

Detection of Runtime Normative Conflict in Multi-Agent Systems based on Execution Scenarios

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Abstract: Norms in multi-agent systems are used as a mechanism to regulate the behavior of autonomous and heterogeneous agents and to maintain the social order of the society of agents. Norms define what is permitted, prohibited and obligatory. One of the challenges in designing and managing systems governed by norms is that they can conflict with another. Two norms are in conflict when the fulfillment of one causes the violation the other and vice-versa. Several researches have been proposed mechanisms to detect conflicts between norms. However, there is a kind of normative conflict not investigated yet in the design phase, here called *runtime conflicts*, that can only be detected if we know information about the runtime execution of the system. This paper presents an approach based on execution scenarios to detect normative conflicts that depends on execution order of runtime events in multi-agent systems.

1 INTRODUCTION

Norms have been used in open multi-agent systems (MAS) as a mechanism to regulate the behavior of autonomous and heterogeneous agents without directly interfering with their autonomy. They are system-level constraints that are independent from the implementation of specific agents and represent the ideals of behavior of these agents (Aphale et al., 2012). They represent a way for agents to understand their responsibilities and the responsibilities of the others. Norms describe actions that must be performed (obligations), actions that can be performed (permissions) and actions that cannot be performed (prohibitions) by a given entity in a certain situation.

An important issue that must be considered while specifying the norms is the conflicts that may arise between them. Due to the numeral norms that may be necessary to govern a normative MAS, the normative conflict might not be immediately obvious to the system designer. Two norms are in conflict when the fulfillment of one causes the violation of the other and vice-versa. For example, there is a conflict when a norm prohibits an agent from performing a particular action and another that

requires the same agent to perform the same action at the same period of time.

There are many approaches in the literature that deal with conflicts between norms in MAS. As stated in Santos and Silva (2016), a normative conflict can be classified as *direct conflict* and *indirect conflict*. Direct conflict involves two norms that are associated with the same entity, regulate the same behavior, have contradictory deontic concepts, and are defined in the same context. The detection of this conflict can be done by simply comparing the norm elements. Indirect conflict involves two norms whose elements are not the same but are related. Its detection requires that the relationships among the norm elements are known.

However, there is another kind of normative conflict not investigated yet in the *design phase* that can only be detected when we know information about the runtime execution of the system. We will call this kind of conflict as *runtime conflict*. This kind of conflict depends on events that only happen at runtime. For example, let us suppose that *N1* is a norm that prohibits an agent *Ag* from performing the action *Ac* after the execution of action *X*. Moreover, suppose that *N2* is another norm that obligates the same agent to perform the same action before the execution of another action *Y*. The execution of the actions *X* and *Y* are runtime situations and we do not

know when they will be performed by the agents in the system. However, analyzing the execution order of them, we can say that if event Y would happen first compared to event X , we could assert that $N1$ and $N2$ will be not in conflict. Otherwise, there will be a conflict between $N1$ and $N2$. Therefore, if we know the information about when the conditions that make the norm active, it would be possible to detect the existence of the conflict. We defined six types of conditions that define the activation period of a norm, which are (i) the execution of an action by an agent, (ii) a fact that become true for an agent, (iii) the fulfillment or (iv) violation of a norm and (v) the activation or (vi) deactivation of a norm.

In this paper, we propose an approach based on execution scenarios to detect normative conflicts that depend on execution order of runtime events in MAS. The system designer may want to evaluate a possible sequence of actions in the system and know if that sequence would cause any normative conflict. The conflict detection approach identifies normative conflicts in case such scenario would be executed in the system. The propose approach uses Semantic Web technologies, such as, SWRL rules, OWL DL and SPARQL query language.

This paper is organized as follows. Section 2 presents the ontology-based definition of a norm and the execution scenario representation. Section 3 describes the normative conflict detection approach and gives an example of detection of this kind of conflict. Our proposal is compared to related works in Section 4, and conclusions and future works are presented in Section 5.

2 ONTOLOGY-BASED NORM REPRESENTATION

Ontologies are used to capture knowledge about some domain of interest. They describe the domain concepts and relationships between these concepts. We propose to use OWL DL and SWRL and reasoning tools to represent the main concepts of a norm in MAS. With this representation we are able to detect norm violations and norm conflict. The OWL Web Ontology Language is an expressive knowledge representation language endorsed by the World Wide Web Consortium (W3C). OWL DL is a sublanguage of OWL that is based on Description Logic (DL), a decidable fragment of the first-order logic (Rudolph, 2011). The Semantic Web Rule Language (SWRL) is a Horn clause rules extension to OWL (Horrocks et al., 2004). One of the most

powerful features of SWRL is its ability to support user-defined built-ins functions to perform operations for comparisons, mathematical, strings, date, and others.

