Norm Defeasibility in an Institutional Normative Framework

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Abstract. Normative environments have been proposed to regulate agent interaction in open multi-agent systems. However, most approaches rely on pre-imposed regulations that agents are subject to. Taking a different stance, we focus on a normative framework that assists agents in establishing by themselves their own commitment norms. With that aim in mind, a model of norm defeasibility is presented that enables exploiting and adapting a normative background to different extents. We formalize the normative state using first-order logic and define rules and norms operating on that state. A suitable semantics regarding the use of norms within a hierarchical context structure is given, based on norm activation conflict and defeasibility.

1 INTRODUCTION

Most approaches regarding the use of norms in multi-agent systems (*MAS*) have addressed one of two ends of a spectrum. On one end, there are systems where norms are pre-imposed on agents, either with no possible deviation [5] or admitting violations [4, 1]. On the other end, social norm emergence from agent interaction is also being addressed [19]. In this paper we consider a midway approach on the use of norms in MAS, where norms are consciously adopted by a group of agents. The Electronic Institution (*EI*) concept has also been studied with this aim in mind [14, 3]. In particular, in [13] a normative framework has been suggested as a core component of an *EI*.

In the present paper, a normative environment assisting agent-based automated contract establishment is formalized. Agents can exploit a supportive normative framework in order to establish their mutual contracts in a more straightforward fashion: contracts [13] can be underspecified, relying on a structured normative environment that fills in any omissions. We define the notion of normative context and context hierarchies, characterize the normative state and give a representation of norm. We then formalize normative conflicts in our approach and their resolution based on norm activation defeasibility.

From the law field, three normative conflict resolution principles have been defined and traditionally used. The *lex superior* is a hierarchical criterion and indicates that a norm issued by a more important legal entity prevails, when in conflict with another norm (e.g. the Constitution prevails over any other legal body). The *lex posterior* is a chronological criterion indicating that the most recent norm prevails. The *lex specialis* is a specificity criterion establishing that the most specific norm prevails. While not firmly adopting any of these options, our approach resembles more the *lex specialis* principle, because broadly speaking a norm defined at a more specific context will typically prevail.

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The paper is organized as follows. Section 2 deals with the normative environment, defines the notion of context and sub-context, describes the normative state and gives a representation for rules and norms. Section 3 is devoted to norm semantics and to the norm activation defeasibility approach. In Section 4 we provide some examples that exploit the usage of the normative environment. Finally, Section 5 discusses related work and Section 6 concludes.

2 AN INSTITUTIONAL NORMATIVE ENVIRONMENT

In this section we define the normative environment and present a context-based normative framework. This framework forms the basis for the norm defeasibility model described in Section 3.

Def. 1: *Normative Environment* $NE = \langle NS, IR, N\rangle$
The normative environment NE *of an EI is composed of a normative state* NS*, a set* IR *of institutional rules (see Def. 7) that manipulate that normative state and a set* N *of norms, which can be seen as a special kind of rules (see Def. 8).*

The role of institutional rules is to maintain the normative state of the system. While norms define the normative positions of each agent, the main purpose of those rules is to relate the normative state with the standing normative positions (see [12] for the use of rules in monitoring those normative positions).

2.1 Contexts

Our model is based on a contextualization of both the normative state and norms. In this subsection we introduce the notion of context and context organization.

Def. 2: *Context* $C = \langle PC, CA, CI, CN\rangle$
A context C *is an organizational structure within which a set* CA *of agents commits to a joint activity* partially *regulated by a set* $CN \subseteq N$ *of appropriate norms. A context includes a set* CI *of contextual info that makes up a kind of background knowledge for that context (see Def. 4).* PC *is the parent context within which context* C *is formed. Let* PCA *be the set of agents in context* PC*: we have that* $CA \subseteq PCA$*.*

Contexts allow us to organize norms according to a hierarchical normative structure. Norm set N is partitioned among the several contexts that may exist, that is, sets CN for each context are mutually disjoint. A norm inheritance mechanism (as explained later) justifies why set CN only *partially* regulates the activity of agents in CA. We identify a *top* level context within which all other contexts are (directly or indirectly) formed.

We now introduce the notion of *sub-context*.

