An Agent-Based Model for Normative Hierarchical Organizations considering Goal Decomposition Process

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Abstract. *The ideas about the structures and interactions that happen in human organizations have been used to model agent-based normative hierarchical organizations. Some works have used social control to regulate the agents' behavior to achieve an organizational goal, i.e., that is decomposed in a set of meaningful sub goals to the agents. Many organizational models have been defined to model these organizations, but they do not relate, more specifically, the agents in the hierarchical structure with the sub goals resulting from the decomposition process. This paper proposes an approach to bridge this gap, i.e., to model agent-based normative hierarchical organizations along with the goal decomposition process. In short, we extended a model found in Literature considering the goal decomposition defined in Moise+. We used UML diagrams to illustrate our extension.*

1. Introduction

Agent paradigm has been used to represent and simulate the interaction that occurs in real world. Moreover, this paradigm has been used with a solution to develop complex systems. As a result, the development of agent-centered systems has requested an effort of Software Engineering to provide methodologies, programming and modeling languages, and tools to support different steps of their development process.

One type of this system is a multi-agent system (MAS) which is composed by a set of agents ordered in an organization which interact between them to achieve a determinate goal. These systems can be regulated by norms to reach an organizational goal. Therefore, when norms and MAS entities are put together we have a normative multi-agent systems (NMAS). In these systems, an agent can decide whether it will comply or not an organizational norm. However, this agent can receive a reward or punishment, respectively.

Some authors [Vázquez and López y López 2007] [Dignum 2003] [Ferber, Gutknecht and Michel 2004] [Ferber and Gutknecht 1998] have researched in NMAS, more specifically in agent-based hierarchical organizations. These authors have analyzed the behavior of agents, the power relation and the interaction between agents to achieve an organizational goal and to follow the organizational norms. In an agent-based hierarchical organization the power relation exists in different level of the hierarchy. In

addition, in this kind of organization, an organizational goal can be divided into sub goals and the agent in a higher level is responsible for all organizational goals and has the power over his/her subordinates.

In this context, some organization models [Hübner, Sichman and Boissier 2002] [Ferber, Gutknecht and Michel 2004] [Dignum, 2003] [Ferber, Stratulat and Tranier 2009] have been proposed to represent organizations and theirs structures. However, none of them allow the modeling of these hierarchical structures completely. In addition, the division of a goal into sub goals and their dependencies are represented partially in these models. Considering this drawback in these organizational models, our paper has the objective to propose a framework to represent the goal decomposition process and the relation between sub goals created in this process for hierarchical organizations. Therefore, we extended the model proposed by Vázquez and López y López (2007) to represent the goal decomposition process defined by Hübner, Sichman and Boissier (2002).

This paper is organized as follows. We present the concepts related to hierarchical organizations, the agent-model proposed by Vázquez and López y López (2007) and Moise+ in Section 2. In Section 3 we discuss the related work. The extension of the model defined by Vázquez and López y López (2007) is detailed in section 4. An example to illustrate our extension is modeled in Section 5. In section 6 we discuss the benefits and the drawbacks of our extension. Finally, conclusions and future works are presented in Section 7.

2. Background

This section describes the main concepts needed to understand this work, including concepts related to hierarchical organizations, the agent-based model defined by Vázquez and López y López (2007) and the organizational model Moise+.

2.1. Hierarchical Organizations

A hierarchy or hierarchical organization is characterized by agents arranged in a tree-like structure, where agents located at the top of the tree have a more global view than those below them [Horling and Lesser 2005]. This structure is used to control larger groups of agents and to decompose task in subtasks. Consequently, these tasks can be performed more efficiently.

Fox (1979) described three types of hierarchical organizations: Simple hierarchy, Uniform hierarchy and Multi-divisional hierarchy. Keeping in mind that our paper will focus in agent-based uniform hierarchy organization, we will describe it in more detail. A uniform hierarchy has a distributed authority in each level of the tree. Consequently, the agent in a higher level is responsible for (i) achieving an organizational goal and (ii) checking the agents that are below him/her (subordinates). In other words, this agent is responsible for the organizational goal, i.e., for all the sub goals of his/her subordinates, over whom he has the power.

It is important to highlight that an organizational goal or sub goal can be decomposed into other sub goals [Hübner, Sichman and Boissier 2002], and each created sub goal can be divided in other sub goals. If necessary, this goal decomposition process and can happen several times. This process results in a tree-like structure and allows to divide tasks and responsibilities between agents in hierarchical organizations.

