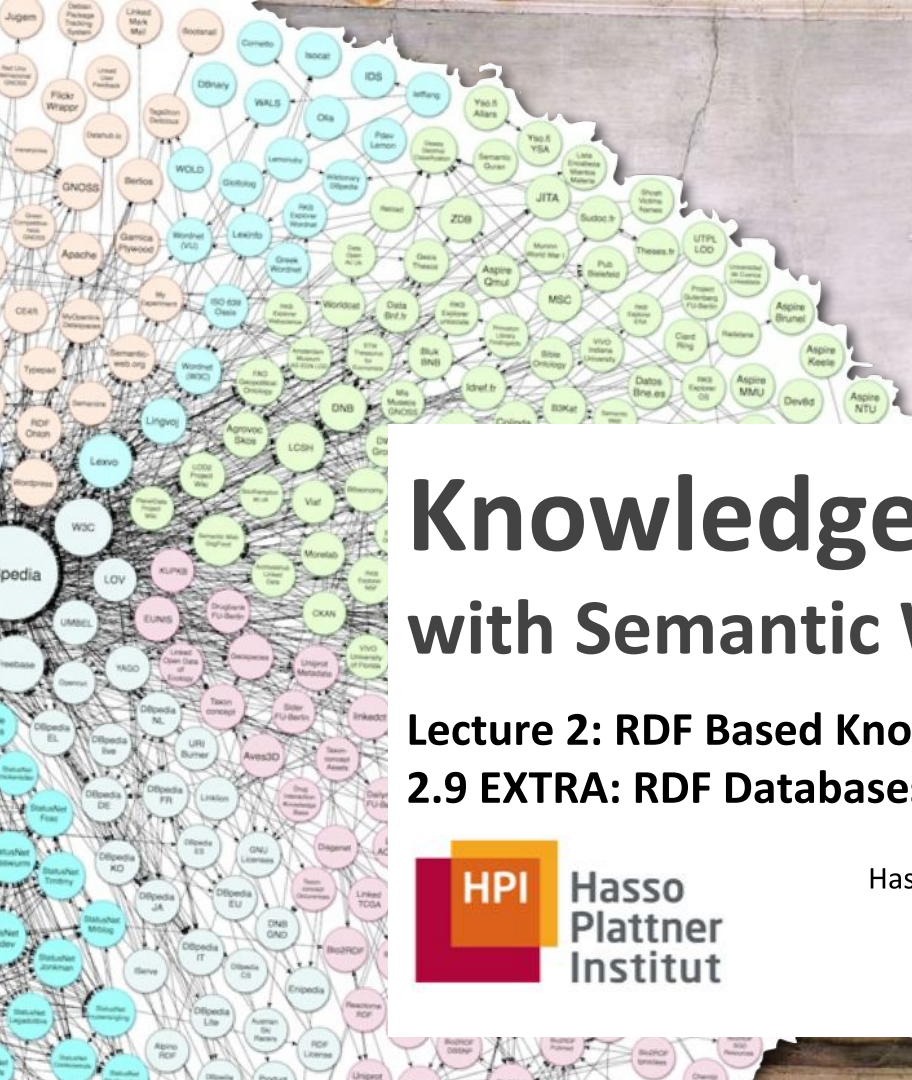


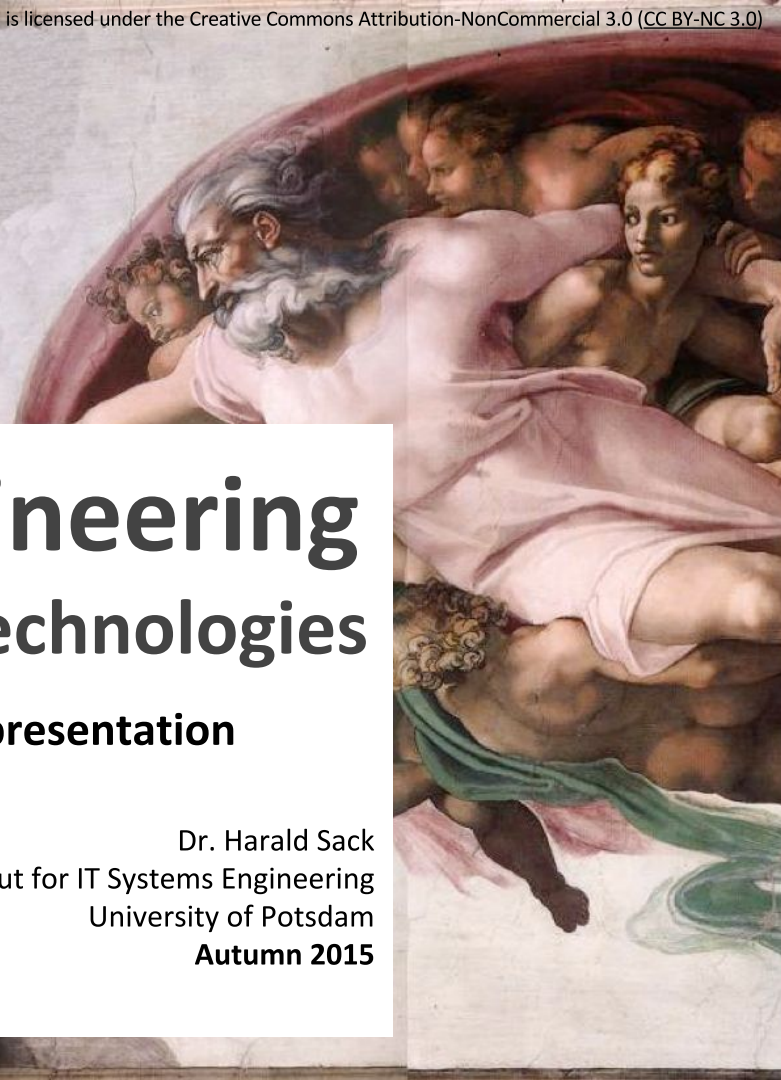


Knowledge Engineering with Semantic Web Technologies

Lecture 2: RDF Based Knowledge Representation 2.9 EXTRA: RDF Databases



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How to Store RDF Data?

RDF in RDBMS

- RDF Graph can be represented by a set of Triples (s,p,o)
- Triples can simply be stored in a **relational database management system** (RDBMS)
- **Motivation:** Use a specific relational schema for RDF data and benefit from 40 years of research in the DB community
- **3 steps for SPARQL query processing:**
 - (1) Convert SPARQL query to SQL query (w.r.t. the schema)
 - (2) Use RDBMS to answer SQL query
 - (3) Generate SPARQL query result from SQL query result

RDF in RDBMS - The Problem

- How to store RDF triples to carry out efficient SPARQL queries?
- 4 alternatives:
 - (1) Monolithic Triple Storage
 - (2) Property Tables
 - (3) Vertically Partitioned Tables (Binary Tables)
 - (4) Hexastore

Monolithic Triple Storage

Subj	Property	Obj
ID1	type	FullProfessor
ID1	teacherOf	'AI'
ID1	bachelorFrom	'MIT'
ID1	mastersFrom	'Cambridge'
ID1	phdFrom	'Yale'
ID2	type	AssocProfessor
ID2	worksFor	'MIT'
ID2	teacherOf	'DataBases'
ID2	bachelorsFrom	'Yale'
ID2	phdFrom	'Stanford'
ID3	type	GradStudent
ID3	advisor	ID2
ID3	teachingAssist	'AI'
ID3	bachelorsFrom	'Stanford'
ID3	mastersFrom	'Princeton'
ID4	type	GradStudent
ID4	advisor	ID1
ID4	takesCourse	'DataBases'
ID4	bachelorsFrom	'Columbia'

- Basic Idea
 - Store all RDF Triples in a single table
 - performance depends on efficient indexing
- Pros:
 - easy to implement
 - works for huge number of properties, if indexes are chosen with care
- Cons:
 - many self joins necessary