2.1 Norm Definition

The main classes represented in the norm ontology are *Norm*, *Context*, *DeonticConcept*, *Entity*, *Action*, *Condition*, *FulfillmentStatus* and *ActivationStatus*. The class *Norm* represents a norm definition used as a mechanism to regulate the behavior of agents in MAS and is defined in DL, as follows.

```

Norm ≡ ∀ hasContext.Context ⊓
    =1 hasDeonticConcept.DeonticConcept ⊓
    =1 hasEntity.Entity ⊓
    =1 hasAction.Action ⊓
    ≤1 hasBefore.Condition ⊓
    ≤1 hasAfter.Condition ⊓
    =1 hasActivationStatus.
ActivationStatus ⊓
    =1 hasFulfillmentStatus.
FulfillmentStatus ⊓
    ∀ hasConflict.Norm
    
```

According to the definition above, a norm can be related to instances of the classes *Context*, *DeonticConcept*, *Entity*, *Action*, *ActivationStatus* and *FulfillmentStatus* through the object properties *hasContext*, *hasDeonticConcept*, *hasEntity*, *hasAction*, *hasActivationStatus* and *hasFulfillmentStatus*, respectively. It also can be connected to the *Condition* class via two object properties: *hasBefore* and *hasAfter*. Moreover, a norm can have a relationship to order instances of norm by using the *hasConflict* property.

The class *Context* determines the application area of a norm. Norms can be defined usually in two different contexts: *Environment* and *Organization* contexts. They are defined in the norm ontology as subclasses of the *Context* class, as shown below.

```

Organization ⊑ Context
Environment ⊑ Context
    
```

The class *DeonticConcept* describes behavior restrictions for agents in the form of obligations, permissions and prohibitions. Thus, the individuals *Obligation*, *Permission* and *Prohibition* were introduced in the norm ontology, and the class *DeonticConcept* was defined as the enumeration of its members using Nominals in DL, as shown below.

```

DeonticConcept ≡
    {Obligation, Permission, Prohibition}
    
```

The *Entity* class describes the entities whose behavior is being controlled by a norm. An entity is the subject of a norm-controlled action. It has a relationship with a context, via the *actsIn* object

property, to determine in which context an entity is acting. The entities represented in this paper are single agents. Instances of the *Entity* class can perform an action in the MAS. Thus, they can have a relationship along the object property *performAction* to individuals that are members of the *Action* class. An entity can also participate in a situation, instance of *Situation* class. A situation is one kind of activation condition that represents a fact in the knowledge base (e.g., an agent has a car, lives in New York or is graduated from a college). An agent can participate in zero, one or many situations by using the object property *participateIn*. Activation conditions will be explained latter in this section. The class *Entity* is defined in DL as follows.

$$\begin{aligned} \text{Entity} \sqsubseteq & \forall \text{actsIn.Context } \sqcap \\ & \forall \text{performAction.Action } \sqcap \\ & \forall \text{participateIn.Situation} \end{aligned}$$

The behavior been controlled by the norm is defined by the *Action* class. An action can be performed by individuals that are members of the *Entity* class via *isPerformedBy* object property, which is the inverse property of the *performAction* property. The *Action* class is defined as follows.

$$\text{Action} \sqsubseteq \forall \text{isPerformedBy.Agent}$$

The class *Condition* determines the period during which a norm is activated. A norm has a relationship with a condition via two object properties, namely, *hasBefore* and *hasAfter*, which are used to delimitate its activation period. For example, let *n1* and *n2* be two norms, and *n1* is defined to be activated *after* norm *n2* is been fulfilled. Thus, the fulfilment of *n2* is the condition of norm *n1* and the activation period of *n1* is whenever norm *n2* is fulfilled until +infinite.

