Semantic Search
A Guide to Web Research: Lecture 4

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Stuttgart, Spring 2007
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

1. Introduction to Semantic Web
   - Concept and History of Development
   - Architecture of Semantic Web
   - Concept of Semantic Search
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2. Three Algorithms for Semantic Search
   - Minimal Answers
   - Concept Matching
   - Computing Interconnections
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3. Directions for Further Research
Part I
Semantic 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
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
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 to translate their websites to this language.

3. Write programs that can search in and reason about all the information in the web.
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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.
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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
1. Syntax for knowledge representation (done: RDF)
Semantic Web Step-by-Step

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6. Logic reasoning about RDF statements (to be done)
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7. Semantic search and semantic agents (to be done)
Cake of Tim Berners-Lee

- Trusted SW
- Signature
- Encryption
- Proof
- Logic
- Rules/Query
- Ontology
- RDF Model & Syntax
- XML Query
- XML Schema
- XML
- Namespaces
- URI/IRI
- Unicode
Concept of Semantic Search

What is *semantic search*?
Concept of Semantic Search

What is semantic search?

- Assistance to classical web search
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- Question answering systems
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- 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
Database is a set of **XML documents**
There are **hyperlinks** between nodes
Every node contain some **text**
Query is a short list of keywords
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A **complete** answer is a node that together with its descendants contain all query terms
A node $v$ is called to be a **minimal answer** if

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

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**Search task:** find all minimal answers and rank them accordingly to the link/containement popularity
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.
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For every keyword **Dewey inverted index** store a list of Dewey codes of nodes (DIL) that directly contain this keyword.
Minimal Answers Problem

Given Dewey inverted lists for all query terms to return a list of Dewey codes of all minimal answers
**Single pass:** every time read a next code in union of DILs
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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 $v$
**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
Query is a tree with labelled edges and nodes

Database is a family of trees

Domain information: similarity between edge/node labels
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
TreeSim(Q, R) = NodeSim(q₀, r₀) +

+ \max_{\text{children matching } \pi} \left( \sum_{i} \text{EdgeSim}(q₀qᵢ, r₀r_{πᵢ}) \cdot \text{TreeSim}(Q|qᵢ, R|r_{πᵢ}) \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
Recursive Algorithm for Graph Matching

Compare query tree with every tree in DB separately:

1. Compute $\text{TreeSim}$ for every pair of $Q$ and $R$ roots’ children

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Complexity for $l$-branch trees of depth $d$:

$$C(d + 1) = l^2 C(d) + l^4 + \text{const}$$

$$C(d) = O(l^{2d+2}) = O(n^2 l^2)$$
Recursive Algorithm for Graph Matching

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Complexity for $l$-branch trees of depth $d$:

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$C(d) = \mathcal{O}(l^{2d+2}) = \mathcal{O}(n^2 l^2)$

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”
**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
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 \( v \):

\[
\text{InCon}[u, v] = \text{InCon}[u, \text{parent}(v)] \& (\text{label}(u) \neq \text{label}(\text{parent}(v))) \& \text{InCon}[\text{son}_v(u), v] \& (\text{label}(\text{son}_v(u)) \neq \text{label}(v))
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Using these formulas we can compute \( \text{InCon} \) for all pairs in \( O(|\mathcal{T}|) \) for all pairs 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.
Call for participation

Know a relevant reference? Have an idea? Find a mistake? Solved one of these problems?

- Knock to my office 1.156
- Write to me yura@logic.pdmi.ras.ru
- Join our informal discussions
- Participate in writing a follow-up paper
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
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- 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

Vielen Dank für Ihre Aufmerksamkeit! Fragen?
Course homepage

http://logic.pdmi.ras.ru/~yura/webguide.html

L. Guo, F. Shao, C. Botev, J. Shanmugasundaram
XRANK: Ranked Keyword Search over XML Documents

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
R. Guha, R. McCool, E. Miller

Semantic Search

http://learning.ncsa.uiuc.edu/1marini/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


T. Berners-Lee, J. Hendler, O. Lassila

Semantic Web

http://wireless.ictp.trieste.it/school_2002/lectures/canessa/0501berners-lee.ps