Knowledge Representation for the Semantic Web

WS 2017/2018

Lecture 1: Introduction

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D5: Databases and Information Systems Group, MPI for Informatics

19/10/2017
Overview

Organization

Content

Semantic Web

Knowledge Representation

KRSW
About me

• **Short CV:**
  - **2005-2010** Diploma in applied informatics from St. Petersburg state university
  - **2011-2015** PhD in computational logic from TU Wien
  - **2015-present** Postdoctoral researcher at D5 group of MPI

• **Research interests:**
  - Knowledge representation and reasoning
  - Semantic web
  - Inductive rule learning

• **Appointments:** by email dstepano@mpi-inf.mpg.de
Basic course info

- **Number of credits**: 6 ECTS
- **Lectures**: Thursdays 14:00-16:00 @ 014, E1.3
- **Tutorials**: In January in small groups (every student is expected to attend three 1-hour tutorials)
- **TA**: Mohamed Gad-Elrab
- **Material** will be put on the course web page
- **Assignments**: two theoretical and two practical assignments will have to be completed
- **Final exams**: in a written form

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Evaluation

- Final number of points sums up from:
  - 2 exercise sheets (max. 10 points)
  - 2 projects (max. 20 points)
  - final exam (max. 70 points)

- The grades are computed as follows:
  - $\geq 91$ 1
  - $\geq 81$ 2
  - $\geq 71$ 3
  - $\geq 60$ 4
  - $< 60$ 5
Course agenda

- Motivation
- Description logics (3 lectures)
- Answer set programming (3 lectures)
- Combining DL and ASP and other advanced topics
- Rule learning
Course agenda

- **Motivation (today)**
  - What is Semantic Web?
  - What is Knowledge Representation?
  - How are KR and SW connected?

- Description logics (3 lectures)

- Answer set programming (3 lectures)

- Combining DL and ASP and other advanced topics

- Rule learning
Syntactic Web

- Typical web page markup consists of
  - Rendering information (font size and color)
  - Hyper-links to related content
- Semantic content is accessible to humans but not machines
Current syntactic Web

- Immensely successful
- Huge amounts of data
- Syntax standards for transfer of structured data
- Machine-processable, human-readable documents

**BUT:**
- Content/knowledge cannot be accessed by machines, i.e. machine-processable but not machine-understandable
- Meaning (semantics) of transferred data is not accessible
What can we see?

- KR for SW course is an advanced course of 6 ECTS
- It takes place on Thursdays at 14:00-16:00
- The location is 014 of E 13
- Offered by D5: Databases and Information systems
- Other courses offered by D5 in winter semester 2017/2018 are ...
What can machines see?
WWW: humans only!

How can we answer the queries:

- Which advanced lectures does the department headed by Prof. G. Weikum offer in WS 2017/2018?
- Which papers has Prof. G. Weikum published in 2017?

Just google “Prof. G. Weikum”!

- Web page contains enough info to answer queries, but
  - this info is implicit
  - we understand it because we know the context
  - machines cannot make sense of it
Why Syntactic Web is not enough?

Cannot answer “knowledge queries” such as:

- Which politicians are also scientists?
- What genes are involved in signal transduction and are related to pyramidal neurons?
- What is the price, duration of warrantee, and technical features of phones that cost less than 300 Euro and are not of Apple brand?
- Which papers has Prof. G. Weikum published in 2017?
- Which advanced lectures does the department headed by Prof. G. Weikum offer in WS 2017/2018?
How can we liberate the Web data?

How can we answer the queries:

- Which papers has Prof. G. Weikum published in 2017?
- Which advanced lectures does the department headed by Prof. G. Weikum offer in WS 2017/2018?

- some extra information-metadata must be added to links and data
- this information links data to other data and gives meaning to it
- this information must be machine readable
- everything must be done in a standardized way
Need for semantics!

„The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation"

Semantic Web is ...

- the Web of Data as an upgrade of the Web of documents
- the Web as a huge decentralized database (knowledge base) of machine-processable data

**Main challenge:**

How to represent knowledge and reason about it?
Knowledge representation

**General goal:**

develop formalisms for providing high level description of the world that can be effectively used to build intelligent applications

Cognitive approaches, e.g., network-structures

Logic-based approaches, e.g., fragments of First Order Logic
History of cognitive KR

Plato: “Knowledge is justified true belief”

Tree of Knowledge
History of cognitive KR

Plato: “Knowledge is justified true belief”
History of cognitive KR

Semantic Networks introduced in [Quillan, 1967]
Modern days: Knowledge graphs
Knowledge graphs

