Requirements Engineering in the Development of Multi-Agent Systems: A Systematic Review

David Blanes, Emilio Insfran, Silvia Abrahão
ISSI Research Group, Department of Information Systems and Computation
Universidad Politécnica de Valencia
Camino de Vera, s/n, 46022, Valencia, Spain
dablado@posgrado.upv.es, {einsfran, sabrahao}@dsic.upv.es

Abstract. The goal of this paper is to investigate which requirements engineering techniques have been applied in the development of Multi-Agent Systems (MAS) and how they were applied. We performed a systematic review of 58 of a total of 835 papers found in scientific digital libraries. The results show that most of the proposals for dealing with requirements (79%) use already defined methods or techniques from other software development paradigms and that 69% of these techniques are based on the goal-oriented paradigm. A total of 95% of the reviewed papers focus on techniques for analyzing requirements, and only 45% of them explicitly consider some type of elicitation technique. Finally, only 5% of the papers give some empirical evidence about the effectiveness of their approaches by conducting empirical studies. The results of our study are particularly important in the determination of current research activities in Requirements Engineering for MAS and in the identification of research gaps for further investigation.

Keywords: requirements engineering, multi-agent systems, systematic review.

1 Introduction

In order to meet customer needs, the Requirements Engineering (RE) activity plays a key role in software development. General approaches for identifying, modeling, and analyzing user requirements for specific types of software systems may not be totally effective. A Multi-Agent System (MAS) is a specific system that is composed of multiple interacting intelligent agents. These systems can be used to solve problems that are difficult or impossible for an individual agent or monolithic system to solve.

Agent-oriented software engineering (AOSE) has emerged as a new software development paradigm and new methodologies for developing MAS have been proposed to guide the software development process. These methodologies are influenced by different fields such as Psychology, Biology, and Social Science [1]. This variability makes necessary classification of the methodologies according the employed techniques. Although there are some publications that compare MAS methodologies, there is a lack of specific studies focusing on RE methods, techniques, and notations applied in MAS development. In [2], we shortly reported results of a first study on this topic considering three criteria for analyzing published research work and two digital libraries (ACM DL and IEEExplore).

In this paper, we present a systematic review to determine the current research activity in Requirements Engineering for MAS development taking as primary source four digital libraries (ACM DL, IEEExplore, Inspect, and Science Direct). A systematic literature review is a means of identifying, evaluating, and interpreting all the available research that is relevant to a particular research question, topic area, or phenomenon of interest [3]. This document is organized as follows. Section 2 discusses related works about comparing MAS methodologies. Section 3 describes the method used in this work to analyze existent works about MAS and requirements engineering. Section 4 presents the results obtained in the systematic review. Finally, section 5 presents the conclusions and further work.

2 Related Work

Systematic literature reviews have been successfully applied in many fields of software engineering (e.g., RE [4], web engineering [5]). However, in the AOSE field, most of the studies are informal literature reviews with subjective comparison criteria, some of which only include a small number of methodologies and techniques, concepts, or notations for RE applied to MAS development.

Included in these reviews Henderson-Sellers and Gorton [6], depict a genealogy of many of the current AOSE methodologies. This work classifies AOSE methodologies in: i) independent of object-oriented methodologies; and ii) extension of existing object-oriented methodologies to give support to agent concepts. In a similar manner, Sudeikat [7] depicts a genealogy with three possible ancestors for AOSE methodologies: object–orientation, knowledge engineering, and RE. This work also proposes a comparison framework with four selection groups: concepts, notations, process and pragmatics. In [8], Silva et al. propose a novel approach to compare AOSE methodologies using a Non-Functional Requirements (NFR) framework. In [9], Cernuzzi makes a classification of many AOSE methodologies according to the life cycle adopted.

3 Research Method

In order to provide a more objective approach for systematic exploration, we follow the approach presented in [3] for systematic literature review. The activities involved in a systematic review can be grouped in three phases: planning, conducting, and reporting. In the *planning* stage, the need for the review is identified, the research questions are specified, and the review protocol is defined. In the *conducting* stage, the primary studies are selected, the quality assessment is defined, the data extraction and monitoring are performed, and the obtained data is synthesized. Finally, in the *reporting* stage, the dissemination mechanisms are specified, and the review report is presented. The activities concerning the planning and conducting are described in the following subsections of Section 3, and the reporting is presented in Section 4.

