SONIA: A Methodology for Natural Agent Development

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Abstract. *Agent-Oriented Software Engineering* has emerged as a powerful engineering discipline that can deal with the complexity of today's software systems (primarily in distributed and open environments) better than other more traditional approaches. However, AOSE does not provide a software development process that naturally leads, if the problem so requires, to an agent architecture or, where appropriate, an agent society. In current agent development methodologies, either the development processes target an agent organization, which is not necessarily always the best structure, as of the requirements definition stage, or the identification and design of agents are complex, and designer experience plays an essential role in their definition. In this paper, we present the SONIA methodology (Set of mOdels for a Natural Identification of Agents) in an attempt to solve this problem. Based on a generic problem-independent analysis and a bottom-up agent identification process, SONIA naturally outputs an agent-based system and, where appropriate, an agent society design.

1 Introduction

Agent-Oriented Software Engineering (AOSE), based on the agent paradigm, has materialized as a powerful technology for developing complex software systems, and it is well suited for tackling the complexity of today's software systems [1]. Having emerged, like so many other disciplines, from artificial intelligence, it is now a melting pot of many different computing sciences areas (artificial intelligence, software engineering, robotics, and distributed computing).

The AOSE concept includes the development of *autonomous software agents* (autonomous elements, with reactive and proactive social ability, trying to accomplish their own task [2]), *multi-agent systems* (MAS) (a set of autonomous agents that interact with each other, each representing an independent focus of system control [3]), and *agent societies* (where the social role of the agents and social laws delimit agent operation [4]).

Agents, MAS and agent societies are now well enough known for researchers and companies to be attracted by the prospects of large-scale agent engineering. The interest they are showing is actually the logical consequence of the successes achieved in this direction, resembling the sequence of events that already took place in other development engineering disciplines (like objects, for example) [5].

In this paper, we describe the SONIA methodology, an approach for naturally producing a MAS or agent society from the system requirements. In section 2, we explain what problems AOSE faces. Section 3 contains an analysis of current agent development methodologies. Section 4 describes the structure of the proposed SONIA methodology and its application to the ALBOR project. Finally, section 5 states the conclusions on the natural development of agents.

2 Problems of AOSE

AOSE is obviously not a panacea, as its use is not always justified. There are problems that an agent approach cannot solve, and others where the outlay and development time required by such an approach would be too costly to be acceptable for companies. We have identified a set of topics to be taken into account when applying AOSE to real problems [6]:

- *Reach agreement on agent theory*. This new paradigm will not be able to expand unless the agent model is standardized with respect to what characteristics define an agent, what types of architecture are available for agents, what agent organizations are possible, what types of interactions there are between agents, etc. Just as UML (Unified Modeling Language) [7] was established to model objects, a modeling language for agents needs to be agreed upon (perhaps AUML [8]).
- *Provide mechanisms for deciding whether the problem should be dealt with using a MAS*. Even if it is initially justified to conceive a multi-agent solution for a given problem, a MAS could turn out to be no good in the end, because, for example, no agents can be identified or there are no interactions between the identified agents.
- *Train development team members in the field of agents and MAS*. A team of developers is not usually familiar with agents and MAS these days, which means that they will have to be trained beforehand in this field if they are to be receptive to such projects and to prevent delays in project development.
- *Provide special-purpose programming languages and development tools*. Although the last few years have seen new languages for programming agent behavior take root, general-purpose languages like Java and C++, etc., are widely used. On the other hand, there are fewer development tools for representing agent structure, and they focus mainly on a particular agent architecture.
- *Use methodologies suited to the development processes*. For organizations to adopt MAS development, the right methodology needs to be provided to guide the team of developers towards the achievement of objectives, without this requiring in-depth training in this field. A critical stage in the development of a MAS is the selection of the methodology to be followed. A good methodology should provide the models for defining the elements of the multi-agent environment (agents, objects and interactions) and the design guidelines for identifying these elements, their components and the relationships between them.

