Normative Multi-Agent Systems and Kelsenian Jurisprudence

Christiano Braga¹ and E. Hermann Haeulser²

¹ Instituto de Computação, Universidade Federal Fluminense
² Departamento de Informática, Pontifícia Universidade Católica do Rio de Janeiro
cbraga@ic.uff.br, hermann@inf.puc-rio.br

Abstract. A multi-agent system (MAS) is a collection of autonomous entities, called agents, that interact to fulfill the system’s intended behavior. When regulated by a collection of rules, also called norms, such a system is referred as a Normative MAS (NorMAS). The standard technique to reason on NorMAS uses Deontic Logic as underlying logic where norms become formulae in the associated theory. However, it is known to fail on the modeling of contrary-to-duty scenarios, also called deontic paradoxes, since the resulting theories turn out to be inconsistent. In this paper, we propose a new approach to reason on NorMAS, based on Intuitionistic Hybrid Logic (IHL) and Kelsenian Jurisprudence. Essentially, norms are represented as nominals in the associated IHL theory. We discuss normative conflict identification according to Hill’s functional taxonomy, that generalizes from standard identification by impossibility-of-joint-compliance test. Norm conflicts are resolved by norm precedence, naturally captured by the underlying Heyting algebra.

1 Introduction

A multi-agent system (MAS) [17] is a collection of autonomous entities, called agents, that collaborate with one another to solve a problem. Modal Logic is a suitable formalism to model and reason on MAS, both from knowledge and time perspectives [5, Ch. 4]. When we consider Normative MAS (NorMAS) [3], that is, a MAS that is regulated by a set of rules also called norms, the state-of-affairs become more subtle. Scenarios where a norm regulated, or simply regulated, MAS may misbehave must be accounted for in a proper logical formalization. An example of misbehavior is when negative transitions are specified, assuming a labeled state-transition system formalization of MAS, and conflict arise between MAS behavior and its regulation.

To illustrate the second scenario, let us consider the Contract Net [6] agent interaction protocol, standardized by the Foundation for Intelligent Physical Agents (FIPA). Informally, it specifies that: (i) when an
(initiator) agent realizes it has a problem to solve, (ii) it may announce it to other agents, (iii) which in turn will bid for the task of solving (part) of the given problem, (iii) being then notified by the initiator which was the awarded agent, that then (iv) expedites solving the problem. Figure 1 illustrates the protocol.

Let us consider now a subclass of Contract Net implementations regulated by the norms in Table 1. Now, if in an implementation of Contract Net with norms from Table 1, say an electronic commerce system, an agent refuses to implement action bid, it would give rise to a misbehaving NorMAS, as action bid, at the same time, must and can not occur. This scenario is depicted in Figure 2 where $P_3$ is the misbehaving agent that does not implement action bid, with the interrupted or negative transition (loosely dashed, with double tip and
a ray symbol denoting interruption) denoting the lack of implementation for action *bid*. (Note that specifying a negative transition is part of the *description* of what the system does (or does not), not its *description*, or what properties it should have.)

What we have just described is an example of the so-called contrary-to-duty scenarios that become paradoxical when Deontic Logic [16], an extension of basic Modal Logic for sentencing obligations, permissions and prohibitions, is chosen as the underlying logic to model and reason on NorMAS. More precisely, the norms in Table 1, together with the situation where it is not the case that once a problem is announced then all agents must bid (that is only the case when at least one agent can not bid), is an instance of the so-called Chisholm paradox [4]. (We defer its formal presentation to Section 4 while discussing normative contradictions.)

Reasoning on NorMAS have received substantial attention in the past few years. Section 2 discusses some of them. However, most of them fall prey of the interpretation that a norm is a proposition in the underlying logic. In [7, 9], the authors proposed, in the context of legal systems, ontological requirements that a logic for a legal system should fulfil. Their proposal embodies the Kelsenian Jurisprudence [13] that only individual laws are inhabitants of the Legal knowledge base. A consequence of their proposal is that a *norm* may be interpreted as a world in the Kripke structure that models a normative system. In Hybrid Logics (HL) [1], an extension to Modal Logics, worlds may be named. Thus, norms in HL, under Kelsenian interpretation, are named worlds, or nominals in HL terminology.

In this paper, we build on previous work and propose Kelsenian NorMAS, a Normative Multi-Agent System that has Intuitionistic Hy-
brid Logic (IHL) [2], with the Kelsenian interpretations of norms, as underlying logical framework.

