UNIVERSITY OF BABEȘ-BOLYAI CLUJ-NAPOCA
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BUSINESS INFORMATION SYSTEMS DEPARTMENT

CONTRIBUTIONS TO RESOURCE MANAGEMENT IN COLLABORATIVE SYSTEMS

- SUMMARY -

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„The researcher is the practical man,
the adventurer, the inquisitive,
who believes in research,
who asks questions,
who refuses to believe that
perfection has been reached”

(Henry R. Harrover)

Abstract

In decentralized collaborative systems, the service procurement problem represents one of the main challenges, because in order to build an effective mechanism, the designer must deal with different objectives and policies of various consumers and providers and with the lack of a central authority that coordinates the interactions between participants. Due to the efficiency properties they have, auctions proved to be adequate mechanisms to solve problems characterized by lack of structure. However, in such decentralized environments, establishing a virtual currency to express the price of a certain service also raises difficulties. In this research, we propose a collaborative mechanism based on a *Qualitative English Auction (QEA)* model, to automate the efficient trading of services. The rules of the mechanism should provide incentives for individuals to participate in the system and to collaborate, increasing the social welfare of the entire community. We demonstrate that by approximating the proposed QEA, even with a minimum disclosure of information and in an environment with non-transferable utilities (without price) we obtain optimal results of the mechanism, that are Pareto efficient.

Keywords: *decentralized collaborative systems, resource allocation, service procurement, Mechanism Design, Game Theory, market models, Microeconomics, intelligent agents, strategies, Qualitative English Auction (QEA)*

Contents

INTRODUCTION

i. Motivation

In the context of Globalization and as a result of new existing trends in the Internet field, including Peer-to-Peer [1], Grid [2], ad-hoc networks used in disaster management scenarios or corporations restructured as virtual organizations [3], decentralized computing systems, where resources are distributed geographically, gain more popularity as they help overcoming organizational barriers.

Building a collaborative mechanism for efficient resource allocation and service procurement in such systems is still a challenging and complex task for designers. They must deal with the various objectives and policies of different resource and service providers or consumers, who are interested in maximizing their individual satisfaction. Thus, the trading mechanism should provide incentives for participants to join the decentralized system and to collaborate. In this case, the incentives derive from the individuals' trust in the social fairness provided by the interaction protocol implemented. They have to estimate that they will obtain greater benefits from joining the mechanism and collaborating with other participants, than by acting exclusively on their own.

We are dealing with a *collaboration-competition* duality, which coexists in a decentralized system, where, on the one hand, the participants work together to obtain a particular resource or service and on the other hand, they are competitive, being interested in maximizing their individual satisfaction. In order to induce competition between those who negotiate and seek to maximize their own utility, an efficient collaborative mechanism should treat both aspects: ensure an optimal communication between all participants and provide leverage for the individual who holds the resource or the service. In this context, the collaborative and competitive dual game induced by the mechanism, generates a fair distribution for all participants and ensures Pareto efficient outcomes.

In the present research, our fundamental objective is to address the service procurement problem in decentralized systems, starting from the current difficulties or gaps and to build, step by step, an automated collaborative mechanism to solve this problem in an efficient way. This study is characterized by a high degree of interdisciplinarity, the main objectives being treated in terms of three major areas or axes:

1. *Artificial Intelligence* (decentralized systems, intelligent agents, intelligent search techniques);

2. *Microeconomics* (utilities, preferences, social welfare, market models);
3. *Game Theory and Mechanism Design* (games with incomplete information, strategic behavior, Nash equilibrium, Pareto optimality).

In the next sections, we offer a brief motivation for the existence of duality in decentralized systems, we define the service procurement problem and we discuss the main objectives covered by this thesis.

ii. The collaboration process in decentralized systems

In decentralized environments, such as P2P [1], the main difficulty lies in motivating the free riders to contribute with their own resources or services in the system, in order to collaborate with other members. Peers can be seen as intelligent agents, characterized by individual rationality and selfishness, whose main goal is to realize their objectives and strategies, the interaction between them resulting in a *Multi-Agent System* (*MAS*) [11].

The intelligence attribute plays an essential role in the context of the induced *competition* between individuals, who negotiate for the same service or resource. The result of the collaboration generates Pareto optimal solutions [25] and individual utilities that are fair for all participants.

The *collaboration process* [13] in a decentralized system is based on the idea that the participants from the society, such as consumers and providers, meet the requirements of *communication*, *coordination* and *cooperation* to achieve a favorable agreement regarding the resource or service being transacted. According to the *3C model of collaboration* [14], these elements are detailed as follows:

- *Communication*: is conducted through a protocol which is the cornerstone of interaction between participants. The protocol defines the "rules of the game" and the conditions applied in the case of breaking these rules;
- *Cooperation*: is accomplished through the offers launched by the participants, to achieve the final objectives of the trading mechanism: obtaining Pareto efficient outcomes and maximizing the social welfare of the whole society (fundamental efficiency criteria);
- *Coordination*: is defined considering the actions or strategies adopted by the participants from the society, who are competing to obtain a particular resource or service.

