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An organizational model for multi-scale and multi-formalism simulation: Application in carbon dynamics simulation in West-African Savanna

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A B S T R A C T

This paper presents Organization-Role-Entity-Aspect (OREA) model, an organizational model for multi-scale and multi-formalism description of complex systems. OREA is based on the assumption that one issue in complex system simulation is to integrate multi-scale and multi-formalism representation. To achieve this issue, we use an approach based on organization-centered multi-agents systems and Discrete Event System Specification (DEVS) formalism. While the organizational approach allows to deal with an explicit representation of global and local levels, DEVS formalism allows integration of models of different types to describe a system perceived at different scales. Integration of OREA formalism within DEVS allows multi-formalism specification of a model both at global and local levels. In addition, this allows specification of the social structure of a complex system following DEVS formalism. In OREA, the organizational structure is specified without any assumption on entities structure. The roles description in OREA concerns only the detailed description of interactions within organization. The way that individuals conceive their system and make decision is defined through the concepts of aspect. OREA is applied in implementation of a generic model for carbon dynamics simulation in West-African Savanna. Future works would concern the integration of organizational dynamics and holonic representation in OREA.

1. Introduction

Complex systems simulation takes more and more an important place in many domains: ecosystem management [1,2], social science [3], economy [4], transport [5], etc. A complex system (1) is as a set of individuals with non-linear behavior, interacting with each other and evolving at different scales of time and space and (2) such that the behavior at the global level cannot be reduced to the composition of the local behaviors [6]. In general, the analysis and the management of such systems are based on the articulation of at least three levels of description: the individuals (local) level, the global level, and underlying environment [6]. The representation of such systems requires a multi-scale and a multi-formalism approach. The individuals' behavior can be described using utilities optimization process as behavior rules. The interactions among individuals and between individuals and their environment are easily represented by multi-agents systems (MAS) [7]. Finally, the global level can emerge from the individuals interactions [8] or be described by compartment models [9]. From what precede, one issue in complex system simulation is to integrate the multi-scale and multi-formalism simulation since we con-

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sider these three levels of description. Multi-formalism simulation allows the integration of heterogeneous models of a same system perceived at different scales [10,11], increases model reuse and makes model a collaborative tool for scientists from different disciplines. However, a complex system is perceived under several points of view both at global level and local level [12,13]. If several persons from different disciplines are involved in a modeling process, it results several representations of the system and entities compounding the system due to the fact that these various persons have not necessarily the same perceptions on the system and the real objects of the system. Then, multi-formalism representation must exist both at global level and local level.

The objective of this study is to propose a conceptual framework for multi-scale and multi-formalism simulation of complex systems. Specifically, we aim to take account:

1. the explicit representation of the articulations between local level, global level and underlying environment;
2. the multi-formalism representation both at global level and local level.

We propose the Organization-Role-Entity-Aspect (OREA) model basing on organizational-centered of multi-agents systems (OCMAS) approach [14–17] and Discrete Event System Specification (DEVS) formalism [18]. OCMAS are based on the assumption that the social structure of MAS must be explicitly defined to constraint the agents behavior and their interactions [19]. OCMAS treat a system as organizations made of roles through which agents interact. The OCMAS approach makes it possible to represent explicitly both the global and local levels and their articulations.

In OREA, we are concerned with the explicit separation between the global level and local level seriously by distinguishing between (1) the decomposition of an organization into functional roles from an external and global point of view, and (2) the decomposition of an entity into aspects from internal point of view. In effect, there is no reason to assume that the decomposition of the behavior of an entity (agent, environment or object) corresponds to the decomposition of its behavior in terms of its expected outcomes within an organization. Then, the organizational structure is specified without any assumption on entities structure as stated by the first principle of OCMAS models [20]. The roles description in OREA concerns only the detailed description of interactions within organization. The way that individuals conceive their system and make decision is defined through the concepts of aspect. OREA integrates environment and objects within organizations. Then, environment, objects as agents can play roles.

OREA is implemented basing on DEVS formalism [18] and using Mimosa platform [21]. DEVS formalism provides a unique formalism for the integration of heterogeneous models evolving at different scales of time and space. Groups, roles and entities are specified as DEVS atomic models with their own dynamics. Integration of OREA structure within DEVS presents many advantages. Firstly, this makes it possible taking account the multi-formalism representation both at global level and local level. Secondly, this allows specification of the social structure of a complex system following DEVS formalism. Finally, it takes account the explicit representation of the circular relationships between the global level and local; showing the effectiveness of OREA to deal with the sociological methodological constructivism theory [22] (cf. Section 2).

A methodology is proposed to make it easy the OREA use in complex systems description. This methodology is applied in the modeling of carbon dynamics at village scale in West-African Savanna [1].

The reminder of this paper is organized as following. Next, it presents the sociological approaches to institutions with a focus on the articulations between the global level and local level. After, the paper presents the OREA meta-model and dynamics. The fourth section details the OREA implementation and highlights the multi-formalism aspect of OREA. The fifth section presents a short description of OREA application in carbon dynamics modeling at territory village scale. The last section discusses the results of this study.

2. The sociological theories for the articulations between global and local levels

As defined previously, a complex system description requires to take account both the macro-level and micro-level. The actual question is how to represent these two levels of description. Three sociological approaches to institutions discuss the representation and articulations between the macro-and the micro-levels [22]: the methodological holism, the methodological individualists and the methodological constructivism theories. According to the methodological holism theory, the global level (social institutions and phenomena) is external to the individuals (components) and must be defined explicitly and independently from the individuals compounding the whole system. The individuals' social behavior should be explained in terms of the positions or functions of these individuals within the social system and the laws which govern it [23]. The methodological holism is more interested in the macro-phenomena than the micro-phenomena.

In contrast, the methodological individualists see macro-phenomena accounted by the macro-level properties and behavior of individuals [22]. The methodological individualists is a bottom-up emergent-flavored approach [24]. The representation of a complex system according to the methodological individualists theory should only take into account the micro-level by assuming that the macro-level should arise from the individuals behavior and interactions.

The methodological constructivism theory asserts that there is a duality between macro and micro-phenomena. The humans reproduce the social structure (rules, laws) through their actions. In turn, the social structure constrains and enables the humans' actions. Then, structure is at the same time both the outcome of the knowledgeable humans conduct and the medium how conduct occurs [25]. Building a model according to the methodological constructivism theory requires an explicit representation of the macro and micro-levels. The macro-level properties (rules, laws, etc.) must be expressed explicitly and understandable by the individuals to allow them to reason about their society and act in. In addition, the individuals must have their own behavior, their own decision model which allows them to reproduce the social structure.

Our proposition is closed to methodological constructivism theory. We intend to represent explicitly the articulations between the global and local levels. For that, we use an approach based on individual-centered and organization-centered approaches. The global level is explicitly defined through the notion of organization and role. It is defined explicitly without any assumption about the local level. The global level defines the relationships and the interactions among entities through the roles they play within organizations. The way that entities make decision, reason about their system is defined at local level. However, there is interdependency between the global level and local level. The interactions within organizations are an outcome of entities behavior at local level that can be influenced by the interactions in which they are involved within organizations.

