REUSING NEGOTIATION STRATEGY FOR MULTI-AGENT SYSTEM DEVELOPMENT

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by
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Abstract

The dynamic nature of the agent technology and the inherent characteristics of the agent are aptly suited in the implementation of a negotiation system. Even with such a promising technology, the development of the multi-agent negotiation system is not widely accepted by the software community. With a lack of standardised approach in the development process, it has become a deterrent for software developers to adopt the agent technology, as it is laborious to learn and to reinvent the wheel in the development of multi-agent negotiation systems.

Thus, this research is carried out with the intention to alleviate the gap identified by proposing an alternative approach through the use of agent negotiation patterns. Agent patterns are used to document the multi-agent system development experience and to provide a generic solution to recurring problems within a problem domain. Through that, the agent's conceptual designs are reusable to expedite development process and to provide a structured guideline to the development of the multi-agent negotiation system.

To provide a comprehensive description of the agent negotiation patterns, a pattern template by WaiShiang(2010) is used as a basis for documenting the patterns in an organised manner. The pattern template identifies the elements required to describe the multi-agent negotiation system at different levels of abstraction. In this research, the pattern template uses the AOR/ROADMAP models (Taveter & Sterling, 2008) to depict the agent's concepts.

Based on the pattern template, nine patterns are derived for different negotiation strategies, which are adapted from the existing research works. To evaluate and demonstrate the
reusability of the agent negotiation patterns derived, two patterns are used in the practical implementation of a case study. Coupled with that, quantitative evaluation is performed. Two evaluators are selected to analyse the viability of the agent negotiation patterns, and questionnaires are used to capture various metrics. The outcome from the two evaluation techniques prove that the patterns are reusable, extensible and adaptable.
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Chapter 1

Introduction

"Negotiation is a form of interaction among autonomous agents to cooperate and compromise to resolve conflicting interests by reaching a mutually acceptable agreement. To resolve the conflicts, negotiation strategies are engaged. They delineate different approaches to reach a mutually acceptable agreement, such as the multi-attribute negotiation strategy or interest-based negotiation strategy."

The explosion of information technology had been a catalyst for the advancement in software engineering. The desire to use software to automate processes had ushered in a new computing paradigm transcending the computing landscape which led to the birth of the agent technology. Software agent technology presents the engineering process and the development cycle for conceptualizing, modelling and developing software systems for software agents and the environment they inhabit (Oluyomi, 2006). An agent-oriented system is particularly suited to be implemented in a distributed, open system (Sycara, 1998) and a dynamic environment. The formation of agent technology stems from various disciplines: the artificial intelligence, the object-oriented programming and the concurrent object-based system (Briola, 2012). The ultimate goal of an agent is to mimic human characteristics as closely as possible, to the extent that it is capable of upholding its role as a human surrogate or to achieve its goals with minimum human intervention or supervision (Chow, Siu, Chan, & Chan, 2013). Among the many qualities they would have, agents are endowed with reasoning capabilities, they are autonomous with the ability to act independently, are reactive in responding to changes in the
environment through interaction and are proactive in nature (Jennings & Wooldridge, 2000). It has the cognitive ability to adapt to changes as well as to achieve new objectives. However, the key feature that is emphasised within this research is the social aspect of the agent (Briola, 2012). This has created the platform for the formation of a multi-agent system (MAS), whereby several loosely coupled and autonomous agents are capable of interacting and coordinating with each other to achieve a particular objective or to resolve complex problems. As stated by Sycara (1998), the ability of the agents to interact is vital to solving problems.

The interaction among agents ranges from simple interactions, such as sending a request to another agent to query or to search for information to complex interaction through cooperation, coordination or negotiation to achieve a goal (Jennings & Wooldridge, 2000). Coordination is normally used among agents to collect information for planning and scheduling purposes. Apart from that, it ensures that interdependencies among agents are properly managed (Sycara, 1998) by decomposing complex problems into smaller sets of problems, whereby each agent will take its respective role in solving each component of the problem through cooperation. Whereas, negotiation among agents is engaged to resolve conflicting interests over scarce resources (service, time, commodities) to reach mutual agreements (Ashri, Iyad, & Luck, 2003). During the negotiation process, the parties involved exchange proposals with an intention to explore the possibilities of reaching an ideal agreement. Negotiation that involves more than a single attribute provides for higher possibilities to reach an acceptable agreement to both parties especially when there is a conflict of preferences (Vahidov & Kersten, 2012).
Negotiation comes in different approaches: collaborative or argumentative (Oliva, McBurney, & Omicini, 2010), auction-based and contract net. These negotiation approaches have been infused in the agents to broaden their applications in different domains particularly in the e-commerce systems involving solving problems arising from a conflict of interests between buyers and sellers. It provides a platform for negotiation to reach an agreement that satisfies both parties based on their beliefs, goals and plans. Apart from that, it is aptly suited for systems dealing with resource and task allocation, resource management, scheduling, supply chain management and any related issues that require conflict resolution. For example, in a scenario such as in a room booking system in a college, where a lecturer needs a particular room that has been booked by another lecturer. Agents can be engaged to represent different parties to reach a mutual agreement through negotiation by identifying the opponent's requirements and goals. In a multi-tasking resource sharing environment, agents are required to handle multiple tasks related to negotiation such as assigning tasks to other agents and addressing requests from other agents (Zhang & Lesser, 2002).