Def. 3: *Sub-context* $C' \lhd C$
Context $C' = \langle PC', CA', CI', CN' \rangle$ *is a sub-context of context* $C = \langle PC, CA, CI, CN \rangle$, *denoted* $C' \lhd C$, *if* $PC' = C$ *or if* $PC' \lhd C$. *When* C' *is either a sub-context of* C *or* C *itself, we write* $C' \unlhd C$. *From Def. 2 we also have that* $CA' \subseteq CA$.

A sub-context defines an organizational structure committed to by a subset of the parent context's agents. Notice that the sub-context relationship is an explicit one. Every context is a sub-context of the *top* context.

We now define contextual information as a foundational component of a context.

Def. 4: *Contextual info* $Info^C$
Contextual info $Info^C$ *is a fully-grounded atomic formula in first-order logic, which comprises founding information regarding a context* $C = \langle PC, CA, CI, CN \rangle$. $Info^C \in CI$.

The CI component in a context definition is therefore composed of first-order logic formulae that provide background information for that context.

2.2 Normative State

The normative state is organized through contexts, and concerns the description of what is taken for granted in a model of institutional reality. Therefore, we call every formula in NS an institutional reality element, or IRE. Each institutional reality element refers to a specific context within which it is relevant.

Def. 5: *Contextual institutional reality element* IRE^C
A contextual institutional reality element IRE^C *is an* IRE *regarding context* C. *We distinguish the following kinds of* IRE^C *and with the following meanings:*

$ifact^C(f, t)$	*institutional fact* f *has occurred at time* t
$time^C(t)$	*instant* t *has elapsed*
$obl^C(a, f, t)$	*agent* a *is obliged to bring about fact* f *until deadline* t
$fulf^C(a, f, t)$	*agent* a *has fulfilled, at time* t, *his obligation to bring about* f
$viol^C(a, f, t)$	*agent* a *has violated, at time* t, *his obligation to bring about* f

Note that the use of context C as a superscript is only a syntactical convenience – both contextual info and institutional reality elements are first-order formulae (C could be used as the first argument of each of these formulae). While contextual info is confined to background information that is part of the context definition, contextual institutional reality elements represent occurrences taking place after the context's creation, during its lifetime.

We consider institutional facts as *agent-originated*, since they are obtained as a consequence of some agent action. The remaining elements are *environment events*, asserted in the process of norm activation and monitoring [13]. Our model of institutional reality is based on a discrete model of time. The $time$ elements are used to signal instants that are relevant to the context at hand. Obligations are deontic statements, and we admit both their fulfillment and violation.

Def. 6: *Normative State* $NS = \{IRE_1^{C1}, IRE_2^{C2}, ..., IRE_n^{Cm}\}$
The normative state NS *is a set of fully-grounded atomic formulae* IRE_i^{Cj}, $1 \le i \le n$, *in first-order logic.*

The normative state will contain, at each moment, all elements that characterize the current state of affairs in every context. In that sense, NS could be seen as being partitioned among the several contexts, as is the case with norms; however, IRE's are not part of a context's definition, since they are obtained at a later stage, during the context's operation. Some of the IRE's are interrelated: for instance, a fulfillment connects an obligation to bring about a fact with its achievement as an institutional fact. These interrelations are captured with institutional rules.

2.3 Rules and Norms

Given the "contextualization" of the normative state, we are now able to define rules and norms. Institutional rules allow us to maintain the normative state of the system. They are not contextualized, but yet they operate on contextual IRE's.

Def. 7: *Institutional rule* $R ::= Antecedent \rightarrow Consequent$
An institutional rule R *defines, for a given set of conditions, what other elements should be added to the normative state. The rule's* $Antecedent$ *is a conjunction of patterns of* IRE^C *(see Def. 5), which may contain variables; restrictions may be imposed on such variables through relational conditions. We also allow the use of negation (as failure):*

$$Antecedent ::= IRE^C \mid \neg Antecedent \mid RelCondition \mid Antecedent \wedge Antecedent$$

The rule's $Consequent$ *is a conjunction of* IRE^C *which are not deontic statements* ($IRE\text{–}^C$), *and which are allowed to contain bounded variables:*

$$Consequent ::= IRE\text{–}^C \mid IRE\text{–}^C \wedge Consequent$$

When the antecedent matches the normative state using a first-order logic substitution Θ, and if all the relational conditions over variables hold, the atomic formulae obtained by applying Θ to the consequent of the rule are added to the normative state as fully-grounded elements.

