RE4Gaia: A Requirements Modeling Approach for the Development of Multi-Agent Systems*

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Abstract. This paper presents RE4Gaia, which is a requirements modeling approach for the development of multi-agent systems extending the Gaia methodology. The approach focus on dealing with the organizational structure as a means to adequately capturing and understanding required roles and associated functions, in the context of a organization, prior to the analysis and design of the MAS using Gaia. In addition, a traceability framework is introduced in order to facilitate moving from the requirements models to the analysis and design models proposed in Gaia.

Keywords: Requirements engineering, multi-agent systems, methodology, agent-oriented development.

1 Introduction

The Requirements Engineering (RE) process is recognized as being the most critical process of software development. Errors made during this process can have negative effects on the quality of the resulting software. A Multi-Agent System (MAS) is a specific type of system that is composed of multiple interacting intelligent agents used to solve problems that are difficult for an individual agent or monolithic system to solve. In the last few years, many agent-oriented methodologies [1][2][3][4][5] have been proposed to support the development of this type of systems.

Perhaps the most developed agent-oriented software engineering methodology is Gaia [2]. Gaia is based on the organizational metaphor and founded on the view of multi-agent systems as a computational organization. In Gaia, requirements are just *statements,* independent of the paradigm used for analysis and design, rather than a model oriented to capture requirements relevant to a MAS. Another drawback for Gaia, from our point of view, is the lack of explicit traceability from requirements to the artifacts produced along the MAS development. A better traceability mechanism could help to improve the overall quality of the developed software [3].

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In this work, we introduce RE4Gaia, which is a requirements modeling approach for the development of MAS extending the Gaia methodology. This approach focus on dealing with the organizational structure as a means to adequately capturing and understanding required roles and associated functions.

This paper is organized as follows. Section 2 presents the related work including characteristics of some methodologies for the development of MAS. Section 3 briefly introduces the Gaia methodology. Section 4 presents our requirements modeling proposal. Section 5 describes a case of study used to validate our approach. Finally, section 6 presents the conclusions and further work.

2 Related Work

As we presented in a previous work [3], we identified that the majority of MAS methodologies focus only on the analysis and design and do not give support to the requirements phase. This is the case of the Gaia methodology and the MASIVE [4]. Others MAS development approaches give a partial support to the requirements phase through use cases or scenarios, i.e. ROADMAP [6] or MaSE [7]. Perhaps the most developed and "well-accepted" approach in the community for dealing with the developing of MAS is Tropos [8]. Tropos is based on the i* framework following a goal-oriented approach. This fact reveals that there is a dearth of alternative methods and techniques for appropriately dealing with requirements for MAS development [3]. Moreover, most of the alternative requirements methodologies are focused in understanding the problem domain and communicate requirements among stakeholders. They lack traceability mechanisms to trace this requirements information towards analysis and design artifacts and backward. We believe that this fact is an important issue that constraints a wider use of these alternative proposals.

In summary, there are many attempts to provide techniques and methods to deal with some aspects of the RE process. However, there is a lack of solutions that allow developers to go systematically from well-defined requirements models to design models in a guided or automated way.

3 The Gaia Methodology

Gaia is a methodology with the purpose of guide the design of open systems using organizational concepts. Gaia is tailored the analysis and design of MAS. We describe only the analysis phase, which is directly related to our proposal.

This phase starts with the definitions of the *global organization goal*. It includes the decomposition of the global organization into sub-organizations. The next step is to build the *environmental model*. This model list all resources that one agent can access. The resources are represented as variables or tuples, where one agent can do three types of actions: sensing, effecting or consuming. The *preliminary role model* is build to capture the basic skills. In this model, a role is represented is represented with an abstract and semiformal description. There are two types of attributes to describe a role: *permissions* and *responsibilities*. The permissions are used to identify the

resources accessed by the role and establish the limits for the role. The responsibilities are used to indicate the expected behavior of a role. They are divided in two types: liveness properties and safety properties. The *preliminary interaction model* determines dependencies and interaction between roles through protocols. The protocol is defined with a set of attributes: name, initiator role or roles, partner role or roles, inputs, outputs and a description to explain the purpose of the protocol. Finally, the organizational rules represent the responsibilities of the organization. They are two types of *organizational rules*: liveness rules and safety rules.