A norm can have no relationship with any condition. When that happens, its activation period is since the beginning of the system's execution until +infinite, i.e., the norm is always active. There are six types of condition defined in the norm ontology as subclasses of the *Condition* class. They are *ExecutionOfAction*, *ActivationOfNorm*, *DeactivationOfNorm*, *FulfillmentOfNorm*, *ViolationOfNorm* and *Situation*, and are defined as follows.

$$\begin{aligned} \text{ActivationOfNorm} \sqsubseteq & \text{Condition } \sqcap \\ & =1 \text{ hasRelatedNorm.Norm} \\ \text{DeactivationOfNorm} \sqsubseteq & \text{Condition } \sqcap \\ & =1 \text{ hasRelatedNorm.Norm} \\ \text{FulfillmentOfNorm} \sqsubseteq & \text{Condition } \sqcap \\ & =1 \text{ hasRelatedNorm.Norm} \\ \text{ViolationOfNorm} \sqsubseteq & \text{Condition } \sqcap \\ & =1 \text{ hasRelatedNorm.Norm} \\ \text{ExecutionOfAction} \sqsubseteq & \text{Condition } \sqcap \\ & =1 \text{ hasRelatedAction.Action } \sqcap \\ & =1 \text{ hasRelatedEntity.Entity} \\ \text{Situation} \sqsubseteq & \text{Condition} \end{aligned}$$

Individuals that are members of any of the classes *ActivationOfNorm*, *DeactivationOfNorm*, *FulfillmentOfNorm* and *ViolationOfNorm* must specify a norm that is related to the condition through the object property *hasRelatedNorm*. The class *ExecutionOfAction* was defined as subclass of *Condition* that has exactly one relationship to the *Action* and *Entity* classes through *hasRelatedAction* and *hasRelatedEntity* object properties, respectively. The *Situation* class is one type of condition that represents a fact in the knowledge base.

The class *ActivationStatus* represents the activation status of a norm and can be either *activated*, *deactivated* or *none*. When a norm is *activated*, it means the norm becomes active and must be somehow fulfilled. Once a norm is activated, it can be *deactivated* at some time and no action is required anymore. The *none* activation status means that the norm has not been neither *activated* nor *deactivated* yet. All instance of *Norm* are started in the system with *none* value for its activation status. This status is useful to let the agents know about the existences of the norms. The individuals *Activated*, *Deactivated* and *None* were introduced in the ontology, and the class *ActivationStatus* was defined as the enumeration of its members, as shown below.

$$\begin{aligned} \text{ActivationStatus} \sqsupseteq & \\ & \{ \text{Activated, Deactivated, None} \} \end{aligned}$$

The class *FulfillmentStatus* describes the fulfillment status of a norm, which can be either *fulfilled*, *violated* or *unknown*. The *unknown* fulfillment status means that the norm has not been neither *fulfilled* nor *violated* yet. For example, let us suppose we have an activated obligation norm stating that a given action must be performed, but that action has not been execute yet. Hence, in that case, the fulfillment status is *unknown*. However, if that action is executed, the fulfillment status will become fulfilled. But if that norm turns into deactivated and the action has not been executed yet, then the fulfillment status would be violated. All norms are started with *unknown* value for its fulfillment status. The individuals *Fulfilled*, *Violated* and *Unknown* were introduced in the ontology, and the class *FulfillmentStatus* was defined as the enumeration of its members, as follows.

$$\begin{aligned} \text{FulfillmentStatus} \sqsupseteq & \\ & \{ \text{Fulfilled, Violated, Unknown} \} \end{aligned}$$

A norm can have a relationship to individuals that are members of the *Norm* class by using the object property *hasConflict*, which represents a normative conflict between two instances of norms.

In order to classify the norms regarding their compliance, the classes *FulfilledObligationNorm*,

ViolatedObligationNorm, *FulfilledProhibitionNorm*, *ViolatedProhibitionNorm* and *ViolatedPermissionNorm* were introduced in the norm ontology as subclass of *Norm* class, as follows.

```
FulfilledObligationNorm ⊆ Norm ⊓
    hasDeonticConcept.(Obligation) ⊓
    hasFulfillmentStatus.(Fulfilled)
ViolatedObligationNorm ⊆ Norm ⊓
    hasDeonticConcept.(Obligation) ⊓
    hasActivationStatus.(Deactivated) ⊓
    ¬ ObligationNormFulfilled
FulfilledProhibitionNorm ⊆ Norm ⊓
    hasDeonticConcept.(Prohibition) ⊓
    hasActivationStatus.(Deactivated) ⊓
    ¬ ProhibitionNormViolated
ViolatedProhibitionNorm ⊆ Norm ⊓
    hasDeonticConcept.(Prohibition) ⊓
    hasFulfillmentStatus.(Violated)
ViolatedPermissionNorm ⊆ Norm ⊓
    hasDeonticConcept.(Permission) ⊓
    hasFulfillmentStatus.(Violated)
```

