iStar4RationalAgents: Modeling Requirements of Multi-Agent Systems with Rational Agents

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Abstract. Multi-agent systems (MAS) involve a wide variety of agents that interact with each other to achieve their goals. Usually, the agents in a MAS can be reactive or proactive, this choice defines the rationale of its elements. Rational Agents is the term used to mention a set of four kinds of reactive and proactive agents. Conceptual models which represent the rational agents' intentionality can be used to design and analyze MAS in a systematic and structured manner. Conceptual modelling can be used to uncover mistakes and gaps in reasoning that are missed or obscured via ad hoc evaluation. However, the modelling of MAS with different rational agents is a non-trivial task, due to the specificity of their domain concepts, also at requirements level. This paper presents an approach to model MAS with rational agents in requirements level using iStar. This is part of a Model-Driven Development approach which has been proposed to support the development of MAS with rational agents involving requirements, architecture, code and test. We extended iStar to support the modelling of main concepts of this domain in a systematic way based on a process to conduct iStar extensions. We modelled a MAS to validate and illustrate the usage of our extension and evaluate the results using a survey with experienced researchers/developers in MAS.

Keywords: Multi-agent system, Rational agents, Modeling, iStar.

1 Introduction

Autonomous software based on artificial intelligence (AI) have been widely applied to solve a vast set of problems in companies. In this context, agents are complex entities with behavioral properties, such as autonomy and interaction [7]. Multi-agent system (MAS) is the area of AI that investigates the behavior of a set of autonomous agents, aiming to resolve a problem beyond the capacity of a single agent [7].

A simple agent can act based on reactive or proactive behavior and can be classified according to its internal architecture that determines distinct agency properties, attributes and mental components [11]. Russell and Norvig [11] define four types of agents according to their internal structure: Simple Reflex Agent, Model-Based Reflex Agent, Goal-based Agent and Utility-Based Agent. The type of agent is selected according to the environment characteristics and to the subproblem that the agent will resolve. A MAS may encompass multiple types of agents [11].

A model-driven approach has been proposed to model MAS with rational agents. Modelling of the architectural level of MAS with rational agents is supported by MAS-ML 2.0 [3], the code generation is supported by the approach proposed by [9] and the test is supported by the proposal of [12]. Therefore, it is important a proposal of modelling at requirements level to complete the support of the development of MAS with rational agents. The modelling of requirements for a multi-agent system can be preferably an extension of a known and trusted modelling language, such as iStar [14]. We have chosen iStar since it supports the modeling of part of the concepts of MAS with rational agents such as goal, belief, agent, tasks and supports the modeling of organizational concepts as well. This language has a process to conduct iStar extensions (PRISE[1]) which makes it easy the proposal of new iStar extensions.

The aim of this paper is to present an iStar extension to model MAS with rational agents named iStar4RationalAgents. The paper is structured as follows. Section 2 presents the main concepts of MAS. Section 3 presents related work. iStar4RationalAgents is described in Section 4. In Section 5 shows the modelling of the MAS to support the distance education course of programming people with disabilities. The evaluation of MAS is presented in Section 6. Finally, conclusions and future work are discussed in Section 7.

2 Background

According to Silva et al. [13], organization is an element that groups agents and sub-organizations. Environment is an element that is the habitat for agents, objects and organizations. Environment has state and behavior. Agent is an autonomous, adaptive and interactive element. MAS-ML defines an agent composed of beliefs, goals, plan and actions. On the other hand, the agent internal structures can be categorized based on proactive and reactive foundations. In this context, four types of internal agent architectures were defined by Russell and Norvig [11].

Simple Reflex Agents. A Simple Reflex (or reactive) Agent [11] selects actions based on the current perception. These perceptions consist of the representation of state aspects that are used by the agent for making decisions. **Model-Based Reflex Agents** have condition-action rules as well. This agent is also able to store its current state in an internal model (beliefs). A function called next function is introduced to map the perceptions and the current internal state into a new internal state used to select the next action. **Goal-Based Agents**. Goal-Based Agents set a specific goal and select the actions that lead to that goal. Planning activity is devoted to find the sequence of actions that is able to achieve the agent's goals [11]. The sequence of actions previously established that leads the agent to reach a goal is a termed plan [13]. Thus, the Goal-Based Agent with planning involves the next function component and also includes the following elements: *Formulate goal function*, which receives the state and returns the

[1] http://www.cin.ufpe.br/~ler/prise

formulated goal; *Formulate problem function*, which receives the state and the goal and returns the problem; *Planning*, which receives the problem and uses search and/or logic approaches to find a sequence of actions to achieve a goal; and *Action*. **Utility-Based Agents**. Considering the existence of multiple goal states, it is possible to define a measure of how desirable a particular state is. In this case, aiming to optimize the agent performance, the utility function is responsible for mapping a possible state (or group of states) to that measure, according to the current goals [11]. Thus, the utility function is incorporated into the architecture. Also, Utility-Based Agent preserves the same elements as those of a Goal-Based Agent: next function, formulate goal function, formulate problem function, planning and action.