Only agents in higher levels of this type of organization may do this process. Thus, when an agent performs this process, this agent divides its own power with other agents which take some sub goals. Consequently, they start to have responsibility for the agents hierarchically below them.

2.2. The Agent-based Model defined by Vázquez and López y López (2007)

This section presents the main elements, structures, and concepts defined in the model of Vázquez and López y López (2007). The main elements in this model are norms, normative agents, resources, organizational goals, organizational services, contracts, position profiles, and organizational agents. Figure 1 presents the global view of this model represented in UML class diagram [OMG, 2017].

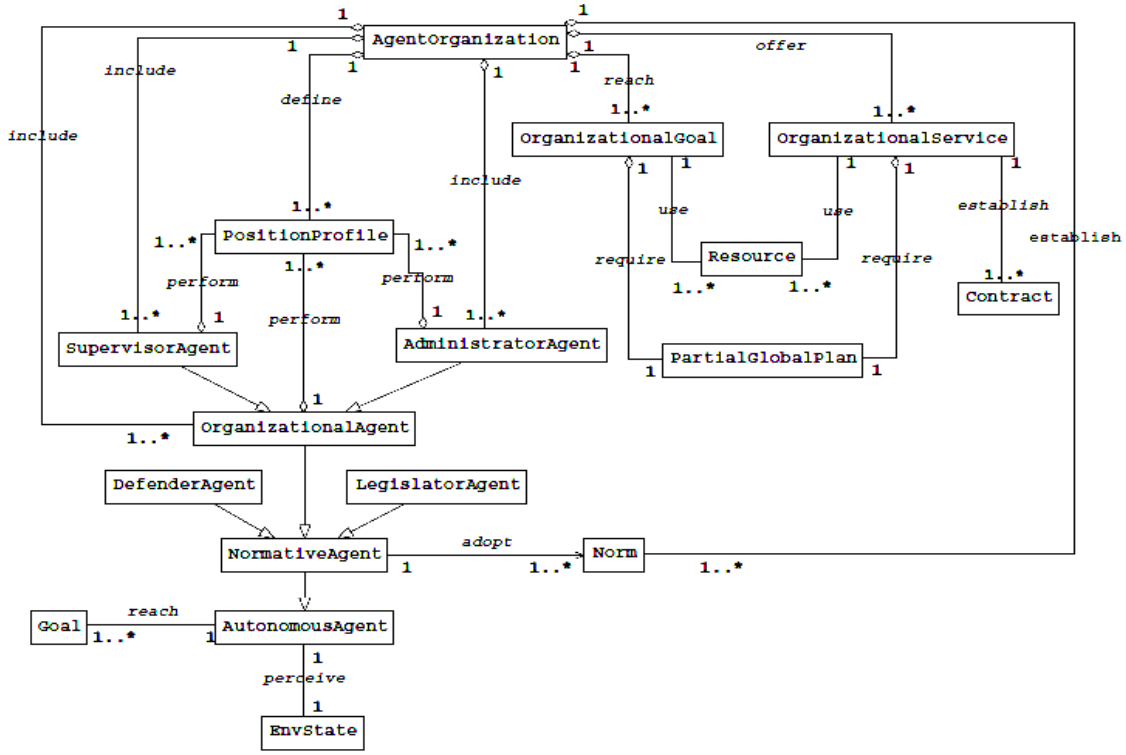

Figure 1. Global view of model [Vázquez and López y López 2007]

According to López y López, Luck and d'Inverno (2005), norms are used to regulate agents in a society and have the following elements:

- ***Normative Goals***: they comprehend the goals defined by a norm;
- ***Addressee Agents***: they represent that the agents must achieve the normative goals defined by a norm;
- ***Beneficiaries Agents***: these elements represent that the agents could receive some benefits due to norm compliance;
- ***Context***: it represents the conditions used to activate a norm;
- ***Exceptions***: they represent events where an agent may decide to follow a norm or not;
- ***Punishments***: these elements represent the penalties that an agent receives when it does not follow a norm; and

- ***Rewards***: they are the benefits applied to an agent when he/she follows a norm.

In addition, López y López and Luck (2004) defined a set of organizational norms to regulate the behavior of an agent in NMAS [Boella et al. 2006]. Moreover, this set is composed by following norm types:

- ***Defender Norms***: these norms are used to give rewards or to apply punishments to agents that follow or violate a norm, respectively;
- ***Enforce Norms***: they help to enforce and to determine the fulfillment of the most recent set of norms;
- ***Reward Norms***: these norms promote the fulfillment of norms by using rewards; and
- ***Emitted Norms***: they allow the creation and the abolition of norms.