Due to the open word assumption of OWL, in order to the classification of the classes *ViolatedObligationNorm*, *FulfilledProhibitionNorm* work properly, it is necessary to explicitly limit the universe of known individuals of the classes *FulfilledObligationNorm* and *ViolatedProhibitionNorm* by setting them equivalent to the enumeration of their members. Thus, suppose that the class *FulfilledObligationNorm* has two individuals, called *oblig1* and *oblig2*. Therefore, the following axiom is added to the norm ontology.

```
FulfilledObligationNorm ≡
    {oblig1, oblig2}
```

2.2 Execution Scenario Ontology

The norm ontology allows to represent an agent performing an action, participating in a situation, and a norm being fulfilled, violated, activated and deactivated. However, in order to detect normative conflict that depends on execution order of runtime events in MAS, it is not enough to know only that those events occurred in the system. More than that, it is necessary to know when such events were executed in the system and if they happened before or after another one. In other words, if we know the time when each condition of the system norms happened in the system, then it is possible to ensure if such norms are in conflict or not.

Therefore, the execution scenario ontology extends the norm ontology in order to add the notion of *time*. The time when a condition of a norm happens in the system is captured by the *hasConditionTime* datatype property and is

represented by an integer value. The range of this property is an *xsd:integer*. The following axiom was added to the *Condition* class.

```
Condition ⊆ ∀ hasConditionTime.Integer
```

The execution scenario ontology also introduced the class *Time* to represent the moment when an action is performed by an agent and when a situation becomes true in the system for an agent. The *Time* class is related to *hasTime* datatype property, which range is an *xsd:integer*. The following axioms were added to the classes *Entity*, *Action* and *Situation*, and the *Time* class is defined as follows.

```
Entity ⊆ ∀ entityTime.Time
Action ⊆ ∀ actionTime.Time
Situation ⊆ ∀ situationTime.Time
Time ⊆ ∀ hasTime.Integer ⊓
    (∀ timeEntity.Entity ⊔
    ∀ timeAction.Action ⊔
    ∀ timeSituation.Situation)
```

As described in section 2.1, a norm is activated during a period of time, which is determined by the *Condition* class along with *hasBefore* and *hasAfter* object properties. An agent can perform an action at any time in the system. However, in order to an obligation norm to be fulfilled by the agent, the regulated action must be performed only while the norm is active, i.e., during the period of time where the norm is active. It is necessary to know when the norm start and finish its activation. Therefore, the datatype properties *hasStart* and *hasEnd* were included to the execution scenario ontology. Their domain and range are the *ActivationPeriod* class and *xsd:integer*, respectively. The class *ActivationPeriod* represents the timeline period during which a norm is active. The following axiom was added to the *Norm* class and the *ActivationPeriod* class is defined as follows.

```
Norm ⊆ ∀ hasActvPrd.ActivationPeriod
ActivationPeriod ⊆
    ∀ hasStart.Integer ⊓
    ∀ hasEnd.Integer
```

In this paper, we are considering that a norm can have at most one before condition and one after condition. Therefore, a norm can have one of the five types of activation intervals showed in Figure 1. The first type is when a norm has no condition and is always active, i.e., its activation interval starts at time zero and lasts until +infinite. The second type refers to a norm associated with only one before condition. This interval starts from zero and lasts until whenever that condition happens in the system. The third type represents a norm with only one after condition and the interval starts whenever that condition happens and lasts until +infinite. The

fourth and fifth types refer to a norm associated with both before and after conditions. They differ each other by when each condition happens in the system. If the before condition happens first, then the norm activation period is characterized by the fourth interval type. Otherwise, the norm activation period is represented by the fifth interval type.

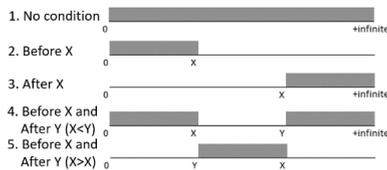


Figure 1: Five types of activation intervals.

