# Norm Contextualization

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**Abstract.** Agents interact with each other regulating by a set of norms which is expressed at different levels of abstraction that capture different contexts and operationalizations. Current normative frameworks deal with norm operationalization, yet few consider the contextual aspects of norms. Moreover, most frameworks are based on the independent evaluations of norms, which makes it difficult to evaluate interrelated effects of different norms and contexts. In this paper, we propose *Norm Nets* as a formalism to capture the structure of contextualized norm sets. This formalism will enable (1) the analysis of interrelations between norms, (2) the contextualization of normative statements, and (3) the verification of properties of interrelated norms. We apply this framework to a case study taken from the domain of international trade.

## 1 Introduction

Open regulated Multi-Agent Systems (MAS) assume that agents are subjected to norms (explicit or implicit) that regulate their behavior. A large number of research in normative agent systems focuses on how agents can decide whether to comply with norms (e.g., [12,6,8]). Another research area concerns consistency aspects of the normative structure in MAS (e.g., [9,19,14]). However, the traditional way of organizing norms does not emphasize their interrelations and application environments at a large scale, which is very important in nowadays' business operations. For example, in the domain of international trade, different regulations would be applied when an importer imports the same kind of goods from different countries. The changes will result in cost if the importer could not follow the right set of regulations with respect to its associated business environment. Moreover, given a specific situation, the set of applicable regulations are not independent with each other but have different interrelationships. A typical example of such interrelationships is a regulation and its sanction, indicating a conditional and exclusive relation between two regulations.

In order to explore the interdependencies between norms and their application environments, this paper proposes an approach to represent and analyze sets of norms that takes into consideration both the interrelationships between different norms and the context of their application. More importantly, the explicit representation of institutional contexts on norms facilitates a contextual refinement normative structure, which supports norm design at multiple levels of abstraction. Our approach is different from those based on deontic reasoning,

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as we do not aim at identifying the deontic consequences of actions. Instead, we try to detail how norms can be abstracted from reality and organized in a structured way to facilitate contextualization and compliance checking.

To illustrate our proposal, we adopt a scenario in the domain of international trade in which a trading network may include a variety of entities (e.g., software, organizations and people) that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital, and goals. In this domain, agents represent real interests and real entities, i.e., different agents have different owners, goals, interests, and preconditions for collaboration. For example, importers are motivated by profit and quality of products, while customs authorities are motivated by safety and security concerns. At any given moment, most agents will be conditioned by different regulations and norms, originating from different institutional contexts.

In general, our contributions are three-fold. First, we use *context* to organize norms in such a way that the interrelationships between norms and their application environments are structured at multiple abstraction levels. Second, we formalize a methodology of practicing contextualization, with which designers can easily build up their own context-aware normative models. Third, in order to ground the operational aspects of our framework, we design a mapping method which translates models of our framework to Colored Petri Nets (CPNs) that can be used for checking consistency of the designed models.

The rest of this paper is organized as follows. In the next section, we present a simplified scenario from the domain of international trade. In section 3, we introduce a normative model *Norm Nets*, which is further extended to include contexts refinement in section 4. Section 5 present the mapping from Norm Nets into CPNs. Related work is discussed in Section 6. Finally, we conclude our work and raise directions for future work in section 7.

## 2 Scenario

In this section, we introduce a simplified scenario in the field of international trade concerning the issues of *origin of goods* in importing and exporting under EU's regulation [1]. This scenario is used throughout the paper to explain our proposal.

Origin is the "economic" nationality of goods in international trade, which is generally required to be indicated in the export/import documents and governmental submissions when transporting goods from one country to another. This is checked in different ways. For example, certificates have to be presented when importing goods from a certain country. Such certificates usually contain the country of origin, the national goods code, etc. These should match the information that is listed on the invoice and the packing list. According to the characteristics of the trading goods, there are two types of origin: *non-preferential origin* and *preferential origin.* Regulations for non-preferential origin are used for all kinds of commercial policy measures such as anti-dumping duties, countervailing duties, trade embargoes, safeguard and retaliation measures, quantitative restrictions, but also for some tariff quotas, trade statistics, public tenders, and origin marking etc. In addition, the EU's export refunds in the framework of the Common Agricultural Policy are often based on non-preferential origin. Preferential origin is conferred on goods from particular countries, which have fulfilled given criteria. In order to obtain preferential origin, it is generally required that the goods be wholly obtained or have undergone specific processing activities. Preferential origin confers certain tariff benefits (entry at a reduced or zero rate of duty) on goods traded between countries which have agreed such an arrangement or where one side has granted it autonomously.

