Towards distributed RDF querying

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Towards Distributed RDF Querying

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Introduction / motivation
- Hera
- Integration model
- Query Processing
- Optimization

Motivation
- Demand for combining distributed data on the Web
  - Comparative Shopping
  - Virtual Museums
  - Digital Libraries
  - Web Portals
- User:
  - formulate his query
  - split the query
  - assemble results

The RDF data model
- statements are <Subject, Predicate, Object> triples:
  - <http://wwwis.win.tue.nl/~houben/, dc:creator, "Geert-Jan">}
  - statements describe properties of resources
  - a resource is everything that has an identifier: URI
  - Directed Labelled Multi-graph

Sem. Web / RDF(S) to the Rescue (?)
- RDFS
  - The Pivot Language of the Semantic Web
  - Solves the problem of syntactic heterogeneity of different sources
  - Provides basic modelling primitives and reasoning techniques for conceptual knowledge
  - Built on an extremely simple data model that avoids complications of other object oriented formalisms
  - And (most importantly): It is a standard!

Sem. Web / RDF(S) to the Rescue (?)
- Benefits
  - Common Syntax
  - Formal (limited) Semantics
  - Flexible
    - easy to express
    - anything about anything
- Our User?
  - formulate his query
  - split the query
  - assemble results
- ...
  - (still unhappy)
Possible Solution: Data Warehousing
- Gather All Data Locally
- Watch for Updates
- Insert New Data
- Delete Old Data
- Evaluate (locally) User Query

Another Solution: Virtual Repository
- Split the User Query into Sub-Queries
- Translate Sub-Queries to Source Schemata
- Distribute Sub-Queries
- Assemble Sub-Queries

Challenges/ Requirements for Integration of RDF(S) Sources
- Unified Interface to data sources
  - Usually only a part of a source is of interest
  - “Freshness” of data must be guaranteed
- Sources are many, autonomous, and volatile
  - Semantic Heterogeneity
  - Schema heterogeneity
  - Designation heterogeneity
- Distributed Query processing
  - Complex/Join queries (SeRQL language)
  - Flexibility w.r.t. user needs/query
    - (the order of importance changes)
    - Correctness, Completeness
    - Performance

Introduction: Data Warehousing

Introduction: Virtual Repository

Introduction: Requirements

Data Warehousing: Problems
- Performance Bottleneck
- Freshness
- Copyright / Data Ownership issues

Introduction: Data Warehousing

Data Back-end

Another Solution: Virtual Repository

Challenges/ Requirements for Integration of RDF(S) Sources

Introduction: Data Warehousing

Introduction: Virtual Repository

Introduction: Requirements

Hera Design Methodology
- Data retrieval is just a beginning
- Navigational Structure
- Presentation Rendering
- Adaptation / Adaptivity

The Semantic Layer
Hera Back-end
Hera Front-end

Hera Semantic Layer
**Conceptual Model (CM)**
- Interface between data retrieval and presentation generation (via SeRQL)
- CM exists on its own (even without instances)
  - Made by a system designer
  - Top down approach
- Specifies the application’s semantics
  - What is the information system about
- Expressed in RDF(S)
  - Populated on demand with data from several heterogeneous information sources
- Challenge: Map the Sources to the defined CM

**Integration Model (IM)**
- A generic framework for describing, integrating and relating concepts from sources to their CM counterparts
  - View Definition/Translation Language +
  - Object reconciliation language +
  - Language for programming the mediator +
- Expressed in RDFS
  - Instantiated by the integration designer into IMIs: program the mediator to overcome the semantic heterogeneity between the sources and the CM

**Integration Model in RDF(S)**

**Schema heterogeneity**
- Sources are autonomous and can therefore differ a lot from each other
- Mappings are formed through the notion of Path Expressions (PE) which form articulations
  - An articulation is a pair of two PEs, one in an external source, one in the CM
  - consists of a link between the start-classes and a link between the ending-edges
**Schema heterogeneity**

