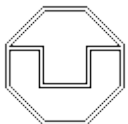


Description Logics

Franz Baader

Literature:

- F. Baader, D. Calvanese, D. McGuinness, D. Nardi, P. Patel-Schneider (ed.): **The Description Logic Handbook**. Cambridge University Press, 2003.
- F. Baader, C. Lutz: **Description Logics**. In *The Handbook of Modal Logic*, Elsevier, 2006.
- F. Baader: **Description Logics**. In *Reasoning Web: Semantic Technologies for Information Systems*, 5th International Summer School 2009, Springer LNCS 5689, 2009.



Description Logics

subfield of **knowledge representation**,
which is a subfield of **Artificial Intelligence**

Description comes from **concept description**, i.e., a formal expression that determines a set of individuals with common properties

Logics comes from the fact that the **semantics** of concept descriptions can be defined using **logic**;
in particular, most Description Logics can be seen as **fragments of first-order logic**.



Description Logics

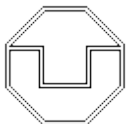
subfield of knowledge representation,
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Description Logics: name of a research field

Description Logics: a family of knowledge representation languages

Description Logic: a member of this family

$DL(s)$



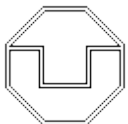
Knowledge Representation

general goal

“develop formalisms for providing high-level descriptions of the world that can be effectively used to build intelligent applications”

[Brachman & Nardi, 2003]

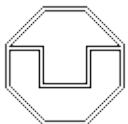
- **formalism:** well-defined **syntax** and formal, unambiguous **semantics**
- **high-level description:** only relevant aspects represented, others left out
- **intelligent applications:** must be able to reason about the knowledge, and infer implicit knowledge from the explicitly represented knowledge
- **effectively used:** need for practical reasoning tools and efficient implementations



Syntax

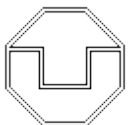
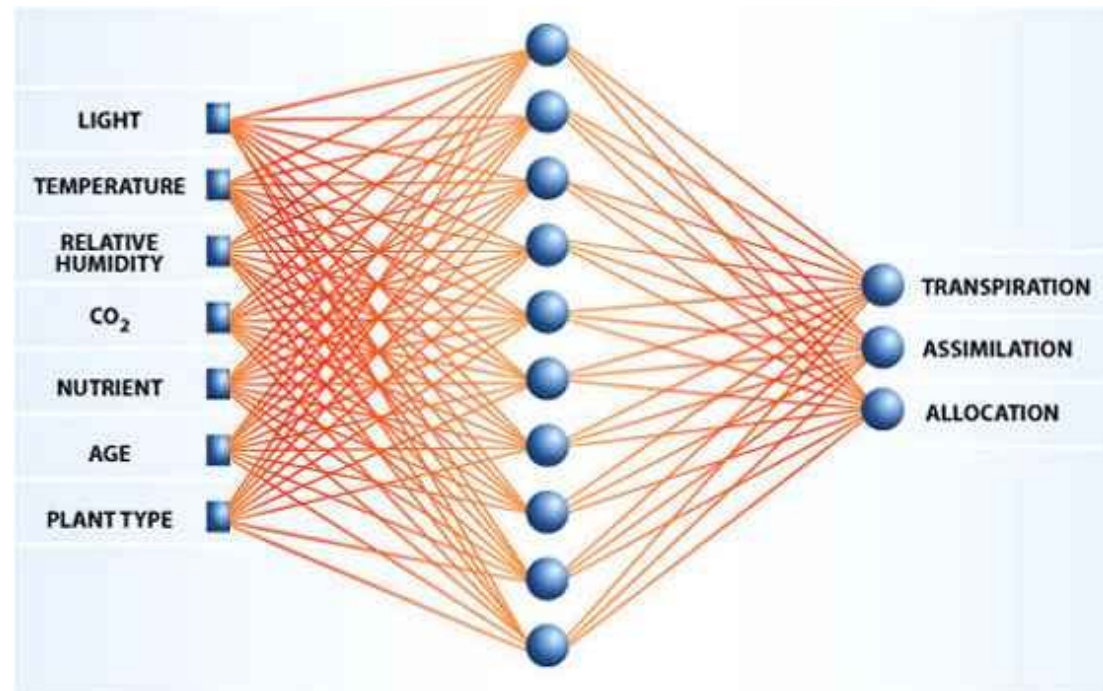
- provides an **explicit symbolic representation** of the knowledge
- **not** just implicit, as e.g. in neural networks

Woman	\equiv Person \sqcap Female	
Man	\equiv Person \sqcap \neg Female	
Mother	\equiv Woman \sqcap \exists hasChild. \top	
Person	\equiv Man \sqcup Woman	Male(JOHN)
\perp	\equiv Male \sqcap Female	Male(MARC)
		Male(STEPHEN)
hasChild(STEPHEN , MARC)		Male(JASON)
hasChild(MARC , ANNA)		Female(MICHELLE)
hasChild(JOHN , MARIA)		Female(ANNA)
hasChild(ANNA , JASON)		Female(MARIA)



