The Semantic Web for Application Developers

Oracle New England Development Center
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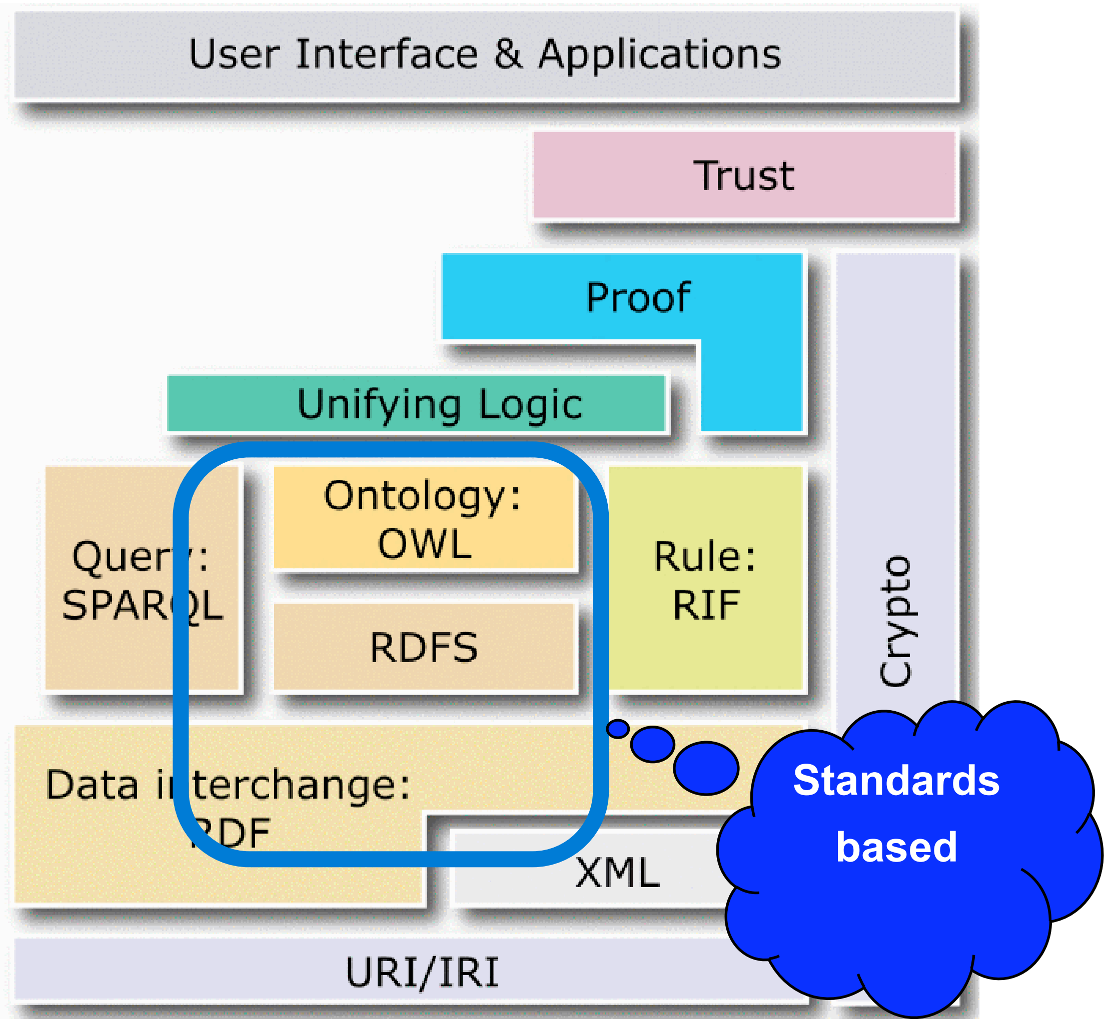
Agenda

- Background
  - 10gR2 RDF
  - 11g RDF/OWL
- New 11g features
  - Bulk loader
  - Semantic operators
  - Native OWL inferencing
- Oracle Jena adaptor
- Example usage flow
- Performance
- Summary

