A Framework for Argumentation-Based Agent Negotiation in Uncertain Settings

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A Thesis

in

The Department

of

Electrical and Computer Engineering

Presented in Partial Fulfillment of the Requirements

for the Degree of Doctor of Philosophy at

Concordia University

Montréal, Québec, Canada

January 2016

CONCORDIA UNIVERSITY

Division of Graduate Studies

This is to certify that the thesis prepared

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Entitled: **A Framework for Argumentation-Based Agent Negotiation in Uncertain Settings**

and submitted in partial fullfilment of the requirements for the degree of

Doctor of Philosophy

complies with the regulations of this University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

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Concordia University, 2016

Automated negotiation technologies are being increasingly used in business applications, especially in the e-Commerce domain. Argumentation-Based Negotiation (ABN), among the existing approaches, has been distinguished as a powerful approach to automated negotiation due to its ability to provide more sophisticated information (arguments) that justifies and supports agents' proposals in order to mutually influence their preference relations on the set of offers, and consequently on the negotiation outcome. During the recent years, argumentation-based negotiation has received a considerable attention in the area of agent communication. However, current proposals are mostly concerned with presenting protocols for showing how agents can interact with each other, and how arguments and offers can be generated, evaluated and exchanged under the assumption of certainty. Therefore, none of these proposals is directly targeting the agents' uncertainty about the selection of their moves nor designing the appropriate negotiation strategies based on this uncertainty in order to help the negotiating agents better make their decisions in the negotiation settings where agents have limited or uncertain information, precluding them from making optimal individual decisions. In this thesis, we tackle the aforementioned problems by advocating an Argumentation-Based Agent Negotiation (ABAN) framework that is capable of handling the problem of agents' uncertainty during the negotiation process.

We begin by proposing an argumentation framework enriched with a new element called *agent's uncertainty* as an important parameter in the agent theory to allow negotiating agents to decide which moves to play and reason about the selection of these moves under the assumption of uncertainty. Then, a method for agents' uncertainty assessment is presented. In particular, we use *Shannon entropy* to assess agent's uncertainty about their moves at each dialogue step as well as for the whole dialogue. Negotiation strategies and agent profiles issues are also explored and a methodology for designing novel negotiation strategies and agent profiles under the assumption of uncertainty is developed. Moreover, two important outcome properties namely, completeness and Nash equilibrium are discussed. Finally, the applicability of our framework is explored through several scenarios of the well-known *Buyer/Seller* case study. The obtained empirical results confirm the effectiveness of using our uncertainty-aware techniques and demonstrate the usefulness of using such techniques in argumentation-based negotiations.

ACKNOWLEDGEMENTS

First and foremost, I am thankful to Allah for endowing me with health, patience, knowledge, and for all the bounties he bestowed on me to enable me to successfully finish this thesis.

This thesis appears in its current shape due to the assistance and guidance of several people. I would therefore like to take this opportunity to express my sincere thanks to all of them. In particular, I would like to sincerely thank my thesis supervisors, Dr. Jamal Bentahar and Dr. Rachida Dssouli, for their invaluable support, patience, precious and never lacking enthusiasm for research, continued encouragement and guidance in preparing and writing papers and this thesis and doing my research during my PhD journey. I would also like to thank Dr. Mohamed Mbarki for his useful and insightful online discussions.

I would also like to extend my gratefulness to all advisory committee members including, Dr. Paolo Torroni, Dr. O. Ormandjieva, Dr. A. Ben Hamza, and Dr. Roch H. Glitho for accepting to serve in the examination committee and for their constructive criticisms that helped me to improve this work.

I am grateful for the opportunity I have been granted to study at the department of Electrical and Computer Engineering (ECE) – Concordia University, which has provided me with an excellent environment and research facilities in which I was able to innovate and come up with new research ideas. In this respect, I would like to thank all the faculty members and staff at ECE and CIISE for their assistance during my studies.

This work was funded by the Ministry of Higher Education and Scientific Research in Libya through the Libyan/North American Scholarship Program represented by Canadian Bureau for International Education (CBIE). I would like to take this opportunity to thank them for their financial support. I am also grateful to Al-Mergeb University, Alkums-Libya for nominating me to pursue my graduate studies in Canada.

I appreciate the truly wonderful friends that I have been blessed with, in Montreal and elsewhere, who have contributed in one way or another to a rich and less stressful life in Canada and helped me enjoy the little free time this PhD allowed me. My gratefulness extends to all my colleagues in the Multi-Agent Systems and Web Services laboratory at Concordia University. Special thanks go to Khalid Sultan, Faisal Alsaqqar, and Ehsan Khosrowshahi-Asl for their nice company and support.

Each member of my family truly deserves my deepest appreciation. I would like to take this opportunity to express my profound gratitude to my beloved mother, brothers, and sisters for their moral support, patience, and continuous supplications during the whole period of my studies.

Finally, but most importantly, my special thanks to my wife (Muna) and my wonderful little boys (Mohamed, Ahmad, and Tameem) for their much needed encouragement, support, love, relentless patience, and sacrifices which have been a pillar of strength for me during the time-consuming process of this thesis.

DEDICATION

To the memory of my father,

To my mother, brothers, and sisters who have been incredibly patient and supportive,

To my wife and little boys who have been giving me the strength through their patient, cheers and sweet smiles.

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LIST OF ACRONYMS

ABAN	Argumentation-Based Agent Negotiation
ABN	Argumentation-Based Negotiation
ACL	Agent Communication Language
MASs	Multi-Agent Systems
AI	Artificial Intelligence
KQML	Knowledge Query and Manipulation Language
FIPA	Foundation for Intelligent Physical Agents
KSE	Knowledge Sharing Effort
DARPA	Defense Advanced Research Projects Agency
KIF	Knowledge Interchange Format
PA	Potential Arguments
AF	Argumentation Framework
RFA	Risk of Failure over Arguments
FRA	Favorite Relation over Arguments
PRA	Preference Relation over Arguments
CS	Commitment Store
CD	Certainty Degree
ROF	Risk Of Failure
CSP	Constraint Satisfaction Problem
CR	Concession Rate
CS_{tr}	Concession Strategies
CWP	Concede Whenever Possible
CNS	Concede if Not Sure

CONS	Concede Only if Not Supported
AS_{tr}	Acceptance Strategies
EA	Easily Accept
RA	Reasonably Accept
HA	Hardly Accept
SSF	Strategy Selection Function
AP	Agent Profile
NE	Nash Equilibrium
CG	Completeness Guaranteed
MDP	Markov Decision Process

Chapter 1

Introduction

In this chapter, we first discuss the scope of our research, which is mainly about decision making in argumentation-based negotiations under the assumption of uncertainty. More precisely, we focus on the problem of agents' uncertainty about the selection of their moves and the strategies they consider in order to make better decisions. Then, we identify the motivations and develop the research questions that we will address in this thesis. After that, we present the contributions of this thesis along with the proposed methodology. Finally, we conclude the chapter by stating the thesis outline.

1.1 Research Scope

Autonomous agents and Multi-Agent Systems (MASs) provide an alternative technology for the design of intelligent and cooperative systems. Over the last decade, considerable efforts have been made to develop novel tools, methods, and frameworks to establish the necessary standards for a wider use of MAS as an emerging paradigm [40]. An increasing interest within this paradigm has been on modeling agent interactions and dialogue systems.

In this direction, several dialogue systems have been put forward in the literature for modeling *Information Seeking* dialogues, e.g., [99, 101], *Inquiry* dialogues, e.g., [31, 32, 90], *Deliberation* dialogues, e.g., [120], *Persuasion* dialogues, e.g., [11], and *Negotiation* dialogues, e.g., [60, 117, 115, 122].

Our focus in this thesis is on one of these dialogue systems namely, "*Negotiation Dialogue Games*", which can be defined as "a form of interaction in which a group of autonomous agents, with conflicting interests, but a desire to cooperate, try to come to a mutually acceptable agreement on the division of scarce resources" [127]. The aim of this interaction is to enable negotiating agents to coordinate their activities, cooperate to reach common objectives, or exchange resources to better achieve their individual objectives.

In agent-based applications, autonomous agents may have conflicts with one another because of their different goals, constraints, and preferences. Hence, it is quite natural that agents with conflicting preferences over multiple issues need to cooperate to achieve their goals. This cooperation can be through the process of negotiation that aim to resolve these conflicts by reaching an agreement on certain issues, taking into account the preferences of each other. Examples of such applications are multi-agent systems that include conflicts over the usage of joint resources or task assignments, conflicts concerning documents allocation in multi-server environments, and conflicts between a buyer and a seller in e-commerce settings. In the literature, there exist three approaches to negotiation namely, *Game-Theoretic Approach* (e.g., [95, 112]), *Heuristic-Based Approach* (e.g., [49, 67]), and *Argumentation-Based Negotiation Approach* (ABN) (e.g., [8, 13, 18, 29, 33, 62, 87]).

The ideal negotiation process would enable negotiating agents to follow their proposals, which they value most, with supporting information so that they can reach a faster agreement. Given this, a growing body of research is now emerging to advocate ideas by which agents can increase the likelihood and quality of an agreement by advancing arguments for and against proposals, which influence each others' beliefs and objectives. In fact, the argumentation-based approach, which is the focus of this thesis, is distinguished as a powerful approach to negotiation [1, 18, 33, 87, 109]. This approach came to overcome the limitations of the two other approaches; game-theoretic and heuristic-based approaches, by using additional information supporting the exchanged offers, so as to make these offers more attractive to the opponent and therefore facilitate the achievement of an agreement. The aim of this extra information is to provide explanations and justifications about the offer made which, in turn, can reduce the uncertainty about the negotiating agents' preferences (without revealing their exact preferences) and moves selections. By so doing, this information reduces the time and effort to reach the desired agreement by allowing the negotiating agents to limit their search to a small number of proposals they value most. The main idea behind using argumentation in negotiation is to provide negotiating parties with the ability to support their offers with arguments that play a key role in the negotiation process to convince each other [30, 54]. Therefore, it allows the participants in the negotiation to not only exchange offers, but also reasons and justifications that support these offers in order to mutually influence their preference relations on the set of offers, and consequently on the dialogue outcome. Argumentation theory has recently gained an increasing popularity in the area of Artificial Intelligence (AI). It has been widely investigated and used in various applications such as modeling and analyzing dialogue games [26, 30, 110], and supporting decision making under uncertainty [16, 19, 43, 55, 83, 94]. Moreover, argumentation theory provides a powerful tool to represent, model and reason about dialogue moves, strategies and dialogue outcome. In this context, argumentation-based negotiation is considered as an effective way to enrich the agents' knowledge about each other to coordinate their negotiation moves and cooperate to achieve agreements as collective goals. It has been proposed

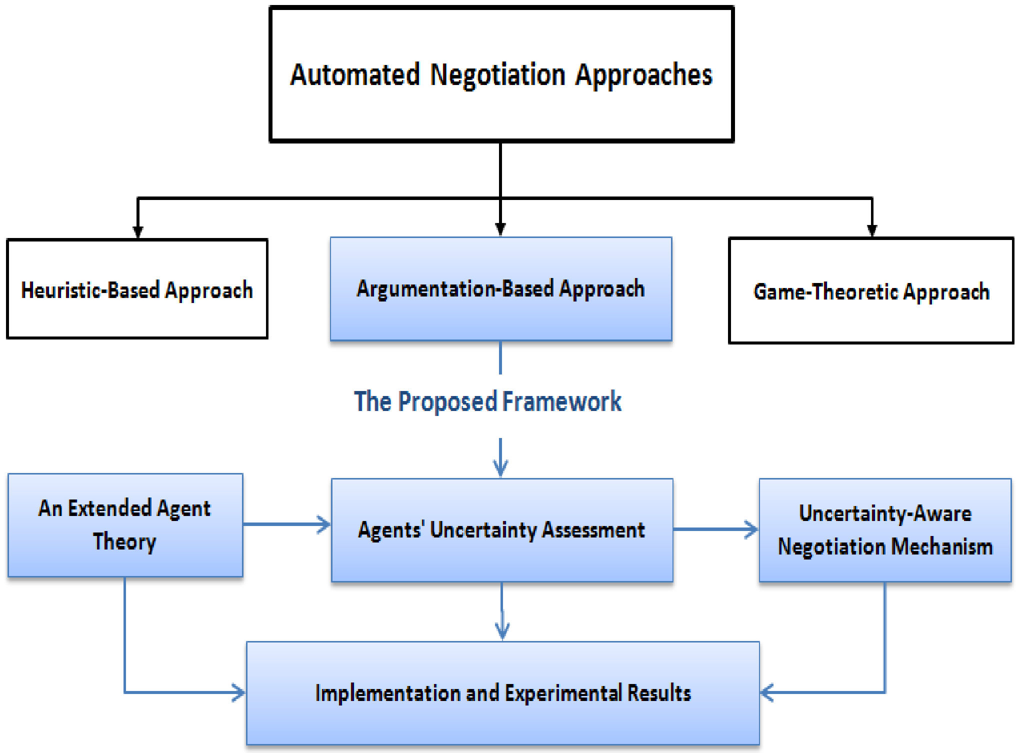

Figure 1.1: Research scope

and studied with the purpose to contribute in the success of automated negotiation, which needs solid decision making mechanisms and effective strategies to ensure the quality and efficiency of the achieved agreements. It is worth mentioning that we only focus on bilateral argumentation-based negotiation in which only two agents are involved in the dialogue. Figure 1.1 depicts the context of our research.

1.2 Motivations and Research Questions

Automated negotiation applications are becoming important tools in our everyday life. In most cases, these applications are composed of multiple agents (i.e., multi-agent system) interacting with one another, each with its own aims, preferences, and objectives for the sake of achieving some goals over some issue(s) of contention. In such complex systems, agents' uncertainty related to decision making is inevitable, and generally speaking, cannot be predicted in advance. However, current proposals for automated argumentation-based negotiation, for instance [37, 53, 57, 77], assume typical negotiation settings in which agents negotiate under the assumption of certainty, where in fact, the role of uncertainty cannot be neglected and it is essential in any negotiation settings in order to achieve better outcome. Therefore, a mechanism to deal with this uncertainty is needed to help negotiating parties make better decisions about their actions in order to manage and resolve any conflicts that might occur during the course of negotiation. Moreover, a carefully designed negotiation mechanism is required in order to allow negotiating agents to better decide about the acceptance of other's proposals or to make concessions in order to convince others about their offers. To elaborate more on the agent's uncertainty when they make their decisions, let us consider the following motivating example.

Motivating Example: In the telecommunication market in Canada, let us assume that there are three different companies namely Bell, Rogers, and Telus that provide customers with different services such as home phone, cell phone, internet, etc. Assume that these companies are deploying software agents to call and receive calls from customers regarding these services. Moreover, assume that these software agents are authorized to negotiate with customers to provide the service within specific limitations based on the flexibility they have been granted, and on the customer interest (preferences). Our interest here is to investigate the agents' uncertainty when they select their offers to advance to the customers at each step, and the strategies that they can play in order to achieve better outcome. Suppose that the software agent that represents the customer is calling the software agent that represents one of the companies (let's say Bell) to ask for a specific service (let's say internet). At that moment, the agent representing the company has various choices of offers

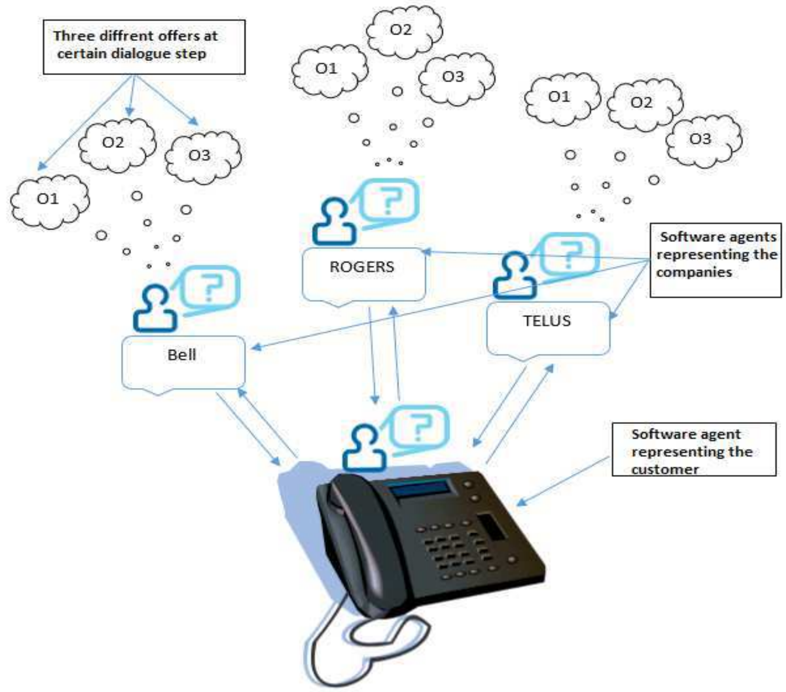

Figure 1.2: Motivating example: Telecommunication market

to advance to its customer; e.g., (o_1, o_2, o_3). In order to be sure that it picks the right choice for its customer, which can be a deal (the customer accepts the offer), Bell agent needs to know the probability of each offer to be accepted by the customer in order to play the one with higher probability, which means avoiding choices with high risk of failure. In other words, the agent needs to know the uncertainty degree about its choice, and its uncertainty about the selected offer to be accepted by the addressee (the customer). Moreover, which strategy to adopt based on the opponent's strategy considering the encountered uncertainty degree about the selected moves is another important factor that has to be considered in the negotiation process in order to guarantee the achievement of agreement. Figure 1.2, depicts the whole picture of this scenario.

The underlying motivation of this thesis is to address the above mentioned uncertainty issues by providing a technique that assess this uncertainty, and provide the negotiating agents with flexible capabilities so that agents can reach better agreements through automated negotiation in uncertain and dynamic environments. To do so, we address some research questions, we name them **RQ1**, **RQ2**, **RQ3** ...... etc., and we will provide the answers for all these questions later on throughout the main contributions of this thesis. We also back our contributions by a proof of concept using a concrete case studies.

Our first research question will be on the argumentation system and the agent theory that are being used in argumentation-based negotiation. We have noticed that most proposals in the literature are either using the same abstract argumentation system of Dung [42], which simply contains a set of arguments and attack relation among them, or extending this argumentation system to include some new parameter(s) that serve the proposed framework (see e.g., [4, 8, 18, 20, 56, 57, 88]). However, none of the existing approaches has considered the uncertainty factor in the agent theory to assess negotiating parties in making better decisions about their moves. Thus, the first research question would be as follows:

- **RQ1:** *Which argumentation system and agent theory to use in order to allow negotiating agents to reason about their uncertainty?*

It has been demonstrated in [87] that an intelligent agent uses its argumentation theory and its reasoning models to always select the most relevant argument (here relevant argument means that the argument is related to the negotiation subject) at each dialogue step. However, there is still a doubt that the selected argument is the right one, and it will be accepted by the addressee. This selection mechanism assumes typical negotiation settings, in which agents negotiate under the assumption of certainty, which means, it ignores the uncertainty aspect during the selection process. Also, the selection mechanism is not linked to the agent's reasoning models. Therefore, a selection mechanism that considers these important factors is required. So, the second research question is:

- **RQ2:** *How can we design a selection mechanism that allows an agent to reason about and decide on the selection of the most relevant argument based on its uncertainty?*

To allow negotiating agents to pick up the move with less uncertainty degree of acceptance (the most likely to be accepted), this uncertainty has to be known or there should be a way to assess this uncertainty at each dialogue step. Therefore, evaluating the uncertainty degree of the dialogue moves is a very significant issue, yet to be addressed to ensure quality developments of negotiating agents. Thus, the third research question would be:

- **RQ3:** *Which method to be used in order to assess agents' uncertainty in argumentation-based negotiation?*

The decision about which proposal to advance is based on the evaluation of the set of available moves at each dialogue step in terms of agents' constraints, preferences, and uncertainty degree which directly influence the negotiation outcome. This is because the actions of the negotiating parties, their preferences, and the constraints under which they are negotiating to determine their individual areas of interest (agreement space) are not known a priori. Thus, in order to increase the chance of successfully entering the agreement space, and consequently achieving an agreement, negotiating parties need to be provided with a mechanism to evaluate their proposals in terms of their constraints, preferences, and uncertainty degree which, in turn, help them decide better about the selection of their moves. Hence, the fourth research question is:

- **RQ4:** *How can we help the negotiating agents evaluate their proposals (offers/arguments) at each dialogue step based on their constraints, preferences, and uncertainty degree to better decide about the selection of their moves?*

Another point that attracted our attention while reviewing the literature is the limitation of the existing approaches in handling the negotiation strategies. In fact, designing an effective negotiation mechanism for open distributed applications is a major research challenge. Although negotiation strategies have been widely studied, e.g., [23, 24, 37, 53], considering agents' uncertainty in the design of such strategies has never been materialized in former studies. Moreover, the vast majority of existing proposals in argumentation-based negotiation have focused on one negotiation strategy at the time, and without considering uncertainty issues (e.g., [24, 56, 77, 111]). However, strategies such as concession and acceptance cannot be separated and they are closely influencing each other in the negotiation settings. Thus, there is a need for designing an uncertainty-aware negotiation mechanism that considers both concession and acceptance strategies. Therefore, the fifth research question would be:

- **RQ5:** *How can we design a negotiation mechanism that considers both strategies (acceptance and concession) in order to insure better negotiation outcome, and how those strategies could be evaluated?*

The last research question would be about the validation of the proposed techniques and mechanisms as follows:

- **RQ6:** *How can we validate the proposed technique for agents uncertainty assessment, and the proposed negotiation mechanism?*

1.3 Thesis Contributions and Methodology

The ultimate objective of this thesis is to develop a framework for decision making under the assumption of uncertainty in argumentation-based agent negotiation. The discussion in

Section 1.2 shows that agents' uncertainty about the selection of their moves and considering this uncertainty in adopting the appropriate negotiation strategies in argumentation-based negotiation is an important and challenging topic of research. So, in this thesis we aim to investigate how agents can make better decisions about the selection of their moves considering their uncertainty. More precisely, we show how an agent can decide which move (offer/argument) to play from a set of potential proposals in the presence of uncertainty. A part of this thesis is built on and extends the preliminary results of my Master's thesis [81]. However, in that work the focus was on a general negotiation dialogue game where arguments are not considered. Moreover, only the uncertainty about the moves was investigated, without taking the opponent and its beliefs into consideration. Hence, considering the probability for a move to be accepted by the addressee in the selection process based on the classification of arguments, formalizing and identifying the impact of strategies and tactics on the selection process, and analyzing the computational complexity of this process, are novel contributions of this thesis. Therefore, the aim of this thesis is to propose a flexible negotiation mechanism that ensures and facilitates the achievement of an agreement (if such an agreement exists) under the assumption of uncertainty. This thesis adds to the state-of-the-art of argumentation-based negotiations six contributions as listed below. The methodology we are following is illustrated in Figure 1.3. The figure depicts the whole structure of our framework in which we link the contributions to each other, map these contributions to the thesis chapters, and show where we answered each research question.

Contribution 1: An extended agent theory that allows the negotiating parties to reason about and decide on the selection of their moves in the presence of uncertainty.

More precisely, we take as a staring point, the argumentation system and agent theory proposed by Mbarki et al. in [88], and the work of Amgoud and her colleagues [18], which

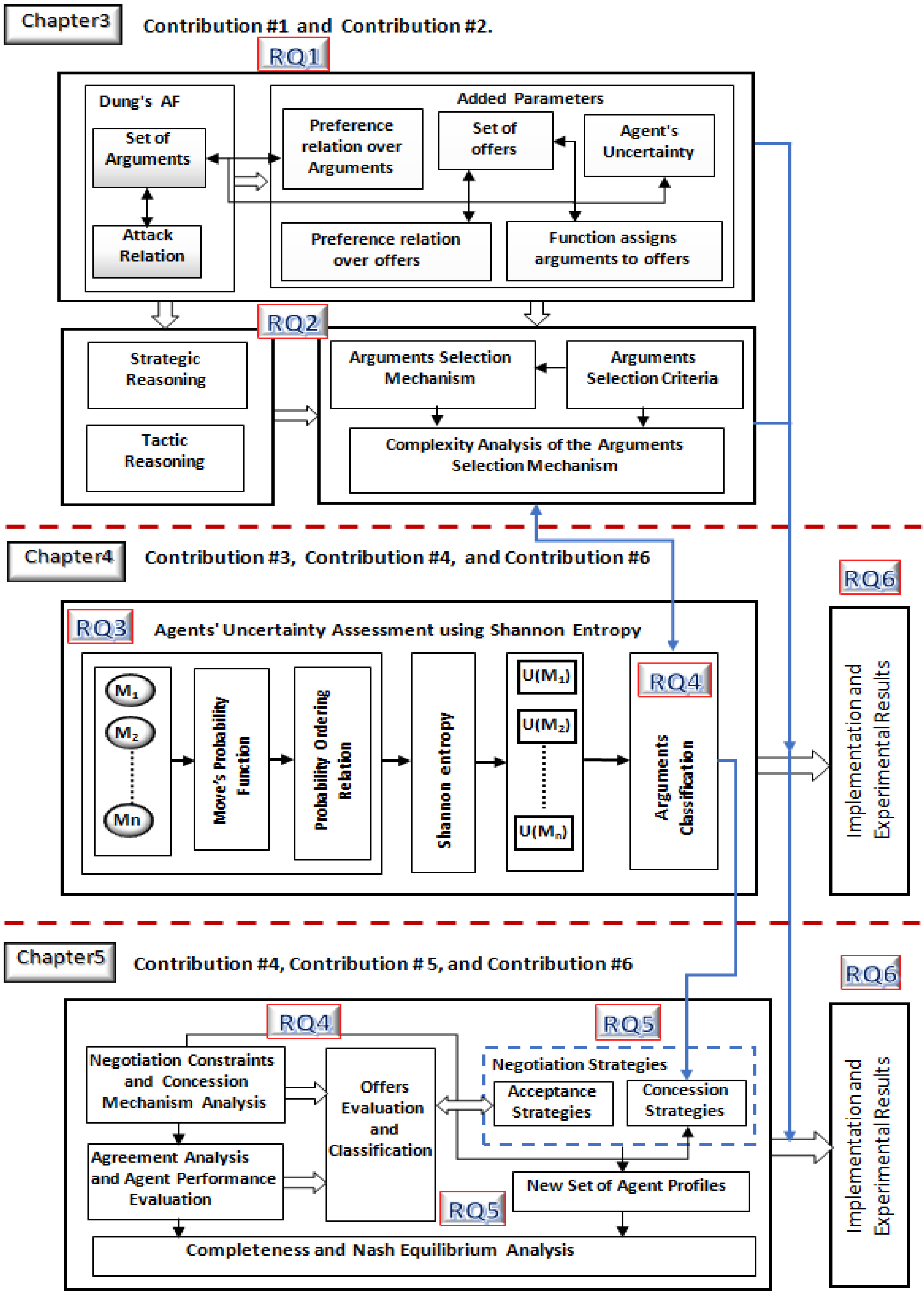

Figure 1.3: The proposed framework

were built on Dung's abstract argumentation framework [42]. Then, we incorporate a new operator, *agent's uncertainty*, to present the agent's theory in a more abstract way to include the negotiation constraints, the arguments owned by the agent, a conflict relation among those arguments, a preference relation over arguments, a set of offers, a preference relation over offers, a function that specifies the argument(s) supporting each offer, and a function that returns a real number representing the agent's uncertainty about the selection of its moves [83, 84, 89]. This contribution answers the research question **RQ1**.

Contribution 2: A new argument selection mechanism that allows the negotiating agents to select the most appropriate argument based on its uncertainty degree, i.e., the more likely to be accepted by the opponent.

The selection mechanism is mainly designed based on the risk of failure of argument (the likelihood for the move to be rejected by the addressee), how much it favors an argument over other arguments, and how much an agent prefers an argument over others. We call these three criteria "Arguments Selection Criteria", we examine these criteria for the set of available arguments to order them based on their relevance degree (here the relevance of argument is based on the probability to be accepted, and consequently on the agent's uncertainty) to help the negotiating parties select the most appropriate (relevant) argument. In addition, we present an analysis of the computational complexity of the argument selection mechanism and discuss two reasoning mechanisms namely, strategic and tactic reasoning to allow the negotiating parties reason about the selection of their moves. [84]. Thus, this contribution answers the research question **RQ2**.

Contribution 3: An evaluation method to assess agents' uncertainty in argumentation-based agent negotiations.

More precisely, we use Shannon entropy to assess agents' uncertainty about the selection of their moves. In fact, at each step, the agent is assumed to have different choices, each choice is associated with a probability value reflecting the importance of the information included in that move, which can be used to convince the opponent. The higher probability an argument has, the more likely to be accepted. We conducted our analysis under the assumption that negotiating agents are rational and aim to perform actions that will result in the optimal outcome for themselves in the presence of uncertainty. So we measure the uncertainty of each move at each dialogue step, then we measure it for the whole dialogue in three methods; i) by taking the average of the uncertainty degrees of all dialogue moves, ii) by computing all possible dialogues that can be generated from all possible moves and compute their probabilities, then use Shannon entropy to get the uncertainty of the dialogue, iii) using hypothesis testing, especially in the case of dialogues that last long. Moreover, based on the uncertainty assessment, we proposed a novel classification for the set of the potential arguments and showed that this classification is compatible with the probability that the moves supported by those arguments will be accepted. Thus, considering the probability for a move to be accepted by the addressee in the selection process based on the classification of arguments is another novelty of this research. Moreover, we analyze different situations of agents' uncertainty based on the available arguments and their respective classes at each dialogue step. In addition to the theoretical analysis of agents' uncertainty, we discuss the implementation of the proposed approach by applying it on a concrete case study (Buyer/Seller) scenario [83, 84]. This contribution answers the research questions **RQ3** and part of question **RQ4**.

Contribution 4: The analysis of the needed negotiation parameters and the proposition of some metrics that are related to the negotiation progress, negotiation outcome, and the agents' performance.

To help negotiating parties make better decisions about whether to make concessions or not and whether to accept others' proposals or reject during the negotiation process.

In particular, we analyze the negotiation constraints to specify the negotiation space and the possible agreement space to help negotiating parties enter this area and consequently achieve their goals. To enter the agreement space, negotiating agents should make some concession until reach an acceptable offer for both of them. Therefore, we present an assessment for the concession mechanism and compute the amount of the concession an agent can make at each dialogue step to assess agents reach better outcome that makes each agent as much as it can better-off. We also propose some metrics that evaluate the negotiation outcome and the negotiating agents' performance. Finally, we present an evaluation for the set of potential offers and classify them into four groups based on their acceptability by the opponent and the possibility to concede and make another offer[1]. By so doing, we provide the answer of the rest of research question **RQ4**.

Contribution 5: A new uncertainty-aware mechanism for automated bilateral negotiation using arguments. This mechanism allows the negotiating parties to reason about and decide on the selections of their moves considering their uncertainty.

In particular, the mechanism considers two main sets of negotiation strategies namely, Concession and Acceptance strategies, each of which is composed of three components. The concession strategy set is based on the arguments classification (in contribution 3), whereas the acceptance set is based on the offers classification (in contribution 4). Moreover, a new set of agents' profiles that results from the combination of all possible strategies is presented. Each agent profile consists of one concession and acceptance strategy. Furthermore, we discuss two important outcome properties namely, completeness and Nash equilibrium, which are related to the negotiation outcome and according to the different agent profiles[2]. This contribution addresses the research question **RQ5**.

Contribution 6: The applicability of our framework is explored through several scenarios

[1]Part of these results are published in [89]. An extended and modified version of this contribution is submitted to the Journal of Group Decision and Negotiation.

[2]this contribution has been submitted to the Journal of Group Decision and Negotiation [85].

of the well-known Buyer/Seller case study. The obtained empirical results confirm the effectiveness of using our uncertainty-aware techniques and demonstrate the usefulness of using such techniques in argumentation-based negotiations. By doing so, we answer the last research question **RQ6**.

We believe that these contributions are of great importance since they can be used as guidelines for protocol and agent design in order to contribute to the automation of agent negotiation.

1.4 Thesis Outline

The remainder of this thesis is organised into five chapters. Chapter 2 is dedicated to review the basic concepts and background needed for this thesis. Chapters 3, 4, and 5 are devoted for our contributions, each chapter starts by introducing the related research problems, reviewing relevant work, and then, describes the contribution. In particular, Chapter 3 presents the argumentation system and agent theory that will be used throughout this thesis, Chapter 4 tackles the problem of agents' uncertainty assessment, and Chapter 5 presents a flexible mechanism for automated bilateral negotiation using arguments. Finally, Chapter 6 presents some closing remarks and provides few hints for future directions.

Chapter 2

Research Background

The aim of this chapter is to provide the background needed for this thesis. In Section 2.1, we present the basic concepts of software agent, Multi-Agent Systems (MASs), and Agent Communication Languages (ACLs). Section 2.2 is devoted to dialogue games and their types. In Section 2.3, we explore in details the negotiation in multi-agent systems as it is the focus of this thesis. More precisely, we discuss the need for negotiation and the main components of negotiation which include the negotiation protocol, agent strategies, and negotiation outcome. In Section 2.4, we explore the existing approaches to automated negotiation. Finally, we summarize the chapter in Section 2.5.

2.1 Software Agent and Multi-Agent Systems

In this section, we discuss the basic concepts of software agent, multi-agent systems, and communication languages that agents are using in order to be able to communicate with each other.

2.1.1 Software Agent (SA)

A Software Agent (SA) is a computer program working autonomously and continuously in a particular environment. This implies that this agent is authorized to decide on behalf of the user to reach some goals. In fact, there is no universally agreed definition of the term software agent, however, there is general agreement that *autonomy* is a central issue to the notion of intelligent agent. Therefore, the definition presented here and the Figure 2.1 which represents a simple structure of software agent are adopted from [129].