The fourth interval type is the only one which a norm has two activation periods, i.e., from zero to whenever the before condition happens and from whenever the after condition happens to +infinite. Therefore, the norms can have one or at most two activation intervals.

In the norm ontology, six conditions were defined as subclass of *Condition* class, which were the classes *ExecutionOfAction*, *ActivationOfNorm*, *DeactivationOfNorm*, *FulfillmentOfNorm*, *ViolationOfNorm* and *Situation*. The time when such conditions happen in the system can be inferred automatically from the normative system, if the times when an action was performed by an agent and when a situation became true to an agent are known in advance. Assuming these times are known, the remaining times can be inferred by using SWRL rules, as follows. The time of the conditions *ExecutionOfAction* and *Situation* can be easily inferred by using the following rules, respectively.

Rule1: ExecutionOfAction(?c) \wedge
 $\text{hasRelatedAction}(\text{?c}, \text{?a}) \wedge \text{Action}(\text{?a}) \wedge$
 $\text{hasRelatedEntity}(\text{?c}, \text{?e}) \wedge \text{Entity}(\text{?e}) \wedge$
 $\text{entityTime}(\text{?e}, \text{?t}) \wedge \text{Time}(\text{?t}) \wedge$
 $\text{timeAction}(\text{?t}, \text{?a}) \wedge \text{hasTime}(\text{?t}, \text{?ti})$
 $\rightarrow \text{hasConditionTime}(\text{?c}, \text{?ti})$

Rule2: Situation(?c) \wedge participateIn(?e,
 $\text{?c}) \wedge \text{Entity}(\text{?e}) \wedge \text{entityTime}(\text{?e}, \text{?t}) \wedge$
 $\text{Time}(\text{?t}) \wedge \text{timeSituation}(\text{?t}, \text{?c}) \wedge \text{hasTime}$
 $(\text{?t}, \text{?ti}) \rightarrow \text{hasConditionTime}(\text{?c}, \text{?ti})$

The norm's fulfillment depends on its deontic concept, i.e., if the norm is an *obligation*, *prohibition* or *permission*. As described in section 2.1, the fulfillment can be *unknown*, *fulfilled* or *violated*. When the norm is an *obligation*, it becomes *fulfilled* when the agent performed the action while the norm is active. If the norm was deactivated, but the agent did not perform the action, then the norm becomes *violated*. If the norm is a *prohibition*, then the

opposite behavior can be observed. It becomes *violated* when the agent performed the action while the norm is active, and *fulfilled* when the norm was deactivated, but the agent did not perform the action. When the norm is a *permission*, it becomes *violated* when the agent performed the action, but he/she has no permission to do that, i.e., the norm is not active. A *permission* norm never becomes *fulfilled* because a permission is an authorization and it is not expected to be performed by the agent. The condition's time for fulfillment and violation of an obligation norm are shown in rules 3 and 4, respectively.

Rule3: FulfillmentOfNorm(?c) \wedge
 $\text{hasRelatedNorm}(\text{?c}, \text{?n}) \wedge \text{Norm}(\text{?n}) \wedge$
 $\text{hasDeonticConcept}(\text{?n}, \text{Obligation}) \wedge$
 $\text{hasAction}(\text{?n}, \text{?a}) \wedge \text{Action}(\text{?a}) \wedge$
 $\text{hasEntity}(\text{?n}, \text{?e}) \wedge \text{Entity}(\text{?e}) \wedge$
 $\text{entityTime}(\text{?e}, \text{?t}) \wedge \text{Time}(\text{?t}) \wedge$
 $\text{timeAction}(\text{?t}, \text{?a}) \wedge \text{hasTime}(\text{?t}, \text{?ti}) \wedge$
 $\text{hasActvPrd}(\text{?n}, \text{?ap}) \wedge \text{hasStart}(\text{?ap},$
 $\text{?ts}) \wedge \text{hasEnd}(\text{?ap}, \text{?te}) \wedge$
 $\text{swrlb:greaterThanOrEqual}(\text{?ti}, \text{?ts}) \wedge$
 $\text{swrlb:lessThan}(\text{?ti}, \text{?te}) \rightarrow$
 $\text{hasConditionTime}(\text{?c}, \text{?ti}) \wedge$
 $\text{hasFulfillmentStatus}(\text{?n}, \text{Fulfilled})$