After reviewing related work in Section 2, in Section 3 we revisit the ontological commitments in [7] from a NorMAS perspective, show IHL to be their underlying logic, and define Kelsenian NorMAS in terms of IHL models. Section 4 relates Hill’s normative conflict taxonomy and Kelsenian NorMAS. Section 5 concludes this paper with our final remarks.

2 Related work

There are many approaches to model NorMAS, and to detect and solve normative conflicts, nicely summarized in [15] but there are still many open issues [3].
In this related work we discuss some of the points raised by [3]. The authors identify many key issues and open problems. Some of them discussed in this paper. First, they identify that norms are neither true nor false. However, their proposal is to reconstruct Deontic Logic. We agree with their point of view that norms should not have truth value. However, we do not follow the proposed engineering approach to Deontic Logic. We chose a different approach, based on intuitionistic hybrid logics (IHL), where norms are nominals. Second, as Deontic Logic is their chosen underlying logical framework, Deontic Logic paradoxes are inherited by NorMAS. Section 3 shows how deontic paradoxes are not paradoxes in our approach, that is, an agent or the agency may chose not to follow a norm. Third, norm conflict identification and resolution is a key issue in NorMAS. In Section 4 we discuss it in our approach.

The authors in [8] propose the logic iALC, an Intuitionistic Description Logic, for reasoning about laws. The logic iALC, which is a notation variant of IHL, was designed to cope with the ontological requirements in [7]. In particular, iALC handles Commitment III very nicely as iALC concepts represent different normative systems (understood as a collection of norms) quite naturally. IHL, has support for normative systems (by the partial order on worlds $\langle W, \leq \rangle$, described in Section 3) which appears indeed to be less expressive than the one available iALC. However, as opposed to iALC, IHL has support for (action-based) temporal reasoning. A characteristic that we believe makes it more suitable to model and reason about NorMAS than iALC.

3 Kelsenian Normative Multi-Agent Systems

Kelsenian Jurisprudence [13], in a nutshell, advocates that “the law”, in legal terms, or the norms in a NorMAS, is a set of individual regulatory statements, each of them created to enforce a positively desired behavior in the system. In [7], the authors propose the following requirements (or ontological commitments) from an analysis of Kelsenian Jurisprudence. Table 3 interprets the three ontological commitments in [7] in the context of NorMAS. Henceforth, we will refer to the contents of Table 3 as Kelsenian regulation.

Ontological commitment (I) is fulfilled by the choice of Hybrid Logic representing norms as nominals, an extension to Modal Logics that
(I) Individuals are norms;

(II) There is a transitive and reflexive relationship between individuals and norms that reflects a precedence relationship between norms;

(III) There are normative connections between individual norms in different normative systems or between different agent organizations in the same normative system.

Table 2. Kelsenian regulation

adds a new sort of propositional symbols which are true at exactly one possible world. Logics with such an extension are called (basic) Classical Hybrid Logics [1, 14]. Syntactically, new operators, called satisfaction operators, are written $a : \varphi$ (sometimes written $\varnothing_a \varphi$) where $a$ is a nominal (a possible world) and $\varphi$ is a formula. Models of Classical Hybrid Logic are Kripke structures $(W, R, V)$, with non-empty set of worlds $W$, world accessibility relation $R \subseteq W \times W$ and $V : W \times AP \rightarrow \{0, 1\}$, where $AP$ is the set of atomic propositions, together with a function $g$, called an assignment, that, to each nominal, assigns an element of $W$. An assignment $g'$ is an $a$-variant of $g$ if $g'$ agrees with $g$ on all nominals save possibly $a$. The relation $M, g, w \Vdash \varphi$ is defined by structural induction in the language of the Classical Hybrid Logic, where $g$ is an assignment, $w$ is an element of $W$, and $\varphi$ is a formula. The satisfaction relation for Classical Hybrid Logics is as follows:

\[
M, g, w \Vdash p \iff V(w, p) = 1, \\
M, g, w \Vdash a \iff w = g(a), \\
M, g, w \Vdash \varphi \land \psi \iff M, g, w \Vdash \varphi \text{ and } M, g, w \Vdash \psi, \\
M, g, w \Vdash \varphi \implies \psi \iff M, g, w \Vdash \varphi \text{ implies } M, g, w \Vdash \psi, \\
M, g, w \Vdash \neg \varphi \iff M, g, w \nvDash \varphi, \\
M, g, w \Vdash \Box \varphi \iff \text{for any element } v \text{ of } W \text{ such that } wRv, \text{ it is the case that } M, g, v \Vdash \varphi, \\
M, g, w \Vdash a : \varphi \iff M, g, g(a) \Vdash \varphi.
\]

However, Classical Hybrid Logic is not enough.