"An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives".

Ideally, an agent uses its capability to decide about the most appropriate actions. It can also apply some reasoning techniques to analyze the outcome of its actions, act autonomously to achieve its predefined objectives, and cooperate with others to achieve some common goals. Generally, intelligent agents possess the following properties [129]:

- Reactivity: the ability to respond in a timely fashion to the changes in its environment, including those changes that result from the actions of other agents, to satisfy its design objectives.
- Pro-activeness: the ability to exploit opportunities to satisfy its goals, rather than constraining itself to predefined rules (goal-directed behaviour).
- Autonomous: the ability to act independently without direct intervention of other agents.
- Social ability: the ability to interact with other agents in its environment to satisfy its goals.

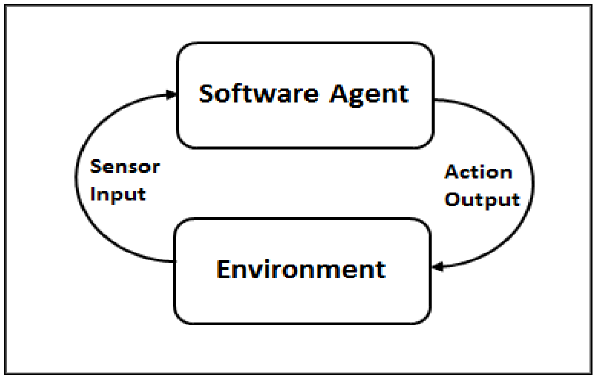

Figure 2.1: A simple structure of software agent in its environment ([129]).

2.1.2 Multi-Agent Systems (MASs)

A multi-agent system is a computerized system in which a group of software agents interact with each other within an environment to solve complex problems that an individual agent cannot tackle alone [129]. The settings of such systems allow participating agents to freely enter and leave the system, thus making the environment continuously changing. Figure 2.2 (from [66, 129]) illustrates the typical structure of a multi-agent system, which contains a set of agents interacting with each other in their environment; different agents have different spheres of influence.

An attractive characteristic of multi-agent systems is that agents can act more effectively in groups. Thus, agents are designed to communicate with each other, with individual or collective tasks, different resources, and different skills to autonomously collaborate in order to satisfy both their internal goals and the shared external demands generated through their participation in agent societies. Multi-agent systems paradigm offers a powerful set of metaphors, concepts and techniques for conceptualising, designing, implementing and verifying complex distributed systems. As a result, these agent societies are becoming more and more similar to the human ones [45].

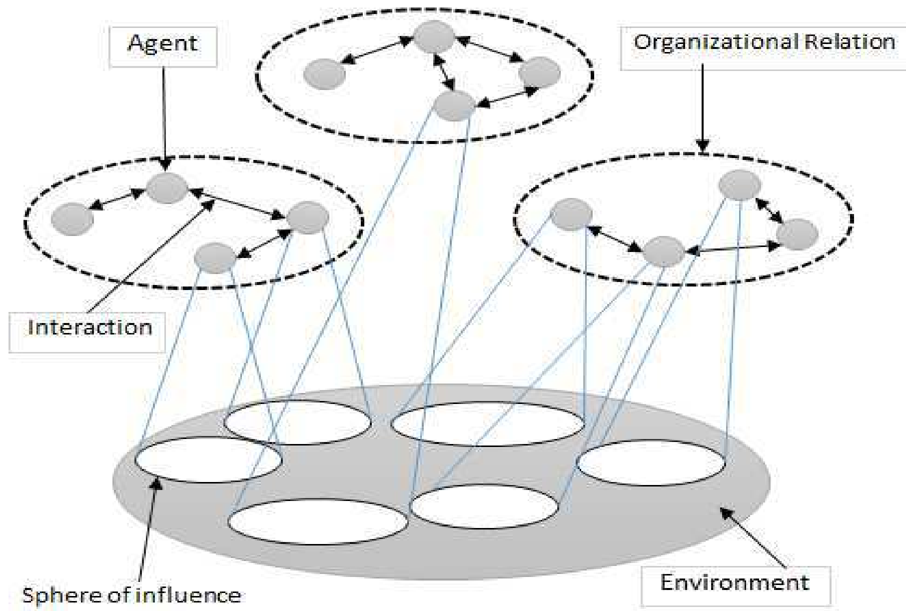

Figure 2.2: Typical structure of a multi-agent system ([129]).

2.1.3 Agent Communication Languages (ACLs)

Communication among agents is a key issue in multi-agent systems. It allows interacting entities to coordinate their actions, share information, and cooperate in order to jointly achieve their goals. Technically, agents are designed in such a way to be able to interact with one another in their environment for the sake of solving complex problems that an individual agent cannot handle. Agents may interact in different ways depending on the underlying objectives. That is, they may communicate to negotiate deals, exchange information, cooperate and even compete in order to satisfy their individual and social goals. In order to communicate, agents firstly need a shared understood, unambiguously specified language to talk to each other and decide what information to exchange or what actions to take. Hence, the artificial language used by those agents to communicate is called Agent Communication Language (ACL). The main objective of such a language is to model a suitable framework that allows heterogeneous agents to interact and to communicate with meaningful statements that convey information about their environment or knowledge [72]. There have been two main attempts for developing ACLs: KQML and FIPA-ACL.

1- KQML

The Knowledge Query and Manipulation Language (KQML) is a language and protocol for exchanging information and knowledge. This language came about as a result of the Knowledge Sharing Effort (KSE)– an initiative of the Defense Advanced Research Projects Agency (DARPA) of the US Department of Defense in the early of 1990s, which became the first *de facto* standard for ACLs in several areas [51]. The overall aim of the KSE is to develop techniques and methodologies for building large scale knowledge bases which are sharable and reusable. Knowledge Interchange Format (KIF) is the content language suggested by the KSE, but KQML messages can use any language for content.

The main primitives of this language are called *performatives* (i.e., message types). As the term suggests, the concept is related to the speech act theory [22]. Performatives define the permissible actions such as ask-about, tell, ask-if and ask-one that agents may attempt when communicating with each other. The syntax of KQML messages consists of a performative and a number of parameters. For example, a message representing a query about the price of a share of IBM stock might be encoded as:

```
(ask-one
        :content (PRICE IBM ?price)
        :receiver stock-server
        :language LPROLOG
        :ontology NYSE-TICKS)
```

2- FIPA-ACL[1]

In the late of 1990s, the Foundation for Intelligent Physical Agents - Agent Communication Language (FIPA-ACL) [52] was formed to produce standards for autonomous and possibly heterogeneous agents interacting within agent-based environments. It arose from attempts to develop an industry and academia standard for agent communication through providing a set of specifications that can be utilized by the developers of agents as a part of their solutions. The term performative is identified by a verb such as *tell* or *ask* which is the core meaning of a speech act.

FIPA-ACL distinguishes two levels in communication messages. At the inner level, the content of messages can be expressed in any logical language. The outer level describes the locutions that agents can use in their communication. The FIPA-ACL's message contains the following attributes: performative, sender, receiver, content, ontology, and language, which closely resemble that of KQML. The FIPA-ACL standard defines 22 distinct locutions, and these have been provided with an operational semantics using speech act theory [22]. For instance, the informal meaning of the request act is that the sender requests the receiver to perform some action.

Besides ACLs, many proposals in the literature have adopted the view of the communication and interactions among autonomous agents as a joint activity regulated by means of dialogue games. In the next section, we will present this concept and discuss the key types of dialogue games in the literature.

2.2 Types of Dialogue Games

Over the last decade, considerable efforts have been made to develop novel tools, methods, and frameworks to establish the necessary standards for a wider use of MAS as an emerging

[1]FIPA-ACL specifications (1997,1999,2001,2002) available at http://www.fipa.org/repository/aclspecs.php3

paradigm [40]. An increasing interest within this paradigm has been on modeling agent interactions and dialogue systems. A dialogue game is a normative model of dialogue, which mainly consists of [6]:

1. A set of moves, e.g., propose, challenge, assertion, question, etc.

2. One commitment store for each conversant where the advanced moves are stored.

3. A communication language for specifying the locution that will be used by agents for exchanging moves during a certain dialogue.

4. A protocol specifying the set of rules governing the dialogues, and

5. A set of agents' strategies realized different tactics agents for selecting dialogue moves (the difference between strategic and tactic reasoning will be defined in Chapter 3).

A dialogue correctly proceeds as long as the participants conform to the dialogue rules, and eventually ends when some termination rules are achieved [6, 86, 102]. In fact, several dialogue systems have been proposed in the literature. Before going further, we discuss the six primary types of dialogue games recognized by Doug Walton and Erik Krabbe in the argumentation literature [127].

Walton and Krabbe Classification of Dialogue Games

Walton and Krabbe [127] have classified dialogue games into six primary types based on first, the information that the participants have at the commencement of the dialogue; second, the goal of each participant; and third, the shared goals between the participants (i.e., goal of the dialogue). The six types of dialogues are summarized in Table 2.1, which lists the initial situation of each type, the participant's goal, and the goal of the dialogue. However, it is possible to refine these six types to subtypes by giving more elaborated conditions on the dialogues, e.g., the type of conflict and the degree of rigidity of the rules. Therefore, for instance, a dispute is a subtype of persuasion, where each participant tries to defend its own point of view.

Table 2.1: Walton and Krabbe classification of dialogues

Type of Dialogue	**Initial Situation**	**Participant's Goal**	**Goal of Dialogue**
Information-seeking	Personal ignorance (One party lacks information)	Acquire or give information	Exchange information
Inquiry	General ignorance (Need to have proof)	Find and verify evidence	Growth of knowledge (Prove or disprove hypothesis)
Persuasion	Conflicting point of view	Persuade other party	Resolution of conflict
Negotiation	Conflict of interest	Get what you most want	Making a deal
Deliberation	Need for action (Dilemma or practical choice)	Co-ordinate goals or actions	Reaching a decision (Decide best course of action)
Eristic	Personal Conflict	Verbally hit out at opponent	Accommodation in relationship (Reveal deeper basis of conflict)

- **Information-seeking Dialogues**

  Nowadays, many spoken dialogue systems implement information seeking dialogues. This means, the user is interacting with the system trying to obtain information from it and perform a transaction, such as travel information, stocks information/banking, movie information and voice portal systems. Essentially, information seeking dialogues implement three main tasks [101].

  1. Elicit the information goal and related attribute-value pairs from the user,
  2. Perform database queries with the information supplied by the user, and
  3. Present query results and allow the user to navigate through the query results.

In addition to these three main tasks, the user may also constrain or expand the queries interactively, correct errors, ask clarification questions, and try to explicitly modify system beliefs and task definitions. Therefore, the main goal of these dialogues is the information exchange, where one participant seeks the answer to question or some questions from another participant, who is believed by the first to know the answer(s).

- **Inquiry Dialogues**

  In inquiry dialogues, the goal is to find collectively an answer to a given question, which cannot be built from the knowledge of each participant individually. So the main goal of the participants to these dialogues is to jointly discover new knowledge. Therefore, an inquiry dialogue does not start from conflict, but rather from a lack of information. When the dialogue starts, the two parties will try to establish the truth or the falsity of some proposition (p), and the dialogue will end when either this has been achieved or they realise that they cannot find a proof [11].

- **Persuasion Dialogues**

  A persuasion dialogue, according to Walton and Krabbe [127], starts when a conflict between two agents appears, so that one agent arguing in favor of a proposition (let's say p) and the opponent defending the opposite ($\neg p$). This means, one party seeks to persuade the other to adopt a belief or point of view it does not currently hold. These dialogues begin with one party supporting a particular statement, which the other party does not support, and the first seeks to convince the second to adopt the proposition. The second party may not share this objective. In this dialogue type, each participant tries to persuade the other to change its mind by presenting some arguments in support of their believes. The dialogue continues until the conflict is resolved [11, 103].

- **Negotiation Dialogues**

  Negotiation dialogues are the most fundamental and powerful mechanism for managing conflicts among negotiators. For instance, negotiation dialogues arise when a resource needs to be divided, and they can commence with a proposal by a participant to divide the resource in some manner, perhaps optimally for that participant. The negotiation will then proceed via responses to this proposal, including counter-proposals which, in the best case, converge on a mutually acceptable settlement. If a negotiation dialogue terminates with an agreement, then the resource has been divided in a manner acceptable to all participants [60].

  Negotiation can be defined as a process by which a group of self-interested agents with a conflict of interest, but a desire to cooperate are trying to come to a mutually acceptable agreement on some issues. In this process, negotiating parties attempt to cooperate or coordinate between both artificial and human agents to achieve a common objective. So, the main goal of the dialogue is to make a deal, however, the individual aim of each agent is to make a deal that maximizes its profit. For an agent to influence an opponent, the opponent needs to be convinced that it should act in a particular way. The means of achieving this state are to make proposals, trade options, offer concessions, and (hopefully) come to a mutually acceptable agreement [67]. Thus, the goal of the dialogue may be in conflict with the individual goals of each participant. Given the ubiquity and the importance of negotiation dialogues in many different contexts, this type will be the focus of this thesis.

- **Deliberation Dialogues**

  While the persuasion dialogue is highly adversarial, deliberation is a collaborative type of dialogue in which parties collectively steer actions towards a common goal by agreeing on a proposal that can solve a problem affecting all of the parties concerned, taking all their interests into account. In deliberation dialogues, the participants are collaborating to decide what course of action is to be taken in some circumstances. Thus, the participants share a responsibility to decide the course of action, and either share a common set of intentions or a willingness to discuss rationally whether they have shared intentions. A key property of this type of dialogues is that the proposal that is optimal for the group may not be optimal for any individual participant. Another property is that each participant in the deliberation must be willing to share its preferences and information with the other party [90].

- **Eristic Dialogues**

  The ultimate objective of eristic dialogues is to win an argumentative exchange over an opponent. In such dialogues, participants quarrel verbally with each aiming to gain victory. Hence, eristic dialogue is not a technique of argumentation, but rather a sort of forum in which an agent can use some argumentation techniques, such as sophistry and vagueness, to get the best from its opponent [126].

We have discussed briefly the six primary types of dialogue games, however, our interest in this research is on one of these six types namely, *negotiation dialogue*. More specifically, we will be focusing on the *argumentation-based negotiations*. The following section elaborates more on negotiation dialogues in multi-agent systems.

2.3 Negotiation in Multi-Agent Systems

Negotiation plays a key role in multi-agent systems. For instance, when one business organization wants to buy or sell goods or have services in an electronic environment, then it always needs some processes that involve negotiation. So, the aim of this section is to specify some fundamental concepts used in the automated negotiation literature. As a starting point, one might ask what is the need for automation of negotiation in multi-agent systems? Indeed, automation of negotiation, which corresponds to negotiation-based e-commerce, has received a great attention from the multi-agent community, because such topics have the potential to reduce significantly the negotiation time and to remove some of the reticence of humans to engage in negotiation [104]. In fact, in multi-agent systems settings, agents need to interact with each other in order to fulfil their objectives or improve their performance. Generally speaking, different types of interaction mechanisms suit different types of environments and applications. Thus, agents need mechanisms that facilitate information exchange, coordination (in which agents arrange their individual activities in a coherent manner), collaboration (in which agents work together to achieve a common objective), and so on. One such type of interaction that is gaining increasing prominence in the agent community is *negotiation*. Negotiation supports endeavors to cooperate and coordinate, and is required both when the participating agents are self interested and when they are cooperative. We adopt the following definition of negotiation from the work by Walton and Krabbe on the philosophy of argumentation [127]:

"Negotiation is 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".

Another question that might be asked would be: why do current electronic commerce technologies not support automated negotiation? The answer, briefly, is that negotiation is difficult, and automated negotiation is even harder. Therefore, automated negotiation is required to facilitate this process by hiring intelligent agents to negotiate on behalf of users. Thus, by conducting this research, we are trying to contribute to the automation of negotiation. Basically, negotiation dialogue has the following three main components [41]:

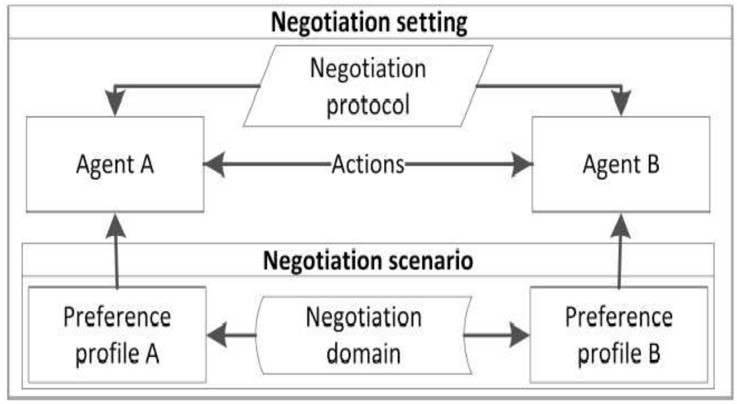

Figure 2.3: Elements of an automated bilateral negotiation ([104]).

- ◇ The mechanism or the protocol, which are the rules of the game that determine who is allowed to say what, and when.
- ◇ The agent strategies within the rules of the protocol (e.g., what offer should the agent make, what information should it provide). It worth mentioning that agents' strategies are incorporating agents' goals and resources.
- ◇ The outcome; which can be one deal from the set of possible deals or it can be a conflict.

In short, we can say that:

$$\textbf{\textit{Negotiation mechanism}} + \textbf{\textit{Participants strategies}} \Rightarrow \textbf{\textit{Outcome}}.$$

An overview of the elements defining an automated bilateral negotiation is depicted in Figure 2.3 [104].

2.3.1 Negotiation Protocols

Communication among negotiating agents is governed by means of protocols. A negotiation protocol is the set of rules that govern the interaction between negotiating parties. This includes the permissible agent types such as the negotiators and any relevant third parties, the negotiation actions such as accepting offers or terminating the negotiation, the conditions that lead to the change of negotiation states, e.g., no more offers or an offer has been accepted by the addressee, and the valid actions of the participants in certain negotiation states [67]. In Argumentation-Based Negotiation (ABN), agents are usually allowed to perform some actions such as proposing an offer, accepting an offer, rejecting an offer, justifying the rejection of an offer, or attacking an argument that supports an offer [41].

Roughly speaking, a protocol determines which messages can be exchanged and in which order. Therefore, negotiation protocols enable agents to exchange and understand messages under specific rules. For instance, a negotiation protocol can specify the exchange of the following messages between two agents [128].

- ◇ Propose an offer
- ◇ Accept an offer
- ◇ Reject an offer
- ◇ Disagree with a proposed offer
- ◇ Give a counter-proposal for an offer

Based on these message types, the following conversation that may occur between two negotiating agents i and j is considered as a part of an interaction protocol for negotiation [128].

- ◇ Agent i proposes a course of action to agent j

◇ Agent *j* evaluates the proposal, and

- sends acceptance to agent *i*,
- sends counter-proposal to agent *i*,
- sends disagreement to agent *i*, or
- sends rejection to agent *i*

In the literature, there exist several proposals for bilateral negotiation protocols. One of the most general negotiation protocols was proposed by Parsons et al. [98]. In this work, the authors described the negotiation as a process of exchanging proposals, critiques, counter-proposals, and explanations. A proposal represents the basic component of the negotiation that refers to an offer or a request. While a critique represents the rejection of an offer and indicates the cause of the rejection, and it can be followed by a counter-proposal. An argument can be seen as an explanation or justification for a proposal or a critique [96]. The focus of this thesis is not on the negotiation protocols, however, we adopt a well-known negotiation protocol in bilateral automated negotiation, which is the alternating offers protocol proposed by Rubinstein in [114]. We use this protocol because of its simplicity, and its variety of use in the literature. This protocol states that the two negotiating agents alternate offers in turns. That is, the agents create a bidding history: one agent proposes an offer, after which the other agent proposes a counter-offer, and this process is repeated until the negotiation is finished under some constraints, for instance, time running out, or by achieving an agreement. This protocol is illustrated by the state transition diagram in Figure 2.4 [130].

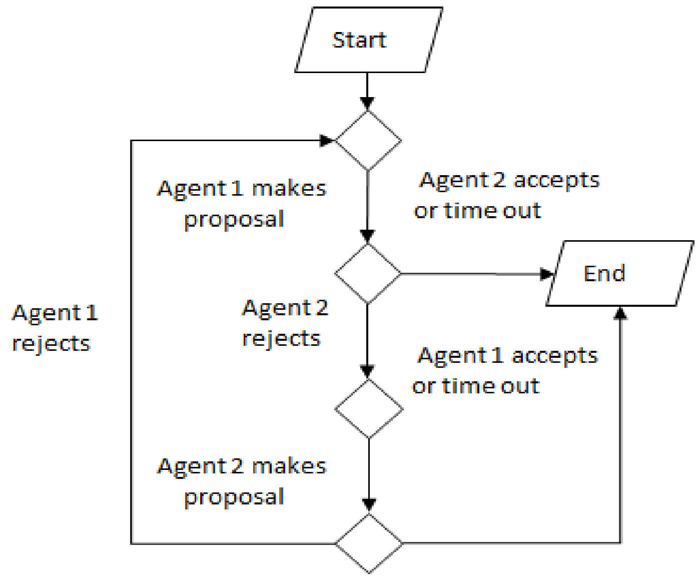

Figure 2.4: Alternating offers protocol ([130]).

2.3.2 Negotiation Agent Strategies

The second component of the negotiation is the agent strategies within the rules of the protocol. With the continuous introduction of new negotiation domains, negotiating agents may encounter different types of opponents with different characteristics. Therefore, an important factor for agents' developers to be considered in automated negotiation is the design of intelligent agents that can perform perfectly in a variety of circumstances. Such automated negotiation agents should be capable of negotiating proficiently within randomly generated negotiation scenarios, with various opponents that are behaving differently according to their designed objectives. The key issue here is the design of a particular strategy that an individual agent can use while negotiating to maximize its own individual welfare. A key difficulty is that, typically, the strategies that work best in theory tend to be computationally intractable, and are hence unusable by agents in practice [67].

Several proposals have been advanced for automated negotiation strategies. Most of them are designed to operate in specific and relatively simple scenarios and are often based on simplifying assumptions (e.g., [47, 50, 53, 64, 111, 132]). A typical example of such an assumption is that the opponent strategies and preferences are known or partially known. This is generally unrealistic, as negotiators tend to avoid revealing their private information, because the shared information may be used to the revealer's disadvantage. As an example, if one agent's negotiation strategy is known to the other agent, the first agent may be at a significant disadvantage. Suppose the buyer knows that the seller's strategy is to accept all offers above a certain (unknown) threshold value. The buyer can begin at 0.00, and repeatedly offer the seller a penny more each time, until the seller's threshold value is reached, at which point the (worst possible, for the seller) deal is made. Given a set of possible deals and a negotiation process, a negotiation strategy represents a tactic that an individual agent may employ to make decisions and achieve its goal. Hence, the negotiation protocol, as well as the set of agent's characteristics such as the amount of knowledge it has about its environment determine the complexity of the agent decision model [104]. As a result, agents' strategies are always required for proper planning and managing the negotiation process. In order to develop such strategies, the automation of negotiation processes is necessary because it is one of the most important issues in business domains.

2.3.3 Negotiation Outcome Space

"Recall that the main goal of negotiation is the allocation of some resources that are acceptable to all negotiating parties. Since in real negotiation settings there are usually different possible allocations (i.e., different possible agreements, deals, or outcomes)" [105]. Then, "negotiation can be seen as a distributed search through a space of potential agreements"

[67]. Hence, the outcome space is a useful way to capture the preferences of both negotiating parties, and there should be some ways to characterize this space under the consideration of some constraints (in Chapter 5, we will discus the notions of agreement space and negotiation constraints in details). Abstractly, the negotiation outcome space can be seen as a set of possible deals $\Psi = \{\psi_1, \psi_2, ..., \psi_n\}$, where n is the size of the search space [105]. Each agent is trying to achieve the best possible outcome that satisfies its constraint and maximizes its utility. Thus, during the negotiation process, a rational agent would not propose an offer that makes its utility less than the utility of the last offer received from its opponent. So, the ultimate goal of each negotiating agent is to maximize its profit by proposing a possible outcome (say ψ_i) from the set of all possible outcomes Ψ by which it gets the maximum utility. As an example, suppose that there are two agents, a seller s and a buyer b negotiating over the purchase of a used car, where the negotiation issue is the price. In this case, one of the negotiation constraints is the budget and each agent will propose and accept offers only within its budget constraint, which ranges between minimum price and maximum price, and an agreement will happen only if there is an accepted price that satisfies the constraints of both agents.

2.4 Approaches to Automated Negotiation

Automated negotiations take place when the negotiation function is performed by software agents—computer programs that act on behalf of users [46, 67, 71]. Even though the current human-to-human negotiation appears to be an extremely complex process, automated agents may not need to be similarly complex. Indeed, in agent-based settings, agents might have conflicts with each other because of their different goals, constraints, and preferences. However, perhaps the most primitive and powerful mechanism for managing these conflicts is negotiation. In the literature, there exist three approaches to automated negotiation as discussed in [67]. These approaches are:

- *Game-Theoretic* approach,
- *Heuristic-Based* approach, and
- *Argumentation-Based* approach.

2.4.1 Game-Theoretic Approach

Game theory, a mathematical and economic theory, is about analyzing strategic interactions among rational agents. This approach shares with decision theory many of the economic concepts originated by von Neumann and Morgenstern [95]. The basic idea of the approach came from the study of some games such as chess. Then rapidly the idea applied to all interactions between rational and self-interested agents such as automated negotiations. Hence, game-theoretic is recognized as the first approach to automated negotiation and it concerns with studying and developing strategic negotiation models based on game theory precedents [95, 112]. The basic idea of this approach is to see the negotiation process as a game in which each participant tries to maximize its own utility. Despite its promising results analysis, this approach suffers from some drawbacks due to the assumptions upon which it was built [18, 67].

Limitations:

- The approach assumes fixed preference relation over offers during the course of negotiation (i.e., it characterises each agent's preferences with respect to the possible outcomes), while in fact, this assumption is not realistic, and it is very common that preference relation over offers may change during the negotiation process.

- The approach assumes perfect computational rationality. This means, each agent knows the space of possible deals and strategies and knows how to evaluate them. Thus, no computation is required to find mutually acceptable agreement within the range of possible outcomes. In other words, agents have an accurate way of determining the quality of the negotiation outcome. However, in most real world cases, this assumption is not true; where agents typically know their own information space, but they know nothing about that of their opponents.

- The approach allows agents to exchange offers only, but not reasons or justifications. However, in everyday life, agents need to exchange more information other than offers in order to support their proposals.

- The approach says nothing about how to program the agent, e.g., it is not clear how to compute the space of possible strategies and how to compute the utility function.

2.4.2 Heuristic-Based Approach

Heuristic-based is the second approach to automated negotiations. It arose as a way of overcoming the limitations of the game-theoretic approach. This approach states that there is often a cost associated with the decision making and computation models. As such, a non-exhaustive way to search for the negotiation space is required. Therefore, heuristic protocols aim to achieve a good solution, but not necessarily an optimal one. Moreover, this approach relaxes some of the strong assumptions made in the game-theoretic approach such as the notion of agent's rationality and their resources [18, 49, 67].

Unlike the game-theoretic approach, the heuristic-based approach specifies how to program the agent's strategies and study the performance of these strategies empirically. However, it does not solve other problems of the game-theoretic approach. In particular, the heuristic-based approach also has some disadvantages as described in [67, 105].

Limitations:

- The approach does not solve the problem of the fixed preference relation over offers.
- The approach adopts an approximate notion of rationality and does not examine all possible outcomes. So, as a result, the outcomes are often sub-optimal instead of optimal.
- In this approach, it is not easy to predict precisely the behavior of both the system and the negotiating agents. Thus, it needs an extensive simulation and empirical analysis.
- Like the game-theoretic approach, it assumes that agents know what they want. That is, agents have an accurate way of determining the quality of the negotiation outcome.

2.4.3 Argumentation-Based Approach

Game-theoretic and heuristic-based approaches as discussed above have some common limitations such as agents are allowed to only exchange offers and the assumption of fixed preference relations and utility function, etc. Thus, in order to outdo these problems, the need for a new approach that can remove these limitations has emerged. So, the third approach to automated negotiations is the Argumentation-Based Negotiation (ABN) approach.

In the last decade, this approach has become popular and powerful. It has been extensively investigated and studied as witnessed by several publications (see e.g., [18, 27, 33, 84]). The main idea behind the argumentation-based approach is to allow the negotiating parties to exchange additional information (justifications and explanations) that support their proposals. Therefore, it allows them to exchange not only offers, but also reasons and justifications that support these offers in order to mutually influence their preference relations on the set of potential offers, and consequently the outcome of the dialogue. The extra information is exchanged in a form of arguments that explain explicitly the opinion of the agent who sent it. Hence, besides rejecting a proposal, an agent can send a critique of the proposal, explaining the reason of the rejection. In addition, an agent may accompany an offer with an argument to convince its opponent to accept this offer.

Argumentation-Based Agent Structure

Before proceed to describe the structure of an argumentation-based agent, let us discuss the main components that constitute a basic or classical non argumentation-based agent, which allow it to engage in any negotiation dialogue. As it can be seen in Figure 2.5, an agent needs to be equipped with the following basic components [105, 109].

1. Locution interpretation: parses incoming messages;

2. Proposal database: stores proposals for future use;

3. Proposal evaluation and generation: ultimately makes a decision about whether to accept, reject, generate a counter proposal or terminate the dialogue; and

4. Locution generation: sends the response to the relevant party or parties.

However, these components are not an idealisation of all proposed models, it is rather a good starting point to show the main differences between a non-ABN agent and an ABN agent.

Unlike the conventional negotiating agents, an ABN agent can exchange more sophisticated information by means of arguments that can influence the decisions these agents can make. Therefore, an argumentation-based negotiating agent must be equipped with additional elements and mechanisms that make it capable of participating in such negotiation dialogues. Thus, in addition to the above mentioned elements of a non-ABN agent, an ABN agent must be equipped with the following [105, 109].

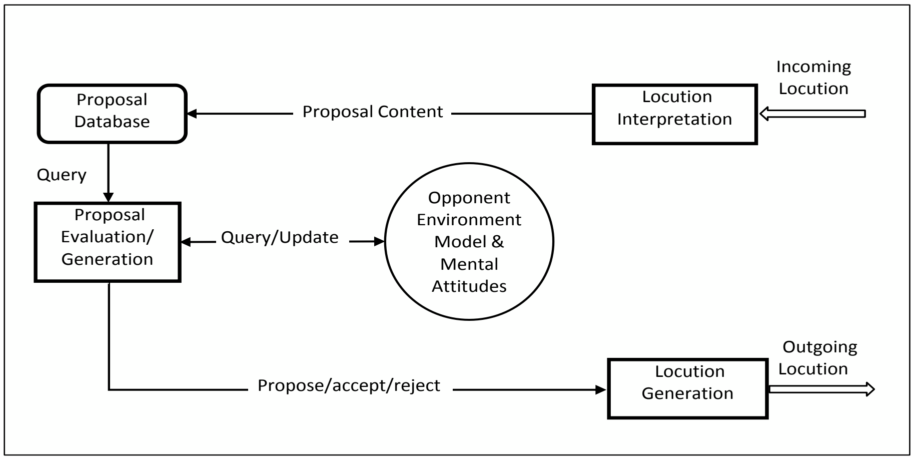

Figure 2.5: Conceptual elements of a classical negotiating agent [105, 109].

1. A mechanism for evaluating incoming arguments and updating the mental state accordingly;
2. A mechanism for generating arguments; and
3. A mechanism for selecting the best outgoing argument from the set of potential arguments.

2.5 Summary

For a convenience reading, we discussed in this chapter the main research concepts and background related to our work. Through our presentation of this background, we emphasized that the argumentation-based approach to automated negotiation is gaining increasing interest and popularity for its potential ability of generating more flexible dialogues than game-theoretic and heuristic-based approaches. However, this approach is typically more complex compared to the other two. The challenge is how to define a clear process for evaluating, generating and selecting proposals (offers and/or arguments), to ensure generating better dialogues and consequently achieving the best agreement, especially in uncertain settings. To do so, in the next chapter, we propose an argumentation system and reasoning models that enable negotiating agents to decide about the selection of their proposals under the assumption of uncertainty.

Chapter 3

Argumentation System and Reasoning Models

In this chapter[1], we present the argumentation system and agent theory that will be used throughout this thesis. The main goal is to allow negotiating parties to reason about and decide on the selection of their moves under the assumption of uncertainty. We also propose a new argument selection mechanism based on some selection criteria and analyze the computational complexity of this mechanism. Moreover, we discuss two reasoning mechanisms namely, strategic and tactic reasoning that allow the negotiating parties to reason about the selection of their moves. The chapter contains a lot of notations, so for convenience reading we listed all the notations in Table 3.1.

[1]The argumentation system, agent theory, and the reasoning models presented in this chapter have been published in the Journal of Expert Systems with Applications [83], and in the Journal of Ambient Intelligence and Humanized Computing [84].