3.1 The Research Questions

The goal of our review is to study the current development work on MAS by answering the following Research Question: "*What requirements engineering techniques are applied to give support to the requirements engineering activity in the development of MAS and how they are applied?*"

This research question will allow us to summarize the current knowledge about the use of RE techniques in the development of MAS and to identify gaps in current research to suggest areas for further investigation or to propose smooth integration of these techniques into already existing analysis and design MAS methodologies.

In order to understand the Research Question, [3] recommends consider the following four viewpoints: i) **Population:** research papers presenting methodologies or frameworks for multi-agent software systems; ii) **Intervention:** requirements engineering methods and techniques; iii) **Outcomes:** not focused in achieving any specific result; iv) **Experimental design:** none.

This review is more limited than a full systematic review since we did not follow up references in the included papers and we did not include grey literature sources.

3.2 Identifying and Selecting Primary Studies

We used four scientific digital libraries as sources for primary studies: ACM Digital Library (ACM), IEEEXplore Electronic Database (IEEExplore), Inspec (IE), and Science Direct (SD). In addition, we have included as a source a book on AOSE methodologies [10] published in 2005. Other publications such as the proceedings from the conferences on Artificial Intelligence (AAAI) or Springer published works unfortunately were excluded since we did not have access to them. We understand that this fact may reduce the validity and scope of the study.

We tested several search strings until have obtained one that retrieved the greatest number of relevant papers. The search string was: *((multiagent or multi-agent or "multi agent" or "agent-based") and (methodology or method or process or approach) and ("requirements elicitation" or "requirements modeling" or "requirements modeling" or "requirements analysis" or "requirements specification"))*. This string was used in ACM, IEEExplore, IE, and SD. The search includes journals, magazines and conference proceedings from 1998 to March 2009.

3.3 Inclusion Criteria and Procedures

The selection criteria are intended to identify those primary studies that provide direct evidence about the research question. We included papers with techniques, methods or notation proposals that have dealt with the RE activity during the development of multi-agent systems. We excluded papers that present: i) the development of specific tools; ii) the development of agent platforms; iii) evaluation and comparison of AOSE methodologies; iv) methods for the development of architectures; v) short papers; and vi) introductory papers from special issues, workshops, or conferences.

3.4 Data Extraction Strategy

The data extracted were compared according to the research question stated above, which is decomposed into the criteria presented in Table 1.

The purpose of the first criterion is to determine whether the paper proposes a *new or adapted* **method for RE**. Most of the current MAS methodologies are adapted from other paradigms such as object-orientation or knowledge engineering; however, some new methods have been proposed. The second criterion is about the **supported tasks** in RE: elicitation, modeling, and analysis [12]. *Elicitation* refers to the activities performed to be able to understand the goals, objectives, and high-level functions necessary for the proposed software system. *Modeling* allows requirements to be expressed in terms of one or more models. *Analysis* consists of evaluating the quality of requirements. The third criterion analyzes the **concepts and notations** used to identify and model the requirements of the software system to be built. Some works employ *goals, scenarios, or NFR* as a conceptual framework to identify user requirements. The use of *object models, entity-relationship models, or behavioral models* are also alternatives. *Formal methods* are strongly related to models with mathematical foundations. The fourth criterion analyzes the **techniques employed** to deal with requirements, including *stakeholder identification, metaphors, patterns, ontologies*. The fifth criterion, **traceability**, refers to the ability to follow the life of a requirement either back to its origin or forward to its transformation into a design artifact. We use Gotel's classification [13] for *pre-traceability* and *post-traceability*. The sixth criterion is **automated support**. This refers to the automation of *specification* facilities, *transformation to design artifacts, validation* support (e.g., correctness, consistency), *baseline* definition, etc. The last criterion analyzes how the reviewed work **validates** its proposal: *case studies* (a study to examine a phenomenon or unit, collect data, and analyze the results of a single case) or *empirical studies* (testing the hypotheses against an experiment without the influence of the observer).

3.5 Conducting the review

The search to identify the primary studies in the ACM, IEEExplore, IE, and SD was conducted in a first round on December 20th, 2008, and completed in a second round on March 6th, 2009 (adding the new results to the list). The application of the review protocol produced 58 papers (see the complete list of reviewed papers at www.dsic.upv.es/~einsfran/review_mas.htm).

