Engineering of ontologies with Description Logics

1. introduction

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Abstract

Description Logics are formal languages for knowledge representations used to define ontologies. The Web Ontology Language (OWL) and its profiles are based on Description Logics. We present the syntax and the semantics of the main Description Logics, and their computational complexity of reasoning. We also present selected topics that occupy researchers and practitioners in the field, e.g.: ontology-based data access, concept learning, ontology repair, etc. We use Protégé and Ontop for a hands-on session.

This course is about

Symbolic AI: many aspects of intelligence can be achieved by the manipulation of symbols.

Knowledge representation and reasoning.

How to formalise knowledge, how to manipulate knowledge, how to query knowledge.

Description Logics.

Semantic science and technologies.

Why semantics?

Person

id	name
1	Mary Jones
2	John Smith

Child

id	name
1	John Smith
2	Elisabeth Boer

Filiation

id	parent	child
1	Juliet Goff	Elisabeth Boer
2	Robert Roderick	Yohan Escampe

Age

id	name	age
1	Yohan Escampe	6
2	John Smith	7
3	Mary Jones	54
4	Elisabeth Boer	15

- Is Elisabeth Boer a person?
- Are Juliet Goff, Robert Roderick, Yohan Escampe persons?
- Is Yohan Escampe a child? Is Mary Jones a child?

Domain knowledge

Databases are great for organising, storing, and querying extensional knowledge.

But this knowledge often needs to be organised and queried with respect to intensional knowledge, e.g.:

- individuals in a filiation relationship are persons;
- a child is a person below the legal age of majority.

What if we could **augment** the extensional knowledge of databases with intensional knowledge, and **automatically reason** about it?

- check of consistency of data wrt. domain knowledge
- classify data wrt. domain knowledge
- find all data in a complex class (e.g., all children of two parents aged less than 35) wrt. domain knowledge
- ...

What is Ontology?

Expressions using subjects, predicates, and objects are useful and flexible to represent knowledge.

Discussion of entities and their relationships: traditionaly in philosophy.

Since ancient Hindus and Greeks, philosophers have been concerned with nature of things that exist or may exist, and how they relate to each others.

> *Of things said without any combination, each signifies either substance or quantity or qualification or a relative or where or when or being-in-a-position or having or doing or being-affected. To give a rough idea, examples of substance are man, horse; of quantity: four-foot, five-foot; of qualification: white, grammatical; of a relative: double, half, larger; of where: in the Lyceum, in the market-place; of when: yesterday, last-year; of being-in-a-position: is-lying, is-sitting; of having: has-shoes-on, has-armour-on; of doing: cutting, burning; of being-affected: being-cut, being-burned. [Aristotle, Categories (1b25-2a4)]*[1]

This is Ontology.

[1] Aristotle. *Categories*. Transl. J. L. Ackrill.

What is an ontology? (1)

[Guarino 1998][2]

We can distinguish Ontology, the discipline that studies the nature of being, from ontologies (written with lower-case initial) that are systems of categories that account for a certain view or aspect of the world.

Such ontologies act as standardized reference models to support knowledge sharing and integration:

1. they support human understanding and communication, and
2. they facilitate content-based access, communication, and integration across different information systems; to this aim, it is important that the language used to express ontologies is formal and machine-processable.

[2] Nicola Guarino. “Formal Ontologies and Information Systems”. In: *FOIS 1998*. 1998, pp. 3–15.

What is an ontology? (2)

[Gruber 1995][3]

An ontology is a formal, explicit specification of a shared conceptualization.

- A conceptualization is an abstract representation of some aspect of the world (or of a fictitious environment) which is of interest to the users of the ontology.
- Explicit means that constructs used in the specification must be explicitly defined.
- Formal means that the specification is encoded in a precisely defined language whose properties are well known and understood; usally this means that the languages used for the specification of an ontology is logic-based.
- Shared means that the ontology is meant to be shared across several people, applications, communities, and organizations.

[3] Tom Gruber. "Towards principles for the design of ontologies used for knowledge sharing". In: *Int. J. of Human and Computer Studies* 43.5/6 (1995), pp. 907–928.

What makes an ontology

Knowledge in ontologies is mainly formalized using five kinds of components:

- concepts (or classes), which represent sets of objects with common properties within the domain of interest; (e.g., Person)
- relations, which represent relationships among concepts by means of the notion of mathematical relation; (e.g., childOf)
- functions, which are functional relations; (e.g., hasSSN)
- axioms, which are sentences that are always true and are used in general to enforce suitable properties of classes, relations, and individuals; (e.g., a Person has an SSN, and the SSN of Mary is 46234)
- individuals, which are individual objects in the domain of interest. (e.g., mary)

This course is not about

Not about Ontology.

Not about conceptual modelling (why we organise knowledge one way or another, and good practices).

Outline

Literature (basics)

- Introduction to Description Logic [Baader et al. 2017][4]
- Description Logic handbook [Baader et al. 2003][5]
- Description Logic and conceptual modelling [Berardi et al. 2005][6], [Artale et al. 2007][7]

[4] Franz Baader et al. *Introduction to Description Logic*. Cambridge University Press, 2017.

