Defeasible Normative Reasoning: a Deontic Equilibrium Logic approach

Ovidio Manteiga[1,*]

[1]University of A Coruña, A Coruña, Spain.
PhD Supervisors: Pedro Cabalar and Concepción Vidal

Abstract

This PhD research aims to develop new deontic logic formalisms grounded in Equilibrium Logic and implemented in Answer Set Programming (ASP). The work starts from Deontic Equilibrium Logic with Explicit Negation (DELX) and its ASP implementation in `deolingo`, and aims to improve the representation and automation of normative reasoning in cases where existing approaches remain limited. The first line of research aims to develop a new deontic modal logic formalism that strictly extends DELX and captures more expressive deontic constructions, including obligations over disjunctions, which DELX cannot represent appropriately. A draft specification of this formalism is already available, and proofs of its main theoretical properties are currently being completed. The second line of research extends `deolingo` with temporal deontic reasoning capabilities by implementing the deontic temporal framework DeoTEL (Deontic Temporal Equilibrium Logic), enabling the treatment of norm dynamics over time within an ASP-based workflow. A preliminary implementation of this extension is already available. Overall, the ultimate objective is to provide both solid logical foundations and practical tooling for richer and more efficient normative reasoning by leveraging mature ASP technology for implementation.

Keywords

Deontic Logic, Equilibrium Logic, Answer Set Programming, Modal Logic, Normative Reasoning, Explainable AI, Trustworthy AI,

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1. Introduction

Normative reasoning in AI requires handling obligations, prohibitions, permissions, exceptions, and violations in a way that is both logically sound and computationally practical. In deontic logic, defeasibility means that a norm may be overridden—or *defeated*—by a more specific or stronger norm in a particular context, rather than applying unconditionally in every situation. Defeasibility is especially relevant in normative reasoning in scenarios such as default rules being overridden by more specific ones, which can be naturally represented in non-monotonic formalisms such as Equilibrium Logic and Answer Set Programming. Several logical frameworks and tools exist to address this kind of reasoning [1, 2, 3, 4, 5], yet deontic formalisms often struggle with key benchmark phenomena (for instance, dilemmas and contrary-to-duty scenarios), or lack direct support from mature reasoning engines.

Consider the following example of contrary-to-duty reasoning [6] concerning the regulation of holiday cottages:

1. There must be no fence.
2. If there is a fence, it must be a white fence.
3. If the cottage is by the sea, there may be a fence.

When reasoning about those norms, one must be able to conclude, for example, that there is an obligation that the fence is white, provided that there is a fence, even when that somehow contradicts (violates) the more general (default) prohibition of fences.

Our research problem is to design deontic logics with the expressiveness needed for realistic normative domains while preserving a clear computational path through Answer Set Programming (ASP) [7].

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*Corresponding author.
ovidio.manteiga@udc.es (O. Manteiga)
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The motivation is twofold. First, from a knowledge representation perspective, we need formalisms that faithfully model nuanced normative statements, including cases where obligations interact with disjunction and conflicting normative statements. Second, from a systems perspective, adoption depends on efficient implementability: representations should be executable with existing ASP technology in an efficient way, and, thus, allowing to model and reason about real normative problems.

Consider now the following example involving a disjunctive obligation [8]: "one must fight in the army or perform alternative civil service" can be informally formulated as $obligatory(army \vee civil\ service)$. Such formulation is equivalent in some deontic logic formalisms — including DELX — to the disjunction $obligatory(army) \vee obligatory(civil\ service)$, which counterintuitively states that it is enough if one of the two obligations holds separately. Any model where either the fact of fighting in the army is true or the fact of performing alternative civil service is true (or both are), fulfills the obligation $obligatory(army \vee civil\ service)$. So if all the models have either of those facts, all of them comply with the obligation. But in the case of the disjunction of obligations ($obligatory(army) \vee obligatory(civil\ service)$), in some models one obligation might hold and, in others, the other obligation; so the fact that each model verifies $army \vee civil\ service$, does not imply that all of them comply with the obligations (e.g. if one model contains $obligatory(army)$ and $civil\ service$) for example.

2. Background

A central starting point for this research is Deontic Equilibrium Logic with eXplicit negation (DELX) [9], which extends Equilibrium Logic with deontic operators over a three-valued setting and provides a non-monotonic treatment of normative reasoning. DELX was designed to address recurring deontic challenges, including defeasible obligations, explicit versus implicit permission, and a refined treatment of conflicts such as dilemmas versus contrary-to-duty reasoning[10][11], to name a few.

The system `deolingo` [12] implements DELX in ASP by relying on the efficient ASP solver Clingo [13]. It translates deontic specifications into regular ASP artifacts that can be solved with Clingo, plus, it includes explainability support via Xclingo annotations [14]. This is important because it connects formal deontic semantics with practical, inspectable reasoning and explainable workflows.

The other main foundation for this research is related to temporal deontic reasoning. Recent work on DeoTEL [15] "Tackling Temporal Deontic Challenges with Equilibrium Logic" extends the line of research to temporal settings by combining temporal and deontic reasoning under semantics based on Temporal Equilibrium Logic. DeoTEL provides a formal framework to express and reason about temporal deontic statements, such as obligations that ought to be maintained over time and achievement obligations (i.e., obligations that are applicable until some condition is achieved before a deadline). This new temporal deontic framework shows how temporal normative challenges can be addressed while remaining implementable in existing temporal ASP systems like Telingo [16]. Our research is positioned as a next step in this trajectory: extending the representational power of DELX limits by consolidating temporal deontic reasoning into robust ASP implementation by expanding `deolingo` with the DeoTEL capabilities.

