Semantic Search

Algorithmic Problems Around the Web #8

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The challenge of the Semantic Web, therefore, is to provide a language that expresses both data and rules for reasoning about the data and that allows rules from any existing knowledge representation system to be exported onto the Web.

T. Berners-Lee, J. Hendler, O. Lassila
Semantic Web, 2001

Outline

Part I
Sematic Web

What is it?

What is already done?

What remains to be done?

Motivating Scenarios

A person asking his web-agent:

- Book the ticket for the movie "The Lives of Others" in the nearest cinema that shows it today evening
- Find a suitable wine for every item in this menu. If possible, choose French
- Microwave, please, go to the website of the dish manufacturer and download the optimal parameters for cooking

Timeline

- **1994:** Foundation of W3C. They develop standards such as: HTML, URL, XML, HTTP, PNG, SVG, CSS
- **1998:** Tim Berners-Lee published "Semantic Web Road Map"
- **1999:** W3C launched groups for designing Sematic Web foundations, the first version of RDF is published
- **2000:** American defence research institution started investigations for ontology descriptions (DAML+OIL project)
- **2001:** "The Sematic Web" paper in Scientific American
- **2004:** New version of RDF, ontology description language OWL
- **2006:** Candidate recommendation of SPARQL, a query language for Semantic Web

Naïve Plan

1. Develop a MEGA-language that is powerful enough to describe all human knowledge and is machine understandable at the same time.
2. Force all web publishers translate their websites to this language
3. Write programs that can search in and reason about all the information in the web

There is a more practical solution for the first step

RDF and OWL

Tim Berners-Lee suggested to **separate** development of syntax and semantic of this MEGA-language:

Resource Description Framework (**RDF**) is a syntax for documents of Semantic Web. It uses links to **ontologies**

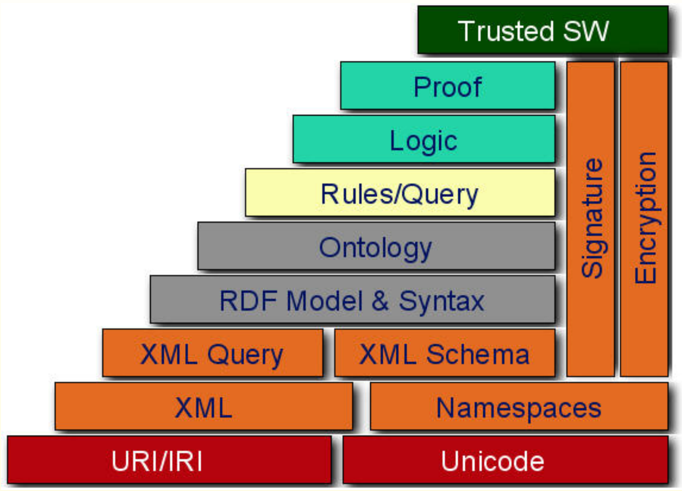
Ontology Web Language (**OWL**) is a language for ontology description

Ontology describes classes of objects, their properties and relationships in some domain, e.g. toy shops

Semantic Web Step-by-Step

1. Syntax for knowledge representation (done: RDF)
2. Ontology description language (done: OWL)
3. Web-services description language (started: OWL-S)
4. Tools for reading/publishing Semantic Web documents (started: Jena, Haystack, Protege)
5. Query language for data represented by RDF (started: SPARQL)
6. Logic reasoning about RDF statements (to be done)
7. Semantic search and semantic agents (to be done)

Cake of Tim Berners-Lee



Concept of Semantic Search

What is **sematic search**?

- Assistance to classical web search
- Question answering systems
- Queries that returns concepts (nodes in XML documents), not documents themselves
- Query is a complex concept (small XML tree), semantic search returns the most similar object
- SQL-like queries to database of RDF statements
- Automated logical inference for RDF statements

Part III
Three Algorithms for Semantic Search

Finding the most specific answer

Concept matching

Identifying related nodes in XML documents

XRANK: Model

Database is a set of **XML documents**
There are **hyperlinks** between nodes
Every node contain some **text**
Query is a short list of keywords

A **complete** answer is a node that together with its descendants contain all query terms

Minimal Answers

A node v is called to be a **minimal answer** if

$$\forall k \in Q :$$
$$[v \text{ contains } k]$$
$$\text{OR}$$
$$[\exists u \text{ son of } v \text{ s.t. } u \text{ contains}^* \ k$$
$$\text{AND } u \text{ is not complete answer}]$$

