A DESCRIPTION LOGICS PRIMER

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Description Logics (DLs), also known as terminological logics, describe knowledge in terms of concepts and (restrictions on) their roles. DLs provide a means of describing structured knowledge in a way that one can reason about it efficiently (i.e., infer new knowledge). DLs are subsets of the First-Order Logic, thus, providing decidability and computationally feasible reasoning at the cost of expressiveness. Knowledge bases expressed in DLs are decomposed to two components, the TBox (Terminological base) and the ABox (Assertional base). The former constitutes the vocabulary of an application domain, i.e., the terminology, whilst the latter contains real world assertions of individuals (instances) in terms of that vocabulary. A terminology consists of concepts and roles. Concepts denote sets of asserted individuals. Roles denote binary relationships between individuals. The key characteristic of DL terminologies is the inclusion axiom (subsumption relations) between their concepts, which is used for building IS-A hierarchies (a.k.a. taxonomies) from concepts. The elementary DL descriptions are atomic concepts and atomic roles. Complex descriptions can be built inductively from them through concept constructors (see Table 1). Moreover, DLs have terminological axioms, which make statements about how concepts or roles are related to each other (see Table 2).

Table 1. Main DL constructors (C, D: concepts - R: role)

Constructor	**DL syntax**	**Example**	**Meaning**
Intersection	$C \sqcap D$	Young ⊓ Male	All individuals that are Young and Male
Union	$C \sqcup D$	Young ⊔ Male	Any individual that is either Young or Male
Value restriction	$\forall R.C$	∀ hasInterest.Movies	All individuals that are interested only in Movies
Existential role quantification	$\exists R.C$	∃ hasInterest.Sports	All individuals that are interested, at least, in Sports
Atomic negation	$\neg C$	¬Male	Any individual that is not Male

Table 2. DL axioms (they also apply to roles)

Axiom	**DL syntax**	**Example**	**Meaning**
Inclusion (subsumption)	$C \sqsubseteq D$	Young ⊑ Person	An individual of type Young is also of type Person
Equality	$C \equiv D$	Young ≡ Teenager	Every Young is also a Teenager and vice versa
Disjoint	$C \sqsubseteq \neg D$	Teenager⊑¬Adult	Someone cannot be Teenager and Adult at the same time

The concepts of a terminology may be either *primitive* (described through necessary conditions, i.e., inclusion axioms) or *defined* (described through necessary and sufficient conditions, i.e., equality axioms).

Example: The following DL description illustrates the primitive concept of those young males (C) that are interested in sports and dislike all kinds of movies. Hence, in DL syntax:

$C \sqsubseteq Young \sqcap Male \sqcap \exists hasInterest.(Interest \sqcap Sports) \sqcap \forall dislikes.(Movies)$

Through this description it is implied that if a person is a kind of C, then she is interested in sports and dislikes all kinds of movies. The inverse does not hold. If, on the other hand, we define C as:

$C \equiv Young \sqcap Male \sqcap \exists hasInterest.(Interest \sqcap Sports) \sqcap \forall dislikes.(Movies)$

we additionally imply that if a young male person is interested in sports and dislikes all kinds of movies, then it definitely is a kind of C, which may not be the case in general. Thus, one should be sure that the defined concepts are well defined, or else she may receive false inferences.

The popularity of DL-based ontologies is based on the fact that DL reasoning engines (a.k.a. reasoners) offer efficient services over the TBox and ABox assertions (i.e., concepts, roles and individuals). The most important services are *concept satisfiability* (i.e., if a concept can be populated with instances and, thus, the TBox knowledge is consistent), and determination of *concept subsumption* (i.e., whether a concept C is more general than a concept D, or, otherwise stated, C *subsumes* D). Another service that is provided by a DL reasoner is the decision on whether a set of ABox assertions is *consistent*, that is, the *instances* do not have contradicting implications. Satisfiability and consistency checking are useful to determine whether a knowledge base is meaningful at all. The following example illustrates the concept of *concept satisfiability*.

Example: There could never exist a person P who has an interest I which is both Sports and Movies, i.e., $I \sqsubseteq (Interest \sqcap Movies \sqcap Sports)$, since the latter two concepts are disjoint. Hence, the TBox containing a concept P such that:

$P \sqsubseteq Person \sqcap \exists\, hasInterest.(Interest \sqcap Movies \sqcap Sports)$

is considered inconsistent (i.e., the concept P is not satisfiable). Instead, concept P':

$P' \sqsubseteq Person \sqcap \exists\, hasInterest.(Interest \sqcap Movies) \sqcap \exists\, hasInterest.(Interest \sqcap Sports)$

is satisfiable, since it describes a person interested, at least, one interest in Movies and at least another interest in Sports.

DL reasoners also perform *classification* in a TBox. This is the task of placing a new concept expression in the proper position in a hierarchy of concepts. An example of classification is the following:

Example: A young person, who is interested in SciFiMovies (concept C), is subsumed by another young person, who is interested in Movies (concept D). On the other hand, a young person who is interested in Sports (concept E) does not subsume C, since Movies (and consequently SciFiMovies) are considered as disjoint with Sports. Hence, the following TBox statements, could only infer that $C \sqsubseteq D$:

$C \sqsubseteq Young \sqcap \exists\, hasInterest.(Interest \sqcap SciFiMovies)$

$D \sqsubseteq Young \sqcap \exists\, hasInterest.(Interest \sqcap Movies)$

$E \sqsubseteq Young \sqcap \exists\, hasInterest.(Interest \sqcap Sports)$

$SciFiMovies \sqsubseteq Movies \sqsubseteq Interest$

$Sports \sqsubseteq Interest$

Sports $\sqsubseteq \neg$Movies.

The reader is referred to (Baader, 2003) for further information on DL theory and applications.

References

Baader, F., Calvanese, D., McGiuness, D., Nardi, D., & Patel-Schneider, P. (2003). *The Description Logic Handbook: Theory, Implementation, and Applications*. Cambridge: Cambridge University Press.