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Towards Distributed RDF Querying

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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 \(<\text{Subject}, \text{Predicate}, \text{Object}>\) triples:
  - \(<\text{http://wwwis.win.tue.nl/~houben/}, \text{dc:creator}, \text{"Geert-Jan"}>\)

- statements describe properties of resources
- a resource is everything that has an identifier: URI
- Directed Labelled Multi-graph

Introduction: motivation

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!

Introduction: motivation

Introduction RDF(S)

Introduction: RDF(S)
Possible Solution: Data Warehousing
- Gather All Data Locally
- Watch for Updates
- Insert New Data
- Delete Old Data
- Evaluate (locally) User Query

Introduction: Data Warehousing

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

Introduction: Data Warehousing

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

Introduction: Virtual Repository

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: Requirements

Hera Design Methodology
- Data retrieval is just a beginning
- NavigationalStructure
- Presentation Rendering
- Adaptation / Adaptable

Hera

The Semantic Layer

Hera Back-end
- RDF Data
- Repository

Hera Front-end
- User Interface
- Presentation

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**

- Design the CM like source 1:
**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 Worldwide

**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 -> jg)
  - Direct translation
    - In case of homogeneous Schemas/sources
    - Lists of classes with identical outgoing edges

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

**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**
- Given the CMI
- User Query:
  - Retrieve all writers
  - Extended query:
    - Retrieve also the name, age, hasPortrait P4,P5

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Integration Model: Expressive power
Integration Model: Extra features
Query Processing: CMI definition
Query Processing: CMI generation example
**Introduction / motivation**

**Integration model**

**Query Processing**

**Optimization**

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**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), Hypernyms (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 msec)
- The performance drops with the size of the result set due to extensive joining and communication overhead

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**Where the Time Goes?**

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

**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)

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**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:

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**Optimization Approaches**

**Optimization: Initial Performance**

**Optimization: Where the Time Goes?**

**Optimization: Improving the Performance**

**Optimization: Schema/Path Indexing**

**Optimization: Path Indexing**

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**Optimization: Initial Performance**

**Optimization: Where the Time Goes?**

**Optimization: Improving the Performance**

**Optimization: Schema/Path Index Hierarchy**

**Optimization: Path Indexing**
Schema/Path Index Hierarchy

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

From a RDF Path to Relational Tables

- 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

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

Optimization: Path Indexing

Performance Results: Full Index vs 1-path Index

Optimization: Join Ordering

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A Cost Model for RDF Querying

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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