3 Related Work

Our paper is part of an MDD approach to develop MAS with rational agents. In [3], an extension to MAS-ML (Multi-Agent Systems Modeling Language [13]) to model MAS with rational agents in the architectural level is presented. Complementary, an extension was proposed to JADE framework to support the development of rational agents and other MAS entities such as organization, environment and agent roles [9]. In addition, the code generation from MAS-ML models was created by MAS-ML tool to the JADE extended version. Finally, in [12] an agent-based approach was proposed to select test cases and test the performance of rational agent. These works cover a great part of the software development life cycle, but the requirements level is not covered by them. Also, PRISE (**PR**ocess to conduct **iS**tar **E**xtensions) has been proposed. It is based on a Systematic Literature Review (SLR) of iStar extensions [2] and interviews and survey with experts [5]. PRISE is supported by a catalogue of iStar extensions [4] and a tool for the creation of PRISE artefacts [6]. This paper presents a new iStar extension that followed the PRISE approach.

4 Extending iStar for Model Rational Agents

We represented the extension in the iStar metamodel and created validation rules. The extension metamodel and validation rules are available[2]. We represented each kind of rational agent and their roles in the metamodel by stereotypes (simple-reflex, model-based-reflex, goal-based and utility-based) associated with Agent and AgentRole metaclasses. MAS-ML agent is represented by an agent without any additional stereotype. Organization, Environment, Planning, Plan and Perception are represented by new metaclasses. Therefore, Belief, a metaclass that was removed in iStar 2.0, was added as an intentional element again. We represented the stereotypes to represent of next-function, formulate-problem, formulate-goal and utility-function and action. The relationship *neededby* was extended to link beliefs and next-function tasks. The Cause/effect was included to connect perception and Action (*Task* metaclass) and

[2] www.cin.ufpe.br/~ler/iStar4rationalagents/metamodel&rules

connect next-function and action (*Task* metaclass). Finally, we created a set of validation rules to analyze the well-formedness of the four kinds of agents and roles.

4.1 Representing the extension constructs in the concrete syntax

The representations of the extension concepts can be classified into three groups:

1. **Constructs represented by iStar constructs as proposed:** five domain concepts are represented by the iStar constructs. They are used to represent an agent being part of an organization, an agent inhabiting an environment, an organization inhabiting an environment, an agent playing a role in an organization which inhabits an environment and a dependency between an agent and an environment. Furthermore, we extended the *neededby* relationship to connect next-function and beliefs establishing that beliefs are needed by the next-function;
2. **Constructs represented by iStar constructs added with textual markers:** These constructs have a similar meaning of the iStar constructs and specialize them by textual markers. They are four stereotypes (<<simple-reflex>>, <<model-based-reflex>>, <<goal-based>> and <<utility-based>>) applied to agents or agent roles, <<action>> and the specific functions (<<next-function>>, <<formulate-problem>>, <<formulate-goal>> and <<utility-function>>) applied to task. When an action is represented inside the agent roles, it can be defined as a right (an action that can be executed) using the property {type='right'} or a duty (an action that should be executed) using the property {type='duty'}.
3. **Constructs represented by new graphical representations of iStar:** we found the Plan in an existing iStar extension and reused it. Four concepts (Environment, Organization, Perception and Planning) are represented by new symbols. Thus, the new symbols proposed to these four concepts were created using an experiment based on the work of Caire et al. [1]. We performed a five-step experiment with 152 participants. All steps of this experiment are available[3]. Fig. 1 presents the final graphical representations of this experiment, used by the extension.

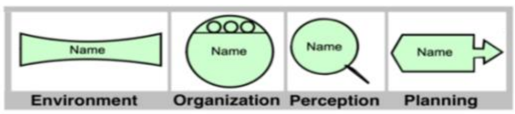

Fig. 1. Symbols related to Environment, Organization, Perception and Planning.