Commitment (II) requires an ordering relation between norms. It is a natural way to prevent norm conflicts [15] as it imposes a precedence between norms. Hybrid Logic, however, does not offer it. Heyting algebras [11], models of Intuitionistic Logics [2], provide such a structure: is a bounded lattice, with join and meet operations written $\sqcup$ and $\sqcap$, least element $\bot$, greatest element $\top$, and implication $\rightarrow$.

The formulas of Intuitionistic Hybrid Logic are the same as those of Classical Hybrid Logic. However, connectives $\lor$ and $\lozenge$ are primitive as
they are not intuitionistically definable in terms of the other con-
nectives, contrary to the classical case.

A model for Intuitionistic Hybrid Logic [2] (IHL) is a tuple

\[(W, \leq, \{D_w\}_{w \in W}, \{\sim_w\}_{w \in W}, \{R_w\}_{w \in W}, \{V_w\}_{w \in W})\]

where \(W\) is a non-empty set partially ordered by \(\leq\), for each \(w, D_w\) is a
non-empty set such that \(w \leq v\) implies \(D_w \subseteq D_v\), for each \(w, \sim_w\) is an
equivalence relation on \(D_w\) such that \(w \leq v\) implies \(w \subseteq v\), for each
\(w, R_w\) is a binary relation on \(D_w\) such that \(w \leq v\) implies \(R_w \subseteq R_v\), and
for each \(w, V_w\) is a function that to each ordinary propositional symbol
\(p\) assigns a subset of \(D_w\) such that \(w \leq v\) implies \(V_w(p) \subseteq V_v(p)\).

Given a model \(M = (W, \leq, \{D_w\}_{w \in W}, \{\sim_w\}_{w \in W}, \{R_w\}_{w \in W}, \{V_w\}_{w \in W})\)
and an element \(w\) of \(W\), a \(w\)-assignment is a function \(g\) that to each
nominal assigns an element of \(D_w\). Note that if \(g\) is a \(w\)-assignment
and \(w \leq v\), then \(g\) is also a \(v\)-assignment (this is used in the clauses be-
low for implication and the \(\Box\) operator). The relation \(M, g, w, d \models \varphi\)
is defined by induction, where \(w\) is an element of \(W\), \(g\) is a \(w\)-assignment,
\(d\) is an element of \(D_w\), and \(\varphi\) is a formula.

\[
\begin{align*}
M, g, w, d \models p & \Leftrightarrow d \in V_w(p), \\
M, g, w, d \models a & \Leftrightarrow d \sim_w g(a), \\
M, g, w, d \models \varphi \land \psi & \Leftrightarrow M, g, w, d \models \varphi \text{ and } M, g, w, d \models \psi, \\
M, g, w, d \models \varphi \lor \psi & \Leftrightarrow M, g, w, d \models \varphi \text{ or } M, g, w, d \models \psi, \\
M, g, w, d \models \varphi \Rightarrow \psi & \Leftrightarrow \text{ for all } v \geq w, M, g, v, d \models \varphi \text{ implies } M, g, v, d \models \psi, \\
M, g, w, d \models \bot & \Leftrightarrow \text{ falsum } \\
M, g, w, d \models \Box \varphi & \Leftrightarrow \text{ for any element } v \geq w, \text{ for all } e \in D_v, dR_we \text{ implies } M, g, v, e \models \varphi, \\
M, g, w, d \models \Diamond \varphi & \Leftrightarrow \text{ for some } e \in D_w, dR_we \text{ and } M, g, w, e \models \varphi, \\
M, g, w, d \models a : \varphi & \Leftrightarrow M, g, w, g(a) \models \varphi.
\end{align*}
\]

Finally, commitment (III) requires a relation between named worlds.
This is accomplished by the partial order \((W, \leq)\) in the IHL model, with
each \(w \in W\) being a named world.