[5] Franz Baader et al., eds. *The Description Logic Handbook: Theory, Implementation, and Applications*. Cambridge University Press, 2003.

[6] Daniela Berardi, Diego Calvanese, and Giuseppe De Giacomo. "Reasoning on UML class diagrams". In: *Artificial Intelligence* 168.1 (2005), pp. 70–118.

[7] Alessandro Artale et al. "Reasoning over Extended ER Models". In: *ER 2007*. 2007.

Literature (classics)

Expressive Description Logics:

- $\mathcal{ALC}$: DL and modal logic [Schmidt-Schauß and Smolka 1991][8], [Schild 1991][9]
- $\mathcal{ALCQ}$: DL Reasoning with cardinality restrictions [Tobies 2000][10]
- $\mathcal{SROIQ}$: OWL2 [Horrocks et al. 2006][11]

Light-weight Description Logics:

- $\mathcal{EL}$ [Baader et al. 2005][12]
- $\mathcal{DL}$-Lite [Calvanese et al. 2007][13],

[8] Manfred Schmidt-Schauß and Gert Smolka. "Attributive concept descriptions with complements". In: *Artificial Intelligence* 48.1 (1991), pp. 1–26.

[9] Klaus Schild. "A Correspondence Theory for Terminological Logics: Preliminary Report". In: *IJCAI 1991*. 1991.

[10] Stephan Tobies. "The Complexity of Reasoning with Cardinality Restrictions and Nominals in Expressive Description Logics". In: *J. Artif. Intell. Res.* 12 (2000), pp. 199–217.

[11] Ian Horrocks, Oliver Kutz, and Ulrike Sattler. "The Even More Irresistible SROIQ". In: *KR 2006*. 2006.

[12] Franz Baader, Sebastian Brandt, and Carsten Lutz. "Pushing the EL Envelope". In: *IJCAI-05*.

[13] Diego Calvanese et al. "Tractable Reasoning and Efficient Query Answering in Description Logics: The *DL-Lite* Family". In: *J. Autom. Reason.* 39.3 (2007), pp. 385–429.

Literature (current trends, very biased)

Concept refinement and applications:

- Concept refinement and ontology repairs [Troquard et al. 2018][14]
- Almost-sure terminating algorithms [Confalonieri et al. 2020][15] (also EPIA'22)
- Ontology aggregation [Porello et al. 2018][16]
- Concept combination [Righetti et al. 2021][17] (also invited submission IJCAI sister conf)

Perceptron operators and applications:

- Perceptron operators and learning from data [Galliani et al. 2020][18]
- Counting perceptron operators [Galliani et al. 2021][19]

Learning theory:

- Learning ontologies with epistemic reasoning [Ozaki and Troquard 2019][20]

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[14] Nicolas Troquard et al. "Repairing Ontologies via Axiom Weakening". In: *Proc. of AAAI 2018*. 2018.
[15] Roberto Confalonieri et al. "Towards Even More Irresistible Axiom Weakening". In: *DL 2020*.
[16] Daniele Porello et al. "Two Approaches to Ontology Aggregation Based on Axiom Weakening.". In: *IJCAI 2018*. 2018.
[17] Guendalina Righetti et al. "Asymmetric Hybrids: Dialogues for Computational Concept Combination". In: *FOIS 2021*. 2021.
[18] Pietro Galliani et al. "Perceptron Connectives in Knowledge Representation". In: *EKAW 2020*.
[19] Pietro Galliani, Oliver Kutz, and Nicolas Troquard. "Perceptron Operators That Count". In: *DL 2021*. 2021.
[20] Ana Ozaki and Nicolas Troquard. "Learning Ontologies with Epistemic Reasoning: The *EL* Case". In: *JELIA 2019*. 2019.

Some technologies

- RDF, RDFS, OWL, SWRL, R2RML, SPARQL, SHACL
  - https://www.w3.org/TR/rdf11-concepts/
  - https://www.w3.org/TR/rdf-schema/
  - https://www.w3.org/TR/r2rml/
  - https://www.w3.org/TR/sparql11-query/
  - https://www.w3.org/TR/shacl/
- OWL API
  - http://owlcs.github.io/owlapi/
  - Tutorial: http://syllabus.cs.manchester.ac.uk/pgt/2021/COMP62342/introduction-owl-api-msc.pdf
- Protégé
  - https://protege.stanford.edu/
  - Tutorial: https://drive.google.com/file/d/1A3Y8T6nIfXQ_UQ0pCAr_HFSCwpTqELeP/view
  - Syntax: http://protegeproject.github.io/protege/class-expression-syntax/
- Ontop
  - https://ontop-vkg.org/
  - Tutorial: https://ontop-vkg.org/tutorial/

What's next?

- knowledge engineering with PL and FOL
- description logics
- semantic technologies – representating and querying knowledge
- some current trends – very biased