Detection and Resolution of Normative Conflicts in Multi-agent Systems: A Literature Survey

JAAMAS Track

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ABSTRACT

The detection and resolution of conflicts among norms are key processes to guarantee the proper behavior of multi-agent systems (MAS) regulated by norms. A way of regulation is required to restrict and guide the autonomous and possibly heterogeneous software agents that act according to their own interests. When norms are applied to regulate MAS, normative conflicts may arise. A conflict between norms is a situation in which the fulfillment of a norm causes a violation of another one. We present and compare different techniques proposed to detect and resolve conflicts.

KEYWORDS

Norms; Conflict Detection; Conflict Resolution; Multi-agent Systems

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1 INTRODUCTION

In open multi-agent systems (MASs), agents are independently designed and act according to their own interests. Norms can be applied to regulate such systems influencing and restricting the behavior of their agents but not directly interfering with their autonomy. Norm-governed agents are able to reason about norms and choose their actions following or not obligations, permissions, and prohibitions [25]. However, conflicts among norms may arise. A normative conflict arises when the fulfillment of one norm causes the violation of another. When there is a normative conflict, whatever the agents do or refrain from doing may lead to a state that is not norm-compliant [30, 40]. We present and compare different techniques for the detection and resolution of normative conflicts in MAS. This paper is a shorter version of [37].

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2 DETECTION OF NORMATIVE CONFLICTS

Dealing with normative conflicts involves two fundamental steps: detection and resolution. In this section, we describe different approaches and techniques to detect normative conflicts. Normative conflicts can be classified as *direct* or as *indirect* conflicts. A *direct* normative conflict arises between norms that regulate the same behavior of the same agent and have opposite or contradictory deontic modalities (prohibition (F) *versus* obligation (O) or permission (P)). On the other hand, an *indirect* conflict arises when the elements of the norm definition are not the same, but are related. An example of *indirect* conflict is a situation in which an agent is associated with the norms Oq and Fp and $q \rightarrow p$. Note that q and p are different, but q implies p. *Indirect* conflicts may also arise between norms that have the same deontic modality. For instance, a conflict can occur when two norms oblige actions that cannot be performed simultaneously by the same agent [11].

The detection of normative conflicts may be done either at *runtime* or at *design time*. In the approaches that detect normative conflicts at *runtime* [13, 17, 19, 20, 26, 28], the agents must be able to solve such conflicts dynamically. On the other hand, the approaches that detect conflicts at *design time* [1, 6, 10, 12, 16, 44] resolve the conflicts before agents/MAS execute. Some approaches, *e.g.*, [31, 32, 40], only consider *direct* normative conflicts and other approaches can also detect *indirect* normative conflicts, *e.g.*, [1, 15, 16, 28, 29]. The main techniques found in the literature to detect normative conflicts include: normalization, unification, constraint satisfaction and substitution. The remainder of this section introduces these techniques and presents approaches that adopt them as a way to detect conflicts.

Normalization is a technique that detect conflicts based on changing norms in order to transform these into an alternative format better suited for comparing them. The aim is to find norms that overlap with each other. The algorithm used by the conflict checker program [11, 12, 43, 44] is based on such a technique. Normalization is similar to the unification method [17, 39–41] used to check if variables of a prohibition overlap with variables of an obligation. The unification technique has been used with substitution [1, 10, 17, 39, 41], which tries to unify some elements in order to verify particular properties in the normative system.

Some approaches use an ontology to describe the application domain. [11, 12, 43, 44] consider an ontology that describes the norms and the relationships among entities, behaviors and contexts.

An algorithm analyzes the relationships described in the ontology in order to detect conflicts. [1, 10] represent norms as conjunctive formulas (conjunction of atomic assertions). A conjunctive formula over an ontology associates the variables used in the assertions (concepts or relations from the ontology) with a set of constraints that restrict the values that they can assume.

There are approaches that consider plans to check normative conflicts [26–29]. These implement norm-governed practical reasoning agents and promote an architecture that provides a means to preserve the consistency of the set of norms associated with an agent. Before adopting a new norm, an agent must check if this norm is consistent with its set of norms currently held, preserving consistency. [9, 10, 19, 20] identify conflicts between norms by anticipating contexts in which norms may arise. A norm conflict turns into an ontology consistency checking problem handled by Pellet [36].

Some approaches such as [15, 16, 31, 33] use trace analysis to detect normative conflicts. In [15], for instance, an algorithm to detect conflicts generates an automaton that accepts all those traces satisfying a contract.