## 3 Normative Structure

Usually, norms are perceived as a set of dos and don'ts. For example, in sociology, a norm is considered as a rule or standard of behavior accepted by members within a society or group[1]. In economics, a norm is a model of what should exist or be followed, or an average of what currently does exist in some context, such as an average salary among the members of a large group [7]. Formalized by E. Ostrom [16], a norm can be defined by the ADICO syntax which describes who (Attribute) is obliged/forbidden/permitted (Deontic) to do or achieve what (aIm), when and where (Condition), otherwise (Or else) leading to consequences of violation.

To reflect the reality, many MAS variants tried to incorporate norms as a formal specification of deontic statements that aim at regulating the behavior of software agents and the interactions among them [2,11,12], which focus more on the operational level. While, the ADICO syntax is a natural expression of norms which (1) provides a clear description of opportunities and constraints that create expectations about actors' behavior, and (2) makes it intuitive for the actors to understand their dos and don'ts. Therefore, we follow the ADICO syntax with adaptation to a MAS-integrable definition of norm, as shown in Definition 1.

**Definition 1 (norm).** *A norm is defined as a tuple* $n = (role, deontic, action, condition)$ *such that:*

- *role indicates the organizational position to whom the norm applies;*
- *deontic is one of the three modal verbs "may" (Permitted), "must/should" (Obliged) and "must not/should not" (Forbidden);*
- *action specifies the particular action to which the deontic is assigned;*
- *condition describes when and where the norm holds.*

If a norm does not specify a particular role or condition, the default value is for all participants, or at all times and in all places covered by that norm. The building blocks of our norm definition are expressed using lowercase (with or without subscripts). Corresponding expressions using uppercase indicate sets of a particular element, e.g., $ROLE$ indicates a set of roles such that $role \in ROLE$.

[1] cf. Encyclopedia Britannica: `http://www.britannica.com/`

When a set of norms are imposed on a multi-agent system, they are usually not independent of each other but interrelated in different ways. For example, as an undergraduate student in the Netherlands, one should on the one hand pay the tuition fee, and on the other hand, obtain a certain amount of academic credits. This indicates that both norms have to be complied with when enrolled as a Dutch undergraduate student. Another typical relation between two norms is a norm and its sanction. In particular, obligations and prohibitions may have corresponding sanctions when the norms are violated. Sanctions are norms which will be triggered when violations are detected, indicating a conditional and exclusive relation between norms. To model the possible relationships between norms, we introduce three logical operators *AND*, *OR*, and *OE* (representing Or else). Taken from the scenario introduced in section 2, the following are examples of how norms are interrelated.

- $AND(n_1, n_2)$: both norms should be met.
  **(ex1)** $(n_1, n_2)$ [*role*: The customs authorities] [*deontic*: should] $(n_1)$ [*action*: grant to the approved exporter a customs authorization number]. *AND* $(n_2)$ [*action*: monitor the use of the authorization by the approved exporter].
- *OR* $(n_1, n_2)$: choice between the two norms.
  **(ex2)** $(n_1)$, $(n_2)$ [*role*: The customs authorities] [*deontic*: may] [*action*: exceptionally issue a certificate of origin] $(n_1)$ [*condition*: after exportation of the products to which it relates, if the certificate of origin was not issued at the time of exportation because of errors]; *OR* $(n_2)$ [*condition*: after exportation of the products to which it relates, if it is demonstrated to the satisfaction of the competent governmental authorities that a certificate of origin was issued but was not accepted at importation for technical reasons].
- *OE* $(n_1, n_2)$ indicates the two norms are exclusive and conditional (only when $n_1$ is violated can $n_2$ be met).
  **(ex3)** $(n_1)$ [*role*: The approved exporter] [*deontic*: should] [*action*: offers all guarantees necessary to verify the originating status of the products], [*condition*: irrespective of the value of the products concerned]. *OE* $(n_2)$ [*role*: The customs authorities] [*deontic*: should] [*action*: withdraw the authorization] [*condition*: at any time where the approved exporter no longer offers the guarantees necessary to verify the originating status of the products].

As seen from these examples, the interrelationships between norms are attached to different normative components. For instance, the *AND* relation of the two norms in (**ex1**) is attached to two different *actions* while refers to the same *role* and *deontic*, and the *OR* relation of the two norms in (**ex2**) is attached to two different *conditions* while refers to the same *role*, *deontic* and *action*. However, there is no restriction that an interrelationship between two norms is attached to a specific normative component.

Furthermore, the application of such a set of interrelated norms is usually associated with a certain institutional environment, representing which situations are constrained by the norms. For this purpose, we use an explicit representation of *contexts* to characterize the situations where a set of norms is applied. Zimmermann et al. [20] proposed a formal structure of context information, which constricts and clusters this information into five fundamental categories, i.e., individuality, time, location, activity and relations. The *individuality* category contains properties and attributes describing an entity. The *activity* category covers all tasks the entity may be involved in. The *location* and *time* categories provide the spatio-temporal coordinates of the respective entity. Finally, the *relations* category represents information about any possible relation an entity may establish with another entity.