Table 3.1: List of the notations used in Chapter 3

The notation	**The meaning of the notation**
s and b	Seller and Buyer agents
$\mathscr{L}$	A logical language
Γ	The knowledge base of both agents
Γ^i	The knowledge base of agent i
CS	The commitment store of both agents
CS^i	The commitment store of agent i
$\mathscr{O}$	A finite set of offers
$\mathscr{A}$	Set of arguments
$Arg(\mathscr{L})$	The set of all arguments built from $\mathscr{L}$
$Arg = (H,h)$	An argument, where H is the support and h is the conclusion
$\rhd \subseteq \mathscr{A} \times \mathscr{A}$	A binary attack relation between arguments
$\mathscr{T}(S)$	A function that specifies all arguments defended by S, where $S \subseteq \mathscr{A}$
$\mathscr{T}^i$	Agent i's theory
$\mathscr{C}^i$	The set of agent i's constraints
$\mu^i(M)$	The uncertainty degree of agent i about its move M
$\mathscr{M}$	The set of all possible moves
$\mathscr{A}^i$	The set of agent i's arguments
$\preceq^i_{pref-ar}$	A partial preorder preference relation over agent i's arguments
$\mathscr{O}^i$	The set of agent i's offers
$\preceq^i_{pref-o}$	A partial preorder preference relation between agent i's offers
$\mathscr{F}(o^i_t)$	A function that specifies the supporting arguments for the offer o^i_t of the agent i at step t
$NC_{i,j}$	The negotiation context for an agent i committed in a negotiation with an agent j
$\mathscr{S}$	The speaker's strategy
$\mathbb{T}$	A set of negotiation topics
$\mathscr{T}$	The current speaker's tactic,such that $\mathscr{T} \in \mathbb{T}$
T	A formula of $\mathscr{L}$ representing the negotiation topic that corresponds to the global goal
τ	A formula of $\mathscr{L}$ representing the argument on which the speaker should act
$P_{i,j}$	The set of agent i's beliefs about agent j's beliefs $P^{bel}_{i,j}$ and about agent j's preferences $P^{pref}_{i,j}$
Tr	Argumentation tree
$\|H\|_{\emptyset}$	the number of formulas in H that are not in $(\Gamma \cup P_{i,j})$
$\|H\|_{\Gamma}$	The number of formulas in H that are in Γ
$\|H\|_{P_{i,j}}$	The number of formulas in H that are in $P_{i,j}$
$\succeq_{risk}$	Risk binary relation that is complete and transitive
$=_{risk}$	The equal risk relation between any two arguments
$\mathbb{O}_{\mathscr{L}}$	A set of non-strict orders over arguments using the binary relation $\succeq_{risk}$
$Bel_{i\rightarrow j}(p)$	Agent i believes that agent j believes that p holds, where p is a proposition representing a preference
$\preceq^i_{fav}$	Favorite relation over arguments
$\prec^i_{fav}$	The strict favorite relation over arguments
$L(H)$	The preference level of an argument (H,h)
$W^{P_{i,j}}_{(H,h)/(H',h')}$	The weight of an argument (H,h) compared to another argument (H',h')
$\preceq_{rel}$	A relevance ordering relation over arguments
$\mathbb{B}$	A set of goals

3.1 Introduction

The central aim of this chapter is to define the agent argumentation system needed in negotiation dialogues to enable negotiating parties to generate and evaluate their arguments in order to rationally select their best proposals considering their uncertainty. This is mainly a decision making problem based on arguments, and it is usually subject to uncertainty, especially in the absence of enough information. Argumentation systems provide a powerful tool to represent, model, and reason about dialogue moves, strategies, and dialogue outcomes. The main idea lies in the ability to support moves with justifications and explanations, which play a key role in persuasion and negotiation settings [54]. During the last decade, argumentation systems and agent theories have been widely investigated and used to model and analyze dialogue games [26, 30, 76, 79, 87, 110]. Most of the existing proposals are either using the same abstract argumentation system of Dung [42], which simply contains a set of arguments and attack relation among them, or extending this argumentation system to include some new operator(s) that serve the proposed framework (see e.g., [4, 8, 18, 20, 56, 57, 88]). However, to the best of our knowledge none of these approaches has considered the uncertainty factor in the agent theory to assess negotiating parties in making better decisions about their moves. To this end, we present in this chapter an argumentation framework that extends and goes beyond the existing argumentation frameworks [18, 42, 88]. We take as a staring point, the argumentation system proposed by Mbarki and his colleagues in [88], which was built on the work of Amgoud and her colleagues [18], and both of them are extensions of the well-known Dung's abstract argumentation framework [42]. And then, we extend the agent's theory by incorporating a new operator namely, *agent's uncertainty degree* as an important parameter in the agent theory. By doing so, we allow the negotiating agents to reason about and decide on the selection of their moves based on their uncertainty degree.

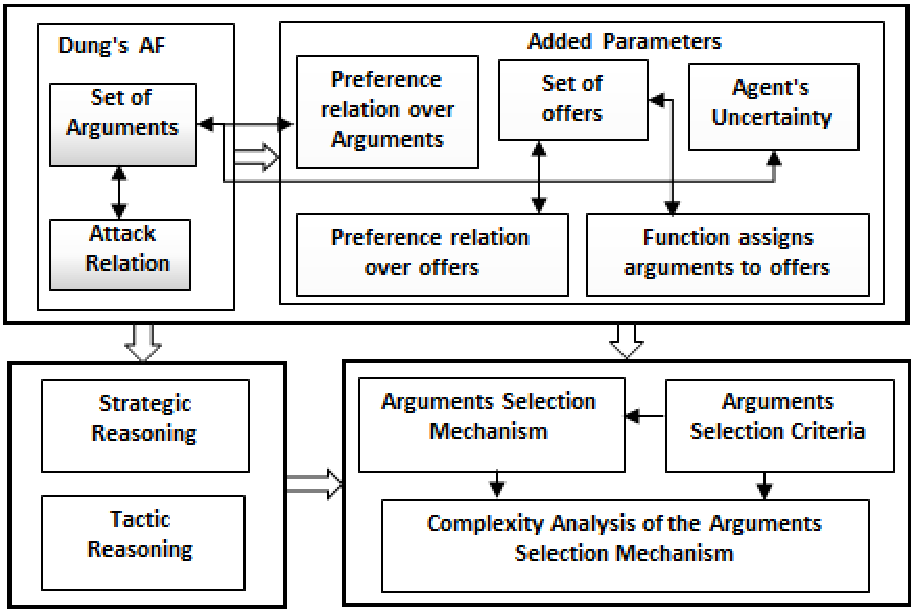

Figure 3.1: A schematic view of the chapter contributions

The chapter makes three main contributions to the automated negotiation literature as illustrated in Figure 3.1. The first contribution is an extended argumentation framework that allows negotiating agents to explicitly influence each other's preferences and reason about the selection of their moves during negotiation, thus dealing with fundamental limitations of bargaining and auction protocols. The second contribution is the proposition of new argument selection mechanism using three criteria that examine the set of potential arguments and order order them to facilitate the selection of the most appropriate argument (the most likely to be accepted by the addressee), and studying the complexity analysis of this selection mechanism. The third contribution is the formalization of the strategic and tactic reasoning to allow the negotiating agents to reason and decide about the selection of the most appropriate argument locally at each dialogue step (using tactic reasoning), and decide about the global communication plan (using strategic reasoning) according to the adopted strategy.

The rest of this chapter is organized as follows. In Section 3.2, we define the Argumentation Framework (AF), in which we make our assumption for our framework and discuss the argumentation system. Section 3.3 is devoted to the agent theory. In Section 3.4, we discuss the relevance of arguments, and in Section 3.5.2, we present a new argument selection mechanism based on some criteria, then we analyze the computational complexity of the proposed selection mechanism. In Section 3.6, we present two reasoning capability for agent's strategic and tactic reasoning. Finally, a brief summary is given in Section 3.7.

3.2 Argumentation Framework

In this section, we briefly discuss the key elements of the argumentation system we use in the thesis. We begin with Dung's abstract argumentation framework [42], which simply consists of a set of arguments and a binary attack relation among them. Thereafter, we present our agent theory in a more abstract way that includes the negotiation constraints, the arguments owned by the agent, a conflict relation among those arguments, the set of potential offers, a preference relation over offers, a preference relation over arguments, a function that specifies the argument(s) supporting each offer, and a function that returns a real number representing the agent's uncertainty about the selection of its proposals. This encodes the fact that when an agent receives an argument from another agent, it can interpret it correctly, and it can also compare it with its own arguments. This also allows an agent to recognize whether the received argument is in conflict or not with its own arguments. However, in its theory, only the conflicts between the agent's own arguments are considered. Moreover, an agent has the ability to decide which move to play based on its uncertainty degree about its moves.

3.2.1 Assumptions

For simplification reasons, we consider in the rest of this thesis a bilateral negotiation in which only two agents are involved in the dialogue. More specifically, we will consider the case of Buyer/Seller scenario in which two agents Seller s and Buyer b are involved in a negotiation dialogue. Generalization to multi party negotiation (i.e., one-to-many or many-to-many) is left to future work.

In our settings, we assume that the following elements are described in a formal language $\mathscr{L}$, where $\vdash$ stands for classical inference.

- A finite and possibly inconsistent knowledge base Γ such that: $\Gamma = \Gamma^b \cup \Gamma^s$, where Γ^b and Γ^s represent the knowledge bases of the buyer and seller respectively.
- An uncertainty degree μ which includes two types of agent's uncertainty; Type I: agent's uncertainty about the selection of its moves, and Type II: agent's uncertainty about the selected move to be accepted by the addressee.
- A finite set of constraints denoted by $\mathscr{C}$. In this thesis, we will deal mostly with the *Budget* and *Time* constraints.
- A finite set of offers denoted by $\mathscr{O}$.
- A Commitment Store CS. As in [78], we assume that each agent is equipped with a negotiation commitment store which will keep track of its different acts and is accessible for all negotiating agents. Formally, for each agent i, where $i \in \{b, s\}$, we denote by CS^i the commitment store of agent i, and the commitment store of the negotiation is $CS = CS^b \cup CS^s$, which is updated as usual after each negotiation turn [12].

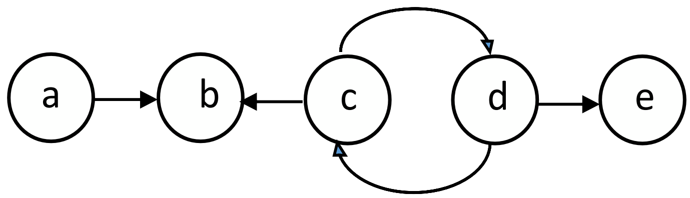

Figure 3.2: A simple argumentation system

- A set of arguments, $\mathscr{A} \subseteq Arg(\mathscr{L})$, where $Arg(\mathscr{L})$ is the set of all arguments built from $\mathscr{L}$. The elements of $\mathscr{A}$ maybe conflicting and in what follows, these conflicts will be captured by an attack relation $\triangleright$.

3.2.2 Argumentation System

Now that we have introduced the key elements that constitute our framework, let us define the argumentation system used in the thesis starting with Dung's abstract framework [42].

Definition 3.1 (Dung's argumentation framework)**.** An Argumentation Framework (AF) is a pair $AF = \langle \mathscr{A}, \triangleright \rangle$ where $\mathscr{A}$ is a set of arguments and $\triangleright$ is a conflict based binary attack relation between arguments.

In fact, an argumentation framework can be represented as a directed graph, called argumentation graph, whose nodes are arguments $\mathscr{A}$ and edges represent the binary attack relation $\triangleright$. Figure 3.2 shows a simple argumentation system that consists of a set of arguments and attack relations between these arguments.

Following the abstract argumentation system proposed by Dung, an argument can be defined as a reason or justification for some conclusion (belief, action, value, goal, etc.). This means, arguments can be information about the agent's state, about the world, or about the target of the discussion that an agent send to another agent to persuade it to accept its position about the issue under discussion. On the other hand, an argumentation system is the reasoning about these arguments (i.e., decide on conclusion).

Definition 3.2 (Argument structure)**.** An argument Arg is a pair (H,h), where h is a formula of $\mathscr{L}$ and H a subset of Γ such that:

1. $H \subseteq \Gamma$.

2. H is consistent.

3. $H \vdash h$

4. H is minimal, so that no subset of H satisfying 1,2 and 3 exists.

H is called the support of the argument, and h is its conclusion.

Example 3.1. : Given a set of well defined formulae (wff) in a language $\mathscr{L}$, where $\mathscr{L} = \{q \rightarrow p, \neg t, g \rightarrow p, m \rightarrow \neg p, p, m, t, q\}$, we can construct the following arguments.

1. $X = [\{q, q \rightarrow p\}, p]$, the support of X is $H = \{q, q \rightarrow p\}$ and the conclusion is $h = p$.

2. $Y = [\{m, m \rightarrow \neg p\}, \neg p]$, the support of Y is $H' = \{m, m \rightarrow \neg p\}$ and the conclusion is $h' = \neg p$.

3. $Z = [\{g, g \rightarrow p, \neg t\}, p \wedge \neg t]$, the support of Z is $H'' = \{g, g \rightarrow p, \neg t\}$ and the conclusion is $h'' = p \wedge \neg t$.

Agent's arguments may be conflicting by contradicting themselves or they can be used to attack the opponent's arguments. In this context, this conflict or attack relation is denoted by $\triangleright$, and defined as follows.

Definition 3.3 (Attack)**.** Let $X = (H,h)$ and $Y = (H',h')$ be two arguments. The argument Y attacks the argument X (denoted by $Y \triangleright X$) iff $H' \vdash \neg h$. That is, an argument Y attacks another argument X iff the negation of the conclusion of X can be inferred from the support of Y.

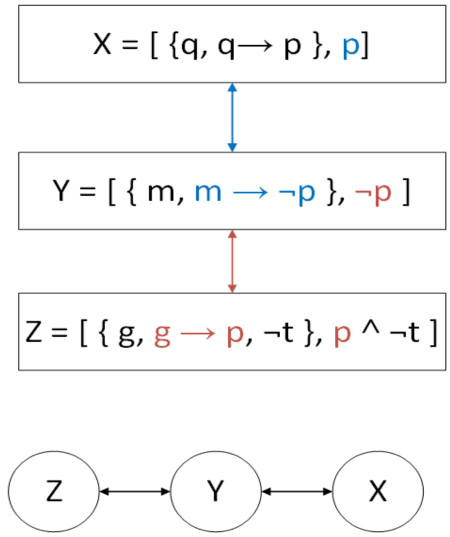

Figure 3.3: A simple attack relations between three arguments

In the previous example (Example 3.1), and by looking at the support and the conclusion of the three arguments X, Y, and Z, we can figure out the attack relations among them. It is obvious that the argument Y is attacking the argument X because the negation of the conclusion of argument X can be inferred from the support of Y, as we can infer $\neg p$ from the support of argument Y. In other words, p is provable in X and it is not provable in Y. In the mean while, the argument X attacks Y for the same reason. Likewise, the argument Z attacks Y and Y attacks Z. The attack relations between these three arguments is depicted and explained in Figure 3.3.

A set of arguments S is said to be conflict-free if and only if there is no attack relation between any pair of its arguments.

Definition 3.4 (Conflict-free)**.** A set $S \subseteq \mathscr{A}$ is said to be conflict-free iff $\nexists$ X,Y $\in S$ such that $X \rhd Y$ or $Y \rhd X$.

A set S defends its elements if and only if any of its arguments is being attacked by another argument that is not part of S, then there is an argument among its elements attacks that argument.

Definition 3.5 (Defense)**.** Let $S \subseteq \mathscr{A}$. An argument X is defended by S iff $\forall\, Y \in \mathscr{A}$ if $Y \rhd X$, then $\exists\, Z \in S$ such that $Z \rhd Y$.

Definition 3.6 (Acceptability semantics)**.** Let $S \subseteq \mathscr{A}$ be a conflict-free set of arguments and $\mathscr{T} : 2^{\mathscr{A}} \rightarrow 2^{\mathscr{A}}$ be a function such that $\mathscr{T}(S) = \{x, x \text{ is defended by } S\}$, then:

- S is an admissible extension iff it defends all its elements.
- S is a complete extension iff it is admissible and contains all the arguments it defends "$S = \mathscr{T}(S)$".
- S is a preferred extension iff S is a maximal (w.r.t set $\subseteq$) complete extension.
- S is a grounded extension iff S is the smallest (w.r.t set $\subseteq$) complete extension.
- S is a stable extension iff it attacks any element in $\mathscr{A} \backslash S$

3.3 Negotiating Agent Theory

In the previous section, we presented and explained the concepts of the argumentation system. In this section, we introduce the agent. Agent theory has been extended in several ways to include more parameters than just a set of arguments and attack relation among them. In this thesis, we take as starting point the agent theory proposed in [88] and extend it by adding the following two components.

1. The agent's uncertainty about the selection of its moves, and
2. A partial preorder preference relation over agent's arguments.

The theory of a negotiating agent i is then defined as follows.

Definition 3.7 (Negotiating agent theory)**.** The theory of a negotiating agent i is a tuple $\mathscr{T}^i = \langle \mathscr{C}^i, \mu^i, \mathscr{A}^i, \preceq^i_{pref-ar}, \mathscr{O}^i, \preceq^i_{pref-o}, \mathscr{F}, \triangleright \rangle$ such that:

- $\mathscr{C}^i \subseteq \mathscr{C}$ is the set of agent i's constraints.
- μ^i is a function that maps each move to a real number between [0,1] to capture the agent's uncertainty about the move.

  $$\mu^i : \mathscr{M} \rightarrow [0,1].$$

  Where $\mathscr{M}$ is the set of all possible moves.
- $\mathscr{A}^i \subseteq \mathscr{A}$ is the set of agent i's arguments.
- $\preceq^i_{pref-ar} \subseteq \mathscr{A}^i \times \mathscr{A}^i$ is a partial preorder relation denoting a preference between agent's arguments. This preference is based on the facts constituting the support of arguments.
- $\mathscr{O}^i \subseteq \mathscr{O}$ is the set of agent's i offers ($\mathscr{O}^i = \{o^i_1, \ldots, o^i_n\}$). This preference is based on value of the offers.
- $\preceq^i_{pref-o} \subseteq \mathscr{O}^i \times \mathscr{O}^i$ is a partial pre-order relation denoting a preference between agent's offers.
- $\mathscr{F} : \mathscr{O}^i \rightarrow 2^{\mathscr{A}^i}$ is a function that assigns to each offer the set of supporting arguments.
- $\triangleright \subseteq \mathscr{A} \times \mathscr{A}$ is a binary attack relation between arguments. For two arguments α and β, we say that α attacks β (or β is attacked by α) if $\alpha \triangleright \beta$ or $\triangleright = (\alpha, \beta)$ holds.

The following example serves as an illustration of the basic components of the agent theory.

Example 3.2. For the argumentation system presented in Figure 3.2, let $\mathscr{O}^i = \{o^i_1, o^i_2, o^i_3, o^i_4\}$ be the set of agent i's offers. Then we can represent the following basic components of the agent theory.

- $\mathscr{C}^i = \{Budget, Time\}$
- $\mathscr{A}^i = \{a, b, c, d, e\}$
- $\mathscr{F}(o^i_1) = \{a\}$, $\mathscr{F}(o^i_2) = \{b\}$, $\mathscr{F}(o^i_3) = \emptyset$, $\mathscr{F}(o^i_4) = \{c\}$.
- $\preceq^i_{pref-o} = \{(o^i_1, o^i_2), (o^i_2, o^i_3), (o^i_4, o^i_3), (o^i_2, o^i_4)\}$
- $\preceq^i_{pref-ar} = \{(a, b), (c, b), (c, d), (d, e)\}$
- $\rhd = \{(a, b), (c, b), (c, d), (d, c), (d, e)\}$
- Associated with each move is the agent's uncertainty (agent's uncertainty will be introduced in the next chapter). Assume that i is involving in a negotiation dialogue, and M_0 is its first move at $t = 0$, and assuming that i was confusing about the selection of the right move at that dialogue step, let us say it was uncertain about 0.25%, then we say that the uncertainty degree about the selection of its move M_0 is 0.25, and we write it as: $\mu^i(M_0) = 0.25$

3.4 Relevance of Arguments

Investigating the relevance of an argument is a crucial issue in argumentation-based negotiation. We define the relevance of arguments based on the negotiation context and according to the selection criteria, that will be presented in the next subsection, in order to allow the negotiating parties to select the most appropriate (relevant) argument from the set of potential arguments at each dialogue step, considering their uncertainty and the last communicative act as well as the previous ones. By doing so, we give the negotiating agents the ability to backtrack and revise their choices in case the selected argument is shown to be weak (i.e., uncertain) or got rejected by the addressee.

Let $\mathscr{L}$ be a logical language, and i and j be the two negotiating agents that represent, in our case, the buyer and the seller agents (i.e., if i represents the buyer, then j represents the seller and vice versa). In what follows, we define the negotiation context for an agent i committed in a negotiation with another agent j as follows.

Definition 3.8 (Negotiation context)**.** The negotiation context for an agent i (speaker) committed in a negotiation with an agent j (addressee) is a 7-tuple $NC_{i,j} = \left\langle \mathscr{S}, \mathscr{T}, T, \tau, P_{i,j}, \Gamma \right\rangle$ where:

- $\mathscr{S}$ is the speaker's strategy,
- $\mathscr{T}$ is the current speaker's tactic, which will be defined after introducing all the context elements,
- T is a formula of $\mathscr{L}$ representing the negotiation topic,
- τ is a formula of $\mathscr{L}$ representing the argument on which the speaker should act,
- $P_{i,j}$ is the set of agent i's private beliefs about agent j's beliefs $P_{i,j}^{bel}$ and about agent j's preferences $P_{i,j}^{pref}$. Thus $P_{i,j} = (P_{i,j}^{bel} \cup P_{i,j}^{pref})$,
- Γ is the common knowledge base that the two agents share about the negotiation context.

This definition refines the definition proposed in [87] by considering the speaker's strategy, its current tactic, and the negotiation topic that corresponds to the global goal.

During the negotiation process, the common knowledge base Γ is constantly updated by adding all the information the two agents agreed upon, including the accepted arguments. We also assume that ($\Gamma \cap P_{i,j} = \emptyset$). It is worth mentioning that if an agent discloses its own private beliefs ($P_{i,j}$), then it will become common knowledge.

In order to define the logical relation between T and τ, let us define the notion of argumentation tree and the notion of path.

Definition 3.9 (Argumentation tree)**.** Let i and j be the participating agents, and $\mathscr{A} \subseteq Arg(\mathscr{L})$ be the set of arguments used by the agents in the negotiation dialogue. An argumentation tree Tr is a 2-tuple $Tr = \langle N, \rightarrow \rangle$ where:

- $N = \{(i,(H,h)) \mid i \in \{b,s\}, (H,h) \in \mathscr{A}\}$ is the set of nodes. Each node is described as a pair $(i,(H,h))$, which indicates that the argument (H,h) is used by the agent i.
- $\rightarrow \subseteq N \times N$ is a relation between nodes. We write $n_0 \rightarrow n_1$ instead of $(n_0,n_1) \in \rightarrow$ where $\{n_0,n_1\} \subseteq N$. The relation $\rightarrow$ is defined as follows: $(i,(H,h)) \rightarrow (j,(H',h'))$ iff $i \neq j$ and (H',h') attacks (H,h).

Definition 3.10 (Path)**.** Let $Tr = \langle N, \rightarrow \rangle$ be an argumentation tree. A path in Tr is a finite sequence of nodes $n_0, n_1, \cdots, n_m$ such that $\forall i, 0 \leq i < m : n_i \rightarrow n_{i+1}$.

In order to distinguish between relevant and irrelevant arguments in a given negotiation context, let us define the notion of irrelevant argument.

Definition 3.11 (Irrelevant argument)**.** Let $NC_{i,j} = \langle \mathscr{S}, \mathscr{T}, T, \tau, P_{i,j}, \Gamma \rangle$ be a negotiation context, i and j be the participating agents, $Tr = \langle N, \rightarrow \rangle$ be the argumentation tree associated to the negotiation, and $(i,(H,h))$ be a node in Tr where $i \in \{b,s\}$. (H,h) is irrelevant in the negotiation context $NC_{i,j}$ iff:

1. There is no path between the node $(i,(H,h))$ and the root of Tr or;

2. $\exists x \in \Gamma : H \vdash \neg x$.

The distinction between relevant and irrelevant arguments allows the negotiating agents to eliminate irrelevant arguments at each dialogue step before ordering the relevant arguments in order to select the most relevant one. In what follows, we discuss three criteria for evaluating the potential arguments and order them based on their relevance to help negotiating agents select the most relevant one at each dialogue step.

3.5 Argument Selection Mechanism

In this section, we propose a new selection mechanism for the set of potential arguments. To do so, we introduce three criteria that can be used for evaluating and ordering the set of potential arguments (PA) in such a way that allows them to better decide about the selection the most relevant argument.

3.5.1 Argument Selection Criteria

1. **Risk of Failure over Arguments (RFA).**

   In order to allow the negotiating agents to select the most appropriate argument during the negotiation process, we first, examine the risk of failure over arguments. This notion is based on the fact that Γ contains certain knowledge, whereas the set of agents' beliefs and preferences $P_{i,j}$ contains uncertain beliefs. Intuitively, the more subjective the justifications, the more risky the arguments. To define the notion of risk formally:

   - let $|H|_\Gamma$ be the number of formulas in H that are in Γ, and
   - let $|H|_{P_{i,j}}$ be the number of formulas in H that are in $P_{i,j}$.

- let $|H|_{\emptyset}$ be the number of formulas in H that are not in $(\Gamma \cup P_{i,j})$,

Definition 3.12 (Risk of failure over arguments)**.** Let (H,h) and (H',h') be two arguments from the set of all arguments $Arg(\mathscr{L})$ that can be built from the logical language $\mathscr{L}$ and $\mathbb{O}_{\mathscr{L}}$ be a set of non-strict orders over arguments using a binary relation $\succeq_{risk}$ that is complete and transitive. The risk of failure over arguments is a function mapping a subset of arguments to a non-strict order.

$$risk : 2^{Arg(\mathscr{L})} \rightarrow \mathbb{O}_{\mathscr{L}} \tag{3.1}$$

The function risk should satisfy the following: $(H,h) \succeq_{risk} (H',h')$ iff:

- $|H|_{\emptyset} \geq |H'|_{\emptyset}$; or
- $|H|_{\emptyset} = |H'|_{\emptyset}$ and $|H|_{\Gamma} \leq |H'|_{\Gamma}$; or
- $|H|_{\emptyset} = |H'|_{\emptyset}$, $|H|_{\Gamma} = |H'|_{\Gamma}$, and $|H|_{P_{i,j}} \leq |H'|_{P_{i,j}}$

The intuition behind using the number of formulas in the definition of risk is that the higher number of uncertain formulas, the higher probability of being attacked.

Example 3.3. :

Let (H_1,h_1), (H_2,h_2) and (H_3,h_3) be three arguments such that:

$|H_1|_{\Gamma} = 3$, $|H_1|_{P_{i,j}} = 1$, and $|H_1|_{\emptyset} = 0$.

$|H_2|_{\Gamma} = 1$, $|H_2|_{P_{i,j}} = 2$, and $|H_2|_{\emptyset} = 0$.

$|H_3|_{\Gamma} = 0$, $|H_3|_{P_{i,j}} = 1$, and $|H_3|_{\emptyset} = 3$.

In this example, the argument (H_3,h_3) is more risky to fail (i.e., rejected by the addressee) than arguments (H_1,h_1) and (H_2,h_2) because the number of formulas in H_3

that are not in $(\Gamma \cup P_{i,j})$, which means in $|H_3|_\emptyset$, are greater than those of $|H_1|_\emptyset$ and $|H_2|_\emptyset$. On the other hand, the argument (H_2, h_2) is more risky to fail than argument (H_1, h_1) because $|H_2|_\Gamma$ (i.e., the certain knowledge) is less than $|H_1|_\Gamma$. So, the function *risk* produces the following order over the three arguments:
$(H_3, h_3) \succeq_{risk} (H_2, h_2) \succeq_{risk} (H_1, h_1)$.

2. **Favorite Relation over Arguments (FRA).**

   The second step for evaluating the set of potential arguments PA, is checking the favorite relation over these arguments. In order to characterize this notion, we use the beliefs of agents about the preferences of other agents. We use the notation $Bel_{i \to j}(p)$, where $i, j \in \{s, b\}$, which means agent i believes that agent j believes that p holds, where p is a proposition representing a preference. So the second criterion, which is the favorite relation over arguments, can be defined as follows.

   Definition 3.13 (Favorite over arguments). Let (H, h) and (H', h') be two arguments for an agent i. We define the favorite and the strict favorite relations over arguments as follows.

   - $(H, h) \preceq^i_{fav} (H', h')$ iff $B_{i \to j}((H, h) \preceq^i_{pref-ar} (H', h'))$,

   - $(H, h) \prec^i_{fav} (H', h')$ iff $B_{i \to j}((H, h) \prec^i_{pref-ar} (H', h'))$.

3. **Preference Relation over Arguments (PRA).**

   Agents also may have private preferences about different knowledge bases. Therefore, they may have private preferences about arguments. So the third step in ordering the arguments, is checking the preference relation over arguments. This relation is denoted by $(H, h) \preceq^i_{pref-ar} (H', h')$, which means that agent i prefers the argument

(H',h') to the argument (H,h). Because $\leq$ is an ordering relation, the preference relation $\preceq^i_{pref-ar}$ is reflexive, antisymmetric, and transitive.

In order to define the preference relation over arguments, we need to define the preference level of an argument. We assume that, the knowledge base of an agent i, Γ^i, is stratified into non-overlapping sets $\Gamma_1,...,\Gamma_n$ such that facts in Γ_1 are the most preferred ones, and facts in the same set are equally preferred. Here the preference among facts is related to the certainty degree of those facts. That is, the most preferred facts are the more certain ones.

Therefore, we define the preference level as follows.

Definition 3.14 (Preference level)**.** The preference level of a non-empty subset $H \subseteq \Gamma$ denoted by $L(H)$ is the number of the highest numbered subset of H.

Example 3.4. Let $\Gamma = \Gamma_1 \bigcup \Gamma_2$ with $\Gamma_1 = \{a,b\}$ and $\Gamma_2 = \{c,d\}$. If $H = \{a\}$ and $H' = \{a,d\}$, then we have: $L(H) = 1$ and $L(H') = 2$.

So the preference relation over arguments can be defined formally as follows.

Definition 3.15 (Preference over arguments)**.** Let (H,h) and (H',h') be two arguments for an agent i. We say that:

- Agent i prefers the argument (H',h') over the argument (H,h) denoted by: $\preceq^i_{pref-ar} = ((H',h'),(H,h))$ or $(H,h) \preceq^i_{pref-ar} (H',h')$ iff $L(H') \leq L(H)$, and
- Agent i strictly prefers the argument (H',h') over the argument (H,h) denoted by: $\prec^i_{pref-ar} = ((H',h'),(H,h))$ or $(H,h) \prec^i_{pref-ar} (H',h')$ iff $L(H') < L(H)$.

3.5.2 Relevance Ordering Relation

From the above discussed three criteria, we define the relevance ordering relation for ordering the set of potential arguments as follows.

Definition 3.16 (Relevance ordering relation)**.** Let $NC_{i,j} = \langle \mathscr{S}, \mathscr{T}, T, \tau, P_{i,j}, \Gamma \rangle$ be a negotiation context, (H,h) and (H',h') be two relevant arguments in this context, and let $=_{risk}$ be the equal risk relation between any two arguments. (H',h') is more relevant than (H,h) denoted by $(H,h) \preceq_{rel} (H',h')$ iff:

- $(H,h) \succeq_{risk} (H',h')$; or
- $(H',h') =_{risk} (H,h)$ and $(H,h) \prec^{i}_{fav} (H',h')$; or
- $(H',h') =_{risk} (H,h)$ and $(H,h) \preceq^{i}_{fav} (H',h')$ and $(H',h') \preceq^{i}_{fav} (H,h)$ and $(H,h) \prec^{i}_{pref-ar}$ (H',h').

According to this definition, (H',h') is more relevant than (H,h) if the risk of (H,h) is greater than the risk of (H',h'). If the two arguments have the same risk, the more relevant argument is the more favorable one according to the favorite relation. If the two arguments have the same risk and they are equal according to the favorite relation, the more relevant argument is the more preferable one according to the preference relation. The two arguments have the same relevance if in addition they are equal according to the reference relation.

3.5.3 Computational Complexity of the Selection Mechanism

Computationally speaking, the arguments selection mechanism is based on:

1. The elimination of irrelevant arguments;
2. The ordering of the relevant arguments using the relevance ordering relation; and
3. The selection of one of the most relevant arguments.

This process is executed by each participating agent at each dialogue step at the tactical level. The relevant arguments that are not selected at a step t, are recorded and added to the set of potential arguments (PA) because they can be used at a subsequent step. The set of potential arguments can be viewed as a stack in which the higher level argument is the most relevant one. A relevant argument constructed at a step t and used latter at a step t', ($t < t'$), simulates the backtracking towards a previous node in the argumentation tree and the construction of a new path.

In this thesis, we prove that our selection mechanism is tractable if arguments are represented using propositional Horn clauses. Propositional Horn clauses is a restricted language that has been proved to be sufficient to represent and reason about knowledge in many concrete applications [28]. A propositional Horn clause is a disjunction of literals, which are atomic propositions (called positive literals) or their negations (called negative literals), with at most one positive literal. Formally, a propositional Horn clause has the form $\neg p_1 \vee \neg p_2 \vee \cdots \vee \neg p_n \vee c$ or also $p_1 \wedge p_2 \wedge \cdots \wedge p_n \rightarrow c$, which is simply an implication. A propositional Horn formula is a conjunction of propositional Horn clauses. We focus on a further restriction called propositional definite Horn clauses, where each clause has exactly one positive literal. A propositional definite Horn formula is a conjunction of propositional definite Horn clauses. This restriction is of particular interest in modeling argumentation reasoning for negotiation, because formulas of the type $p_1 \wedge p_2 \wedge \dots p_n \rightarrow c$ are adequate to describe interrelationships between premises (i.e., reasons or justifications) and conclusions (i.e., offers). Thus, agents could support their offers (the part c) as positive literals using the support $p_1 \wedge p_2 \wedge \dots p_n$.

