Knowledge Representation for the Semantic Web

Winter Quarter 2011

Slides 7 – 02/08/2011

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Textbook (required)

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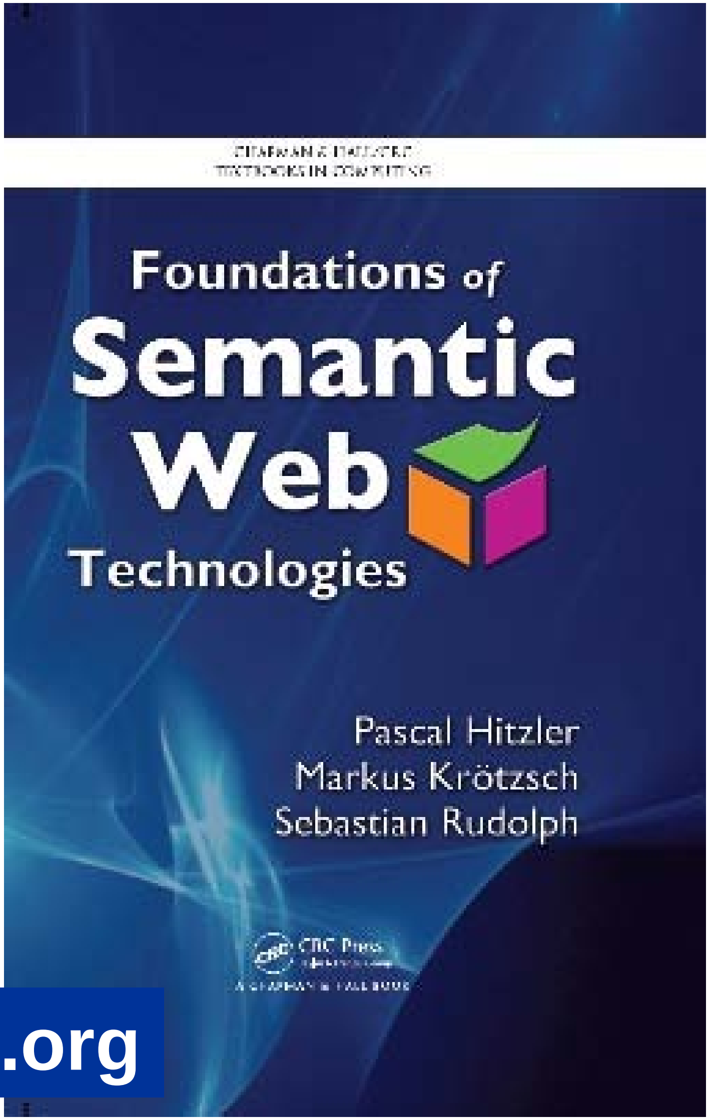
Foundations of Semantic Web Technologies

Chapman & Hall/CRC, 2010

Choice Magazine Outstanding Academic Title 2010 (one out of seven in Information & Computer Science)



http://www.semantic-web-book.org

A Semantic Puzzle

From Horridge, Parsia, Sattler, From Justifications to Proofs for Entailments in OWL. In: Proceedings OWLED2009.
http://sunsite.informatik.rwth-aachen.de/Publications/CEUR-WS/Vol-529/