Semantic Technology Stack



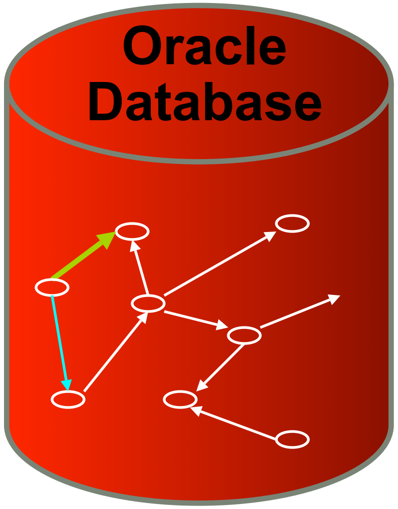
http://www.w3.org/2007/03/layerCake.svg

Advancing W3C Semantic Standards

- Our implementation entirely based on W3C standards (RDF, RDFS, OWL)
  - SPARQL support is planned
- Members of following W3C Web Semantic Activities:
  - W3C Data Access Working Group (DAWG)
  - W3C Semantic Web Education & Outreach (SWEO)
  - W3C Health Care & Life Sciences Interest Group (HCLS)
  - W3C Multimedia Semantics Incubator group
  - W3C OWL 1.1 Working group

Oracle 10gR2 RDF

- **Storage and Load**
  - Stored after normalization in Oracle Tables
  - Incremental Load using DMLs
    - insert into rdf_data values (…, sdo_rdf_triple_s(1, **‘<subject>’, ‘<predicate>’, ‘<object>’));**
  - Java API based Batch Loader Utility
- **Inference** (forward chaining based)
  - Supports RDFS inference
  - Supports User-Defined rules
  - PL/SQL API create_rules_index
- **Query** using SDO_RDF_MATCH Table function
  - Select x, y from table(sdo_rdf_match(
    ‘(?x rdf:type :Protein) (?x :name ?y)’ ….));
  - Seamless SQL integration
- **Model level security and access control**
- **Shipped in 2005**



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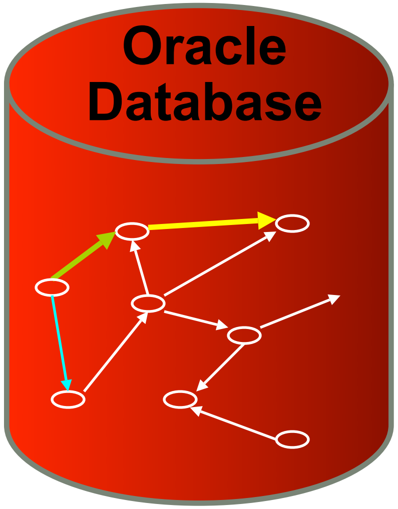

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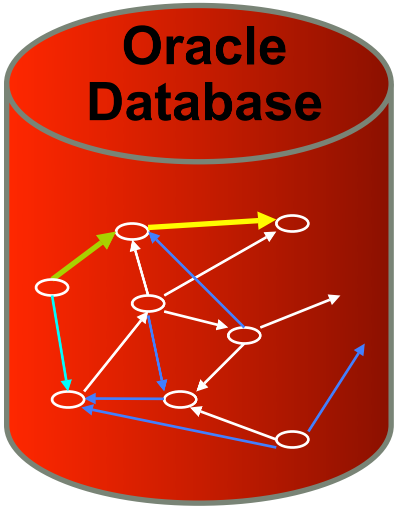

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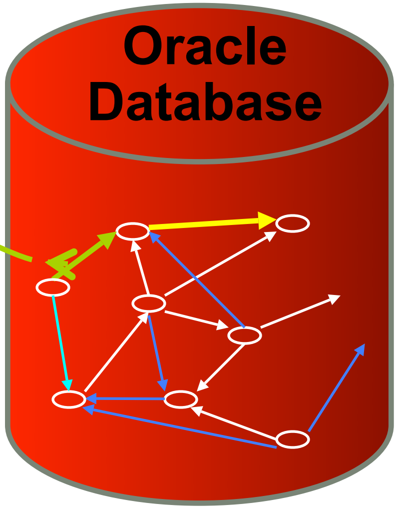

