Normative Systems require Hybrid Knowledge Bases

(Extended Abstract)

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ABSTRACT

In this extended abstract we borrow an example from the Portuguese Penal Code to advocate that norms used to regulate interaction in human societies, just as those used in multi-agent systems, require the joint use of the features based on the Closed World Assumption of rules in Logic Programming and those based on the Open World Assumption of ontologies in Description Logics, all of which are provided by Hybrid MKNF Knowledge Bases.

Categories and Subject Descriptors

I.2 [**Artificial Intelligence**]: Knowledge Representation Formalisms and Methods

General Terms

Languages, Theory

Keywords

Norms, Knowledge representation, Organisations and institutions, Design languages for agent systems

1. INTRODUCTION

Normative systems have long been advocated as an effective tool to regulate interaction in multi-agent systems, and the theory and practice of normative multi-agent systems is a young and very active research area.

Essentially, norms encode desirable behaviours for a population of a natural or artificial society. For example, a (conditional) norm might specify that drivers are expected to stop if so signalled by an authority. In general, norms are commonly understood as a specification of what is expected to follow (obligations, goals, contingency plans, advices, actions, ...) from a specific state of affairs.

Nowadays, many popular organisational models for specification and practical implementation of multi-agent systems are partly based on normative notions (see, e.g., [2] and references therein). Typically, these systems take a formal representation of the normative system and, through automated reasoning, check observable agents' behaviours against the norms, in order, for instance, to detect norm violation and to apply sanctions.

One key problem to implement such practical normative systems involves the representation of, and reasoning with norms. On the one hand, we need a representation language that is expressive enough to represent the norms we wish to encode, on the other hand it must be such that we can reason with it efficiently.

Ever since the formalisation of the British Nationality Act using Logic Programming (LP) by Sergot et al. [7], *non-monotonic* formalisms have been used to deal with many aspects of legal rules and regulations. The non-monotonic features common to existing approaches which implement the Closed World Assumption have been shown necessary in the context of reasoning with norms, laws and regulations, for example, to allow default reasoning needed, e.g., to represent exceptions.

Despite the specificities of multi-agent systems, many of their aspects are inspired by human societies, and an intimate parallel between laws in real-world legal systems and norms in multi-agent systems can often be drawn. Therefore, in this paper, instead of tailoring an artificial multi-agent based scenario to illustrate our points, we exploit the Portuguese Penal Code (PPC), that is filled with examples rich in intrinsic subtleties.

Example 1. To illustrate the need for default reasoning to represent exceptions, consider the following PPC articles:

Article 131. Murder

Who kills another person shall be punished with imprisonment from eight to sixteen years.

However, exceptional circumstances for murder increase the duration of the conviction:

Article 132. Aggravated murder

1 – If death is produced in circumstances which present a special censurability, the agent is punished with imprisonment of twelve to twenty-five years.
2 – Is likely to reveal the special censurability referred to in the preceding paragraph, among others*, the fact that the agent:*

(...)
d) employs torture or cruel act to increase the suffering of the victim;
(...)
h) performs the act with at least two other people;

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Accordingly, killing someone is punished with imprisonment from eight to sixteen years, *except* if some additional facts are established, in which case the penalty is aggravated. In other words, unless one of these aggravating facts is proved, *by default* this crime is punished with imprisonment from eight to sixteen years. The relevant part can easily be captured by LP rules using non-monotonic default negation as follows:

$$\begin{aligned}\mathsf{Murder}(X,Y) \leftarrow\ & \mathsf{Killing}(X), \mathsf{Guilty}(X,Y),\\ & {\sim}\mathsf{AggrMurder}(X,Y).\\ \mathsf{AggrMurder}(X,Y) \leftarrow\ & \mathsf{Killing}(X), \mathsf{Guilty}(X,Y),\\ & \mathsf{Censurable}(X).\end{aligned}$$

together with the definition of $\mathsf{Censurable}(X)$, and where $\mathsf{Guilty}(X,Y)$ represents the fact that subject Y was found guilty of punishable event X.

However, in legal reasoning, we sometimes need to represent concepts that cannot be handled by the LP approach, namely those involving open world knowledge. Whereas some extensions of LP allow the representation of some open world knowledge, e.g., through the use of strong negation, they cannot deal with cases that require reasoning with existential knowledge and unknown individuals, often required when dealing with norms.

Description Logics (DLs) [1], decidable fragments of classical first-order logic, offer an alternative and are considered the standard logical representation for expressive ontologies. They are based on the Open World Assumption and allow for reasoning with unknown individuals.

Example 2. Going back to the previous example, encoding item h) as a condition to establish special censurability requires that we refer to (at least) two possibly unknown individuals (a witness or a security camera recording could be sufficient to establish that the culprit acted together with two more people, but not their identity). The relevant part can be encoded in DLs as

$$\geq 3\ \mathsf{PerformedBy.Person} \sqsubseteq \mathsf{Censurable}\ ,$$

meaning that special censurability of the act is established if it was committed by at least three people. Such a condition cannot be expressed in the body of an LP rule since it does not permit encoding unknown individuals. Similarly, it would not be possible to assert in a rule that some act was performed by, e.g., five people, but whose identities, besides that of the accused, are unknown.

Not only can DLs be seen as a solution to properly deal with existential knowledge and unknown individuals, they are quite appropriate for taxonomic representations of facts and concepts, and have been acknowledged in the area of legal reasoning as a fundamental tool for modelling and reasoning about the hierarchy of legal concepts [6]. Unfortunately, DLs do not allow for default reasoning.

Despite the fact that the example used was extracted from a human legal system, normative multi-agent systems are not different when it comes to norms requiring exceptions (e.g., agents should not be allowed to access some confidential information *unless* they have specific privileges) and reasoning with existential knowledge and unknown individuals (which is becoming increasingly relevant, now that privacy issues in MAS are receiving more attention, and the identity of the agent that performed an action might not be available).

In order to properly represent and reason with rich norms that include all these features, we need an approach that tightly combines the best of the two families of formalisms – LP rules and DLs – and exhibits, at least, the following key features:

- have a formal rigorous semantics so that norms can be shared by agents and institutions, and both can reason with the norms to determine their actions and sanctions;
- support both the Open and Closed World Assumption, and the ability to represent and reason with existential knowledge and unknown individuals;
- be equipped with efficient operational semantics to be usable in practical multi-agent systems.

To the best of our knowledge, no existing system concurrently provides seamlessly the expressivity of LP and DLs to represent norms.

With these requirements in mind, we propose that normative frameworks use the joint expressivity of LP and DLs. In such frameworks, facts are represented as a DL ABox, and norms as a combination of a DL TBox and LP rules. The semantics can then be rooted on Hybrid MKNF [5], a language that tightly integrates rules and ontologies, or on its well-founded version [4] for which top-down querying procedures have been introduced and an implementation with support for the DL $\mathcal{ALCQ}$ is available [3].

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