$$\mathsf{Person} \sqsubseteq \neg\mathsf{Movie}$$

$$\mathsf{RRated} \sqsubseteq \mathsf{CatMovie}$$

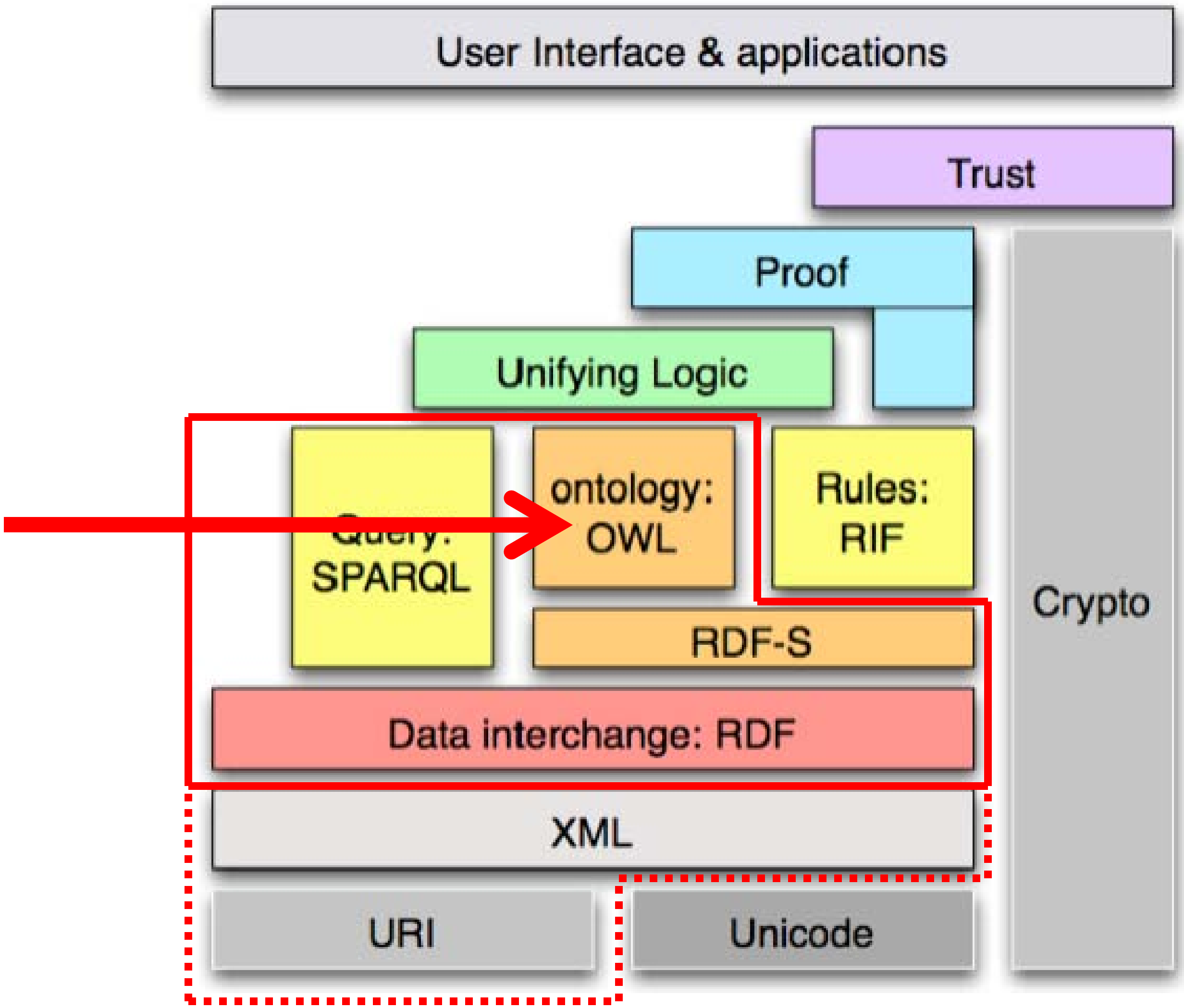
$$\mathsf{CatMovie} \sqsubseteq \mathsf{Movie}$$

$$\mathsf{RRated} \equiv (\exists \mathsf{hasScript}.\mathsf{ThrillerScript}) \sqcup (\forall \mathsf{hasViolenceLevel}.\mathsf{High})$$

$$\mathsf{Domain}(\mathsf{hasViolenceLevel},\ \mathsf{Movie})$$

Fig. 1. A justification for $\mathsf{Person} \sqsubseteq \bot$

Today: Model-theoretic Semantics



Today's Session: DL Semantics

1. Model-theoretic Semantics of SROIQ(D)
2. Class Project
3. Class Presentations

Model-theoretic Semantics

- **Recall:**

  How does one make a model-theoretic semantics?

  What – which mathematical entity – actually captures the "meaning"?

  How would we get at this here?

Model-theoretic Semantics

- There are two semantics for OWL.

1. Description Logic Semantics
   also: Direct Semantics; FOL Semantics
   Can be obtained by translation to FOL.
   Some global restrictions apply! (see next slide)

2. RDF-based Semantics (requires RDF/XML syntax: done later)
   No syntax restrictions apply.
   Extends the direct semantics with RDFS-reasoning features.

In the following, we will deal with the direct semantics only.

Direct Semantics

To obtain decidability, syntactic restrictions apply.

- **Type separation / punning**
- **No cycles in property chains.**
  (See global restrictions mentioned earlier.)
- **No transitive properties in cardinality restrictions.**
  (See global restrictions mentioned earlier.)