In this model, a Normative Agent knows the organizational norms. Additionally, there are agents called ***Legislator Agent*** which are entitled to create new norms or abolish previous norms in the system; and agents called ***Defender Agent*** which are entitled to apply rewards or punishments according to the norm compliance. Considering the administrative process functions defined by Chiavenato (2005), the model of Vázquez and López y López (2007) has the following agent types:

- ***Organizational Agent***: it is a specialization of Normative Agent, and it must recognize and fulfill organizational norms;
- ***Administrator Agent***: it is a specialization of Organizational Agent and Legislator Agent because it is entitled to generate plans, and to create or abolish norms in the system; and
- ***Supervisor Agent***: it is a specialization of Organizational Agent and Defender Agent because it is entitled to make own subordinates to reach the organizational goals, to give rewards or to apply punishments.

These elements, norms and agents, can be put together in an organization. In the model of Vázquez and López y López (2007), the organization uses the position profile to identify a functional position in a hierarchy, to describe the set of obligations and rights in a position and to specify the superior (chief) and own set of inferior elements (subordinates) in each position. The position profile has the same function that an agent role. In addition, this organization has resources to operate to achieve its goals.

An organizational goal is a set of desired states. A state represents a situation which an organization comes across a period. A plan is the result of the decomposition of goals into sub goals, and it is depicted in PartialGlobalPlan. Additionally, a set of organizational services are provided by an organization. These services can be accessed by individual agents or other agent-based organizations. It is important to point out that an organizational service is guaranteed by means of contract. A contract is a set of obligation norms that represents benefits and obligations for own participants.

This model [Vázquez and López y López 2007] allows the representation of main elements that form a hierarchical organization for agent-based systems. In addition, it uses norms to control the behavior of its entities in different levels of hierarchy.

2.3. Moise+

Moise+ is an agent-centered organizational model defined by Hübner, Sichman and Boissier (2002). It was based on two main ideas: (i) Organizational Specification (OS) that defines the structure, the working and the norms that restrict the organization of agents; and (ii) Organizational Entity (OE) is the combination of an organizational structure and the set of agents that inhabit in it. More specifically, an OS has three dimensions: (i) Structural dimension: defines roles, interactions between roles and groups; (ii) Functional dimension: defines the organizational goal and its sub goals; (iii) Deontic dimension: defines the agents in the Structural dimension that are committed to the sub goals in the Functional dimension.

An agent playing a role can interact with other agents by three kinds of links: authority, communication and acquaintance links. In a scheme, it is possible to decompose a goal or a sub goal into sub goals using one of three operators, as depicted in Figure 2:

- **Sequence**: consider the goal g0 was decomposed into three sub goals (g1, g2, g3), meaning that g0 will be achieved only if the g1, g2, and g3 that are reached, sequentially in that order (the same occurs with sub goal g2);
- **Parallel**: consider that sub goal g3 was decomposed into two sub goals (g31 and g32), meaning that g3 will be reached when g31 and g32 are achieved, in any order of execution; and
- **Choice**: consider that sub goal g1 was decomposed into two sub goals (g11 and g12), meaning that g1 will be reached if g11 or g12 is achieved, i.e., exclusively one of the sub goals.

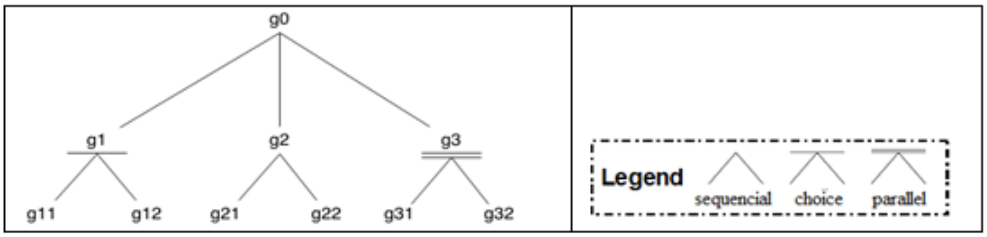

Figure 2. Operators for goal decomposition process

3. Related Work

This section involves works related to organization representation. Some organizational models have been proposed for NMAS [Hübner, Sichman and Boissier 2002] [Ferber, Gutknecht and Michel 2004] [Dignum 2003] [Ferber, Stratulat and Tranier 2009]. Our aim is to analyze four organizational models considering the support provided to the modeling of hierarchical organizations and the division goals into sub goals and their dependencies between them.