4 The Requirements Modeling Approach

The proposed requirements modeling approach (Figure 1) is aimed to deal with the organizational structure as a means to adequately capturing and understanding required roles and associated functions. It includes: i) A *Requirements Modeling Phase*. ii) *A Requirement Analysis Process*.

4.1 Requirements Modeling

The goal of the Requirements Model is to gather and represent the software requirements. This phase starts defining the Mission Statement (MS), the Functional Refinement Tree (FRT), the Requirements Role Model (RRM), and the Domain Model (DM). The MS set the goals of the global organization. The FRT helps to determine the sub-organizations forming the global organization and it participant roles. The RRM is used to detect intheritance relations between role and reason about their structural relationships, detecting possible inconsistencies. Finally the DM is used detect the entities that could be possible organizational resources.

The **Mission Statement** is the most general service (the main goal) that the system to be developed provides to its environment [13]. It is written in natural language with typically one or two paragraphs.

The **Functional Refinement Tree** is used to represent a hierarchical decomposition of the business functions independently of the software system structure. We put in the root of this tree the MS and then is successively refined looking for the functions of the system that are represented as leaf nodes in the FRT. In this process, we can find several levels. The nodes between the root and the leaf nodes are *intermediate nodes*. We distinguish two levels: i) *first*, we find sub-organizations. A sub-organization is part of the system which is oriented to achieve a goal in the system and that weakly interacts with other parts of the systems; ii) *second*, we find that sub-organizations are decomposed into roles. A role is a representation of an abstract entity that provides (several) functions for the system. A function is a task performed by a role in the organization independently if it needs to collaborate with other roles or not.

The **Requirements Role Model** describes the roles belonging to sub-organizations from the FRT. The purpose of this model is to represent the different roles discovered in the organization and create a hierarchy of roles using an inheritance relationship. In order to graphically represent this information, we use the UML Use Case diagram showing only the roles as actors, labeled with the stereotype «*role*», and the relationships among them. An example is shown in Figure 2 (b).

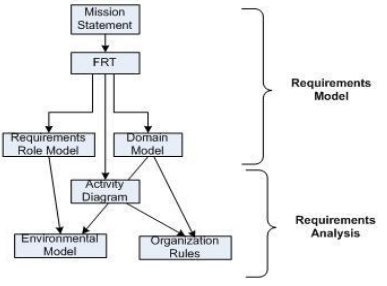


Fig. 1. Overview of RE4Gaia models and their relations

The **Domain Model** shows entities identified in the problem domain. The purpose is to gather key concepts and their relationships depicting a first structural view. These entities must make sense in the application domain. In addition, we represent associations among domain entities and inheritance relationships. In order to graphically represent all these information, we use the UML Class diagram as show the Figure 2 (a).

4.2 Requirements Analysis

The Requirements Analysis Process takes as input the identified functions in the FRT and decomposes them into: tasks and protocols with the help of the Activity Diagram (AD). Moreover, the AD is used to understand the internal flow of one role in order to determine its responsibilities into the Gaia role model. Next, we identify the resources (Environmental Model) refining the entities discovered into the DM. Once we have the internal task and protocols of a role and his accessed resources, we define the organizational rules to define the behavior and restrictions of the organization.

The **Activity Diagram** shows a sequence of steps showing a workflow necessary to realize the identified functions. A representation of the task flow can be useful to understand the logical flow of one role; helping to identify when a role needs to collaborate with others roles. Some guidelines regarding AD are: i) It's necessary to build at least one AD for each sub-organization identified in the FRT; ii) We suggest building one AD for each role that is the initiator of other protocols; iii) We create at least one Activity Partition. Each partition models the role logical flow. We suggest that the left partition is used for the role that starts the protocol. The others partitions represent the other roles that interacts with the initiator role; iv) If we identify that the role needs to interact with other roles, then we add a new activity partitions in the diagram.

The **Environmental Model** is a set of tuples with the following structure: <*role, resource, permission*>. For each **role** from the AM, we set the rightful resources accessed by the role. The information extracted from the AD will help to the analyst to identify which **resources** are accessed. Finally, we set the **permission** type for access to the resource between three types: *read*, *write,* and *consuming*.