3 RESOLUTION OF NORMATIVE CONFLICTS

In addition to detecting normative conflicts, in many circumstances it is necessary to solve these so that agents can be norm-compliant. This section presents and compares different approaches for resolving normative conflicts. The work surveyed can be broadly divided into two approaches: norm prioritization (one norm overrides another in particular circumstances) and norm adjustment (one of the norms in conflict is changed). The majority of proposals establish an order of prioritization between norms to specify which norm should be given more importance. In this sense, there are three classic principles found in the literature [40] that have been used to solve deontic conflicts: *lex posterior* prioritizing the most recent norm, *lex specialis* prioritizing the most specific norm, and *lex superior* prioritizing the norm imposed by the most important/powerful issuing authority. These three strategies are adopted to resolve conflicts in the work described in *e.g.*, [10, 19, 20].

Other approaches extend/reduce the scope of influence of the conflicting norms in order to eliminate the overlap between them. They do so by manipulating the components of one of the norms. In [6, 7] conflicts are resolved by establishing an order between regulations/roles at *design time*. All norms associated with the role with higher precedence take precedence over the norms associated with the other one. The work in [18] resolve conflicts based on three criteria: *lex posterior*, *lex specialis*, and relevance of the norm. In [3] an ordering is also established among norms.

The approach of [31, 32] is based on inductive learning and consists of revising a logic program that represents a formal model containing the rules of a specific normative system. A precedence order is established among the institutions, similarly to *lex superior*. The work in [22, 23] resolve *direct* conflicts at *runtime* according to a predefined priority order over either certain policies (based on the issuing authority) or the preferred modality, *i.e.*, positive policies override negative policies or vice-versa. In [35], agents prioritize a norm based on their social context preferences. Similarly, the conflict resolution strategy presented in BOID approach [4, 5] is an order of overruling according to the agent type (*viz.*, realistic, simple-minded, selfish, or social): a realistic agent always prioritizes its beliefs, *i.e.*, beliefs override obligations, intentions or desires; the desires of a selfish agent override obligations; and so on. In the NoA architecture [26] conflicts between prohibitions and permissions can be solved through a ranking of norms, using *lex posterior*.

[40, 41] use constraints to refine the scope of influence of norms on action. It adjusts conflicting norms by adding constraints and thus reducing the scope of influence. The NS model [17] annotates norms thus establishing which values they cannot have so as to avoid a conflict (in essence, curtailing the scope of influence of norms). [8] resolves *direct* conflicts at *runtime*: given a context, a subset of maximal coherence is chosen in order to resolve the conflicts. A resolution algorithm considers the agents' goals and beliefs and the kind of conflict.

In [21], a commitment-based approach, conflicts are resolved by modifying the antecedents of the commitments or reconsidering the commitments that must be part of the role. [13] resolves a normative conflict by performing two calculations: 1) the motivation for fulfilling the first norm plus the motivation for violating the second is calculated; 2) after that, the motivation for violating the first norm plus the motivation to fulfilling the second norm is calculated. When the first calculation results in a greater value than the second, the agent selects the first norm to fulfill. In the NBDI architecture [14], when a conflict is detected, the two conflicting norms are evaluated based on their influence over the agent's desires/intentions. The norm with the highest influence is prioritized over the other one.

4 CONCLUSION

We have surveyed and compared different approaches to detect and resolve normative conflicts. We conclude that there is no single detection/resolution method that is best to detect/resolve conflicts in normative MASs. The inevitability of dealing with specific domains and the need for more practical solutions justify and motivate the diversity of approaches. In order to decide which approach to adopt when dealing with normative conflicts, practitioners must take into account the purpose and characteristics of the normative MAS and pay attention to several factors, such as, the norm expressiveness needed, the deontic modalities considered, the availability and efficiency of mechanisms (ideally implemented), the relationships that can be captured by the detection method, whether the strategy to detect and resolve normative conflicts has guarantees such as correctness, completeness and termination, if the approach is for *design time* or *runtime*, and the computational complexity (time and/or space) of the strategy [37]. We detect an important gap in the current literature on the study of normative conflict, namely, the absence of work on ethical and moral aspects of norm conflict detection and resolution. In spite of the significant overlap between norms and moral/ethical issues, as studied in, for instance, [2, 34, 42], to name a few, such concerns feature only peripherally, if at all, in the surveyed literature. Given the current interest in ethical autonomy [24, 38], especially related to technologies which will impact day-to-day activities of many people, such as autonomous vehicles, it is imperative that more attention should be devoted by the community to the topic.

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