Decidability

- A problem is *decidable* if there exists an always terminating algorithm which determines, whether or not a solution exists.
- A problem is *semi-decidable* if there exists an algorithm which, in case a solution exists, finds this out in finite time.
- A problem is *undecidable* if if it not decidable.

- Note there exist problems which are semi-decidable and undecidable.

Decidability of DLs

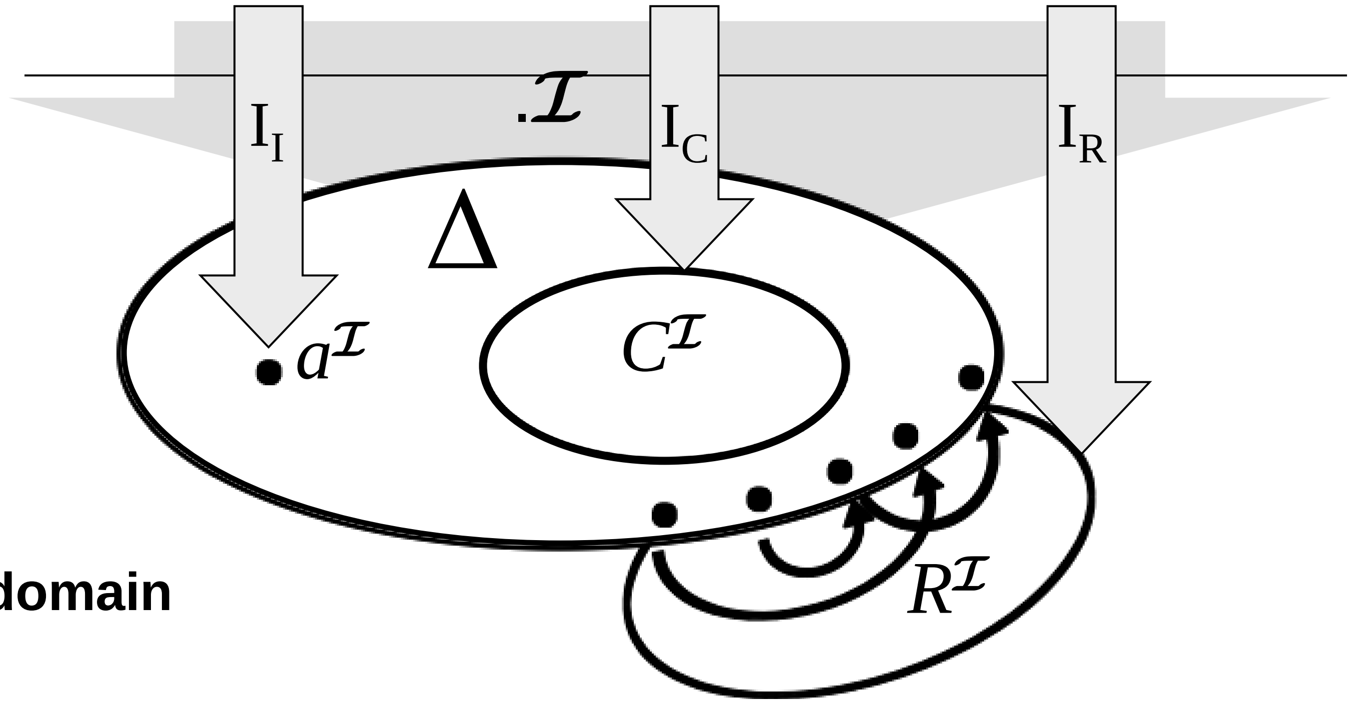
- **A description logic is decidable if “entailment of axioms” is decidable.**

- **Most description logics are decidable.**
  Decidability is one of the design criteria for “good” description logics.

Direct Semantics

- model-theoretic semantics
- starts with interpretations
- an interpretation $\mathcal{I}$ maps

  individual names, class names and property names...