In order to allow entities to reason about the structure of their system and make decision, we introduce an ontology that is accessible for entities. This ontology provides an explicit description of concepts defining a system.

3. The OREA model

OREA is based on a meta-model organized along two dimensions (Fig. 1): the granularity dimension and the abstraction dimension. Along the granularity dimension, we distinguish the system or global level and the entity or local level. At the global level, a system is described as organizations made of interacting roles the entities can play; at the local level, entity internal structure is decomposed into a set of aspects. Through the concept of aspects, entities can play a same role in different ways. Along the abstraction dimension, we distinguish between the abstract and the concrete levels. The abstract level provides the description of ontology on a system. The concrete level defines the actual groups, entities and their structures; it represents an instance of the abstract level. In OREA, these two levels are concretely defined. This makes it possible to use OREA as a framework for both knowledge representation and model implementation. In addition, entities can reason about the structure of their system (organizational structure, description of entities, their interrelationships and interactions) through the ontology defined at the abstract level. Then, entities in a system have the same understanding of the concepts of their system and can behave coherently as stated by Weyns et al. [26].

3.1. The abstract level

From the abstraction point of view, a system is decomposed into a set of organizations (Fig. 2). Organization in OREA provides an abstract description of groups. It describes a context of interactions of the entities basing on the description of possibly relationships and the interactions that may exist among the entities. Then, an organization is composed by a set of role types, their relationships and a set of protocol descriptions.

A role type provides an abstract description of a function. It describes entity external features i.e. the observable behavior and the relationships among entities. The description of a role type is based only on a set of competence types and the detailed description of interactions in which entity types evolve. These interactions are defined through the protocol descriptions.

A competence type is the abstraction of a service which is needed or provided by an entity and more particularly by a component. The notion of competence allows entities to reason about their behavior and to interact coherently. In addition,

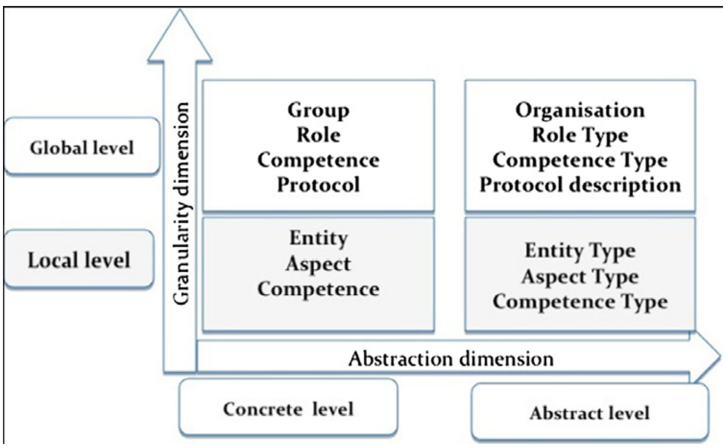

Fig. 1. The concepts of OREA along the granularity and abstraction dimensions.

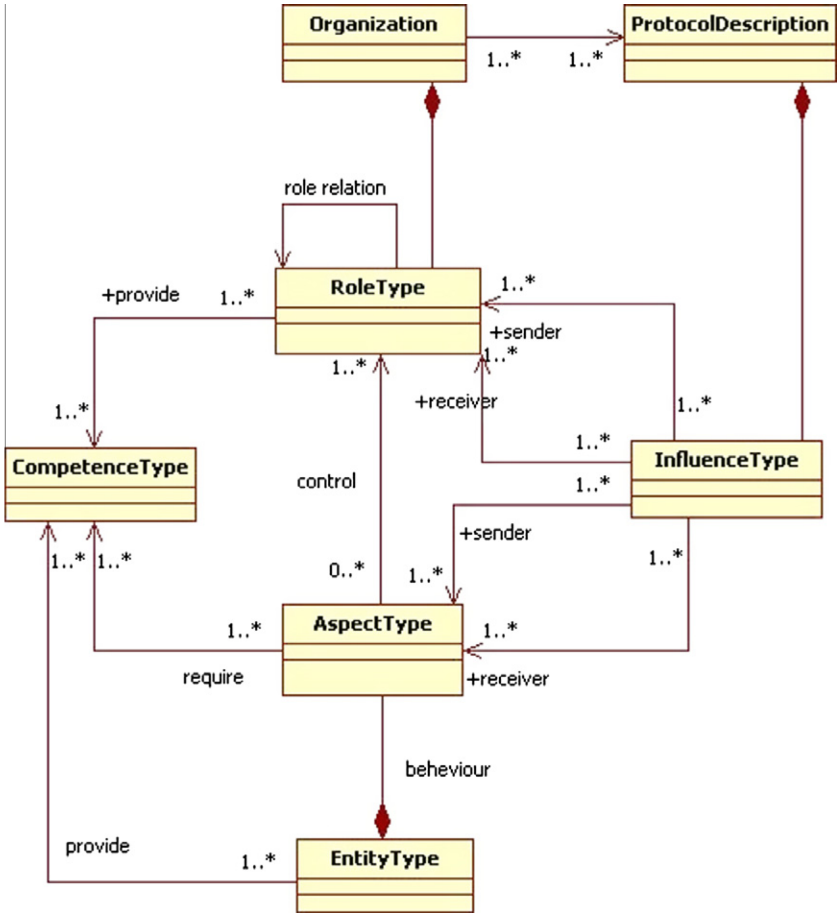

Fig. 2. UML description of the OREA abstract level.

it allows a generic description of the entities behavior [27], increases modularity and the independence of organizational structure from entities structure.

Protocol description structures interactions within organizations. A protocol description is characterized by a name, a set of role types, the rules of interactions defined as sending and receiving of influence types. An influence type is an abstract description of physical actions or basic messages, in other terms influences [28].

As defined previously, we aim to integrate objects and environment within organization. For that, we bring together the description of agent, objects and environment within the concept of entity type. Entity type provides an abstract description of a category of entities having the same structure. Then, an entity type describes a type of object, agent or environment. Two categories of features characterize an entity structure: the external feature and the internal feature. The external feature is characterized by a set of role types that define the expected place of entities in the system. The internal feature is decomposed into aspect types. In addition, an entity type is characterized by a set of competence types that define the services that an entity type can provide.

Aspect types describe separately the properties of an entity type and its behavior. Unlike role type that describes the functional aspect of entities i.e. the "what", the aspect type describes the non-functional aspects, i.e. the "how". It defines how entities achieve the functional aspects (roles) according to their internal goals and external disturbances. Each aspect type is characterized by a set of attributes defining the properties of entity type and a set of role types, competence types, and its relationships with other aspect types. The competence types of aspect types define the services provided by an entity type. Some competence types are intrinsic to entity type and other to roles types. The specification of aspect type behavior is based on these competence types. In other terms, the way that competence is achieved is defined through aspect types. The execution of competences is triggered according to the incoming influence types. Then, an aspect type is characterized by a set of incoming influence types that trigger its behavior. These influence types can be external or internal; i.e. coming from other aspects. The interactions between aspect types depend on their relationships that define the whole structure of an entity type. An aspect type behavior is defined using a statechart. In this study, we are concerned with reactive systems that behave and react according to the internal and external influences. Statecharts are relevant to describe the dynamics of such systems. Statecharts allow to specify explicitly how a component reacts to external and internal influences and the change in its state according to the incoming influences. In aspect description with statecharts, a transition is characterized by (1) an incoming influence representing the event that triggers the transition, (2) a condition and (3) action to execute that concerns execution of tasks provided by competence types.