Theorem 3.1. *If arguments are represented in proportional definite Horn clauses, the arguments selection mechanism runs in polynomial time.*

Proof. *It is known from Bentahar et al. [28], that given a Horn knowledge base* Γ*, a subset* $H \subseteq \Gamma$*, and a formula h; checking whether* (H,h) *is an argument is polynomial. To decide if an argument is irrelevant, we have to check if:*

1. $H \vdash \neg x$ *for an* $x \in \Gamma$*, which can be done in polynomial time since H is a definite Horn formula; or*

2. *there is a path from the root to* (H,h)*, which is a graph reachability problem, and it is known by Jones [69] that the problem is in NLOGSPACE.*

Since NLOGSPACE $\subseteq$ *P, the problem can be solved in polynomial time. To decide about the preference, we only need to compute the level of an argument from the level of a subset of* Γ*, which is a simple procedure that is obviously polynomial. Computing the favorite argument given two arguments needs the computation of the arguments' weight, which is again a polynomial procedure as shown by Algorithm 1. To compere two given arguments using the risk, we only need to compute the number of formulas in H and check if they are part of different sets, which is a polynomial procedure. Finally, the relevance ordering relation is simply based on comparing risks and favorites, which are both polynomial, so we are done.* ■

3.6 Reasoning Models

A preliminary framework for strategic and tactic reasoning for agent communication was proposed in [87]. This reasoning framework is specified using argumentation theory combined to a relevance theory. In this chapter, we refine and use these notions of strategic and tactic reasoning. In particular, we adopt strategic reasoning to enable the negotiating agents to decide about the global communication plan in terms of the macro-actions to perform in order to achieve the main dialogue goal (i.e., agreement). On the other hand, we use tactic reasoning to allow the negotiating agents to locally select, at each dialogue step the most relevant argument according to the adopted strategy. So an agent uses its tactic reasoning at each dialogue step for the assessment of the available arguments to achieve some sub-goals of the global goal (i.e., the agreement in our case). In other words, how an agent can select the right argument from a set of potential arguments at certain dialogue step depends on its tactic reasoning, and how an agreement could be achieved is based on the strategic reasoning of both agents. In the following section, we discuss the strategic reasoning.

3.6.1 Strategic Reasoning

Before engaging in a negotiation, agents must build a global strategy on the sub-goals to achieve. Sub-goals determine the general steps to follow so that the global goal can be realized. Strategy is subject to the agent's current beliefs and constraints, such as the agent's budget and negotiation time limit. To achieve the same negotiation goal, an agent can have several alternative strategies reflected by different sets of sub-goals. The dialogue goal, sub-goals, and constraints can be expressed using propositional logic. The set of constraints can be inconsistent, but the sub-set of those constraints and the sub-set of beliefs the agent decides to consider should be consistent. In this thesis, we define the strategy as a function that associates to a goal and a sub-set of consistent beliefs and constraints a sub-set of alternatives, each of which is a set of sub-goals, which means an element of the set $2^{2^{\mathbb{B}}}$, where $\mathbb{B}$ is the set of goals.

Definition 3.17 (Strategy). [2]

Let $\mathbb{B}$ be a set of goals, $\mathscr{C}$ a set of constraints and Γ the agent's knowledge base. A

[2] The definition that we introduce in this thesis is different from the one proposed in [87], in the sense that the new function associates a set of sub-goals to a sub-set of agent's knowledge base and constraints instead of associating a set of goals to a set of operational constraint and a set of conversational criterions. The new definition is more complete as it considers the agent's knowledge base and generates different alternatives of different sub-goals from $2^{2^{\mathbb{B}}}$, and not just one alternative from $2^{\mathbb{B}}$ as in [87].

strategy is a function:

$$\mathscr{S} : \mathbb{B} \times 2^{\mathscr{C}} \times 2^{\Gamma} \rightarrow 2^{2^{\mathbb{B}}} \tag{3.2}$$

3.6.2 Tactic Reasoning

Tactics allow agents to select one action (i.e., the content of the move or the argument) from a set of possible actions in order to achieve a sub-goal as computed by the adapted strategy. The purpose of this theory is to ensure that the selected argument is the most relevant one according to the current context, that is, the one with less risk of failure, more favorable, and the more preferable one. In our framework, this turns to be the move with the higher probability to be accepted by the addressee.

In the negotiation context $NC_{i,j} = \left\langle \mathscr{S}, \mathscr{T}, T, \tau, P_{i,j}, \Gamma \right\rangle$, the influence of the strategy on the tactic is reflected through the link between the topic T, the current argument s and the strategy $\mathscr{S}$.

Let $\mathbb{T}$ be the set of topics ($T \in \mathbb{T}$), g the current goal ($g \in \mathbb{B}$), C the sub-set of current constraints ($C \in \mathscr{C}$), γ the sub-set of beliefs the agent is currently considering ($\gamma \in \Gamma$), and $\mathscr{A}$ the set of arguments ($\tau \in \mathscr{A}$). We define the tactic function as follows.

Definition 3.18 (Tactic)**.** A tactic is a function:

$$\mathscr{T} : \mathbb{T} \times \mathscr{S}(g, C, \gamma) \times \mathscr{A} \rightarrow \mathbb{B} \tag{3.3}$$

The key idea is that the current action (at the tactic level) is related to a sub-goal, which is determined by the strategy. From the operational perspective, the current argument s can attack or support the formula representing the sub-goal T.

3.7 Summary

In this chapter, we introduced the argumentation system and agent's theory needed for our framework. Our agent's theory incorporates important parameters that allow the negotiating parties to explicitly influence each others' preferences and reason about the selection of their moves during negotiation. Then, we proposed a new arguments selection mechanism based on three criteria and analyzed the computational complexity of this selection mechanism. Finally, we presented two reasoning mechanisms namely, strategic and tactic reasoning. These reasoning capabilities allow negotiating parties to reason and decide about the selection of the most relevant argument locally at each dialogue step (using tactic reasoning), and decide about the global communication plan (using strategic reasoning) to achieve their goal (the agreement) according to the adopted strategy. As such, this chapter has answered the first two research questions (**RQ1** and **RQ2**) raised in Chapter 1. In the next chapter, we investigate the agent's uncertainty in bilateral argumentation-based agent negotiations.

Chapter 4

Shannon Entropy for Agents' Uncertainty Assessment

In this chapter[1], we address the problem of agents' uncertainty about their moves and consequently about the whole dialogue in Argumentation-Based Agent Negotiation (ABAN). In particular, we propose an efficient method for agents' uncertainty assessment to help the negotiating agents make better decisions about their selections under the assumption of uncertainty. More precisely, we use *Shannon entropy*—a well-known method in information theory to quantify the information based on the randomness degree—to assess the agent's uncertainty about its moves at each dialogue step. To do so, we assume that at each dialogue step, each agent will have multiple choices of moves with different probabilities to advance. The probability of each move reflects its degree of acceptability by the addressee. The higher probability the move has, the more likely to be accepted by the addressee. Intuitively, a rational agent will select the move with higher probability, which means the less degree of uncertainty. To measure this uncertainty, we define a function called *Move's*

[1]The results of this chapter have been published in the journal of Expert Systems with Applications [83], the Journal of Ambient Intelligence and Humanized Computing [84], and in The 5th International Conference on Ambient Systems, Networks and Technologies (ANT 2014) [82].

Probability Function based on the three criteria we discussed in Chapter 3. This function assigns a probability value between [0,1] to each move, such that the summation of all moves' probability at each dialogue step is equal to 1. Then, we order the moves based on their probability using what we call *Probability Ordering Relation*. Finally, we apply the general formula of Shannon entropy. We also, measure the uncertainty of the whole dialogue in three methods: i) by taking the average of the uncertainty degrees of all dialogue moves, ii) by determining all possible dialogues that can be generated from all the moves, and iii) by using a *Hypothesis testing* approach, this can be used in particular for those dialogues who last long. Moreover, we present a novel classification for the potential arguments based on their uncertainty degree, which will be used in the next chapter for designing the negotiation strategies, then we analyze different situations and raise up some special cases based on the number of available arguments and their respective classes. Finally, in addition to the theoretical analysis of agents' uncertainty, we discuss the implementation of the proposed technique by applying it on a concrete case study (Buyer/Seller) scenario.

For a convenience reading of this chapter, we refer the reader to the list of notations presented in Table 4.1.

Table 4.1: List of the notations used in Chapter 4

The notation	**The meaning of the notation**
s and b	Seller and Buyer agents
$\mathscr{L}$	A logical language
$H(X)$	Shannon entropy for a discrete random variable X
$P(x)$	The probability mass function for random variable x
S_t	A set of moves the agent has at dialogue step t
$\mu^i(M_t)$	The uncertainty degree of agent i about the move M at step t
Γ^i	The knowledge base of agent i
CS_t^i	The commitment store of agent i at step t
m_t^k	The k^{th} move among the possible moves an agent has at the step t
$P(m_t^k)$	The probability of the move m_t^k
$\zeta(\Gamma^i \cup CS_t^j)$	A function produces a set of moves along with their respective probabilities
$P_{i,j}$	The set of agent i's beliefs about agent j's beliefs $P_{i,j}^{bel}$ and about agent j's preferences $P_{i,j}^{pref}$
$\mathscr{M}$	The set of all possible moves
Δ	A function associates a set of knowledge, preferred arguments, and favorable arguments to a set of possible moves and their respective probabilities
f_r	The set of favorable arguments
p_r	The set of preferable arguments
$P(Arg_l)$	The probability of argument Arg_l
$\succeq_{risk}$	Risk binary relation that is complete and transitive
$=_{risk}$	The equal risk relation between any two arguments
$NC_{i,j}$	The negotiation context for an agent i committed in a negotiation with an agent j
$H(M_t)$	Shannon entropy of the move M_t
$CD^i(M_t)$	The certainty degree of agent i about move M_t
$\mu(D)$	The uncertainty index of the dialogue
N_D	The number of all possible dialogues
$\preceq_{fav}^i$	Favorite relation over arguments
$\prec_{fav}^i$	The strict favorite relation over arguments
$=_{fav}^i$	The favorite equality relation
$=_{pref-ar}^i$	The preference equality relation
$\mathscr{A}^i$	The set of agent i's arguments
H_0	The null hypothesis
H_1	The alternative hypothesis

4.1 Introduction

The process of selecting moves (offers/arguments) in argumentation-based negotiation is usually associated with a high degree of uncertainty. Generally speaking, uncertainty can be thought of as being the inverse of information. Information about a particular engineering or scientific problem may be incomplete, imprecise, fragmentary, unreliable, vague, contradictory, or even deficient [118]. Uncertainty about values of given variables (e.g., the disease affecting a patient in medical applications) can result from some errors and hence from unreliability (in the case of sensors) or from different background knowledge (in the case of agents). As a result, it is possible to obtain different uncertain pieces of information about a given value from different sources [65]. We aim to investigate how an agent can assess its uncertainty about its moves when more than one possible choice is available to advance to its opponent in argumentation-based agent negotiations.

Basically, the notion of uncertainty was first introduced by Helton in [59], where he classified uncertainty into two main groups, "objective uncertainty" and "subjective uncertainty".

- **Objective uncertainty - *Type A*:** this type corresponds to the variability that emerges from the stochastic characteristics of an environment.

- **Subjective uncertainty - *Type B*:** this type, which is the focus of our work, concerns the uncertainty that comes from scientific ignorance, uncertainty in measurements, impossibility of confirmation or observation, censorship, or other knowledge deficiency.

The focus of this chapter is on the second type "the subjective uncertainty", which is mainly about the agents' uncertainty about the exchanged moves (offers/arguments) and their acceptance. The main issue we are investigating is the agent's uncertainty about selecting its moves during the negotiation process from not only the perspective of the agent itself, but also from its beliefs about the acceptance criteria of the opponent. We are interested in measuring this uncertainty and analyzing the different argument classes under the consideration of such an uncertainty.

In our settings, we assume that each negotiation dialogue D consists of a set of moves $\{M_0, M_1, ..., M_n\}$. At each dialogue step (state), an agent has more than one option (i.e., offer and/or argument) to choose and each one has different available choices with different probabilities to play, see Figure 4.1. In the figure, the rectangle on the left side represents the set of offers and the rectangle on right side represents the set of arguments. So, in order to select one of theses choices, an agent has to evaluate the candidate moves and find the appropriate strategy that specifies which move to play that satisfies both agents in order to achieve their goal. The probability assignment for those moves will be based on the "Move's Probability Function" and the "Probability Ordering Relation", which can be evaluated based on the selection mechanism we discussed in Chapter 3. The agent should select the move with the higher probability (i.e., less uncertainty) and less risk of failure to be accepted by its opponent. In negotiation dialogues, the probability associated with a move corresponds to the probability for the move to be accepted by the addressee.

To the best of our knowledge, this work is the first attempt of its kind in dealing with the agents' uncertainty to help the agents reason about their moves, especially, in uncertain settings so that they can make better decisions at each dialogue step, and select the right moves by considering their beliefs on the opponents' preferences.

The main contributions of this chapter is depicted in Figure 4.2 and are categorized as follows. First, we use Shannon entropy to assess the uncertainty degree of selecting the right moves during the dialogue (Type I), the uncertainty degree that the selected move will

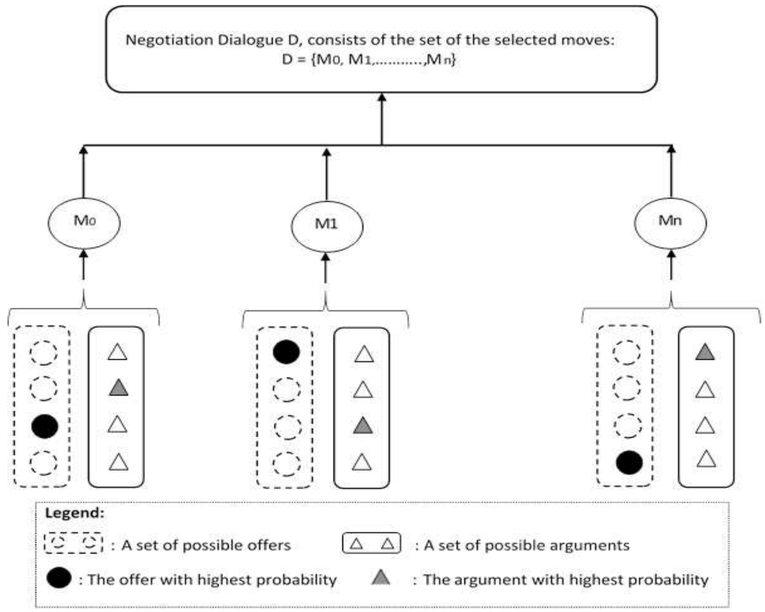

Figure 4.1: A negotiation dialogue D consists of n moves $\{M_1, ..., M_n\}$, each move was selected among different options of offers/arguments

be accepted by the addressee (Type II), and the uncertainty degree of the whole dialogue. Then, based on the uncertainty degree we propose a novel classification for the set of the potential arguments. Further, we advanced our research by analyzing the different situations of agents' uncertainty based on the available arguments at each dialogue step. More precisely, we discuss the agent's uncertainty in two special cases based on the different classes that arguments can belong to. The main idea is to give a good indicator about the played move to be accepted by the addressee. In addition to the theoretical analysis of agents' uncertainty, we discuss the implementation of the proposed approach by applying it on a concrete case study (Buyer/Seller) scenario. The obtained empirical results confirm the effectiveness of using our uncertainty-aware technique and show that our negotiating agents outperform others, which use pure argumentation with no uncertainty consideration.

We expect a significant contribution of the measurements and analysis we introduce

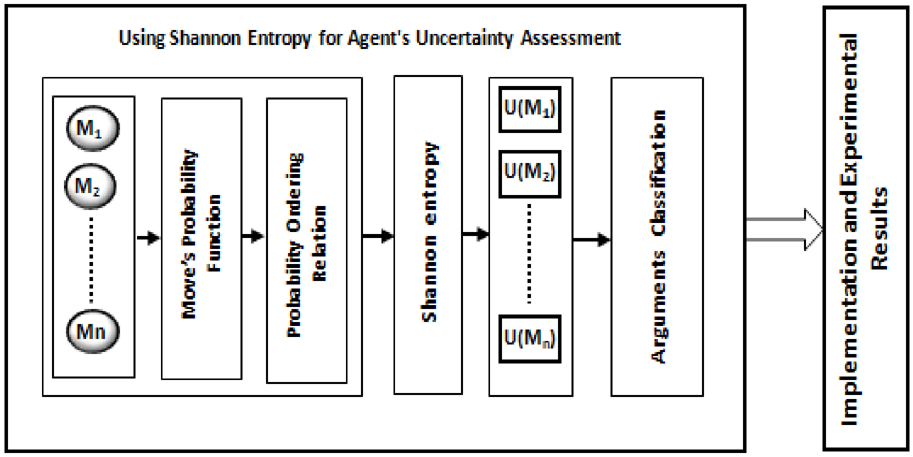

Figure 4.2: A schematic view of the chapter contributions

in this chapter in the elaboration of guidelines and strategies that aim to enhance the negotiation process between autonomous agents and advance the research in the area of automated argumentation-based agent negotiation in multi-agent systems.

The remainder of this chapter is organized as follows. In Section 4.2, we discuss the most relevant literature. In Section 4.3 we briefly review the concept of Shannon entropy, then in Section 4.4, we present our approach for agent's uncertainty assessment using Shannon entropy. Section 4.5 discusses the implementation and the experimental results. Finally, we conclude the chapter in Section 4.6.

4.2 Related Work

While negotiation has been studied in various disciplines for many years, the study of automated negotiations using argumentation in agent-based environments is relatively new. Indeed, in everyday life, decision making is based on the exchange of arguments and counter arguments. Therefore, in artificial intelligence, researchers have adopted the same idea and a similar decision system using argumentation. They have studied extensively the argumentation in computing, especially for inference, decision making, dialogues, and negotiation. Argumentation has been incorporated into negotiation dialogues in the early 1990s by Sycara in [117]. In that work, the author introduced a specific argumentation framework and emphasized the advantages of using argumentation in negotiation dialogues. In addition to that, other frameworks were proposed [74, 97, 119]. In [74], the authors discussed the different types of arguments that are used in a negotiation dialogue, such as threats and rewards, in addition to proposing a particular framework for negotiation. From the literature it can be noticed that some researchers have mainly focused on linking argumentation with protocols for agent communication, while others have focused on the decision-making problem, see for instance the approaches [14, 55, 70], in which the authors argued that selecting an offer to make at a given dialogue step is a decision-making problem. Although several studies have focused on argumentation-based negotiation (e.g., [4, 5, 18, 56, 70, 107]), little is known about agents' uncertainty, especially during the decision making process. Unfortunately, most of current proposals are concerned with proposing protocols to show how agents can interact with each other, and how arguments and offers can be generated, evaluated, and exchanged during the negotiation process. However, none of the current proposals has investigated the agents' uncertainty about the exchanged moves and how such uncertainty could be measured to assist negotiating agents to make a better decision. To this end, decision making under uncertainty is usually based on the comparative evaluation of different alternatives by means of a decision criterion. Kraus in [73] proposed decision making techniques for reaching agreements in automated negotiation for multi-agent systems environments. More specifically, she discussed game-theory and economics techniques such as strategic negotiation, auctions, coalition formation, market-oriented programming and contracting. However, the use of alternative arguments and counter arguments and investigating the agents' uncertainty about the selection of their moves is neglected in this study.

Amgoud [3] proposed a decision model in which some decision criteria were articulated in terms of two steps argumentation process. The first step, called *inference step*, uses Dung's style system [42] in which arguments in favor/against each option are built, then evaluated using a given acceptability semantics. The second step, called *comparison step*, in which the alternatives are compared using a given criterion based on the accepted arguments computed at the inference step. A similar approach was proposed by Amgoud et al. [15] in which the authors indicate optimistic and pessimistic decision criteria in terms of an argumentation process that consists of constructing arguments in favor/against decisions, evaluating the strengths of those arguments, and comparing pairs of alternatives in terms of their supporting/attacking arguments. In [8], a more general setting decision model was proposed. The authors proposed an abstract argument-based decision system, in which a simple protocol allowing the negotiating agents to exchange offers and arguments is presented. Although these proposals are concerned with rank-order the offers to select the best option, however, they have some drawbacks related to the separation of the two/three steps (for the first/second approach respectively). Moreover, these proposals have said nothing about the agent's uncertainty about the selection of their proposals, which play a key role in decision making systems.

Another study was presented by Morge [92] in which he presented a decision support system using arguments in legal disputes. This decision system was built upon argumentation framework for decision making. Even though the author has considered different priorities attached to the data structure for holding the statements like knowledge, goals, and decisions corresponding to the uncertainty of knowledge about circumstances, preferences, and the expected utilities, yet, he did not mention how such uncertainty could be assessed to help the negotiating agents make better decisions. A later decision making approach through preference-based argumentation was proposed by Amgoud et al. [9]. This approach came to overcome the limitations of the above mentioned proposals [3] and [15]. However, the underlining ingredients are still the same, the only difference is that the rank-order of the different options and the selection of the best offer among the alternatives are done in one step. Our work differs from these proposals in the sense that it rank-orders the different choices based on their probabilities to be accepted, and consequently on their risk of failure (i.e., rejected by the addressee) besides considering the preference of each other.

Huang and Lin [61] have proposed an argumentation-based approach for designing a multi-agent e-marketplace. In this system, buyers and sellers delegate agents to argue about products via an argumentation mechanism. Another argumentation-based multi-agent decision support system for freight planning was proposed by Chow et al. [38]. The later work presents a system that supports the automatic collecting and updating of the relevant information to the freight planning process, and implements the argumentation mechanism for determining the best freight plan based on the principles of both cost minimization and risk reduction. Even though all these frameworks are based on different logics, and use different definitions of arguments, they all have at their heart an exchange of offers and arguments. Nevertheless, none of those proposals explains when arguments can be used within negotiation dialogues, and how they should be dealt with by the agent that receives them. Moreover, none of them touches the agents' uncertainty issues and explains how to assess agents' uncertainty about the selection of their moves at each dialogue step and the uncertainty about their dialogue. Thus, measurements for handling arguments together with their uncertainty are missing.

Müller and Hunter [94] presented an argumentation-based system for decision analysis in which they used a grounded extension as acceptability criterion and added the capability to generate decisions. They also analyzed the requirements of some engineering companies for decision analysis and documentation systems. This work is more concerned about the decision analysis, in terms of defining semantics, that is being used to choose the accepted arguments, which is in fact different than our approach that examines the uncertainty degree of arguments based on some criterion, and selects the one with lower uncertainty degree, which means the more likely to be accepted. Later on, a general method that can be used as a tool for uncertainty assessment and management is identified by Ross et al. in [118]. They started by defining different types of uncertainty such as ambiguity, fuzziness, randomness, non-specificity, ignorance, etc., and concluded with a method for assessing the total uncertainty. Even though the work was described in the context of physical science and engineering applications, however, nothing is said about the assessment of uncertainty in the field of multi-agent systems, especially in the argumentation-based agent negotiations. In [25], an adaptive decision making approach based on three families of tactics namely, time dependent tactic, behavior dependent tactic, and time independent tactic in automated negotiation has been proposed. Despite that the authors have considered very important factors in negotiation, which are time and behavior, however, they neglected the agents' uncertainty resulting from the lack of information at the moment of making their decision. Considering the preferences of each other is another aspect missing in this work.

Hunter in [63] proposed a probabilistic approach to modeling uncertain logical arguments. In this work, the author considered a logic-based argumentation with uncertain arguments based on a probability distribution over models of the language, which leads to a probability distribution over arguments that are constructed using classical logic. A recent work concerning one-side uncertain reserve prices in bilateral negotiation was proposed by An et al. [21]. The authors provided an algorithm based on the combination of game theoretic analysis and search techniques that can find all sequential equilibria in incomplete information bargaining games with deadline constraint. This work is more about agents' rationality (i.e., strategic behavior of the agent) in bilateral negotiation alternating offers, and it focuses more on one side-uncertainty reserve prices. That is, it has neither resolved the problem of agents' confusion (uncertainty) when choosing their offers, nor considered the preferences of the opponent at each dialogue step, which are crucial factors in the assessment of uncertainty when making decisions. More recently, Amato et al. [2] proposed agents based multi-criteria decision-aid framework for designing and developing multi-agents solution of problems. They modeled the decision problem as a problem of choosing among several alternatives or proposals to be retrieved according to the user's need.

To the best of our knowledge, the only proposals that have focused on measurements are by Amgoud and Florence [6, 7], and by Yuan et al. [131], for dialogue strategies. In [6], the authors have defined a set of quality measures for persuasion dialogue games from an external agent's point of view. They analyzed already generated dialogues whatever the protocol used is, and whatever the strategies of the agents are. Moreover, they have proposed measurements for the quality of exchanging arguments in terms of their persuasive weights and measurements of the behavior of the participants to the dialogue from the perspectives of their coherence, aggressiveness, and the novelty of their arguments. They also proposed metrics for the quality of the dialogue itself in terms of the relevance and usefulness of the exchanged moves. These measures are important to set the foundation of measuring the quality of the dialogue and compare different dialogues on the same subject. Yuan et al. [131] proposed some heuristics to measure strategies in order to allow the participants to choose moves in debating settings. However, these measures have been analyzed in a symbolic manner, and no numerical functions have been proposed.

To summarize, most of the above mentioned approaches are on the one hand, similar to ours in the sense that argumentation is used to generate arguments relating to decisions, but on the other hand, they are different in the way agents make their decision, and the sort of uncertainty they deal with. Our approach is more concerned with the agents' uncertainty about the selection of their moves at each dialogue step. To conclude, despite the huge number of publications on argumentation-based negotiation, agents' uncertainty has not been thoroughly studied in the available research literature. So this chapter is devoted to close this gab.

4.3 Shannon Entropy: Overview

Shannon entropy is a measure of uncertainty. It is a well-known method that defines and quantifies the information based on its randomness degree. That is, the entropy of a message is its amount of uncertainty; this uncertainty increases when the message is closer to random, and decreases when it is less random. The idea behind using Shannon entropy in information theory is based on the amount of randomness that exists in a random event. Indeed, Shannon entropy is a measure of the uncertainty associated with a random variable (i.e., in our case, the uncertainty associated with the selection of one argument from a random set of potential arguments). The more uncertain we are about the content of the message, the more informative it is. Shannon entropy (or entropy in short) for a random variable X is defined as follows [39].

Definition 4.1 (Shannon entropy)**.** Shannon entropy for a discrete random variable X taking its values from a set of values S (sample space), with probability mass function $P(x)$ is given by Equation 4.1.

$$H(X) = -\sum_{x \in S} P(x) Log P(x) \tag{4.1}$$

In negotiation dialogues, Shannon entropy $H(X)$ depends on the probability distribution of X rather than the actual values of X. The logarithm in Equation 4.1 is considered to be of base 2 in the computations. The value of $H(X)$ varies from zero to $Log(|S|)$, where zero means that there is no uncertainty, while $Log(|S|)$ is the maximum value of uncertainty. The aim is to investigate to what extent we can use Shannon entropy to evaluate the agent's uncertainty in negotiation dialogues. We assume that at each dialogue step, the agent has to select one choice among the different choices of arguments (i.e., the set of potential arguments PA at that step). The selection process is based on the speaker's knowledge base and characterized by an amount of uncertainty over this base and an amount of randomness over the addressee's knowledge, beliefs, and preferences. We place ourselves in the role of an external observer trying to evaluate the uncertainty of the participants to the dialogue, i.e., how uncertain each agent is about the selected move, how uncertain it is about the selected move to be accepted by the addressee, and the distinction between these two types of uncertainty when it is necessary.

The main idea is to adopt the Equation 4.1 to be suitable with the settings of our negotiation dialogue, then we use it to measure how much an agent is uncertain about selecting the right move (let's say M_t in a dialogue D) at step t by assuming that there is a set S_t of choices facing the agent at each dialogue step. Throughout this chapter, we measure this uncertainty using the general formula of Shannon entropy, then we normalize it to have a value between [0,1]. We call this measure the *Uncertainty Degree* for the move M_t and denote it by "$\mu^i(M_t)$". Further, we calculate the agents' uncertainty about the whole dialogue in three methods. The first one is by taking the average of the uncertainty degree of all moves in this dialogue (taking the minimum is another choice that we also discuss). In the second method, we measure the uncertainty degree of the whole dialogue by computing all possible dialogues, using the Cartesian product of all possible moves, and determining the probability of each dialogue, and then, we apply the general formula of Shannon entropy for the whole dialogue (exactly as what we do in the case of calculating the uncertainty of the moves). The third method, we measure the uncertainty degree of some moves randomly and we assume it is the uncertainty of the dialogue, then we use hypothesis testing to decide about this assumption and see what is the uncertainty of the dialogue.

To allow agents to refer to their dialogue history, a data structure called commitment store " CS " is used to restore utterances that agents utter during the dialogue [58]. Let i and j be the two negotiating agents $i \neq j$. Also, let Γ^i be agent i's knowledge base ($i \in \{b, s\}$). CS_t^i is the commitment store of agent i at step t of the dialogue. Suppose that at step $t-1$, agent j uttered a move. To utter a move at the next step t, agent i should consider its knowledge base and the content of agent j commitment store. Let m_t^k be the k^{th} move among the possible moves an agent has at step t and $P(m_t^k)$ be the associated probability such that the relationship between the move M_t and m_t^k is as follows.

$$\forall t \; \exists k : M_t = m_t^k \tag{4.2}$$

Where M_t is the selected move the agent utters at the step t, and the production of moves for agent i along with their probabilities is a function of Γ^i and CS_t^j:

$$\zeta(\Gamma^i \cup CS_t^j) = \{(m_t^k, P(m_t^k)) | m_t^k \in S_t\} \tag{4.3}$$

Where S_t is the set of choices facing the agent at the dialogue step t.

The measures of agent's uncertainty that we advocate in this chapter aim to help the participants to a negotiation dialogue to make better decisions about the selection of the most appropriate argument at each moment (i.e., at the tactical level) in order to facilitate the achievement of their goals based on the adapted strategy. In the next section, we discuss how can we use Shannon entropy to measure the agent's uncertainty in argumentation-based agent negotiation.

4.4 Agent's Uncertainty Assessment

In this section, we will discuss to what extent we can use Shannon entropy in negotiation dialogues to assess the agents' uncertainty about their moves and dialogues. To do so, we first, define a function that assigns the probabilities to the different moves based on the three criteria we discussed earlier in the previous Chapter, then we use a probability ordering relation to order these moves based on their probabilities. Finally, we use the general formula of Shannon entropy to measure the uncertainty for each move first, and then for the whole dialogue. Moreover, this section introduces a novel classification for the set of potential arguments based on their uncertainty degree, and presents a valuable discussion and analysis for the different situations and raise up some special cases based on the number of possible arguments and their relative classes in order to be able to distinguish between the uncertainty of selecting the right move, *Type I*, and the uncertainty of a move to be accepted by the addressee, *Type II*. Recall that the argument selection criteria are as follows.

1. Risk of Failure over Arguments (RFA).
2. Favorite Relation over Arguments (FRA).
3. Preference Relation over Arguments (PRA).

These criteria have precedence relation over each other, that is, the order of examining these criteria is important in order to assign probability to the different arguments available at each dialogue step. The procedure is as follows.

First, we check *RFA* to examine the risk of failure of each possible argument in the move and assign the probability so that the less move's risk of failure, the more likely to be accepted by the addressee. Second, if there is more than one argument with the same risk of failure, then we check the second criterion FRA, which examines the favorite relation over these arguments, and we assign higher probability to the more favorable argument. Third, if there are some arguments with the same risk and are equally favorable, then we check the third criterion *PRA*, which examines the preference relation. This process follows the argument selection mechanism and it depends on the strategic and tactic reasoning presented in Chapter 3.

The notion of argument's probability is subjective and different heuristic approaches to evaluate it can be proposed. In this thesis, we use a heuristic similar to the one used to evaluate the risk of failure. Probabilities are based on the fact that the knowledge base Γ contains certain knowledge and the set of agent's beliefs and preferences $P_{i,j}$ contains uncertain beliefs. Therefore, the probability of an argument that belongs to Γ to be accepted by the addressee is higher than the probability of another argument that belongs to the set $P_{i,j}$. Consequently, the risk of failure of an argument belonging to Γ is less than another argument belongs to $P_{i,j}$. In fact, in negotiation dialogues, the probability of a move at a given step t depends on the knowledge the agent has at that step (i.e., the content of the agent's knowledge base at that step), the favorite relation, and the preference relation. Now let us proceed to define the "Move's Probability Function".

4.4.1 Move's Probability Function

Definition 4.2 (Move's probability function)**.** Let Γ be the set of common agents' knowledge base, $P_{i,j}$ be the set of agent i's beliefs about agent j's beliefs, f_r the set of favorable arguments, p_r the set of preferred arguments, and $\mathscr{M}$ the set of all possible moves. We define Δ as a function associating a set of knowledge and preferences and favorites to a set of possible moves and their probabilities. We call this function the *Move's Probability Function*.

$$\Delta : 2^{k_n} \times 2^{f_r} \times 2^{p_r} \rightarrow 2^{\mathscr{M} \times [0,1]} \tag{4.4}$$

Where:

$k_n = \Gamma \times P_{i,j}$,

$f_r = \{(Arg_k, Arg_l) \in \mathscr{A} \times \mathscr{A} \mid Arg_l \preceq^i_{fav} Arg_k\}$, and

$p_r = \{(Arg_k, Arg_l) \in \mathscr{A} \times \mathscr{A} \mid Arg_l \preceq^i_{pref-ar} Arg_k\}$.

We assume that Γ contains of a set of propositions $P_1, P_2, \cdots P_n$, i.e., $\Gamma = \{P_1, P_2, \cdots, P_n\}$.

f_r: is the set of favorable arguments and we represent them as pairs (Arg_1, Arg_2) which means Arg_1 is more favorable than Arg_2. So, $f_r = \{(Arg_1, Arg_2), (Arg_2, Arg_4), \cdots\}$.

p_r: is the set of preferred arguments and we represent them also as pairs (Arg_1, Arg_2) which means Arg_1 is more preferable than Arg_2. So, $p_r = \{(Arg_1, Arg_2), (Arg_2, Arg_4), \cdots\}$.

