Logic-based Rule Learning for the Web of Data

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Abstract. This tutorial introduces to Inductive Logic Programming (ILP), being it a major logic-based approach to rule learning, and surveys extensions of ILP that turn out to be suitable for applications to the emerging vision of the Semantic Web as a Web of Data.

1 Outline of the tutorial

Rules are widely used in Knowledge Engineering (KE) and Knowledge Representation (KR) as a powerful way of modeling knowledge. However, the acquisition of rules for very large Knowledge Bases (KBs) still remains a very demanding KE activity. A partial automation of the rule authoring task, *e.g.*, by applying *Rule Learning* algorithms [1], can be of help even though the automatically produced rules are not guaranteed to be correct. A major logic-based approach to Rule Learning is that bunch of techniques collectively known under the name of *Inductive Logic Programming* (ILP) [2,3,4]. ILP has been historically concerned with Rule Learning from examples and background knowledge within the KR framework of Horn rules and with the aim of prediction (see, *e.g.*, the system Foil [5]). However, ILP has also been applied to tasks - such as association rule mining - other than classification where the scope of induction is description rathen than prediction. A notable example of this kind of ILP systems is Warmr [6].

New challenges to Rule Learning come from the emerging vision of the Semantic Web as a *Web of Data*. In particular, when applying ILP to data on the Web, two key issues are the *incompleteness* and the *imprecision* of this data. Incompleteness is naturally treated under the *Open World Assumption* (OWA) as opposed to databases and (I)LP for which the *Closed World Assumption* (CWA) holds. The OWA indeed underlies many Semantic Web languages such as RDF, RDF(S), and OWL. The semantic mismatch between OWA and CWA is elegantly overcome by so-called hybrid KR formalisms that integrate LP and Description Logics (DLs) (see, *e.g.*, [7] for a survey). One of these formalisms is the KR choice in $\mathcal{AL}$-QuIn [8], an ILP system inspired by Warmr, which supports the descriptive task of association rule mining in the new context of the Semantic Web. Imprecision is a weak form of vagueness, not to be mistaken for uncertainty, which is often formalized with fuzzy set theory. In order to deal with vagueness in the Semantic Web context several fuzzy extensions of DLs have been proposed (see, *e.g.*, [9] for a recent overview). The ILP system FOIL-$\mathcal{DL}$ [10] is an adaptation of FOIL to the novel case of learning fuzzy DL axioms where the axioms are in a form easily traducible into rules and fuzzification involves numerical properties of the data.

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