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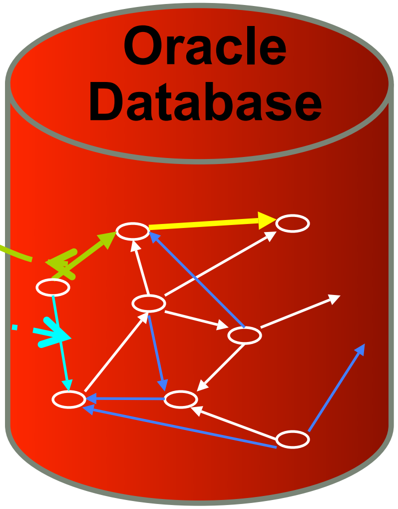
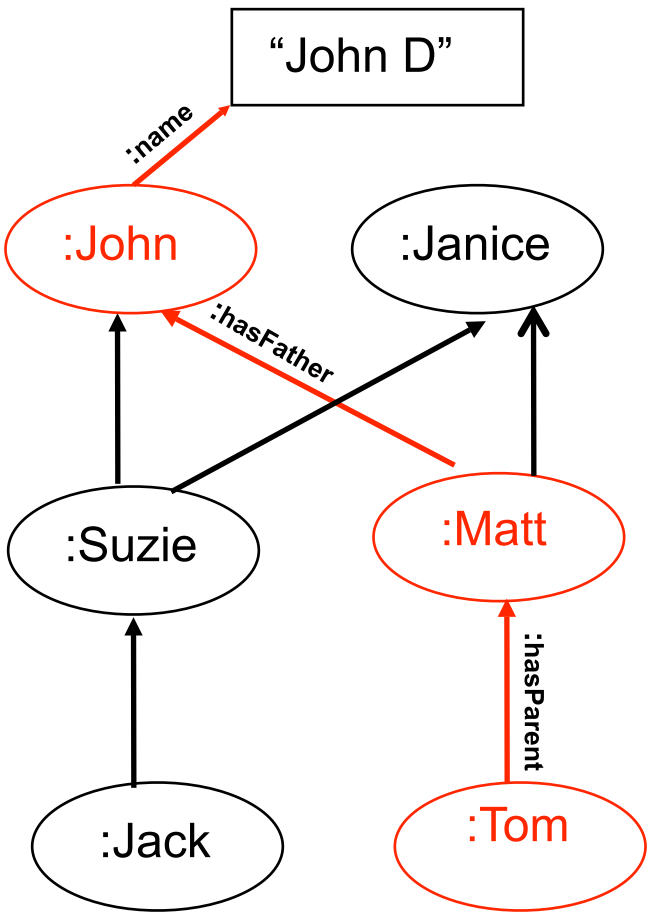


Oracle 11g RDF/OWL

- **New features**
  - Bulk loader
  - Native OWL inference support (with optional proof generation)
  - Semantic operators
- **Performance improvement**
  - Much faster compared to 10gR2
    - Loading
    - Query (table function re-write, query hints)
    - Inference
- **Shipped in 2007**
- **Java API support**
  - Oracle Jena adaptor (released on OTN)
  - Sesame (forthcoming)

Example RDF Graph and Query



A simple RDF graph

SEM_MATCH returns the name of Tom's grandfather **in the form of a relational table**

```
select x, y, name from
    TABLE(SEM_MATCH(
            '(:Tom :hasParent ?x)
             (?x   :hasFather ?y)
             (?y   :name      ?name)',
      SEM_Models('family'),     .., .., ..));
```

X	Y	NAME
Matt	John	"John D"

A simple graph pattern query

Oracle 11g Feature: Bulk Loader

- **Scalable, efficient solution for loading hundreds of millions of triples and beyond**
  - **Re-architected, re-designed in 11gR1**
  - Usage flow
    - Using SQL Loader to load an N-TRIPLE file into a staging table
    - Invoke sem_apis.bulk_load_from_staging_table PL/SQL API
  - To load RDF graphs in RDF/XML or N3 format
    - Use named pipe together with a third-party tool that converts source file into N-TRIPLE file, ***or***
    - Use Oracle Jena adaptor
      - oracleBulkUpdateHandler.addInBulk(GraphUtil.findAll (sourceGraph), tbs);

N-TRIPLE format

<:Mary> <:motherOf> <:John> .
<:Mary> <:motherOf> <:Sue> .
<:Sue> <:sisterOf> <:John> .
<:Tom> <:hasParent> <:Matt> .

Oracle 11g Feature: Semantic Operators

- **Scalable, efficient SQL operators to perform ontology-assisted query against enterprise relational data**