This paper does not focus on how to model contexts but tries to explore an effective way of using contexts to organize norms. Therefore, we only give an abstract definition of *Context* based on the context structure proposed by Zimmermann et al.

**Definition 2 (context).** *A context c is a set of states defined by predicates concerning aspects such as individuality, time, location, activity, relations.*

For example, a context might be characterized by a certain location, indicating that the norms applied in this context are mainly concerned with specific spatio coordinates. Contexts won't change the specification of norms but provide additional information about the situations in which the norms are applied from a higher-level perspective.

Note that the *condition* of a single norm is only a local prerequisite of when and where the norm holds, e.g., (importers should submit importing declaration) [*condition*: before goods arrive at the EU boarder] is a specific description of the deadline for this norm, while a *context* characterizes the situations in which a set of interrelated norms are applied from a broader perspective, e.g., [*context*: preferential origin] characterizes the situation in which norms concerning beneficial treatments for certain countries are applied. That is, conditions are at the level of individual norm specifications and usually represent situational differences between different norms, while contexts are at the level of collective norm sets and indicate situational commonalties of a norm set.

Putting all these together, we formalize the definition of *Norm Net* that not only represents the interrelationships between norms but also reflects their application environments.

**Definition 3 (Norm Net).** *A Norm Net* $NN = (c, NS)$*, where*

- *c indicates the context of the norm net, and*
- $NS = n$*, or* $NS = AND(NS_i, NS_j)$*, or* $NS = OR(NS_i, NS_j)$*, or* $NS = OE(NS_i, NS_j)$ *where n is a norm,* $NS_i$*,* $NS_j$*, and* $NS$ *are norm sets.*

Each norm net is associated with an institutional context which describes all the situational elements that characterize the application environment of a normative structure. Making the context explicit enables actors to control the evolution of the norm net, to accommodate compliance and resolution of conflicts from higher-level views. A norm set *NS* can be a single norm or a nested structure composed of norms, which are connected by the three operators *AND*, *OR*, and *OE* in a certain context. The norms and their sanctions are exclusive and conditional, i.e., one either conforms to the norms or accepts the sanctions when violating the norms. This is reflected by the semantics of *OE* operator. (ex3) shows an example of this situation where an obligation is connected with its sanction.

Figure 1 presents a graphical construction of a norm net $NN_1 = (c_1, NS_1)$, represented as an oval. $NS_1$, represented as a rectangle, is composed of two norm sets $NS_2$ and $NS_3$ connected by *AND*. Similarly, $NS_2$ is another *AND* connection of two sub norm sets $NS_4$ and $NS_5$ while $NS_3$ is an *OR* connection of two sub norm sets $NS_6$ and $NS_7$. Connected by an *OE*, $NS_8$ with $NS_9$ as the consequence of not following $NS_8$ build up $NS_4$. Specifically, we use dashed lines to indicate the consequence $NS_9$. As can be seen, the proposed framework enables a modular way of representing the interrelationships between norms in a specific context.

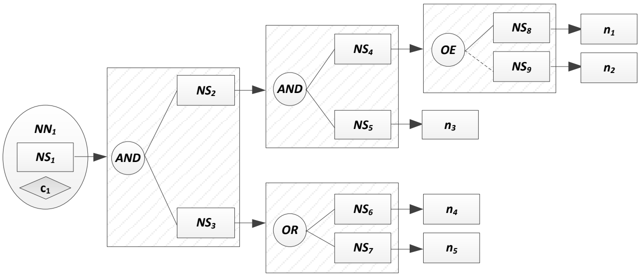


**Fig. 1.** An example of Norm Net

## 4 Contextualization

Laws and regulations are a system of textual rules and guidelines that are enforced through social institutions to govern behavior. They are specified as a normative structure, which describes the expectations and boundaries for agent behavior. We have already presented the representation of norms using *norm nets* in Definition 2 to capture the declarative meaning of the laws/regulations and also the relations between them. However, in real world domains, norms are not specified at a single level of abstraction. Usually, laws/regulations are first issued at a higher abstraction level stating the dos, don'ts and sanctions to regulate actors' behavior. Based on this abstract set of norms, elaboration will be conducted according to the specific characteristics and requirements of different situations, i.e. their application environments, which results into sets of contextual norms. This elaboration process facilitates detailed explanation of abstract norms in a concrete implementing environment.