Search task: find all minimal answers and rank them accordingly to the link/containement popularity

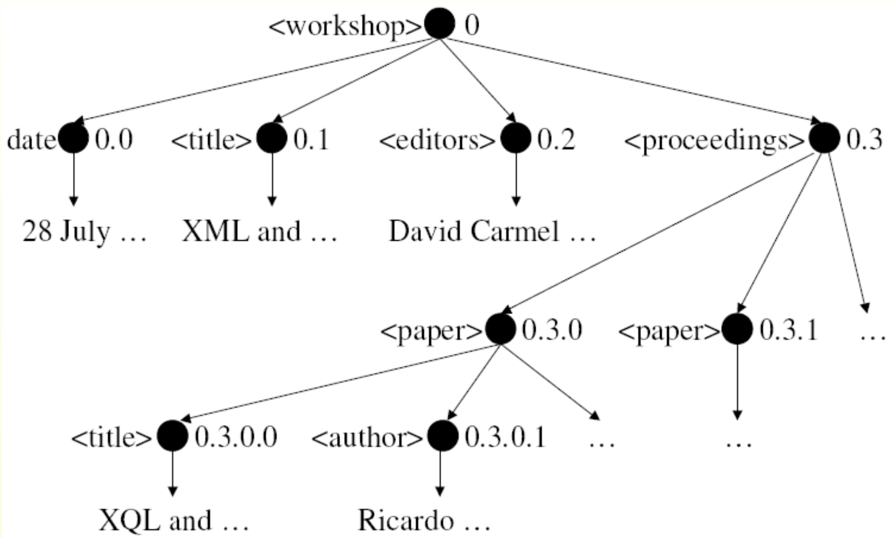
Dewey Code

Nodes in database have Dewey codes $n_1.n_2.\ldots.n_h$

For example, Dewey code 7.2.12 denotes the 12th left son of the 2nd left son of the root of the 7th document in our collection.

For every keyword **Dewey inverted index** store a list of Dewey codes of nodes (DIL) that directly contain this keyword

Illustration from XRANK paper



Minimal Answers Problem

Given Dewey inverted lists for all query terms to return a list of Dewey codes of all minimal answers

Algorithm for Minimal Answers (1/2)

Single pass: every time read
a next code in union of DILs

Keep an auxiliary data structure **Dewey stack**
for the last scanned read node v:

for every predecessor of v
keep a set of keywords
that are contained* prior-or-equal to v
ignoring complete nodes

Algorithm for Minimal Answers (2/2)

Update for Dewey stack from v to u:

1. find a lowest common predecessor w for v and u
2. Sequentially consider ancestors of u from bottom to top, add keywords of u to their set in Dewey stack
3. Stop at root, or with identical set update or on the first complete node
4. In latter case output this node to the list of minimal answers

Conceptual Graph Matching

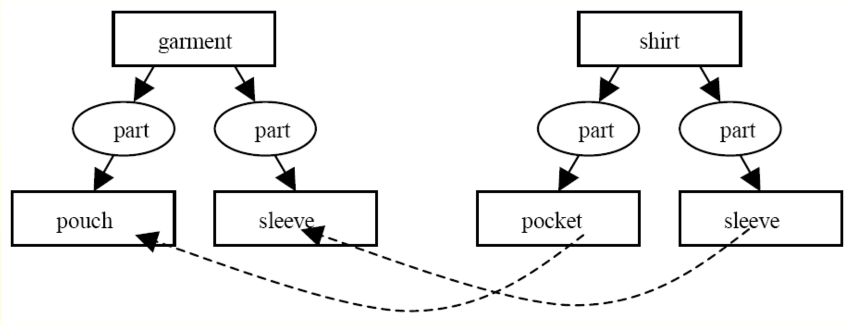
Query is a tree with labelled edges and nodes

Database is a family of trees

Domain information: similarity
between edge/node labels

Task: to find a tree in DB
with maximal similarity to query tree

Illustration from Conceptual Matching Paper



Similarity Formula

$$TreeSim(Q, R) = NodeSim(q_0, r_0) +$$

$$+ \max_{\text{children matching } \pi} \left(\sum_i EdgeSim(q_0 q_i, r_0 r_{\pi_i}) \cdot TreeSim(Q|_{q_i}, R|_{r_{\pi_i}}) \right)$$

Recursive Algorithm for Graph Matching

Compare query tree with every tree in DB separately:

1. Compute *TreeSim* for every pair of Q and R roots' children
2. Find the best matching by applying Bellman-Ford algorithm