The main subject of the collaborative model that will be developed is represented by the resource or service being transacted. In the next section, we define the service procurement problem in a decentralized system.

iii. The service procurement problem in open systems

Services represent an abstract notion, in the same way that methods are part of the object oriented paradigm [16], the agents having a local ability to perform tasks. In real life situations, there are many services needed by an individual from society. Database validations, financial predictions, medical diagnosis, errors prediction, are just a few examples where an agent's ability is represented by the services he can offer to other members who need them [17].

We will consider multidimensional services, characterized by several attributes, such as: price, quality, delivery time or the penalty factor. This specific detail increases the complexity of the interaction model that will be developed for trading services and it also amplifies the complexity of the agreements that will be concluded between service consumers and providers.

In this context, we believe that the collaborative automated mechanism for services trading in a decentralized system should answer the following fundamental questions:

1. What incentives are offered to providers and consumers to participate in the mechanism?
2. How to ensure social equity within the collaborative decentralized system?
3. How to achieve collaboration between the participants in the mechanism?
4. What will be the rules of the communication protocol between individuals?
5. What strategic behavior will adopt the participants that are in competition for the same service?

All these aspects will be treated after setting some specific objectives that we intend to achieve through this work.

iv. Research objectives

The main objective is to develop an automated collaborative mechanism for the efficient trading of services in decentralized systems. This includes the following aspects:

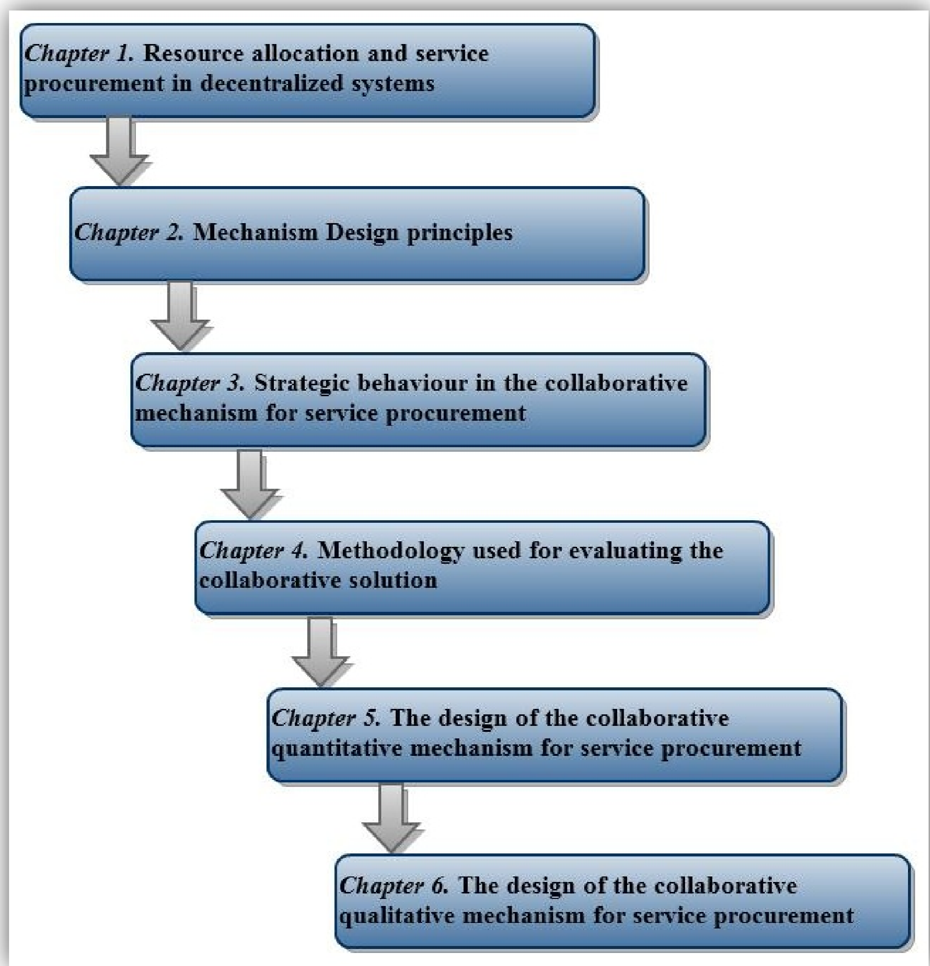
- ❖ Identify the actual difficulties in open systems for developing an automated collaboration in the case of service procurement;
- ❖ Define the specific service procurement problem;
- ❖ Identify the efficiency criteria that should be obtained through the designed model;
- ❖ Compare different market models from the *Microeconomics* theory (especially auctions and negotiations) and analyze which of these models suit best with the proposed scenario;
- ❖ Establish the rules of the interaction protocol in order to provide incentives for collaboration and to ensure social fairness in the community;

- Building intelligent strategies for the participants who compete for the same service, so that the result of the mechanism meets the two fundamental efficiency criteria: Pareto optimality and social welfare.

v. Thesis overview

The thesis is organized in 6 major chapters that present the service procurement problem in a decentralized environment using a deductive approach, from general to particular. Starting from the difficulties or shortcomings encountered in open systems (*Chapter 1*) and considering the general mechanism design principles (*Chapter 2*), we defined step by step the details of a specific model for service procurement: the strategic behavior of the participants in the mechanism (*Chapter 3*), the framework used for implementing the collaborative solution (*Chapter 4*) and the two mechanisms developed: the quantitative one (*Chapter 5*) and the qualitative one (*Chapter 6*).