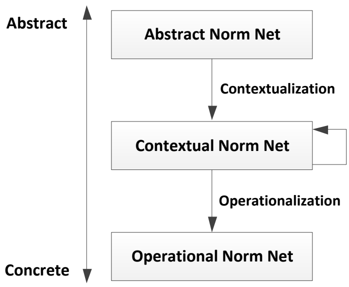


**Fig. 2.** Contextualization and operationalization

Our approach depicts three modeling layers of norms from abstract statements to concrete operations as shown in Figure 2. It starts from an abstract norm net which describes the expectations and boundaries for agent behavior in general. At this layer, norm specification is abstract and assumed to be stable throughout the life cycle of systems. The second layer uses contexts to organize the interrelated norms in different application environments derived from the abstract norm net. That is, the abstract norm net refers to a set of contextual norm nets which give more specific information on the roles, actions, conditions and the relations between the elaborated norms. Moreover, a contextual norm net can again refers to sets of contextual norm nets in a recursive manner, which enables a flexible normative structure and facilitates norm designing at different abstraction levels. In this way, the contexts of these norm nets establish a refinement relation captured in Definition 4.

**Definition 4 (context refinement relation).** *A context $c'$ refines a context $c$, denoted as $c' \preceq c$ iff $c' \subseteq c$ assuming the ontologies of $c'$ and $c$ are unified.*

Note that in a context refinement relation $c' \preceq c$, the ontology used in $c'$ may be more concrete than that in $c$ (e.g., where in $c$ one may talk about *vehicles* while in $c'$ one may talk about *cars*). The unification of contexts is done via "counts-as" statements [3,7].

Given this context refinement relation, norm nets can be structured at multiple abstraction levels through contextualization defined in Definition 5.

**Definition 5 (contextualization).** *Given a context refinement relation $c' \preceq c$, a contextualization can be defined between two norm nets $NN' = (c', NS')$ and $NN = (c, NS)$ such that*

- *$NS'$ elaborates $NS$ with refined normative components, or*
- *$NS'$ adds new norms to $NS$, or*
- *$NS'$ removes some of the norms from $NS$, or*
- *$NS'$ elaborates the interrelations between norms from $NS$.*

Definition 4 and 5 are reflections of the laws/regulations in practice. In this sense, contextual norm nets describe what properties should the concepts have from the specification of the abstract norm net to the refined contexts. For example, whether a document should be considered as a required certificate in international trade depends on the context in which the concept of *certificate* is used. A required certificate for importing fruit from China to the EU might not *counts as* a required certificate for importing textile.

In general, a norm net can have multiple contextualizations with respect to different contexts while different norm nets may be referred to in one contextualization. Moreover, there is no clear boundary between two contexts, i.e., the contexts of different norm nets may overlap, e.g., a context of the regulations for importing goods from Asia and another context of the regulations for importing textile products.

Finally, at the third layer, based on the contextual norm nets which contain enough information of the dos and don'ts in a specific situation, the norms will be extended with operational aspects to capture the operational meaning of the norms such as how the violation is detected (detection mechanism), and what can be done by the institution to repair the violation and minimize the negative influence[2]. Actors only need to reason about the norms at the most concrete level but the process of contextualization helps them to identify the applicable norms according to their runtime environment.

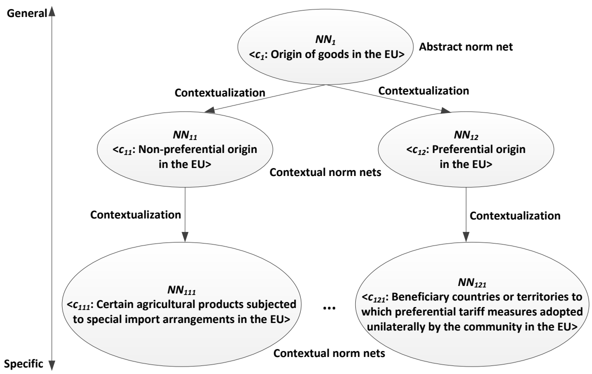


**Fig. 3.** Contextualization in the scenario

Continuing with the scenario, Figure 3 shows how the normative structure is built into a set of norm nets in a hierarchy from general to specific through contextualization. At the top level, a norm net $NN_1$ specifies a general set of regulations applied in the context $c_1$ "origin of goods in the EU". The norms at this level consist of coarser-grained components and provide an abstract view of the domain. As stated in Section 2, goods with different types of origin will be treated differently, which results in two exclusive sub contexts $c_{11}$ "non-preferential origin in the EU" and $c_{12}$ "preferential origin in the EU". For goods of preferential origin, more constraints as well as benefits are identified for exporters and importers in $NN_{12}$, which can be further contextualized. For example, a contextualization $NN_{121}$ is built for certain beneficiary countries and territories to which preferential tariff measures are adopted. Similarly for goods of non-preferential origin, more specific regulations are formulated in $NN_{11}$ and a further contextualization $NN_{111}$ is constructed for certain agricultural products subjected to special import arrangements.