As regards the question of methodology, a wide variety of *methodological proposals* have emerged for AOSE development [9][10][11][12]. Although they have all played

an important role in establishing this field, they do not provide suitable mechanisms for formulating a *natural* process for developing a MAS system or an agent society from system requirements. That is, the gradual discovery and identification of concepts, associations, tasks, knowledge, behaviors, objects, agents, MAS and agent societies from the problem statement. Additionally, a good methodology should not force a given architecture (object-oriented, agent-oriented, etc.) upon developers from the beginning. It is the system specifications analysis that should point developers towards the best suited architecture for solving the problem.

Based on research and development efforts in the field of AOSE, we think that an agent-oriented development methodology should have the following features [6]:

- *It should not condition the use of the agent paradigm right from analysis*. It is too risky to decide whether the system is to be designed using a multi-agent architecture in the analysis or conceptualization phase, as the problem is not fully specified at this early stage of development. It is not until the design phase that enough is known about the problem specifications and architecture to make this decision.
- *It should naturally lead to the conclusion of whether or not it is feasible to develop the system as a MAS*. At present, it is the developer who has to decide, based on his or her expertise, whether or not to use a MAS to solve the problem. Because of its high cost, this is a tricky decision that cannot be made using heuristics. Note that, depending on the application domain, design and implementation using a multi-agent architecture may have a high development cost (time, money and resources), apart from calling for experienced personnel. On the other hand, the modularity of multi-agent systems may improve development costs.
- *It should systematically identify the components of a MAS*. Current methodologies leave too much to the designer with respect, for example, to agent identification. Designer experience is therefore vital for producing a quality MAS.
- *If the problem specifications call for an agent society, it should naturally lead to this organizational model*. The development of a software system using a reductionist, constructivist or agent society architecture should be derived from the problem specifications, which will lead to the best suited architecture. Current agent-oriented methodologies focus on the development of the actual agent architecture (internal agent level) and/or its interactions with other MAS agents (external agent level), but very few cover the concept of social organization.
- *It should produce reusable agents, should be easy to apply and not require excessive knowledge of agent technology*. The concept of reuse has been one of the biggest contributions to software development. The provision of libraries has furthered procedure-, object-, or component-oriented engineering. For this advance to take place in AOSE, agent components (interaction protocols, etc.) need to be reusable and easy to use. Current agent-oriented design methodologies and methods do not account for reusable systems and call for high proficiency in MAS technology for use. As MAS technology is related to many disciplines (artificial intelligence, psychology, sociology, economics, etc.), intensive knowledge of agent technology is required. This relegates the design of these systems to universities, research centers and companies with the latest technology.

The specific characteristics of MAS and MAS development-related problems indicate that agent-based problem solving cannot be dealt with intuitively. It calls for a methodological process that naturally leads to the use of agents in problem solving.

3 Analysis of Current Agent Development Methodologies

On account of the advance in agent technology over the last ten years, several methodologies have emerged to drive MAS development [9][10][11][12]. These methodologies are classed according to the discipline on which they are based as Agent Technology-Based, Object Orientation-Based, and Knowledge Engineering-Based Approaches (Fig. 1).
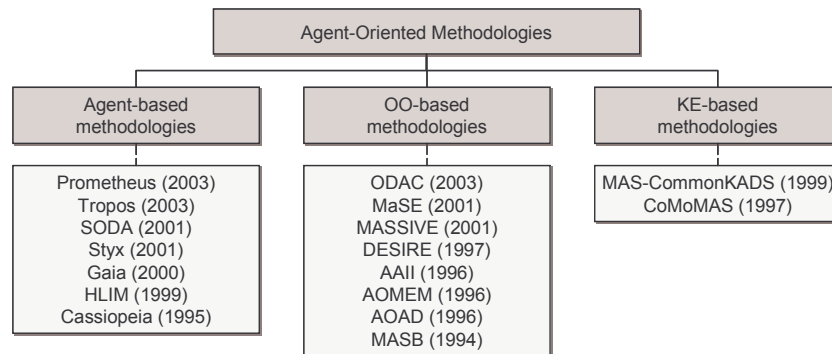
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                    Agent-Oriented Methodologies