The strength and advantages of the multi-agent negotiation system have been realised among agent community for many years and extensive research effort had been invested in this domain. Having reviewed numerous research literatures, it can be observed that most work focused on the various strategies and algorithms of negotiation such as using the game theory (Sycara, 1998) or genetic algorithm for resolving conflicting issues. Very little attention has been devoted to the adoption of a proper development approach of agent-oriented negotiation system specifically the usage of the appropriate agent-oriented modelling techniques in the software life cycle.
Based on our knowledge, some works have been introduced like the use of Unified Modelling Language (UML) to model agent’s concepts in the work of Ha & Kim, (2009). On the other hand, the petri nets, the architecture-based (2003) and the formal specification modelling have been adopted to develop negotiation in MAS.

From there, it is apparent that there is no systematic roadmap for the development of multi-agent negotiation system. It was also identified by (Wooldridge & Jennings, 1998) that the greatest hurdle in the wide acceptance of agent technology is caused by the lack of standardized approach that can be used to develop the basic agent infrastructure. We argue that this statement is still valid up till now. Ashri, Iyad & Luck (2003) stressed that many of such systems are implemented in an ad hoc manner. Moreover, the software development techniques aforementioned are not suitable or are inadequate to capture the agent’s concepts. For instance, there is an unparalleled representation of the object-oriented notations and concepts, with that of the agent’s, particularly in the representation the autonomous behaviour and the societal aspect of the agent. (Wooldridge, Jennings, & Kinny, 1999). And according to Jennings et al. (1998), a system can be considered as an agent-based system without the existence of the agent structures in its implementation. However, it is more effectual that an agent-based system should be designed and implemented with supporting agent concepts (Jennings & Sycara, 1998) to fully utilise its potential and strength.

Consequently, without a proper approach and guideline to the development of multi-agent negotiation system, there will be a deficiency of pragmatic values to the system design. Different approaches were used and this had resulted in a system design specifically tailored to the problem domain. This will inadvertently contribute to the lack of qualitative attributes
especially the reusability of the negotiation framework. In addition to that, these existing multi-agent negotiation systems were developed from scratch and it is an intricate process (Luo, Miao, Jennings, He, Shen, & Zhang, 2012). Thus, for every MAS project, a considerable amount of time and money are spent to develop the system in this manner (Wooldridge & Jennings, 1998). Developers are plagued with the need to reinvent the wheel, following through the entire stages of the system development cycle, which is time consuming and cumbersome. This poses as a deterrent especially to novice agent developers.

Hence, this thesis introduces a reusable approach to address the issues brought forward by adopting a set of design patterns to capture solutions to recurring problems. Through this, the reusability attributes will be cultivated and it will eliminate the need for developers to build from scratch. This will indirectly improve other key qualities such as flexibility, scalability and productivity of the system (Singh, Thapa, Singh, & Singh, 2010). Such inherent qualities will also contribute to rapid prototyping, providing the grounds to hasten system development time and consequently reducing development cost.

1.1 Research problems

Despite the range of research works that have been invested on the construction of the multi-agent negotiation system, agent-oriented software engineering techniques have not been properly addressed in the existing work. There is a need for a pragmatic approach that serves as a guideline to such developments (Luo, Miao, Jennings, He, Shen, & Zhang, 2012). To narrow down the scope, there is still a lack of adoption of pattern for developing negotiation in MAS. From the work compiled by WaiShiang (WaiShiang, 2010), after analysing and classifying 204 agent patterns based on a Two-way classification scheme, he has discovered that negotiation agent pattern is available only for the interaction component. Many are still
developing in an ad-hoc manner (Cao, 2010) specific to the application domain, without a proper roadmap and most designs are not adaptable, reusable or extensible. Therefore, developers will have to re-design the negotiation framework from scratch and this will inevitably slow down the development process.