The thesis overview can be seen in the figure below:



Chapter 1. This chapter starts with identifying the actual challenges in decentralized systems, after that we detail the aspects regarding collaboration and competition among participants and we define the concrete problem for procuring services. Next, we present the main criteria for evaluating the efficiency of a trading model, criteria also grouped in two categories: collaborative and competitive. The chapter ends with a study of several models from literature, developed for solving the resource and service trading problem.

Chapter 2. In this chapter, we discuss the main elements and notations used to define a collaborative economic mechanism. These notations are universally applied in the *Mechanism Design* domain and we introduce them in order to facilitate the understanding of the mechanism design problem, introduced in *Chapter 1*. Also, we present some market models from the *Microeconomics* theory (auction and negotiation models), that we consider appropriate for addressing this problem in the case of decentralized environments.

Chapter 3. We tackle the competitive side of a decentralized system, induced by the strategic behavior of the agents who want to purchase the same service. Collaboration is maintained between all members, but the strategic behavior induces the individuals' desire to maximize their own individual satisfaction, while ensuring as well a result of the mechanism which is according to the principles of social welfare. We use a comparative approach to present different intelligent search techniques, focusing on the advantages and disadvantages of each of these techniques and we describe in detail our own strategy, developed for simulating the qualitative mechanism presented in *Chapter 6*.

Chapter 4. We expose the methodological framework used to evaluate the proposed collaborative solution. We present the initial functionalities offered by the *GENIUS (**G**eneral **E**nvironment for **N**egotiation with **I**ntelligent multi-purpose **U**sage **S**imulation)*[1] negotiation environment and our contribution, which consists of the extension of this framework, namely in the interaction layer, with negotiation protocols that enable the concurrent interaction between multiple participants from the system.

Chapter 5. We present the design of the quantitative model for the automated and efficient trading of services while identifying the main requirements to be met.

Chapter 6. We propose a *Qualitative English Auction* (*QEA*) to model the service procurement problem, where the service is characterized by several attributes, such as: delivery time, quality, expected duration of use or the penalty factor. We present the main motivation for building a qualitative mechanism, the rules of the protocol and the winner determination algorithm. We also describe the possibilities for approximating the *QEA* by concurrent negotiation protocols, to eliminate the shortcomings related to information revelation. This chapter ends by illustrating the

[1] The *GENIUS* [135] intelligent negotiation environment was studied and then extended after the author conducted a doctoral internship at the Technical University of Delft, The Netherlands, Faculty of Electrical Engineering, Mathematics and Computer Science, Man-Machine Interaction Group, under the supervision of Prof. Dr. Catholijn M. Jonker: http://mmi.tudelft.nl/negotiation/index.php/Genius

results obtained in experimental simulations and interpreting the statistics, by which we can evaluate the efficiency of the designed mechanism.

Chapter 1.
Resource allocation and service procurement in decentralized systems

In this chapter, we address the *collaboration-competition* duality that exists in a decentralized system, outlining the difficulties encountered in the process of building an efficient mechanism for trading resources and services. The chapter begins with identifying the current challenges and afterwards we describe aspects regarding the collaboration and competition among participants. We also formulate the service procurement problem and present the main criteria for evaluating the efficiency of a trading mechanism. These criteria are grouped into two categories: collaborative and competitive. The chapter ends with the study of some economics models, extracted from literature, that were designed for solving the defined problem.

In decentralized computing systems, in order to cope with the high flow of messages exchanged between the participants and also with the dynamic evolution of the environment as a whole, the services trading model should be automated. Furthermore, it is important to enhance the society's confidence regarding the social fairness ensured by the mechanism, which represents the basic premise for achieving collaboration in the system.

In this sort of environment, there is both collaboration and competition: each participant is interested in maximizing his individual satisfaction and the optimum is obtained by maximizing the society's overall satisfaction as a result of the collaboration. We also outlined that due to the lack of a central authority, the implementation of intelligent agents that have a high degree of self-determination, represents a viable solution for the existing challenges.

In addition, in this chapter we defined the service procurement problem, emphasizing its main characteristics and presenting the efficiency requirements for developing a potential model. Next, we discussed the main concepts from *Game Theory*, used for evaluating the efficiency of a model and for comparing two or more models. The individuals express their preferences for certain characteristics of the service being transacted and the fundamental criterion to quantify their satisfaction after negotiation is their individual utility. Our main goal is to build strategies for the participants who interact, so that the solution resulted from the mechanism could also meet the Pareto optimality criterion.

In the next chapter, we discuss the issue of purchasing a service, introducing key elements used in designing a trading mechanism. These notations are universally applied in the literature related to Mechanism Design. However, we will present them adapted to our specific scenario.