Patients diagnosis table

ID	DIAGNOSIS
1	Hand_Fracture
2	Rheumatoid_Arthritis

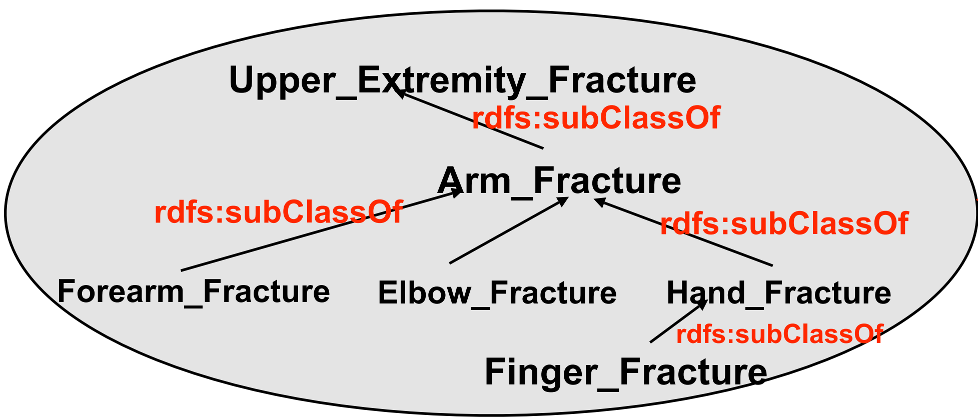
Query: **"Find all entries in diagnosis column that are related to 'Upper_Extremity_Fracture'"**

Syntactic query against relational table will not work!

SELECT p_id, diagnosis
FROM Patients → **Zero Matches!**
WHERE diagnosis = 'Upper_Extremity_Fracture;

Traditional Syntactic query against relational data

New Semantic query against relational data (while consulting ontology)



SELECT p_id, diagnosis
FROM Patients
WHERE **SEM_RELATED (**
diagnosis,
'rdfs:subClassOf',
'Upper_Extremity_Fracture',
'Medical_ontology') = 1;

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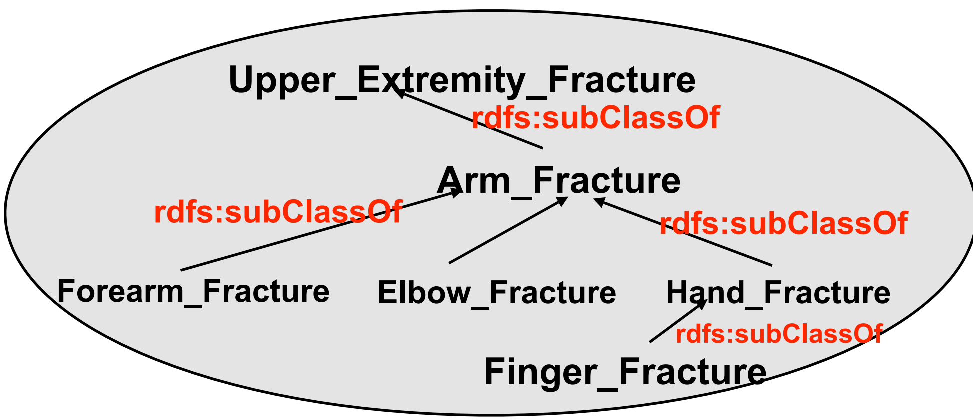


```
SELECT p_id, diagnosis
 FROM Patients
WHERE SEM_RELATED (
        diagnosis,
        'rdfs:subClassOf',
        'Upper_Extremity_Fracture',
        'Medical_ontology' = 1)
AND SEM_DISTANCE() <= 2;
```

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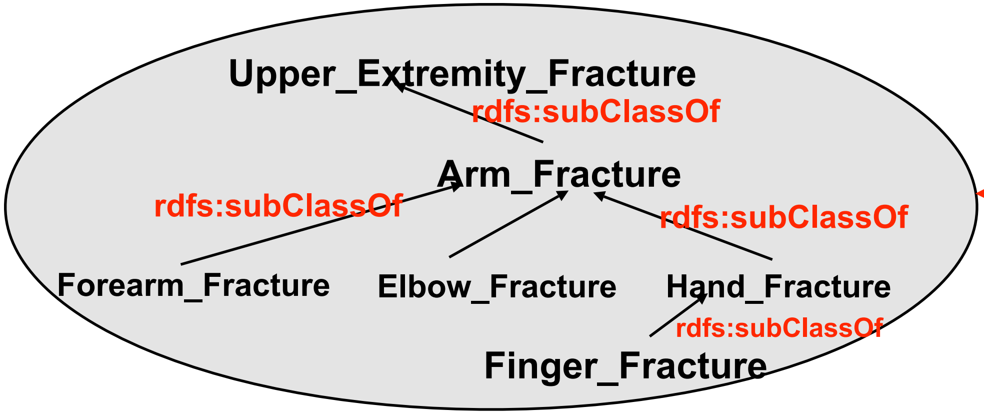



```
SELECT p_id, diagnosis
 FROM Patients
WHERE SEM_RELATED (
          diagnosis,
          'rdfs:subClassOf',
          'Upper_Extremity_Fracture',
          'Medical_ontology') = 1;
```