1.2 Aims and objectives

The aims of this thesis are to introduce a systematic and methodological approach to the development of multi agent negotiation through design patterns and to promote the reusability approach in MAS development. This provides a novel approach to the modelling of a multi-agent negotiation system. This thesis underlines the following objectives to achieve the aims stated above:

- To introduce the agent's negotiation patterns by adopting the agent-oriented models, specifically the models from the AOR/ROADMAP methodology, based on a pattern template structure.
- To derive agent negotiation patterns on nine different negotiation strategies from the existing literature or research work using the template structure introduced.
- To perform an empirical study through a case study to validate the negotiation patterns and their applicability by transforming them into platform specific constructs using JADE platform. This will demonstrate and substantiate the feasibility of the patterns derived.
- To observe the development time taken to transform the agent's pattern into implementation. Through this, the effectiveness of the patterns can be measured, the
ease with which the conceptual model can be transformed to concrete construct and the parallelism between both forms can be compared.

1.3 Research scope

This thesis delves into the research area of “Multi Agent System”, limiting the research domain within the negotiation in MAS and particularly, deriving the agent patterns for various negotiation strategies. The main focus is centered on transforming the agent negotiation strategies into a reusable form to serve as a medium to share the problems, context and solutions among agent developers and researchers. The agent patterns derived is focused on the modelling of the agent’s behaviour model in negotiation, which embodies the negotiation protocol, interaction, rules and reasoning. While there are many negotiation strategies developed within the academia, this thesis will focus on transforming nine negotiation strategies from the existing research work into agent patterns. They are the single attribute negotiation, multi-attribute negotiation, multi-attribute negotiation with time constraints, heterogeneous negotiation, threat and reward negotiation, trust and reputation negotiation, interest-based negotiation, human-oriented negotiation by mobile agent and simple negotiation mediated by mobile agent. Entailed with it is the implementation of the negotiation component based on two negotiation strategies mentioned above, in a functional multi-agent prototype. The prototype is built on the JADE platform using the FIPA-ACL communication language embedded on the platform. The prototype is taken from the case study by Fu (2012), on a restaurant finder system, where agents are created to search for dining places queried by the user or technically known as the Traveller. The negotiation component is assimilated into the prototype to produce a reservation function.
1.4 Thesis Structure

Figure 1.1 shows the structure of this thesis. This thesis is organised into 5 chapters. An overview of each chapter will be given below.

The first chapter presents an introduction to the research topic, outlines the aims and objectives, identifies the scope of the research and lays out the thesis structure.

Chapter two provides a further insight into the negotiation framework for MAS and presents the literature review through a comparative evaluation of the development approaches from other research work to highlight the research problem. Three development approaches are explored which include the modelling approach, architecture based approach and pattern based approach. It is then followed by the introduction to the proposed solution by using the agent patterns to address the problems identified. A brief discussion on the agent’s pattern is presented.

Chapter three introduces the agent pattern template structure that is used to document the agent development experience and the solutions to recurring problems. The desired properties of the pattern template structure are explored to highlight the requirements that should be included in the template. The properties of the pattern template structure are described through a set of attributes and each attribute is explained in more detail. The fixed attributes consist of name, problem, context and solution. Focusing on the solution element, it is presented with the conceptual models using the AOR behaviour model to depict the dynamic behaviour of the agent during runtime on a platform independent phase. With that, a range of various negotiation strategies is presented based on the pattern template structure.
Chapter four presents the case study adopted to incorporate the negotiation component into
the Restaurant Finder system as a proof of concept and to verify the agent negotiation patterns
derived. The negotiation component is plugged into the reservation function of the Restaurant
Finder System. The Restaurant Finder System consists of a Restaurant Finder agent
interfacing with a Traveller agent. The Traveller agent will convey its preferences to the
Restaurant Finder agent and negotiate with the Restaurant Finder agent on its reservation
preferences. The main tasks of the Restaurant Finder agent are to map the Traveller's
preferences with the available restaurants in the repository and to propose alternative
reservations to resolve any conflicts in reservation preferences, if any. Two negotiation
strategies are selected for the implementation: single-attribute negotiation and multi-attribute
negotiation. Conceptual models are included to depict the different aspects of the agent: the
motivation, the interaction, the knowledge and the behaviour of the agent based on the pattern
template structure leading to the implementation. Discussion on the implementations of the
negotiation components is carried out. A walkthrough of the case study prototype is presented
to demonstrate the logical flow of the system. A short discussion is presented to reflect on the
experience, observation and the lesson learnt from the entire development process. And to
strengthen the notion, a qualitative evaluation is performed using questionnaires to obtain
feedbacks. Two evaluators were selected as candidates and the results conclusively showed
that the objectives were achieved.