...into a domain

Interpretation Example

If we consider, for example, the knowledge base consisting of the axioms

$$\begin{gathered}\mathtt{Professor} \sqsubseteq \mathtt{FacultyMember}\\ \mathtt{Professor}(\mathtt{rudiStuder})\\ \mathtt{hasAffiliation}(\mathtt{rudiStuder}, \mathtt{aifb})\end{gathered}$$

then we could set

$$\begin{aligned}\Delta &= \{a, b, \mathrm{Ian}\}\\ \mathrm{I}_{\mathbf{I}}(\mathtt{rudiStuder}) &= \mathrm{Ian}\\ \mathrm{I}_{\mathbf{I}}(\mathtt{aifb}) &= b\\ \mathrm{I}_{\mathbf{C}}(\mathtt{Professor}) &= \{a\}\\ \mathrm{I}_{\mathbf{C}}(\mathtt{FacultyMember}) &= \{a, b\}\\ \mathrm{I}_{\mathbf{R}}(\mathtt{hasAffiliation}) &= \{(a, b), (b, \mathrm{Ian})\}\end{aligned}$$

Intuitively, these settings are nonsense, but they nevertheless determine a valid interpretation.

OWL Direct Semantics

- mapping is extended to complex class expressions:
  - $\top^I = \Delta^I$ $\qquad \bot^I = \emptyset$
  - $(C \sqcap D)^I = C^I \cap D^I$ $\qquad (C \sqcup D)^I = C^I \cup D^I$ $\qquad (\neg C)^I = \Delta^I \setminus C^I$
  - $(\forall R.C)^I = \{\, x \mid \text{for all } (x,y) \in R^I \text{ we have } y \in C^I \}$
    $(\exists R.C)^I = \{\, x \mid \text{there is } (x,y) \in R^I \text{ with } y \in C^I \}$
  - $(\geq nR.C)^I = \{\, x \mid \#\{\, y \mid (x,y) \in R^I \text{ and } y \in C^I \} \geq n \,\}$
  - $(\leq nR.C)^I = \{\, x \mid \#\{\, y \mid (x,y) \in R^I \text{ and } y \in C^I \} \leq n \,\}$
- ...and to role expressions:
  - $U^I = \Delta^I \times \Delta^I$ $\qquad (R^-)^I = \{\, (y,x) \mid (x,y) \in R^I \,\}$
- ...and to axioms:
  - $C(a)$ holds, if $a^I \in C^I$ $\qquad R(a,b)$ holds, if $(a^I,b^I) \in R^I$
  - $C \sqsubseteq D$ holds, if $C^I \subseteq D^I$ $\qquad R \sqsubseteq S$ holds, if $R^I \subseteq S^I$
  - Disjoint(R,S) holds if $R^I \cap S^I = \emptyset$
  - $S_1 \circ S_2 \circ \ldots \circ S_n \sqsubseteq R$ holds if $S_1^I \circ S_2^I \circ \ldots \circ S_n^I \subseteq R^I$

OWL Direct Semantics

- **what's below gives us a notion of *model*:**

  An interpretation is a model of a set of axioms if all the axioms hold (are evaluated to true) in the interpretation.

- **Notion of *logical consequence* obtained as usual.**

- **...and to axioms:**
  - **C(a) holds, if $a^I \in C^I$ R(a,b) holds, if $(a^I,b^I) \in R^I$**
  - **$C \sqsubseteq D$ holds, if $C^I \subseteq D^I$ $R \sqsubseteq S$ holds, if $R^I \subseteq S^I$**
  - **Disjoint(R,S) holds if $R^I \cap S^I = \emptyset$**
  - **$S_1 \circ S_2 \circ \dots \circ S_n \sqsubseteq R$ holds if $S_1^I \circ S_2^I \circ \dots \circ S_n^I \subseteq R^I$**

Not a model!

If we consider, for example, the knowledge base consisting of the axioms

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then we could set

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Intuitively, these settings are nonsense, but they nevertheless determine a valid interpretation.

A model

$$\mathtt{Professor} \sqsubseteq \mathtt{FacultyMember}$$
$$\mathtt{Professor}(\mathtt{rudiStuder})$$
$$\mathtt{hasAffiliation}(\mathtt{rudiStuder}, \mathtt{aifb})$$

$$\Delta = \{a, r, s\}$$
$$\mathrm{I}_{\mathbf{I}}(\mathtt{rudiStuder}) = r$$
$$\mathrm{I}_{\mathbf{I}}(\mathtt{aifb}) = a$$
$$\mathrm{I}_{\mathrm{C}}(\mathtt{Professor}) = \{r\}$$
$$\mathrm{I}_{\mathrm{C}}(\mathtt{FacultyMember}) = \{r, s\}$$
$$\mathrm{I}_{\mathrm{R}}(\mathtt{hasAffiliation}) = \{(r, a)\}$$