Thus the product of $2^{k_n} \times 2^{f_r} \times 2^{p_r}$ = $\{(M_1, P(M_1)), (M_2, P(M_2)), \cdots\}$, and the function Δ should satisfy the following properties:

- **Minimality:** $\forall I, I' \in 2^{k_n} \times 2^{f_r} \times 2^{p_r}$ if $I \subseteq I'$ and no relevant argument can be generated from $I' - I$, then $\Delta(I) = \Delta(I')$.

- **Uniqueness:** $\forall I \in 2^{k_n} \times 2^{f_r} \times 2^{p_r}$ and $\forall k, l$ s.t. $\{(M_k, P(M_k)), (M_l, P(M_l))\} \subseteq \Delta(I)$, if $k \neq l$, then $M_k \neq M_l$.

- **Universality:** $\forall I \in 2^{k_n} \times 2^{f_r} \times 2^{p_r}$ if $\Delta(I) = \{(M_1, P(M_1)), \cdots, (M_n, P(M_n))\}$, then $\sum_{i=1}^{n} P(M_i) = 1$.

4.4.2 Probability Ordering Relation

The probability ordering procedure is as follows. First, we examine the first criterion, which is the risk of failure of each possible move based on the supporting arguments for the sake of ordering them ascending based on their risk. Second, if there is more than one move with the same risk of failure, then we examine the second criterion for the equivalent arguments in terms of their risk, which is the favorite relation, and reorder them descending based on this relation. Third, if there is more than one argument equally favorable, then we examine the third criterion, which is the preference relation over arguments, and reorder them descending based on their preferences.

The negotiating agents have to perform this procedure at each dialogue step in order to be able to assign probabilities to the moves based on the order of arguments supporting them. After that, the uncertainty can be measured using the general formula of Shannon entropy based on their probabilities. So probability order relation can be defined formally as follows.

Definition 4.3 (Probability ordering relation)**.** Let $NC_{i,j} = \langle \mathscr{S}, \mathscr{T}, T, \tau, P_{i,j}, \Gamma \rangle$ be a negotiation context, and Arg_k and Arg_l be two relevant arguments in this context. The probability of argument Arg_k is greater than the probability of argument Arg_l denoted by $P(Arg_l) \leq P(Arg_k)$ iff $(Arg_l) \succeq_{risk} (Arg_k)$.

Algorithm 1 explains how to order and assign probabilities to a set potential arguments PA at each dialogue step. The notation $Arg_k =_{risk} Arg_l$ means the two arguments Arg_k and Arg_l are risk equal, i.e., $Arg_k \succeq_{risk} Arg_l$ and $Arg_l \succeq_{risk} Arg_k$.

The process of selecting arguments is always associated with a degree of uncertainty. Despite the fact that agents are rational and always select the most relevant argument at each dialogue step, there still exists a doubt that the selected argument is the right one, and it will be accepted by the addressee. The selection of one of the possible choices is based

Algorithm 1 How to assign probabilities to the set of potential arguments PA

```
Let n be the number of possible arguments at dialogue step t.
Examine the first criterion and order the set of PA ascending based on their risk.
if ∃k,l ≤ n, k ≠ l such that Arg_k =_risk Arg_l then
    Check the second criterion, and reorder these arguments descending based on their favorite relation.
else
    if ∃k,l ≤ n, k ≠ l such that Arg_k =_risk Arg_l and (Arg_k ⪯^i_fav Arg_l) and (Arg_l ⪯^i_fav Arg_k) then
        Check the third criterion and reorder these arguments descending based on their preference relation.
    end if
end if
Assign a value between [0,1] to each possible argument, such that:
```

- The sum of all probabilities satisfies the probability condition $\sum_{x=1}^{n} P(m_t^x) = 1$.
- Assign the same probability to all arguments having the same order.
- Assign $1/n + \varepsilon_1$ to $P(m_t^1)$, $(1 - P(m_t^1))/(n-1) + \varepsilon_2$ to $P(m_t^2)$, and so on, where $\varepsilon_i \geq 0$.

on the speaker's knowledge base, and characterized by an amount of uncertainty over this base, as well as the amount of randomness over the addressee's knowledge, beliefs, and preferences. In what follows, we discuss in details how to measure the agents' uncertainty about their moves.

4.4.3 Agents' Uncertainty about their Moves

To measure the uncertainty degree of an agent about its moves, we calculate Shannon entropy of that move using the "Move's entropy function", the modified version of the general formula of Shannon entropy, which can be defined as follows.

Definition 4.4 (Move's entropy)**.** Let $D = [M_0, M_1, \ldots, M_n]$ be a negotiation dialogue, and suppose that at each dialogue step t a set $S_t = \{m_t^1, m_t^2, \ldots, m_t^x\}$ of moves are possible, and each move is associated with a given probability $P(m_t^k)$, such that $\sum_{m_t^k \in S_t} P(m_t^k) = 1$. Shannon entropy for a random move M_t taking its values from the set of moves S_t is defined by:

$$H(M_t) = -\sum_{m_t^k \in S_t} P(m_t^k) Log P(m_t^k) \quad (4.5)$$

The value of $H(M_t)$ varies from zero to $Log(|S_t|)$, where zero means that there is no uncertainty (i.e., there is only one choice), while $Log(|S_t|)$ means that the uncertainty is at its maximum value (i.e., all moves have the same probability). Note that, here we consider only possible moves (i.e., moves whose associated probability is within [0,1]). Further, we normalize $H(M_t)$ to have a metric that ranges from [0,1]. This can be obtained by dividing $H(M_t)$ by $Log(|S_t|)$. Hence, the uncertainty about selecting the right move is given by:

$$\mu^i(M_t) = \begin{cases} 0 & iff \quad |S_t| = 1 \\ H(M_t)/Log(|S_t|) & otherwise \end{cases} \quad (4.6)$$

Proposition 4.1. *The uncertainty (or entropy) of a move M_t at a certain step t during the dialogue is equal to zero (i.e., $\mu^i(M_t) = 0$) iff at that step the agent has only one choice.*

Proof. $\mu^i(M_t) = 0 \Leftrightarrow Log(|S_t|) = 0$

$\Leftrightarrow |S_t| = 1.$ ■

So, there is only one move in S_t available to the agent at step t. Intuitively, at the beginning steps of any dialogue, the uncertainty is expected to be high as all possible moves have close probabilities, then the uncertainty decreases gradually because agents are rational and they learn from each other when advancing in the dialogue.

Proposition 4.2. *The uncertainty (or entropy) of a move M_t at a certain step t during the dialogue is equal to one (i.e., $\mu^i(M_t) = 1$) iff at that step, all the moves in S_t have the same probability.*

Proof. Let us first prove the direct implication $\Rightarrow$.

We assume that all the moves at a certain step t have the same probability, and prove that the uncertainty is equal to one. Without loss of generality, we assume that $|S_t| = X_t$. So we have:

$\mu^i(M_t) = H(M_t)/Log(X_t)$

$= -\sum_{m_t^k \in S_t, k=1}^{X_t} P(m_t^k) Log P(m_t^k)/Log(X_t)$

$= -X_t[(1/X_t)Log(1/X_t)]/Log(X_t)$

$= -[Log(1/X_t)]/Log(X_t)$

$= Log(X_t)/Log(X_t)$

$= 1$

Let us now prove the inverse implication $\Leftarrow$.

We assume that the uncertainty is equal to one, and prove that all moves have the same probability. So we have:

$\mu^i(M_t) = 1$

$\Rightarrow 1 = H(M_t)/Log(X_t)$

$\Rightarrow 1 = -\sum_{m_t^k \in S_t, k=1}^{X_t} P(m_t^k) Log P(m_t^k)/Log(X_t)$

$\Rightarrow -Log(X_t) = \sum_{m_t^k \in S_t, k=1}^{X_t} P(m_t^k) Log P(m_t^k)$

$\Rightarrow Log(1/X_t) = \sum_{m_t^k \in S_t, k=1}^{X_t} P(m_t^k) Log P(m_t^k)$

$\Rightarrow Log(1/X_t) = P(m_t^1) Log P(m_t^1) + P(m_t^2) Log P(m_t^2) + \ldots + P(m_t^{X_t}) Log P(m_t^{X_t})$

By taking the exponential of both sides of the equation, we obtain:

$\exp^{Log(1/X_t)} = \exp^{P(m_t^1) Log P(m_t^1) + P(m_t^2) Log P(m_t^2) + \ldots + P(m_t^{X_t}) Log P(m_t^{X_t})}$

$\Rightarrow 1/X_t = \exp^{P(m_t^1) Log P(m_t^1)} * \exp^{P(m_t^2) Log P(m_t^2)} * \ldots * \exp^{P(m_t^{X_t}) Log P(m_t^{X_t})}$

$\Rightarrow 1/X_t = \exp^{Log P(m_t^1)^{P(m_t^1)}} * \exp^{Log P(m_t^2)^{P(m_t^2)}} * \ldots * \exp^{Log P(m_t^{X_t})^{P(m_t^{X_t})}}$

$\Rightarrow 1/X_t = P(m_t^1)^{P(m_t^1)} * P(m_t^2)^{P(m_t^2)} * \ldots * P(m_t^{X_t})^{P(m_t^{X_t})}$

$\Rightarrow 1/X_t = \Pi_{m_t^k \in S_t, k=1}^{X_t} P(m_t^k)^{P(m_t^k)}$

Because 1 is the maximum uncertainty, the solution of this equation can be obtained by resolving the following optimization problem:

$$Max[\Pi_{m_t^k \in S_t, k=1}^{X_t} P(m_t^k)^{P(m_t^k)}]$$

$$subject\ to:$$

$$\begin{cases} \sum_{m_t^k \in S_t, k=1}^{X_t} P(m_t^k) = 1 \\ 0 < P(m_t^k) \leq 1 \quad \forall\, 1 \leq k \leq X_t \end{cases}$$

Using the nonlinear programming techniques, we can easily find the solution of this problem, which is: $\forall\, 1 \leq k \leq X\ P(m_t^k) = 1/X_t$. ■

To the contrary of agents' uncertainty, it is interesting sometimes to see how certain an agent is about its moves. This can be simply done by subtracting the normalized value of agent's uncertainly from one as it will be given in the following definition.

Definition 4.5 (Move's certainty degree)**.** Let $D = [M_0, M_1, \ldots, M_n]$ be a negotiation dialogue, and suppose that at each dialogue step t a set S_t of moves m_t^k are possible, and each one of them is associated with a given probability $P(m_t^k)$ such that $\sum_{m_t^k \in S_t} P(m_t^k) = 1$. If Shannon entropy of the move M_t at step t is $H(M_t)$, we define the certainty degree of the move as follows.

$$CD^i(M_t) = \begin{cases} 1 & \text{iff} \quad |S_t| = 1 \\ 1 - H(M_t)/Log(|S_t|) & otherwise \end{cases} \tag{4.7}$$

Using the certainty degree, we can determine at each dialogue step how much an agent is certain about its move. The following lemmas are straightforward from Propositions 4.1 and 4.2.

Lemma 4.1. *The certainty degree of a move M_t at a given step t in the dialogue is at its maximum value "1" iff the agent has only one choice at that step.*

Lemma 4.2. *The certainty degree of a move M_t at a given step t in the dialogue is at its minimum value "0" iff the agent has more than one move at the same step with equal probabilities.*

By considering the uncertainty and certainty degrees of the dialogue moves, agents should resolve at each dialogue step one of the following equivalent optimization problems.

1. At each dialogue step the agent should minimize the uncertainty degree.

$$M_t^* = \underset{M_t}{\operatorname{argmin}}\, \mu^i(M_t) \tag{4.8}$$

2. At each dialogue step the agent should maximize the certainty degree.

$$M_t^* = \underset{M_t}{\operatorname{argmax}}\, CD^i(M_t) \tag{4.9}$$

Theorem 4.1. *There is an algorithm for solving these optimization problems in a polynomial time.*

Proof. *Because these problems are equivalent, we consider only one of them, for example the maximization one. Without loss of generality, we assume that agent i should solve this problem. The algorithm is as follows:*

1) Agent i should calculate the probability of each possible move m_t^k $(1 \leq k \leq x)$ using the move's probability function*: $\zeta(\Gamma^i \cup CS_t^j)$ considering its knowledge base Γ^i and agent j's commitment store CS_t^j;*

2) Take the move with the highest probability. Because Γ^i and CS_t^j are bounded at each *step t, this calculation is clearly polynomial and searching the maximum probability is polynomial, so we are done.* ■

This theorem is compatible with the intuition that by adding new information in CS_t^j, the number of possible choices decreases. However, this is only true when we consider just the next move. When we consider the whole dialogue, the complexity is much higher.

Example 4.1. Let D be a negotiation dialogue between two negotiating agents i and j such that $D = [M_0, M_1, M_2]$, and the number of possible moves at each dialogue step is $|S_t| = 3$. In the following, we explain how to measure the certainty degree of the move M_0. Using Equation 4.7, we obtain:

$CD^i(M_0) = 1 - H(M_0)/Log(|S_0|)$

$CD^i(M_0) = 1 - [(-\sum_{j=1}^{3} P(m_0^j) Log P(m_0^j))/Log(3)]$

$CD^i(M_0) = 1 + [(P(m_0^1) Log P(m_0^1) + P(m_0^2) Log P(m_0^2) + P(m_0^3) Log P(m_0^3))/Log(3)]$

From Table 4.2, we have:

$CD^i(M_0) = 1 + [((0.33 * -1.599) + (0.33 * -1.599) + (0.34 * -1.556))/Log(3)]$

$CD^i(M_0) = 1 - 1 = 0$

Table 4.2 shows the possible choices of the moves that facing agent i at step $t = 0$ to play its first move M_0 in the first column, and their associated probabilities in the second column. From the above calculations, we notice that the certainty degree of the agent i about selecting the right move at this step is at its minimum value "0" because agent i had different choices of moves with equal probabilities of acceptance by its opponent agent j. This means that agent i was uncertain 100% about which move to play.

The above calculations and Table 4.2 are just for the first move M_0, and to obtain the certainty degree of the other two moves M_1 and M_2, we use the same procedure as for M_0.

At step $t = 1$, agent j to play its move M_1 as a reply to agent i has three different choices of moves with different values of probabilities $(0.05, 0.12, 0.83)$, such that the sum

Table 4.2: The uncertainty/certainty degree of the move M_0 in Example 4.1.

Possible Moves	P(m_0^k)	**Log P(m_0^k)**	**P(m_0^j)Log P(m_0^k)**
m_0^1	0.33	-1.599	-0.528
m_0^2	0.33	-1.599	-0.528
m_0^3	0.34	-1.556	-0.529
	H(M_0)=1.58	$\mu^i(M_0) = 1$	$CI^i(M_0) = 0$

is equal to one. From the calculation, it can be noticed that agent j was uncertain about 0.50%, $(i.e., \mu^j(M_1) = 0.50\%)$ that the selected move is the right one, which has the higher probability (0.83), that is, a higher chance to be accepted by agent i.

At step $t = 2$, when agent i wanted to reply with its move M_2, it has also three different choices of moves with different values of probabilities $(0.9999, 1E-8, 1E-8)$. One of these choices has a very high chance to be accepted (probability close to one), where as, the other two have a very low chance of acceptance (their probabilities are close to zero). So, the agent i was almost certain 100% about its choice, and the uncertainty degree is at its minimum value “0”.

4.4.4 Agents’ Uncertainty about their Dialogues

In Section 4.4.3, we discussed how we could assess agents’ uncertainty about their moves at each dialogue step. In this section, we discuss how to assess this uncertainty for the whole dialogue. This can be done in three different methods. i) *Method I*: is by taking the average of the uncertainty degree of all moves in the dialogue, ii) *Method II*: is by finding the number of all possible dialogues and the probability of each one, and then applying Shannon entropy in the same way as for the moves, and iii) *Method III*: is measuring the uncertainty degree of some moves (sample) randomly, take the average and assume it is equal to the uncertainty of the dialogue, and then apply a hypothesis testing approach to find out whether this assumption is true. In what follows, we discuss these three methods.

Method I: Taking the Average of Uncertainty Degrees of All Dialogue Moves

The basic idea is to measure how much each agent is uncertain about its moves at each dialogue step. Then we calculate how much the two agents are uncertain about the whole dialogue by taking the average of the uncertainty degree of all the moves in the dialogue.

Definition 4.6 (Dialogue's uncertainty)**.** Given an ABAN dialogue $D = [M_0, M_1, \ldots, M_n]$. Let $|D| = n+1$ be the length of this dialogue, i and j be the two negotiating agents, where i utters the even moves and j utters the odd ones, and $\mu^i(M_t)$ be the uncertainty degree of the move M_t at step t. We define the uncertainty degree of the dialogue "$\mu(D)$" as follows.

$$\mu(D) = \sum_{M_t \in D} \mu^i(M_t)/(|D|) \tag{4.10}$$

Example 4.2. Assume that we have three negotiation dialogues D_1, D_2, and D_3, each dialogue consists of 10 moves, i.e $D_x = [M_0, M_1, \ldots, M_9]$, $(1 \leq x \leq 3)$. The uncertainty degree of each move for the three dialogues is given in Table 4.3. Below, we calculate the uncertainty degree of D_1, and in the same way we can calculate it for D_2 and D_3.

Using Equation 4.7, we have:

$\mu(D_1) = \sum_{M_t \in D_1} \mu^i(M_t)/(|D_1|)$

From Table 4.5, we obtain:

$\mu(D_1) = [0.01+0.20+0.15+0.05+0.22+0.02+0.11+0.21+0.10+0.05]/10$

$\mu(D_1) = 0.112$

In the same way we obtain the uncertainty degree of the other two dialogues

$\mu(D_2) = 0.503$, and

$\mu(D_3) = 0.936$

It can be noticed that for the dialogue D_1, the uncertainty degree is very low, and that is because the uncertainty degrees of all dialogue moves are low, where they range between

Table 4.3: The uncertainty degree of the dialogues of Example 4.2

Dialogue Moves	$\mu^i(M_t)$ **of** D_1	$\mu^i(M_t)$ **of** D_2	$\mu^i(M_t)$ **of** D_3
M_0	0.01	0.01	0.99
M_1	0.20	0.99	0.98
M_2	0.15	0.15	0.95
M_3	0.05	0.95	0.99
M_4	0.22	0.22	0.90
M_5	0.02	0.80	0.90
M_6	0.11	0.11	0.80
M_7	0.21	0.75	0.95
M_8	0.10	0.05	0.90
M_9	0.05	1	1
	$\mu(D_1)$=0.112	$\mu(D_2)$=0.503	$\mu(D_3)$=0.936

[0.01, 0.22]. This means that the participants were certain about their dialogue moves, and if they achieve their goal (agreement), it could be the best agreement (the notion of agreement and the evaluation of this agreement will be introduced in the next chapter).

In D_2, the negotiating agents were moderately uncertain about their dialogue. It is clear that agent i was always certain about its moves during the dialogue because its uncertainty is very low, while agent j was highly uncertain about its moves in the same dialogue. Not surprisingly, taking the average of the uncertainty degrees of all moves shows that it is medium which reflects the uncertainty degree of both agents.

In the third dialogue D_3, both agents were highly uncertain about their moves at each step, which results in a very high uncertainty degree for the whole dialogue.

Method II: Using the Probability of All Possible Dialogues

In this method, we measure the uncertainty degree of the dialogue by calculating the number of all possible dialogues that can be generated from all choices of moves, which can be obtained by taking the Cartesian product of all possible moves at each dialogue step. Therefore, by knowing the probability of each possible move, we can calculate the probability of each possible dialogue, and then we apply the general formula of entropy.

Definition 4.7 (Number of possible dialogues)**.** Let $D = [M_0, M_1, \ldots, M_n]$ be an ABAN dialogue, and i and j be the two negotiating agents. Suppose that at each dialogue step t, to utter the move M_t, an agent has a set S_t of alternative moves $S_t = \{m_t^1, m_t^2, \ldots, m_t^{x_t}\}$, each of which is associated with a probability value $P(m_t^k)$. The number of all possible moves is equal to $\sum_{t=1}^{n} x_t$. The union of all the sets of moves is $\Omega = S_1 \cup S_2 \cup \ldots \cup S_n$, such that there is no intersection between these sets: $S_1 \cap S_2 \cap \ldots \cap S_n = \emptyset$. So, the number of all possible dialogues can be obtained by: $N_D = |S_0 \times S_1 \times \ldots \times S_n|$.

As explained in Equation 4.2, each move M_t in a possible dialogue D_l is equal to a possible move m_t^k for a given k. Thus, $P(M_t) = P(m_t^k)$. Having known this probability, we can calculate the probability of a dialogue D_l as follows.

$$P(D_l) = P(M_0) \times P(M_1) \times \ldots \times P(M_n) \tag{4.11}$$

Because $\forall t \sum_{k=1}^{x_t} P(m_t^k) = 1$, the sum of the probabilities of all possible dialogues is equal to one (i.e., $\sum_{l=1}^{N_D} P(D_l) = 1$). Now we can define the uncertainty degree of the dialogue as follows.

First, we adopt the general formula of Shannon entropy to find the entropy for the dialogue.

$$H(D) = -\sum_{l=1}^{N_D} P(D_l) Log(D_l) \tag{4.12}$$

Then, we normalize the obtained result by dividing it by $Log(N_D)$ to have the uncertainty degree as a quantitative value between [0,1].

$$\mu(D) = H(D)/Log(N_D) \tag{4.13}$$

Example 4.3. Let us consider the negotiation dialogue in example 4.1, where $n = x_t = 3$, $1 \leq t \leq 3$. The number of all possible dialogues $N_D = 27$ dialogues, and the probability of each possible dialogue is computed by the product of probability of its moves. For example for D_1, we take the first possible choice of the moves (m_0^1, m_1^1, m_2^1) with their respective probabilities $(0.33, 0.05, 1)$. So, the probability of D_1 is equal to 0.02, and in the same way, we compute the probability of all possible dialogues. By applying Equation 4.12, we get the entropy of the dialogue, which is $H(D) = 2.39$, and by applying Equation 5.13, we get the uncertainty degree of the dialogue $\mu(D) = 0.503$. Here it can be noticed that the uncertainty degree of the dialogue is medium, and if we compare the result in this method with the result in the previous one, which uses the average of uncertainty degrees of all moves, and apply it on the same example (Example 4.1), we notice that the result is almost the same. Which confirms the consistency of the two methods.

Method III: Using Hypothesis Testing

- Hypothesis Testing Terminology:

A hypothesis testing is a procedure for determining if an assertion about a characteristic of a population is reasonable [91]. The characteristic of our interest here is the uncertainty degree which we want to estimate from the performance of the participants to the dialogue. Suppose someone is monitoring a negotiation dialogue between two agents and he claimed that the average of uncertainty degree of the dialogue is $(\mu = 0.50)$. How would you decide whether this assertion is true? One of the direct results could be obtained by calculating the uncertainty degree of each move as we did in Section 4.4, and then calculate the uncertainty degree of the whole dialogue and compare it with this estimation. This approach might be definitive, however, it could end up with costing more than the information is worth (waste of time).

A simpler approach is to find the uncertainty degree of sample of moves, take the average and compare it with estimated uncertainty degree of the dialogue. Of course, the average of the uncertainty degree will probably not be exactly (0.50%) due to the variability in the choices at each dialogue step. Suppose that the obtained average of uncertainty degree of the dialogue was (0.60%). Does this (0.10%) difference result from a chance of variability, or from an incorrect original assertion? A hypothesis test can provide us with the answer.

- Hypothesis Testing Steps

    1. Calculate the uncertainty degree μ of some moves (randomly).
    2. Take the average of the uncertainty degree (which represents the μ of the dialogue).
    3. Assume that the uncertainty for the whole dialogue is (μ_0).
    4. Give the two sided hypothesis:
        - Null hypothesis $H_0 : \mu(D) = \mu_0$,
        - Alternative $H_1 : \mu(D) \neq \mu_0$.
    5. Use the significance level ($\alpha = 0.05$).
    6. Compute the test statistic (t_0), which is given by the following equation:

$$t_0 = \frac{\bar{x} - \mu_0}{\frac{S}{\sqrt{n}}} \tag{4.14}$$

where:

$\bar{x}$ is the average of the uncertainty degree of the selected moves, μ_0 is the assumed uncertainty degree for the dialogue, n is the number of the selected moves, and S is the sample standard deviation of these moves, which can be computed using the following equation:

$$S = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} \tag{4.15}$$

7. Reject the null hypothesis H_0 if the test statistic $|t_0| > t_{\alpha/2,n-1}$, where $t_{\alpha/2,n-1}$ is the upper $\alpha/2$ percentage of the t-distribution with $(n-1)$ degree of freedom (DF).

Example 4.4. Suppose that we have a negotiation dialogue D between two agents, s and b. Assume that the length of the dialogue is $n = 20$ moves, so $D = [M_1, M_2, ..., M_{20}]$. Assume that the uncertainty degrees of agent i, $i \in \{s, b\}$ about randomly selected moves are as follows: $\mu^i(M_1) = 0.4$, $\mu^i(M_3) = 0.7$, $\mu^i(M_6) = 0.3$, and $\mu^i(M_9) = 0.5$.

Can we claim that the actual uncertainty degree of the dialogue is 0.50? To answer this question, let us go through the hypothesis testing steps:

- The uncertainty degrees of the randomly selected moves are given.
- The average of the uncertainty degree of these moves: $\bar{x} = 0.475$.
- Assume that the actual uncertainty degree of the dialogue is: $\mu_0 = 0.50$.
- Give the two sided hypothesis:
  - Null hypothesis $H_0 : \mu(D) = 0.50$,
  - Alternative $H_1 : \mu(D) \neq 0.50$.

From Equation (4.15), the sample standard deviation $S = 0.17$, where $n = 4$, and from Equation 4.14, we can find the test statistic t_0 as follows:

$t_0 = (0.475 - 0.50)/(0.17/2)$ =(-0.025 / 0.085)= $-0.294 \simeq -0.3$.

Using the student's t-distribution, $t_{\alpha/2,n-1} = t_{0.025,3}$ = 3.182

$\because |t_0| < t_{\alpha/2,n-1}$. Hence we cannot reject the null hypothesis H_0, and the uncertainty degree of dialogue can be 0.50. We reject the null hypothesis only if $|t_0| > t_{\alpha/2,n-1}$

4.4.5 Arguments Evaluation and Classification

In this section, we discuss how an agent can evaluate the arguments supporting its own offers, specifically in terms of its uncertainty degree about their selection, and consequently about their acceptance by the addressee. We classify the set of potential arguments into three main classes based on their uncertainty degree. In fact, the uncertainty degree of the arguments is obtained based on the evaluation criteria that have been proposed in Chapter 3.

Having the three criteria assessed based on their definitions for all the available arguments, and the uncertainty degree of each possible argument is measured, we then classify the set of potential arguments into three main classes; *Class A: Highly Certain Arguments*, *Class B: Moderately Certain Arguments*, and *Class C: Uncertain Arguments*. The highest class of argument is, the lowest risk of failure its arguments are. The three classes are disjoint, i.e., $A \cap B = A \cap C = B \cap C = \emptyset$, and each of which is divided into three subclasses, see Figure 4.3. Indeed, measuring uncertainty is mainly based on the probability distribution of the available arguments, which is in turn based on the above mentioned criteria.

In what follows we describe and formally represent the three main classes of arguments and their subclasses.

- `Class` A `- Highly Certain Arguments`: this class represents arguments and consequently moves supported by those arguments having very low risk of failure. Arguments of this class are equally risky, and the risk of failure of each argument in this class is less than the risk of failure of any other argument not part of this class. Let $=_{risk}$ be the risk equality relation and $\succ_{risk}$ be the strict risk relation, then we define

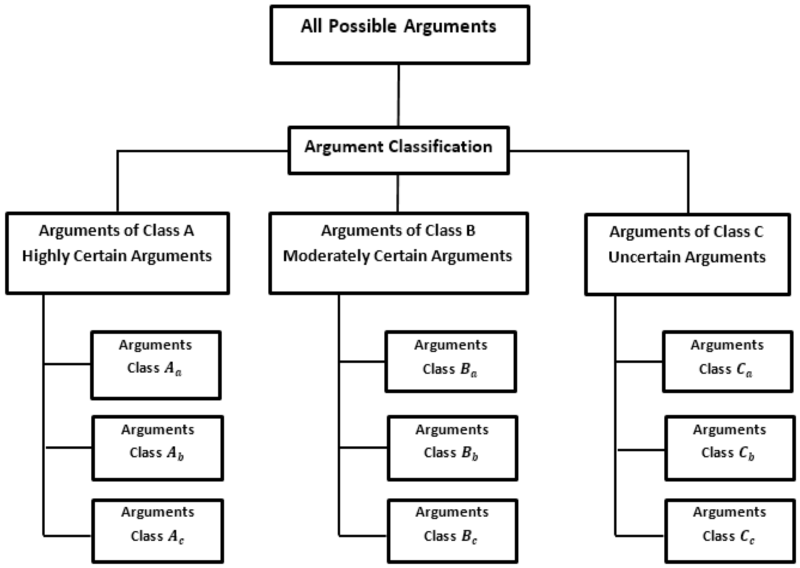

Figure 4.3: Arguments classification

the class A formally as follows:

$$Arg_k \in A \text{ iff} : \begin{cases} Arg_k =_{risk} Arg_l & \forall Arg_l \in A \\ Arg_l \succ_{risk} Arg_k & \forall Arg_l \notin A \end{cases} \tag{4.16}$$

This class is composed of three disjoint subclasses: A_a, A_b, and A_c, i.e., $A_a \cap A_b = A_a \cap A_c = A_b \cap A_c = \emptyset$, and to define these three subclasses, we need to define the following relations:

- let $=^i_{fav}$ be the favorite equality relation defined as follows:
  for two arguments Arg_k and Arg_l, $Arg_k =^i_{fav} Arg_l$ iff:
  $Arg_k \preceq^i_{fav} Arg_l$ and $Arg_l \preceq^i_{fav} Arg_k$; and
- let $=^i_{pref-ar}$ be the preference equality relation defined from $\preceq^i_{pref-ar}$ in the

same way.

So we formally define the three subclasses of the class A as follows.

$$Arg_k \in A_a \text{ iff}: \begin{cases} Arg_k \in A \\ Arg_k =^i_{fav} Arg_l & \forall Arg_l \in A_a \\ Arg_l \prec^i_{fav} Arg_k & \forall Arg_l \in A - A_a \\ Arg_k =^i_{pref-ar} Arg_l & \forall Arg_l \in A_a \\ Arg_l \prec^i_{pref-ar} Arg_k & \forall Arg_l \in A - A_a \text{ s.t. } Arg_k =^i_{fav} Arg_l \end{cases} \tag{4.17}$$

This means, arguments in A_a are equality favorable and preferable, more favorable than any other argument which is not part of A_a, and more preferable than any other favorably equally argument.

In the sam way, the second class A_b is defined as follows:

$$Arg_k \in A_b \text{ iff}: \begin{cases} Arg_k \in A - A_a \\ Arg_k =^i_{fav} Arg_l & \forall Arg_l \in A_b \\ Arg_l \prec^i_{fav} Arg_k & \forall Arg_l \in (A - A_a) - A_b \\ Arg_k =^i_{pref-ar} Arg_l & \forall Arg_l \in A_b \\ Arg_l \prec^i_{pref-ar} Arg_k & \forall Arg_k \in (A - A_a) - A_b \text{ s.t. } Arg_k =^i_{fav} Arg_l \end{cases} \tag{4.18}$$

Finally, the third class A_c is defined as follows:

$$A_c = (A - A_a) - A_b = A - (A_a \cup A_b) \tag{4.19}$$

- `Class` B `- Moderately Certain Arguments`: this class represents arguments having medium risk of failure. Arguments of this class have equal risk, which is less than the risk of any other argument not part of the union of that class and Class A. Formally:

$$Arg_k \in B \text{ iff}: \begin{cases} Arg_k =_{risk} Arg_l & \forall Arg_l \in B \\ Arg_l \succ_{risk} Arg_k & \forall Arg_l \notin A \cup B \end{cases} \tag{4.20}$$

As for Class A, this class is composed of three disjoint subclasses: B_a, B_b, and B_c. We define B_a formally as follows:

$$Arg_k \in B_a \text{ iff}: \begin{cases} Arg_k \in B \\ Arg_k =^i_{fav} Arg_l & \forall Arg_l \in B_a \\ Arg_l \prec^i_{fav} Arg_k & \forall Arg_l \in B - B_a \\ Arg_k =^i_{pref-ar} Arg_l & \forall Arg_l \in B_a \\ Arg_l \prec^i_{pref-ar} Arg_k & \forall Arg_l \in B - B_a \text{ s.t. } Arg_k =^i_{fav} Arg_l \end{cases} \tag{4.21}$$

In a similar way, the second class B_b is defined as follows:

$$Arg_k \in B_b \text{ iff}: \begin{cases} Arg_k \in B - B_a \\ Arg_k =^i_{fav} Arg_l & \forall Arg_l \in B_b \\ Arg_l \prec^i_{fav} Arg_k & \forall Arg_l \in (B - B_a) - B_b \\ Arg_k =^i_{pref-ar} Arg_l & \forall Arg_l \in B_b \\ Arg_l \prec^i_{pref-ar} Arg_k & \forall Arg_l \in (B - B_a) - B_b \text{ s.t. } Arg_k =^i_{fav} Arg_l \end{cases} \tag{4.22}$$

Finally, the third class B_c is defined as follows:

$$B_c = (B - B_a) - B_b = B - (B_a \cup B_b) \tag{4.23}$$

- `Class` C `- Uncertain Arguments`: this class represents arguments having a high risk of failure, and it is simply defined from the two other classes. knowing that $\mathscr{A}^i$ is the set of agent i arguments, then the third class C is defined as follows:

$$C = \mathscr{A}^i - (A \cup B) \tag{4.24}$$

  The subclasses C_a, C_b, and C_c are defined in the same way as the subclasses of A and B.