Chapter 2.
Mechanism Design principles

Since the second half of the twentieth century, *Game Theory* and *Mechanism Design* have been widely used for various collaborative engineering applications. These are considered fundamental tools for modeling, analyzing and solving distributed design problems that involve autonomous agents that interact strategically in a rational and intelligent manner. *Mechanism Design* lays at the intersection of several other fields, such as: *Game Theory*, *Microeconomics* and *Artificial Intelligence*, this area being extended by famous economists like: *Leonid Hurwicz* [81], *Eric Maskin* [82] and *Roger Myerson* [83], who obtained the Nobel Prize in Economics in 2007 for their latest and important research [84]. In the same context, another famous result awarded with Nobel Prize in 1996, was developed by *William Vickrey*, for proving the famous auction that bears his name [85].

Among the fundamental collaborative applications, in the context of decentralized systems, we mention [86]:

- the procurement problem in electronic commerce, between companies and different suppliers;
- the problem of packet routing and network routers interested only in their objectives;
- logistics problems involving the allocation of tasks in several non-cooperative shipping companies;
- airport scheduling problems.

These problems can be regarded as distributed optimization problems, where there is an objective function which depends on the private information held by each participant in the system. A rational agent, who is interested exclusively in increasing his utility, acts strategically and sometimes he will reveal incomplete or incorrect information regarding his goals and preferences. The *Mechanism Design* theory is based precisely on this framework of non-cooperative games with incomplete information and it studies how the private information can be obtained, in order to ensure an effective collaboration within the system. In other words, *Mechanism Design is a reverse engineering of Game Theory* and considers the specification of a game's rules, for achieving a certain objective [84].

Next, we present the main elements and notations used to define a collaborative economic mechanism. These elements are universally applied in the literature and we introduce them in order to facilitate the service procurement problem, described in *Chapter 1*. We also describe some market models from the *Microeconomics* theory (auctions and negotiations) that are suitable for addressing this issue in decentralized systems.

Summarizing *remarks 2.1.-2.5.* specified in this part, we drew the following conclusions:

- The first step in designing a collaborative economic mechanism is to *establish the social choice function* which is mapped on the design problem and will be implemented by the mechanism;
- An appropriate economic mechanism should treat two major issues: *the aggregation of individual preferences* and obtaining each participant's *i* real evaluation θ_i regarding the service (information revelation);
- In order to obtain the individuals' real types, the designer may use *direct* or *indirect* mechanisms;
- The direct mechanisms are not suitable in our case, because, being an environment where there is competition, the participants never reveal their true evaluation of the service;
- However, there are some indirect mechanisms (e.g. Vickrey auctions), which stimulate the disclosure of the real value;
- The final goal in a mechanism is to obtain Pareto optimal outcomes, this being the fundamental efficiency criterion.

In a decentralized system with multiple competing participants, a concurrent negotiation model between service providers and consumers may be a viable solution to tackle the free and unstructured communication, also considering that one individual could be service provider and consumer in the same time. The alternating offers protocol represents a flexible and easy to implement solution for such open systems.

Another solution would be the development of an auction model, which is more structured and with well founded properties in literature. However, these models have a major disadvantage: the relatively centralized organization, which imposes the need for an auctioneer that represents a drawback in the case of decentralized systems.

As a main conclusion, we can say that the development of a hybrid model, which combines the advantages offered by negotiations and auctions, would be appropriate for service trading as it would ensure the maximization of participants' satisfaction, as well as the achievement of Pareto efficient solutions and a high level of social welfare.

In the next chapter of this research, we address the competition side of a decentralized system, generated by the strategic behavior of the agents who want to purchase the same service. Collaboration is maintained between all members, but the participants' strategies induce the desire to maximize their individual utility, while also ensuring a result of the game which is compatible with the social fairness principles.

Chapter 3.
Strategic behavior in the collaborative mechanism for service procurement

In *Chapters 1 and 2* of this research, we indentified the main problems that arise in the case of developing an automated collaborative model for the efficient trading of services in a decentralized system and we presented in detail the main elements used to construct such a model.

The collaborative economic mechanism should include two fundamental parts:

- *The rules of the mechanism*: the stages and the ending conditions;
- *The strategies adopted by individuals involved in purchasing a particular service.*

The first element defines the collaborative aspect of a decentralized system, the effective communication being ensured through the interaction protocol. As discussed in *Chapter 2, section 2.8.,* auction and negotiation models are the most appropriate market mechanisms to cope with the distributed nature of the system, because they offer desirable advantages regarding the rules of the protocol.

The intelligent agents' strategic behavior emphasizes the competition side, specifying how they build their next offer, depending on the evaluation of the service and other information obtained during the interaction. Considering the desire to reach a favorable agreement and the intelligence attribute, the agents' main goal is to maximize their individual utility, the interactions between them generating an optimal outcome.

The fundamental aim of this chapter is to present, using a comparative approach and from our own point of view, different intelligent search techniques, focusing on the advantages and disadvantages of each of them, analyzing if they fit in the proposed scenario. In the first part of the chapter, we discuss the concepts regarding agents' tactics and strategies, describing them in detail, starting from the most rudimentary and inefficient strategy, towards the more intelligent ones, that incorporate different learning techniques.