Syntax

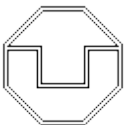
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Semantics

describes the connection between the **symbolic representation** and the **real-world entities** it is supposed to represent

- **no procedural semantics**, i.e., should **not** just be defined by how certain programs using the symbolic representation behave
- instead **declarative semantics**:
 - mapping of the symbolic expressions to an abstraction of the “world” (**interpretation**)
 - notion of “**truth**” that allows us to determine whether a symbolic expression is true in the world under consideration (**model**)

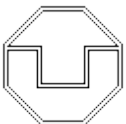


Syntax & Semantics

determine the **expressive power** of a formalism

Adequate expressive power:

- **not too low**: can all the knowledge relevant for solving the problem at hand be represented?
- **not too high**: are the available representational means really necessary in this application?



Reasoning

deduce implicit knowledge from the explicitly represented knowledge

$$\forall x.\forall y. (male(y) \wedge \exists z.(child(x, z) \wedge child(z, y)) \rightarrow grandson(x, y))$$

child(John, Mary)

child(Mary, Paul)

male(Paul)

grandson(John, Paul)

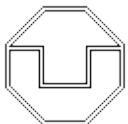
implicit knowledge

Knowledge representation systems

should provide their users with inference tools
that can deduce (certain) implicit consequences

results should **depend only on the semantics** of the representation language,
and **not on the syntactic representation**:

semantically equivalent knowledge should lead to the same result



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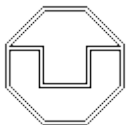
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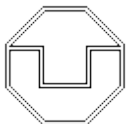
semantically equivalent knowledge should lead to the same result



Reasoning procedures

requirements in knowledge representation

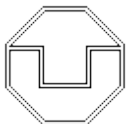
- The procedure should be a **decision procedure** for the problem:
 - **soundness**: positive answers are correct
 - **completeness**: negative answers are correct
 - **termination**: always gives an answer in finite time
- The procedure should be as **efficient** as possible:
preferably **optimal** w.r.t. the (worst-case) complexity of the problem
- The procedure should be **practical**:
easy to implement and optimize, and behave well in applications



Reasoning procedures

example

- Satisfiability in **first-order logic** does not have a decision procedure.
 - full first-order logic is thus not an appropriate knowledge representation formalism
- Satisfiability in **propositional logic** has a decision procedure, but the problem is NP-complete.
 - there are, however, highly optimized **SAT solvers** that behave well in practice
 - **expressive power** is, however, often **not sufficient** to express the relevant knowledge



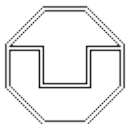
Terminological knowledge

formalize the terminology of the application domain:

- define important notions (classes, relations, objects) of the domain
- state constraints on the way these notions can be interpreted
- deduce consequences of definitions and constraints:
subclass relationships, instance relationships

Example: domain conference

- **classes** (concepts) like **Person, Speaker, Author, Talk, Participant, Workshop, ...**
- **relations** (roles) like **gives, attends, likes, ...**
- **objects** (individuals) like **Richard, Frank, Paper_176, ...**
- **constraints** like: every talk is given by a speaker, every speaker is an author, every workshop must have at least 10 participants, ...

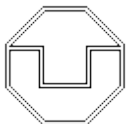


Ontologies

terminological knowledge bases are nowadays often called ontologies

Ontologies are, for example, used in:

- the **Semantic Web** to enable a common understanding of important notions, which can be used in the semantic labeling of Web pages
- **Information Retrieval** to support the automatic extraction of information from text documents
- **Medicine** to provide formal definitions for important notions that can be used by medical doctors to describe findings and procedures, insurance companies to determine payment, ... (SNOMED CT, GALEN, ...)
- **Biology** to enable semantic access to gene databases (Gene Ontology)
- ...



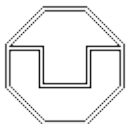
Description Logics

class of logic-based **knowledge representation formalisms**
tailored towards representing **terminological knowledge**

Prehistory:

- Descended from **early approaches** for representing terminological knowledge
 - **semantic networks** (Quillian, 1968)
 - **frames** (Minsky, 1975)
- problems with **missing semantics** lead to
 - **structured inheritance networks** (Brachman, 1978)
 - the first DL system **KL-ONE** (Brachman&Schmolze, 1985)

Chapter 1



Description Logics

history

Phase 1:

- implementation of systems (Back, K-Rep, Loom, Meson, ...)
- based on incomplete structural subsumption algorithms

Phase 2:

- development of tableau-based algorithms and complexity results
- first implementation of tableau-based systems (Kris, Crack)
- first formal investigation of optimization methods

Phase 3:

- tableau-based algorithms for very expressive DLs
- highly optimized tableau-based systems (FaCT, Racer)
- relationship to modal logic and decidable fragments of FOL

Phase 4:

- Web Ontology Language (OWL-DL) based on very expressive DL
- industrial-strength reasoners and ontology editors for OWL-DL
- investigation of light-weight DLs with tractable reasoning problems