Besides institutional reality elements, the norms themselves are also contextual.

Def. 8: *Norm* $N^C ::= Situation^{C'} \rightarrow Prescription^{C'}$
A norm N^C *is a rule with a deontic consequent, defined in a specific context* C. *The norm is applicable to a context* $C' \unlhd C$. *The norm's* $Situation^{C'}$ *is a conjunction of patterns of* $Info^{C'}$ *and* $IRE\text{–}^{C'}$ *(no deontic statements). Both kinds of patterns are allowed to contain variables; restrictions may be imposed on such variables through relational conditions:*

$$Situation^{C'} ::= Info^{C'} \mid IRE\text{–}^{C'} \mid RelCondition \mid Situation^{C'} \wedge Situation^{C'}$$

The norm's $Prescription^{C'}$ *is a (possibly empty) conjunction of deontic statements (obligations) which are allowed to contain bounded variables and are affected to the same context* C':

$$Prescription^{C'} ::= \epsilon \mid OblConj^{C'}$$
$$OblConj^{C'} ::= obl^{C'}(...) \wedge OblConj^{C'} \mid obl^{C'}(...)$$

Conceptually, the norm's $Situation^{C'}$ can be seen as being based on two sets of elements: *background (Sb)* and *contingent (Sc)*. Background elements are those that exist at context C' creation (the founding contextual info), while contingent elements are those that are added to the normative state at a later stage. This distinction will be helpful when describing norm semantics.

Observe the distinction between the context where the norm is defined, and the context to which the norm applies. While, in order to make the model as simple as we can, we define a norm as being applicable to a specific context, in Section 3.1 we relax this assumption, which will in part clarify the usefulness of the model.

3 NORM SEMANTICS

In this section we define the semantics of norms and formalize a model for norm defeasibility in the ambit of a supportive normative framework. We start by exploring norm applicability according to the normative state. For that, we make use of the notion of *substitution* in first-order logic. We denote by $f \cdot \Theta$ the result of applying substitution Θ to atomic formula f.

Def. 9: *Norm activation*
Norm $N^C = S^{C'} \rightarrow P^{C'}$*, applicable to a context* $C' = \langle PC', CA', CI', CN' \rangle$*, is activated if there is a substitution* Θ *such that:*

- $\forall_{c \in Sc}\ c \cdot \Theta \in NS$*, where* Sc *is the set of contingent conjuncts (*$IRE\text{–}^{C'}$ *patterns) in* $S^{C'}$*; and*
- $\forall_{b \in Sb}\ b \cdot \Theta \in CI'$*, where* Sb *is the set of background conjuncts (*$Info^{C'}$ *patterns) in* $S^{C'}$*; and*
- *all the relational conditions in* $S^{C'}$ *over variables hold.*

We are now able to define the notion of conflicting norm activations, as follows.

Def. 10: *Norm activation conflict*
Let Act_1 *be the activation of norm* $N_1^{C1} = S_1^{C1'} \rightarrow P_1^{C1'}$ *obtained with substitution* Θ_1 *and* Act_2 *the activation of norm* $N_2^{C2} = S_2^{C2'} \rightarrow P_2^{C2'}$ *obtained with substitution* Θ_2*. Let* $NS_1 = \{c \cdot \Theta_1 | c \in Sc_1\}$*, and* $NS_2 = \{c \cdot \Theta_2 | c \in Sc_2\}$*, where* Sc_1 *and* Sc_2 *are the sets of contingent conjuncts of* $S_1^{C1'}$ *and* $S_2^{C2'}$*, respectively. Both* NS_1 *and* NS_2 *represent fractions of the whole normative state* NS*. Norm activations* Act_1 *and* Act_2 *are in conflict, written* $Act_1 \bigotimes Act_2$*, if* $NS_1 = NS_2$ *and either* $C1 \lhd C2$ *or* $C2 \lhd C1$*.*

Succinctly, we say there is a norm activation conflict if we have two applicable norms activated with the same fraction of the normative state and defined in different contexts. Notice that the fact that both norms are activated with the same contextual IRE's already dictates that the norm contexts, if different, have a sub-context relationship (there is no multiple inheritance mechanism in our normative structure). This becomes clearer when taking into account the sub-context (Def. 3) and norm (Def. 8) definitions: a context has a single parent context, and a norm N^C applies to a context $C' \unlhd C$.