   Agent-based              OO-based                 KE-based
   methodologies            methodologies            methodologies

  Prometheus (2003)       ODAC (2003)           MAS-CommonKADS (1999)
  Tropos (2003)           MaSE (2001)           CoMoMAS (1997)
  SODA (2001)             MASSIVE (2001)
  Styx (2001)             DESIRE (1997)
  Gaia (2000)             AAII (1996)
  HLIM (1999)             AOMEM (1996)
  Cassiopeia (1995)       AOAD (1996)
                          MASB (1994)
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Fig. 1. Agent-Oriented Methodologies

3.1   Agent Technology-Based Methodologies

These methodologies focus on social level abstractions, like the agent, group or organization. The most representative methodologies are: Tropos [13], Gaia [14], Prometheus [15], SODA [16], Styx [17], HLIM [18] and Cassiopeia [19].

Although this methodological line is gaining in importance in agent development, the methodologies suffer from some limitations on key points:

– These methodologies propose the use of the agent paradigm as of the specification (Prometheus, HLIM, Cassiopeia) or analysis (Tropos, Gaia, SODA, Styx) phases. The choice of a multi-agent system should be a *design* decision. Therefore, a good agent-oriented methodology should not conduct a specific agent-oriented analysis. None of the methodologies account for the use of a generic analysis model that can be used to evaluate whether or not a multi-agent approach is suitable.

- All of the methodologies identify agents from social roles (Gaia, SODA, Styx, HLIM, Cassiopeia) or actors (Tropos, Prometheus) following a top-down identification process and none from their components. Component-driven bottom-up agent identification is the most objective criterion, as it depends exclusively on the problem and eases the systematization and automation of the identification process. On the other hand, the role (or actor)-driven criterion is more subjective, as roles or actors depend on the analyst/designer who identifies them.
- Three aspects need to be dealt with to develop a MAS: intra-agent structure, inter-agent structure and social structure. Most of the methodologies cover the intra-agent and inter-agent aspects (Tropos, Gaia, Prometheus, Styx, HLIM), but only SODA and Cassiopeia account for social structure.
- The analysis of the environment is a key point. SODA is the only methodology to analyze the environment, its entities and their interactions.

3.2 Object Orientation-Based Methodologies

These methodologies are characterized by extending object-oriented techniques [20] to include the notion of agency. The most representative are: ODAC [21], MaSE [22], MASSIVE [23], DESIRE [24], AAII [25], AOMEM [26], AOAD [27] and MASB [28].

From the viewpoint of correct agent orientation, this methodological line is beset by the following problems. It does not account for the use of a generic analysis model. Some methodologies (ODAC and AOAD) identify agents during analysis. Only the DESIRE methodology implements a proper component-driven bottom-up agent identification process. Almost all the methodologies (ODAC, MASB, DESIRE, AAII, AOMEM, AOAD and MASB) cover the intra-agent and inter-agent aspects, but only MASSIVE and AOAD cover the social structure. Finally, with the exception of MASSIVE, none of the methodologies takes into account the environment features.

These methodologies treat agents like complex objects, which is wrong, because agents have a higher level of abstraction than objects. They also fail to properly capture the autonomous behavior of agents, interactions between agents, and organizational structures [17].

3.3 Knowledge Engineering-Based Methodologies

These methodologies are characterized by emphasizing the identification, acquisition and modeling of knowledge used by the agent components. The most representative methodologies originate from the CommonKADS [29] methodology and are MAS-CommonKADS [30] and CoMoMAS [31].

These methodologies also present some problems. Like the other approaches described earlier, these methodologies do not account for the use of a generic analysis model. MAS-CommonKADS identifies agents during analysis, following a role-

driven top-down process (identifying actors). Both of them account for the intra-agent and inter-agent aspects, but do not cover social issues or analysis of the environment.