We now define Kelsenian NorMAS in terms of an IHL model. Following Kelsen, for each norm we have a world \(w \in W\) in the IHL model,
ordered in \(\leq\) according to the order of declaration of the norms. In
other words, the pair \((W, \leq)\) captures the normative part of the Nor-
MAS. The MAS description is represented by the tuple \((D, R^{Act,A})\) of the
IHL model, where \(D\) denotes the set of the states of MAS and \(R^{Act,A}\) its
(action-labeled) transition relation, for actions in \( Act \), defined as the disjoint union of the relations for each agent in \( A \). (In this paper we consider relation \( \sim \), in the IHL model, to be empty, without loss of generality, that is, there is no equivalence among states of the MAS.)

**Definition 1 (Kelsenian NorMAS).** A Kelsenian Normative Multi-Agent System is an IHL model \( \mathcal{K} = (N, \leq, D, \emptyset, \{R_n^{Act, A}\}_{n \in N}, V) \) where \( Act \) is a finite set of actions, and \( A \) is a finite set of agents, such that, for all \( n \in N \), 
\[
R_n^{Act, A} = \bigcup_{i=1}^{|A|} R_i,
\]
with \( R_i \subseteq D \times Act \times D \) and \( V : D \times AP \rightarrow \{0, 1\} \) with \( AP \) the set of atomic propositions.

A state \( n_i \in N \) is such that norm \( n_i \) is upheld. Note that upheld does not mean “the norm holds” as norms have no truth value. It means that \( R_i \) complies with \( n_i \).

**Example 1 (Kelsenian NorMAS for the misbehaving Contract Net).** The Kelsenian NorMAS for the Contract Net instance in Figure 2 is the tuple \( \mathcal{K} = (N, \leq, D, \emptyset, \{R_n^{Act, A}\}_{n \in N}, V) \) where \( N = \{n_1, n_2, n_3, n_1 \sqcap n_2, n_1 \sqcap n_2 \sqcap n_3\} \), where operation \( \sqcap \) denotes the meet operation of IHL’s underlying Heyting algebra. The ordering \( \leq \) is as pictured in Figure 3, \( D = \{Recognized, Announced, Bade, Awarded\} \), relation \( R \) is pictured in Figure 2, \( A = \{I, P_1, P_2, \ldots, P_n\} \), \( Act = \{recognize, announce, bid, award\} \), and \( V = \emptyset \). Let \( p \) denote “Once a problem is announced then all agents bid”.

The least element of \( (N, \leq) \) is state \( n_1 \sqcap n_2 \sqcap n_3 \), that is, the join of states \( n_1, n_2 \) and \( n_3 \) denoting a world which is not a model for “Once a problem is announced then all agents bid”. State \( n_3 \), larger than \( n_1 \sqcap n_2 \sqcap n_3 \), is such that proposition \( p \) does not hold, that is, a state where the agency does not comply with the first norm of Table 1.\(^3\)

### 4 Hill’s taxonomy and Kelsenian NorMAS

In [12] H. Hamner Hill proposes a taxonomy for normative conflict, an important reference in the normative systems literature in the context

\(^3\) Note that not being a model for \( p \) and \( \neg p \) holding in a state are different things. In the former case state \( n_1 \sqcap n_2 \sqcap n_3 \) is not a model for \( p \) while in the latter case state \( n_3 \) is a model for \( \neg p \), that is, \( \neg p \) is satisfiable.
of norm conflict identification and resolution [15]. Hill argues, developing ideas by Kelsen and others, that normative conflicts identified by impossibility-of-joint-compliance test, when it is impossible for a norm subject to comply with both of a pair of norms, is too restrictive. Let us briefly recall why.

The impossibility-of-joint-compliance test can only be applied to norms that one can construct obedience statements for, that is, a statement that certifies compliance of a norm subject with a given norm. For example, let us consider norm \( n_1 \) from Table 1 from the introductory section, that says "Once a problem is announced then all agents must bid". Its obedience statement would be "A problem has been announced and all agents bade". Therefore, impossibility-of-joint-compliance test only applies to deontic imperatives.

There are, however, scenarios where: (i) deontic permissions conflict with deontic permissions, (ii) there are regulatory modalities other than the deontic modalities, as in power-conferring norms [10], and (iii) conflicts considering non-deontic norms. Quoting Hill [12, pg. 238 and 239]:

For Kelsen, a normative conflict is a clash of forces, forces which operate in different directions in a single point. (…) The generic phenomenon of normative conflict occurs when norms interact
in ways that the function of one or more of the norms involved is thwarted.