The main ***contribution*** of this chapter is represented by the own developed strategy, which is based on learning the opponent's preference profile, but also considering a differentiated concession factor on various time intervals. This strategy was built for simulating the *Qualitative*

English Auction (QEA) mechanism (as we shall see in *Chapter 6* of this research). We will also evaluate the efficiency of this strategy, showing that it generates much better results comparing to other strategies based on learning.

The development of an optimal strategic behavior for the agents who interact in order to purchase a service, represents a crucial issue. *Remarks 3.1. – 3.7.* presented in this chapter, lead us to the following conclusions:

- ❖ Obtaining Pareto efficient solutions in a partially competitive environment, where there is incomplete information on both sides (service consumer and provider), is the fundamental goal of a strategy and is a complex issue;
- ❖ If an agent wants to propose favorable offers for his opponent, he has to build a model of his preferences, which he will update after each piece of information received (the opponent's offer in a round);
- ❖ There is a need to include learning techniques in an agent's strategic behavior, to succeed in estimating the competitor's preferences;
- ❖ Considering an appropriate concession factor is also important, to avoid the situation of disagreement (in this case the agent's utility will be 0).

The observations above, regarding the advantages and disadvantages of different strategies, can be viewed in *Appendix 2* of this study.

We also developed a comprehensive strategic behavior that combines the advantages offered by Bayesian learning with a time dependent tactic, considering a differentiated concession factor on various time intervals, until the end of the negotiation. We noticed that the agent who adopts this strategy achieves a higher personal satisfaction than any other agent who adopts for example the classical Bayesian learning strategy. This is due to the concession which depends on time: on the first time intervals, the agent does very small concessions, focusing on learning the opponent's preferences more. The concession step is increased as the time limit approaches. This strategy generates Pareto efficient solutions compared to other strategies presented in this chapter: those based on random walk, trade-off, or classical concession.

After the description of the strategic behaviors that may be adopted by the participants, we focused on describing the own developed solution. Before doing this, we present the methodological framework used to implement the collaborative solution and the changes made in the system to achieve this objective. In *Chapter 4*, we present in detail the *GENIUS* [135] negotiation environment.

Chapter 4.
Methodology used for evaluating the collaborative solution

In this chapter, we describe in detail the negotiation simulator used to evaluate the proposed collaborative solution (which we will present in *Chapter 6* of this research). We mention the initial functionality offered by the system, referring to the execution of bilateral negotiation sessions (of *one-to-one* type), where the communication is ensured by the *Rubinstein*'s alternating offers protocol [114].

The main ***contribution*** lies in extending the negotiation environment, i.e. the interaction layer, by implementing and including negotiation protocols that allow concurrent interaction between multiple participants from the system (of *one-to-many* type). These protocols will be used to simulate the *Qualitative English Auction (QEA)*, described in *Chapter 6*. Also, we have developed intelligent agents that adopt strategies based on Bayesian learning and incorporate the rules of the concurrent protocols.

In this chapter we presented the architecture of the negotiation environment used for evaluating the performance of the collaborative solution proposed in this research. *GENIUS* [135] ensures an easy integration of new interaction protocols between individuals and also the development of the individuals' strategies who adhere to these protocols.

At the beginning, the system included only one communication protocol that provided interaction only between two participants. For testing the collaborative solution, we extended the negotiation environment to allow concurrent interactions, by developing two negotiation protocols and two negotiation strategies adapted for these protocols. The first strategy considers the classical Bayesian learning of the opponent's model, while the second strategy is based on learning, but also considering a differentiated concession according to time. The latter was detailed in *section 3.6.2.*, being originally developed for the case of bilateral negotiation and adapted later for the case of concurrent.

In the next two chapters we will integrate all the concepts described in *Chapters 1-4* and we detail the proposed collaborative mechanism for automated services trading in decentralized systems.

Chapter 5.
The design of the collaborative quantitative mechanism for service procurement

The design of a quantitative mechanism involves establishing the rules of the game, so that they strengthen the individuals' confidence in the social fairness offered, stimulating their adhesion to the mechanism, which are the main prerequisites for achieving collaboration. Social fairness means that, besides an individual's overall objective, which is to obtain a favorable contract for a service, he estimates that he will get a high personal satisfaction, a fact that explains his individual rationality. Thus, considering collaboration between all participants on the one hand and competition between those who "play" for the same service on the other hand, the mechanism must generate results that maximize the social welfare and are Pareto efficient.

In this chapter, we investigate various design models for an automated and quantitative collaborative trading mechanism, while indentifying the main requirements to be met. *Quantitative* means that the price is one of the fundamental attributes evaluated by participants.

In the context of the designed mechanism, we will analyze the following criteria:

- ❖ The *agents' noncooperative nature*: it must be possible for them to take effective decisions locally, based on their own private information and the strategies adopted in the game;
- ❖ The *rules of the protocol* to ensure an efficient communication and social fairness in the mechanism;
- ❖ The process of purchasing a particular service to be completed in a *reasonable time limit*;
- ❖ *Information revelation*: to obtain the participants' true evaluation regarding a service being transacted;
- ❖ The final solution to meet the *Pareto optimality* criterion, this being the most important efficiency criterion.