The methodological approach based directly on agent technology is perhaps better than the other two, because it is based on the intrinsic concept of agent and agent organization in a MAS. It basically falls down on the point that it confines problem analysis to the agent paradigm, whereas this paradigm may turn out to be unsuitable if agent technology is not a good option for dealing with the problem in question.

Briefly, we believe that a good AOSE methodology is one that defines an architecture-independent *generic analysis model* and a *design model* that can systematically identify agents following a component-driven bottom-up agent identification process, can identify the intra-agent, inter-agent and social structure of the agent, can analyze the environment and can identify environment objects.

4 SONIA Methodology

The SONIA (Set of mOdels for a Natural Identification of Agents) methodology [6] allows the generation of a multi-agent architecture to solve a problem (whose conceptualization is not conditioned by the agent paradigm) according to a *Multi-Agent Design Model* that systemizes and automates the activities of identifying the MAS components (Fig. 2). Likewise, using this MAS architecture, the methodology defines an *Agent Society* that flexibly and dynamically facilitates problem solving and can be used to integrate indispensable legacy systems.
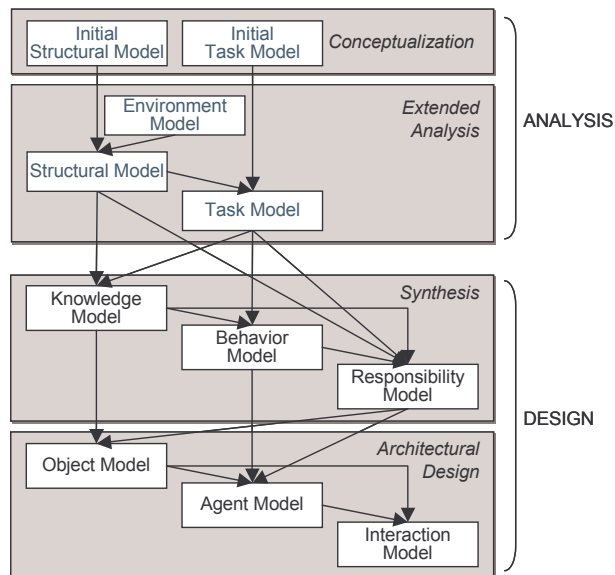

Fig. 2. Phases of the SONIA methodology

In the following, the phases and stages of the SONIA methodology and their application to the development of the ALBOR project (Barrier-Free Computer Access) are briefly described [32][33].

ALBOR was conceived as an Internet-based intelligent system designed to provide guidance on the evaluation of disabled people's computer access skills and on the choice of the best suited assistive technologies. Each system session is divided into four stages: *user identification* (user personal particulars and other information are collected in order to start the session), *session preparation* (goals of the questionnaire, how the session will be performed and whether any preliminary training is necessary), *survey taking* (a series of questions, which will be depend on responses to questions already answered and will be confined to the questions strictly necessary for the evaluation of the person in question) and *result evaluation* (an evaluation report with several recommendations for the user to decide which is best suited for her/him.

4.1 Analysis

The elicited requirements are analysed using the Set Theory Based Conceptual Model (SETCM) [34], an analysis method that was defined to combine a formal foundation with a pragmatic approach. This analysis method is design-independent: it uses a terminology other than design language to provide a real comprehension of the problem under analysis. It has been applied to develop real systems, which were finally designed using a variety of paradigms (structured, object-oriented, knowledge-based) and even a combination of paradigms.

The *Initial Structural Model* and the *Initial Task Model* are built using SETCM. The *Initial Structural Model* describes the general structure of the problem domain (based on concepts, concept attributes, associations, association attributes, concept classification and association classification), and the *Initial Task Model* describes how the problems raised in the domain are solved (based on tasks and methods).