Hill defines a functional taxonomy of normative conflicts: (i) normative contradiction, (ii) normative collision and (iii) normative competition. Normative contradictions are “a purely deontic phenomena” where only deontic norms may contradict each another. In normative collisions, deontic imperatives and deontic permissions collide, mixtures of deontic and non-deontic norms collide or only non-deontic norms collide. Normative competition regards norm conflicts from distinct normative systems. In what follows, we present Kelsenian NormAS for normative contradictions and normative collisions between deontic imperatives and deontic permissions.

**Normative contradiction.** Important examples of normative contradictions come from scenarios where the norm subject finds oneself faced with duties one cannot fulfil. These scenarios are the so-called contrary-to-duty paradoxes when Deontic Logic is used to formalize them. One such contrary-to-duty paradox is Chisholm paradox which is embodied in the “misbehaved” Contract Net implementation in Figure 2. When formalized in Deontic Logic, it gives rise to an inconsistent theory. To see why we just need to see why the “misbehaved” Contract Net implementation is an instance of the Chisholm paradox. Let us first recall the paradox and its proof of inconsistency.

Logic KD, also known as SDL, has the following axioms and inference rules.

- **TAUT** All the tautologies of classical propositional logic.
  - $K (O(p) \Rightarrow q) \Rightarrow (O(p) \Rightarrow O(q))$
  - $D O(p) \Rightarrow \neg O(\neg p)$
  - $MP$ if $\vdash p$ and $\vdash p \Rightarrow q$ then $\vdash q$
  - **OB-NEC** if $\vdash p$ then $\vdash O(p)$.

The SDL formalization of the Chisholm paradox is the conjunction of the following sentences

$$O(p)$$  \hspace{1cm} (1)
$$O(p) \Rightarrow q$$  \hspace{1cm} (2)
$$\neg p \Rightarrow O(\neg q)$$  \hspace{1cm} (3)
$$\neg p$$  \hspace{1cm} (4)
where \( O \) is the deontic modality for obligation, \( p \) is a propositional variable and so is \( q \). As for the proof of inconsistency, from (2) and \( K \) we get \( O(p) \implies O(q) \), and then from (1) and \( MP \), we get \( O(q) \), but by \( MP \) alone we get \( O(\neg q) \) from (3) and (4). From these two conclusions, by Propositional Calculus, we get \( O(q) \land O(\neg q) \), contradicting the SDL principle that obligations cannot conflict [16].

Now, to see the misbehaved Contract Net implementation in Figure 2 as an instance of the Chisholm paradox we just need to replace \( p \) above for “Once a problem is announced then all agents bid”, and \( q \) as “an agent is awarded”. When action \( bid \) is not implemented by an agent, thus leading to the negative transition in Figure 2, “all agents must bid” becomes false and so does \( p \). Therefore, Figure 3 pictures an IHL model for a NorMAS that is an instance of the Chisholm paradox.

**Normative collision.** Following the same approach for deontic imperatives, deontic permissions do not have truth value: there are nominal states denoting when the agency avails itself of a permission and otherwise.

We can illustrate this situation by considering Contract Net instance from Figure 1, the norms from Table 1, and a permission, say \( p \), prescribing that “An agent is not allowed to bid”. Note that this normative system is slightly different from the “misbehaving” Contract Net instance in Figure 2. There, the negative transition is part of the description of the system (the behavior of the system) and here the permission not to act is at the prescription (what it should do) level. There is clearly a normative collision here between norm \( n_i \) and permission \( p \). Figure 3 pictures the IHL model for the normative collision example where world \( n_i \) denotes norm \( n_i \), with \( i \in \{1, 2, 3\} \), \( p_1 \) denotes the state where the agency avails itself of permission \( p \) and \( \overline{p} \) otherwise. The resulting Kelsenian NorMAS is a lattice with combinations of \( n_i \), \( p \), and \( \overline{p} \), as depicted in Figure 4. (All arrows denote relation \( \leq \).)

The infimum of the lattice is \( n_1 \sqcap n_2 \sqcap n_3 \sqcap p \sqcap \overline{p} \models \bot \) denoting a state of the Kelsenian NorMAS where no property holds since a join between states \( p \) and \( \overline{p} \) results in a state where agents are permitted to bid and are not permitted to bid making it impossible to uphold norms \( n_1 \) to \( n_3 \). In particular, either norm \( n_1 \) or \( n_2 \) can not be upheld when agents are not permitted to bid as they must when a problem is announced. (A similar argument is used to justify state \( n_3 \sqcap \overline{p} \models \bot \).) On the other hand,
when either $n_1$ or $n_2$ can be upheld in a state when agents may bid and therefore $(n_1 \sqcup n_2) \cap \overline{p} = T$. Norms are upheld in states where single norms alone are upheld (not a join or meet of worlds) or a permission is upheld, such as $n_1$ or $p$. The join of all the worlds (not to be confused with their conjunction) represents the supremum of the lattice.