Oracle 11g Feature: OWL Inference

- **Scalable, efficient, forward-chaining based reasoner that supports an expressive subset of OWL-DL**

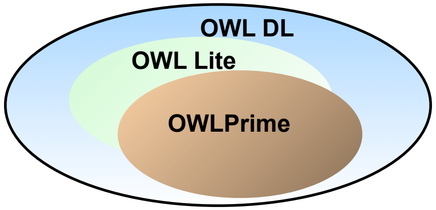
- **Why OWL-DL subset?**
  - Have to support large ontologies (with large ABox)
    - Hundreds of millions of triples and beyond
    - No existing reasoner handles complete DL semantics at this scale
      - Neither Pellet nor KAON2 can handle LUBM10 or ST ontologies on a setup of 64 Bit machine, 4GB Heap[1]

- **Why forward chaining?**
    - Efficient query support
    - Can accommodate any graph query patterns

1 The summary Abox: Cutting Ontologies Down to Size. ISWC 2006

OWL Subsets Supported

- **Three subsets for different applications**
  - RDFS++
    - RDFS plus owl:sameAs and owl:InverseFunctionalProperty
  - OWLSIF (OWL with IF semantics)
    - Based on Dr. Horst's pD* vocabulary[1]
  - OWLPrime
    - rdfs:subClassOf, subPropertyOf, domain, range
    - owl:TransitiveProperty, SymmetricProperty, FunctionalProperty, InverseFunctionalProperty,
    - owl:inverseOf, sameAs, differentFrom
    - owl:disjointWith, complementOf,
    - owl:hasValue, allValuesFrom, someValuesFrom



1 Completeness, decidability and complexity of entailment for RDF Schema and a semantic extension involving the OWL vocabulary

11g OWL Inference PL/SQL API

- **SEM_APIS.CREATE_ENTAILMENT**(
  - Index_name
  - sem_models('GraphTBox', 'GraphABox', …),
  - sem_rulebases('OWLPrime'),
  - passes,
  - Inf_components,
  - Options

)
  - Use "PROOF=T" to generate inference proof

Typical Usage:

- First load RDF/OWL data
- Call create_entailment to generate inferred graph
- Query both original graph and inferred data

Inferred graph contains only new triples! Saves time & resources

- **SEM_APIS.VALIDATE_ENTAILMENT**(
  - sem_models(('GraphTBox', 'GraphABox', …),
  - sem_rulebases('OWLPrime'),
  - Criteria,
  - Max_conflicts,
  - Options

)

Typical Usage:

- First load RDF/OWL data
- Call create_entailment to generate inferred graph
- Call validate_entailment to find inconsistencies

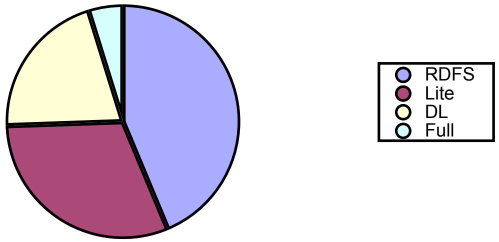
- **Above APIs can be invoked from Java clients through JDBC**

Applications of Partial DL Semantics

- “One very heavily used space is that where RDFS plus some minimal OWL is used to enhance data mapping or to develop simple schemas.”

  -James Hendler [1]

- Complexity distribution of existing ontologies [2]
  - Out of 1,200+ real-world OWL ontologies
    - Collected using Swoogle, Google, Protégé OWL Library, DAML ontology library …
  - 43.7% (or 556) ontologies are RDFS
  - 30.7% (or 391) ontologies are OWL Lite
  - 20.7% (or 264) ontologies are OWL DL.
  - Remaining OWL FULL



1 http://www.mindswap.org/blog/2006/11/11/an-alternative-view-for-owl-11/

2 A Survey of the web ontology landscape. ISWC 2006

Support Semantics beyond OWLPrime (1)

- Option1: add user-defined rules
  - Both 10gR2 RDF and 11g RDF/OWL supports user-defined rules in this form (filter is supported)