The bibliographic database search identified 835 potential publications (300 from ACM, 12 from IEEE, 83 from IE, and 440 from SD). After applying the exclusion criteria (see section 3.3), we selected 48 publications: 30 from ACM, 8 from IEExplore, 2 from IE, and 8 from SD. The significant difference between the number of papers retrieved in the ACM and IEEEXplore was due to the following: i) when the paper appeared in both ACM and IEEExplore, we took only the ACM one; ii) the ACM included most of the conferences related to agents such as: AAMAS, IAT, ICSE, etc. The low number of publications selected from IE and SD is due to the fact that most of the results already appeared in ACM or IEEE. The manual bibliographic review identified 13 relevant publications from the book [10]. After applying the exclusion criteria, we finally selected 10 papers.

Table 1. Research questions and corresponding criteria.

Question	Options
Does the work propose a new/adapted method for requirements engineering?	New method, Adapted.
Which tasks of the requirements engineering activity are supported?	Elicitation, Modeling, Analysis.
What concepts and notations are used?	Goals, Use Cases or Scenarios, NFR, Object Models, ER models, Behavioral models, Formal methods, Other.
Techniques Employed	Stakeholder Identification, Metaphors, Patterns, Ontologies.
Traceability	Pre-requirements, Post-requirements.
Automated Support	Specification, Design Artifact Transformation, Validation, Base Line.
Validation	Case Study, Empirical Study (controlled experiment), None.

4 Results

Table 2 presents the results of the study. They are grouped by selection criteria and publication source. A total of 79% of the papers reviewed used *adapted methods* from other fields, and 21% of them proposed a *new method* to **deal with requirements**.

Table 2. Systematic Review Results.

Selection Criteria		ACM	IEEE	EI	SD	Book	Total
Requirements Engineering Support	New	9	0	0	2	1	12
	Adapted	21	8	2	6	9	46
Phase in which the RE support is given	Elicitation	15	3	1	6	1	26
	Modeling	21	4	2	6	10	43
	Analysis	29	7	2	7	10	55
Notation and Concepts Employed	Goals	23	4	1	6	6	40
	Scenarios	8	3	2	2	7	22
	RNF	11	4	0	3	1	19
	Object Models	6	1	2	4	5	18
	Entity-Relationship	0	0	0	1	0	1
	Behavioral Model	7	2	1	3	5	18
	Formal Methods	10	2	1	1	0	14
	Other	11	3	2	2	4	22
Techniques Employed	Identifying Stakeholders	10	0	0	2	0	12
	Metaphors	1	1	0	0	1	3
	Patterns	11	1	0	6	5	23
	Ontologies	4	0	0	2	2	8
Traceability	Pre-requirements	0	1	0	1	0	2
	Post-requirements	9	2	2	6	1	20
Automatic support	Specification	9	2	1	3	7	22
	Validation	8	1	0	2	3	14
	Design Artifacts Transformation	4	1	1	1	3	10
	Base Line	0	0	0	0	0	0
Validation	Case Study	18	4	1	5	9	37
	Empirical study	3	0	0	0	0	3
	None	9	4	1	3	1	18

ACM - ACM Digital library; EI - Inspect
IEEE - IEEEXplore electronic database; SD - Science Direct
Book - The Henderson-Seller Book [10]

The most frequently **supported task** was the *analysis* task (95%), followed by the *modeling* task (74%), and then by the *elicitation* task (45%). This result highlights the fact that MAS methodologies give more attention to the modeling and analysis tasks (see Figure 1.a). With respect to the elicitation task, 17 of 26 works were i* framework-based. This is the case of GORMAS [11] that extends the requirements analysis of Tropos to deal with functional and operative goals. A different approach was proposed in [14], which applies agent concepts at the Business Process level. Another alternative to the i* framework was [15], which offers requirements gathering using four models: the product model, the organization model, the system user model, and the cognitive model. A further alternative was HOMER [16], an elicitation technique to gather requirements for AOSE methodologies. Finally, [17] presents a Requirements Elicitation Guide. This guide provides a set of questions that customers and developers must answer in order to identfiye athde de requirements of a MAS. With respect to **notations and concepts** (see Figure 1.b), the most widely used were goal-oriented-based ones (69%). Other alternatives included the following (though not exclusively) approaches: *Scenarios* (38%); *NFR* (33%); *Behavioral models* (31%); *Object models* (31%); and *Formal Methods* (24%). In this context, we must point out the intensive use of role models in MAS methodologies [18], [19], [15] and the fact that only one (2%) of the papers reviewed used the ER model. Another result of our study is that 62% of the papers did not have explicit **traceability support** (see Figure 1.d). *Post-requirements* traceability was applied in 35% of the cases, mostly in transformations from requirements to some source code or design artifacts. Only [20] has applied *pre-requirements* traceability through a map from an operation workflow (at the business process level) to a cognitive flow diagram. With respect to **automation** (see Figure 1.e), 38% of the papers mentioned a tool to give support to the *specification* management. In addition, 24% of the papers provided some type of automated *validation*. However, 21% of the papers did not provide *any type* of automated support. Moreover, 17% of the papers support transformation from requirements to design artifacts. We did not find any tool that supported baseline.