Next, we define the quantitative mechanism design problem, in the context of the notations specified in *Chapter 2* of this study.

Summarizing *remarks 5.1. – 5.14.* specified in this chapter, we extract the following fundamental conclusions: The design of the quantitative mechanism for service procurement in a decentralized environment takes place based on some essential steps:

- *The description of the design problem*: specifying the domain, number of participants, their types and the true evaluation of them;
- *Modeling the problem* through a social choice function for which we search for an optimal solution x^* and specifying the monetary transfers to be made by the participants. As a quantitative mechanism, the price is the fundamental characteristics of the attribute being transacted.
- *The final decision regarding the mechanism* that will implement the social function defined above: *auction* or *negotiation*.

To *evaluate the efficiency* of the chosen mechanism, we define the following *requirements*:

- *A game theoretic approach is of vital importance*: based on the participants' preference profiles an equilibrium is determined, in the context that each individual adopts a best response strategy to that of the opponents', in order to maximize his own utility;
- We also use *solution concepts*, especially Nash equilibrium, to determine whether an outcome is optimal or not. The solution generated by the mechanism should also meet the requirement of Pareto optimality.

In this chapter, we defined the service procurement scenario, considering 1 buyer and 2 possible service providers. We described in detail the design of two types of quantitative mechanism that are suitable to solve this problem: *auction* and *negotiation*.

The quantitative mechanism was designed starting from the following premises:

- *The evaluation of the service*: Each participant $i \in \{0,1,2\}$ from the mechanism extracts his true evaluation regarding the service in a random way, applying a probability distribution. For simplicity, we considered that the *probability distribution is uniform*, so the participants i extract the values from the interval $[0,1]$;
- *The value* of the service depends exclusively on the participant's preferences. Each individual knows exactly the value of the service for him, but this *information is private*;
- *Risk neutrality:* The participants' utility functions related to the welfare will be linear;
- *Information symmetry:* All agents i from the system, where $i \in \{0,1,2\}$, have the same set of possible values for the service. This means that all participants use the same probability density function ϕ to obtain the value of the service (it follows that $\phi_1 = \phi_2 = \ldots = \phi_n = \phi$).

In the case of designing the quantitative auction mechanism, we extracted the following conclusions:

- No matter which auction mechanism is implemented, based on the strategic equivalence of the auction mechanisms, we can always use the properties of the equivalent mechanisms;
- Designing a quantitative mechanism that has a dominant strategy (*English* or *Vickrey*) represents an optimal solution, as there is no additional effort to estimate other participants' evaluation. The auction mechanisms can be also modeled as multiple concurrent negotiations between the consumer and each provider (on different negotiation threads). In the next chapter, we will exploit particularly this detail, in the context of developing a qualitative trading mechanism. We prove that the proposed *Qualitative English Auction (QEA)* can be approximated by two concurrent negotiation models, thus combining the advantages of the two mechanisms.

Chapter 6.
The design of the collaborative qualitative mechanism for service procurement

In a decentralized environment, purchasing a service generates complex interactions between individuals who cooperate to achieve a favorable contract with the opponent, but also are competitive, in pursuit of their interests. Such a dual society, where *collaboration* and *competition* coexists, is formed by aggregating the different and sometimes conflicting preferences of service consumers and providers and the social optimum is represented by the equilibrium of the game induced by the mechanism.

In this chapter, we proposed an *English auction type of qualitative mechanism (QEA)*, to model the service procurement problem, where a particular service is defined by several attributes: delivery time, quality, expected duration of use and penalty.

Because the proposed mechanism is a *qualitative* one, it has the main *advantage* that eliminates the difficulties encountered by the designer in the process of establishing a virtual currency for a service. However, the main *disadvantage* is that the auctioneer needs to publicly announce his preferences and the bidders can take advantage of this situation.

To eliminate this drawback, we proposed the approximation of the qualitative mechanism using two *concurrent negotiation protocols*. These models generate optimal results even in the case of incomplete information on any side. Thus, the consumer is not forced to reveal his preference profile, is it enough to provide clues after each negotiation round, indicating his current level of satisfaction.

The main ***contributions*** of this chapter can be summarized as follows:

1. We formalize the *Qualitative English Auction (QEA)* for the efficient trading of services in a decentralized system, this model ensuring the social fairness through the rules imposed by the communication protocol;
2. We build two concurrent negotiation protocols to approximate the *QEA*, in order to eliminate the shortcoming related to information revelation;
3. The evaluation of the proposed mechanism through simulations, using the negotiation protocols.