Roger Federer (born 8 August 1981) is a Swiss professional tennis player. Many players and analysts have called him the greatest tennis player of all time. He turned professional in 1996 and was continuously ranked in the top 10 from October 2002 to November 2016. He is currently ranked world No. 4 by the Association of Tennis Professionals (ATP). Federer has won 18 Grand Slam singles titles, the most in history for a male tennis player, and held the No. 1 spot in the ATP rankings for a total of 309 weeks. In majors, he has won seven Wimbledon titles, five Australian Open titles, six US Open titles and one French Open title. He is among the eight men to capture a career Grand Slam. He has reached a record 28 men's singles Grand Slam finals, including 10 in a row from the 2005 Wimbledon Championships to the 2007 US Open.

Federer's ATP tournament records include winning a record six ATP World Tour Finals and playing in the finals at all nine ATP Masters 1000 tournaments. He also won the Olympic gold medal in doubles with his compatriot Stan Wawrinka at the 2008 Summer Olympic Games and the Olympic silver medal in singles at the 2012 Summer Olympic Games. Representing Switzerland, he was part of the 2014 winning Davis Cup team. He was named the Laureus World Sportsman of the Year for a record four consecutive years from 2005 to 2008.

Country (sports)
- Switzerland
Residence
- Birmensdorf, Switzerland
Born
- 8 August 1981
- Basel, Switzerland
Height
- 1.85 m (6 ft 1 in)
Turned pro
- 1998
Height
- 1.85 m (6 ft 1 in)
Games
- Right-handed (one-handed backhand)
Prize money
- US$ 103,990,195
Official website
- rogerfederer.com

Singles
- Career record
- 1699-246 (68.71%)
- Grand Slam and ATP World Tour main-draw matches
- in Grand Slams and in Davis Cup
- Career titles
- 91 (3rd in the Open Era)
- Highest ranking
- No. 1 (2 February 2004)
- Current ranking
- No. 4 (3 April 2017)
- Grand Slam Singles results
Knowledge graphs

KGs are huge collections of positive unary and binary facts

tennisPlayer(rogerFederer)
bornIn(rogerFederer, basel)
Semantic Web search today

winner of Australian Open 2017

Roger Federer
Tennis player

Roger Federer is a Swiss professional tennis player who is currently ranked world No. 10 by the Association of Tennis Professionals. Many players and analysts have called him the greatest tennis player of all time. Wikipedia

Born: August 8, 1981 (age 35 years), Basel, Switzerland
Height: 1.85 m
Weight: 85 kg
Spouse: Mirka Federer (m. 2009)
Children: Lenny Federer, Myla Rose Federer, Charlene Riva Federer, Leo Federer
Semantic Web search today

∃X winnerOf(X, AustralianOpen2017)
Semantic Web search today

∃X winnerOf(X, AustralianOpen2017)
Problem: Inconsistency

Web pages

Noisy

Information Extraction

Difficult

Knowledge Graph

Contains mistakes
Problem: Incompleteness

Google KG **misses** Roger’s living place, but contains his wife’s Mirka’s..
Need for logical reasoning on top of KGs

Google KG misses Roger’s **living place**, but contains his **wife’s** Mirka’s.

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**Roger Federer’s glass mansion**: Tennis star’s £6.5m Swiss waterfront

[www.telegraph.co.uk](http://www.telegraph.co.uk) > Sport > Tennis > Roger Federer

Tennis star **Roger Federer** is to move his family into a £6.5milion glass mansion on the shores of Lake Zurich after work was completed on the state-of-the-art...

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**Roger Federer’s Luxurious Houses | Basel Shows**


**Roger Federer** also owns a lavish apartment in Dubai apart from properties in Switzerland. He has chosen this **location** as a base of training to get use to heat...

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**Bottmingen, Switzerland**
Need for logical reasoning on top of KGs

Google KG misses Roger’s living place, but contains his wife’s Mirka’s..

Need for reasoning!