These models are refined and expanded to capture the system Environment and External Entities, successively producing:

− An *Environment Model*, which defines the system external entities and their interactions with the system.
− A *Structural Model*, which includes structures from the knowledge domain of the external entities that interact with the system.
− A *Task Model*, which adds the functionalities required to interact with the system external entities defined in the Environment Model.

4.2 Design of the Multi-agent Architecture

The Analysis phase is followed by the Multi-Agent Architecture Design, which is divided into two stages: Synthesis and Architectural Design.

The *Synthesis* stage provides for the later component-driven identification of agents (bottom-up process). The elements of the Structural Model and Task Model are grouped depending on concepts characteristic of agents, such as knowledge, behaviors and responsibilities, outputting the following models:

- A *Knowledge Model*, which identifies the knowledge components by grouping Structural Model concepts and associations. These groupings are identified because the internal cohesion of their members is high, coupling with other groupings is low and they are used to perform tasks of the same behaviors. The knowledge components will be used internally or shared by the agents.
- A *Behavior Model*, produced by grouping Task Model tasks, subtasks and methods. The behaviors will be part of the agents. These groupings are identified because their tasks and subtasks depend on each other through their methods and they use the same knowledge components in problem solving.
- A *Responsibility Model*, output by relating knowledge components to behaviors. The purpose of this model is to be able to identify agents and environment objects.

The *Architectural Design* stage focuses on the definition of the architectural components by means of the following models:

- An *Agent Model*, which identifies and defines, from the Responsibility, Knowledge and Behavior Models, what entities should be designed as autonomous agents.An agent is identified because it is an environment-sensitive entity (it perceives and acts in the environment) that has knowledge to bring into play its behaviors in pursuit of goals and is activated when its utilities are required.
- An *Object Model*, which identifies and defines, from the Responsibility, Knowledge and Behavior Models, what passive elements are part of the environment. These objects are knowledge components identified during the synthesis phase. The main feature of an object is that the knowledge of this object is responsible for more than one behaviour or, in other words, is shared by several behaviors. Access to objects will be divided by *levels*, and the knowledge components that are accessed by the same behavior tasks will be grouped at the same level.
- An *Interaction Model*, which identifies and defines what relationships there are in the system between agents and between agents and objects.

4.3 Design of the ALBOR System

Fig. 3 shows how the Analysis, Synthesis and Architecture Models are built. For simplicity's sake, it shows only the concepts and associations that are the source of the "Questionnaires" knowledge component, and tasks and methods that are the source of the "TakeSurvey" behavior.

The concepts and associations gathered in the Analysis phase were synthesized as knowledge components using a technique based on Kelly's constructs [35], and the tasks and methods as behaviors using heuristics applied to task decomposition and task dependencies. These techniques, used to output the knowledge components and behaviors, assure highly coherent and low-coupled groupings. Then the responsibilities between knowledge components and behaviors were established from the rela-

tionships of concept/association used in task/subtask. These responsibilities lead to changes in the Knowledge and Behavior Models. The models are modified according to knowledge and behavior grouping/division rules based on the cardinalities of the relationships of concept/association used in task/subtask. The Knowledge, Behavior and Responsibility Models are the final result of the synthesis.

It is not until the Agent Model is built that a decision is made as to whether the architecture can be implemented by means of agents or a different paradigm needs to be used. This choice is chiefly based on whether or not agents can be identified. For an entity to be able to be considered as an autonomous agent, it should have a behavior and the right knowledge components to perform the tasks of this behavior, have at least one defined goal and one utility, and perceive and act in the environment.