Hübner, Sichman and Boissier (2002) defined an organization model called Moise+. It supports the modeling of organizations composed by power levels (similar to hierarchical organizations), but it does not allow to apply sanction based on actions of agent. In this sense, Moise+ allows the description of permission and prohibition norms

for roles in the organizational context. In addition, CASE Moise API and Platform allows to create and specify organizations and to manage their entities.

AGR (*Agent-Group-Role*) [Ferber, Gutknecht and Michel 2004] is based on AALAADIN model [Ferber and Gutknecht 1998] that describe hierarchy organizations. In AGR, the agents can have their behavior regulated by interaction protocols. An organization modeled in this organizational structure is represented by congregations and colligations [Isern, Sánchez and Moreno 2011] of agents. These entities can communicate only with others owned same group. In the same way of Moise+, AGR does not allow sanction specifications.

In OperA [Dignum 2003], the description of obligation, permission and prohibition norms for agents, agent roles and agent groups is allowed in organizational context, interaction and scene transaction. Nevertheless, this model does not give support to model agent's structural aspects neither environments. In addition, norms can be applied to agents, in order to play a role as mean of a contract. In addition, every agent knows all the sanctions related to a contract. However, OperA does not allow the goal decomposition process.

MASQ (*Multi-Agent System based on Quadrant*) [Ferber, Stratulat and Tranier 2009] allows the sanction definition for each member associated in an organization, but it is not possible to describe perception mechanisms for these sanctions. In other words, punishments can be detailed and related with norms that restrict agent roles and the interactions inside a group of agents. However, this organizational structure does not have an associated sanction mechanism neither allows the goal decomposition process.

Unfortunately, all organizational structures presented and discussed in this subsection do not give totally support to model hierarchy organizations, all their structures and the goal decomposition process. Only Moise+ has the supporting to model the goal decomposition process.

4. Extending the Model of Vázquez and López y López (2007)

According to Vázquez and López y López (2007), a hierarchical organization is composed by a group of agents organized in a tree-like structure. A chief agent is responsible to divide a goal into sub goals and to choose agents situated in inferior levels to execute these sub goals. However, a sub goal could have a dependency with another sub goal. As a result, Hübner, Sichman and Boissier (2002) defined three goal operators, explained in Section 2: **Parallel**, **Sequence** and **Choice**.

To represent these goal decomposition operators in the model of Vázquez and López y López (2007), we defined new classes and relationships in this model. It is important to notice that our extension did not change the semantic and the structure of the previous version. In other words, we did a conservative extension in this model. Figure 3 presents the new version of the model depicted in UML class diagram.

In this context, we defined the classes *GoalRelation*, *SequentialNumber* and *GoalRelationTypes*. In Figure 4 (a), the *GoalRelation* class is a structure for each one kind of goal decomposition. It *has* relationship with *OrganizationalGoal* class, allows to identify the list of sub goals related with themselves. In Figure 4 (b), the associate class *SequentialNumber* defines the order that goals can be performed considering the

sequential decomposition goal through its *orderingNumber*. The *GoalRelationTypes* class (See Figure 4 (c)) is an enumeration class that has the kind of decomposition goals. It enables to identify the type of decomposition goal used by *GoalRelation* class through *hasType* relationship.