- Sometimes a value should be mapped to a list of values
- A transformer is needed for the necessary action
- Denoted in the IM as “obtained by list”

**Designation heterogeneity**

- Different sources may have different ways to uniquely identify instances
- Need to define the identifying properties “primary key” of objects in every source
- Consolidate them into the CM so that a join can be performed across multiple sources

**Designation heterogeneity**

- IM offers three kinds of data-identification:
  1. id By Uri → every object has a unique URI
  2. id By Value → a value is unique for an object
  3. id By Property → a “super resource” defines the uniqueness of an object

**Examples:**

**Designation heterogeneity : idByUri**

- An object is uniquely defined by its URI
- Can be used/imposed within closed communities, e.g. corporate IS
- Does not work World Wide

**Designation heterogeneity : idByValue**

- Value based (similarly to the relational model)
- A object is uniquely defined by one(or more) of its own properties

**Designation heterogeneity : idByProperty**

- idBy-information provided by a super-resource
- Recursive path until either idByUri or idByValue is encountered
Join Example
- If the primary key is the same data is joined.
  - The two idBy-paths are different but joining is still possible if the end-values for the primary key are the same.

Different sources - different qualities
- Sources can “get points” for certain qualities:
  - Data reliability
  - Data quality: e.g., picture quality for a Photo database
  - Reachability
  - Speed
- Sources can be consulted in different order based on the current user preferences
- Decorations
  - making background knowledge explicit
  - “exported” into the CM (extending the Schema)

Extra IM features
- Process Instructions:
  - (Need to compare (primary) keys
    - Transformers/Comparators
    - Conversion functions (date of birth → Personal number)
    - Look-up table value translations
    - Unit conversions (km→mile)
    - Formal conversion (ft→jig)
- Direct translation
  - In case of homogeneous Schemas/sources
  - Lists of classes with identical outgoing edges

CM Instance (CMI)
- The Hera presentation engine needs more data than that resulted from a “bare” user query
- The user query is extended to retrieve literal values (the real content)
- An RDF graph is constructed out of the “flat” SeRQL output

CMI generation
- User Query:
  - Retrieve all writers
  - Extended query:
    - Retrieves info the name, age, hasPortrait P4,P5
Initial Performance experiments
- Queries against small-size applications (e.g. the comics database or virtual museum) answered within ms
- Medium Test Set: RDF version of Wordnet
  - Naturally split into four parts: Nouns (10MB), Glossary (15MB), Similar-To Definitions (2MB), Hyponyms (8MB)
- Test Setting:
  - Three local stores: Vrije Universiteit Amsterdam, CWI (Amsterdam) and Eindhoven Technical University, Mediator at Vrije Universiteit
- Results:
  - When installed locally Performance of distributed system is between 50 and 200% of the original Sesame (200-1000 m sec.)
  - The performance drops with the size of the result set due to extensive joining and communication overhead

Where the Time Goes?
Depends on many factors
- Data Size / Source Processing Speed
- Query (complexity, result size ...)
- Connection Speed

Optimization: Initial Performance

Improving the Performance
- Large applications (hundreds of MB) require sophisticated optimization techniques:
- Currently
  - Schema/path Indexing
  - Join ordering
  - Algebraic optimizations
- Work in progress
  - Reducing the transferred data
    - requires an architecture change (similar to P2P)

Where the Time Goes?