3.2. The concrete level

At the concrete level, a system can be viewed as a set of groups interacting through entities playing roles in these groups (Fig. 3). A group is an instance of an organization. It is composed by a set of roles, each role instancing a role type. Several groups of the same type (organization) can be created simultaneously.

A role is closed to a group and interacts only with roles of the same group following a protocol. A protocol is an instance of protocol description. It defines a state of a current interaction in which a role evolves. In addition, role provides competences to entities. Then, playing a role allows entities to provide some services.

Entities can play simultaneously several roles that define their relationships within groups. An entity can be an object, an agent or a physical environment. Then, environment in OREA can enter groups, play roles and interact with other entities (objects and agents) compounding it. Agents perceive and interact with environment through their roles.

If the entities interact through roles, they behave and make decision through their aspects. An aspect is an instance of an aspect type. It is internal to the entity structure and defines partially the entities mental state and entity reaction to the external and internal events. An aspect is characterized by a set of roles an entity plays and a set of competences. Aspects control partially entity state, coordinate roles playing and ensure consistency of entity state and behavior. Suppose an entity "Family" is playing simultaneously the "Seller", "Buyer" and "Producer" roles. It is clear that the buying capacity of the entity depends on what it sells which depends on its production. This dependency is internal and requires the integration of a mechanism in the entity structure which allows ensuring the consistency of the decision processes. This mechanism of control is managed by the aspects. The aspects implement the decision rules for products buying and selling according to the available cash and resources. Each aspect is autonomous vis-à-vis of others aspects of entity. An aspect controls its own state

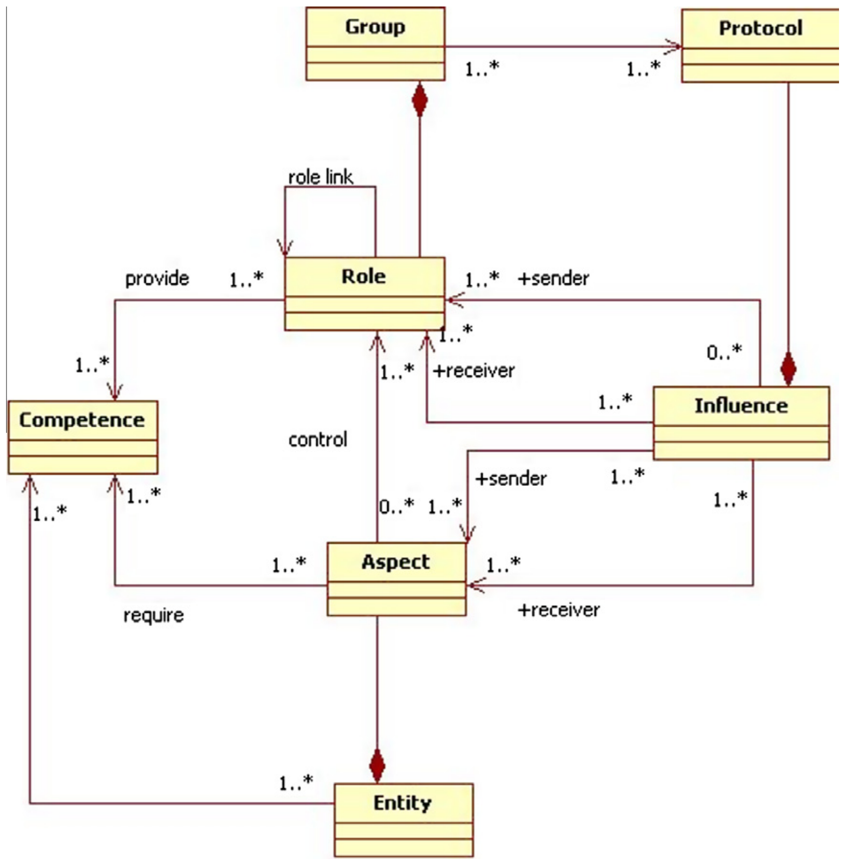

Fig. 3. UML description of the OREA concrete level.

and behavior. Then, other aspects cannot modify directly the state of an aspect. They must interact among them to exchange data.

3.3. OREA dynamics

The dynamics in OREA comprise two separated dynamics: individuals dynamics and organizational dynamics (Fig. 4). The individuals dynamics are related to the entities domain specific behavior and the organizational dynamics are related to roles playing, interactions between roles and groups management.

The entities can enter and leave dynamically groups and roles. If an entity plays a role, it acquires all competences of this role. The entities create groups according to their objectives. If all members leave a group, this last is automatically destroyed.

The roles playing depend on aspects handled by an entity. If an entity handles an aspect, it must play all roles required by this last because the behavior of aspect depends in part on the competences of roles. An entity can leave dynamically its aspects. For example, if an entity leaves all roles required by an aspect, it leaves also this aspect because this last cannot be executed.

Groups and roles entering by entity are managed by a specific aspect: InteractionAspect. InteractionAspect allows to separate the domain specific behavior from the organizational behavior of entity. The whole behavior of an entity is based on the interactions with its roles (Fig. 5), the interactions among aspects and their execution as summarized as follow:

– get influences from its own aspects and roles;
– select aspects to execute according to the incoming influences;
– dispatch influences to selected aspects;
– execute selected aspects;
– get influences from executed aspects;
– send influences to roles and others aspects;

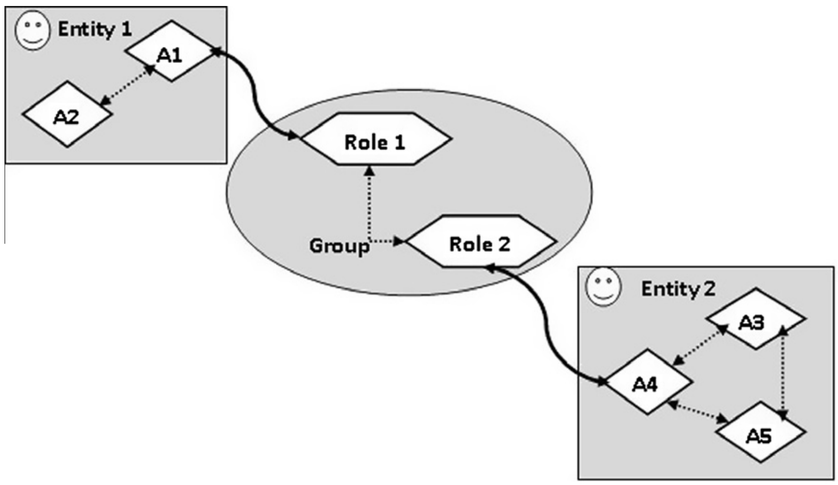

Fig. 4. Separation between individuals and organizational dynamics in OREA.