Complexity for l-branch trees of depth d:
$C(d+1) = l^2 C(d) + l^4 + const$
$C(d) = \mathcal{O}(l^{2d+2}) = \mathcal{O}(n^2 l^2)$
In general, time complexity is $\mathcal{O}(n^4)$

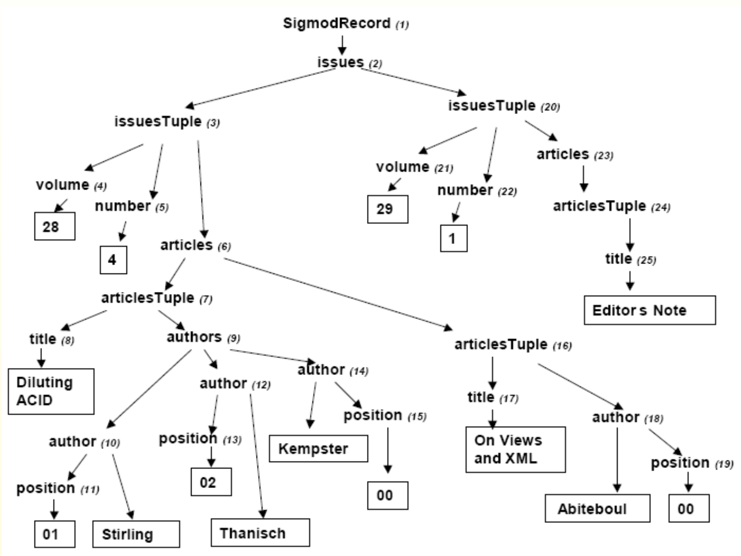
XSEarch Model

Database: huge XML tree with labels on internal nodes and keywords on leafs

Query terms: "label:keyword", "label:", ":keyword"

Answer: a set of **interconnected** nodes that together satisfy all query terms

Illustration from XSEarch Paper



Interconnection

Nodes u and v are **interconnected** iff on the shortest path between them only labels of u and v can coincide

Properties of Interconnection

For u being ancestor of v:

$$InCon[u,v] = InCon[u, parent(v)] \& \\ (label(u) \neq label(parent(v))) \quad \& \quad InCon[son_v(u), v] \& \\ (label(son_v(u)) \neq label(v))$$

Otherwise:

$$InCon[u,v] = InCon[u, parent(v)] \& \ (label(u) \neq \\ label(parent(v))) \quad \& \quad InCon[parent(u), v] \& \\ (label(parent(u)) \neq label(v))$$

Using these formulas we can compute $InCon$ for all pairs in $\mathcal{O}(|\mathcal{T}|)$ time by dynamic programming

Directions for Further Research

- Algorithms for **online** conceptual graph matching
- Queries using arithmetic: "what is the most popular movie (according to IMDB) I have not seen yet?"
- Automated inference for RDF statements? Semantic search for the case when the answer is not in the DB, but can be derived from it.

Highlights

- XRANK: merging Dewey inverted lists by a single pass
- Concept matching: finding the most similar tree to the query tree
- XSEarch: computing interconnection by dynamic programming

Thanks for participating in this course!

References (1/2)

Course homepage

http://yury.name/algoweb.html

L.Guo, F.Shao, C.Botev, J.Shanmugasundaram
XRANK: Ranked Keyword Search over XML Documents
http://www.cs.fiu.edu/~vagelis/classes/COP6727/publications/XRank.pdf

S.Cohen, J.Mamou, Y.Kanza, Y.Sagiv
XSEarch: A Semantic Search Engine for XML
http://wwwdb.informatik.uni-rostock.de/Archiv/vldb2003/papers/S03P02.pdf

J.Zhong, H.Zhu, J.Li, Y.Yu
Conceptual Graph Matching for Semantic Search
http://apex.sjtu.edu.cn/docs/iccs2002.pdf

References (2/2)

R.Guha, R.McCool, E.Miller
Semantic Search
http://learning.ncsa.uiuc.edu/lmarini/papers/p700-guha.pdf

S.Harris
SPARQL query processing with conventional relational database systems
http://eprints.ecs.soton.ac.uk/11126/01/harris-ssws05.pdf

E.Brill, S.Dumais, M.Banko
An Analysis of the AskMSR Question-Answering System
http://www.stanford.edu/class/linguist180/EMNLP2002.pdf

T.Berners-Lee, J.Hendler, O.Lassila
Semantic Web
http://wireless.ictp.trieste.it/school_2002/lectures/canessa/0501berners-lee.ps