Models

$$\texttt{Professor} \sqsubseteq \texttt{FacultyMember}$$

$$\texttt{Professor}(\texttt{rudiStuder})$$

$$\texttt{hasAffiliation}(\texttt{rudiStuder}, \texttt{aifb})$$

	Model 1	Model 2	Model 3
Δ	$\{a, r, s\}$	$\{1, 2\}$	$\{\spadesuit\}$
$I_I(\texttt{rudiStuder})$	r	1	$\spadesuit$
$I_I(\texttt{aifb})$	a	2	$\spadesuit$
$I_C(\texttt{Professor})$	$\{r\}$	$\{1\}$	$\{\spadesuit\}$
$I_C(\texttt{FacultyMember})$	$\{a, r, s\}$	$\{1, 2\}$	$\{\spadesuit\}$
$I_R(\texttt{hasAffiliation})$	$\{(r, a)\}$	$\{(1, 1), (1, 2)\}$	$\{(\spadesuit, \spadesuit)\}$

Is FacultyMember(aifb) a logical consequence?

Counterexample

Returning to our running example knowledge base, let us show formally that $\texttt{FacultyMember}(\texttt{aifb})$ is not a logical consequence. This can be done by giving a model M of the knowledge base where $\texttt{aifb}^M \notin \texttt{FacultyMember}^M$. The following determines such a model.

$$
\begin{aligned}
\Delta &= \{a, r\} \\
\mathrm{I}_{\mathbf{I}}(\texttt{rudiStuder}) &= r \\
\mathrm{I}_{\mathbf{I}}(\texttt{aifb}) &= a \\
\mathrm{I}_{\mathbf{C}}(\texttt{Professor}) &= \{r\} \\
\mathrm{I}_{\mathbf{C}}(\texttt{FacultyMember}) &= \{r\} \\
\mathrm{I}_{\mathbf{R}}(\texttt{hasAffiliation}) &= \{(r, a)\}
\end{aligned}
$$

OWL Direct Semantics via FOL

- **but often OWL 2 DL is said to be a fragment of first-order predicate logic (FOL) [with equality]...**
- **yes, there is a translation of OWL 2 DL into FOL**

$$\pi(C \sqsubseteq D) = (\forall x)(\pi_x(C) \rightarrow \pi_x(D))$$
$$\pi_x(A) = A(x)$$
$$\pi_x(\neg C) = \neg\pi_x(C)$$
$$\pi_x(C \sqcap D) = \pi_x(C) \wedge \pi_x(D)$$
$$\pi_x(C \sqcup D) = \pi_x(C) \vee \pi_x(D)$$
$$\pi_x(\forall R.C) = (\forall x_1)(R(x, x_1) \rightarrow \pi_{x_1}(C))$$
$$\pi_x(\exists R.C) = (\exists x_1)(R(x, x_1) \wedge \pi_{x_1}(C))$$
$$\pi_x(\geq nS.C) = (\exists x_1)\dots(\exists x_n)\left(\bigwedge_{i\neq j}(x_i \neq x_j) \wedge \bigwedge_i (S(x, x_i) \wedge \pi_{x_i}(C))\right)$$
$$\pi_x(\leq nS.C) = \neg(\exists x_1)\dots(\exists x_{n+1})\left(\bigwedge_{i\neq j}(x_i \neq x_j) \wedge \bigwedge_i (S(x, x_i) \wedge \pi_{x_i}(C))\right)$$
$$\pi_x(\{a\}) = (x = a)$$
$$\pi_x(\exists S.\mathrm{Self}) = S(x, x)$$

$$\pi(R_1 \sqsubseteq R_2) = (\forall x)(\forall y)(\pi_{x,y}(R_1) \rightarrow \pi_{x,y}(R_2))$$
$$\pi_{x,y}(S) = S(x, y)$$
$$\pi_{x,y}(R^-) = \pi_{y,x}(R)$$
$$\pi_{x,y}(R_1 \circ \dots \circ R_n) = (\exists x_1)\dots(\exists x_{n-1})\left(\pi_{x,x_1}(R_1) \wedge \bigwedge_{i=1}^{n-2} \pi_{x_i,x_{i+1}}(R_{i+1}) \wedge \pi_{x_{n-1},y}(R_n)\right)$$
$$\pi(\mathrm{Ref}(R)) = (\forall x)\pi_{x,x}(R)$$
$$\pi(\mathrm{Asy}(R)) = (\forall x)(\forall y)(\pi_{x,y}(R) \rightarrow \neg\pi_{y,x}(R))$$
$$\pi(\mathrm{Dis}(R_1, R_2)) = \neg(\exists x)(\exists y)(\pi_{x,y}(R_1) \wedge \pi_{x,y}(R_2))$$

- **...which (interpreted under FOL semantics) coincides with the definition just given.**

Inconsistency and Satisfiability

- A set of axioms (knowledge base) is satisfiable (or consistent) if it has a model.
- It is unsatisfiable (inconsistent) if it does not have a model.