This norm refinement relation through contextualization is not only a natural reflection of how norms are evolved in real life but also makes it easier for actors to recognize their dos and don'ts according to their runtime environments. Moreover, norm nets are distributed into well-defined reusable components and enable hiding of details in a consistent way.

Based on the normative structure shown in Figure 3 and the practical regulations in the EU, we illustrate the contents of the norm nets abstracted from the scenario, which have been partially shown as $ex1, ex2, ex3$ in Section 3. However, due to space limitations, we can only present a small part for explanation.

$\mathbf{NN_1} = (\mathbf{c_1}, \mathbf{NS_1})$ where

- $c_1$ = "origin of goods in the EU",
- $NS_1 = AND(AND(n_1, n_2), OE(n_3, n_4))$, where
  - $n_1$: [*role*: Exporters] [*deontic*: should] [*action*: apply for certificate of origin] [*condition*: when exporting goods to the EU].
  - $n_2$: [*role*: The customs authorities] [*deontic*: should] [*action*: issue certificate of origin to the qualified applicants].
  - $n_3$: [*role*: Importers] [*deontic*: must] [*action*: present Customs with a specific origin documents] [*condition*: at the moment of import].
  - $n_4$: [*role*: The customs authorities] [*deontic*: should] [*action*: reject the import] [*condition*: when the origin documents cannot be presented].

$\mathbf{NN_{11}} = (\mathbf{c_{11}}, \mathbf{NS_{11}})$ where

- $c_{11}$ = "non-preferential origin in the EU",
- $NS_{11} = OE(AND(AND(n_{a1}, n_{a2}), OR(n_{a3}, n_{a4})), n_{a5})$, where
  - $n_{a1}$: [*role*: The certificate of origin] [*deontic*: should] [*action*: measure $210 \times 297$ mm].
  - $n_{a2}$: [*role*: The certificate of origin] [*deontic*: should] [*action*: allow a tolerance of up to minus 5 mm or plus 8 mm in the length].
  - $n_{a3}$: [*role*: The certificate of origin] [*deontic*: should] [*action*: be printed in one or more of the official languages of the Community],
  - $n_{a4}$: [*role*: The certificate of origin] [*deontic*: should] [*action*: be printed in any other language] [*condition*: depending on the practice and requirements of trade].
  - $n_{a5}$: [*role*: The certificate of origin] [*deontic*: should not] [action: be approved] [condition: when it is not in the prescribed format].

$\mathbf{NN_{12}} = (\mathbf{c_{12}}, \mathbf{NS_{12}})$ where

- $c_{12} =$ "preferential origin in the EU",
- $NS_{12} = AND(AND(n_{b1}, ex1), AND(ex2, ex3))$, where
  - $n_{b1}$: [*role*: The competent governmental authorities of the beneficiary country] [*deontic*: should] [*action*: ensure that certificates and applications are duly completed].

$\mathbf{NN_{111}} = (\mathbf{c_{111}}, \mathbf{NS_{111}})$ where

- $c_{111} =$ "certain agricultural products subject to special import arrangements in the EU",
- $NS_{111} = OE(AND(AND(n_{a1}, n_{a2}), n_{a3}), n_{a5})$

From the description above, we can see that the norms in $NN_1$ only give a general idea about the regulations concerning the origin of goods in the EU. While in $NN_{11}$ and $NN_{12}$, more specific norms are given in terms of descriptions about roles, actions and conditions such as the format of certificate of origin, the expected behavior of the approved exporter and under which conditions the customs should withdraw the authorization. Specifically, we can find the similarities and differences between the norms in $NS_{11}$ and $NS_{111}$, which indicate that contextualization may not only add detailed information but also make changes.

## 5 Verification

To enable consistency and compliance checking of norm nets, we introduce a verification based on the mapping to the Colored Petri Nets.

### 5.1 Colored Petri Nets

CPN is a graphical language for modeling and validating distributed systems or systems in which concurrency plays a major role [13]. Not only do CPNs model the states of a system and the events that change the system from one state to another, but also replace tokens by data objects of programming languages.

