# Semantic Search

## A Guide to Web Research: Lecture 4

Yury Lifshits

Steklov Institute of Mathematics at St.Petersburg

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

# Outline

# Outline

1. Introduction to Semantic Web
   - Concept and History of Development
   - Architecture of Semantic Web
   - Concept of Semantic Search
2. Three Algorithms for Semantic Search
   - Minimal Answers
   - Concept Matching
   - Computing Interconnections
3. Directions for Further Research

# 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

# 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 translate their websites to this language
3. Write programs that can search in and reason about all the information in the 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

# 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)

# Semantic Web Step-by-Step

1. Syntax for knowledge representation (done: RDF)
2. Ontology description language (done: OWL)

# 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)

# 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)

# 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)

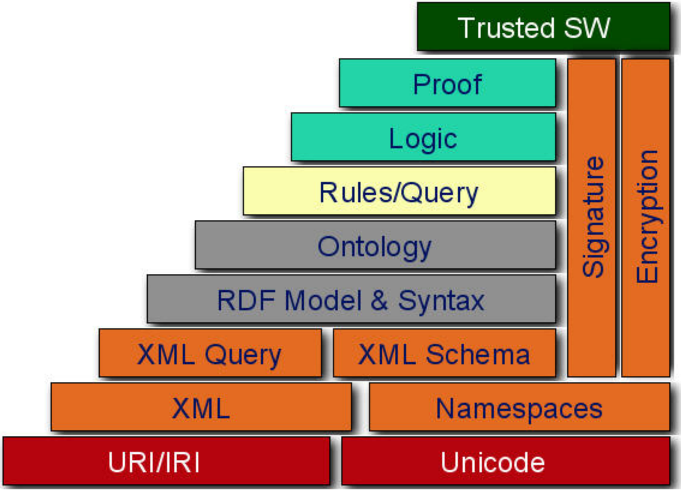
# Semantic Web Step-by-Step

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)

# 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**?

# Concept of Semantic Search

What is **sematic search**?

- Assistance to classical web search

# Concept of Semantic Search

What is **sematic search**?

- Assistance to classical web search
- Question answering systems

# 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

# 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

# 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

# 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

# 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

$$\forall k \in Q :$$

$[v$ contains $k]$

OR

$[\exists u$ son of $v$ s.t. $u$ contains* $k$

AND $u$ is not complete answer$]$

# 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.

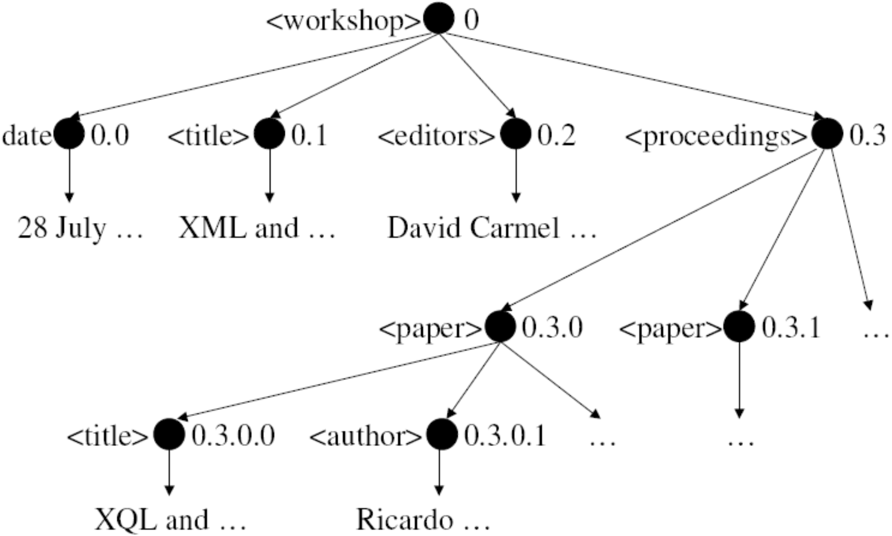
# Dewey Code

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

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

# 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 $v$

# 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

# Conceptual Graph Matching

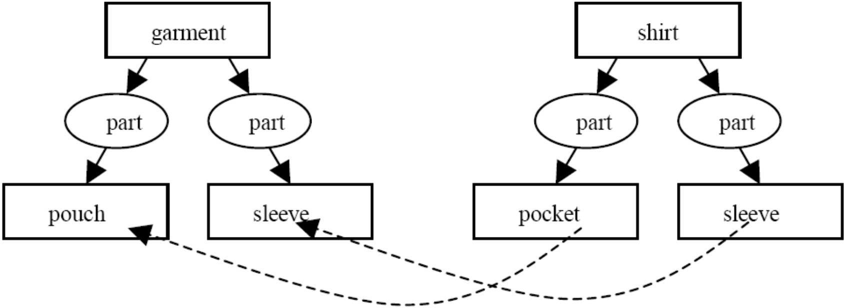
**Query** is a tree with labelled edges and nodes

**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

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

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

# 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

# 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 $d$:

$$C(d+1) = l^2 C(d) + l^4 + const$$

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

# 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”

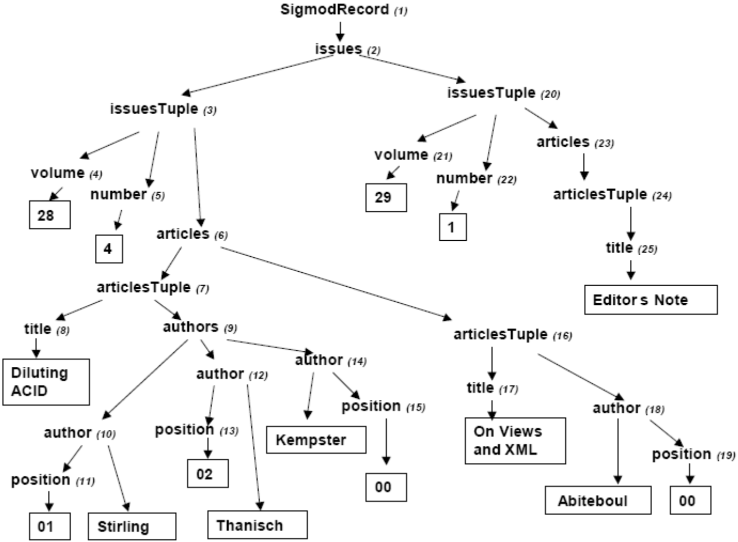
# XSEarch Model

**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 $v$:

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

# 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:

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

# 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 $\mathcal{O}(|\mathcal{T}|)$ 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

# 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

Vielen Dank für Ihre Aufmerksamkeit!
Fragen?

# References (1/2)

**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

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