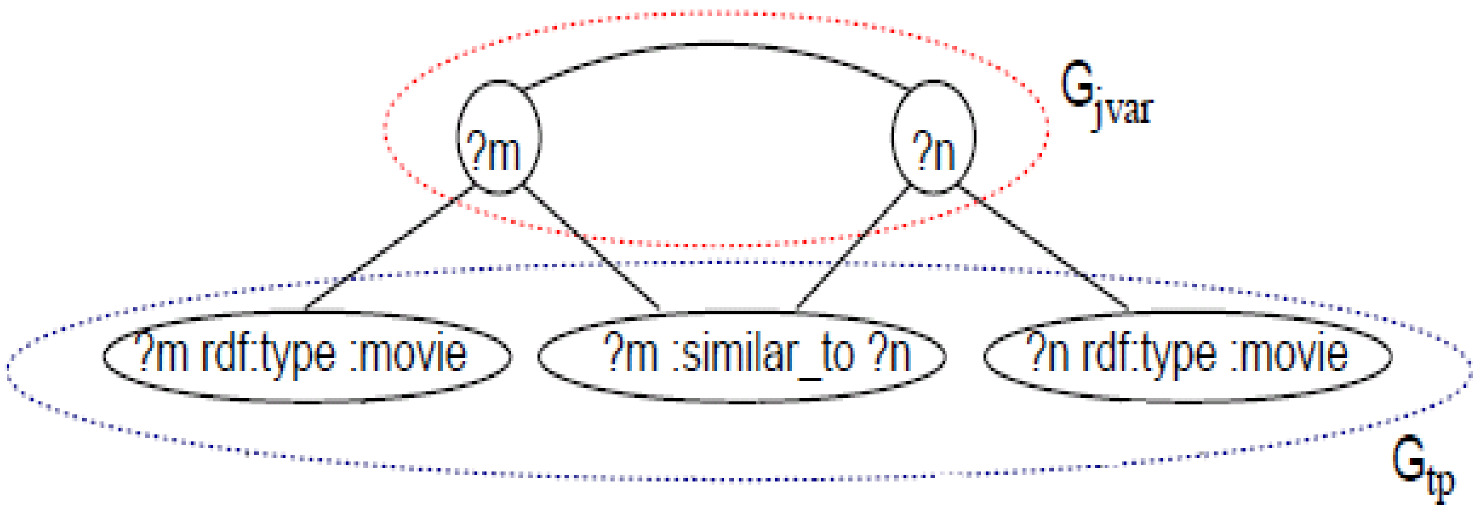
Constructing the Constraint Graph G

- undirected, unlabeled edge between a jvar-node and a tp-node



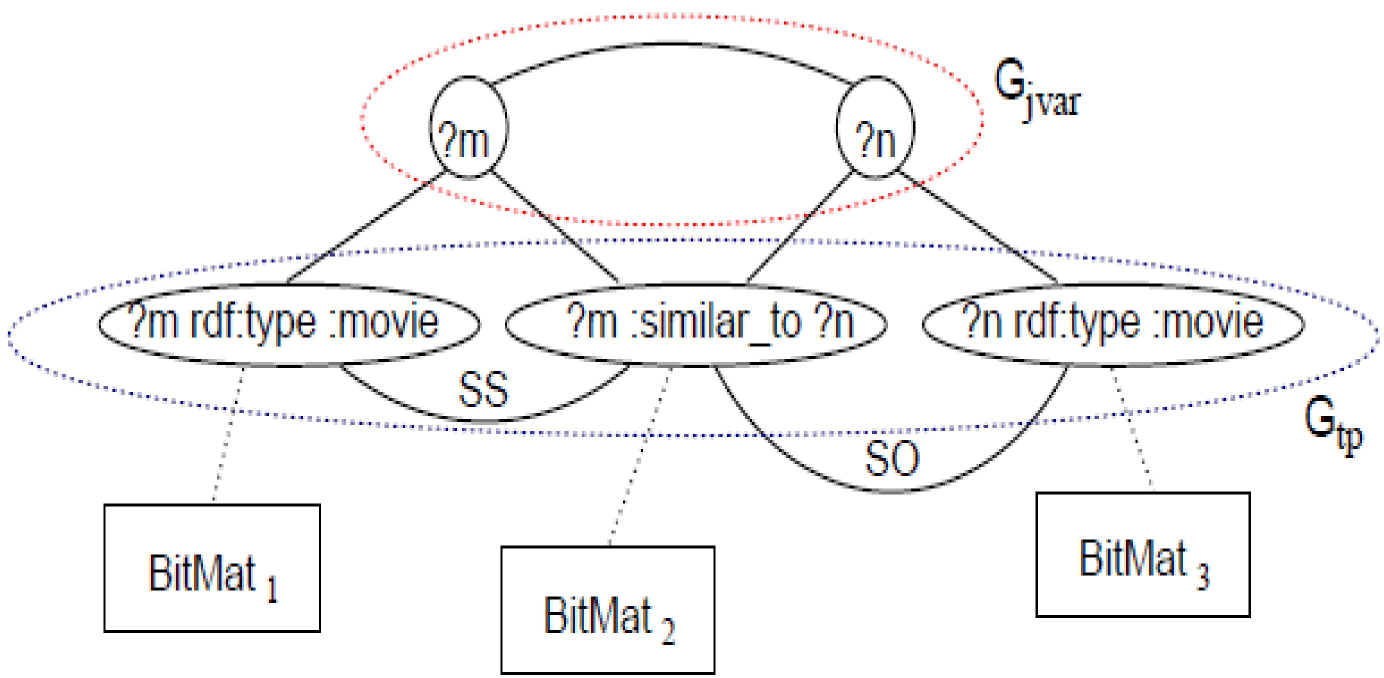
Constructing the Constraint Graph G

- Edge between two jvar-nodes



Constructing the Constraint Graph G

- Edge between two tp-nodes



Join Processing Algorithm – Step 1

Preparation for the pruning algorithm

- Initialize each tp-node by loading the triples which match that triple pattern
- Construct the 4 BitMats S-O, O-S, P-S, P-O