Generalization of Arguments Classification

The above arguments classification categorizes the set of potential arguments according to their uncertainty degree into three main classes, each of which consists of three subclasses. This classification seems to be a little strict, in the sense that it groups the arguments in just three main groups. However, this classification can be generalized to include n classes, each class is stratified into m disjoint subclasses as follows.

We classify the set of potential arguments into n classes $C_1, C_2, ..., C_n$, where C_1 is the highest class of arguments and it has the lowest risk of failure. Arguments of each class C_x have equal risk, which is less than the risk of any other argument in any class $C_{x'}$, where

$x < x'$. Formally:

$$Arg_k \in C_x \text{ iff} : \begin{cases} Arg_k =_{risk} Arg_l & \forall Arg_l \in C_x \\ Arg_k \prec_{risk} Arg_l & \forall Arg_l \in \bigcup_{l=x+1}^{n} C_l \\ Arg_k \succ_{risk} Arg_l & \forall Arg_j \in \bigcup_{l=1}^{x-1} C_l \end{cases} \tag{4.25}$$

From this equation, the following theorem holds.

Theorem 4.2. *The n classes $C_1, \ldots, C_n$, are disjoint, i.e., $C_1 \cap C_2 \cdots \cap C_n = \emptyset$.*

Each class C_x is stratified into m disjoint subclasses: $C_x^1, \ldots, C_x^m$. Let $=_{fav}^i$ be the favorite equality relation defined as follows: for two arguments Arg_k and Arg_l, $Arg_k =_{fav}^i Arg_l$ iff $Arg_k \preceq_{fav}^i Arg_l$ and $Arg_l \preceq_{fav}^i Arg_k$. The preference equality relation $=_{pref-ar}^i$ is defined from $\preceq_{pref-ar}^i$ in the same way. Each subclass C_x^a is defined as follows:

$$Arg_k \in C_x^a \text{ iff} : \begin{cases} Arg_k \in C_x \\ Arg_k =_{fav}^i Arg_l & \forall Arg_l \in C_x^a \\ Arg_l \prec_{fav}^i Arg_k & \forall Arg_l \in \bigcup_{l=a+1}^{m} C_x^l \\ Arg_l \succ_{fav}^i Arg_k & \forall Arg_l \in \bigcup_{l=1}^{a-1} C_x^l \\ Arg_k =_{pref-ar}^i Arg_l & \forall Arg_l \in C_x \\ Arg_l \prec_{pref-ar}^i Arg_k & \forall Arg_l \in \bigcup_{l=a+1}^{m} C_x^l \text{ s.t. } Arg_k =_{fav}^i Arg_l \\ Arg_l \succ_{pref-ar}^i Arg_k & \forall Arg_l \in \bigcup_{l=1}^{a-1} C_x^l \text{ s.t. } Arg_k =_{fav}^i Arg_l \end{cases} \tag{4.26}$$

This means, arguments in C_x^a are equally favorable and preferable, more favorable than any other argument which is in another class $C_{x'}^a$ such that $x' > x$, and more preferable than any other equally favorable arguments in $C_{x'}^a$.

From this equation, the following theorem holds.

Theorem 4.3. *For each class C_x, the m subclasses $C_x^1, \ldots, C_x^m$, are disjoint, i.e., $C_x^1 \cap C_x^2 \cdots \cap C_x^m = \emptyset$.*

The following theorem is straightforward from the above equations.

Theorem 4.4. *let x and x' be two integers such that $x < x'$. Arguments in the class C_x have higher probability to be accepted than arguments in the class $C_{x'}$.*

4.4.6 Agents' Uncertainty: Analysis and Discussion

In this section, we focus on the analysis of agents' uncertainty based on the available number of arguments and their relevant classes at each dialogue step in order to be able to determine the uncertainty type of each move. For instance, if there is only one possible choice (argument), then the probability of playing this argument will be "1", and consequently, the uncertainty will be "0". So in this case, do we consider this uncertainty as the agent's uncertainty about selecting the right move (argument) *Type I*, or as its uncertainty about the selected move (argument) to be accepted by the opponent *Type II*?. To answer these questions, we discuss the different possible scenarios of the number of arguments that an agent could have at each dialogue step, analyze them, and provide good justifications. Indeed, this analysis of uncertainty is very important and we believe that considering these cases in the agents' design phase can help the negotiating parties to better decide about the selection of their moves in order to achieve their goals.

In the previous sections, we explained in details how probabilities can be assigned and presented a novel classification for the set of potential arguments based on three main criteria (presented in Chapter 3) involving the addressee's preferences, and showed that probability assignment is based on the fact that the knowledge base Γ contains certain knowledge, whereas the set of agents' beliefs about each other preferences $P_{i,j}$ contains uncertain beliefs. Therefore, the probability of an argument that belongs to Γ to be accepted by the addressee is higher than the probability of another argument that belongs to the set $P_{i,j}$. Consequently, the probability of an argument belongs to Γ to be rejected is less than another argument belongs to $P_{i,j}$. In what follows, we discuss agents' uncertainty issues in two different cases based on the number of the available arguments and their relative classes at each dialogue step (the discussion will be based on the general classification for the set of potential arguments).

Case 1: If there is only one possible argument per class

If the agent has just one possible argument at any dialogue step, then the probability of playing this argument will be at its maximum value (i.e., equal to one to satisfy the probability condition). In fact, since there is no other choice at that step, the agent will be very certain to play this move. That is, the uncertainty Type I will be at its minimum value (i.e., equal to zero). For an argument, being a unique to form the class C_1 does not guarantee that the opponent will accept it because this depends merely on the risk failure of that argument.

On the other hand, if there are n classes C_1 to C_n, but only one possible argument per class, then the argument should be in C_1 and it has the highest probability to be accepted, which means uncertainty Type II is represented. However, the agent is uncertain about its move and it is possible that the argument in C_1 is not the most preferred one. Uncertainty Type I is then represented.

Proposition 4.3. *In ABAN dialogue games, at any dialogue step if there is only one possible argument Arg_1, then $Arg_1 \in C_1$, and the proponent faces only uncertainty Type II. If more than one class exist with only one argument, then the proponent faces both Types I and Type II.*

Case 2: If there is more than one possible argument in one or more classes

On the one hand, if the agent has more than one possible argument to play at any dialogue step, and all possible arguments have the same class, then this class is C_1 and all the arguments will have the same risk of failure, but they will not necessarily be equally likely selected. This depends on the number of subclasses. Arguments belonging to the highest subclass are more likely, and equally, to be selected. This equality will confuse the agent and make the uncertainty Type I at its maximum value, i.e., equal to one. The agent is also uncertain about the acceptance of these arguments depending on the risk of failure. For instance, if the possible arguments have very low risk of failure, the acceptance probability will be high. In fact, when we look at the class of the argument and its risk of failure, we can guess how likely this argument will be accepted, because it reflects the knowledge about the addressee.

On the other hand, if the possible arguments belong to different classes from C_1 to C_n, then those arguments are highly uncertain. The probability assignment will be based on the class of the argument. The higher argument class is, the more probably to be selected. Thus, the agent will be uncertain about which argument to play "*Type I*", and even after the argument selection, it will be uncertain that the selected argument will be accepted by its opponent "*Type II*". The two types of uncertainty are then represented.

Proposition 4.4. *In ABAN dialogue games, at any dialogue step if all possible arguments are in the same class, then the uncertainty of the selected argument will be at its maximum value "1". The proponent faces the two types of uncertainty Type I and Type II If the possible arguments are in the same class or in different classes.*

Theorem 4.5. *In all cases of addressing the uncertainty issues in ABAN dialogue games, the proponent always faces uncertainty Type II.*

Proof: The proof of this theorem is straightforward from the above propositions 4.4.

Table 4.4 summarizes the aforementioned cases, and shows when each of the two types of uncertainty is represented.

Table 4.4: Arguments classes vs. Uncertainty type

One possible argument			More than one possible argument		
Argument Class	Uncertainty Type I	Uncertainty Type II	Argument Class	Uncertainty Type I	Uncertainty Type II
Class C_1		$\surd$	Same class C_1	$\surd$	$\surd$
C_1 to C_n	$\surd$	$\surd$	C_1 to C_n	$\surd$	$\surd$

4.5 Implementation

4.5.1 Buyer/Seller Scenario

Let us consider a buyer/seller scenario between two negotiating agents *Seller* and *Buyer*. We assume that the buyer agent is interested in buying a laptop with certain specifications (preferences) and a low price from the seller agent. The seller agent on the other hand, has different laptops to offer with different specifications and prices, and it is trying to convince the buyer to buy one of them based on its request. Each agent is provided in its knowledge base with a set of different laptops with different specifications (e.g., price, screen size, memory, brand name, etc), as well as a preference relation over these specifications. We let the two agents negotiate by generating offers and counter-offers until they achieve an agreement or end the negotiation without achieving an agreement.

In order to compare our proposed method against others (which use pure argumentation system with no uncertainty consideration), we run each scenario twice with the exact agents' setting. In the first run, we let the agents negotiate using our proposed technique to choose the best argument/offer at each dialogue step in attempt to realize their goal. And in the second run, we let the agents negotiate without uncertainty consideration (i.e., using pure argumentation with no uncertainty consideration).

4.5.2 System Overview

In this section, we describe the implementation of a proof of concept prototype[2]. The implementation was done using Java language. In this prototype, we have developed agent superclass, which contains the argumentation system, negotiation strategies along with the tools needed for agents to reason and engage in negotiation based on its uncertainty, the risk of failure of each argument, and the agents' preferences. Our implementation can be adapted to a wide range of applications; however, in our case we considered only two agents; buyer and seller (i.e., bilateral negotiation). These two agents are inherited from agent class and we have added specific negotiation strategies on top of the agent model. On each run, these agents are initialized with different set of preferences over the available arguments/offers. We let the agents exchange offers based on the information available in the knowledge base and the agent's believes and preferences.

4.5.3 Experimental Results

To discuss our results, we have chosen three different scenarios presented in the following tables from Table 4.5 to Table 4.10.

Table 4.5: Scenario 1a: Negotiation dialogue using our uncertainty-aware technique

Step	Agent	# of offers	Uncertainty	Type I	Type II	ROF of Chosen Arg.	Available Arg. Class.	Chosen Arg. Class	Arg. Status
1	Buyer	8	0.92	√	√	0.69	C_2, C_3	C_2	Rejected
2	Seller	1	0.0		√	1.48	C_3	C_3	Rejected
3	Buyer	3	0.79	√	√	0.13	C_1, C_3	C_1	Rejected
	Negotiation ended without achieving an agreement								

In Table 4.5 Scenario 1a, even though the agents always select the argument with the higher class and less Risk Of Failure (ROF), in all cases the selected arguments were rejected. The interpretation of this is, for instance, the buyer agent in "step 1", had "8"

[2]The source code of the implementation and data are available at: https://github.com/Marooned202/negotiation

Table 4.6: Scenario 1b: Negotiation dialogue using pure argumentation without the uncertainty-aware technique

Step	Agent	# of offers	Uncertainty	Type I	Type II	ROF of Chosen Arg.	Available Arg. Class.	Chosen Arg. Class	Arg. Status
1	Buyer	8	0.92	N/A	N/A	N/A	C_1,C_2, C_3	C_3	Rejected
2	Seller	2	0.99	-	-	-	C_3	C_3	Rejected
3	Buyer	2	0.84	-	-	-	C_1, C_3	C_1	Rejected
4	Seller	2	0.99	-	-	-	C_1	C_1	Rejected
5	Buyer	2	0.96	-	-	-	C_2, C_3	C_2	Rejected
6	Seller	2	0.99	-	-	-	C_1, C_2	C_1	Rejected
7	Buyer	2	0.18	-	-	-	C_1, C_3	C_1	Rejected
8	Seller	2	1.00	-	-	-	C_2	C_2	Rejected
9	Buyer	2	0.83	-	-	-	C_1, C_3	C_1	Rejected
	Negotiation ended without achieving an agreement								

possible choices with different classes (from C_2 and C_3), and its uncertainty was very high "0.92", which represents the two types of uncertainty, uncertainty Type I, about which moves to play in order to persuade the seller, and uncertainty Type II, about the selected move to be accepted. The same thing applies to "step 3". However, in "step 2", the seller agent had just one choice with class C_3, but its uncertainty was very low to play this move. It is worth mentioning that this does not mean that this move will be accepted by the buyer, and this is because of the high risk of failure of this argument. The negotiation was ended without achieving an agreement because all offers and counter-offers were rejected and there were no more offers for both agents to play. In scenario 1a, the negotiation was ended in very short time compared to scenario 1b, since there is no theoretical agreement that could be achieved and our negotiating agents realized that very early, which confirms the efficiency of applying our techniques compared to Scenario 1b in 4.6, where the same negotiation was ended without achieving an agreement in much more time. In this scenario, agents do not select the most appropriate move at each dialogue step and this results in consuming more time and at the end they were not able to achieve an agreement.

In the same way, we interpret the other scenarios. In Table 4.7 Scenario 2a, our negotiating agents were able to achieve an agreement in a very short time compared to Scenario

2b in Table 4.8, where the agents could not achieve such an agreement. Likewise, the negotiations in Scenarios 3a and 3b which are included in Tables 4.9 and 4.10 respectively were ended successfully with achieving an agreement on the sellers offer in both scenarios, but in our case, the negotiating agents reached the agreement in much less time.

Table 4.7: Scenario 2a: Negotiation dialogue using our uncertainty-aware technique

Step	Agent	# of offers	Uncertainty	Type I	Type II	ROF of Chosen Arg.	Available Arg. Class.	Chosen Arg. Class	Arg. Status
1	Buyer	8	0.97	√	√	0.27	C_1, C_2, C_3	C_1	Rejected
2	Seller	1	0.0		√	0.83	C_1	C_1	Accepted
			Negotiation ended with achieving an agreement on the seller's offer						

Table 4.8: Scenario 2b: Negotiation dialogue using pure argumentation without the uncertainty-aware technique

Step	Agent	# of offers	Uncertainty	Type I	Type II	ROF of Chosen Arg.	Available Arg. Class.	Chosen Arg. Class	Arg. Status
1	Buyer	8	0.93	N/A	N/A	N/A	C_2, C_3	C_3	Rejected
2	Seller	2	1.00	-	-	-	C_3	C_3	Rejected
3	Buyer	1	0.0	-	-	-	C_3	C_3	Rejected
4	Seller	2	0.95	-	-	-	C_3	C_3	Rejected
	Negotiation ended without achieving an agreement								

Table 4.9: Scenario 3a: Negotiation dialogue using our uncertainty-aware technique

Step	Agent	# of offers	Uncertainty	Type I	Type II	ROF of Chosen Arg.	Available Arg. Class.	Chosen Arg. Class	Arg. Status
1	Buyer	10	0.93	√	√	0.08	C_1, C_2, C_3	C_1	Accepted
2	Seller	1	0.0		√	0.83	C_3	C_3	
	Negotiation ended with achieving an agreement on the seller's offer								

4.6 Summary

In this chapter, we presented an efficient method for agents' uncertainty assessment to help the negotiating agents make better decisions about their moves selection under the assumption of uncertainty.

In particular, we used Shannon entropy to assess the agents' uncertainty about their moves at each dialogue step, and consequently for the whole dialogue. In our negotiation

Table 4.10: Scenario 3b: Negotiation dialogue using pure argumentation without the uncertainty-aware technique

Step	Agent	# of offers	Uncertainty	Type I	Type II	ROF of Chosen Arg.	Available Arg. Class.	Chosen Arg. Class	Arg. Status
1	Buyer	10	0.90	N/A	N/A	N/A	C_1,C_2, C_3	C_3	Rejected
2	Seller	2	0.99	-	-	-	C_2	C_2	Rejected
3	Buyer	2	0.96	-	-	-	C_1, C_3	C_3	Rejected
4	Seller	2	0.98	-	-	-	C_1, C_2	C_2	Rejected
5	Buyer	2	0.52	-	-	-	C_1, C_3	C_3	Rejected
6	Seller	2	0.90	-	-	-	C_1, C_3	C_1	Accepted
7	Buyer	2	0.98	-	-	-	C_1, C_2	C_1	
	Negotiation ended with achieving an agreement on the seller's offer								

settings, we assume that the negotiating agents have multiple choices of moves with different probabilities to advance at each dialogue step. The probability of each move reflects its degree of uncertainty. The higher probability the move has, the more likely to be accepted by the addressee. To calculate this uncertainty, we defined a function called "Move's Probability Function". This function assigns a probability value between [0,1] to each move, such that the summation of all moves' probabilities at each dialogue step is equal to 1. Then, the moves are ordered based on their probability using what we call "Probability Ordering Relation". Finally, we apply the general formula of Shannon entropy to measure moves' uncertainty. We also, measured the agents' uncertainty about their dialogue in three methods, the first one is by taking the average of uncertainty degrees of all dialogue moves, and in the second method, we compute the number of all possible dialogues using the Cartesian product of all possible moves, then we compute the probability of each dialogue, and finally we apply entropy to measure the uncertainty. In the third method, instead of going through the process of calculating the uncertainty of all dialogue moves, we proposed to use a hypothesis testing approach for agents' uncertainty about their dialogue, especially, for those dialogues who last long. Using this approach, we calculate the uncertainty for a sample of moves, take the average of uncertainty for these moves and assume that the uncertainty of the dialogue is equal to this average, then we apply the hypothesis testing to decide about this assertion. Furthermore, based on the obtained moves' uncertainty, we presented a novel classification for the set of potential arguments, which will be used in the next chapter for designing some concession strategies. Moreover, we analyzed different situations and raised up some special cases based on the number of available arguments and their relative classes at each dialogue step. Finally, we implemented the proposed framework by applying it on a real case study (Buyer/Seller) scenario from the business domain. The obtained results confirm the effectiveness of using our uncertainty-aware approach.

To summarize, this chapter has answered the research questions (**RQ3**, part of **RQ4**, and **RQ6**) raised in Chapter 1. In the next chapter, we explore some negotiation strategies and introduce new agent profiles taking into account the uncertainty assessment and arguments classification presented in this chapter.

Chapter 5

Uncertainty-Aware Mechanism for Bilateral Negotiation

In this chapter[1], we investigate the influence of agents' uncertainty on their decisions to make concessions or accept the opponent's proposals in argumentation-based negotiation. In particular, we focus on a specific type of negotiation namely, *bargaining*. We analyze the needed negotiation parameters and propose some new metrics related to the negotiation progress, negotiation outcome, and the performance of the negotiating parties. This includes: i) the analysis of the negotiation constraints to specify the negotiation space and the possible agreement space, ii) the assessment of the concession by computing the amount of the loss of an agent at each dialogue step and at the end of the dialogue, iii) the proposition of some metrics to evaluate the negotiation outcome and the agents' performance such as the difference between the achieved agreement and the best agreement, the goodness degree of an agent in the real dialogue, and farness degree of an agent from the ideal dialogue, and iv) evaluating of the set of potential offers and classifying them into four groups based

[1] Part of this chapter's results are published in the 26th IEEE International Conference on Tools with Artificial Intelligence (ICTAI) [89], and an extended and modified version of this work is submitted to the Journal of Group Decision and Negotiation.

on their acceptability. Thereafter, we use the output of these parameters to design a new negotiation mechanism for automated bilateral negotiation using arguments. The developed mechanism allows negotiating parties to reason about their moves selections considering their uncertainty. More precisely, we propose two main sets of negotiation strategies namely; Concession and Acceptance strategies, each of which is composed of three subsets. The concession strategy set is based on the arguments classification proposed in Chapter 4, whereas, the acceptance strategy set is based on a new offers classification (that will be discussed in this chapter). Further, based on these two set of strategies, we introduce a new set of agents' profiles. Each agent profile consists of one concession and one acceptance strategy. Furthermore, this chapter discusses two important properties namely, completeness and Nash equilibrium, which are related to the negotiation outcome and according to the different agent profiles. Finally, we empirically validate the proposed negotiation mechanism by applying it on a concrete case study namely, Buyer/Seller scenario.

For a convenience reading of this chapter, we refer the reader to the list of notations presented in Table5.1.

Table 5.1: List of the notations used in Chapter 5

The notation	**The meaning of the notation**
s and b	Seller and Buyer agents
Ag	The set of all negotiating agents
μ	Uncertainty degree
Ψ	The set of all possible outcomes
ψ	A possible outcome
U	The utility function
$\preceq^{i}_{pref-o}$	Preordered preference relation over offers for agent i
$\mathscr{O}^{i}$	The set of agent i's offers
o^{i}_{t}	The offer made by agent i at step t
$\mathscr{P}\mathscr{O}^{i}_{t}$	The set of potential offers for agent i at step t
$\mathscr{P}\mathscr{A}^{i}_{t}$	The set of potential supporting arguments for agent i at step t
$\mathscr{F}(o^{i}_{t})$	A function that specifies the set of supporting arguments for the offer o^{i}_{t}
$\mathscr{C}$	The negotiation constraint
$\mathscr{A}S_{\mathscr{C}}$	The constraint agreement space
$\mathscr{T}\mathscr{P}^{i}$	The target point of agent i
$\mathscr{R}\mathscr{P}^{i}$	The resistance point of agent i
$\mathscr{N}S^{b\leftrightarrow s}_{\mathscr{C}}$	The negotiation space for both agents
$\mathscr{A}S^{b\leftrightarrow s}_{\mathscr{C}}$	The agreement space for both agents
$\mathscr{V}(o^{i}_{t})$	The value of the offer o^{i}_{t} made by agent i at step t
$loss^{i}_{t}$	The loss of agent i at step t
$\mathscr{T}loss^{i}$	The total loss of agent i
$\mathbb{CR}$	The concession rate
$\mathbb{NC}$	Number of concessions
ψ^{Ach}	The achieved agreement
ψ^{Ach*}	The desired outcome
$U^{i}(\psi^{Ach})$	The utility of the achieved agrement for agent i
Γ^{i}	The knowledge base of agent i
ψ^{Best}	The best outcome
$\mathscr{G}\mathscr{D}^{i}(\psi^{Ach})$	The goodness degree of agent i based on the achieved agreement
$\mathscr{G}\mathscr{D}^{i}(\psi^{Best})$	The goodness degree of agent i based on the best agreement
$\mathscr{F}\mathscr{D}^{i}$	The farness degree of agent i
ψ^{Ach}_{S}	The achieved agreement (the offer is made by the Seller)
ψ^{Ach}_{B}	The achieved agreement (the offer is made by the Buyer)

5.1 Introduction

In the last decade, various approaches have been carried out to model the negotiation process, negotiating agents, arguments, and preferences (see e.g., [17, 36, 56, 80, 108, 125]). While other approaches have focused on the analysis of offers and counter-offers generation and on the classification of negotiation strategy based on the agents' willingness of making concession against different types of opponents [24, 68, 124]. Moreover, other studies have concentrated on the analysis and optimization of the decision making strategies, and on the supporting systems for the negotiating parties [34, 93, 100]. However, most of these proposals lack the analysis of the dialogue outcome quality under the assumption of uncertainty, especially, when different agent profiles and negotiation strategies are considered. In fact, deciding about which move to advance among the alternatives considering the different classes of the supporting arguments based on their uncertainty, and the acceptance of other's proposals based on the adopted acceptance strategies in argumentation-based negotiation has not been investigated yet. Indeed, providing the negotiating agents with such a mechanism that helps them better decide about the selection of their moves in the presence of uncertainty is a key issue in automated negotiations.

In our approach, to improve the quality and efficiency of the negotiation process, negotiating parties are allowed to provide a feedback with more sophisticated and useful information (arguments) about their proposals in a form of a critique or a counter-offer. From such feedback, the proponent should be in a position to generate a new offer that is more likely to be accepted by the opponent and will possibly lead to a mutually acceptable agreement. In addition, the negotiating agents are assumed to be rational and consider their uncertainty about the played moves at each dialogue step. To do so, negotiating parties are provided with a negotiation mechanism that allows them to adopt some concession strategies based on the supporting argument classes (i.e., the uncertainty degree of the supporting arguments). Further, each participant is allowed to evaluate its opponent's proposals besides evaluating its own offers using what we call acceptance strategies. We also assume that agents exchange information in the form of offers/arguments, each offer consists of a value assignment to the negotiation constraint. Therefore, offers are not values of constraints, but values that satisfy the negotiation constraints. In other words, constraints are used to model the conflict of interest between agents and to specify the agreement space for each agent. Constraints are also used to analyze the agent's satisfaction so that each agent avoids the risk to concede everything to its opponent. In our work, we view the negotiation as a process of cooperative and competitive decision making between two agents in which arguments and negotiation constraints are essential in generating offers and counter-offers. Based on the fact that the negotiating parties have limited information about the preferences and constraints of each other, they can make their decisions based on the adopted negotiation strategies, which can be specified based on the available information about their individual preferences, constraints, and the uncertainty degree about the supporting arguments. Hence, the ultimate goal of each participant is to achieve the agreement that maximizes its profit or utility (resp. minimizes its loss) using arguments while respecting its constraints. By doing so, each negotiating agent is trying to optimize its performance in the negotiation in order to get closer to the best outcome.

The rest of this chapter is organized as follows. In Section 5.2, we present the most relevant literature. Section 5.3 outlines some assumption and gives the settings of our negotiation framework. In Section 5.4, we present evaluation methods for the negotiation outcome and the performance of the negotiating parties. Offers evaluation and classification technique is presented in Section 5.5. Section 5.6 introduces a new set of negotiation strategies, and a new taxonomy of agent profiles is presented in Section 5.7. In Section 5.8, we discuss some outcome properties. A discussion of the implementation and the experimental results are presented in Section 5.9. Finally, a brief summary of the chapter is given in Section 5.10.

5.2 Related Work

Argumentation-based negotiation has been an active area of research for more than a decade. It has attracted the attention of researchers in the area of Multi-Agent Systems (MASs) in general, and automated negotiations in particular. Different perspectives related to argumentation have been already investigated such as modeling the negotiating agents (see e.g., [35, 88, 106, 121]), designing the negotiation strategies (see e.g., [10, 23, 24, 37, 53, 57, 113]), analyzing the agreements about certain actions (see e.g., [123]), Studying the logical approaches to argumentation (see e.g., [76]), and proposing different protocols and techniques showing how these agents can communicate with each other in their environments (see e.g., [8, 44, 56, 70, 108]). The focus of this chapter is on the negotiating agents performance and the adopted negotiation strategies that influence the process of selecting the right moves at each dialogue step under the assumption of uncertainty. Despite the huge number of publications on modeling software agents and negotiation strategies, there still exists room for improvements. However, to the best of our knowledge, none of the existing works has addressed the problem of agents' uncertainty during the process of selecting the right moves and making decisions about their selections.

In [111], Ros and Sierra argued that agents can make concessions by using different tactics and/or a trade-off algorithm. However, this approach does not allow the negotiating agents to reason about their beliefs to justify their offers and to influence the behavior of their opponents. In our approach, negotiating agents use the negotiation constraints to ensure their satisfaction and to avoid the risk to concede everything to the opponent. In addition, by using their argumentation system, negotiating agents are able to make concessions when it is necessary, thus increasing their chances to achieve their best goals.

Kakas and Moraitis in [70] proposed an argumentation-based negotiation protocol in which negotiating agents can link their offers to the different arguments they can build according to their individual negotiation strategy, and make their decisions through an argumentative self-deliberation of the agents with their own theory. This describes the dynamic aspect of this work, where negotiating agents can change their strategies during the course of negotiation based on their environment changes. However, in this case, agents cannot expect the behavior of each other, especially in the absence of enough information (i.e., in uncertain settings). In addition, which strategy to adopt based on the opponent strategy is not considered. In contrast, our framework guarantees that each agent can adopt its profile (i.e., its strategy) based on its opponent's strategy during the course of the dialogue which may lead to the best outcome.

Based on the acceptability semantics proposed by Dung [42], Amgoud and her colleagues [8] proposed a general framework for argumentation-based negotiation in which they formally linked the set of offers and their supporting arguments. In particular, they classified the set of arguments into three sets namely, accepted, rejected and undecided arguments. Moreover, they classified the set of offers into four sets: acceptable, rejected, negotiable and non-supported offers. Although this classification seems to be important and helps somehow negotiating agents make their decisions, neither agents' uncertainty about the supporting arguments nor the appropriate negotiation strategy that agents can apply in order to achieve a better outcome are considered in this work. Rahwan et al. [108] proposed another argumentation-based negotiation approach to maximize the positive interaction among the goals of negotiating agents. This work considers only the context of cooperative negotiation, while in our work, we focus on the connection between offers and the supporting arguments in the context of a non-cooperative negotiation. In addition, we discuss different agent profiles and negotiation strategies that agents can employ with regard to their concession and acceptance decisions.

Lopes and Coelho in [77] introduced a model for bilateral negotiation that incorporates a set of concession strategies and negotiation tactics. The authors have defined the concession strategies as computationally tractable functions that define the tactics to be used during the negotiation, whereas tactics are defined as functions to designate the move to be made at each dialogue step. Even though the authors have considered some concession levels, they did not consider the effect of neither the acceptance strategies nor the agent's profile that can be adopted in each dialogue session. At the same time, Hadidi et al. in [56] introduced an argumentative version of the well known alternating offers protocol in which they linked offers to specific type of arguments called practical arguments, and defined the order relation between offers based on the number of acceptable arguments supporting each offer. This means, each negotiating agent favors offers that are supported by more acceptable arguments. This work has examined only a specific type of agents namely, argumentative agents. Furthermore, unlike our approach, this work does not allow negotiating agents to reason about their beliefs to select the most relevant argument (i.e., the most likely to be accepted by the addressee) among the arguments supporting an offer. Moreover, it does not take into account agents' uncertainty to specify when and how agents can make concessions.

In the context of concession strategies, Baarslag et al. in [24] proposed a quantitative concession-based classification method for negotiation strategies in which they measure the willingness of an agent to concede against different types of opponents. In this work, the authors reached to some extent their goal in addressing the concession strategies. However, the work does not consider the uncertainty issue related to the moves selection when making concessions, and also neglected the other types of strategies that can be considered besides the concession strategies such as acceptance strategies. The first attempt to handle the concession and acceptance strategies together was by Mbarki et al. in [88]. The authors proposed a framework for argumentative agent types in which they defined two concession strategies and two acceptance strategies, and combined these strategies to come up with four agent types. Though this framework seems interesting, it dose not investigate all possible ways to make concession and accept others proposals. Moreover, the uncertainty issue has not been addressed in that work. To overcome these limitations, later on Mbarki et al. in [89] extended that work by having more concession and more acceptance strategies, and combined them to have twelve agent types. This work is the closest one to ours in terms of handling the concession and acceptance strategies together. However, our work is different in the way we propose these strategies. More precisely, they designed their strategies based on the arguments classification proposed by Amgoud and her colleague [8], which does not consider agents uncertainty. Whereas, we designed our concession strategies based on our arguments classification [83] in which we consider the agents incomplete information about the selection of their moves. Moreover, the acceptance strategies we propose are based on a new evaluation and classification for the set of offers. Also, what distinguishes our work from others is the validation of the proposed approach through the empirical results that we provide at the end of this chapter. Studying some properties related to the agents' performance and the negotiation outcome is also a novel contribution advancing the state-of-the-art of argumentation-based negotiation.

5.3 Negotiation Settings

As discussed in Chapter 2, we will adopt the well-known Rubinstein's alternating-offers protocol for bilateral negotiation [114]. However, instead of allowing the negotiating parties to exchange offers only, we allow them to exchange offers and arguments to support their offers. For the rest of this chapter, we assume that the two negotiating agents (Seller s and Buyer b) are exchanging their offers and/or arguments in turns. The two parties negotiate over some issue(s), each of which has an associated range of alternatives or values. Moreover, we consider in our settings another important factor namely, the agents' uncertainty degree μ about their proposals. A negotiation outcome consists of a mapping of every issue to a value. We denote to the set of all possible outcomes by Ψ, and we call it the *negotiation outcome domain*. Also, both parties have certain preferences over offers and arguments prescribed by a preordered preference relation, which can be modeled by a utility function U that maps a possible outcome ($\psi \in \Psi$) to a real number in the range [0,1].

Assumptions: in our negotiation settings, we have the following set of assumptions.

- Agents are rational and always select the offers that maximize their profit and consequently minimize their loss.
- Agents always consider their uncertainty about their moves (offer/argument) selection to play the one with less degree of uncertainty.
- Agent i's offers are ordered based on a preference relation as follows: $(o^i_n \preceq^i_{pref-o} o^i_{n-1} \cdots \preceq^i_{pref-o} o^i_1)$, where o^i_1 is the most preferred offer.
- Each agent starts by offering its most preferred offer (i.e., o^i_1) from the set of potential offers, which has a higher probability to be accepted by the addressee.

- At each dialogue step t, an offer can be chosen from the set of potential offers at that step $\mathscr{PO}^i_t = \{o^i_1, ..., o^i_n\}$.

- Each potential offer o^i_t, $(1 \leq t \leq n)$ is supported by an argument or a set of arguments from the set of potential arguments at that step $\mathscr{A}^i_t \subseteq \mathscr{PA}^i_t$, which can be captured by the function $\mathscr{F}^i(o^i_t) = \mathscr{A}^i_t$. Formally:

$$\forall o^i_t \in \mathscr{PO}^i_t, \exists\, \mathscr{A}^i_t \subseteq \mathscr{PA}^i_t : \mathscr{F}^i(o^i_t) = \mathscr{A}^i_t.$$

One of the negotiating parties (let's say agent i) starts the negotiation by sending its best offer o^i_1 along with the supporting arguments, in its turn, the opponent (agent j) has two possibilities: (1) accept the offer if no counter-offer can be generated; or (2) reject the offer by presenting a counter-argument(s) justifying the rejection and so attacking the argument(s) supporting the offer o^i_1. In the case of acceptance, the negotiation succeeds and ends by achieving an agreement, whereas, in the case of rejection, the proponent uses its argumentation system to compute the new set of its potential offers and arguments, and check the possibility for proposing a new offer. In the following subsection, we briefly discuss the elements that constitute our negotiating agent.

