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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

Sem. Web / RDF(S) to the Rescue (?)
- RDF
  - 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!

The RDF data model
- statements are subject, predicate, object triples:
  - "http://wwwis.win.tue.nl/~houben", dc:creator, "Geert-Jan"
  - http://wwwis.win.tue.nl/~houben/
  - dc:creator
- 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 (?)
- 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 Results

Hera Design Methodology

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

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/queries
  - (the order of importance changes)
- Correctness, Completeness
- Performance

The 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 RDF(S)
- 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. idByUri → every object has a unique URI
  2. idByValue → a value is unique for an object
  3. idByProperty → a “super resource” defines the uniqueness of an object

**Examples:**
- 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->miles)
    - Formal conversion (ft->meters)
  - 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

Query Processing: CMI definition

CMI generation example
In Introduction / motivation

Integration model

Query Processing

Optimization

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 in 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 ms/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?

Small Result Set

Large Result Set

Optimization: Initial Performance

Optimization: Path Indexing

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

![Diagram of Schema/Path Index Hierarchy]

Optimization: Path Indexing

Performance Results: Full Index vs 1-path Index

From a RDF Path to Relational Tables

![Diagram of From a RDF Path to Relational Tables]

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

Optimization: Join Ordering

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.r.t. determining object identity)
- Costs of a Query Plan:
  - Transmission costs for all relations
  - Join costs for the chosen footprint

![Diagram of A Cost Model for RDF Querying]

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
  - Receive a table
  - 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