The pruning algorithm

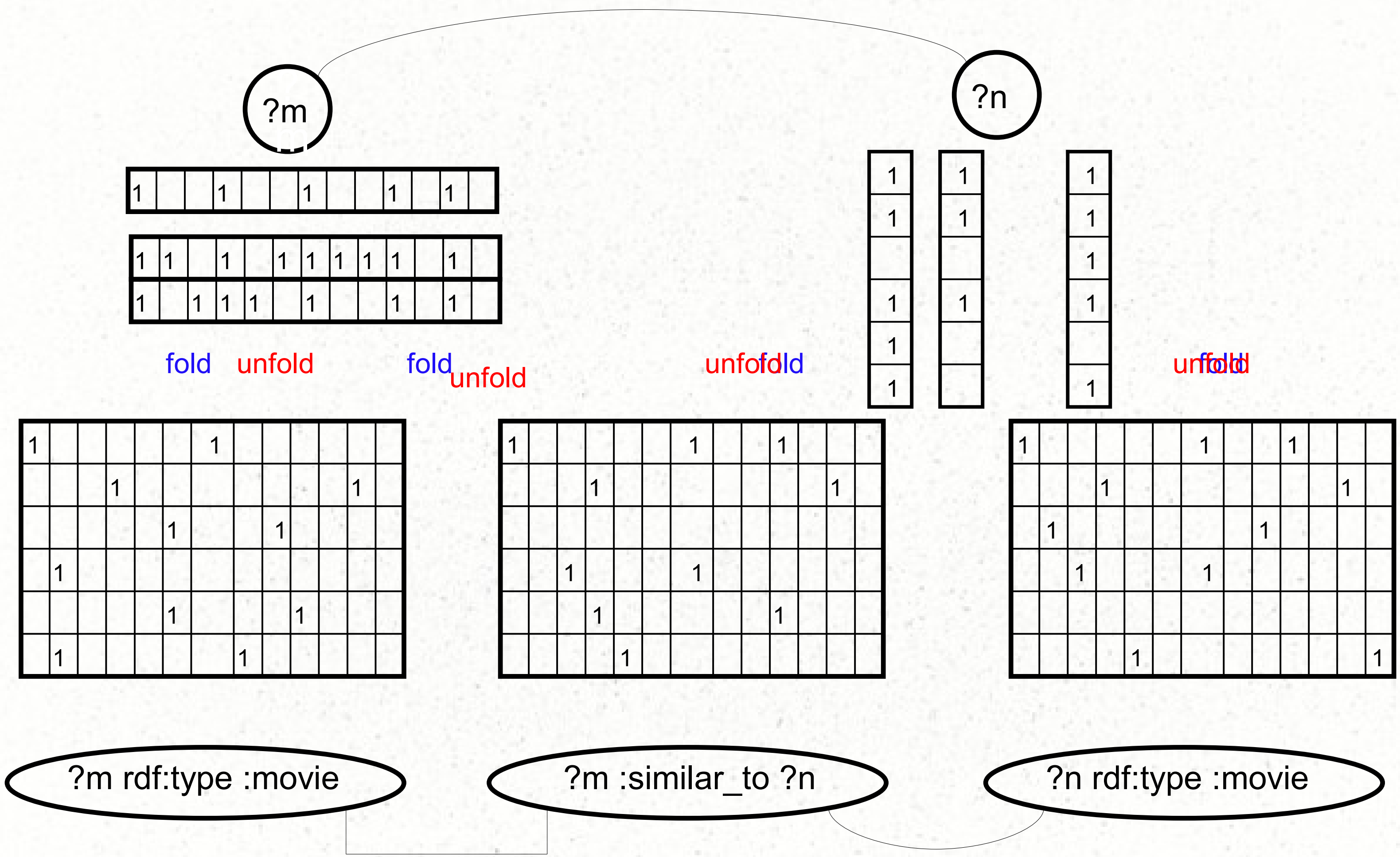
- G_{jvar} contains only jvar-nodes
- Embed a tree on G_{jvar} discarding cyclic edges

Join Processing Algorithm – Step 1

The pruning algorithm (continued)

- Walk the tree from root to the leaves and backwards in a "breadth first search manner"
- At every jvar-node take the intersection of bindings generated by its adjacent tp-nodes
- After the intersection, drop the triples from tp-node BitMats as a result of dropped bindings

Pruning phase



Join Processing Algorithm – Step 1

Algorithm 1 Pruning Step

queue q = topological_sort($V(\mathcal{G}_{jvar})$)
for each J in q **do**
    prune_for_jvar(J)
end for
queue q_rev = q.reverse() - leaves($\mathcal{G}_{jvar}$)
for each K in q_rev **do**
    prune_for_jvar(K)
end for

Algorithm 2 prune_for_jvar(jvar-node J)

$MaskBitArr_J$ = a bit-array containing all 1 bits.
for each tp-node $\mathcal{T}$ adjacent to J **do**
    dim = getDimension(J, $\mathcal{T}$)
    $MaskBitArr_J = MaskBitArr_J$ AND fold($BitMat_{\mathcal{T}}$, dim)
end for
for each tp-node $\mathcal{T}$ adjacent to J **do**
    dim = getDimension(J, $\mathcal{T}$)
    unfold($BitMat_{\mathcal{T}}$, $MaskBitArr_J$, dim)
end for

Join Processing Algorithm – Step 2

- Start with the triple pattern with least number of triples left in its BitMat
- Generate bindings for variables in that triple pattern
- select another triple pattern which shares a join variable with any of the previously selected triple patterns
- Check if it can generate the same bindings for the shared join variable and generate bindings for its other variables
- Continue this and at the end of one round when all triple patterns are processed and all variables have consistent bindings, output the result

Evaluation

Choice of competitive RDF stores

- Considered stores: Hexastore, Jena-TDB, RDF-3X and MonetDB
- Chose RDF-3X and MonetDB because

  → can load a large amount of RDF data

  → gave better performance than others

  → are open-source systems, which can be used by the research community

Evaluation

During the evaluation the following parameters were measured:

1. query execution times (cold and warm cache)
2. initial number of triples
3. the number of results

Cache = A cache in general is a fast temporary store that speeds up access to a (larger) slower store.