**Definition 6 (CPN).** *A CPN is defined as a tuple (*$\sum$*, P, T, A, N, C, G, E, I ) where:* $\sum$ *is a finite set of non-empty types, also called color sets; P is a finite set of places; T is a finite set of transitions; A is a finite set of arcs;* $P \bigcap T = P \bigcap A = T \bigcap A = \Phi$*; N is a node function defined from A into* $P \times T \bigcup T \times P$*; C is a color function defined from P into* $\sum$*; G is a guard function defined on T; E is an arc expression defined on A; I is an initialization function defined on P.*

In CPNs, places indicate states while transitions indicate actions. A place is a node where tokens from a specified color set may reside, and this color set is determined by the color function. Transitions are also represented as nodes. For each transition, a Boolean expression called a *guard* can be specified to restrict the conditions under which the transition can occur. Places may contain a natural number of tokens. A distribution of tokens over the places of a CPN is called a marking. The initial marking of a CPN specifies the initial load of tokens. An arc represents an input or output relationship between a place and a transition. The actual amount and the colors of tokens moved are specified by the corresponding arc expression. Based on the current marking, the guards can calculate which transitions are enabled with respect to which bindings. The bindings indicate the variables in the arc expressions. If there is no conflict with other transitions, an enabled transition may fire, whereby corresponding tokens are removed from the input places of the transition and added to the output places, as specified by the arc expressions. The transitions can be seen as patterns of behavior while the actual binding determines the details of the behavior. The number of tokens moved along an arc depends on the actual binding.

### 5.2 Mapping to CPNs

**Norm Mapping.** The mapping makes use of correspondences between the components in norms and the elements in CPNs.

$$ROLE \rightarrow \sum, \quad ACTION \rightarrow T, \quad CONDITION \rightarrow G$$

Roles in norms are mapped to the color sets in CPNs so that colored tokens correspond to role enacting agents in MAS. Actions in norms are mapped to the transitions in CPNs while conditions in norms are mapped to the guard functions in CPNs. Thus, only when the condition of a norm holds can the corresponding action specified in the norm be permitted, obliged or forbidden. Places in CPNs indicate the states of the role enacting agents, i.e., their behavior status in terms of norms. For the three deontic representations in norms, we use different building blocks with special places and transitions shown in Figure 4.

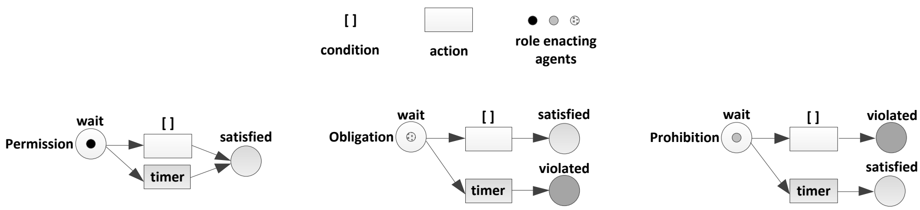


**Fig. 4.** Basic components in norms mapping to CPN

The CPN model of a norm starts with a place of *wait* which indicates the instantiation of the norm and has a color set indicating the role in the norm. Once the condition of the norm is satisfied, the agents in that place are able to perform the specified action. Permissions specify what might be done and won't lead to sanctions. Therefore, no matter the actions specified in a permission are performed or not, the final state of the permission will be *satisfied*. Obligations and prohibitions specify the actions that must and must not be done otherwise sanctions might be imposed, in the sense that the final state will either be *satisfied* or *violated*.

However, we cannot determine that someone does not follow a norm by simply saying that the action specified in the norm is not performed. In practice, whether a norm is satisfied or violated is normally determined within a certain period of time, e.g., the life cycle of an interaction scene. That is, the state of the norm is changed either because of the action specified in the norm is performed or the norm expires (a certain period passes). For this purpose, we adopt a special kind of transitions called *timer* that can be used to change the state of the norm when it expires and at the same time the action specified in the norm is not performed.

For permissions, both the action of the norm and the timer are connected to the place of *satisfied*, indicating that there are two ways to achieve this state: either the permitted action is performed by the agent or the timer is fired (i.e., the permitted action has not been performed when time is up).

Obligations indicate that agents should perform the specified actions and if this is the case, the token moves to the place of *satisfied*. But when the obliged action in the norm is not performed and the timer is fired, the token moves to the place of *violated*.

Prohibitions are a reverse logic of obligations. If the forbidden actions are performed, the corresponding tokens will move to the place of *violated*. But when the forbidden actions are not performed during the specified period of time, the corresponding tokens will move to the place of *satisfied*.

The description above only captures the mapping of individual norms. For norm nets, it requires a mechanism of representing different relationships between norms. To this end, we use extra elements for the mapping.

**Norm Net Mapping.** As an example, we model the norm net $NN_1$ of the scenario as shown in Figure 5. When the corresponding CPN is instantiated, all the tokens, i.e., all role enacting agents, are in the place of *input*. There are three role enacting agents in this example, a Chinese company enacting the role of exporter, a Dutch company enacting the role of importer, and the Dutch Customs enacting the role of customs. Then the *initialization* transition will be unconditionally triggered and all the tokens are moved to the following places of *wait* according to the arc expressions.