- Inconsistency is often caused by modeling errors.

- Unicorn(beauty)
  Unicorn $\sqsubseteq$ Fictitious
  Unicorn $\sqsubseteq$ Animal
  Animal $\sqsubseteq \neg$Fictitious

Inconsistency and Satisfiability

- **A knowledge base is incoherent if a named class is equivalent to $\bot$.**
- **It usually also points to a modeling error.**

$$\begin{aligned} \mathtt{Unicorn} &\sqsubseteq \mathtt{Fictitious} \\ \mathtt{Unicorn} &\sqsubseteq \mathtt{Animal} \\ \mathtt{Fictitious} \sqcap \mathtt{Animal} &\sqsubseteq \bot \end{aligned}$$

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$$\mathsf{Person} \sqsubseteq \neg\mathsf{Movie}$$
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$$\mathsf{RRated} \equiv (\exists \mathsf{hasScript.ThrillerScript}) \sqcup (\forall \mathsf{hasViolenceLevel.High})$$
$$\mathsf{Domain(hasViolenceLevel,\ Movie)}$$

Fig. 1. A justification for $\mathsf{Person} \sqsubseteq \bot$

Rationale behind OWL

- Open World Assumption
- Favourable trade-off between expressivity and scalability
- Integrates with RDFS
- Purely declarative semantics

Features:

- Fragment of first-order predicate logic (FOL)
- Decidable
- Known complexity classes (N2ExpTime for OWL 2 DL)
- Reasonably efficient for real KBs

Today's Session: DL Semantics

1. **Model-theoretic Semantics of SROIQ(D)**
2. **Class Project**
3. **Class Presentations**

Class Project

- **Use the classes and properties from your ontology (if necessary, add some new ones).**
- **Use them as class names and role names, and write down (in DL notation) a number of SROIQ axioms which make sense in the context of your project ontology.**
- **If you find it appropriate, feel free to completely rewrite your ontology.**
- **Make sure you use each of the following constructs at least once:**
  - $\sqcap$, $\sqcup$, $\neg$, $\exists$, $\forall$
  - **a nominal**
  - **an inverse property**
  - **a qualified cardinality constraint**
  - **three of the property characteristics**

Class Project

- Send me by Sunday 13th of February:
  - Current version of your ontology in Turtle syntax (those parts not expressed using DL axioms).
  - The DL axioms (comprising the rest of your ontology).
    - Either on paper, handwritten (e.g. via Tonya Davis for me)
    - Or as a pdf (e.g. generated from LaTex).
  - Each DL axiom accompanied with a natural language sentence which captures its meaning.

Today's Session: DL Semantics

1. Model-theoretic Semantics of SROIQ(D)
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Class presentations –topics

- SPARQL 1.1 entailment regimes:
  http://www.w3.org/TR/2010/WD-sparql11-entailment-20100126/
  http://www.w3.org/2009/sparql/docs/entailment/xmlspec.xml
- Aidan Hogan, Andreas Harth, Axel Polleres: SAOR: Authoritative Reasoning for the Web. ASWC 2008: 76-90
- Jacopo Urbani, Spyros Kotoulas, Jason Maassen, Frank van Harmelen, Henri E. Bal: OWL Reasoning with WebPIE: Calculating the Closure of 100 Billion Triples. ESWC (1) 2010: 213-227
- Yuan Ren, Jeff Z. Pan, Yuting Zhao: Soundness Preserving Approximation for TBox Reasoning. AAAI 2010 (taken)
- Franz Baader, Sebastian Brandt, Carsten Lutz: Pushing the EL Envelope. IJCAI 2005: 364-369