Cold Cache = data that isn't in the CPU cache

Warm Cache = data that is in cache

Evaluation

- A UniProt dataset was used in 845,074,885 triples, 147,524,984 subjects, 95 predicates, and 128,321,926 objects

- Another dataset which was generated using LUMB was used, which gave 1,335,081,176 unique triples with 217,206,845 subjects, 18 predicates and 161,413,042 objects

Evaluation

Table 1: Evaluation – UniProt 845 million triples (time in seconds, best times are boldfaced)

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Cold cache								
BitMat	**451.365**	**269.526**	173.324	9.396	78.35	1.34	9.33	13.06
MonetDB	548.21	303.2134	**124.3563**	9.63	97.28	11.28	9.91	15.93
RDF-3X	Aborted	525.105	244.58	**1.38**	**4.636**	**0.902**	**0.892**	**1.353**
Warm cache								
BitMat	**440.868**	**263.071**	168.6735	8.305	77.442	0.448	8.36	10.87
MonetDB	495.64	267.532	**113.818**	0.584	96.02	0.822	0.861	0.362
RDF-3X	Aborted	487.1815	226.050	**0.077**	**1.008**	**0.0064**	**0.003**	**0.0299**
#Results	160,198,689	90,981,843	50,192,929	0	179,316	0	0	19
#Initial triples	92,965,468	73,618,481	78,840,372	16,626,073	60,260,006	15,408,126	16,625,901	53,677,336

Evaluation

Table 2: Evaluation – UniProt 845 million triples (time in seconds, best times are boldfaced)

	Q9	Q10	Q11	Q12	Q13	Geom. Mean	Geom. Mean* (without Q1)
Cold cache							
BitMat	11.43	10.49	15.56	26.98	17.37	**25.775**	20.304
MonetDB	21.37	21.39	12.33	**2.468**	12.884	27.891	21.761
RDF-3X	**1.718**	**1.549**	**3.268**	2.804	**1.765**	N/A	**4.268**
Warm cache							
BitMat	9.78	8.69	14.13	25.19	15.77	21.754	16.929
MonetDB	0.611	0.563	0.71	0.744	1.02	**3.845**	2.565
RDF-3X	**0.047**	**0.0469**	**0.547**	**0.295**	**0.0486**	N/A	**0.255**
#Results	2	28	8893	2495	9		
#Initial triples	19,312,584	20,594,986	20,951,969	38,141,013	38,064,279		

Evaluation

Queries where BitMat performed better: Q1, Q2

Queries where results were comparable to other systems: Q3, Q6

Queries where BitMat performed worse than other systems: Q4, Q5, Q7, Q8, Q9, Q10, Q11, Q12, Q13

Conclusions and Further Work

- A novel method of processing RDF join queries was introduced, which:

  → works with compressed data

  → doesn't build intermediate join tables

  → produces the final results in a streaming fashion

Conclusions and Further Work

- RDF-3X and MonetDB gave better results in highly selective queries
- BitMat had a better performance on low-selectivity queries

→ develop a hybrid system having BitMat's query processing algorithm and the conventional query processor

→ the optimal method would be chosen based on heuristics and selectivity of the triple patterns in the query

Questions

- Would it actually be feasible to create a hybrid system? Would the structures be compatible in order to be able to implement such a system?
- There have been made improvements to the RDF-3X system. What would the performance comparison look like with the new version for RDF-3X?
- To what extent is BitMat usable for queries of type (?x ?y ?z), as it is not possible to load a BitMat for all-variable tp-node containing the entire data set in memory?