Antecedents	→	Consequents
?x :parentOf ?y . ?z :brotherOf ?x .		?z :uncleOf ?y

- E.g. to support core semantics of owl:intersectionOf

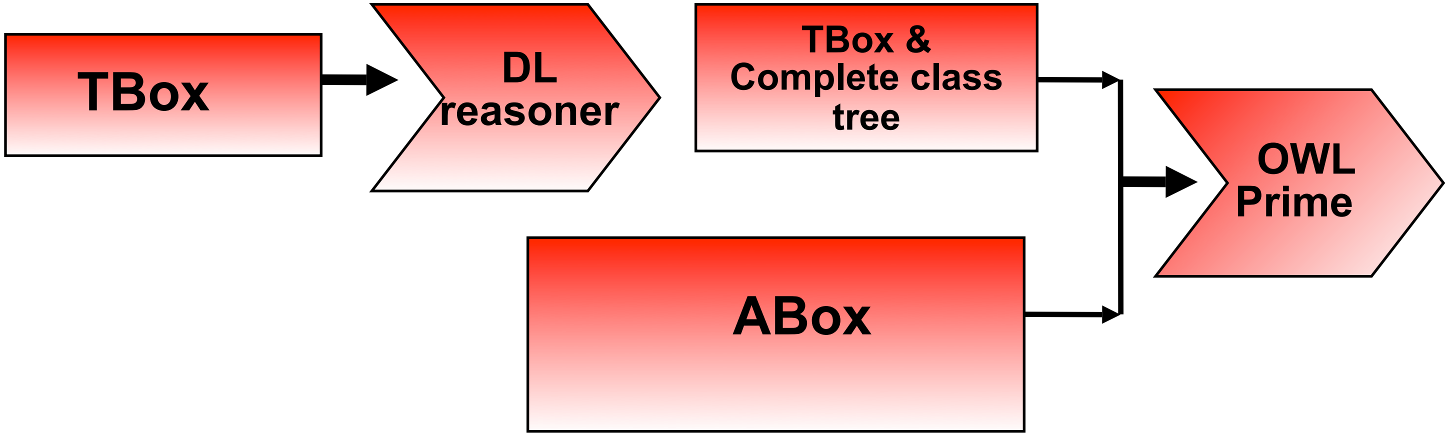
```
<owl:Class rdf:ID="FemaleAstronaut">
  <rdfs:label>female astronaut</rdfs:label>
  <owl:intersectionOf rdf:parseType="Collection">
    <owl:Class rdf:about="#Female" />
    <owl:Class rdf:about="#Astronaut" />
  </owl:intersectionOf>
</owl:Class>
```

➔

1. ➔ :FemaleAstronaut rdfs:subClassOf :Female
2. ➔ :FemaleAstronaut rdfs:subClassOf :Astronaut
3. ?x rdf:type :Female .
   ?x rdf:type :Astronaut . ➔
   x rdf:type :FemaleAstronaut

Support Semantics beyond OWLPrime (2)

- **Option2: Separation in TBox and ABox reasoning through Oracle Jena Adaptor**
  - TBox tends to be small in size
    - Generate a class subsumption tree using complete DL reasoners (like Pellet, KAON2, Fact++, Racer, etc)
  - ABox can be arbitrarily large
    - Use Oracle OWL to infer new knowledge based on the class subsumption tree from TBox



Oracle Jena Adaptor [1]

- **Implementation of Jena's Graph/Model/BulkUpdateHandler API**
  - Started based on UTHSC's request
  - Joint efforts by UTHSC, Top Quadrant, HP Lab, and Oracle
- What is achieved
  - SPARQL support
  - Fast data loading through Java API
  - Easy integration with external OWL-DL reasoners
  - Better 10gR2 performance
  - On-demand statistics collection
- Example

```
Oracle oracle = new Oracle(jdbcUrl, user, password);
GraphOracleSem graph = new GraphOracleSem(oracle, modelName);
Node sub = Node.createURI("http://test/s");
Node pred = Node.createURI("http://test/p");
Node obj = Node.createURI("http://test/o");

Triple triple1 = Triple.create(sub, pred, obj);
```


1 http://www.oracle.com/technology/software/tech/semantic_technologies/index.html

Example 11g RDF/OWL Usage Flow

- Create an application table
  - create table app_table(triple sdo_rdf_triple_s);
- Create a semantic model
  - exec sem_apis.create_sem_model('family', 'app_table','triple');
- Load data
  - Use DML, Bulk loader, or Batch loader
  - insert into app_table (triple) values(1, sdo_rdf_triple_s('family', '<http://www.example.org/family/Matt>', '<http://www.example.org/family/fatherOf>', '<http://www.example.org/family/Cindy>'));
  - …
- Run inference
  - exec sem_apis.create_entailment('family_idx',sem_models('family'), sem_rulebases('owlprime'));
- Query both original model and inferred data

  select p, o

After inference is done, what will happen if

- New assertions are added to the graph

- Inferred data becomes incomplete. Existing inferred data ***will be reused*** if create_entailment API invoked again. Faster than rebuild.