Monolithic Triple Storage

Subj	Property	Obj
ID1	type	FullProfessor
ID1	teacherOf	'AI'
ID1	bachelorFrom	'MIT'
ID1	mastersFrom	'Cambridge'
ID1	phdFrom	'Yale'
ID2	type	AssocProfessor
ID2	worksFor	'MIT'
ID2	teacherOf	'DataBases'
ID2	bachelorsFrom	'Yale'
ID2	phdFrom	'Stanford'
ID3	type	GradStudent
ID3	advisor	ID2
ID3	teachingAssist	'AI'
ID3	bachelorsFrom	'Stanford'
ID3	mastersFrom	'Princeton'
ID4	type	GradStudent
ID4	advisor	ID1
ID4	takesCourse	'DataBases'
ID4	bachelorsFrom	'Columbia'

- Basic Idea

- Store all RDF Triples in a single table
- performance depends on efficient indexing

```
SELECT ?university WHERE {
    ?v rdf:type :GradStudent;
    :bachelorsFrom ?university . }
```

SPARQL

```
SELECT t2.o AS university
FROM triples AS t1, triples AS t2
WHERE t1.p='type' AND
      t1.o='GradStudent' AND
      t2.p='bachelorsFrom' AND
      t1.s=t2.s
```

SQL

ID Based Triple Storage

RDF Term	ID
:ID1	1
rdf:type	2
:FullProfessor	3
:teacherOf	4
"AI"	5
:bachelorsFrom	6
"MIT"	7
:mastersFrom	8
"Cambridge"	9

S	P	O
1	2	3
1	4	5
1	6	7
1	8	9
1	10	11
12	13	14
12	15	7
12	4	16

- **Resource table** for indexing URIs and Literals with numerical identifier
- **RDF Triple table** uses numerical identifier for each RDF term in the dataset
- saves space and enhances efficiency

Quad Tables

RDF Term	ID
:ID1	1
rdf:type	2
:FullProfessor	3
:teacherOf	4
“AI”	5
:bachelorsFrom	6
“MIT”	7
:mastersFrom	8
“Cambridge”	9

g	S	P	O
100	1	2	3
100	1	4	5
101	1	6	7
100	1	8	9
102	1	10	11
100	12	13	14
102	12	15	7
101	12	4	16

- Storing multiple RDF graphs
- used for provenance, versioning, contexts, etc.

Property Tables

ID	type	teacherOf	bachelorsFrom	mastersFrom	phdFrom	worksFor
ID1	FullProfessor	"AI"	"MIT"	"Cambridge"	"Yale"	NULL
ID2	AssocProfessor	"DataBases"	"Yale"	NULL	"Stanford"	"MIT"

Professors

ID	type	advisor	bachelorsFrom	mastersFrom	teachingAssist	takesCourse
ID3	GradStudent	ID2	"Stanford"	"Priceton"	"AI"	NULL
ID4	GradStudent	ID1	"Columbia"	NULL	NULL	"DataBases"

Students

- Combine all (or some) properties of similar subjects in n-ary tables
- Use ID based encoding for efficiency
 - **Pros:**
 - Fewer joins
 - If the data is structured, its a relational DB
 - **Cons:**
 - Potentially many NULLs
 - Clustering is not trivial
 - Multi-valued properties are complicated

Vertically Partitioned Tables

type	
ID1	FullProfessor
ID2	AssocProfessor
ID3	GradStudent
ID4	GradStudent

teacherOf	
ID1	'AI'
ID2	'DataBases'

bachelorsFrom	
ID1	'MIT'
ID2	'Yale'
ID3	'Stanford'
ID4	'Columbia'

mastersFrom	
ID1	'Cambridge'
ID3	'Princeton'

phdFrom	
ID1	'Yale'
ID2	'Stanford'

worksFor	
ID2	'MIT'

advisor	
ID3	ID2
ID4	ID1

bachelorsFrom	
ID1	'MIT'
ID2	'Yale'
ID3	'Stanford'
ID4	'Columbia'

teachingAssist	
ID3	'AI'

takesCourse	
ID4	'DataBases'

- for each unique property create a two column table
- Use ID based encoding for efficiency