Table 1. Excerpt of a FRT for the Settlement sub-organization

Sub-organization	Role	Function
Settlement	Buyer	Purchase good
		Take good away
	Buyer Manager	Update credit
		Send Buyer List
		Send result verify credit
		Sanction buyer
	Seller Manager	Update the credit

The last step in the Requirement Analysis phase is to define the **Organizational Rules**. They are written in natural language with the purpose to gather and represent general constraints for the Organizational behavior. These rules can be viewed as responsibilities of the organization as a whole and can be related to i) *Organization dynamics properties*, defining how should evolve the organization; ii) *Organization constraints*, defining restrictions that the organization must respect in every time.

5 Case Study

We introduce a case of study for an Auction System for a Fish Market. This case study was proposed in [14] and we adapted it in order to illustrate our proposal. The complete specification of the case study can be found at: http://www.dsic.upv.es/~einsfran/RE4Gaia/casestudy.html.

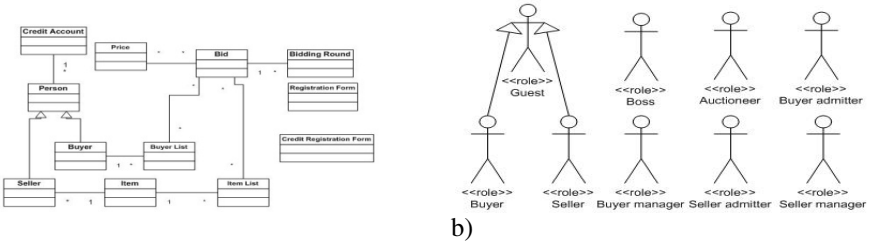
The first phase is the **Admission**. Here the guest can create a buyer account and the existing users can validate their credits. Meanwhile the buyers performs the admission, the sellers bring the goods. For each good the seller's admitter employed fix: the weight, the fish quality and the price and send the good list the Auctioneer. The second stage is the **Auction**, where auctioneer starts a new bidding round. He sends to each buyer: the list of buyers taking part in the round, the list of goods, and the next good to be auctioned. After that, the auctioneer starts broadcasting prices to all buyers in the auction room. The buyers bids for the goods offered by the auctioneer. When one good is sold, then the owner is informed of the new sale. The seller's earnings are updated. Finally In the **Settlements** buyers can collect a statement describing their purchases and pay them up, whereas sellers may collect their earnings at the settlements office once their lot of goods has been sold.

Applying our approach, we firstly build the ***Requirements Model***. The first step is to define the **Mission Statement**. The mission of the Fish Market system is to *automate the management of admission, register the incoming bids, give support to the Auction process and manage the sale of goods*. The next step is to build the **Functional Refinement Tree.** Table 1 represents an excerpt of the FRT showing the branch of the sub-organization Settlement (in a tabular format). The Buyer role does the functions Purchase good and Take good away. The Buyer Manager role does the functions: Update credit, Send Buyer List, Send result, Verify credit, and Sanction Buyer. Finally, the Seller Manager role does the Update credit task. Regarding the **Requirements Role Model**, we identified the following roles: *Guest, Buyer, Seller, Boss, Buyer Manager, Auctioneer, Seller Admitter, Buyer Admitter and Seller Manager*. There is an inheritance from *Buyer* and *Seller* roles to the *Guest*, representing

the fact that everything that can be done by a *Guest* can also be done by a *Buyer* or by a *Seller*. This information is shown in Figure 2 (b). The main domain entities and relationships found are represented in Figure 2 (a). We identify a Person entity that shares common properties with the *Seller* and *Buyer*. A *Buyer List* is related to multiple Buyers, and an Item List is related to multiple Items. An Item belongs to one *Seller*, and a *Bidding Round* is composed by multiple *Bids*. Each *Bid* has *Buyer List*, multiple *Prices* and one *Item List* associated.