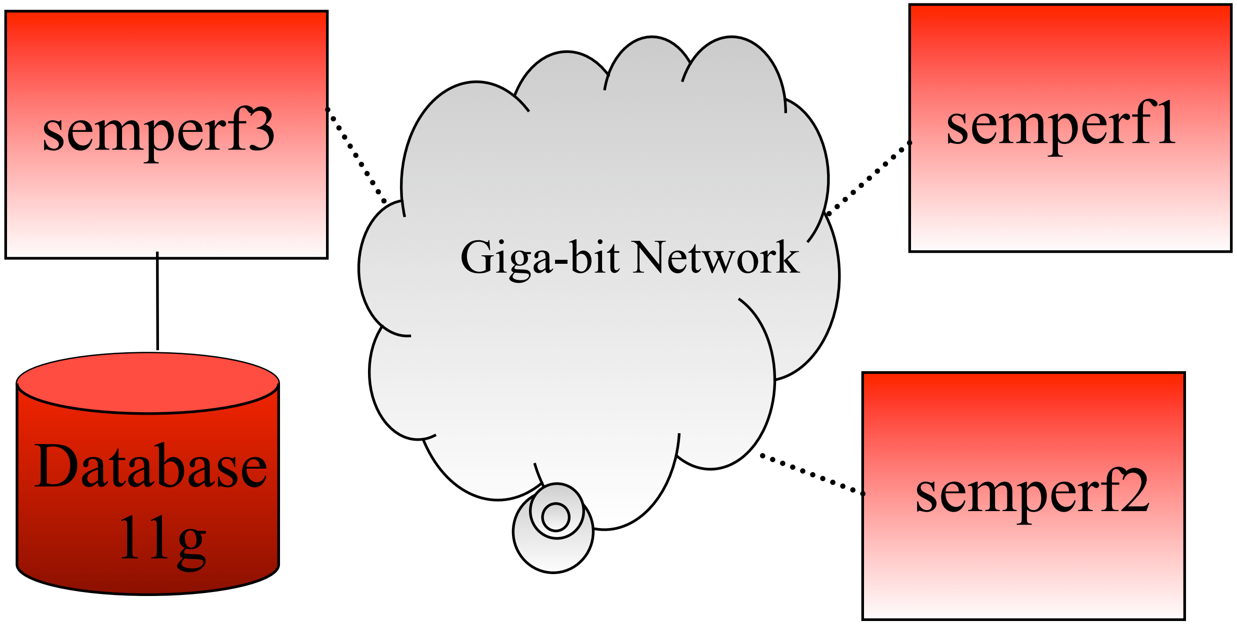
- Existing assertions are removed from the graph

- Inferred data becomes invalid. Existing inferred data ***will not be reused*** if the create_entailment API is invoked again.

Performance Evaluation
using desktop PC

Database Setup

- Linux based **commodity** PC (1 CPU, 3GHz, 2GB RAM) [1]
- Database installed on machine "semperf3"

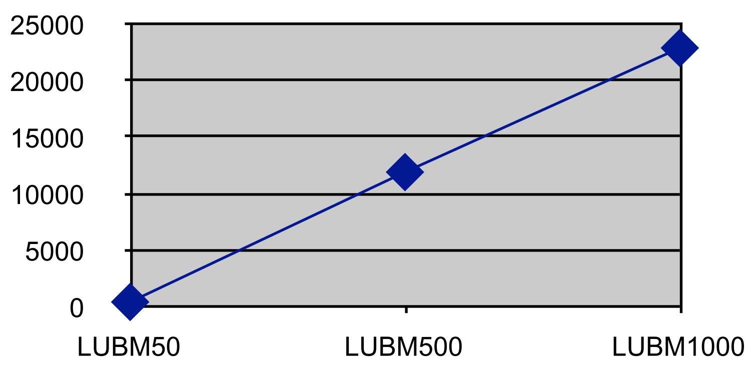


- Two other PCs are just serving storage over network

1 http://ontolog.cim3.net/file/work/DatabaseAndOntology/2007-10-18_AlanWu/RDBMS-RDFS-OWL-InferenceEngine--AlanWu_20071018.pdf