Rule4: ViolationOfNorm(?c) \wedge
 $\text{hasRelatedNorm}(\text{?c}, \text{?n}) \wedge \text{Norm}(\text{?n}) \wedge$
 $\text{hasDeonticConcept}(\text{?n}, \text{Obligation}) \wedge$
 $\text{ViolatedObligationNorm}(\text{?n}) \wedge \text{hasActvPrd}$
 $(\text{?n}, \text{?ap}) \wedge \text{hasEnd}(\text{?ap}, \text{?te}) \rightarrow$
 $\text{hasConditionTime}(\text{?c}, \text{?te}) \wedge$
 $\text{hasFulfillmentStatus}(\text{?n}, \text{Violated})$

In a similar manner, the condition's time for fulfillment and violation of a prohibition norm can be inferred, but in the opposite way. The rules 5 and 6 calculate the condition's time for activation and deactivation of a norm.

Rule5: ActivationOfNorm(?c) \wedge
 $\text{hasRelatedNorm}(\text{?c}, \text{?n}) \wedge \text{Norm}(\text{?n}) \wedge$
 $\text{hasActvPrd}(\text{?n}, \text{?ap}) \wedge \text{hasStart}(\text{?ap},$
 $\text{?ts}) \rightarrow \text{hasConditionTime}(\text{?c}, \text{?ts})$

Rule6: DeactivationOfNorm(?c) \wedge
 $\text{hasRelatedNorm}(\text{?c}, \text{?n}) \wedge \text{Norm}(\text{?n}) \wedge$
 $\text{hasActvPrd}(\text{?n}, \text{?ap}) \wedge \text{hasEnd}(\text{?ap}, \text{?te})$
 $\rightarrow \text{hasConditionTime}(\text{?c}, \text{?te})$

The start and end times of a norm activation period cannot be inferred by using SWRL, because in SWRL there is no way to check the existence of only one if these relationships: *hasBefore* and *hasAfter*. This verification can be done by using NOT EXISTS filter expression in SPARQL queries [Harris et al., 2013]. For example, suppose that *n1* is a norm that has only a relationship with *hasBefore* condition, named *c1*. The activation interval of that

norm starts at time zero and the end time will depend on whether or not the condition $c1$ was satisfied. If not, the end time is unknown. Otherwise, the end time is the time when the condition $c1$ became true in the knowledge base.

3 CONFLICT DETECTION

The execution scenario ontology can be used by the system designer as a means for providing an example of execution scenario performed by the agents in the system. The system designer may want to evaluate a possible sequence of actions in the system and know if that sequence would cause any normative conflict. The conflict detection rule uses the times provided by the execution scenario ontology in order to detect conflicts between the norms in case such execution scenario would be executed in the system. As described in section 2.2, the designer only needs to provide the time when an action would be performed by an agent and when a situation would become true to an agent. The remaining times are automatically calculated.

Two active norms are said to be in conflict when they are associated with the same entity, regulate the same behavior, have contradictory deontic concepts (i.e., prohibition versus permission or prohibition versus obligation), and are defined in the same context. To detect conflict between two norms that depends on execution order of runtime events, we have to compare the activation periods two by two in order to find intersections between them. The rule 7 shows the detection of normative conflict between an obligation and a prohibition.

Rule7: $\text{Norm}(\?n1) \wedge \text{Norm}(\?n2) \wedge \text{hasEntity}(\?n1, \?e) \wedge \text{hasEntity}(\?n2, \?e) \wedge \text{hasAction}(\?n1, \?a) \wedge \text{hasAction}(\?n2, \?a) \wedge \text{hasContext}(\?n1, \?c) \wedge \text{hasContext}(\?n2, \?c) \wedge \text{hasDeonticConcept}(\?n1, \text{Obligation}) \wedge \text{hasDeonticConcept}(\?n2, \text{Prohibition}) \wedge \text{hasActvPrd}(\?n1, \?ac1) \wedge \text{hasStart}(\?ac1, \?st1) \wedge \text{hasEnd}(\?ac1, \?ed1) \wedge \text{hasActvPrd}(\?n2, \?ac2) \wedge \text{hasStart}(\?ac2, \?st2) \wedge \text{hasEnd}(\?ac2, \?ed2) \wedge \text{swrlb:lessThan}(\?st1, \?st2) \wedge \text{swrlb:greaterThanOrEqual}(\?ed1, \?st2) \rightarrow \text{hasConflict}(\?n1, \?n2)$

This rule verifies if any activation periods of two norms intersects each other by comparing the initial and final times of their activation intervals. If that happen, then they are in conflict. A similar rule must be created in order to identify conflicts between a permission and a prohibition.