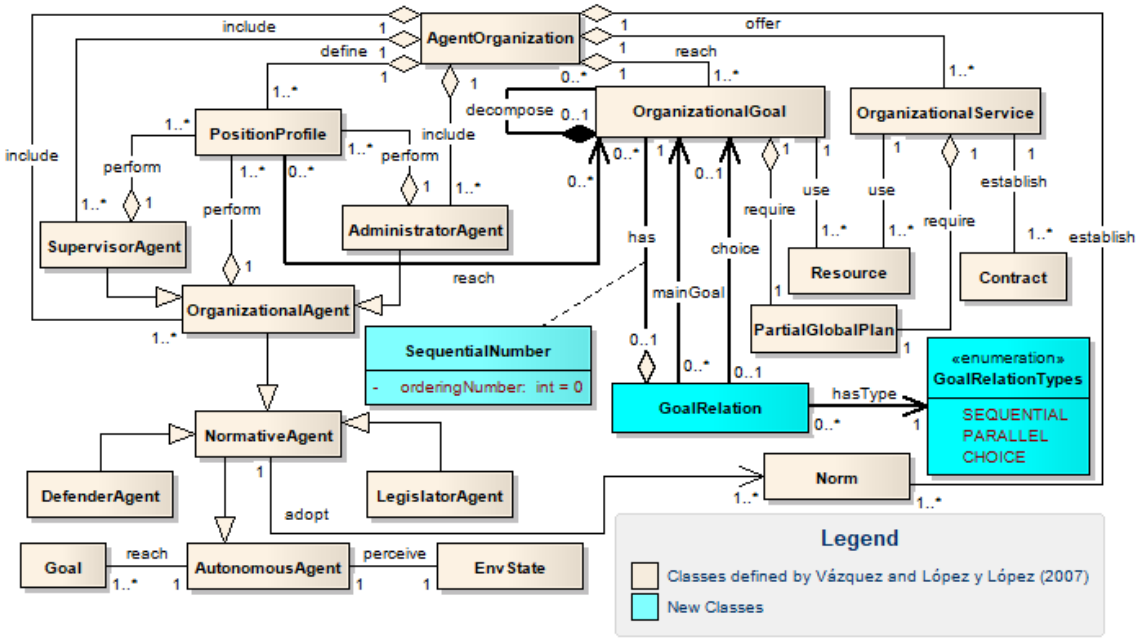

Figure 3. A new version of the model

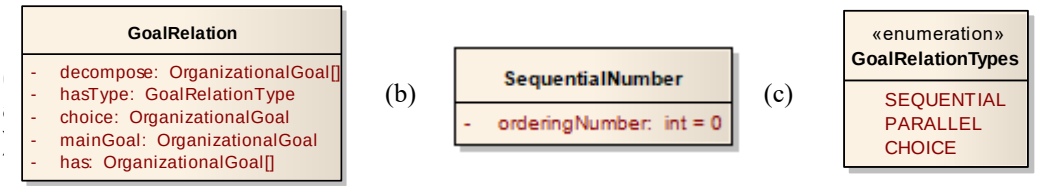

Figure 4. Structure of new classes

When the choice decomposition goal is used, the *choice* relationship in *OrganizationalGoal* class recognizes the sub goal that was chosen to execute. In its turn, the parallel decomposition goal does not need of a specified attribute or a relationship because of the list of sub goals (the self-association called *decompose* in *OrganizationalGoal* class) is already sufficient. In addition, *mainGoal* relationship allows to identify the goal (or sub goal) that was decomposed into sub goals.

In addition to the structure of the *OrganizationalGoal* class, we defined *reach* relationship between *PositionProfile* and *OrganizationalGoal* classes. This relationship represents the set of organizational goals which an organizational agent needs to achieve while plays a determinate position profile. In Vázquez and López y López's metamodel it was possible to identify what organizational goals were related to a position profile when we analyze the norms, because they identify the restricted entities (for instance, position profiles) and the regulated resources (for example, organizational goals). Thereby, the *reach* relationship defined in this new version of the metamodel take easy to identify the relation between *PositionProfile* and *OrganizationalGoal* classes,

allowing that the agent in a higher level to be responsible for achieving an organizational sub goal.

In short, our extension included the definition of three new classes (*SequentialNumber, GoalRelation, GoalRelationTypes*) and the definition of following relationships *decompose, reach, mainGoal, choice, has* and *hasType*. Consequently, these new elements are sufficient to represent the new concepts defined in goal decomposition.

5. Example of Application

To show the applicability of our extension, we used the context of a software development company. The functional positions defined in this company are: *Sponsor*, *Project Manager*, *Requirement Analysts* and *Software developers*. Figure 5 shows the UML use case diagram associated to these functional positions and their functionalities in this example. Figure 6 shows the defined goals. Figure 7 shows the goals and the dependency relation between them modeled through *OrganizationalGoal*, *SequentialNumber*, *GoalRelation* and *GoalRelationTypes* instances.