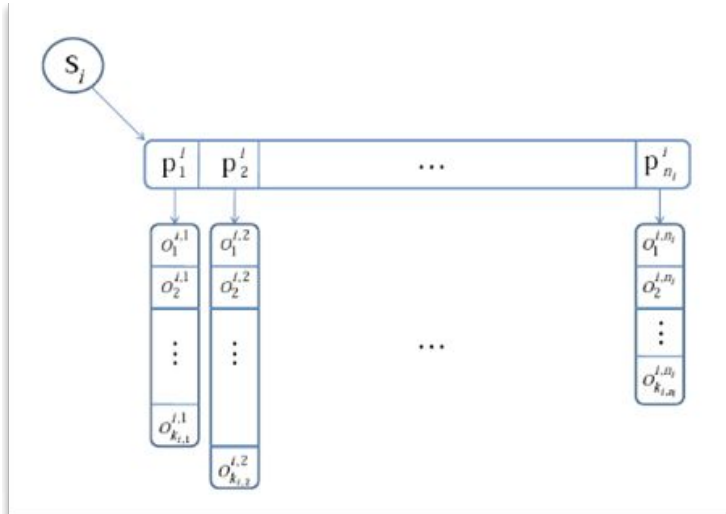
Pros:

- Supports multi-value properties
- No NULLs
- Read only needed attributes (i.e. less I/O)
- No clustering
- Excellent performance (if number of properties is small, queries with bounded properties)

Cons:

- Expensive inserts
- Bad performance (large number of properties, queries with unbounded properties)

Hexastores



- Create an index for every possible combination to enable efficient processing
 - spo, pos, osp, sop, pso, ops

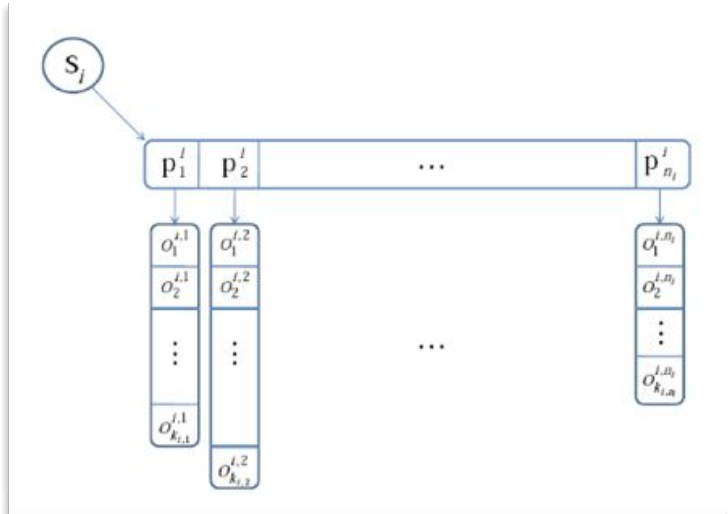
The **spo** index:

Subject key S_i points to sorted vector of n_i property keys $\{p_1^i, p_2^i, \dots, p_{n_i}^i\}$

Each property key p_j^i is linked to a sorted list of object keys.

The object key lists are shared with the **pso** index.

Hexastores



- Create an index for every possible combination to enable efficient processing
 - spo, pos, osp, sop, pso, ops

Pros:

- fast joins (in the beginning)

Cons:

- 5 times more storage
- weak performance when disk access is necessary

Triple Stores

- Native RDF Stores
 - Apache Jena TDB - <http://jena.apache.org>
 - AllegroGraph - <http://www.franz.com/agraph/allegrograph/>
 - GraphDB - <http://ontotext.com/products/ontotext-graphdb-owlim/>
 - 4Store - <http://4store.org/>
- DBMS backed RDF Stores
 - Apache Jena SDB - <http://jena.apache.org>
 - Oracle Spatial and Graph: RDF Semantic Graph <http://www.oracle.com/technetwork/database/options/spatialandgraph/overview/rdfsemantic-graph-1902016.html>
- Hybrid RDF Stores
 - Open Link Virtuoso - <http://virtuoso.openlinksw.com>
 - Sesame - <http://rdf4j.org/>
- W3C maintains a list of triple stores:
https://www.w3.org/2001/sw/wiki/Category:Triple_Store

SPARQL



EXTRA: 10 - SPARQL Data Management & Algebra

OpenHPI - Course Knowledge Engineering with Semantic Web Technologies

Lecture 2: RDF Based Knowledge Representation