3.1 Conflicting Norms Example

This section presents an example of the detection of this kind of conflict. Let us assume a daily home rules for a family with a child called Riley. The following norms are defined for him.

Norm1: Agent *Riley* are obligated to perform the action *doHomework*.

Norm2: Agent *Riley* are permitted to perform the action *playGame* after fulfill the norm *Norm1*.

Norm3: Agent *Riley* are prohibited to perform *playGame* after he performs *haveLunch* and before the situation *doneLunching* becomes true for him.

Norm4: Agent *Riley* are obligated to perform the action *cleanRoom* before he performs *haveLunch*.

Norm5: Agent *Riley* are prohibited to perform the action *playGame* if he violates the norm *norm4*.

Let us suppose now that the designer provided the following execution scenario and wanted to know if there is any normative conflict in case this scenario would be executed in the system.

- *Riley* performs *doHomework* at time 10;
- *Riley* performs *haveLunch* at time 20, and;
- The situation *doneLunching* becomes true for *Riley* at time 30.

According to the proposed conflict detection approached, there is a normative conflict between the norms $N2$ and $N3$, and between $N2$ and $N5$ because they are applied to the same agent and action, they have contradictory deontic concept, and their activation interval intersect each other. Figure 2 depicts the activation periods for each norm.

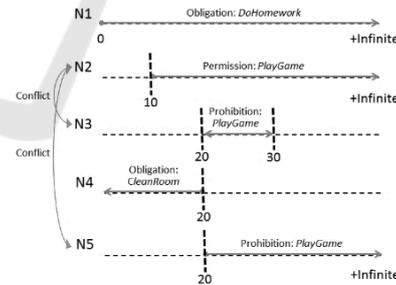


Figure 2: Example of norms in conflict.

4 RELATED WORK

Several researchers have investigated mechanisms to detect normative conflicts in MAS. Some of them deal with the identification of direct conflicts (Li et al., 2014, Dos Santos Neto et al., 2013, Uszok et al., 2008), and others can also detect indirect conflicts (Aphale et al., 2012; Sensoy et al., 2012 Santos and Silva, 2016; Da Silva et al., 2015, Lam et al., 2008).

However, to the best of our knowledge, none of them is able to detect runtime normative conflicts, i.e., conflicts that may occur depending on execution order of runtime events, in the *design phase*.

Lam et al. (2008) proposed an approach that uses SWRL and OWL DL to represent norm-governed organizations. A conditional norm with a deadline was specified where the condition is only a *xsd:dateTime* associated with either *before* or *after* object properties. This approach does not allow a norm to have a relationship with both *before* and *after* properties. Also, the authors did not show how to detect a conflict between norms with conditions. Moreover, runtime conditions such as those described in this paper are not supported.

Sensoy et al. (2012) developed a framework for representing OWL-based policies for distributed agent-based systems called OWL-POLAR. The activation and expiration conditions of a norm in OWL-POLAR are represented by a conjunctive semantic formula, which are facts in the knowledge base. However, the authors did not take into account before and after conditions.

Uszok et al. (2008) developed a policy framework called KAoS that uses OWL ontology-based representation and reasoning to specify, deconflict, and enforce policies. KAoS supports two main types of norms: (positive and negative) authorization and (positive and negative) obligation. However, KAoS does not provide mechanisms to represent deactivation condition of a norm. Also, before and after conditions are not supported.

5 CONCLUSIONS

Normative conflicts is an important issue in the design of multi-agent systems. In this paper, we have presented an approach to deal with the detection of normative conflicts that depends on information about the runtime execution of the MAS based on execution scenarios. The proposal allows the designer to provide examples of execution scenarios of the system and evaluate the conflicts that may arise if those scenarios would be executed in the system.

There are several extensions we continue to work on. Since multi-agent systems are composed of multiple autonomous and heterogeneous agents, there is a huge amount of possibilities of execution scenarios to happen in the system. We would like to investigate how the proposed approach can be extended in order to automatically generate execution scenarios and provide to the designer

potential normative conflicts in the system. Moreover, we want to extend the proposed approach to support repetition of before and after conditions.

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