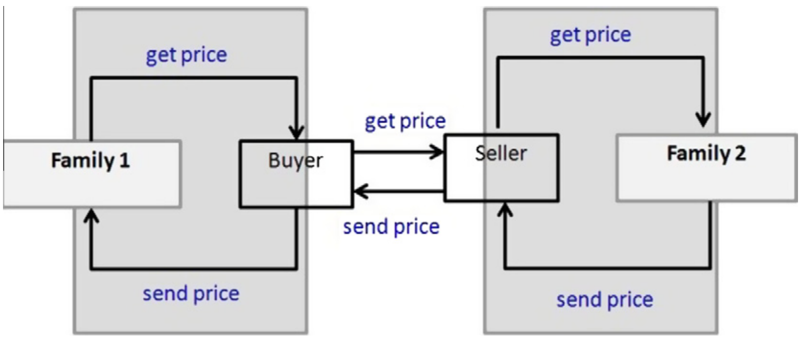

Fig. 5. Interactions between two entities through their roles.

– enter groups and roles;
– manage the evolution of its behavior (handle and leave aspects).

The interactions between roles and between roles and entity are defined as follow:

– get influences from its entity player or others roles of the same group;
– send influences to its player (for incoming influences) or to other roles (for outgoing influences).

The dynamics of aspect is defined as follow:

– get influences from entity;
– manage competences execution according to incoming influences;
– update its state;
– generate influences to send to entity.

4. OREA implementation

OREA model is implemented using Mimosa platform, an event-based platform. Its implementation integrates the two parts of the meta-model: the abstract level and the concrete model. Two components handle these descriptions: "ModelDescription" and "Model".

"ModelDescription" that allows to define ontology about a system handles the abstract level. It provides the description of organizations, role types and entities structure. Each element (organization, role type, entity type, competence type and aspect type) of "ModelDescription" is reified. But their definition concerns only the description of their structure and their relationships. "ModelDescription" is accessible to entities. Entities can manipulate the "ModelDescription" in order to reason about the structure of the system and behave coherently.

As to the concrete level, it is based on DEVS formalism. It is handled by "Model". "Model" manages groups dynamics: creation, removing, entering and leaving.

In Mimosa, the underlying simulation semantics is based on an extension of //-DEVS called M-DEVS (see [29] for more details). M-DEVS is a tuple defined as follow:

$$\langle X, Y, P, S, O, \text{init}, \delta_{\text{ext}}, \delta_{\text{int}}, \delta_{\text{log}}, \delta_{\text{conf}}, \lambda_{\text{ext}}, \lambda_{\text{int}}, \lambda_{\text{log}}, \lambda_{\text{conf}} \rangle$$

"Model", groups, roles and entities are defined basing on an extension of M-DEVS specified as follow:

$$\langle X, Y, P, S, O, \text{init}, \text{Struc}, \delta_{\text{ext}}, \delta_{\text{int}}, \delta_{\text{log}}, \delta_{\text{conf}}, \lambda_{\text{ext}}, \lambda_{\text{int}}, \lambda_{\text{log}}, \lambda_{\text{conf}} \rangle$$

where Struc represents the structure of model, organization, role type or entity type – defined in "ModelDescription" – for "Model", group, role and entity component respectively. This specification allows these various components to reason about the behavior and to control the coherency of the system.

Therefore, a model in OREA is a set of groups, roles and entities interlinked through ports. If several ports of a component have the same name, an index is used to distinguish the different ports. So, a group is linked to roles through two port types: "member" port and role specific port. The "member" port links group to all role members (Fig. 6). The role specific port links a group to roles of the same type. The name of this port is the name of the role type. For example, the port "seller(1)" links the group market to role "seller" in Fig. 6. Role is linked to group, entity and roles through the "owner", "player" and role specific ports respectively. Entity is linked to role by a role specific port defined using the identity of group and the role type name. Group, role and entity are linked to "Model" through "model" port.

Competences and aspects are implemented as components to allow a multi-formalism specification. They are characterized by a set of methods from object oriented point of view. These methods define the tasks provided by a competence. Then, the achievement of a service or a task may be an execution of an external models that can be specified in different formalisms. The fact that roles and entities can encapsulate several competences allows multi-formalism specification both from role and entity side.

Entity structure is implemented using a component-based approach. The components are roles, aspects and competences that can be added and removed dynamically. These components are managed (adding, removing and execution) by a main component: the MetaAspect implementing entity structure (Fig. 7). The fact that entity is a DEVS component, MetaAspect and aspects implement also the different transitions functions (δ_{ext}, δ_{int}, δ_{log}, δ_{conf}, λ_{ext}, λ_{int}, λ_{log}, λ_{conf}). Then, each transition function of entity calls the corresponding transition function of MetaAspect. According to the incoming influences, the MetaAspect selects aspects to execute and calls their corresponding transition function.

5. OREA application in simulation of carbon dynamics at a territory village level

OREA is used to implement a generic model for the simulation of carbon dynamics at territory village level in West-African Savanna. In this paper, we provide a short description of the conceptual model (see [1,13] for more details).

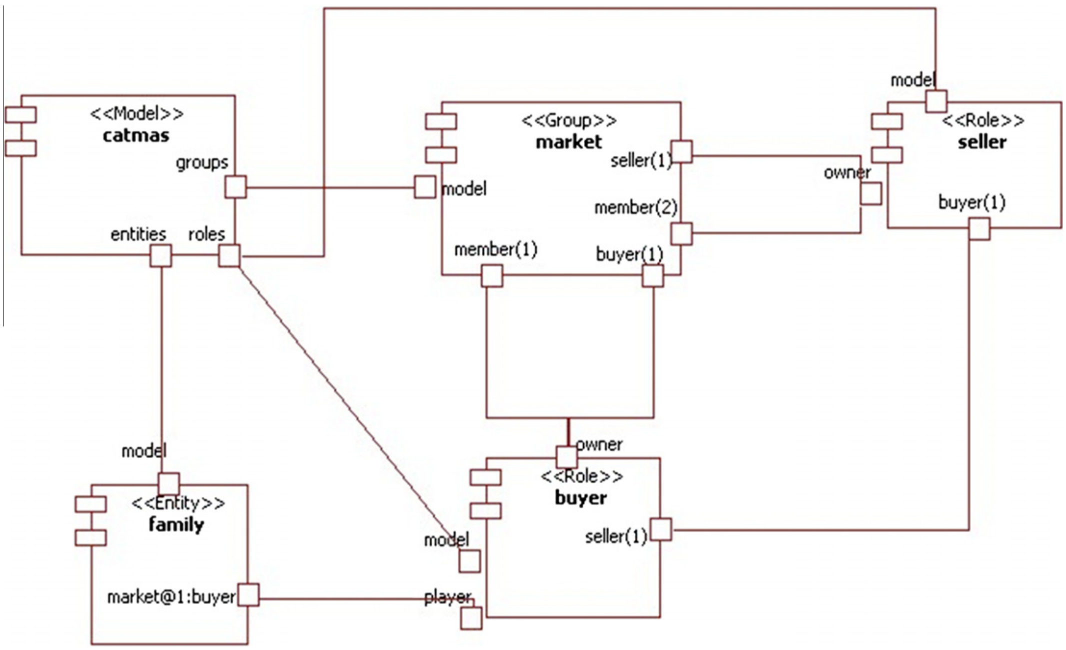

Fig. 6. Representation of the structure of a model using a component-based representation. The model is composed of a group – Market, two roles – "seller" and "Buyer" and an entity – "Family".