5 Conclusion

Standard techniques for modeling and reasoning on Normative Multi-Agent Systems (NorMAS) fall prey of the interpretation that norms are formulas. When Deontic Logic is chosen as underlying formalism for NorMAS, different classes of norm conflicts may arise, such as when
Deontic imperatives (or obligations) conflict among each other, or with deontic permissions.

In this paper, we propose to interpret norms as nominals, following Kelsenian thinking, in Intuitionistic Hybrid Logic. This allows us to construct models for otherwise paradoxical situations and to conflicts involving deontic imperatives and deontic permissions in an elegant and simple way. Our running case is a FIPA protocol for multi-agent communication.

Future work includes further developing our framework, in particular regarding the normative connections from Commitment possibly in the directions of iALC where relations between concepts denote classes of norms. Another direction is the automation of our approach to simulate and (bound) model check Kelsenian NorMAS where the model is the semantics of a description in an appropriate specification language.

References

1. C. Areces, P. Blackburn, and M. Marx. Hybrid logics: Characterization, interpolation and complexity. The Journal of Symbolic Logic, 66(3):977–1010, 2001.
2. T. Braüner and V. de Paiva. Intuitionistic hybrid logic. Journal of Applied Logic, 4(3):231–255, 2006.
3. J. Broersen, S. Cranefield, Y. Elrakaiby, D. Gabbay, D. Grossi, E. Lorini, X. Parent, L. W. N. van der Torre, L. Tummolini, P. Turrini, and F. Schwarzentuber. Normative Multi-Agent Systems, volume 4, chapter Normative Reasoning and Consequence, pages 33–70. Dagstuhl Publishing, 2012.
4. R. M. Chisholm. Contrary-to-duty imperatives and deontic logic. Analysis, 24:33–36, 1963.
5. R. Fablin, J. Y. Halpern, Y. Moses, and M. Y. Vardi. Reasoning about knowledge. MIT Press, 2003.
6. FIPA. Fipa contract net interaction protocol specification. Technical report, Foundation for Intelligent Physical Agents, 2002.
7. E. H. Haesler, V. de Paiva, and A. Rademaker. Using intuitionistic logix as a basis for legal ontologies. Informatica e Diritto, XIX(1-2):289–298, 2010.
8. E. H. Haesler, V. de Paiva, and A. Rademaker. Intuitionistic description logic and legal reasoning. In Database and Expert Systems Applications (DEXA), 2011 22nd International Workshop on, 2011.
9. E. H. Haesler and A. Rademaker. On how kelsenian jurisprudence and intuitionistic logic help to avoid contrary-to-duty paradoxes in legal ontologies. In Logical Reasoning and Computation: Essays dedicated to Luis Fariñas del Cerro, pages 55–68, 2016.
10. H. L. A. Hart. The Concept of Law. Clarendon Law. Oxford University Press, 3 edition, 2012.
11. A. Heyting. Die formalen Regeln der intuitionistischen Logik. I, II, III. Sitzungsber. Preuß. Akad. Wiss., Phys.-Math. Kl., 1930:42–56, 57–71, 158–169, 1930.
12. H. H. Hill. A functional taxonomy of normative conflict. *Law and Philosophy*, 6:227–247, 1987.

13. H. Kelsen. *Pure Theory of Law*. Lawbook Exchange, 2005.

14. A. Prior. *Past, Present and Future*. Clarendon P., 1967.

15. J. S. Santos, J. O. Zahn, E. A. Silvestre, V. T. Silva, and W. W. Vasconcelos. Detection and resolution of normative conflicts in multi-agent systems: a literature survey. *Autonomous agents and multi-agent systems*, doi:10.1007/s10458-017-9362-z:1–47, 2017.

16. G. H. von Wright. Deontic logic. *Mind*, 60(237):1–15, Jan. 1951.

17. M. Wooldridge. *Introduction to MultiAgent Systems*. Wiley, 2 edition, 2009.