Composing Prototypes by Coupling a Non Monotonic Description Logic with Probabilities and Cognitive Heuristics

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Combining typical knowledge to generate novel concepts is an important creative trait of human cognition. Dealing with such ability requires, from an AI perspective, the harmonization of two conflicting requirements that are hardly accommodated in symbolic systems: the need of a syntactic compositionality (typical of logical systems) and that one concerning the exhibition of typicality effects (see Frixione and Lieto, 2012 and the references in Lieto et al. 2018 for a contextualized overview on such a problem). According to a well-known argument (Osherson and Smith, 1981), in fact, prototypical concepts are not compositional. The argument runs as follows: consider a concept like pet fish. It results from the composition of the concept pet and of the concept fish. However, the prototype of pet fish cannot result from the composition of the prototypes of a pet and a fish: e.g. a typical pet is furry and warm, a typical fish is grayish, but a typical pet fish is neither furry and warm nor grayish (typically, it is red).

In this work we provide a logical framework able to account for this type of human-like concept combination. We propose a nonmonotonic Description Logic (from now on DL) of typicality called $\mathbf{T}^{\mathbf{CL}}$ (**Typicality-based Compositional Logic**).

This logic combines three main ingredients (for the details see Lieto and Pozzato, 2018; Lieto and Pozzato submitted). The first one relies on the DL of typicality ALC + TR introduced in (Giordano et al., 2015). In this logic, “typical” properties can be directly specified by means of a typicality” operator T enriching the underlying DL, and a knowledge base (KB) can contain inclusions able to represent that “typical Cs are also Ds”. In ALC + TR one can consistently express exceptions and reason about defeasible inheritance as well.

As a second ingredient, we consider a distributed semantics similar to the one of probabilistic DLs known as DISPONTE (Riguzzi et al, 2015), allowing to label ontological axioms with degrees representing probabilities, but restricted to typicality inclusions. The basic idea is to label inclusions of the type “typical Cs are also Ds” with a real number between 0.5 and 1, representing its probability, assuming that each axiom is independent from each others (the actual probabilistic values are assumed to come from an application domain). The resulting knowledge base defines a probability distribution over scenarios.

As an additional element of the proposed formalization we employ a method inspired by cognitive semantics (see Hampton, 1987 for a review) for the identification of a dominance effect between the concepts to be combined. In particular, for every combination, we distinguish a HEAD, representing the stronger element of the combination, and a MODIFIER. The basic idea is: given a KB and two concepts CH (HEAD) and CM (MODIFIER) occurring in it, we consider only some scenarios in order to define a revised knowledge base, enriched by typical properties of the combined concept.

Selection Criteria

Given a KB K and given two concepts CH and CM occurring in K, our logic allows defining the compound concept C as the combination of the HEAD (CH) and the MODIFIER (CM), where C $\sqsubseteq$ CH $\wedge$ CM and the typical properties of the form T(C) $\sqsubseteq$ D to ascribe to the concept C are obtained in the set of scenarios that: i) are consistent with respect to K; ii) are not trivial, i.e. those with the highest probability, in the sense that the scenarios considering all properties that can be consistently ascribed to C, or all the properties of the HEAD that can be consistently ascribed to C are discarded; iii) are those giving preference to the typical properties of the HEAD CH (with respect to those of the MODIFIER CM) with the highest probability.

Composing the PET FISH

Let K be a Knowledge base containing the rigid inclusion (*) Fish $\sqsubseteq$ *Lives.In.Water* and the following typical inclusions equipped with probabilities:

1. $0.9 :: \mathbf{T}(Pet) \sqsubseteq \exists livesIn.(\neg Water)$
2. $0.8 :: \mathbf{T}(Pet) \sqsubseteq Affectionate$
3. $0.7 :: \mathbf{T}(Fish) \sqsubseteq \neg Affectionate$
4. $0.8 :: \mathbf{T}(Pet) \sqsubseteq Warm$
5. $0.6 :: \mathbf{T}(Fish) \sqsubseteq Greyish$
6. $0.9 :: \mathbf{T}(Fish) \sqsubseteq Scaly$
7. $0.8 :: \mathbf{T}(Fish) \sqsubseteq \neg Warm$

In this case we have $2^7 = 128$ different scenarios. In our logic, we can discard those that are not consistent, are trivial and privilege the MODIFIER with respect to the HEAD. It turns out that our logic is able to select the scenario with the following typical properties:

3. $0.7 :: \mathbf{T}(Fish) \sqsubseteq \neg Affectionate$
6. $0.9 :: \mathbf{T}(Fish) \sqsubseteq Scaly$
7. $0.8 :: \mathbf{T}(Fish) \sqsubseteq \neg Warm$

On the other hand, the composed concept PET FISH also inherits the rigid inclusion (*) Fish ⊑ *Lives.In.Water* .

Notice that in, our logic, adding a new inclusion T(PET ∧ FISH) ⊑ Red, would not be problematic (i.e. $\mathbf{T}^{\mathbf{CL}}$ tackles the phenomenon of prototypical attributes emergence). The proposed logic has been recently applied to a number of cognitive phenomena including: conjunction fallacy, metaphors generation, and iterative conceptual combination (Lieto and Pozzato, submitted).

References

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