3. Research Goals

The proposed approach for this research has two coordinated tracks: one related to a new modal formalism that extends DELX to be able to represent more complex deontic statements, and another related to expanding the `deolingo` with further capabilities, starting by deontic temporal reasoning from DeoTEL.

Track 1 aims to develop a new modal deontic formalism that strictly extends DELX. The main hypothesis is that extending DELX with carefully constrained modal constructions [17] can increase expressiveness — notably, for obligations over disjunction and related composite normative statements

—, without losing the desirable non-monotonic behavior inherited from Equilibrium Logic. Methodologically, this track proceeds through: (i) syntax and semantics definition, (ii) theoretical analysis (characterization, model properties, and comparison with DELX), and (iii) validation on existing deontic scenarios where existing representations are inadequate. For this new deontic modal formalism, validation is primarily theoretical. The main target is to prove that the formalism is strictly more expressive than DELX, namely, that it can represent all DELX-expressible statements while also capturing additional deontic constructions (including cases such as obligations over disjunctions). In parallel, we will characterize its computational complexity to make tractability limits explicit. Given the expected complexity of the extended formalism, implementation is planned as a restricted prototype for simple fragments, mainly to support sanity checks and illustrative examples rather than full-scale deployment. A draft of the formalism has been completed, proofs of the main theorems are in progress, and the first paper introducing the formalism is about to be submitted for publication.

Track 2 aims to extend `deolingo`, mainly with temporal deontic capabilities by implementing DeoTEL. The hypothesis is that temporal deontic reasoning can be made practical by compiling high-level deontic-temporal specifications into lower-level temporal ASP encodings, while preserving the intended semantics of DeoTEL. Methodologically, this track includes: (i) language-level support for temporal normative patterns (e.g., maintenance/achievement-like obligations over traces), (ii) translation and normalization pipelines aligned with Temporal Equilibrium Logic style encodings, and (iii) empirical assessment on temporal normative scenarios. A preliminary implementation already exists and serves as the basis for iterative refinement, benchmarking, and explainability integration. For the temporal deontic track, validation is implementation-oriented. First, the temporal extension of `deolingo` will be tested against canonical scenarios from the literature, with a special focus on the scenarios described in DeoTEL. Second, we will run benchmarking experiments to assess practical behavior (encoding size, runtime, and scalability trends). Third, we will model a realistic normative domain with temporal obligations, representing non-trivial regulations and querying them in `deolingo`. The expected evidence of success is: (i) faithful reproduction of literature scenarios, (ii) acceptable computational performance on benchmark instances, and (iii) useful reasoning outcomes on complex regulation-oriented case studies.

4. Current Status and Preliminary Results

Our current progress is substantial on both research tracks. On the formal side, we have been working a draft of a new modal deontic formalism that supersedes DELX in expressiveness, according to the preliminary results. In particular, it is designed to properly represent constructions such as obligations over disjunctions, which DELX cannot encode satisfactorily. The ongoing stage focuses on consolidating and finishing the main proofs for the formal results.

On the implementation side, we have extended `deolingo` with DeoTEL-oriented temporal deontic capabilities, and the prototype already covers the set of theoretical test scenarios discussed in the DeoTEL paper. This provides a preliminary end-to-end validation that the intended temporal-normative behaviors can be represented and computed within an ASP-based workflow.

Regarding related publications, this line of work is supported by the DEON 2025 paper on `deolingo` (Best Paper Award), while current implementation and formalization advances are being prepared for dissemination in upcoming conferences in the field.

5. Open issues and expected achievements

Our planned timeline is as follows: in 2026, we aim to complete the new modal deontic formalism and finish its main proofs and validation (including expressiveness and initial complexity results). Also in 2026, we plan to release a new version of `deolingo` with temporal extensions and submit a dedicated technical paper describing the system design and empirical behavior.

Going forward, starting next year, we will focus on proving more theoretical properties of the new modal deontic framework, such as computational complexity proofs, comparing it with other existing

formalisms, and analyzing a potential efficient implementation using ASP.

Besides, another important work to accomplish as part of this PhD research is to model a complex normative problem using the new capabilities of the deontic tools developed in order to showcase their power to be used in complex normative reasoning scenarios. Such a normative problem might involve multiple scenarios and normative reasoning tasks over a large body of regulation, for example, finding models for contrary-to-duty scenarios, finding finite traces for temporal obligations, or finding and explaining deontic inconsistencies in the modeled regulation.

A future line of research will explore the intersection between the new modal formalism and the temporal framework by studying whether both can be integrated into a coherent semantic and computational setting, and how to incorporate the expressive power of the new modal logic formalism into the temporal deontic approach (e.g., using disjunctive obligations in the DeoTEL setting).

Some open challenges are: (i) preserving semantic clarity while increasing deontic expressiveness; (ii) maintaining computational efficiency for practically relevant fragments of the theoretical modal deontic framework; (iii) defining robust reasoning paradigms when combining modal and temporal deontic constructs; (iv) validating the unified approach on realistic normative case studies with temporal constraints; and (v) axiomatization of the new deontic modal logic formalism.

Declaration on Generative AI

During the preparation of this work, the author used OpenAI generative AI services to check grammar and spelling, paraphrase and reword text, improve writing style, draft content, and manage citations. After using these services, the author reviewed and edited the content as needed and takes full responsibility for the publication's content.

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