4.2 How to use the Extension

The iStar SD model should be created to represent the MAS concepts. An agent can play a role, inhabit an environment and be part of an organization (Ownership). These relationships are represented by the iStar link participates-in. The dependencies between agents, roles, organizations and environment can be expressed too. Fig. 2 shows an agent playing a role (i), an agent being part of an organization (ii), an agent inhabiting an environment (iii), an organization inhabiting an environment (iv), an agent playing a role in an organization which inhabits an environment (v) and a

[3] www.cin.ufpe.br/~ler/iStar4rationalagents/experiment-representations

dependency between an agent and an environment. We used simple-reflex agents and roles, these links can be used with all kinds of agents.

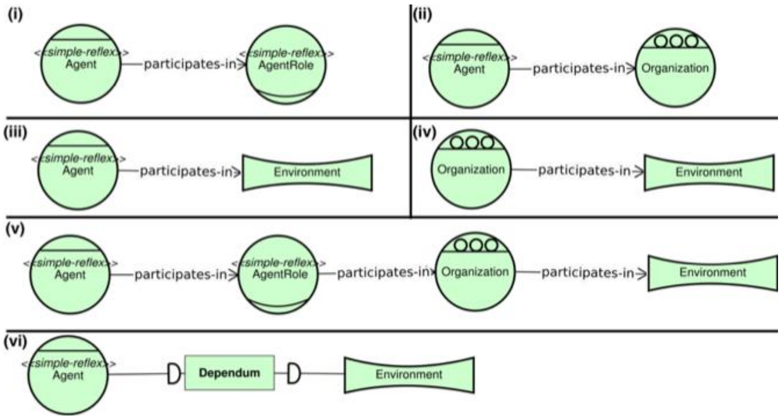

Fig. 2. Generic representations of new constructs in SD model.

Moreover, the SR model should be created to represent the internal details of the agents, roles, organizations and environments involved in the Multiagent System, and representing the relationship between them. The SD model is the starting point to the creation of this model. In our approach, we consider the modelling of the agents' intentional elements as a refinement of their internal elements, similar to the approach used by Mouratidis and Giorgini [10].

The boundaries of the agents should be detailed regarding their intentional elements. The kind of agent defined by MAS-ML is represented by an agent without any stereotype and its boundary is composed of goals, beliefs, plans and actions (i). In the reflex agents (Simple reflex (ii) and Model-based simple reflex (iii)), the perceptions and actions (and next-function in case of model-based reflex agents) should be related by the refinement link with the action as the source. Goals of the goal-based (iv) agents are decomposed on perceptions (which are decomposed on next-function) and planning (which are decomposed into actions). The same to utility-agents (v), but these ones have a utility-function related to the planning by an and-refinement. The beliefs are represented by a *neededby* link connecting a belief and next-function. Fig. 3 presents an example of the usage of agents on an SR diagram.

The boundaries of roles related to goal-based and utility agents and kind of agent defined by MAS-ML should represent goals, beliefs and actions related to the role. The boundary of roles of model-based-reflex agents should contain beliefs and actions related to the role and the roles of simple-reflex agents should contain actions related to the role. The actions in roles related to agents should have the information about which of them are mandatory (duty) and which are optional (right). Fig. 3 presents an example of the usage of agents on SR diagram. In addition, environment and organization can be composed of the original iStar nodes and links, an example of environment and organization is presented in Fig. 3.

We created the pistar4rationalagents tool[4] to support the usage of our extension.

5 A MAS Support Programing Courses in Distance Education

We modelled a MOODLE MAS with our extension. The modeling of SD-extended diagram is available[5]. Fig. 3 shows part of the SR diagram to MOODLE MAS. The complete version is available[6]. Additionally, the MAS presented in these models were designed at the architectural level, coded, tested and deployed at Brazilian Open University, and Universidade Estadual do Ceará.

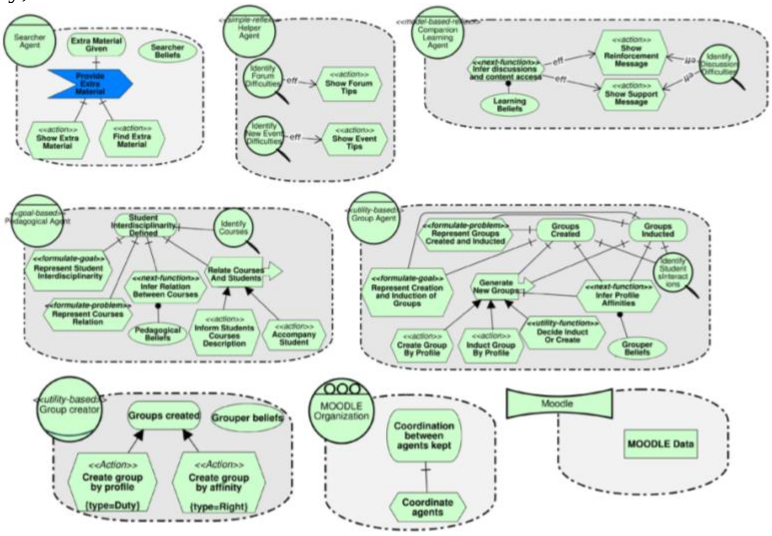

Fig. 3. Agents, Agent Role, Organization and Environment in iStar SR model to MOODLE.