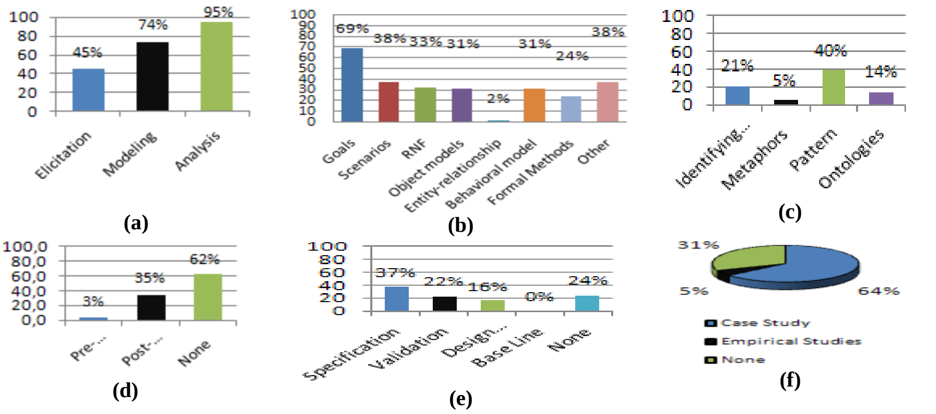

Fig. 1. Percentage of coverage by criteria used for data extraction.

With respect to the **evaluation method** (see Figure 1.f), the case study was the most widely used validation approach (64%). Some works did not offer any validation (31%), and the papers that only show examples of their approach were also included in this category. Finally, only 5% of the papers validated their approach with **empirical studies** (controlled experiments). Figure 2 shows the papers classified by source and year. The bar chart shows that there has been an increasing interest in RE since 2001 (although we found one paper in 1998).

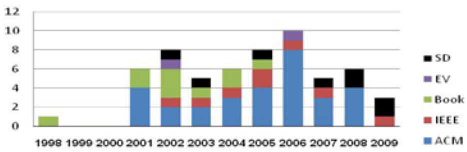

Fig. 2. Number of Publications by Year and Source.

5 Conclusions and Further Work

We have presented the results of a systematic review aimed at investigating what RE methods and techniques for multi-agent system development have been employed in the last 10 years. We decided to conduct the study as a systematic review because it is an objective and repeatable method for evaluation. The results have identified several research gaps. Specifically, the majority of MAS methodologies are focused on modeling and analyzing requirements and not on eliciting them. To elicit requirements, the i* method is the most widely used approach. This reveals that there is a dearth of alternative methods and techniques for appropriately gathering requirements for the MAS.

With regard to the concepts and notations, there are several works that use goals, NFR, scenarios, and role models. In addition, there is interest in the MAS field for the use of patterns to model from an abstract level (e.g., social pattern) to a more detailed and architectural design level. Moreover, there is a significant lack of research on traceability among artifacts produced along the MAS development. Pre-requirements traceability was applied in only one research work. Better mechanisms and tools to deal with (pre and post) traceability in the MAS methodologies could help to meet user needs, improve their understanding of the system, and improve the overall quality of the developed software. Our results have also shown that there is a need for more empirical studies. Empirical studies are the building blocks necessary for building evidence and determining which techniques are better in certain situations.

All these issues provide a clear motivation for further research on RE for MAS development. Our future work includes the analysis of this current knowledge on applying RE techniques to tailor a specific RE method for the analysis and design Gaia methodology [18] and its corresponding empirical evaluation to determine its effectiveness when developing MAS using Gaia.