KG: Mirka lives in Bottmingen
KG: Roger is married to Mirka
Axiom: Married people live together

Derivation: Roger lives in Bottmingen
History of Logic-based KR

- **1950’s:** First Order Logic (FOL) for KR (undecidable)  
  (e.g. [McCarthy, 1959])

- **1970’s:** Network-shaped structures for KR (no formal semantics)  
  (e.g. semantic networks [Quillian, 1967], frames [Minsky, 1985])

- **1979:** Encoding of network-shaped structures into FOL [Hayes, 1979]

- **1980’s:** Description Logics (DL) for KR
  - Decidable fragments of FOL
  - Theories encoded in DLs are called ontologies
  - Many DLs with different expressiveness and computational features
  - Particularly suited for conceptual reasoning
Description Logic Ontologies

Open World Assumption (OWA): what is not derived is unknown

Inclusions: \( \text{Female} \sqsubseteq \neg \text{Male}, \text{hasSister} \sqsubseteq \text{hasSibling}, \text{hasBrother} \sqsubseteq \text{hasSibling} \)
Description Logic Ontologies

Open World Assumption (OWA): what is not derived is unknown

Inclusions: \( \text{Female} \sqsubseteq \neg \text{Male}, \text{hasSister} \sqsubseteq \text{hasSibling}, \text{hasBrother} \sqsubseteq \text{hasSibling} \)

Complex axioms: \( \text{Uncle} \equiv \text{Male} \sqcap \exists \text{hasSibling}. \exists \text{hasChild} \)
What can not be said in DLs?

- Exceptions from theories (due to monotonicity)
What can not be said in DLs?

- **Exceptions** from theories (due to *monotonicity*)

\[
\text{WithBeard} \sqsubseteq \text{Male} \\
\text{Female} \sqsubseteq \neg \text{Male} \\
\text{WithBeard}(c)
\]

\[
\text{People with beards are male} \\
\text{Female are not male} \\
\text{C has a beard}
\]
What can not be said in DLs?

- Exceptions from theories (due to monotonicity)

\( \text{WithBeard} \sqsubseteq \text{Male} \)
\( \text{Female} \sqsubseteq \neg \text{Male} \)
\( \text{WithBeard}(c) \)

______________________________
\( \text{Male}(c) \)

\( \text{People with beards are male} \)
\( \text{Female are not male} \)
\( \text{C has a beard} \)

______________________________
\( \text{C is male} \)
What can not be said in DLs?

- **Exceptions** from theories (due to monotonicity)

\[
\begin{align*}
\text{WithBeard} & \sqsubseteq \text{Male} \\
\text{Female} & \sqsubseteq \neg\text{Male} \\
\text{WithBeard}(c) & \quad \text{People with beards are male} \\
\text{Female}(c) & \quad \text{Female are not male} \\
\text{Male}(c) & \quad \text{C has a beard} \\
\neg\text{Male}(c) & \quad \text{C is female} \\
\hline \\
\text{Male}(c) & \quad \text{C is male} \\
\neg\text{Male}(c) & \quad \text{C is not male}
\end{align*}
\]

**Monotonicity:** the more we add, the more we get!
History of Logic-based KR

- **1970’s:** Logic programming
  (e.g. Prolog)

- **1980’s:** Nonmonotonic logics
  (e.g. circumscription [McCarthy, 1980], default logic [Reiter, 1980])

- **1988:** Nonmonotonic rules under answer set semantics (ASP)
  [Gelfond and Lifschitz, 1988]
  - Logic programs with model-based semantics
  - Disjunctive datalog with default negation *not*
Not is not ¬!

Default negation \textit{not}

At a rail road crossing cross the road if no train is known to approach
\[
\text{walk} \leftarrow \text{at}(X), \text{crossing}(X), \textbf{not} \text{ train\_approaches}(X)
\]

Classical negation ¬

At a rail road crossing cross the road if no train approaches
\[
\text{walk} \leftarrow \text{at}(X), \text{crossing}(X), \neg\text{train\_approaches}(X)
\]
Nonmonotonic Rules

Closed World Assumption (CWA): what is not derived is false

Rule: \[ a_1 \lor \ldots \lor a_k \leftarrow b_1, \ldots, b_m, \text{not } b_{m+1}, \ldots, \text{not } b_n \]

Informal semantics: If \( b_1, \ldots, b_m \) are true and none of \( b_{m+1}, \ldots, b_n \) is known, then at least one among \( a_1, \ldots, a_k \) must be true

Default negation: unless a child is adopted one of his parents must be female

\[ \text{female}(Y) \lor \text{female}(Z) \leftarrow \text{hasParent}(X, Y), \text{hasParent}(X, Z), \]
\[ Y \neq Z, \text{not adopted}(X) \]

Constraint: ensure that no one is a parent of himself

\[ \bot \leftarrow \text{parent}(X, Y), \text{parent}(Y, X) \]
### Answer Set Programs

**Evaluation** of ASP programs is model-based

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**Answer set program (ASP) is a set of nonmonotonic rules**