Each place of *wait* specifies the color sets (role types) from its corresponding norm in the norm net and the arc expression related to the place selects the agents that match the color sets based on their roles. For example, the role of $norm_1$ is *exporter*. Therefore, the color set for the wait place in $norm_1$ and the related arc expression both try to match *exporter*, indicating that only agents enacting the role of exporter can move into this part of the net. Note that a token is only a reference to a role enacting agent and tokens representing the same agent can be in multiple places simultaneously, in the sense that the agent relates to a set of different norms. For example, the tokens representing the Dutch Customs are distributed to the places of both $norm_2$ and $norm_4$ since both norms involves the Dutch Customs. When the condition of a norm is satisfied and the agent in the place of *wait* performed the related action, the corresponding token will move to the state of *satisfied* or *violated* according to the type of the norm.

The *AND* (*OR*) relation between norms is mapped to *AND* transitions (*OR* transitions) in CPNs. However, for norms connected by *OE* operators, a special structure is used to indicate the exclusive and conditional relation between them. For example, the *violated* place of $norm_3$ and an additional *wait* place are joined at an *AND* transition which is then connected to the *wait* place of $norm_4$, indicating that only when $norm_3$ is violated can $norm_4$ be triggered. In this way, the "conditional" part of the relation between the two norms connected by an *OE* operator is captured. For the "exclusive" part of the relation, we use *XOR* transition to connect the two norms, indicating that only one of the two norms can be satisfied. For instance, after the importer in the Netherlands presents the Dutch Customs with the specific origin documents, the state of $norm_3$ changes to *satisfied* while $norm_4$ has no chance to be triggered. However, when the action in $norm_3$ is not performed before the required date, the state of $norm_3$ changes to *violated* and at the same time $norm_4$ is imposed as a sanction. Since the example is only a part of the EU regulations, the sanction to the violations of the norms in Figure 5 is not fully pictured. Finally, the corresponding CPN model ends with a token at the *output* place which indicates the compliance of a norm net instance.

Note that the mappings illustrated in this section is currently dedicated to a single norm net within a specific context. The mapping of hierarchical contextual norm nets is left as our future work.

### 5.3 Verification Properties

Based on the mappings from Norm Nets to CPNs, we can further explore the correspondences between the behavioral properties of Norm Nets and CPNs, so that the analysis techniques of CPNs can be utilized to facilitate the verification of the behavioral properties of Norm Nets. For example, the reachability property and liveness property in CPNs are interpreted as follows.

- **Reachability** indicates that, given a set of norms organized in a norm net, whether there is a possible way to comply with those norms, i.e., a path through the norm net (CPN) that is norm compliant at all steps. This property can be used to identify the inconsistencies between the norms.
- **Liveness** indicates that, given a set of norms organized in a norm net, whether some of the norms are never initiated, i.e., no occurrence sequences through the norm net (CPN) that includes those norms. This property can be used to identify the norms that are redundant or wrongly positioned.

Therefore, given a set of norms in MAS, we can first model them using the proposed normative structure, and then map the resulted norm nets to CPNs