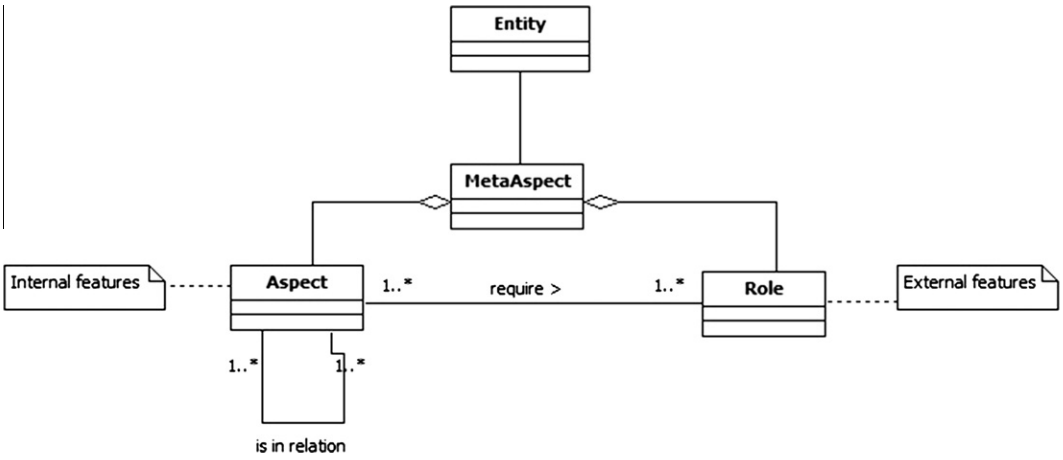

Fig. 7. Entity structure defined through roles and aspects components.

Carbon dynamics of a territory village is a complex system. It involves interactions at several scales of time (day, month, season, year) and space (plot, farm, village territory and beyond). These interactions occur between actors in the system, and between actors and their environment. The environment drives the human activities: crop and animal production. Environment is influenced by complex external factors: climate change, global socio-economic context, etc. Through their activities, farmers transform the environment that in turn modifies the farmers' behavior being to adapt to the new conditions, and so on. In addition, carbon resources are a common resource that the dynamics depends on the articulations between individual and collective management.

From what precede, the representation of carbon resources dynamics requires to take into account the articulation between individual and global levels and socio-economic and biophysical factors. The integration of socio-economic and biophysical in carbon dynamics representation requires a multidisciplinary approach: agronomy, sociology, economy, etc. However, the different disciplines do not necessarily share the same points of view on the system itself and on the real objects of the system, and these can be complementary. Thus, the modeling of carbon dynamics at village territory level requires integrating a multi-point of view description both at local and global and the explicit representation of environment for a realistic description of the biophysical dynamics.

The OCMAS approach provides a relevant framework for representing the local and global levels while integrating the environment dynamics. In addition, OCMAS models make it possible to describe a complex system under multi-points of view but only at global level. Only OREA model allows a multi-point of view description both at local and global levels. Therefore, we apply OREA in order to deal with the complexity of carbon dynamics at global, local and environmental levels.

At the global level, three organizations describe the system (Table 1). Production organization describes the farmer's activities for crop and animal production. Market organization describes carbon resources and other products exchange from economic point of view. Transport organization describes the carbon resources fluxes driven for the entities of the system. Each organization is characterized by a set of role types that characterize the relationships between entities: (1) Market organization is characterized by the roles "Seller" and "Buyer", (2) Transport organization is composed by the roles "Carrier", "Stock" and "WeatherManager", and (3) Production organization is composed of the roles "Producer", "Product" and "ProductionSite" (Fig. 8). In order to structure the physical relationships among entities, the "Physical Organization" is introduced. It is characterized by four roles: "Environment", "Place", "Located Object" and "Agent" roles (Fig. 9).

At the local level, five entities characterize the system: "Family", "Herd", "Plot", "Plant" and "Village". "Family" and "Herd" entities are the main agents of the model while "Plot" and "Plant" are the objects of the environment represented by the entity "Village". Each entity plays roles within organizations (Fig. 10). The roles played by objects and environment correspond to the perceptions of other agents on objects and environment in different organizations. For example, "Plant" is perceived by "Herd" entity as a stock of resource of biomass in Transport organization. The "Plot" entity is perceived by "Family" entity as a site of production in Production organization.

The group structure (Fig. 10) shows that "Family" and "Herd" entities play "Carrier" role within Transport group. However, they do not carry the same resources and do not behave in the same manner. Then, the "Carrier" role achievement is different for the two entity types. The way that they achieve "Carrier" role is defined through their respective aspects. It is the same for the entities "Plot" and "Plant" that play the "Stock" role within Transport group.

"Family" entity structure is decomposed into three aspects: "PlanningAspect", "SocialAspect" and "EconomicAspect" (Fig. 11):

The "PlanningAspect" specifies how "Family" entity plans agricultural and animal production. It is characterized by labor, land area, organic and mineral fertilizers available, food and money needs, and the types of cropping systems. "PlanningAspect" depends on two roles: the "Producer" role to plan production and the "Carrier" role for transportation of resources (organic and mineral fertilization). The "PlanningAspect" depends on the "EconomicAspect" for resources purchase. The "PlanningAspect" uses the following competences: the CroppingStrategyChoiceSkill, the "SellingStrategyChoiceSkill" and the "CultivationSkill" competences.

The "SocialAspect" describes the social properties of a farm. It represents the natality, mortality, immigration and the food consumption of the Family entity. The grain consumed is provided by the "PlanningAspect" through crop production, or by the "EconomicAspect" from the market. The "SocialAspect" controls the "User" role and requires the "FamilyNatalitySkill" (birth, death) and the "EnergyManagementSkill" (food consumption) competences.

The "EconomicAspect" specifies the economic behavior of the Family. It defines how the Family manages its cash to meet cash requirement or to invest in, e.g., animals, equipment and land purchase, food purchase. It controls the following roles: "Seller" and "Buyer". It is characterized by the cash and the resources to buy. The "EconomicAspect" dynamics is based on the "CashManagementSkill", the "SellingSkill" and the "PurchaseSkill" competences.

Table 1
The identification of organizations and underlying processes at different scales of description.