In this chapter, the following *objectives* have been reached:

1. *The detailed description of the building elements of the qualitative mechanism*:
   - The attributes of the service;
   - The weights of the attributes;
   - The evaluation of the service by the consumer and providers;
   - The utility functions;
   - Each participant's reservation value;
   - The preference profile;
2. *The definition of the implementation problem, applied in the case of the qualitative mechanism*, starting from some initial hypotheses and efficiency criteria;
3. *The proof of the Qualitative English Auction (QEA) model*, outlining the differences from the quantitative English auction (based on price);
4. *The building of the algorithm for determine the winner of the QEA*;
5. *Comparing the QEA with other similar mechanisms (e.g. the Qualitative Vickrey Auction* described in [153]);

We believe that the proposed qualitative model is suitable for the challenges that arise in the case of trading services in open computing systems, because the rules motivate the consumers and providers to adhere to this mechanism. Also, the buyer succeeds in maximizing his utility and the result generated by the mechanism is an optimal one in all scenarios.

Next, we treated another important aspect, namely the possibility of approximating the *QEA* by negotiation protocols, evaluating the efficiency of these models through specific simulations.

The main motivation for building concurrent protocols lies in the fact that the buyer does not need to publicly announce his preference profile $\succeq_0$ in order to obtain an optimal outcome of the mechanism. The only information disclosed by the consumer after each negotiation round is related to the winning bid in that round.

In the *first developed negotiation protocol*, we considered that the negotiation between the consumer and the providers ends when all providers except one withdraw from negotiation. Because the total number of possible offers is very high for the considered service negotiation domain, the providers exhaust most of their offers until they reach their reservation values vr_i.

This is the fundamental reason why we have developed a *second concurrent negotiation protocol*, but with a *time limit T* until which the interactions must end. Our goal was to prove that even in the case of a time horizon of 6 minutes available for the negotiation, we can obtain an optimal outcome that is Pareto efficient and maximizes the participants' utilities.

For both protocols, we built intelligent strategies for the providers, based on Bayesian learning, to estimate the consumer's preferences. The learning strategy ensures that the providers propose favorable offers for the consumer and thus obtain a Pareto efficient solution of the mechanism. In the case of the second negotiation protocol, we had to adapt the learning strategy, in order to maintain the efficiency parameters even considering the restrictions regarding the time limit. This learning strategy incorporates a differentiated concession factor depending on the elapsed time of negotiation (*strategy presented in section 3.6.3*)

In the last part of this research, our main objective was to evaluate the effectiveness of the concurrent protocols, thus evaluating the efficiency of the *QEA*. In this context, efficiency is translated into the ability of the protocols to approximate the *QEA*, in terms of the utilities obtained by the consumer and the winning provider after negotiation. Initially, we performed simulations on a sample of 50 negotiation session (randomly drawn from the set of 792 possible games) and then we performed simulations on the whole set of 792 games.

We extracted the following conclusions:

- In the case of the first negotiation protocol with the withdraw condition, the buyer obtained an average utility of 0.087150, which is a little bit higher than that obtained in the *QEA*. On the other hand, the provider obtained an average utility of -0.1134, which is lower than in The *QEA*. The explanation for obtaining a higher utility in the case of the buyer could be due to the learning strategy and also considering the unlimited time for negotiation. Until when they reach their reservation values, the providers exhaust most of their offers and being an ascending mechanism they maximize the consumer's utility in this way;
- In the case of the *second negotiation protocol with the deadline condition*, where *T=6 minutes*, the buyer obtained an average utility of -0.0977, which means that is lower than in the *QEA*. In the same context, the winning provider obtained an average utility of 0.0043 that is a little bit higher than in the *QEA*.

We applied the *Kolmogorov-Smirnov*[157][158] nonparametric statistical test, to verify the correlation between the utility distributions obtained by the consumer and the winning provider, in the case of the two concurrent protocols, comparing with those generated by the *QEA*. We concluded that the concurrent protocol with the deadline condition performs better and this result was obtained also for the whole set of 792 possible games. The main conclusion is that we can achieve efficiency in a short time limit and with a minimum of disclosed information.

CONCLUSIONS

In this thesis, we addressed the problem of achieving an automated collaboration when procuring a particular service in the case of a decentralized system. We tackled the dual nature (*collaboration-competition*) of the system, then we described the service procurement problem, emphasizing the services' main characteristics and we discussed the efficiency requirements for a potential model developed. We also presented the main concepts from *Game Theory*, through which we can evaluate the efficiency of a model and compare two or more possible models.

Next, we described from a personal perspective the main elements used for building a collaborative economic mechanism (*Mechanism Design* domain) and we illustrated, using a comparative approach, the market models from *economic theory* that we considered suitable for solving the existing challenges in decentralized systems.

The competition aspect of the decentralized system was addressed through the intelligent agents' strategic behavior. We specified how they build the next offer that will be launched, depending on the private evaluation of the service and also considering other information obtained during the interaction. We insisted on the intelligence characteristics, which play an important role, as the agents are interested to maximize their individual satisfaction, while the interaction between them generates a result of the mechanism which respects the fairness principles. The ***contribution*** of this part is the detailed description of our own strategic behavior that is based on learning the opponent's preference profile, having various concession factors on different time intervals. This strategy was developed to simulate the collaborative mechanism based on a *Qualitative English Auction* (*QEA*), this model being formalized in the last chapter of this research.

After describing the strategies that may be adopted by the participants in the mechanism, we focused on our own collaborative solution. Before presenting the developed mechanism, we outlined the methodological framework used to implement the solution. We highlighted the *modifications* and *extensions* made in the negotiation environment in order to achieve this objective.