To complete the multi-agent architecture design phase, the environment agents and objects were identified. The objects were identified from the Responsibility Model, and the knowledge shared by several behaviors was chosen as environment objects. Following this criterion, we identified the "Users", "External" and "Media" objects. Agents were also identified from responsibilities. Again, agents should have a behavior, knowledge components, goals and utilities, and environmental awareness and action. For example, the responsibility between "Questionnaires" knowledge and "TakeSurvey" behavior produces "Survey-Taker". The Agent, Object and Interaction Models are the final result of the architecture design stage.
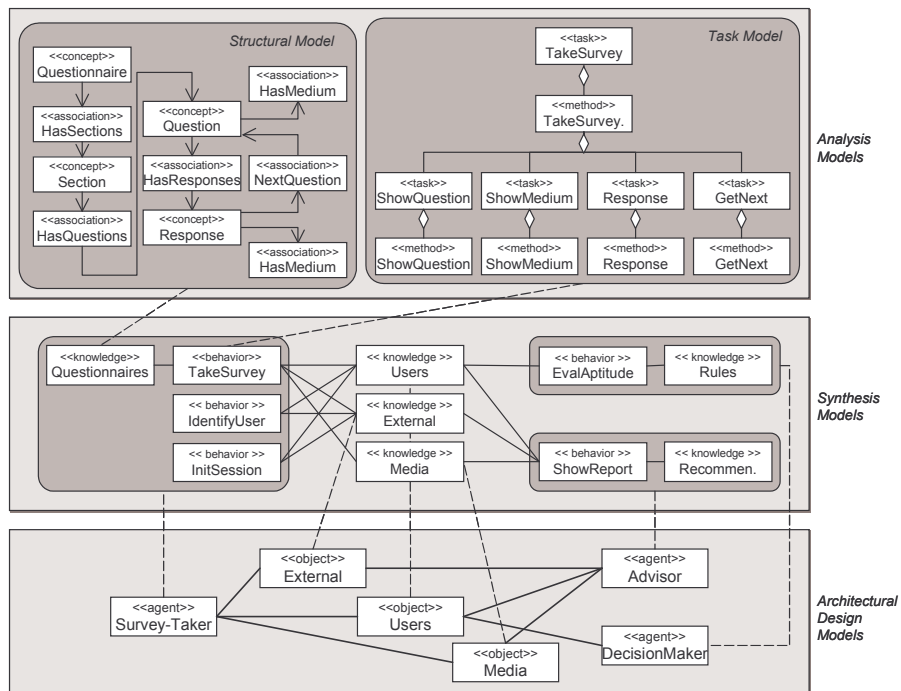

Fig. 3. ALBOR: From analysis models to architectural design models

4.4 Design of the Agent Society

The *Multi-Agent Architecture Design* results in either *distributed problem solving,* in which all the agents in the system share a common goal and the problem is divided into small tasks that are shared out among agents, or an *agent society*, in which the system is designed as a set of agents embedded in a social structure.

In this case, the methodology naturally leads to an *Agent Society Model* based on the publish-subscribe paradigm. A society is composed of agents and objects (black-boards) of the environment:

−   The *agents*, or active entities of the society, can be: Member-Agents, specialized in performing a given task; or Spoke-Agents, representatives of the society before other societies.
−   The *blackboards*, or passive entities of the society, can be: Domain Blackboards, which describe the problem domain and its solution; Subscription Blackboards, which describe the structure of the society in terms of its member agents and the social role of each one; or Statement Blackboards, which describe society input/output knowledge.

5   Conclusions

AOSE is unquestionably a very good technique for solving complex problems, especially in distributed, open and heterogeneous environments. For this technology to be routinely used in companies like object-oriented approaches are, there is a need for mechanisms suited for deciding whether or not the problem should be solved using agents. Also the identification and design of agents should be a natural and straightforward process that does not require a lot of expertise so that there is no obstacle to its application by developers. Although they have made a big contribution to improving AOSE, current agent development methodologies do not satisfactorily solve the above-mentioned problems.

In this paper, we have pointed out some features that an agent-oriented development methodology should have and detailed which of these features are missing from the most important methodologies used within the agent paradigm. Also, we have presented an overview of the SONIA methodology, illustrated by the ALBOR case study, which includes these features and naturally leads from requirements elicitation to MAS and agent society development.

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