Organizations	Processes	Scales
Production	Plant production	Plot
	Land use change	Farm
	Fertility management	Farm
	Cropping system	Farm
	Animal production	Farm
	Animal cycle of production (aging, birth, death, growing, selling)	
Transport	Organic matter storage	Plot
	Water storage	Plot
	Pasture dynamics	Herd
Market	Organic matter	Village
	Labor exchange	Village
	Land exchange (purchase, hiring)	Village
	Global economy change	Village
	Animal selling and purchase	Village

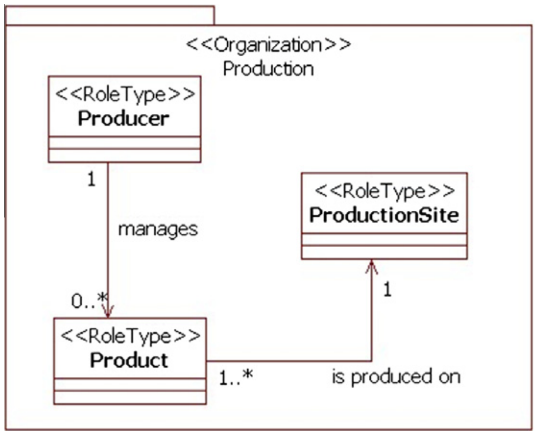

Fig. 8. UML description of production organization characterized by three roles: "Producer", "Product" and "SiteProduction".

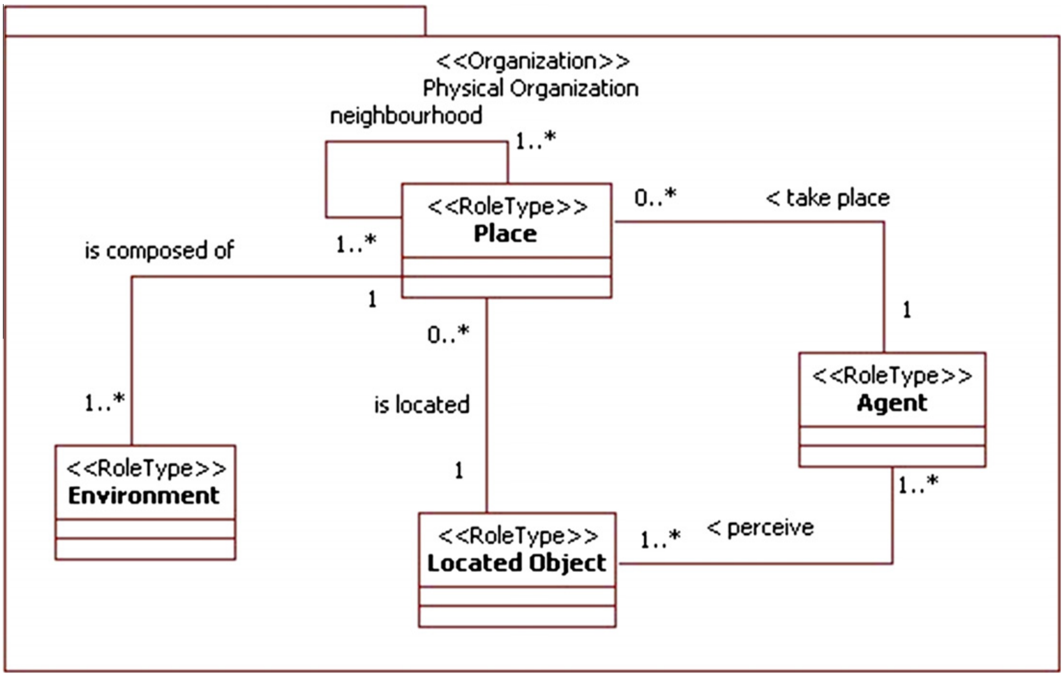

Fig. 9. UML description of physical organization for structuring the physical relationships among entities (agents, objects and environment).

The resulting conceptual model is implemented basing on a multi-formalism approach. The approach couples a MAS with Century [30] and a Geographical Information System. The MAS module represents the socio-economic dimension of carbon dynamics while Century represents the biophysical dimension. The MAS module simulates the carbon dynamics at plot, farm and village levels at different temporal scales. As to Century, it simulates the interactions between soil, plant and atmosphere at plot level. Then, Century model implements in part, the dynamics of entity "Plot". The coupling with GIS is based on a dynamic coupling. In the GIS, the environment is represented as cellular automata where each cell represents a plot. Each GIS cell is represented in the MAS module by a "Plot" entity (Fig. 12). In the model, the interactions between GIS and MAS are made possible thanks to PostGres and PostGis.

6. Discussion

This present study revealed many results that concern many research questions about the complex system modeling and multi-agents systems: the explicit distinction and the articulations between local and global levels, the concerns for environment and multi-formalism simulation. This section discusses these different results.

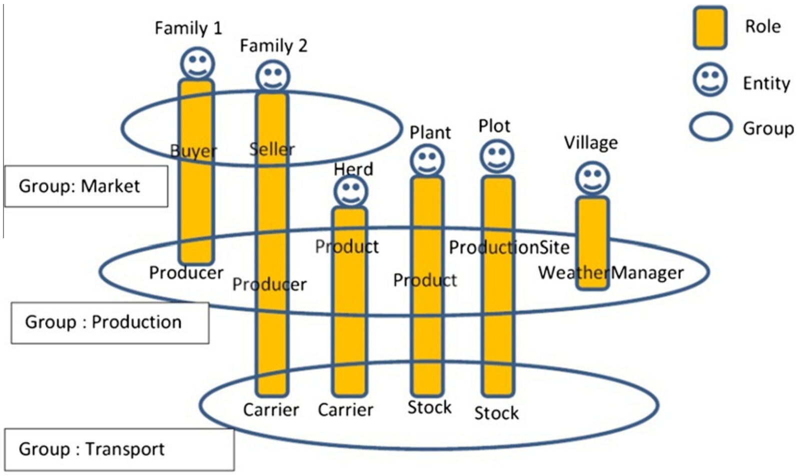

Fig. 10. Concrete representation of carbon dynamics. The model is composed of three groups: "Production", "Market" and "Transport". Different entities evolve in these groups. For example, entity "Family 1" plays "Buyer" and "Producer" roles within "Market" and "Production" groups respectively. Entity "Family 2" plays "Buyer" and "Producer" and "Carrier" roles within "Market", "Production" and "Transport" groups respectively.