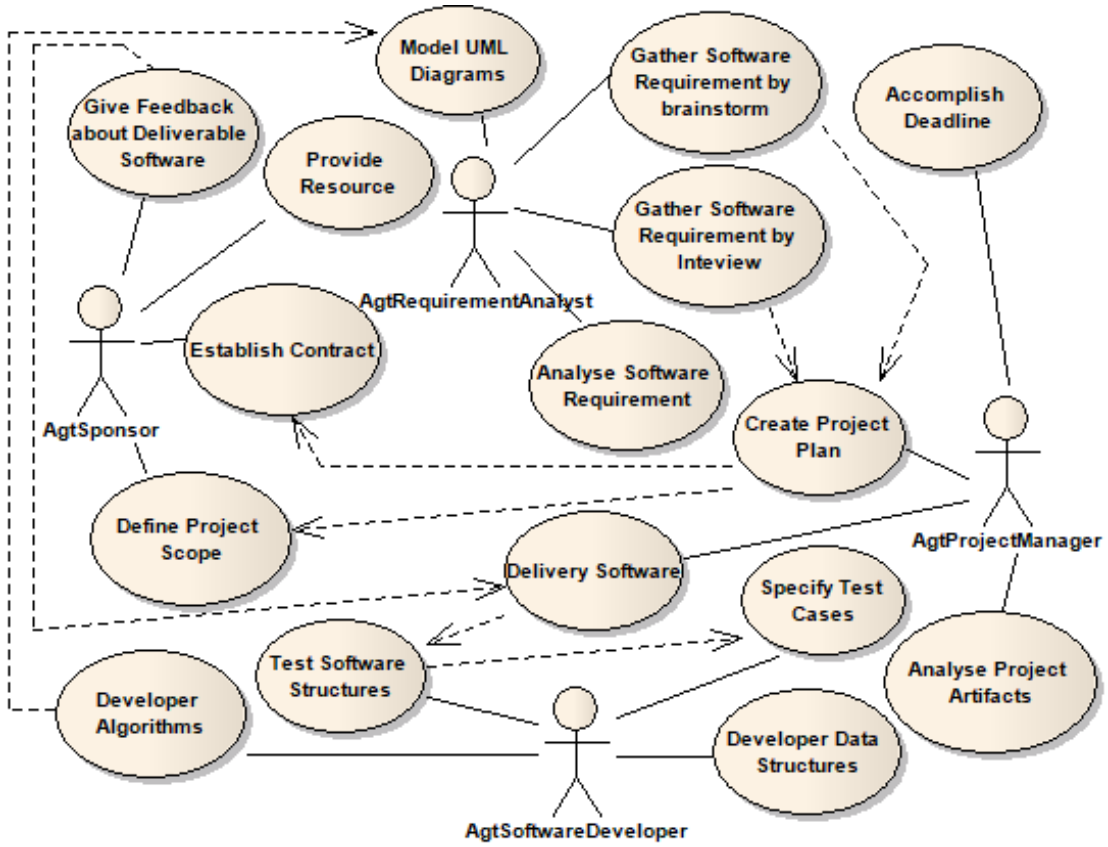

Figure 5. UML Use Case Diagram for Software Development Company

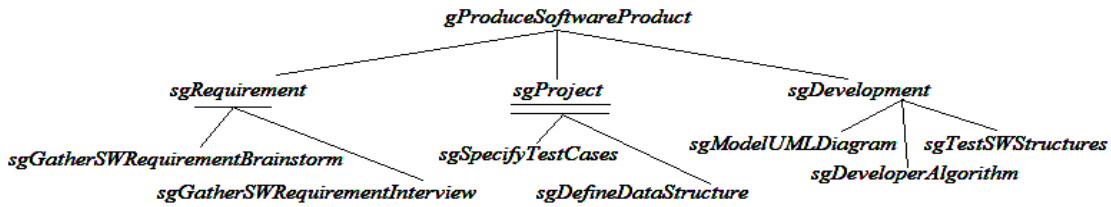

Figure 6. Goal, sub goals, and their dependencies represented in Moise+ syntax

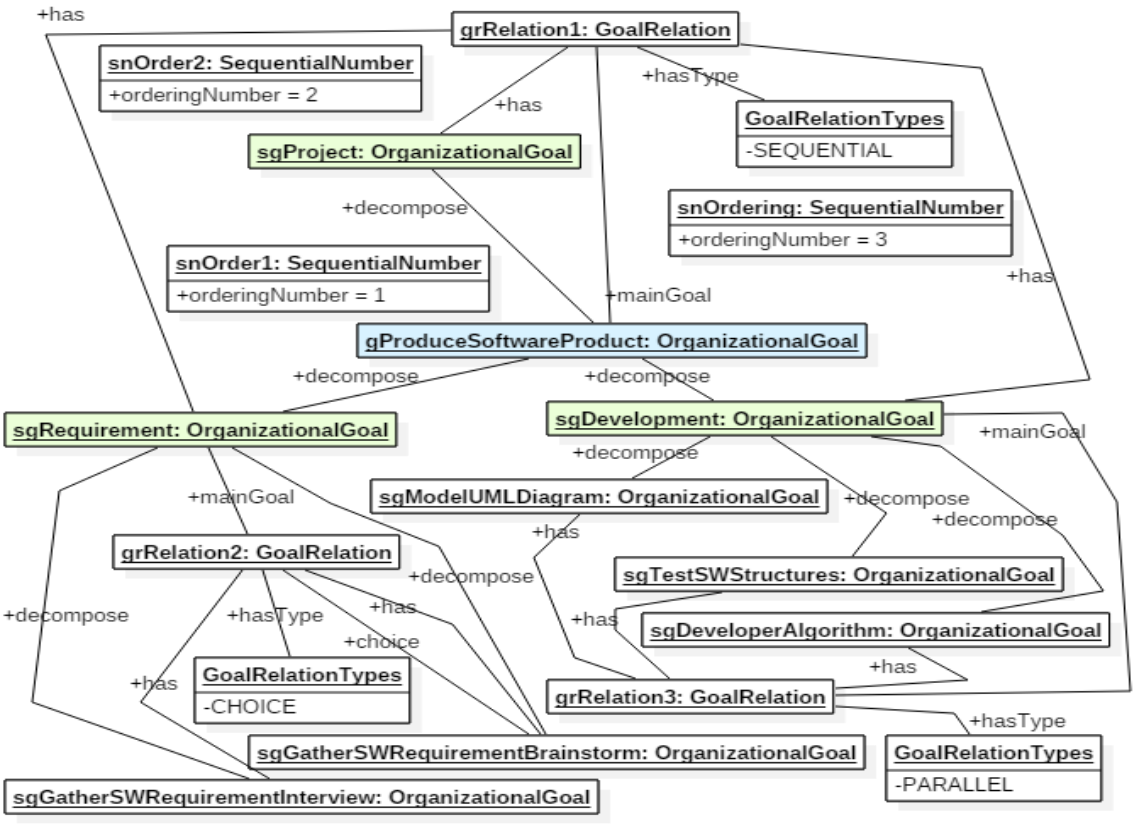

Figure 7. Modelling of goal dependencies

The *gProduceSoftwareProduct* goal was decomposed into *sgRequirement*, *sgProject,* and *sgDevelopment* sub goals, that must be executed in this order because they have a sequential goal relation. The *sgDevelopment* sub goal was decomposed into *sgModelUMLDiagram*, *sgDeveloperAlgorithm,* and *sgTestSWStructures* sub goals, that must be executed orderly because they are related by sequential goal relation. In contrast, the *sgGatherSWRequirementBrainstorm* sub goal must be executed exclusively because it was chosen in a choice goal relation with *sgGatherSWRequirementInterview* sub goal. These sub goals are part of the *sgRequeriment* sub goal. Finally, *sgProject* sub goal was decomposed into *sgSpecifyTestCases* and *sgDefineDataStructure* sub goals and they must be executed in any order because they are related by parallel goal relation.

To model the execution of the goal decomposition process, we defined the *agtProjectManager* agent as the responsible for achieving the *gProduceSoftwareProduct* goal. In this paper, we just modeled the scenario about sequential goal relation involving this goal and its *sgRequirement* sub goal. The same process happens for *sgProject* and *sgDevelopment* sub goals. Figure 8 shows the UML sequence diagram describing the interactions between the instances in the system. Firstly, *agtProjectManager* agent uses *getState*() method to identify the state of the environment and recognize their responsibility for the *gProduceSoftwareProduct* goal. After this, the agent starts the goal decomposition process creating new sub goals and related them in *GoalRelation* instances. This process occurs while the decomposition is happening.