(1) $\text{hasParent}(\text{john}, \text{pat})$  
(2) $\text{hasParent}(\text{john}, \text{alex})$  
(3) $\text{male}(\text{alex})$  
(4) $\text{female}(Y) \leftarrow \text{hasParent}(X, Y), \text{hasParent}(X, Z), Y \neq Z, \text{male}(Z), \text{not adopted}(X)$
Answer Set Programs

Evaluation of ASP programs is model-based

1. Grounding: substitute all variables with constants in all possible ways

Answer set program (ASP) is a set of nonmonotonic rules

(1) hasParent(john, pat)  (2) hasParent(john, alex)  (3) male(alex)
(4) female(Y) ← hasParent(X, Y), hasParent(X, Z),
    Y ≠ Z, male(Z), not adopted(X)
Answer Set Programs

Evaluation of ASP programs is model-based
1. Grounding: substitute all variables with constants in all possible ways

**Answer set program (ASP)** is a set of nonmonotonic rules

(1) \text{hasParent}(john, pat)  
(2) \text{hasParent}(john, alex)  
(3) \text{male}(alex) 

(4) \text{female}(pat) \leftarrow \text{hasParent}(john, pat), \text{hasParent}(john, alex), \text{male}(alex), \text{not adopted}(john)
Answer Set Programs

Evaluation of ASP programs is model-based
1. Grounding: substitute all variables with constants in all possible ways
2. Solving: compute a minimal model (answer set) \( I \) satisfying all rules

Answer set program (ASP) is a set of nonmonotonic rules

\[
(1) \text{hasParent}(john, pat) \quad (2) \text{hasParent}(john, alex) \quad (3) \text{male}(alex) \\
(4) \text{female}(pat) \leftarrow \text{hasParent}(john, pat), \text{hasParent}(john, alex), \text{male}(alex), \text{not adopted}(john)
\]

\( I = \{ \text{hasParent}(john, pat), \text{hasParent}(john, alex), \text{male}(alex), \text{female}(pat) \} \)

CWA: \( \text{adopted}(john) \) can not be derived, thus it is false
**Answer Set Programs**

Evaluation of ASP programs is model-based

1. **Grounding**: substitute all variables with constants in all possible ways
2. **Solving**: compute a minimal model (answer set) \( I \) satisfying all rules

**Answer set program (ASP)** is a set of nonmonotonic rules

1. \( \text{hasParent}(john, pat) \)
2. \( \text{hasParent}(john, alex) \)
3. \( \text{male}(alex) \)
4. \( \text{female}(pat) \leftarrow \text{hasParent}(john, pat), \text{hasParent}(john, alex), \text{male}(alex), \text{not adopted}(john) \)
5. \( \text{adopted}(john) \)

\[ I = \{ \text{hasParent}(john, pat), \text{hasParent}(john, alex), \text{male}(alex), \text{female}(pat) \} \]

**Nonmonotonicity**: adding facts might lead to loss of consequences!
Knowledge Representation Standards in SW context

1994  First public presentation of the Semantic Web idea
1998  Start of standardization of data model (RDF) and a first ontology languages (RDFS) at W3C
2000  Start of large research projects about ontologies in the US and Europe (DAML & Ontoknowledge)
2002  Start of standardization of a new ontology language (OWL) based on research results
2004  Finalization of the standard for data (RDF) and ontology (OWL)
2008  Standardization of a query language (SPARQL)
2009  Extension of OWL to OWL 2.0
2010  Standard Rule Interchange Format (RIF)
Knowledge Representation Standards in SW context

- **User Interface & Applications**: Trust
- **Proof**: Unifying Logic
- **Crypto**: Query: SPARQL, Ontology: OWL, RDFS, Rule: RIF, Data interchange: RDF, XML, URI/IRI

**Timeline**

- **1994**: First public presentation of the Semantic Web idea
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Course Agenda

• Description Logic ontologies (DL)
  • Theoretical background
  • Ontology Web Language (OWL)
  • Tools and applications

• Answer Set Programming rules (ASP)
  • Theoretical background
  • Answer set programming semantics
  • Tools and applications

• Combining DL and ASP
  • DL-programs
  • Inconsistency handling
  • Other advanced topics

• Learning rules from data
  • Relational association rule learning
  • Learning rules with exceptions under incompleteness
  • Other advanced topics
Michael Gelfond and Vladimir Lifschitz.
The stable model semantics for logic programming.

P. J. Hayes.
The logic of frames.

John McCarthy.
Programs with common sense.

John McCarthy.
Circumscription - A form of non-monotonic reasoning.

Marvin Minsky.
A framework for representing knowledge.

M. Ross Quillian.
Word concepts: A theory and simulation of some basic capabilities.

Raymond Reiter.
A logic for default reasoning.