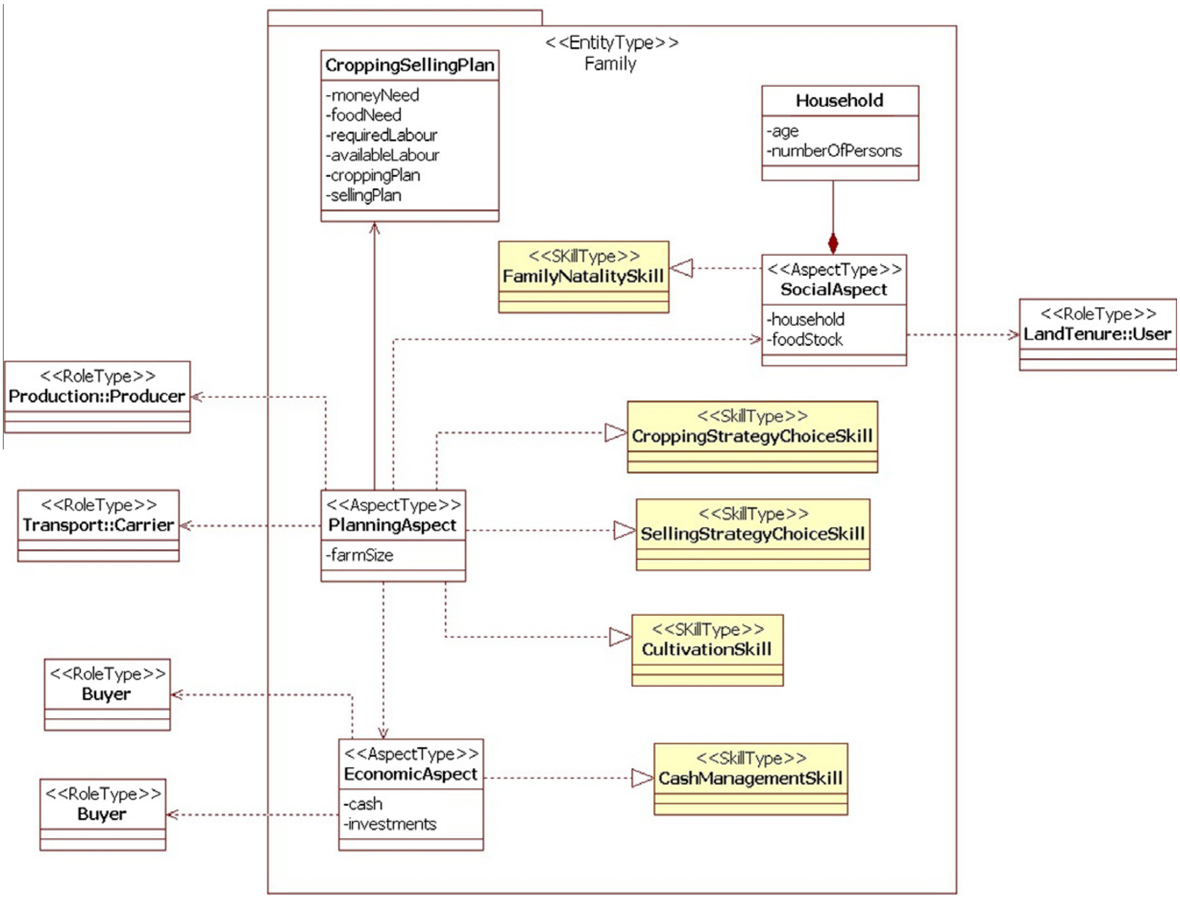

Fig. 11. The structure of "Family" entity.

6.1. Organization-centered multi-agents systems models

OREA is based on Organization-centered multi-agents systems (OCMAS). Several OCMAS models exist in the literature. They can be classified according to the problem they aim to resolve and their structure. According to their objective, there

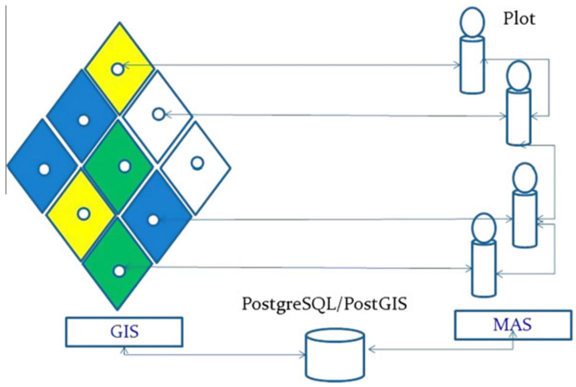

Fig. 12. Dynamic GIS coupling in CaTMAS.

are three categories of models intending (1) to the decomposition of a system into sub-systems [31,32], (2) to the coordination and collective tasks execution in MAS [33,34] and (3) to the design of opened systems [35,36]. According to their structure, we have three categories of models: (1) role-based models intending to propose an organizational model and to take into account heterogeneity and modularity in MAS [15,32,37], (2) component-based models very closed to software engineering intending to increase the reuse and modularity in MAS specification and (3) models coupling the two first approaches [24].

OREA aims to the decomposition of a system into organizations where each organization can be viewed as a sub-system. The decomposition of system into sub-systems reduces the complexity of a system and makes easy its understanding. This helps to tackle complexity because it limits the designer's scope; at any given instant only a portion of the problem needs to be considered [19]. A component-based approach is used as in MOCA model [24]. Component-based approach provides robustness, flexibility, modularity in model development and allows reuse of model structure. Thank to the use of component-based approach, the decomposition in OREA concerns both organization and entity internal structure. The decomposition of entities internal structure into components allows specifying how the behavior of entities evolve dynamically according to the context. In OREA, an entity can add or remove dynamically aspects, roles or competences components that specify its behavior. Then, the fact that aspects – that represent entities properties and behavior – are defined as components makes it possible to specify that only entities with some properties can handle some behavior. For example, the behavior of water depends on its state (liquid, solid and gas). Using different aspects representing each state of water makes it possible to specify easily how water behavior evolves according to the change in its state.

Unlike most existing OCMAS models, OREA allows an explicit separation between entities structure and organizational structure, the integration of environment within organization and multi-formalism specification.

6.2. Separation between entity structure and organizational structure

The first principle of OCMAS [20] introduces a distinction between the "how" from the "what". It means that the role describes the expected behavior of an agent within an organization and not how it is achieved as long as the function of the role is conserved. Therefore, the question is how the actual performance of the role is related to the role specification. Most OCMAS fail to separate explicitly the "what" from the "how". The Gaia model [32] defines a role as an abstract description of the agents' function. At the design stage, the notion of role is not taken into account. The AGR [15] methodology defines a role as an abstract function of an agent in a group. Accordingly no assumption is made on the agent architecture as long as the function is fulfilled. Actually, in the AGR implementation: MadKit, the roles are just represented as labels and nothing is done to enforce any role specification. In Role-Interactions-Organization (RIO) model [38] and MOCA [24], role is both external towards the group and internal towards the agent. A role describes in part both the agents' mental properties and behavior related to it. In addition, in both these approaches, there is a one-to-one correspondence between the "what" and the "how", i.e. each role is achieved by one and only one way by an agent component. Therefore there is no reason to distinguish "what" and "how" as is explained in [24].

In OREA, we have taken into account the separation of concerns between the "what" and the "how" seriously by distinguishing between (1) the decomposition of an organization into functional roles from an external and global point of view, and (2) the decomposition of an agent into aspects from internal point of view. Role in OREA defines the functional aspects of the entities, but it does not specify how this functional aspect is achieved by entities. Aspect defines the non-functional features specifying how entities may behave, make decision and achieve roles. In addition, aspect is used to specify how different entity types play differently the same role type.

The separation between the "what" and the "how" in OREA can be viewed as a distinction between the mind and the body. The mind concerns the internal structure of the entities and the body defines the manifestation of the entity in the environment [39,40]. While the mind description is provided by the entity, the environment provides the body description. The distinction between the mind and the body allows a modular implementation of a system, the autonomy of entities and preserves the integrity of the system both at the local and environment levels. While the entity controls its own features, the environment controls the dynamics at global level. In many OCMAS models, the distinction between the mind and the body is not clear due to the fact the "what" and the "how" are not clearly separated.

The distinction between the mind and the body in OREA has been possible thank to the explicit separation between the organization behavior and the local behavior of the entity. The organizational behavior represents the manifestation of the entity in the environment, then the body and the local behavior based on the internal structure – aspects – represents the mind. Entity perceives and acts on environment, through roles that it plays within groups and makes decision through aspects.