Secondly, we apply the ***Requirement Analysis Process***. This phase starts with the construction of the **Activity Diagrams**. In order to analyze the Settlement sub-organization, we should use build one AD for each role with proactive behavior, in this case: *Buyer* and *Seller*. Figure 3 shows the AD for the *Buyer* role. The *Buyer* when joining in the scenario can start the *Purchase*. When the *Buyer* finishes the protocol *Purchase*, then he exits from the scenario. In the other partition, Auctioneer, is the *Buyer Manager*, which is waiting for the *Purchase* protocol requests. The role checks if the *Buyer* role has enough credit. If it is true then the *Update Credit* task is performed, otherwise it starts the *Bad Credit* protocol to communicate a "bad purchase" to the Auctioneer role. For each role identified in the FRT, and also specified in the RRM, we set the resources with permission granted to the role to consider inheritance relationships. Table 2 shows a partial view of this model, representing two roles: *Auctioneer* and *Buyer Manager*.

Finally, we have the following organizational rules for our case study: i) One buyer must be registered before joining the auction; ii) One buyer cannot join in the settlement if he is not a bid winner; ii) The Auctioneer must wait if there not enough goods to auction; iv) The Auctioneer must wait if there are not enough buyers.



a) b)

Fig. 2. a) Domain Model; **b)** Requirements Role Model

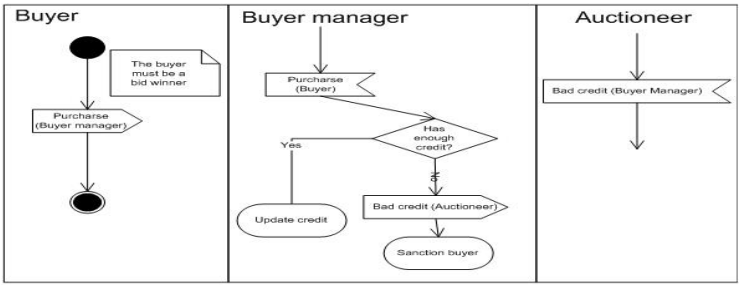


Fig. 3. Activity Diagram for the Buyer role in the Settlement sub-organization

5.1 Traceability Framework

In this section, due to space limitations, we briefly outline the traceability strategy. This traceability framework can be viewed from two perspectives: i) *inner,* which refers to the links established between elements in RE4Gaia; ii) outer, which refers to the links established between elements in RE4Gaia and the Gaia analysis models.

Related to the **inner** traceability, the main relationships are: i) The MS is related to sub-organizations identified in the FRT; ii) Each role identified in the FRT (and specified in the RRM) is related to its corresponding sub-organization in the FRT, iii) Each role identified in the FRT (and specified in the RRM) is related to one role into the EM, iv) Each entity identified in the DM is related to one resource into the EM. The user decides with which roles is related the resource and with which permissions have access granted; v) Each function in the FRT is related to a task or protocol in the AD, depending if the functions needs collaboration with others roles.

Related to the **outer** traceability, the main relationships are: i) Each resource from the EM is related to one resource in Gaia. As at this level the EM is preliminary, new resources can be identified at the Gaia analysis. The permissions are mapped for each role can access to the resource; ii) Each role identified in the RRM is related to a role in the Gaia Role Model. The information extracted from the AD helps to the user to fill the liveness, and safety properties; iii) Each task or protocol identified into the AD is related to one task or protocol in the Gaia Role Model, giving relevant information that is needed to specify in detail during the analysis and design; iv) The organizational rules in natural language are mapped to organization rules in the Gaia methodology. The user can decided if is converted into a liveness o safety rule.

Table 2. Partial Environment Model

Role	Resource	Permission
Auctioneer	Bid	Modify
	Bidding Round	Modify
	Price	Modify
Buyer Manager	Account	Read
	Buyer List	Modify

6 Conclusions and Further Work

We have presented a Requirements Modeling approach extending the Gaia methodology. The approach deals with the organizational structure as a means to adequately capturing and understanding required roles and associated functions, in the context of an organization prior to the analysis and design using Gaia. We believe that our approach fills the gap in the development of MAS providing a systematic approach to deal with requirements establishing better traceability mechanisms that help analysts to meet user needs, improve their understanding of the systems, facilitate the maintainability of produced artifacts, and improve the overall quality of the developed software.

Currently, we are applying the requirements modeling approach for the specification of other MAS with the intention to study the expressiveness and transformation

capacities of our requirements models. We plan to perform controlled experiments with PhD students in order to empirically validate the effectiveness of our method. We are also working in the development of a tool using the Eclipse framework to implement the proposed approach. This tool will allow us to follow a model-driven development approach including model2model transformations from RE4Gaia models to Gaia models.

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