5.3.1 Agent Architecture

Recall that the basic elements of the classical agent (non-ABN) as presented in Chapter 2 are as follows.

1. Locution interpretation: parses incoming messages;
2. Proposal database: stores proposals for future use;
3. Proposal evaluation and generation: ultimately makes a decision about whether to accept, reject, generate a counter proposal or terminate the dialogue; and

4. Locution generation: sends the response to the relevant party or parties.

Also from Chapter 2, recall that an ABN agent must be equipped with the following.

1. A mechanism for evaluating incoming arguments and updating the mental state accordingly;

2. A mechanism for generating arguments; and

3. A mechanism for selecting the best outgoing argument from the set of potential arguments.

Therefore, an ABAN agent simply consists of all the above mentioned components in addition to the following two new elements.

1. Opponent's strategy discovery: discovers the opponent's strategy to play in the next round accordingly; and

2. Argument's uncertainty evaluation and strategy update: evaluates (computes) the uncertainty degree of all the generated arguments and suggests the one with less uncertainty degree and updates the agent's strategy (changes it if needed) based on its opponent strategy.

Figure 5.1 shows the conceptual elements of an ABAN agent, where the additional elements that distinguish ABAN from the classical non-ABN and ABN are potted in double dotted lines.

5.3.2 Negotiation Constraints

Constraints are amongst the different negotiation criteria that need to be satisfied in order to reach an agreement between the negotiating parties. This implies that negotiation can be

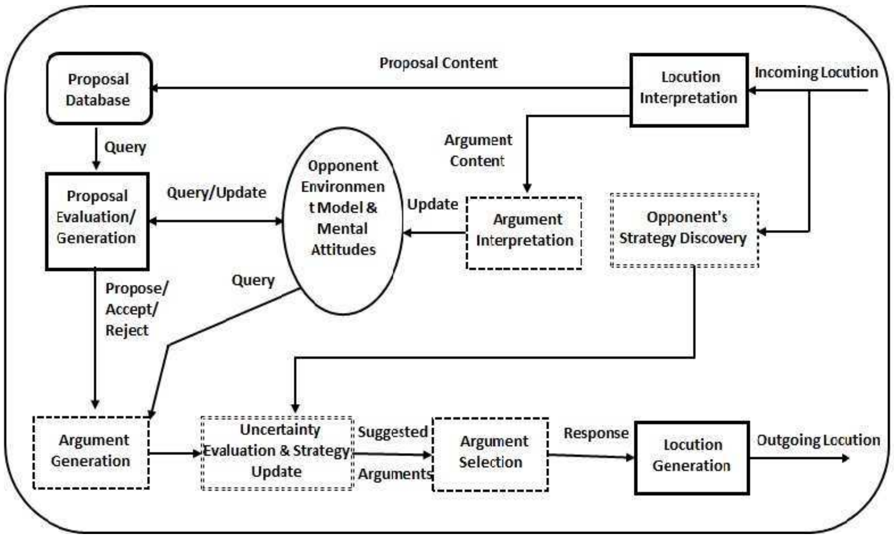

Figure 5.1: Conceptual elements of an ABAN agent.

modeled as a Constraint Satisfaction Problem (CSP) [75], which can be defined as a set of variables with the associated domains and a set of constraints acting on the variables with the aim of finding an instantiation of the constrained variables such that all constraints are satisfied at the same time. As such, negotiation constraints may range over a quantitative constraint (e.g., the price or delivery date) or qualitative constraint (e.g., quality of service). In this thesis, we follow the approach proposed in [48], and define the negotiation constraint as a quantitative variable ranging over a real domain. Such a domain designates all the constraint values that are acceptable by an agent. In the context of negotiation, the constraints are distributed between the negotiating agents and the information is exchanged in the form of offers/arguments, that is, the preferred instantiation of the variables corresponding to the negotiation issues. Moreover, the offers already exchanged between the negotiating agents influence the negotiation process, and consequently their future decisions. For instance, a rational agent would not propose an offer with less value than the offer already received from its opponent. So, the ultimate goal of each negotiating agent is to maximize its profit (or utility) by maximizing the value of the negotiation constraint (for the Seller) and respectively minimizing this value (for the Buyer). For instance, the price of product is a typical example of budget constraint in a bargaining session where the Buyer is looking for the lowest price, whereas the Seller is trying to get the highest possible one.

The value of the negotiation constraint $\mathscr{C}$ for an agent *i*, ranges between *'minimal'* and *'maximal'*. This range represents the agent's aspiration or what we call *"Constraint Agreement Space"* for an agent. The two boundaries of the constraint agreement space are determined by the agent before starting the negotiation. One of them represents what the agent considers as its best offer, we call it the *"Target Point"*, whereas the other one represents the limit that the agent cannot overtake, we call it the *"Resistance Point"*. Moreover, the range of agent's constraint (or the individual area of interest) prescribes the preferred solutions for that agent, whereas the common set of constraints (or the common area of interest of both agents) prescribes the possible joint solutions for both agents. In this context, the final objective of the negotiation is to find any solution from the common area of interest that maximizes the utility of both parties.

The formal representation of the negotiation constraints and the different areas of negotiation (bargaining zones) will be as follows.

- The negotiation constraint for an agent $\mathscr{C} \in [\mathscr{C}_{min}, \mathscr{C}_{max}]$.
- The *Constraint Agreement Space* (or agent's aspiration range) is denoted by $\mathscr{A}S_{\mathscr{C}}$.
- The *Target Point* of an agent *i* is denoted by $\mathscr{T}\mathscr{P}^i$.
- The *Resistance Point* of an agent *i* is denoted by $\mathscr{R}\mathscr{P}^i$.
- The union of the constraint agreement spaces of the two agents represents the *Negotiation Space*, denoted by $\mathscr{N}S_{\mathscr{C}}^{b\leftrightarrow s}$ (Equation 5.1).

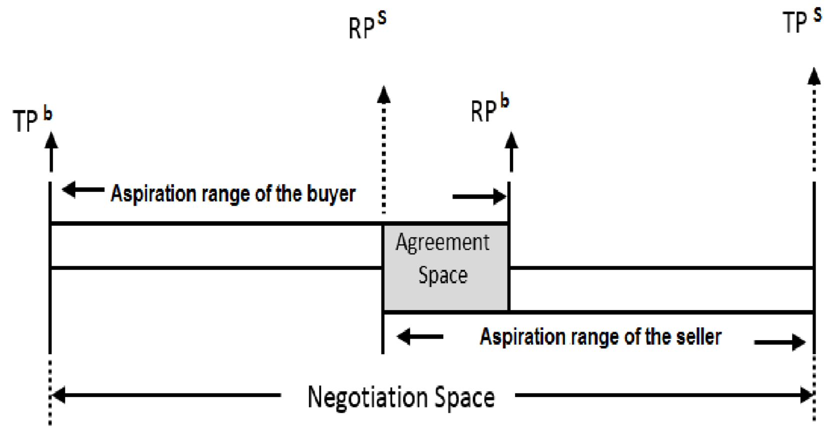

Figure 5.2: An example illustrates the constraint and the bargaining zones for the two negotiating agents s and b

$$\mathcal{NS}_{\mathcal{C}}^{b\leftrightarrow s} = \mathcal{AS}_{\mathcal{C}}^{b} \cup \mathcal{AS}_{\mathcal{C}}^{s} \tag{5.1}$$

- The intersection of the two agents' agreement spaces represents the *Agreement Space* for both agents, denoted by $\mathcal{AS}_{\mathcal{C}}^{b\leftrightarrow s}$ (Equation 5.2).

$$\mathcal{AS}_{\mathcal{C}}^{b\leftrightarrow s} = \mathcal{AS}_{\mathcal{C}}^{b} \cap \mathcal{AS}_{\mathcal{C}}^{s} \tag{5.2}$$

Figure 5.2 illustrates an example of the constraint and the bargaining zones for the two negotiating agents s and b.

Example 5.1. : During the negotiation of a product price, a Buyer agent b is trying to get the lowest price, while a Seller agent s is trying to get the highest one. Let $\mathcal{C}$ be the constraint associated with the price of the product (*budget constraint*). Let us assume that $\mathscr{A}S^b_{\mathscr{C}} = [50,80]$ and $\mathscr{A}S^s_{\mathscr{C}} = [60,100]$. Thus:

$$
\begin{aligned}
\mathscr{N}S^{b\leftrightarrow s}_{\mathscr{C}} &= [50,80] \cup [60,100] = [50,100] \\
\mathscr{A}S^{b\leftrightarrow s}_{\mathscr{C}} &= [50,80] \cap [60,100] = [60,80]
\end{aligned}
$$

The negotiation process consists of a sequence of moves (offers and counter-offers) in turns between the negotiating agents b and s. Since the common area of interest is not known to both agents a priori, this process continues and agents move towards a possible agreement (if such an agreement exists) by making concessions until an offer is accepted by both agents (i.e., an agreement is achieved), or one of the parties terminates the negotiation before achieving an agreement (i.e., the negotiation has failed). Thus, the concession mechanism used by our negotiating agents is outlined in the following subsection.

5.3.3 Concession Mechanism

Negotiation is a process in which the negotiating parties are seeking for jointly acceptable agreement. In order to successfully achieve such an agreement, both parties should be flexible to change their positions and move towards a possible solution within the common area of interest by making concessions. This flexibility often keeps the negotiation ongoing—the more flexible negotiator seems to be, the more its opponent will believe that an agreement is possible. During the concession process, agents move from one offer to another, that is less preferred for it, within the available options. This means, the ranges of available options for each agent shrink until an agreement is reached. Moving from one option to another (i.e., making concession) should be done in a certain way that ensures the constraints consistency and satisfaction.

An agreement can occur when the two parties enter the agreement space $\mathscr{AS}_{\mathscr{C}}^{b \leftrightarrow s}$, that is, the individual areas of interest of each party become the common area of interest of both parties (see Figure 5.2). At this stage, the two parties can accept any solution or may choose to continue the negotiation in order to find better solution/agreement from the available range.

In typical negotiation settings, each agent starts the negotiation by offering its most preferred offer from the set of potential offers and tries to achieve this value or closest value to it. If the offer is accepted by the addressee, then the negotiation succeeds and ends with the agreement of both parties on this offer. If, on the other hand, the addressee did not accept the offer, then it makes a counter-offer in order to move the negotiation closer to a possible agreement. When the achieved agreement goes far from the initial proposal by making concessions, the agent's loss increases and consequently the agent's gain or utility decreases. The decision about whether to make a concession or not is then based on the negotiation constraints and the adopted concession strategy which will be mainly based on the agent's uncertainty.

To define the concession formally, let D be an ABAN between the two negotiating agents b and s, and let $\mathscr{O}^i = \{o_1^i, o_2^i, ..., o_n^i\}$ be the set of agent i's offers, where $i \in \{b, s\}$, and $\mathscr{V}(o_t^i)$ be the value of the offer o_t^i made by agent i at step t, where $(1 < t < n)$. Let us assume that at certain dialogue step $t = m$, ($m \neq 1$) the proposed offer is o_m^i, which is in fact, less preferred than o_1^i. We define the 'CONCESSION' as the difference between the value of these two offers as follows.

Definition 5.1 (Concession)**.** In a given ABAN dialogue D, let b and s be the two negotiating agents, and let $\mathscr{O}^i = \{o_1^i, o_2^i, ..., o_n^i\}$ be the set of agent i's offers, where $i \in \{b, s\}$. Assume that $o_m^i \in \mathscr{O}^i$ is the agent i's offer at dialogue step $t = m$, we say that agent i has conceded iff $\exists\, o^i_{m-1} \in \mathscr{O}^i$ made by agent i at step $t = m-1$, such that:

- $(o^i_m \preceq^i_{pref-o} o^i_{m-1})$
- $\mathscr{V}(o^i_{m-1}) > \mathscr{V}(o^i_m)$ if $(i = s)$
- $\mathscr{V}(o^i_{m-1}) < \mathscr{V}(o^i_m)$ if $(i = b)$

Concession Computation

The amount of concession can be computed either at each negotiation step, which represents the amount of loss incurred up to that step, or at the end of the dialogue, which reflects the total loss incurred by all concessions an agent has made during the dialogue. To compute the agent's loss between any two consecutive dialogue steps, we simply subtract the value of the new offer from the value of its previous one and take the absolute value to avoid having negative value. Thus, the agent's loss (concession) at a certain dialogue step is defined as follows.

Definition 5.2 (Agent's loss at certain dialogue step)**.** Let D be an ABAN dialogue between two agents b and s. The loss of an agent i, $i \in \{b, s\}$ at certain dialogue step t is obtained by taking the difference between the value of the target point and the value of the offer at that step.

$$loss^i_t = \begin{cases} \mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(o^i_t) & if \;\; i = s \\ \mathscr{V}(o^i_t) - \mathscr{V}(\mathscr{T}\mathscr{P}^i) & if \;\; i = b \end{cases} \tag{5.3}$$

Similarly, we compute the total loss of an agent by subtracting the value of the last proposal from the value of first proposal (i.e., target point). Therefore, the agent's total loss at the end of dialogue is defined as follows.

Definition 5.3 (Agent's total loss)**.** Let D be an ABAN dialogue between two agents b and s. The total loss of an agent i, $i \in \{b,s\}$ at the end of the dialogue (i.e., at t_n) is obtained by calculating the difference between the value of the target point and the value of the last offer.

$$\mathscr{T}loss^i = \begin{cases} \mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(o^i_{t_n}) & if \;\; i = s \\ \mathscr{V}(o^i_{t_n}) - \mathscr{V}(\mathscr{T}\mathscr{P}^i) & if \;\; i = b \end{cases} \tag{5.4}$$

We can also obtain the total loss of each agent by taking the sum of all its concessions during the dialogue as follows.

$$\mathscr{T}loss^i_{i\in(s,b)} = \begin{cases} \mathscr{T}loss^s = \sum_{t=0}^{n} loss^s_t, & j = i+2 \\ \mathscr{T}loss^b = \sum_{t=1}^{n} loss^b_t, & j = i+2 \end{cases} \tag{5.5}$$

During the negotiation process, each agent may concede more than once depending on its constraints, its uncertainty degree about each move, and based on the adopted concession strategy. The amount of the concession (loss) each time might be different. So the *"Concession Rate"* (CR) that quantifies the amount of concession an agent has made towards its opponent during the negotiation process can be obtained by dividing the amount of the total loss (concession) by the number of concession times.

Definition 5.4 (Concession rate)**.** Let $\mathscr{T}loss^i$ be the total loss of an agent i, and $\mathbb{NC}$ be the number of concessions made during a dialogue D. Then the concession rate $\mathbb{CR}$ for an agent i is defined as follows.

$$\mathbb{CR} = \mathscr{T}loss^i / \mathbb{NC} \tag{5.6}$$

The final objective of the two negotiating agents is to reach an acceptable agreement on certain issues, which satisfies the negotiation constraint of both agents in the best possible way. Therefore, an agreement about an offer is reached between the two agents b and s iff:

1. The value of the negotiation constraint, which is represented by the offer, belongs to the new agreement space of both agents $\mathscr{AS}_{\mathscr{C}}^{b \leftrightarrow s}$;
2. The addressee does not have any potential argument supporting a better offer; and
3. The addressee does not have any potential argument attacking the argument supporting this offer.

If such an agreement is not reached, and no more offers can be made, then the negotiation breaks down. In the next section, we discuss the dialogue outcome/agreement from different perspectives and evaluate the participating agents performance during the dialogue.

5.4 Agreement and Agent's Performance Evaluation

The aim of this section is to seek the answers of some questions such as:

- What is the outcome/agreement of the dialogue?
- What is a good outcome/agreement from the point of view of a participating agent, and from the point of view of an external agent? and
- How good an agent is in the real dialogue and how far it is from the ideal dialogue?

To answer such questions, we analyze the dialogue outcomes/agreements and show that there are two types of dialogue outcomes depending on who is the evaluator and what kind of information is available for the evaluation process. For instance, if the evaluator is one of the participants to the dialogue, then a good solution is the one that maximizes its utility considering just its knowledge base and ignoring the other party's utility. If on the other hand, the evaluator is an external agent who knows everything about the two parties, then the best outcome is the one that maximizes the profit of both agents without harming any one of them considering the knowledge bases of both parties. Let us start by defining the notion of outcome or agreement first, then we proceed to answer the rest of the questions.

5.4.1 Agreement Evaluation

Definition 5.5 (Dialogue agreement)**.** A dialogue agreement is a possible solution ψ from the negotiation outcome domain Ψ ($\psi \in \Psi$) that satisfies to some extent the preferences of both agents participating in ABAN dialogues.

If such a solution exists and negotiating agents could not reach it, then we say that the negotiation has failed. Let us assume that the rational agents achieved their goal and reached a possible agreement in a given ABAN dialogue. So, we define the achieved agreement formally as follows.

Definition 5.6 (The achieved agreement)**.** Let $D = [M_0, ..., M_n]$ be an ABAN dialogue between two agents b and s under the constraint $\mathscr{C}$. The achieved agreement ψ^{Ach} at certain dialogue step t is the value of the accepted offer by both parties at that dialogue step, $\mathscr{V}(o_t^i)$, which is the last proposal of one of the agents conveyed by the last move M_n, and accepted by the other agent. The achieved agreement should be part of the agreement space of both agents $\mathscr{A}\mathscr{S}_{\mathscr{C}}^{b \leftrightarrow s}$.

$$\psi^{Ach} = \mathscr{V}(o_t^i) \tag{5.7}$$

where $i \in \{b, s\}$ and $\mathscr{V}(o_t^i) \in \mathscr{A}S_{\mathscr{C}}^{b \leftrightarrow s}$

Because agents are rational and self interested, they try to maximize their utility and minimize their losses. The utility function of a possible dialogue outcome ψ^{Ach} at step t for an agent i denoted by $U^i(\psi^{Ach})$ is defined as:

$$U^i(\psi^{Ach}) = \begin{cases} \frac{\mathscr{V}(o_t^i) - \mathscr{V}(\mathscr{R}\mathscr{P}^i)}{\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{R}\mathscr{P}^i)} & if \;\; i = s \\ \frac{\mathscr{V}(\mathscr{R}\mathscr{P}^i) - \mathscr{V}(o_t^i)}{\mathscr{V}(\mathscr{R}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^i)} & if \;\; i = b \end{cases} \tag{5.8}$$

The utility function maps a value between zero and one to each possible solution. It reaches its maximum value, i.e., equal to one if the first offer (i.e., the target point) of the agent accepted by its opponent, and equal to zero when the agent reaches its resistant point. So the final objective of an agent i is then to resolve one of the following optimization problems considering its knowledge base Γ^i and the negotiation constraint $\mathscr{C}$.

$$\psi^{Ach*} = \underset{\mathscr{C},\Gamma^i}{\operatorname{argmax}}\,(U^i) \tag{5.9}$$

$$\psi^{Ach*} = \underset{\mathscr{C},\Gamma^i}{\operatorname{argmin}}\,(\mathscr{T}loss^i) \tag{5.10}$$

Where ψ^{Ach*} is the desired outcome.

In real negotiations, it is not always the case that the desired outcome is the best outcome due to the lack of information. The best outcome usually can be seen by an external agent who knows the knowledge bases of both parties.

Figure 5.3 shows a simple ABAN session between two agents (Buyer and Seller) negotiate over a product price. The negotiation succeeded and ended by achieving an agreement. The figure also shows the different positions that the achieved agreement ψ^{Ach} could take compared to the best agreement ψ^{Best}. As it can be seen, the achieved agreement could be greater than, less than, or equal to the best agreement.

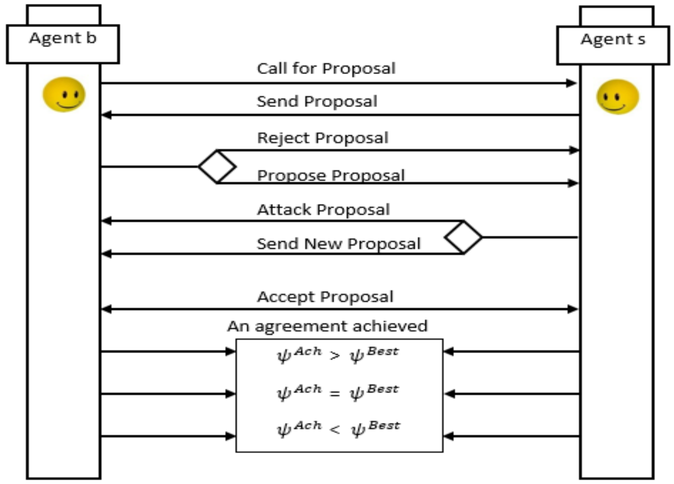

Figure 5.3: An example illustrates ABAN session between two agents (Buyer and Seller) ended with achieving agreement that could be greater, equal, or less than the best agreement

5.4.2 Agent Performance Evaluation

Now that we have distinguished the two types of dialogue outcomes, it is worth to investigate how good an agent is (i.e., *"Goodness Degree"*) in the real negotiation, i.e., the dialogue that effectively took place between the negotiating agents, and how far is it from the ideal dialogue, i.e., the best dialogue that can be produced by the participants if they know the knowledge bases of each other, we call this metric *"Farness Degree"*. In other words, for the achieved agreement ψ^{Ach}, which one of the negotiating agents is doing better and gaining more in the real dialogue compared to its opponent, and considering the best agreement; how far an agent is from this ideal solution which makes both agents better-off. In what follows, we give the formal definitions of the *"Goodness Degree"* and *"Farness Degree"* for the participating agents in an ABAN negotiation.

Definition 5.7 (Goodness degree)**.** Let D be a real ABAN dialogue, i and j be the two negotiating agents, where $i, j \in \{b, s\}$, ψ^{Ach} is the achieved agreement, and $\mathscr{T}loss^i$ be the agent i's total loss in the dialogue. We define the goodness degree of an agent i based on the achieved agreement in the real dialogue as follows:

$$\mathscr{G}\mathscr{D}^i(\psi^{Ach}) = 1 - [\mathscr{T}loss^i / |\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|] \tag{5.11}$$

From the above definition, we can easily prove the following proposition:

Proposition 5.1. *Let i and j be two negotiating agents and* $\mathscr{G}\mathscr{D}^i(\psi^{Ach})$ *and* $\mathscr{G}\mathscr{D}^j(\psi^{Ach})$ *be their goodness degree respectively. Assuming that they achieved an agreement, then:*

$$\mathscr{G}\mathscr{D}^i(\psi^{Ach}) + \mathscr{G}\mathscr{D}^j(\psi^{Ach}) = 1 \tag{5.12}$$

Proof. $\mathscr{G}\mathscr{D}^i(\psi^{Ach}) + \mathscr{G}\mathscr{D}^j(\psi^{Ach}) = 1$

$\Rightarrow$ $(1 - [\mathscr{T}loss^i / |\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|]) + (1 - [\mathscr{T}loss^j / |\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|]) = 1$

$\Rightarrow$ $1 - (\mathscr{T}loss^i / |\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|) + 1 - (\mathscr{T}loss^j / |\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|) - 1 = 0$

$\Rightarrow$ $1 = (\mathscr{T}loss^i / |\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|) + (\mathscr{T}loss^j / |\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|)$

$\Rightarrow$ $1 = \mathscr{T}loss^i + \mathscr{T}loss^j / \mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|$

$\Rightarrow$ $1 = (\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(o_t^i) + \mathscr{V}(o_t^j) - \mathscr{V}(\mathscr{T}\mathscr{P}^j) / \mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|)$

Because $\mathscr{V}(o_t^i) = \mathscr{V}(o_t^j)$ which is equal to the value of the achieved agreement ψ^{Ach} at that step, hence:

$\Rightarrow$ $1 = (\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \psi^{Ach} + \psi^{Ach} - \mathscr{V}(\mathscr{T}\mathscr{P}^j)) / \mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|$

$\Rightarrow$ $1 = (\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j) / \mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|)$. ■

As it can be seen from the above definition, the goodness degree of an agent in the real dialogue is calculated based on the achieved agreement ψ^{Ach}. However, to find how far an agent is from the right dialogue (i.e., best agreement from an external evaluator's point of view), we need to consider the best agreement ψ^{Best} instead of the achieved agreement. Therefore, in our calculation we need to recompute the total loss of an agent based on the best agreement, and then recompute the goodness degree (Equation 5.11) of the agent based on the best agreement.

Indeed, achieving the best agreement means that the participants are doing the right dialogue, i.e., the best dialogue that can be produced by the participants if they know the knowledge bases of each other. In order to find the distance from the right dialogue, we calculate the goodness degree of an agent based on the achieved agreement and recompute it again for the best agreement. Then we simply subtract the goodness degree based on the best agreement from that which was obtained based on the achieved agreement.

The total loss of an agent i in the dialogue based on the best agreement is given by:

$$\mathscr{T}loss^i(\psi^{Best}) = |\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \psi^{Best}| \tag{5.13}$$

And the goodness degree of an agent i in the dialogue based on the best agreement is given by:

$$\mathscr{G}\mathscr{D}^i(\psi^{Best}) = 1 - [\mathscr{T}loss^i(\psi^{Best})/|\mathscr{V}(\mathscr{T}\mathscr{P}^i) - \mathscr{V}(\mathscr{T}\mathscr{P}^j)|] \tag{5.14}$$

We call the distance between the best agreement and the achieved agreement *Farness Degree* of the agent, which represents the distance from the real dialogue to the right one. In other words, it shows how far an agent i is from the best agreement or the right dialogue, which can be defined as follows.

Definition 5.8 (Farness degree)**.** Let D be an ABAN dialogue, and i and j be the two negotiating agents. Let $\mathscr{G}\mathscr{D}^i(\psi^{Ach})$, where $i, j \in \{b, s\}$, be the goodness degree of an agent

i based on the achieved agreement and $\mathscr{GD}^i(\psi^{Best})$ be the the goodness degree of the agent based on the best agreement. We define the farness degree $\mathscr{FD}^i$ of an agent i in the dialogue as follows:

$$\mathscr{FD}^i = \mathscr{GD}^i(\psi^{Ach}) - \mathscr{GD}^i(\psi^{Best}) \tag{5.15}$$

The farness degree of an agent i, $\mathscr{FD}^i$, could be positive, negative or null.

- (+) : positive means that the agent is far from the right dialogue towards the positive side of its performance and it is doing better in the real dialogue.
- (-) : negative means that the agent is far from the right dialogue in the negative side of its performance, and it is doing worst in the real dialogue.
- (0) : zero means that the two agents are doing the right dialogue.

Now, if we compare the goodness degree of an agent based on the achieved agreement in the real dialogue with the goodness degree of the same agent (without loss of generality let us consider the Buyer agent) based on the best agreement that could be achieved, we can readily come up with the following properties.

Property 5.1. *: If* $(\psi^{Ach} < \psi^{Best})$*, then the goodness degree of the Buyer agent b in the real dialogue is better than that of the Seller agent s. That is, in the real dialogue b is doing better than s. Formally:* $\mathscr{GD}^b(\psi^{Ach}) > \mathscr{GD}^s(\psi^{Ach})$

Property 5.2. *: If* $(\psi^{Ach} = \psi^{Best})$*, then the two agents are performing the right dialogue from the evaluator's standpoint. Formally:* $\mathscr{GD}^b(\psi^{Ach}) = \mathscr{GD}^s(\psi^{Ach})$

Property 5.3. *: If* $(\psi^{Ach} > \psi^{Best})$*, then the goodness degree of the Seller agent s in the real dialogue is better than that of the Buyer agent b. That is, in the real dialogue s is doing better than b. Formally:* $\mathscr{GD}^s(\psi^{Ach}) > \mathscr{GD}^b(\psi^{Ach})$

One of the most challenging tasks during the negotiation process is the evaluation of proposals (i.e., offers, counter-offers, arguments, counter-arguments, etc.) considered by both parties. In what follows, we present an efficient method for evaluating and classifying these proposals.

5.5 Offers Evaluation and Classification

In negotiation settings, it is very important for each party to be able to assess its opponent's offers in order to evaluate their acceptability. It is also required that each agent is able to order the available offers within its area of interest to identify and propose the most appropriate offer. To do so, negotiating agents should be provided with a mechanism that allows them to adopt the suitable negotiation strategies (e.g., acceptance strategy) for each negotiation dialogue. In this context, we present a new mechanism for offers evaluation and classification. The proposed mechanism categorizes the set of potential offers into three groups namely, acceptable offers, reasonable offers, and negotiable/non-negotiable offers. Besides, we present an algorithm for each group by which we illustrate how an agent can assess its opponent's offers and its own offers and relate them to one of these groups.

5.5.1 Acceptable Offer

Definition 5.9 (Acceptable offer)**.** Let D be an ABAN dialogue between two negotiating agents s and b. Suppose that agent i sent the offer o_t^i at step t to the agent j, where $i, j \in \{b,s\}$, and let $\mathscr{V}(o_t^i)$ be the value of that offer.

- The offer o_t^i of the agent i is acceptable for the agent j if and only if:

$$\mathscr{V}(o_t^i) \in \mathscr{A}S_{\mathscr{C}}^j, \; where \;\; i, j \in \{b,s\}$$

It should be noted here that one agent is evaluating the other agent's offer, that is, the offer o_t^i, which was sent by agent i, will be evaluated by its opponent j, and it will be accepted only if it belongs to its agreement space. However, theoretically, a possible agreement can be achieved only if the offer belongs to the common area of interest of both agents (i.e., the agreement space $\mathscr{AS}_{\mathscr{C}}^{b \leftrightarrow s}$).

The following algorithm (Algorithm 2) explains how an agent evaluates the acceptability of its opponent's offers. In the algorithm, we assume that the two negotiating agents s and b are exchanging their offers in turns in such a way that the Seller agent utters the even moves and the Buyer agent utters the odd moves.

Algorithm 2 Algorithm for Evaluating Acceptable Offers

Let $D = \{M_0, M_1, \ldots, M_n\}$ be an ABAN, where n is the number of dialogue moves.
Let $\mathscr{O}^s$ be the set of agent s's offers, and
Let $\mathscr{O}^b$ be the set of agent b's offers.
for <i = 0 to n> **do**
    if i = even **then**
        The Seller agent s sends its proposal.
        The Buyer agent b evaluates Seller's proposal as follows.
        if $\mathscr{V}(o_t^s) \in \mathscr{AS}_{\mathscr{C}}^b$ **then**
            The offer o_t^s is acceptable so, (Buyer $\leftarrow$ Accept)
        else
            The offer o_t^s is not acceptable so, (Buyer $\leftarrow$ Reject).
        end if
    else
        The Buyer agent b sends its response
        The Seller agent evaluates buyer's proposal as follows.
        if $\mathscr{V}(o_t^b) \in \mathscr{AS}_{\mathscr{C}}^s$ **then**
            The offer o_t^b is acceptable so, (Seller $\leftarrow$ Accept)
        else
            The offer o_t^b is not acceptable so, (Seller $\leftarrow$ Reject)
        end if
    end if
end for

5.5.2 Reasonable Offer

As mentioned earlier, each agent has the ability to evaluate offers received from its opponent and decide about its acceptability based on the adopted acceptance strategy (the acceptance strategies will be discussed in Section 5.6). One of these strategies allows the agent to accept any offers within its agreement space that has a value close to its last proposal, i.e., a slightly greater than its last proposal for the Buyer and a slightly less than its last proposal for the Seller. According to a specific acceptance strategy, we call this offer a reasonable offer, and we define it as follows.

Definition 5.10 (Reasonable offer)**.** Let D be an ABAN dialogue between two negotiating agents b and s, $\mathscr{O}^b$ be the set of b's offers, $\mathscr{O}^s$ be the set of s's offers, and let t be the current dialogue step ($t-1$ is the previous step and $t+1$ is the future step). Then:

- The Buyer's offer o_t^b at dialogue step t is reasonable for the Seller s if and only if:

  $$\mathscr{V}(o_{t+1}^s) \leq \mathscr{V}(o_t^b) \leq \mathscr{V}(o_{t-1}^s)$$

  Recall that an agent will present its most preferred offer at first, then starts to make concessions until it reaches its resistant point. As such, according to the prordered preference relation over offers, the offer o_{t+1}^s, which is the next offer by the Seller, is less preferred than the offer o_{t-1}^s, which is the last proposal the Seller has made. Consequently, any offer between these two offers is supposed to be reasonably accepted.

- The Seller's offer o_t^s at dialogue step t is reasonable for the Buyer b if and only if:

  $$\mathscr{V}(o_{t-1}^b) \leq \mathscr{V}(o_t^s) \leq \mathscr{V}(o_{t+1}^b)$$

Similarly, the Buyer agent should accept reasonably any offer falls between its previous offer o^b_{t-1} and its next one o^b_{t+1}.

Algorithm 3 explains the process performed by each agent to evaluate its opponent's offers in terms of its reasonability.