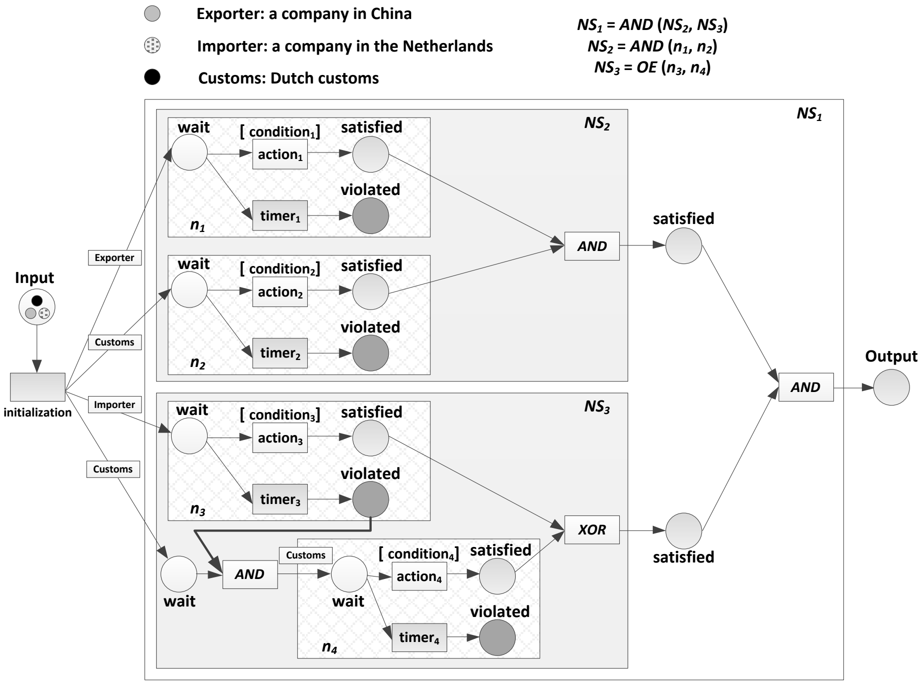


**Fig. 5.** Norm nets mapping to CPN

by which we can perform consistency and compliance checking on the norms. Furthermore, CPNs are fully supported by a number of analysis tools that can be used to implement such verifications [17].

## 6 Related Work

There is a growing interest in the research of norms to regulate and coordinate agents' behavior in MAS. Fruitful results have been achieved from different perspectives such as norm compliance, norm conflict resolution, norm contextualization, etc. [15] presented a formal normative framework intended to be used by agents that reason about why norms must be adopted and complied with, in which the relations between norms are represented as interlocking norms. The framework proposes that norms are applied in particular circumstances or within a specific context, but without considering the refinement relation of contexts, it is at a single level of analysis on norms. Munindar P. Singh proposed to use commitments to capture normative concepts in MAS and define norms as a tuple including subject, object, context, antecedent and consequent [18]. This approach provides a natural way to characterize the bounds of autonomy and interdependence between agents, but the contextual aspects of norms are not considered.

In [12], a formalism called Process Compliance Language (PCL) is proposed for the expression of violation conditions and the reparation obligations which is very important for formalizing norms to determine the compliance of a process with the relevant norms. PCL enables to represent exceptions as well as to capture violations and the obligations resulting from the violations, but it does not take a broader view on norm sets where relationships other than reparation of violation exist between norms. In order to regulate the behavior of agents in open and regulated MAS in a distributed manner, [11] presents a normative structure based on the propagation of normative positions as consequences of agents' actions and provides a mapping into Colored Petri Nets for conflict resolution. The normative structure models norms in normative scenes and builds connections between the scenes by transition rules, which focuses more on the causal relations between norms other than conjunction, disjunction and implication.

Since norms are usually specified at different levels of abstraction, there is a need to relate the abstract concepts used in the specification to concrete ones used in practice, which necessitates the research on norm contextualization. In [3], counts-as statements are used to provide the concrete concepts their institutional and organizational meaning according to different contexts and enable agents to reason about norm compliance by the context they are in. A context-based institutional normative environment is proposed in [5], which enables the use of norms within a hierarchical context structure and norm inheritance as a mechanism to facilitate contract establishment. Another perspective on contextual normative structure, presented in [10], models norms of MAS according to four levels of abstraction: Environment, Organization, Role and Interaction contexts. However, these contextual normative frameworks all concentrate on the effects of individual norms but ignore their relations.

Due to the changing nature of norms, conflicts or inconsistencies may occur. To solve this problem, different approaches have been proposed such as [19], [9], [4]. Eventhough, we do not focus on checking the consistency of normative structures, but since the building blocks (norm nets) are organized in such a way that they can be mapped to CPNs, inconsistencies will be easy to identified using CPNs formal analysis methods and tools.

## 7 Conclusions

In this paper, we proposed a normative structure that not only captures the characteristics of a single norm but also the relationships between norms. Given that agents in MASs interact with each other to achieve certain goals, the interrelated effects of norms on their behavior are very important for both individuals and the system. Therefore, the connections between norms should be explicitly indicated in a structural way. Moreover, contexts play an important role in the construction of norms, in the sense that the application of a norm heavily depends on its institutional context and a norm may have different interpretations in different situations. To this end, the concept of norm net in this paper expresses how a set of recursive norm sets organize in a hierarchy of contexts.

Most importantly, this paper presents a norm net contextualization process that describes norms from general to specific. This enables a modular approach for building normative structures that improves both reusability and flexibility. Furthermore, following this contextualization process, actors can have a better understand of their dos and don'ts with the evolution of contextual norm nets. To verify the proposal, we map norm nets to CPNs and incorporate agents/actors as colored tokens in the analysis, which presents the state transition process of norm nets and provides a potential approach for compliance checking on norms.

In future work, we intend to build a complete mapping for contextual norm nets from general to specific using advanced Colored Petri Nets, e.g., hierarchical CPNs. That is, linking the CPNs of abstract norm nets with that of contextual norm nets in a recursive manner and reflecting the contextualization process from the whole structure. Moreover, we would be interested in implementing simulation of norm nets for compliance checking on norms on the basis of CPN analysis tools and agent based simulation techniques.

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