In principle, all norm activations are defeasible, according to the following definition.

Def. 11: *Norm activation defeasance*
Norm activation Act_1 *for norm* N_1^{C1} *defeats norm activation* Act_2 *for norm* N_2^{C2} *if* $Act_1 \bigotimes Act_2$ *and* $C1 \lhd C2$*.*

A defeated norm activation is discarded, that is, the defeated activation is not applied to the normative state fraction used for activating the norm. Only undefeated norm activations will be applied: the substitution that activated the norm is applied to its prescription part and the resulting fully-grounded deontic statements are added to the normative state (recall that there are no free variables in the prescription part of norms). Observe that we do not talk about norm defeasance, but rather norm activation defeasance. Thus, the defeasance relationship may only materialize on actual norm applicability.

3.1 Norm Contextual Target

A question that may arise when going through the previous definitions can jeopardize the purpose of having defeasible norms as those in the model presented. Why should there be norms that, while being applicable to the same context, are defined in different contexts that have a sub-context relationship? Why not have all norms applicable to context C defined inside context C?

The reason for our approach becomes apparent when considering the stated aim of a supportive normative environment: to have a normative background that can fill-in details of sub-contexts that are created later and that can benefit from this setup by being underspecified. This leads us to the subject of "default rules" in the law field [2]. Thus, part of the normative environment's norms will typically be predefined, in the sense that they are pre-existent to the applicable contexts themselves (which correspond to and result from contracts as they are signed up). What we need is to typify contexts in order to be able to say that a norm applies to a certain type of contexts. This way, a norm might be defined at a super-context and applicable to *a range of* sub-contexts (of a certain type) to be subsequently created.

We can do this adaptation by considering a context identifier C as a pair $id{:}type$, where id is a context identifier and $type$ is a predefined context type. In a norm $N^C = S^{C'} \rightarrow P^{C'}$ (see Def. 8), patterns of $Info^{C'}$ and $IRE^{C'}$ within $S^{C'}$ and $P^{C'}$ will be rewritten to accommodate this kind of context reference, eventually using a variable in place of the context id. For instance, an $IRE^{X:t}$ pattern, where X is a variable, would match IRE's of any sub-context of type t. When activating a norm with this kind of pattern, the substitution Θ (as used in Def. 9) would have to bind X to a specific sub-context identifier; every further occurrence of X is thus a bounded-variable.

This approach allows us to maintain our definitions of norm activation conflict and defeasance, with minor syntactical changes.

4 EXAMPLES

In this section we sketch some examples towards the exploitation of the normative environment. The examples try to focus on the important aspects of our approach; in the following we adopt the convention that variables begin with an upper-case letter.

Our scenario is based on the following: each of a group of companies (agents) provides different resources that may need to be combined in order to present a value-added offering to third-parties. For that, they agree to form a virtual organization (*VO*). This organization will define a *supply-agreement* that translates into a context $sa3{:}sa$ in the normative environment, where $sa3$ is the context id and sa is the context type (see Section 3.1). Notice that $sa3{:}sa \lhd top$, where top is the top context.

Suppose we have, at the top context, the following norm:

$$
\begin{aligned}
N_1^{top} = \\
& ifact^{X:sa}(order(A1, Res, Qt, A2), T) \wedge \\
& supply\text{–}info^{X:sa}(A2, Res, Pr) \\
& \rightarrow \\
& obl^{X:sa}(A2, delivery(A2, Res, Qt, A1), T+2) \wedge \\
& obl^{X:sa}(A1, payment(A1, Qt * Pr, A2), T+2)
\end{aligned}
$$

The norm states that for any supply-agreement, when an order is made that corresponds to the *supply-info* (which is an $Info^C$ for this type of context) of the receiver, he is obliged to deliver the requested goods and the sender is obliged to make the associated payment.