<table>
<thead>
<tr>
<th>Time</th>
<th>Small Result Set</th>
<th>Large Result Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Processing</td>
<td>31%</td>
<td>75%</td>
</tr>
<tr>
<td>Communication</td>
<td>47%</td>
<td>9%</td>
</tr>
<tr>
<td>Result Joining</td>
<td>21%</td>
<td>9%</td>
</tr>
<tr>
<td>Mediator Overhead</td>
<td>1%</td>
<td>7%</td>
</tr>
</tbody>
</table>

Optimization: Initial Performance

Optimization: Improving the Performance

Schema/Path Index Hierarchy
- Central place to store the translatable paths from the articulations
- The main idea: pushing long paths to sources is more efficient than joining many small paths at the mediator
  - fewer joins
  - smaller data traffic
- The index is constructed out of a pool of articulations
- Articulations can be added/deleted or modified on the fly: **flexible source management**
- Index is able to infer “new” paths of its own:

Optimization: Path Indexing

Schema/Path Index Hierarchy
- Inference rules:
  - Inclusion of “super paths”
    Given: \( A \rightarrow B \) and \( B \rightarrow C \)
    Insert \( A \rightarrow C \)
  - Transitive closure of subClassOf / subPropertyOf
    Given: \( A \rightarrow B \), \( C \rightarrow D \) and \( B \rightarrow \text{subClassOf} \rightarrow C \)
    Insert \( A \rightarrow D \)
Schema/Path Index Hierarchy

- **Key** = path (sequence of properties)
- **Value** = list of sources to which this path can be translated

![Path Index Hierarchy Diagram]

**Optimization: Path Indexing**

Performance Results: Full Index vs 1-path Index

<table>
<thead>
<tr>
<th>Source</th>
<th>Path1</th>
<th>Path2</th>
<th>Path3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source1</td>
<td>a11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source2</td>
<td>a12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source3</td>
<td>a13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Evaluation Time**

**Joining Time**

From a RDF Path to Relational Tables

<table>
<thead>
<tr>
<th>Source1</th>
<th>Source2</th>
<th>Source3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>x</td>
<td>y</td>
<td>z</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source1</th>
<th>Source2</th>
<th>Source3</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>b</td>
<td>c</td>
</tr>
<tr>
<td>d</td>
<td>e</td>
<td>f</td>
</tr>
</tbody>
</table>

**Optimization: Join Ordering**

The Problem of Join Ordering

- Determine the optimal order of join execution in a (chain) query
- Different strategies have different execution costs due to different selectivity of the join operations
- Problem is NP-hard: we consider heuristic solutions

<table>
<thead>
<tr>
<th>Query</th>
<th>Source1</th>
<th>Source2</th>
<th>Source3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Q2</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
</tbody>
</table>

**A Cost Model for RDF Querying**

- Data Access Costs
  - Initializing the transmission
  - Transmitting the data
- Join Costs
  - Nested Loop Join
  - Hash Join (potentially faster but less flexible w/ determining object identity)
- Costs of a Query Plan
  - Transmission costs for all relations
  - Join costs for the chosen footprint

\[ AC_p = Cinit + |p| \times |Inst| \times C \]

\[ NJC_{pr} = |p| \times |r| \times K \]

\[ HJC_{pr} = I \times |p| + R \times |r| \times B \]

\[ QPC_p = \sum_{i=1}^{n} AC_{pi} + PC_0 \]

**Optimization: Join ordering**

Join Ordering Heuristics

- Complexity of Task demands heuristic approaches, performance of heuristics depends on class of queries.
- For chain queries the following performs best [Steinbrunn et al. 1997]

1) Iterative Improvement
- Start with random solutions
- Improve solution using a greedy heuristic
- Result: local optima

2) Simulated Annealing
- Further improve solutions allowing for increasing costs with a certain probability
- Helps to get out of local optima and converge towards better solutions

**Optimization: Join ordering**
Optimizing Communication:
Collaborating Network of Mediators

- One coordinator + Set of cooperating nodes
- The coordinator generates the (global) query plan for other nodes
- instructions:
  - obtain data
  - use your local data
  - join obtained data in a given order
  - ship data to another node

Conclusions

- Virtual Repositories are a viable solution for building distributed WIS

Challenges:

- Semantic heterogeneity
  - Source schemas can differ
  - URI is not enough for joining
  - Flexible Evaluation
- Performance / Scalability
  - Path Indexing
  - Join Ordering
  - Collaborating Mediators

Questions