Next, we defined the concrete service procurement problem, considering a scenario with one consumer and two service providers. We described the detailed design of two quantitative mechanisms to solve this problem: *auction* and *negotiation*.

In the last part of this research, we addressed the development of a *qualitative mechanism* of *English auction* type, for the trading of a service characterized by several attributes, such as: delivery time, quality, expected duration of use or penalty. We reasoned that, because the proposed auction mechanism is a qualitative one, it has the main *advantage* of eliminating the difficulties encountered by the designer in the process of establishing a virtual currency to express the price of a service. However, we stated that one of the main *disadvantages* is limited by the need to publicly announce the auctioneer's preference profile, thus facilitating the exploitation of information from the bidders.

To eliminate this drawback, we proposed an approximation of the *Qualitative English Auction (QEA)* by two *concurrent negotiation protocols*. We noticed that these types of models generate optimal results even in the case of incomplete information on any participant's side. This research concludes with some experimental simulations by which we wanted to evaluate the efficiency of the qualitative mechanism developed. We achieved this, seeing that, so far, there is no theoretical proof to analyze the optimality of the outcome generated by the mechanism.

i. Contributions

The author's contributions through this research are summarized as follows:

- We addressed the service procurement problem in decentralized environments, starting from the actual difficulties or gaps in such virtual organizations [162];
- We identified some market models from *Microeconomics* theory that we considered suitable to solve the defined problem [160];
- We treated the dual nature, *collaborative-competitive* of an open system, identifying the main requirements for an efficient service trading mechanism [160];
- The development of a smart strategic behavior, based on learning the opponent's model, which generates an efficient outcome for the individuals who adopt it [161];
- The expansion of the *GENIUS* [135] negotiation environment in order to implement our solution and to allow interactions between multiple participants (at the beginning, the simulator offered the possibility to run only bilateral negotiations) [159];
- The development of a *quantitative model* for trading a service having multiple attributes;
- The development of a *qualitative model* of English auction type (*QEA*) that offers incentives for automated collaboration in the system, the mechanism ensuring through its rules the social equity in the community [159];
- The development of concurrent negotiation protocols that approximate the *QEA*, in order to eliminate the shortcomings related to information revelation by the auctioneer [159];

- Experimental simulations and statistics to evaluate the efficiency of the proposed qualitative mechanism. The main reason is that there is no theoretical proof regarding the optimality of the outcome.

ii. Publications

The dissemination of the research results was done by publishing articles belonging to ISI or BDI category, from top conferences on Artificial Intelligence or Economics. The proposed collaborative qualitative mechanism (*QEA*) was validated through an article presented and included in the proceedings of the *Agent-Based Complex Automated Negotiations (ACAN 2011)* workshop, belonging to the prestigious conference on *Artificial Intelligence*, *Autonomous Agents and Multi-Agent Systems (AAMAS 2011)* [159] and will be published by Springer in 2012. At this moment, two other articles are submitted for evaluation, at the *GECON 2011* and *AAMAS 2012* conferences.

Șerban, L.D., **Ștefanache C.M**., Silaghi G.C., Litan, C.M., *"A Qualitative Ascending Protocol for Multi-Issue One-to-Many Negotiations"*, Proceedings of the 4th International Workshop on Agent-Based Complex Automated Negotiations, ACAN 2011, in conjunction with AAMAS 2011 conference, 2-6 May 2011, Taipei, Taiwan (to be published by Springer in 2012, indexed ISI).

Ștefanache, C.M., *"A Market-Based Approach of Efficient Resource Allocation Mechanisms in Collaborative Peer-to-Peer Systems"*, Economy Informatics Journal, Inforec, 2010, indexed BDI.

Ștefanache, C.M., *"Intelligent Negotiation Strategies for Efficient Service Trading in Open Computing Systems"*, Workshop Intelligent Decission Support Systems, Cluj-Napoca, 2010.

Ștefanache C. M., Simon A. M., Nagy I.M., Sitar-Tăut D.A., "*An Approach of Implementing a Virtual Hotel Organization Using Web Services Technology*", Ambient Intelligence Perspectives, IOS Press, pp. 211-220, 2009, indexed ISI.

Ștefanache C.M., Silaghi G.C., Litan C.M., "*Automated Average Cycle Length Detection in Chaotic Time Series*", International Conference on Intelligent Systems, Modelling and Simulation, Liverpool, England, IEEE Digital Library, pp. 140-145, 2010, indexed BDI.

iii. Future research directions

The future research direction can be conducted based on several axes:

- *Market models from economic theory*: the possibility to formalize a qualitative version of other market models, in addition to auctions;
- *Artificial Intelligence*: The development of other intelligent strategic behaviors, that consider other learning techniques than the Bayesian learning;

- *The negotiation environment*: The expansion of the interaction module, to allow *many-to-many* type of communications between participants;
- *Mechanism Design*: The design of other mechanism than concurrent negotiations, to approximate the qualitative auction mechanism. In this context, before considering this, an excellent research perspective would be the theoretical proof of the approximation mechanism.

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