Different agent architectures based on the distinction between the mind and the body exist in the literature [39,40]. In comparison with the agent architecture proposed by Soulié [39], the aspects in OREA represent the autonomy of agent and the representation of the environment, and roles define the perception and actions of agent on environment.

6.3. Environment and organization

Environment is an essential compound of MAS [26]. Environment constrains the agents behavior and supports their interactions. The agents perceive and modify their environment through their actions. The perception of an agent on environment can depend on its interest and therefore an object may have different roles depending on the object-agent interactions it is embedded in. For example, in an agrosystem, a farmer perceives a piece of land as a site of production while the administration perceives it as tax raising entity. For the breeder, the same piece of land can represent a pastoral site. To represent explicitly how agents perceive environment and objects according to their roles, environment and objects must be explicitly represented within organizations.

Most OCMAS do not take into account the environment and its objects within organizations preventing an explicit description of individuals perceptions on their environment depending on their roles. Parunak and O'dell [17] represent the environment as a social component in an organization. But the environment does not play roles within groups. Their proposition is only a methodology and guideline for OCMAS representation with the concepts of UML and Agent UML [41,42]. In AGRE [43], the environment is explicitly represented in MAS. AGRE is based on the idea that agents are situated in domains called spaces. A space may be physical (area) or social (AGR groups). The agents manifest in spaces through modes. A role and a body are considered as particular kind of modes specifying the agent manifestation respectively in a social space and in a physical space. Two types of world are defined: (1) the social worlds composed by sets of groups and (2) the physical worlds formed by a set of areas (geometrical spaces). An agent may belong simultaneously to a social world and to a physical world. In the social world, an agent can play several roles and belong to several groups. AGRE allows representing explicitly the environment and allows defining adequately the physical constraints. However, the objects cannot be individuated explicitly in their interactions with the agents. MASCARET [44] represents the environment as an organization in order to describe the physical activities of the objects compounding the environment. Then, to take place in an environment an agent may play roles in the physical organization. But as in AGRE, no organization being able to rely on both objects and agents can be described.

To take into account the perception of agents on their environment according to their point of view, we represent the environment and its objects as playing roles within the organization. The fact that objects play roles allows to keep distinct the core behavior of an object from the different interaction possibilities that it offers to different kinds of objects as stated by Baldoni et al. [45]. This distinction is important because objects offer services and their behavior is necessary dependant of different objects interacting with them [45].

In OREA, environment is represented as a single entity. It plays roles within groups through which it interacts with others entities (objects and agents) compounding it. The relationships between environment, objects and agents and between agents and objects are defined through the roles they play in different groups. The fact that group represents a context of interactions, a group can represent also the physical interactions between agents and environment and between agents and objects. Then, one can introduce in a model, a specific group in order to represent the physical relationships between environment and the other entities (location par example) and between entities (neighborhood relationship for example).

Representing environment as a single entity allows integrating in the same model several environments. However, OREA cannot manage the constraints related to the interactions between entities evolving in different environments. In addition, representing environment as a single entity and the use of influence-reaction model in OREA allow defining how environment controls the change in its own state independently from the activities of other entities or on the effects of their activities. Talking about the control of environment state, several agents co-evolve and act simultaneously in an environment. It is necessary for the environment to control the change in its state in presence of simultaneous influences. The use of DEVS formalism to represent the dynamics of different entities in OREA, allows defining how environment reacts to simultaneous external and internal influences.

Weyns et al. [26] identified two categories of concern related to the environment representation in MAS: concerns related to the activity of environment and concerns related to the structure of environment. The above description showed that OREA takes account the concerns related to the activity of environment:

1. communication: entities communicate among them through groups;
2. action: represented as a single entity, environment in OREA can control the change in its state on the effects on entities activities;
3. perception: environment and its objects are observables by the other entities through their roles they play within groups;
4. environmental processes: environment is represented as a single entity with its own behavior on which it has a full control.

As to concerns related to the structure of environment, OREA takes into account the follow concerns:

1. structuring: environment structures the relationships and interactions among entities in an organizational form;
2. resources: resources are represented as entities that can be perceived by agents through their roles. The fact that objects play roles within groups allows to define (1) through organizational structure the relationships between agents and resources and between resources themselves, (2) and through protocol descriptions, the possible actions that agents can drive on a resource;
3. ontology: OREA model integrates an ontology about a system through the ''ModelDescription'' component. This ontology covers the description of organizations, role types and entities structure. Entities can manipulate the ''ModelDescription'' in order to reason about the structure of the system and behaves coherently.

6.4. Multi-formalism and multi-scale simulation

With the increasing use of models in different scientists domains, the integration of models of different types to build more complex and realistic models takes more and more an important place and shows that multi-formalism simulation is the future of complex system simulation. This allows an important reduction of time and financial budget in a model building. Today, many frameworks dealing with multi-formalism simulation of complex system are proposed. One of the most relevant multi-formalism simulation frameworks concerns the Virtual Laboratory Environment (VLE) [46]. VLE is a software and an API which supports multi-modeling, simulation and analysis. VLE is based on DEVS and allows the integration of models of different types to simulate a system perceived at different scales of description. The VLE experience shows the effectiveness of DEVS to deal with multi-formalism and multi-scale simulation. In our study, we used DEVS for this purpose. But, we are concerned with the multi-formalism representation both at local level, global and environmental levels. This supposes that, they are more than one perception on a system at local, global and environmental levels and requires a relevant framework to handle these various points of view. OCMAS provide a way to describe complex systems under various points of view both at these three levels of description. Organizations can be viewed as points of view on a system at global level and roles that compose these organizations can be perceived as various points of view on agents [12,47]. Then, we integrated DEVS within organization in order to take account the multi-scale and multi-formalism simulation at local, global and environmental levels. Groups, roles and entities are implemented as DEVS atomic models with their own dynamics. Groups that compose a system at global level can be specified using different types of model to compute properties of the system at global level. At local level, the structure of a same entity type can be defined using multi-formalism approach.

7. Conclusion and further developments

This paper presented the OREA model, a model for multi-scale and multi-formalism representation and simulation of complex system. We used an approach based on a coupling of (1) the organizational approach for representing the global and local levels and (2) DEVS formalism for multi-formalism representation.

Regarding the trends in complex systems modeling today, OREA provides an effectiveness and innovative framework to tackle complexity. This because, results about OREA deal with multiple research questions in complex system modeling: articulation between local and global levels, the concerns for environment and multi-formalism simulation.

However, OREA could be improved in different ways. A complex system is composed of a set of entities in interaction. Its components can be also complex or single entities interacting between them giving to complex system an holonic aspect. Then, the representation of such systems must exhibit their holonic aspect. In addition, the organizational structure of a complex system can be dynamic. The different entities are in interactions and from their interactions, some organization can emerge at global level and constraints the entities behavior. In further, OREA could be extended to take account the holonic representation of complex system and the dynamic of organizational structure.

OREA allows integrating several environments in a same model. However, no mechanism is provided to manage the interactions between entities evolving in different environments. OREA could be improved to manage the constraints related to the interactions between entities evolving in different environments and the entities mobility across these different environments.

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