Now, suppose context $sa3{:}sa$ includes the following norms.

$$N_1^{sa3:sa} = \\ ifact^{sa3:sa}(order(A1, Res, Qt, jim), T) \wedge \\ supply\text{–}info^{sa3:sa}(jim, Res, Pr) \wedge Qt > 99 \\ \rightarrow \\ obl^{sa3:sa}(jim, delivery(jim, Res, Qt, A1), T + 5) \wedge \\ obl^{sa3:sa}(A1, payment(A1, Qt * Pr, jim), T + 2)$$

This norm expresses the fact that agent jim, when receiving orders with more than 99 units, has an extended delivery deadline.

$$N_2^{sa3:sa} = \\ ifact^{sa3:sa}(order(sam, Res, Qt, A2), T) \wedge \\ supply\text{–}info^{sa3:sa}(A2, Res, \_) \\ \rightarrow \\ obl^{sa3:sa}(A2, delivery(A2, Res, Qt, sam), T + 2)$$

$$N_3^{sa3:sa} = \\ fulf^{sa3:sa}(A2, delivery(A2, Res, Qt, sam), T) \wedge \\ supply\text{–}info^{sa3:sa}(A2, Res, Pr) \\ \rightarrow \\ obl^{sa3:sa}(sam, payment(sam, Qt * Pr, A2), T + 2)$$

These two norms express the higher position of agent sam who, as opposed to other agents, only pays after receiving the merchandise. Suppose we have the following founding contextual info for context $sa3{:}sa$:

$$supply\text{–}info^{sa3:sa}(jim, r1, 1) \\ supply\text{–}info^{sa3:sa}(sam, r2, 1) \\ supply\text{–}info^{sa3:sa}(tom, r3, 1)$$

Table 1 shows what might happen in different normative states. The second column shows which norm activation conflicts come about (and how they are resolved) when the institutional reality elements of the first column are present. Notice that in the first example there is no conflict, since norm $N_1^{sa3:sa}$ is not activated because of a variable restriction. The third column shows the normative state after applying the defeating norm activation. For instance, in the second example NS' contains NS together with the prescriptions of norm $N_1^{sa3:sa}$ (after applying the substitution that activated the norm). The third and fourth examples illustrate sam's advantage in being obliged to pay only after the delivery has been fulfilled. In each case we rely on refraction (a principle used in rule-based systems) to avoid firing a defeating norm more than once on the same activation (which would otherwise happen since our normative state is monotonic).

The norm activation defeasibility model is very flexible, allowing us to easily specify different contracting situations that exploit and adapt the normative background to different extents. Also, although the examples do not show this, it may be the case that a *VO* created by a group of agents defines norms to be applied in sub-contexts of a certain type. This would make up a three-level norm inheritance structure, where a subset of the *VO*'s agents could make further contracts that are covered by the *VO*'s agreement.

5 RELATED WORK

From a theoretical logical stance, norm defeasibility has been mainly guided by deontic reasoning [16], where conflicts regard the deontic operators themselves. Our approach is centered instead on the applicability of norms, not on their prescriptions.

More practical approaches (e.g. in the B2B domain) to normative conflict resolution have also been developed. The application of business rules in e-commerce has been studied in [11], where courteous logic programs allow for an explicit definition of priorities among rules. An extension based on defeasible logic [15] has been advanced in [10]. Also, [9] addresses defeasible reasoning in the e-contracts domain, based on default logic and on the definition of dynamic priorities among rules.

The work in [7] addresses the issue of conflict resolution in a structured setup of compound activities. These resemble our context and sub-context relationships. However, they model deontic conflicts (e.g. an action being obliged and prohibited at the same time), while we model norm (activation) conflicts. They study the inheritance of normative positions (obligations, permissions, prohibitions), based on an explicit stamping of each one of them with a priority value and a timestamp; the specificity criterion is based on the compound activities' structure. We address the inheritance of norms and provide a means to override norm activations based on their defeasibility.

Our approach of context and sub-context definitions, together with the presented norm defeasibility model, is similar to the notion of supererogatory defeasibility in [18]. They model defeasibility in terms of role and sub-role definitions. In fact, they also consider express defeasibility, which is based on the specificity of conditions for norm applicability, but this approach has been followed by several others.

We should also point out that [8] presents a grammar for rules that combines both our rule and norm definitions. However, our concern is to distinguish *a priori* rule definition as a normative state maintenance concern from norm definition as a contracting activity. Furthermore, in [8] there is no attempt to solve any disputes related with possibly conflicting norms.