Chapter five wraps up the thesis with conclusion, which includes the summary of the thesis
content by giving a synopsis of every chapter and the future work.
Ch 1: Introduction

Ch 2: Literature Review

Ch 3: Agent Negotiation Pattern

Ch 4: Evaluation of the reusability of the agent

Ch 5: Conclusion

Figure 1.1: Thesis structure
Chapter 2

Literature Review

Chapter one presented an introduction to the agent technology encompassing the intrinsic nature of the software agent, the properties of the agent that contribute to the negotiation system and a brief overview on previous research works on the development of the multi-agent negotiation system. The gap in the literature was identified and highlighted. To bridge the gap, an approach was proposed through the use of a design pattern. A brief introduction to the design pattern was presented thereafter. This forms the basis for pursuing this research. It went on to instantiate the aims and objectives, the research problem and set the boundary for the research proposed.

This chapter will further discuss the negotiation in multi-agent system, describe the components in the negotiation framework for MAS. Follow suit is a review of how the negotiation strategies were modelled from the previous research works and a critical discussion on the aptness of the models used to capture the agent concepts with reusability as the main motivation. With the agent pattern, the reusability feature in the system can be enrooted by providing a structured way of documenting the solutions.

Section 2.1 begins with a brief introduction to negotiation in MAS, highlighting its value and its application by giving some examples of the well-known systems stemming from the academic research. Section 2.2 attempts to give an overview description of the major components required to build a multi-agent negotiation system and projects a generic architecture to show the activities involved when a negotiation is triggered. Branching out to
section 2.2.1, a review of the existing literatures on the design approaches adopted to model
the negotiation strategies from two broad categories which are the modelling approach and
architecture based approach. Section 2.3 will present the observations synthesized from the
review study conducted and propose the use of agent pattern as an approach to address the
issues identified. Section 2.4 will give an overview of agent pattern and the use of pattern
template as a standardised documentation to ensure that all the necessary information and
agent concepts are recorded. Section 2.5 will summarise the whole chapter.

2.1 Negotiation in MAS

Negotiation, in general is a communication between two or more parties to resolve any
disagreements with an aim to reach a compromised solution, advantageous to all counterparts
if possible. From the literature, the definition of negotiation in MAS comes in many forms.
However, Ashri, Rahwan and Luck (2003) had adequately defined negotiation in MAS as "a
form of interaction in which a group of agents, with conflicting interests and a desire to
cooperate, try to come to a mutually acceptable agreement on the division of scarce
resources." Conflicts occur when there are discrepancies to the internal values such as
behaviour, goals, interests and external influences, and are affected by constraints such as
resources availability, time, price (WaiShiang, 2004). To resolve the conflicts, software
agents either cooperate to reach a common agreement or compete to divide limited resources
until a satisfactory outcome is achieved (McCalley, Zhang, Vishwanathan, & Honavar, 2003).
Agents may also coordinate their tasks among each other to accomplish their individual goal
or objective (Li, 2005). The high level social aspects of these agents have made this plausible
through a common and standardised communication platform.
Negotiation consists of a series of processes carried out in multiple stages. The stages that are commonly applied in various literatures involve four main phases: private preparation, joint exploration, bidding and closing (Jonker C. H., 2012). The private preparation stage covers the information gathering of the parties involved, exploring their preferences and learns about the negotiation domain. The joint exploration stage analyses the information collected, refines the negotiation domain and constructs a model of the opponent. The bidding stage defines the exchange of proposals and counter proposals by engaging the negotiation strategy to determine the next offer to propose. The opponent may accept the incoming proposal, generate a counterproposal or to terminate the negotiation process. Finally the closing phase confirms the agreement of the transaction and finalises the transaction.

Various attempts to bring the theoretical research work into practical implementation had been conducted. Several web-based multi-agent negotiation systems had been deployed with varying degrees of service automation. Several examples will be presented in the following paragraphs to show the possible diverse applications of multi-agent negotiation system.

One of the initial and well-known prototypes, Kasbah (Chavez & Maes, 1996) was a project developed by the MIT media lab, provided a virtual marketplace where buyer and seller agents gathered to trade. Kasbah agents were created by the users and once they were furnished with adequate information, they automatically migrated to the marketplace to find potential buyers or sellers (Guttman & Maes, 1998). Kasbah agents were proactive in nature and they negotiated and made decision based on the knowledge acquired. Kasbah buyers used three negotiation strategies in the proposal process: anxious, cool-headed, and frugal, which applied linear, quadratic, or exponential function to increase their bids (Guttman & Maes, 1998).