Class presentations –topics

- Diego Calvanese, Giuseppe De Giacomo, Domenico Lembo, Maurizio Lenzerini, and Riccardo Rosati. DL-Lite: Tractable Description Logics for Ontologies. In: *Proc. of the 20th Nat. Conf. on Artificial Intelligence (AAAI 2005).* 2005.
- Benjamin N. Grosof, Ian Horrocks, Raphael Volz, Stefan Decker: Description logic programs: combining logic programs with description logic. In: Proceedings of the Twelfth International World Wide Web Conference, WWW2003, Budapest, Hungary, 20-24 May 2003. ACM, 2003, pp. 48-57
- Darko Anicic, Paul Fodor, Sebastian Rudolph, Nenad Stojanovic EP-SPARQL: A Unified Language for Event Processing and Stream Reasoning. In: Proc. *WWW 2011*.
- Raghava Mutharaju, Frederick Maier, Pascal Hitzler. A MapReduce Algorithm for EL+. In: Volker Haarslev, Davind Toman, Grant Weddell (eds.), Proceedings of the 23rd International Workshop on Description Logics (DL2010), Waterloo, Canada, 2010. CEUR Workshop Proceedings Vol. 573, pp. 464-474.

Class presentations –topics

- Jia Tao, Giora Slutzki, Vasant Honavar: Secrecy-Preserving Query Answering for Instance Checking in *EL*. In: Pascal Hitzler, Thomas Lukasiewicz (Eds.): Web Reasoning and Rule Systems - Fourth International Conference, RR 2010, Bressanone/Brixen, Italy, September 22-24, 2010. Proceedings. Lecture Notes in Computer Science 6333 Springer 2010, pp. 195-203
- Jiao Tao, Evren Sirin, Jie Bao, Deborah L. McGuinness: Integrity Constraints in OWL. In: Maria Fox, David Poole (Eds.): Proceedings of the Twenty-Fourth AAAI Conference on Artificial Intelligence, AAAI 2010, Atlanta, Georgia, USA, July 11-15, 2010. AAAI Press 2010
- Giorgos Stoilos, Bernardo Cuenca Grau, Ian Horrocks: How Incomplete Is Your Semantic Web Reasoner? In: Maria Fox, David Poole (Eds.): Proceedings of the Twenty-Fourth AAAI Conference on Artificial Intelligence, AAAI 2010, Atlanta, Georgia, USA, July 11-15, 2010. AAAI Press 2010

Class presentations –topics

- Matthew Horridge, Bijan Parsia, Ulrike Sattler: Laconic and Precise Justifications in OWL. In: Amit P. Sheth, Steffen Staab, Mike Dean, Massimo Paolucci, Diana Maynard, Timothy W. Finin, Krishnaprasad Thirunarayan (Eds.): The Semantic Web - ISWC 2008, 7th International Semantic Web Conference, ISWC 2008, Karlsruhe, Germany, October 26-30, 2008. Proceedings. Lecture Notes in Computer Science 5318 Springer 2008, pp. 323-338
- Harry Halpin, Patrick J. Hayes, James P. McCusker, Deborah L. McGuinness, Henry S. Thompson: When owl: sameAs Isn't the Same: An Analysis of Identity in Linked Data. In: Peter F. Patel-Schneider, Yue Pan, Pascal Hitzler, Peter Mika, Lei Zhang, Jeff Z. Pan, Ian Horrocks, Birte Glimm (Eds.): The Semantic Web - ISWC 2010 - 9th International Semantic Web Conference, ISWC 2010, Shanghai, China, November 7-11, 2010, Revised Selected Papers, Part I. Lecture Notes in Computer Science 6496 Springer 2010, pp. 305-320

Presentation format

- **30 minutes, including 5 minutes questions (timing will be strict)**

- **Content selection is up to you. Presentation must contain the key results from the paper you are presenting. It can also contain material related to these key results which are not in the paper itself (but which you may find more interesting than the rest of the paper).**

- **Let me know by 15th of February (by email) which paper you want to present. It's first come, first serve.**
- **Presentations will be in the last two weeks of classes (I'll fix the sequence until 17th of February).**

Presentation evaluation dimensions

Example criteria – may not all be weighted equally:

- **Quality of slides**
- **Quality and effectiveness of explanations**
- **Quality of presentation style (use of verbal and body language, use of media, flexibility in case of interaction with audience, time management)**
- **Correctness of content**
- **Grade of reaching the audience and getting the content across**
- **How "interesting" the material is presented**
- **Competence in answering questions**