Data Loading Performance

- Oracle 11g bulk loader
  - LUBM50 (6.9 million triples)
    - TOTAL → 13 min 29 sec
      - SQL loader: 4 min 56 sec; sem_apis.bulk_load_from_staging_table: 8 min 33 sec
  - LUBM500 (69 million triples)
    - TOTAL → 3 hour 20 min
      - SQL loader: 46 min; sem_apis.bulk_load_from_staging_table: 2 hour 34 min
  - LUBM1000 (138 million triples)
    - TOTAL → 6 hour 23 min
      - SQL loader 1 hour 34 min; sem_apis.bulk_load_from_staging_table: 4 hour 49 min



Query Performance

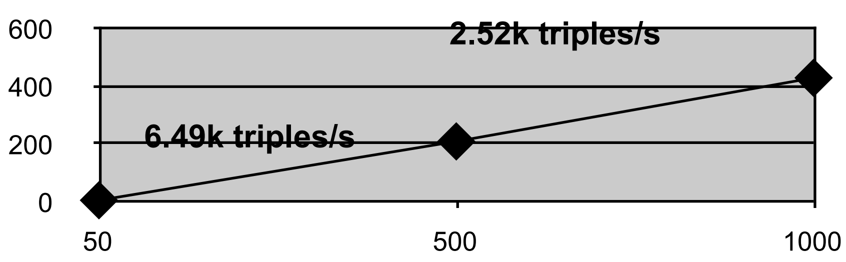
Ontology LUBM50 6.8 million & 3+ million inferred		LUBM Benchmark Queries						
		Q1	Q2	Q3	Q4	Q5	Q6	Q7
OWLPrime	# answers	4	130	6	34	719	393730	59
	Time (sec)	0.09	0.80	0.28	6.1	0.4	36.82	1.05
OWLPrime + Pellet on TBox	# answers	4	130	6	34	719	519842	67
	Time (sec)	0.09	0.79	0.28	9.5	0.4	43.65	1.13

Query Performance (2)

Ontology LUBM50 6.8 million & 3+ million inferred		LUBM Benchmark Queries						
		Q8	Q9	Q10	Q11	Q12	Q13	Q14
OWLPrime	# answers	5916	6538	0	224	0	228	393730
	Time (sec)	2.76	2.08	0.18	0.02	0.01	0.39	31.5
OWLPrime + Pellet on TBox	# answers	7790	13639	4	224	15	228	393730
	Time (sec)	3.9	3.47	0.37	0.02	0.03	0.39	39.4

Inference Performance

Ontology (size) (after duplicate elimination)	RDFS		OWLPrime		OWLPrime + Pellet on TBox	
	#Triples inferred (millions)	Time	#Triples inferred (millions)	Time	#Triples inferred (millions)	Time
LUBM50 6.6 million	2.75	12min 14s	3.05	8m 01s	3.25	8min 21s
LUBM1000 133.6 million	55.09	7h 19min	61.25	7hr 0min	65.25	7h 12m
UniProt 20 million	3.4	24min 06s	50.8	3hr 1min	NA	NA



As a reference (not a comparison)

BigOWLIM ***loads, inferences, and stores*** (2GB RAM, P4 3.0GHz,)

- LUBM50 in 11 minutes (JAVA 6, -Xmx192) [1]
- LUBM1000 in 11h 20min (JAVA 5, -Xmx1600) [1]

Note: Our inference time **does not** include loading time! Also, set of rules is different.

- **Results collected on a single CPU PC (3GHz), 2GB RAM (1.4G dedicate to DB), Multiple Disks over NFS**

1 http://www.ontotext.com/owlim/OWLIMPres.pdf, **Oct 2007**

Summary

- 11g provides a robust, efficient, and scalable semantic data management
  - Data loading
  - Query (graph query and ontology-assisted query)
  - Inference
- Java APIs make application building easier
- Future direction
  - Even better performance
  - Richer semantics
  - More application/tools integrations

For More Information

http://search.oracle.com

semantic technologies

Please visit our demo booth and session (S291507)

Thursday 11.30-.12.30

"Why, When, and How to Use Oracle Database 11g Semantic Technologies"

Acknowledgment

- Parsa Mirhaji, Narendra Kunapareddy (UTHSC)
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- Andy Seaborne (Hewlett-Packard Limited)
- Oracle DB Semantic Technologies development team & product management team