6 CONCLUSIONS

In this paper we formalized a normative environment with a hierarchical normative framework, including norm inheritance as a mechanism to facilitate contract establishment. Contexts were used as a means to organize norms and, more importantly, to guide their inheritance to new contexts. For that, we distinguished the context where a norm is defined from the context(s) to which it can be applied. In order to allow the expansibility of the system, and its application in different contracting scenarios, a model of norm activation defeasibility was designed, allowing an exploitation of the normative framework to different extents. Each signed contract generates a new context. A contract can include norms that defeat some of the norms of its super-contexts (which would otherwise be inherited), thus adapting the normative background to a specific situation.

Considering normative conflict resolution from the law field, as disclosed in the introduction, our approach has some similarities with the *lex specialis* principle. However, the defeating norms are more specific in the sense that they are *defined at* (as opposed to *applied to*) a more specific context (a kind of "lex inferior"). The *lex specialis* flavor comes from the fact that in most cases a defeating norm should also apply to a narrower context-set.

These properties of our norm defeasance approach result from the fact that the original aim is not to impose predefined regulations on

Table 1. Different normative states and norm activation conflicts.

NS	Conflict	NS'
$ifact^{sa3:sa}(order(tom, r1, 5, jim), 1)$	none, N_1^{top} applies	$ifact^{sa3:sa}(order(tom, r1, 5, jim), 1)$ $obl^{sa3:sa}(jim, delivery(jim, r1, 5, tom), 3)$ $obl^{sa3:sa}(tom, payment(tom, 5, jim), 3)$
$ifact^{sa3:sa}(order(tom, r1, 100, jim), 1)$	$N_1^{sa3:sa}$ defeats N_1^{top}	$ifact^{sa3:sa}(order(tom, r1, 100, jim), 1)$ $obl^{sa3:sa}(jim, delivery(jim, r1, 100, tom), 6)$ $obl^{sa3:sa}(tom, payment(tom, 100, jim), 3)$
$ifact^{sa3:sa}(order(sam, r3, 5, tom), 1)$	$N_2^{sa3:sa}$ defeats N_1^{top}	$ifact^{sa3:sa}(order(sam, r3, 5, tom), 1)$ $obl^{sa3:sa}(tom, delivery(tom, r3, 5, sam), 3)$
$ifact^{sa3:sa}(order(sam, r3, 5, tom), 1)$ $obl^{sa3:sa}(tom, delivery(tom, r3, 5, sam), 3)$ $fulf^{sa3:sa}(tom, delivery(tom, r3, 5, sam), 2)$	none, $N_3^{sa3:sa}$ applies	$ifact^{sa3:sa}(order(sam, r3, 5, tom), 1)$ $obl^{sa3:sa}(tom, delivery(tom, r3, 5, sam), 3)$ $fulf^{sa3:sa}(tom, delivery(tom, r3, 5, sam), 2)$ $obl^{sa3:sa}(sam, payment(sam, 5, tom), 4)$

agents, but instead to help them in building contractual relationships by providing a normative background (which can be exploited in a partial way through adaptation). A feature of our approach that exposes this aim is that all norms are defeasible. In this respect we follow the notion from law theory of "default rules" [2]. We leave for future work the possibility of defining non-defeasible norms, that is, norms that are not to be overridden.

This notion of "default rules" might be misleading; it has not a direct correspondence with default logic formalizations [17]. We do not handle the defeasibility of conclusions of default rules in that sense, but instead model defeasibility of the application of the rules themselves (which are called norms).

Although we are primarily concerned with deadline obligations, the inclusion of permissions or prohibitions as possible deontic statements prescribed by norms demands no changes in our norm activation defeasibility approach. We do not rely on conflicts between the content of deontic statements (which are deontic conflicts), but instead on norm activation conflicts. These are closely related to the notion of *conflict set* (or *agenda*) in rule-based forward-chaining systems (e.g. [6]). In those systems, a conflict is a possible application of more than one rule at the same time, and a conflict resolution strategy will decide which rule to apply in each step of the process.

Some open issues in our research include, as already mentioned, the possibility of defining non-defeasible norms, which might be important in certain contracting domains. The development of multiple-inheritance mechanisms within our contextual framework is also an interesting issue, although it poses additional problems regarding norm defeasibility.

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