Acknowledgments. This work is cofunded by the Spanish Department of Science & Technology, under the National Program for Research, Development and Innovation, META project (TIN2006-15175-C05-01), and the European Regional Development Fund.

The article was published by Springer: David Blanes, Emilio Insfrán, Silvia Abrahao. 10th International Conference on Intelligent Data Engineering and Automated Learning (IDEAL 2009), 23rd-26th September, 2009 - Burgos, Spain, Lecture Notes in Computer Science 5788, pp. 510-517, Berlin Heidelberg, Springer, ISBN 3-642-04393-3, http://www.springerlink.com/content/03m8rv208w164333.

References

1. Bernon, C., Cossentino, M., Pavón, J.: An Overview of Current Trends in European AOSE Research Informatica (2005)
2. Blanes, D., Insfran, E., Abrahão, S.: Reviewing the Use of Requirements Engineering Techniques in the Development of Multi-Agent Systems (Short-paper). Salamanca, Spain. Int. Symposium on Distributed Computing and Artificial Intelligence (2009)
3. Kitchenham, B.: Procedures for Performing Systematic Reviews. Version 2.3, EBSE Technical Report, Keele University, UK (2004).
4. Davis, A., Dieste, O., Hickey, A., Juristo, N., Moreno, A.M.: Effectiveness of Requirements Elicitation Techniques: Empirical Results Derived from a Systematic Review. Minnesota, USA. RE (2006)
5. Mendes, E. A systematic review of Web engineering research. Noosa Heads, Australia : International Symposium on Empirical Software Engineering (2005)
6. Henderson–Sellers, B., Gorton, I.: Agent-based Software Development Methodologies: White Paper, Summary of Workshop at the OOPSLA (2002)
7. Sudeikat,J., Braubach, L., Pokahr, A., Lamersdorf, W.: Evaluation of Agent-Oriented Software Methodologies - Examination of the Gap Between Modeling and Platform. New York, USA : AOSE (2004)
8. Silvia, C., Tedesco, P., Castro, J., Pinto, R.: Comparing Agent-Oriented Methodologies Using the NFR Approach. Edinburgh, Scotland, UK : 26th International Conference on Software Engineering (2004)
9. Cernuzzi, L., Cossentino, M., Zambonelli, F.: Process Models for Agent-based Development. Engineering Applications of Artificial Intelligence 18(2), pp. 205-222. (2005.)
10. Henderson-Sellers, B., Giorgini, P. Agent-Oriented Methodologies Idea Group, 2005.
11. Argente, E., Botti, V., Julián, V.: Organizational-Oriented Methodological Guidelines for Designing Virtual Organizations. Salamanca, Spain : Int. Symposium on Distributed Computing and Artificial Intelligence (2009)
12. Cheng, B., Atlee, J.: Research directions in Requirements Engineering. Future of Software Engineering, ICSE (2007)
13. Gotel, O., Finkelstein, A.: An Analysis of the Requirements Traceability Problem. IEEE Int. Conference on Requirements Engineering (1994)
14. Burmeister, B., Arnold, M., Copaciu, Rimassa, F. G.: BDI-agents for agile goal-oriented business processes AAMAS (Industry Track) 2008: 37-44 (2008)

15. Ranjan, P., Misra, A.K.: A hybrid model for agent based system requirements analysis. ACM SIGSOFT Software Engineering Notes 31(3): 1-7 (2006)
16. Wilmann, D. , Sterling, L.: Guiding Agent-Oriented requirements elicitation: HOMER. QSIC (2005)
17. Fuentes-Fernández, R., Gómez-Sanz, J. J., Pavón, J.: Requirements Elicitation and Analysis of Multiagent Systems Using Activity Theory. Transactions on Systems, Man and Cybernetics – Part A: Systems and Humas, Vol. 39, No. 2, (2009)
18. Dehlinger, J., Lutz, R.: A product-line requirements approach to safe reuse in multi-agent systems. ACM SIGSOFT Software Engineering Notes 30(4): 1-7 (2005)
19. Zambonelli, F., Jennings, N. R., Wooldridge, M.: Developing multiagent systems: The Gaia methodology. ACM Trans. Softw. Eng. Methodol. 12(3): 317-370 (2003)
20. Paraense, A., Gudwin, R., Gonçalves, R.: Brainmerge: a Semiotic-Oriented Software Development Process for Intelligence Augmentation Systems. KIMAS (2007)