Reflections on Modelling Vagueness in Description Logics

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Abstract. Description logics are a popular, and widely used, formalism for describing domain knowledge in a structured way. To cope with the vagueness of real-world knowledge, several fuzzy description logics have already been proposed. In this contribution, we argue that, rather than modelling all vagueness in a generalized description logic, it may be more natural to encode vague attributes in concrete domains [1], and to model vague predicates on the level of query processing.

Although description logics (DLs) have gained much popularity during the past decade, applications using them suffer from one important drawback: the information they capture is supposed to be perfect, i.e., well-defined, unambiguous, certain, etc. However, real-world knowledge is often far from perfect; in order to accommodate such imperfections, several extensions to DLs have been proposed, including e.g. non-monotonic and probabilistic reasoning mechanisms. In particular, we focus on techniques dealing with vagueness in DLs.

Fuzzy set theory is by far the best-known and most popular formalism to deal with vagueness in computer science. Accordingly, a wide range of fuzzy description logics have been introduced with the aim of encoding vague knowledge in ontologies, see e.g. [3]. In them, vague concepts are represented as mappings, called fuzzy sets, from a suitable universe U to the unit interval [0,1]. Based on this, fuzzy DLs allow, e.g., to express fuzzy assertional axioms, like "x is an instance of C, at least to degree α". Although most fuzzy DLs are based on well-established theoretical foundations, and the main reasoning tasks are typically in the same complexity class as their crisp counterparts, it is questionable whether their use outside a strictly application-dependent context will ever be successful. Mainly, this is related to the context-dependent nature of membership degrees. After all, in a purely symbolic approach, what does it mean, e.g., to call a book cover red to degree 0.8? For example, knowing that information, is it possible that it is vermillion?

In our view, a more practically workable solution is to equip DLs with concrete domains describing vagueness. A concrete domain [1] is defined as a pair $\mathcal{D} = (\Delta^{\mathcal{D}}, \Phi^{\mathcal{D}})$, where $\Delta^{\mathcal{D}}$ is a set, and $\Phi^{\mathcal{D}}$ a set of predicate names P, each associated with an n-ary predicate $P^{\mathcal{D}} \subseteq (\Delta^{\mathcal{D}})^n$. A typical domain is that of reals equipped with predicates like $\leq$ and $=$, but in general concrete domains can

be arbitrary domains satisfying some weak requirements. An important consequence of this is that in order to cope with vagueness, the idea of concrete domains does not need to be extended; it is possible to use concrete domains whose elements are fuzzy sets. An obvious advantage of this approach is that we can specify exactly what we mean by "red", for instance by means of a fuzzy region in a color space. Note how this idea differs from a related approach by Straccia [4], whose proposal is not to allow fuzzy sets as elements of a concrete domain, but to construct fuzzy DLs with fuzzy relations as predicates.

Furthermore, many of the vague concepts that typically arise in a semantic search setting can be treated on the level of the query processing. For example, consider a query asking for *red books whose author was born in Western Europe during the late 1960s*, and an ontology where colors, locations, and time instants are modelled in a suitable concrete domain. To answer such a vague query, we can first search for instances that satisfy a more general, crisp query, e.g., books that are red to a strictly positive degree, and whose author was born in Europe between 1965 and 1970. Next, we can rank the retrieved instances by the degree to which they satisfy the initial vague query. In this way, the interpretation of vague predicates, which is typically subjective, may be based on some user profile. Moreover, while in fuzzy description logics one operator needs to be fixed to generalize logical conjunction, treating vague predicates on the level of query processing allows for more flexibility w.r.t. the aggregation operator that is used to combine the degrees to which each of the criteria is satisfied.

In conclusion, DLs with concrete domains offer both a realistic and expressive way to model objects with vague attributes. In addition, vague predicates can conveniently be modelled at the level of query processing, drawing upon a rich body of existing work on flexible query answering in databases (see e.g. [2]), and making the need for fuzzy description logics, at least in the context of semantic search, more or less redundant.

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