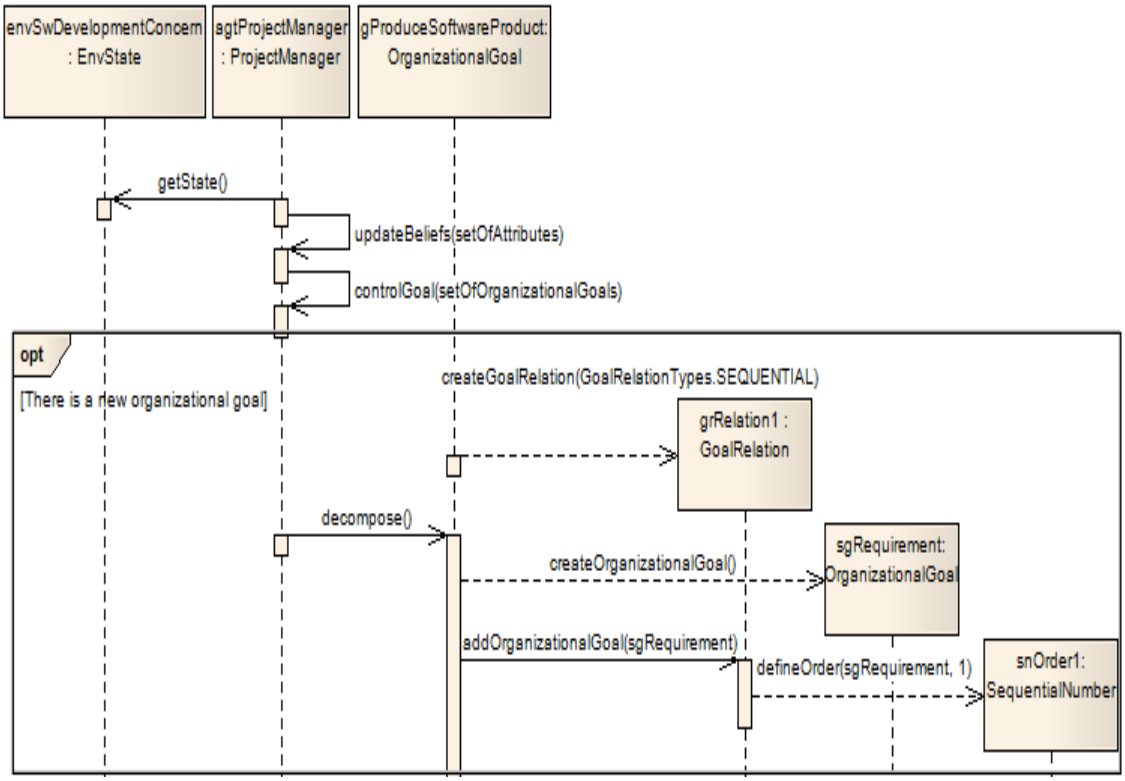

Figure 8. Modelling the goal decomposition process

6. Discussions

By means of our extension, it is possible to model the structure and the goal decomposition process for hierarchical organizations. An example of modelling was showed in section 5 using the context of a software development company. We choose the model of Vázquez and López y López (2007) because (i) it has all structures of hierarchical organizations, (ii) it is based on UML class diagram, allowing the extension and the adjustment of its entities, (iii) it has the definition of supervisor and defender agent that control the changes of norms in an organization, and (iv) it is flexible because normative agents can adopt new norms and update its set of norms.

The new version has the following advantages: (i) the syntax of our model is easy to understand and to use because it was based on UML, (ii) the designers can propose the goal decomposition considering the initial version of the organization focusing on the accomplishment of main organizational goal, and (iii) the division of goals/sub goals into sub goals allows that designers to understand the power and responsible level of their agents in a hierarchical organization. Our model presents the following drawbacks: (i) the designers need to spend time to understand the semantic of the entities in the model, and (ii) the modelling of a large system could ensue in a model of difficult understanding.

In this way, whether we compare our extension with related work, it is possible to notice that all organization models did not give support for the modelling of all entities in a hierarchical organization. For example, although very powerful, the organizational modelling language Moise+ does not allow the modelling of sanctions

based on agent's action. In addition, the goal decomposition process is used only to make plans that agent must be followed to reach an organizational goal. Our model allows the modelling of complex systems improving the understanding of the system that will be developed in technical and user visions, i.e., it is a contribution to the Software Engineering and Artificial Intelligence areas.

7. Conclusions and Future Works

This paper presented a model that allows the modelling of hierarchical organizations considering their structures and the goal decomposition process defined by [Hübner, Sichman and Boissier 2002]. Therefore, we extended the model of Vázquez and López y López (2007) defining three new classes (*SequentialNumber*, *GoalRelation*, *GoalRelationTypes*) and the relationships *decompose*, *reach*, *mainGoal, choice*, *has* and *hasType*. In addition, an example of application was modeled using our extension based on the context of a software development company. A UML use case diagram was modelled to present the main services of the organization and we used a UML object diagram to demonstrate the design of goal decomposition process considering three operators: sequential, parallel and choice. In addition, a UML sequence diagram was used to show the interaction between the entities while the goal decomposition process is happening.

As future works, we can suggest: (i) the implementation of our model using an agent framework, (ii) the formalism of our model using graph theory, and (iii) the analysis of the dynamic of norm compliance considering goal dependencies for individual and group of agents.

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