6 Evaluation by experienced researchers

The purpose of this evaluation is to identify the point of view of the researchers in MAS about our extension by a survey [8]. The universe of this research consists of authors of papers of the last 5 editions of Brazilian events such as WESAAC, AUTOSOFT and BRACIS. Thus, we contacted 164 researchers from 37 different universities/companies. We received a total of 22 responses from 13 universities and 3 companies. 9 mentioned having advanced knowledge on MAS, 9 intermediate knowledge and 4 emerging. The structure of this survey is available[7]. It was submitted between December 2018 and February 2019. Data of this survey is also available[8].

[4] https://www.cin.ufpe.br/~ler/piStar4rationalagents/
[5] www.cin.ufpe.br/~ler/iStar4rationalagents/sdmoodle
[6] www.cin.ufpe.br/~ler/iStar4rationalagents/srmoodle
[7] https://www.cin.ufpe.br/~ler/iStar4rationalagents/evaluationsurvey
[8] www.cin.ufpe.br/~ler/iStar4rationalagents/data

We compared the perception of the participants about the modelling of the MAS using iStar and the iStar extension. The extension improved the perception of the MAS constructs. We also analyzed the difficulty level perceived by the participants to identify the MAS entities and internal nodes and links. The extension reduced the difficulty level to identify MAS elements in about 50% (see Table 1).

Table 1. Comparative of correct identification and difficult level.

Criteria	without extension	with extension
1. Correct identification of MAS entities (Agents, agent role, environment and organization)	47.12%	80.1%
2. Correct identification of MAS internal nodes and links (plan, planning, action, next-function…)	20.7%	62%
3. Difficulty level to identify MAS entities (mean -scale 0-10)	6.3	2.9
4. Difficulty level to identify MAS internal nodes and links (mean -scale 0-10)	7.5	3.8

The participants were also asked about the strong points and weaknesses of the approach. A great part of the participants (13/22 – 59%) recognized that the extension facilitates the identification of MAS entities and their internal elements. The weakness mentioned by two participants was that, with the extension, new concepts are represented in iStar and there is the need to learn and represent these elements in the models. We believe it is a general consequence of all extensions.

6.1 Threats to validity

According to Kitchenham and Pfleeger [8], there are four validity aspects to consider: Criterion, Construct, Face and Content. **Criterion validity:** We did not find a previous quantitative study for this purpose. Thus, we could not compare this evaluation with previous ones. **Construct validity:** We created the survey with different kind of questions: Likert scale questions, measure effort, yes/no/maybe question, open questions and multiple-choice relation questions. Thus, it could confuse the execution of it by the participants. We mitigated this threat presenting an explanation of the kind of questions at the beginning of the survey. **Face validity:** We tested the survey with a computer science professor with experience in MAS. We can consider this previous evaluation a limitation because of the small number of participants (1). We mitigated this threat, however, by asking him to evaluate again after the corrections of his comments. **Content validity:** We consider the profile of the participants suitable for this evaluation since the majority of the participants (18/22) mentioned having advanced/intermediate expertise in MAS. However, there were not a great number of participants with expertise in modelling (~50%). We tried to mitigate this threat presenting iStar in part of the survey.

7 Conclusions

In this paper, we presented the main results of an approach to model MAS with rational agents in requirements level with an extended version of iStar. We followed PRISE, a

process to conduct iStar extensions, during our proposal. We represented the constructs as a set of stereotypes and four new symbols proposed by an experiment similar to the presented by Caire et al. [1]. This approach is supported by piStar4rationalagents tool. We illustrated our proposal by modelling of a MAS with rational agents in a distance education course offered using MOODLE. We modeled a MAS with 5 different kinds of agents, agent roles, organization and environment. Finally, our proposal was evaluated by experienced MAS researchers/developers using a survey. We identified that the extension can ease the identification of these kinds of agents and their elements and can make the interpretation of the diagrams better than using standard iStar. The participants agreed that the proposal of an extension is useful to fill a lack of techniques to represent the MAS with rational agents, the representations of the constructs were considered good and the extension could be useful to model their next MAS.
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