Algorithm 3 Algorithm for Evaluating Reasonable Offers

Let $D = \{M_0, M_1, ..., M_n\}$ be an ABAN, where n is the number of dialogue moves.
Let $\mathcal{O}^s$ be the set of agent s's offers, s.t. at the current dialogue step t, $o^s_t \in \mathcal{O}^s$
Let $\mathcal{O}^b$ be the set of agent b's offers, s.t. at the current dialogue step t, $o^b_t \in \mathcal{O}^b$
for i = 0 to n **do**
    if i = even **then**
        The Seller agent s sends its proposal.
        The Buyer agent b evaluates Seller's agent s proposal as follows.
        if $\mathcal{V}(o^b_{t-1}) \leq \mathcal{V}(o^s_t) \leq \mathcal{V}(o^b_{t+1})$ **then**
            The offer o^s_t is reasonable offer so, (Buyer $\leftarrow$ Accept).
        else
            The offer (o^s_t) is not reasonable offer so, (Buyer $\leftarrow$ Respond).
        end if
    else
        The Buyer agent b sends its response.
        The Seller agent s evaluates Buyer's agent b proposal as follows.
        if $\mathcal{V}(o^s_{t+1}) \leq \mathcal{V}(o^b_t) \leq \mathcal{V}(o^s_{t-1})$ **then**
            The offer o^b_t is reasonable so, (Buyer $\leftarrow$ Accept).
        else
            The offer o^b_t is not reasonable so, (Buyer $\leftarrow$ Respond).
        end if
    end if
end for

Property 5.4. *: From Definition 5.9 and Definition 5.10, any reasonable offer is acceptable offer. However, the reverse is not true.*

5.5.3 Negotiable/Non-negotiable Offer

In contrast to the acceptable and reasonable offers in which agents evaluate their opponents' proposals, agents may evaluate their own offers as well, that is, each agent can evaluate its own offers at each dialogue step to decide whether to make concession and propose a new offer or to stick to its current preferred offer. In other words, if the adopted strategy and negotiation constraint allow an agent to concede and make a new offer, then the current offer is a negotiable offer. Contrary, if the agent reaches its limit and cannot concede any more, then the current offer is non-negotiable.

Definition 5.11 (Negotiable/Non-negotiable offer)**.** Let D be an ABAN dialogue between two negotiating agents s and b. Let $o_t^i \in \mathscr{P}\mathscr{O}_t^i$ be the agent i's offer at step t, where $i \in \{b,s\}$, and $\mathscr{V}(o_t^i)$ be the value of this offer.

- The offer o_t^i is said to be negotiable iff:

$$\begin{cases} \mathscr{V}(o_t^i) > \mathscr{V}(\mathscr{R}\mathscr{P}^i) & \text{if} i = s; \\ \mathscr{V}(o_t^i) < \mathscr{V}(\mathscr{R}\mathscr{P}^i) & \text{if } i = b \end{cases}$$

- The offer o_t^i is said to be non-negotiable iff:

$$\mathscr{V}(o_t^i) = \mathscr{V}(\mathscr{R}\mathscr{P}^i),\ where\ \ i \in \{b,s\}$$

This simply indicates that all individual areas of interest for each agent is considered as negotiable offers except the resistant point, which is considered as non-negotiable offer. When an agent reaches this point and makes its non-negotiable offer, no more offers can be made by the same agent as it reaches its limit, however, it can still support its offer by another argument, if the previous one is attacked. It should be noted that at any dialogue step, the Seller (resp. Buyer) agent can make a new offer only if its value is less than (resp. greater than) its previous offer. Algorithm 4 illustrates how an agent can evaluate its own proposals to decide whether or not to make concession.

Algorithm 4 Algorithm for Evaluating Negotiable/Non-negotiable Offers

Let $D = \{M_0, M_1, ..., M_n\}$ be an ABAN, where n is the number of dialogue moves.
Let $\mathscr{O}^i$ be the set of agent i's offers, where $i \in \{s, b\}$.
for i = 1 to n **do**
  Agent i evaluates its proposal as follows.
  if $i = s$ **then**
    if $\mathscr{V}(o_t^s) > \mathscr{V}(\mathscr{R}\mathscr{P}^s)$ **then**
      The offer o_t^s is Negotiable so, (Seller $\Leftarrow$ Concede)
    else
      if $\mathscr{V}(o_t^s) = \mathscr{V}(\mathscr{R}\mathscr{P}^s)$ **then**
        The offer o_t^s is Non-negotiable so, (Seller $\Leftarrow$ $\neg$ Concede)
      end if
    end if
  else
    if $\mathscr{V}(o_t^b) < \mathscr{V}(\mathscr{R}\mathscr{P}^b)$ **then**
      The offer o_t^b is Negotiable so, (Buyer $\Leftarrow$ Concede)
    else
      if $\mathscr{V}(o_t^b) = \mathscr{V}(\mathscr{R}\mathscr{P}^b)$ **then**
        The offer o_t^b is Non-negotiable so, (Buyer $\Leftarrow$ $\neg$ Concede)
      end if
    end if
  end if
end for

5.6 Adaptive Negotiation Strategies

Negotiation strategies are essential for the negotiating parties in order to realize their goals. In this section, we discuss two main sets of negotiation strategies namely, concession and acceptance. In particular, three concession and three acceptance strategies are proposed. In each negotiation session, each agent is allowed to adopt one concession strategy and one acceptance strategy together, which in turn confirm its profile for that negotiation session. Applying such mechanisms in automated negotiation would allow to generate better negotiation dialogues which, in turn, results in better agreements. The idea is that, well-performing components of strategies together constitute well-performing negotiating agents. Besides, allowing each agent to update its strategy (change it if necessary) during the dialogue after discovering its opponent's strategy is an important feature that leads to a better performance and consequently to a better outcome.

5.6.1 Concession Strategies

Concessions are often necessary in negotiation and negotiating agents need to be flexible in making concessions and moving from one position to another, which constitutes the concession process. In our settings, Concession Strategies (CS_{tr}) are mainly based on agents' constraints and their uncertainty about the played moves, which have a direct effect on the negotiation outcome and consequently on the agent's utility. Rational agents are assumed to consider their uncertainty about their moves at each dialogue step to make concessions — the more uncertain the agent is about its move, the more it will be willing to concede and move from one proposal to another. In this context, we introduce the following concession strategies, which are based on the arguments classification introduced in Chapter 4, Section 4.4.5.

- **Concede Whenever Possible (CWP)**: this concession strategy allows an agent to concede whenever possible within its agreement space even if the current offer is still supported by highly certain arguments (Class A), moderately certain arguments (Class B), or uncertain arguments (Class C).

- **Concede if Not Sure (CNS)**: this concession strategy is less flexible than CWP strategy. It allows an agent to concede and move to the next preferred offer within its agreement space only if its most preferred offer is no longer supported by neither highly certain arguments (Class A) nor moderately certain arguments (Class B), but still supported by uncertain arguments (Class C).

- **Concede Only if Not Supported (CONS)**: this concession strategy is stricter than CWP and CNS strategies in the sense that it allows an agent to concede and move from one position to another within its constraint agreement space only if the current offer is no longer supported by any argument from the three different classes.

5.6.2 Acceptance Strategies

In addition to the aforementioned concession strategies, which are related to the agent's own proposals, agents need to adopt some Acceptance Strategies (AS_{rt}) that determine whether the proposals presented by the opponent are acceptable. In our approach, acceptance strategies are mainly based on the negotiation constraint and offer status that can be captured by the offers classification. The idea is to evaluate the opponent's offers and decide when to accept based on the offer status. In this regard, the following acceptance strategies are proposed.

- **Easily Accept (EA)**: this acceptance strategy allows an agent to accept any acceptable offer (Definition 5.9), that belongs to its constraint agreement space, if there is no other reason to reject.

- **Reasonably Accept (RA)**: this acceptance strategy allows an agent to reasonably accept its opponent's offer if its value is reasonable compared to its best current offer (Definition 5.10).

- **Hardly Accept (HA)**: this acceptance strategy allows an agent to accept only offers that make its utility at least as good as its utility for the current offer which is still supported by some arguments. In other words, an agent who adopts this strategy sticks to its current offer rigorously and does not accept other offers quickly, or at all.

In order to allow negotiating agents to adopt one strategy of each set (concession and acceptance sets), we define a function called *Strategy Selection Function (SSF)*.

Definition 5.12 (Strategy selection function)**.** Let D be an ABAN dialogue, Ag be the set of negotiating agents, CS_{tr} be the set of concession strategies and AS_{tr} be the set of acceptance strategies. The Strategy Selection Function (SSF) is a function that maps to each negotiating agent one concession strategy and one acceptance strategy, which in turn confirms the agent's profile in that dialogue.

$$SSF : Ag \rightarrow CS_{tr} \times AS_{tr} \tag{5.16}$$

In the next subsection, we highlight the different agent profiles resulting from all possible combination of the two sets of strategies.

5.7 Adaptive Agent Profiles

In this section, we present the different Agent Profiles (AP) resulting from all possible combinations of the above outlined negotiation strategies. In particular, this combination results in nine agent profiles denoted by AP1 to AP9, see Table 5.2. The idea is to allow each agent to adopt one concession strategy and one acceptance strategy in each dialogue session.

Definition 5.13 (Agent profile)**.** An agent profile is a tuple AP = $\langle AS_{tr}, CS_{tr} \rangle$ such that in each negotiation session each agent adopts one concession strategy and one acceptance strategy.

Table 5.2: The nine agent profiles and their descriptions

Agent Profile	**Adopted Strategies**	**Description of Strategies**
AP1	CWP/EA	Concede Whenever Possible/Easily Accept
AP2	CWP/RA	Concede Whenever Possible/Reasonably Accept
AP3	CWP/HA	Concede Whenever Possible/Hardly Accept
AP4	CNS/EA	Concede if Not Sure/Easily Accept
AP5	CNS/RA	Concede if Not Sure/Reasonably Accept
AP6	CNS/HA	Concede if Not Sure/Hardly Accept
AP7	CONS/EA	Concede Only if Not Supported/Easily Accept
AP8	CONS/RA	Concede Only if Not Supported/Reasonably Accept
AP9	CONS/HA	Concede Only if Not Supported/Hardly Accept

5.8 Negotiation Outcome Properties

In this section, we analyze two properties related to negotiation outcome namely, completeness and Nash equilibrium. In particular, we show when to say that an ABAN dialogue is complete, and when the outcome of the dialogue is Nash equilibrium.

5.8.1 Completeness

In our settings, the completeness property means that if the ongoing negotiation has a theoretical agreement (i.e., the negotiation agreement space is not empty), then the negotiation dialogue under given agent profiles should lead to the achievement of that agreement.

Definition 5.14 (Completeness)**.** An ABAN dialogue between two negotiating agents b and s is said to be complete if and only if: if $\mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s} \neq \emptyset$, then the negotiation ends successfully by achieving an agreement.

Proposition 5.2. *In a given ABAN dialogue, let b and s be the two negotiating agents, and assume that the agreement space is not empty ($\mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s} \neq \emptyset$). If at least one of the two agents' profiles is of the types AP4 to AP9, then the negotiation completeness is not guaranteed.*

Proof. Let D be an ABAN dialogue between the two negotiating agents b and s, and let o_1^b and o_2^s be the two first offers made by b and s respectively. In order to guarantee achieving an agreement, the two negotiating agents should enter the agreement space. However, if $o_1^b, o_2^s \notin \mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s}$, and they are still supported by some arguments from Classes A, B, or both, then no one can accept, and no one can make concession since both agents are playing CNS or CONS strategy. Consequently, no agent can enter the $\mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s}$ zone, hence the result. ■

Theorem 5.1 (Completeness)**.** *In a given ABAN dialogue, let b and s be the two negotiating agents. If the agreement space under the constraint $\mathscr{C}$ is not empty ($\mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s} \neq \emptyset$), then the completeness is guaranteed if and only if the two agents' profiles are of the types AP1, AP2, or AP3.*

Proof. ($\Rightarrow$): From Proposition 5.2 agent profiles AP4 to AP9 are excluded. Now assuming that a given ABAN is complete (i.e., the completeness is guaranteed) and an agreement is achieved, we prove that the two agent profiles are of type AP1, AP2, or AP3. Achieving agreement means that both agents b and s have entered the agreement space $\mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s}$, and to enter this area both agents have to make the necessary amount of concessions that bring them inside this zone. It follows that both agents should adopt a flexible concession strategy that allow them to concede even if their current best offers are still supported with any argument from the different classes. Consequently, both agents should adopt concession whenever possible CWP strategy, that is, the two agents must be of AP1, AP2, or AP3. Hence the result. ■

(⇐): Being not of agent profiles (AP4 to AP9) means that the agent adopts CWP concession strategy with the different acceptance strategies. Therefore, since both negotiating agents are playing CWP, then it is certain that they will enter the agreement space $\mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s}$ zone, and whatever their acceptance strategies are, they will reach to a compromise that satisfies both of them, and consequently, an agreement will be achieved, so we are done. ■

5.8.2 Nash Equilibrium

Definition 5.15 (Nash equilibrium)**.** Nash equilibrium is a set of strategies, one for each agent, such that an outcome ψ of a negotiation dialogue is Nash equilibrium if the change of strategy by any agent would lead that agent to earn less than if it remained with its current strategy. That is, no agent can do better by unilaterally changing its strategy.

Theorem 5.2. *In a given ABAN dialogue, let b and s be the two negotiating agents. Assuming that the agreement space is not empty ($\mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s}$), and an agreement is achieved. Then the negotiation outcome is a Nash equilibrium if and only if both negotiating agents' profiles are of type AP9.*

Proof. If a negotiating agent chooses AP9 as a profile, the opponent has no better choice than choosing a AP9 profiles, as any other profile with less strict concession strategy or acceptance strategy will end up with a less preferable outcome, and consequently will lead that that agent to earn less. ■

The different results found in this section are summarized in Table 5.3. The abbreviations in the table are as follows, where if the property holds then we put (✓), otherwise we put (x).

- NE: Nash Equilibrium

- CG: Completeness Guaranteed.

Table 5.3: Completeness and Nash equilibrium results for the different combination of agent profiles

Agent i	**AP1**		**AP2**		**AP3**		**AP4**		**AP5**		**AP6**		**AP7**		**AP8**		**AP9**	
Agent j	NE	CG	NE	CG	NE	CG	NE	CG	NE	CG	NE	CG	NE	CG	NE	CG	NE	CG
AP1	x	✓	x	✓	x	✓	x	x	x	x	x	x	x	x	x	x	x	x
AP2	x	✓	x	✓	x	✓	x	x	x	x	x	x	x	x	x	x	x	x
AP3	x	✓	x	✓	x	✓	x	x	x	x	x	x	x	x	x	x	x	x
AP4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AP5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AP6	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AP7	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AP8	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AP9	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	✓	x

5.9 Implementation and Experimental Results

5.9.1 Buyer/Seller Scenario

To validate the proposed negotiation mechanism, we take the Buyer/Seller scenario as a case study. We assume that two negotiating agents *Seller* and *Buyer* are negotiating the purchases of a used car. We assume that a Buyer agent is interested in buying a car (e.g., Toyota) with certain specifications (preferences) and a low price from a Seller agent who has different choices of Toyota to offer with different specifications and prices, and it is trying to convince the Buyer to buy one of them based on its request. The ABAN system has been tested with several trading scenarios and is publicly available online [2].

[2] https://github.com/Marooned202/ABAN-Negotiation

5.9.2 System Overview

The ABAN system has been implemented in Java using a single Intel *Xeon X*3450 machine with 6*GBs* of memory. We implemented *Buyer* and *Seller* classes which inherit behaviors from an *Agent* interface. The *Agent* interface contains the shared functionalities between all agent profiles. The agents can be initiated with parameters from their respective knowledge bases, also they can adopt different agent profiles. We have implemented two important functions for the *Buyer* and *Seller* objects. The first function is for evaluating the received offers, where upon receiving an offer an agent will decide whether or not to accept or reject it based on the adopted acceptance strategy (i.e., its profile). While the second function is for making concessions. This function helps the agent decide whether to concede or not based on the adopted concession strategy (i.e., its profile). These two functions use the internal agent parameters such as agent profiles (APs) and their knowledge bases to make decisions, and function independently in an object oriented manner. Then, a negotiation engine class will initiate a *Buyer* and a *Seller* and let them trade offers and make their decisions. The results for each step and also the final agreement criteria are analysed and reported in formatted log files.

The ABAN environment consists of two autonomous agents representing the *Seller* and the *Buyer*. They negotiate on behalf of users and try to find the best agreement for them based on the adopted strategies. The negotiation engine allows the users to enter their negotiation constraints, the set of potential offers, and the supporting arguments for each offer for both agents. It also provides the main decision making functionality of an agent during negotiation based on its profile by allowing it to evaluate its own supporting arguments of each offer before making any concession and evaluate the received offers to decide about their acceptance as well as the generation of the counter-offers from the set of potential offers according to the negotiation constraints and agent profiles.

A number of experiments have been conducted to test the feasibility of the proposed approach and to demonstrate how the agents can or cannot reach an agreement based on the adopted agent profiles (or negotiation strategies). Two scenarios are discussed. In the first scenario, we implemented non-argumentative negotiating agents, i.e., we neglect the effect of the supporting arguments and consequently the effect of the agents uncertainty on making their decisions, whereas in the second one, we implemented argumentative agents. We provided negotiating agents with some supporting arguments for each offer and allowed them to test the effect of the agents' uncertainty on their decisions by considering the different classes of the supporting arguments.

Table 5.4 gives the negotiation settings for the two scenarios which include the target and the resistant point of each agent, the negotiation space and the agreement space for both agents. We ran the negotiation under these settings several times by changing the agents' profiles each time and report the achieved agreement and the utility of each agent as well as the number of steps (i.e., the negotiation length).

Table 5.4: Negotiation settings: constraint and bargaining zones

Seller				**Buyer**			
$\mathscr{T}\mathscr{P}^s$	$\mathscr{R}\mathscr{P}^S$	$\mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s}$	$\mathscr{N}S_{\mathscr{C}}^{b\leftrightarrow s}$	$\mathscr{T}\mathscr{P}^b$	$\mathscr{R}\mathscr{P}^b$	$\mathscr{A}S_{\mathscr{C}}^{b\leftrightarrow s}$	$\mathscr{N}S_{\mathscr{C}}^{b\leftrightarrow s}$
15000	12000	[12000-13000]	[10000-15000]	10000	13000	[12000-13000]	[10000-15000]

5.9.3 Experimental Results

Scenario 1: Non-Argumentative Agent Profiles

In this scenario, we intentionally disabled all supporting arguments (i.e., there is no supporting arguments for all offers) to allow negotiating agents always reach an agreement in all possible combinations of agent profiles (as long as the agreement space is not empty). By doing so, the effect of agent's uncertainty on making concessions will be neglected and the agents will always be able to concede in all cases. However, the effect of acceptance strategies will be very important on making decisions and reaching agreement and consequently on the obtained agents' utility. In what follows, we discuss some examples in which the two agents adopt the same or different agent profiles.

Table 5.5 shows the negotiation progress in case of the two agents' profiles are of type AP1. This profile allows an agent to concede whenever possible and easily accept any offer within its area of interest. So the negotiation successfully ended by achieving an agreement in 9 steps on the Seller's offer (13000), which equals to the resistant point for the Buyer that makes it worse-off with utility (U^b(13000)=0), while it makes the Seller better-off with utility (U^s(13000)=0.33). The Buyer accepted this offer because its acceptance strategy, which is EA, allows it to do so.

Table 5.5: Negotiation progress Scenario 1, example 1; (AP1 vs. AP1)

Seller (AP1)						**Buyer (AP1)**					
Step	Offer	Supporting Arguments Class A	Supporting Arguments Class B	Supporting Arguments Class C	Status	Step	Offer	Supporting Arguments Class A	Supporting Arguments Class B	Supporting Arguments Class C	Status
1	15000	x	x	x	Rejected	2	10000	x	x	x	Rejected
3	14500	x	x	x	Rejected	4	10500	x	x	x	Rejected
5	14000	x	x	x	Rejected	6	11000	x	x	x	Rejected
7	13500	x	x	x	Rejected	8	11500	x	x	x	Rejected
9	13000	x	x	x	Accepted						
The agreement was achieved in 9 steps on the Seller's offer, Seller's Utility=0.33 and Buyer's Utility=0											

Table 5.6 shows another example for the negotiation progress between two different agents' profiles, where the Seller's profile is AP4 and the Buyer's profile is AP3. In this example, the agreement was reached in 10 steps on the Buyer's offer this time and that is because the Buyer is adopting HA strategy that did not allow it to accept the Seller's offer at step 9. Thus the Buyer rejected that offer and proposed a new offer (12000), which equals the resistant point for the Seller. This offer was accepted by the Seller because of its acceptance strategy EA. This agreement makes the Seller worse-off with utility (U^s(12000)=0), whereas it makes the Buyer better-off with utility (U^b(12000)=0.33).

Table 5.6: Negotiation progress Scenario 1, example 2; (AP4 vs. AP3)

Seller (AP4)						**Buyer (AP3)**					
Step	Offer	Supporting Arguments Class A	Class B	Class C	Status	Step	Offer	Supporting Arguments Class A	Class B	Class C	Status
1	15000	x	x	x	Rejected	2	10000	x	x	x	Rejected
3	14500	x	x	x	Rejected	4	10500	x	x	x	Rejected
5	14000	x	x	x	Rejected	6	11000	x	x	x	Rejected
7	13500	x	x	x	Rejected	8	11500	x	x	x	Rejected
9	13000	x	x	x	Rejected	10	12000	x	x	x	Accepted
The agreement was achieved in 10 steps on the Buyer's offer, Buyer's Utility=0.33 and Seller's Utility=0											

Another example is shown in Table 5.7 in which the two agents' profiles are of type AP9. In this example, the two agents were successfully able to achieve an agreement in 11 steps on the Seller's offer (12500), which is also the Buyer's next best offer. Despite both agents are playing HA strategy, this offer was accepted by both agents because there is no supporting arguments for better offer for both agents and they were able to make concessions until they reached this offer that makes both agents better-of and the utility of each is (U^b(12500)=U^s(12500)=0.17).

Table 5.7: Negotiation progress Scenario 1, example 3; (AP9 vs. AP9)

Seller (AP9)						**Buyer (AP9)**					
Step	Offer	Supporting Arguments Class A	Class B	Class C	Status	Step	Offer	Supporting Arguments Class A	Class B	Class C	Status
1	15000	x	x	x	Rejected	2	10000	x	x	x	Rejected
3	14500	x	x	x	Rejected	4	10500	x	x	x	Rejected
5	14000	x	x	x	Rejected	6	11000	x	x	x	Rejected
7	13500	x	x	x	Rejected	8	11500	x	x	x	Rejected
9	13000	x	x	x	Rejected	10	12000	x	x	x	Rejected
11	12500	x	x	x	Accepted						
The agreement was achieved in 11 steps on the Seller's offer, Seller's Utility=0.17 and Buyer's Utility=0.17											

Scenario 1: Summary of Results

The above discussed examples are just samples of the negotiation progress and the complete results are reported in Table 5.8. The table reports three main results as follows.

- The achieved agreement: where ψ_S^{Ach} means the agreement is on the Seller's offer, whereas ψ_B^{Ach} means the agreement is on the Buyer's offer.

- The utility of both agent is represented as a pair: U=(Buyer's Utility, Seller's Utility).
- The number of steps N.O.S.
- No deal in case the negotiation fails.

Table 5.8: Scenario 1 - Results summary for all possible combination of agent profiles: Agreement, utility, and number of steps

Seller Buyer	AP1	AP2	AP3	AP4	AP5	AP6	AP7	AP8	AP9
AP1	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9
AP2	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11
AP3	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12
AP4	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9
AP5	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11
AP6	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12
AP7	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9
AP8	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11
AP9	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11

Scenario 2: Argumentative Agent Profiles

In this negotiation scenario, we randomly enabled some supporting arguments for some offers to examine the effect of the argument classes on the agents' decisions about whether to concede or not based on their profiles. Similar to what we did in the first scenario, we ran the negotiation several times under the same settings presented in Table 5.4, and for the sake of the comparison between the two scenarios, we reported the same results again (i.e., the achieved agreement, the utility of each agent, and the number of steps). Hereafter, we selected some examples for different combination of agent profiles to demonstrate the negotiation progress when supporting arguments for some offers exist, and to show the impact of these arguments and their relevant classes on the agents' decisions.

In Table 5.9, we present a negotiation session between two parties having the same agent profile AP1. This agent profile allows an agent to concede whenever possible and to accept easily, so even if there is some supporting arguments, the negotiating agents will still be able to concede and move to the next preferred offer until they find first compromise. We noticed here that the Buyer agreed on the Seller's offer for the first time the Seller entered the Buyer's agreement space and the achieved agreement was the same as the one reported in Table 5.5.

Table 5.9: Negotiation progress Scenario 2, example 1; (AP1 vs. AP1)

Seller (AP1)						**Buyer (AP1)**					
Step	Offer	Supporting Arguments			Status	Step	Offer	Supporting Arguments			Status
		Class A	Class B	Class C				Class A	Class B	Class C	
1	15000	x	x	✓	Rejected	2	10000	x	x	x	Rejected
3	14500	x	x	✓	Rejected	4	10500	x	x	✓	Rejected
5	14000	x	x	x	Rejected	6	11000	x	x	✓	Rejected
7	13500	x	x	✓	Rejected	8	11500	x	✓	x	Rejected
9	13000	x	✓	x	Accepted						
The agreement was achieved in 9 steps on the Seller's offer											

However, in Table 5.10 in which the Seller's profile is AP5 (i.e., CNS/RA), whereas the Buyer's profile is AP8 (i.e., CONS/RA), the case is different and the impact of the supporting arguments is very clear. In this example, the negotiation was terminated after 10 rounds without achieving an agreement and that is because the Buyer's concession strategy allows it to concede if the current offer is not supported. Hence, the Buyer was allowed to concede just one time when there is no supporting arguments, after that, it insisted on its second offer which was supported by some arguments from the Class C. On the other hand, the Seller's concession strategy allows it to concede only if not sure about the current offer, which means it can still concede even if there are some supporting arguments from Class C, as in steps 1, 3, and 7. However, in step 9, the Seller did not concede because its offer was supported by some arguments from Class B. At this point, both agents insisted on their last offers and the negotiation failed and ended without reaching an agreement.

Table 5.10: Negotiation progress Scenario 2, example 2; (AP5 vs. AP8)

Seller (AP5)						**Buyer (AP8)**					
		Supporting Arguments						Supporting Arguments			
Step	Offer	Class A	Class B	Class C	Status	Step	Offer	Class A	Class B	Class C	Status
1	15000	x	x	✓	Rejected	2	10000	x	x	x	Rejected
3	14500	x	x	✓	Rejected	4	10500	x	x	✓	Rejected
5	14000	x	x	x	Rejected	6	10500	x	x	✓	Rejected
7	13500	x	x	✓	Rejected	8	10500	x	x	✓	Rejected
9	13000	x	✓	x	Rejected	10	10500	x	x	✓	Rejected
Negotiation terminated after 10 steps without achieving an agreement											

Another negotiation scenario that ended without achieving agreement is presented in Table 5.11. In this example, the two agents' profiles are of type AP9, which is the toughest combination of the agents' profiles, especially when there are supporting arguments. So if the agreement space is not empty and an agreement is achieved, then the negotiation outcome should be a Nash equilibrium. Unfortunately, in this example, the negotiating parties failed to reach this agreement and the negotiation was terminated in short number of rounds (in 6 steps) because there were some supporting arguments for the offers of both agents. However, they were able to successfully achieve this agreement in the first scenario as we discussed in the third example (Table 5.7) in the absence of the supporting arguments (without considering the agents' uncertainty).

These three examples are just samples of the negotiation progress for the second scenario, and the complete results are reported in Table 5.12.

Table 5.11: Negotiation progress Scenario 2, example 3; (AP9 vs. AP9)

Seller (AP9)						**Buyer (AP9)**					
Step	Offer	Supporting Arguments Class A	Supporting Arguments Class B	Supporting Arguments Class C	Status	Step	Offer	Supporting Arguments Class A	Supporting Arguments Class B	Supporting Arguments Class C	Status
1	15000	x	x	✓	Rejected	2	10000	x	x	x	Rejected
3	15000	x	x	✓	Rejected	4	10500	x	x	✓	Rejected
5	15000	x	x	✓	Rejected	6	10500	x	x	✓	Rejected
Negotiation terminated after 6 steps without achieving an agreement											

To summarize, from the reported results in Table 5.8, it can be observed that in the absence of the supporting arguments (i.e., the absence of uncertainty consideration), the negotiating parties were able to achieve an agreement in all agent profiles combinations, which is not a good indicator because in some situations the achieved agreement is undesirable for at least one of the two agents, but it was achieved because the agents did not consider their uncertainty about the selection of their moves. On the other hand, from Table 5.12, we noticed that the negotiating parties could not reach this agreement in the presence of some supporting arguments and the consideration of their respective classes. For instance, the agents could not achieve an agreement in all possible combinations of agent profiles in which at least one of the two agent's profile is AP8 or AP9. Furthermore, as discussed in the theoretical part, if the two negotiating agents' profiles are of type AP1 to AP3, then the negotiating parties will always successfully reach an agreement (i.e., the negotiation is complete).

Scenario 2: Summary of Results

Table 5.12 reports the final negotiation results for the second scenario. These results were agreed by both agents Seller and Buyer using all possible combinations of agent profiles and under the effect of argument classes on the agents' decisions.

Table 5.12: Scenario 2 - Results summary for all possible combination of agent profiles: Agreement, utility, and number of steps

Seller Buyer	AP1	AP2	AP3	AP4	AP5	AP6	AP7	AP8	AP9
AP1	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	No deal U=(0,0) N.O.S=6	No deal U=(0,0) N.O.S=15
AP2	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_S^{Ach}=12500 U=(0.17,0.17) N.O.S=11	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=13	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	No deal U=(0,0) N.O.S=15	No deal U=(0,0) N.O.S=15
AP3	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	ψ_B^{Ach}=12500 U=(0.17,0.17) N.O.S=12	ψ_B^{Ach}=13000 U=(0,0.33) N.O.S=14	ψ_B^{Ach}=12000 U=(0.33,0) N.O.S=10	No deal U=(0,0) N.O.S=15	No deal U=(0,0) N.O.S=15
AP4	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	No deal U=(0,0) N.O.S=9	No deal U=(0,0) N.O.S=9	No deal U=(0,0) N.O.S=9
AP5	ψ_S^{Ach}=12000 U=(0,0.33) N.O.S=13	ψ_S^{Ach}=12000 U=(0.33,0) N.O.S=13	ψ_S^{Ach}=12000 U=(0.33,0) N.O.S=13	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=9	No deal U=(0,0) N.O.S=9	No deal U=(0,0) N.O.S=9
AP6	No deal U=(0,0) N.O.S=14	No deal U=(0,0) N.O.S=14	No deal U=(0,0) N.O.S=14	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=9	No deal U=(0,0) N.O.S=9	No deal U=(0,0) N.O.S=9
AP7	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	ψ_S^{Ach}=13000 U=(0,0.33) N.O.S=9	No deal U=(0,0) N.O.S=5	No deal U=(0,0) N.O.S=5	No deal U=(0,0) N.O.S=5
AP8	No deal U=(0,0) N.O.S=14	No deal U=(0,0) N.O.S=14	No deal U=(0,0) N.O.S=14	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=5	No deal U=(0,0) N.O.S=5	No deal U=(0,0) N.O.S=5
AP-9	No deal U=(0,0) N.O.S=14	No deal U=(0,0) N.O.S=14	No deal U=(0,0) N.O.S=14	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=10	No deal U=(0,0) N.O.S=5	No deal U=(0,0) N.O.S=5	No deal U=(0,0) N.O.S=5

5.10 Summary

In this chapter, we proposed an efficient and flexible mechanism for argumentation-based agent negotiation in uncertain settings. Using this mechanism, agents can adopt the suitable negotiation strategies to be able to decide about the selection of their moves and the acceptance of the other parties proposals. In particular, we started by addressing important issues related to the negotiation environment such as the negotiation constraints, concessions, and the negotiation outcome. And then, we introduced new classification and evaluation for the set of potential offers that assist the agents to decide about the acceptance of other agents' offers. Afterward, we proposed two main sets of negotiation strategies namely, CONCESSION and ACCEPTANCE strategies, each of which is composed of three subsets. The combination of all possible strategies of these two sets resulted in nine agent profiles (AP1 to AP9). In each negotiation session, each agent has to select one agent profile that consists of one concession and acceptance strategy using the *"Strategy Selection Function"*. Furthermore, we discussed two important outcome properties namely, completeness and Nash equilibrium. These properties are related to the negotiation outcome and corresponding to the adopted agent strategy. Finally, we validated our work by implementing the proposed approach using a Java-based tool developed mainly for this purpose. We tested the ABAN framework in the e-commerce environment with the used car trading problem, and we analyzed the dialogue outcome for the different agent profiles in two different scenarios. In the first scenario, we tested non-argumentative agent profiles (i.e., we neglected the impact of the supporting arguments and their respective classes), while in the second scenario, we provided the negotiating agents with a set of supporting arguments associated to different classes for each potential offer, and tested the impact of these arguments and their respective classes on the agents' decisions.

To summarize, this chapter has answered the research questions (**RQ5**, **RQ6**, and

RQ7). By doing so, we have answered all the research questions and met all the research objectives raised in Chapter 1. Therefore, in the next chapter, we conclude our research, highlight some shortcomings of our work, and put forward some future directions that can be done as a continuation of this work.

Chapter 6

Conclusion and Future Work

This chapter concludes the thesis. We first give a summary of the main contributions of the thesis. Then, we present a critical assessment of the proposed framework. Finally, we provide some hints for future directions.

6.1 Contributions Summary

In this dissertation, we have proposed and implemented a framework for argumentation-based agent negotiation in uncertain settings. The main goal of this research is to develop techniques and design negotiation mechanisms that allow negotiating agents to make better decisions about the selection of their moves and the acceptance of their partner's proposals in dynamic and uncertain circumstances. In particular, the thesis makes three major contributions presented in Chapters 3, 4, and 5 respectively.

In Chapter 3, we established the necessary argumentation framework that allows negotiating parties to precisely reason about and make the right decisions on the selection of their moves in uncertain settings. The proposed agent theory is basically built based on the argumentation-based mechanism proposed by Mbarki et al. in [88] and Amgoud and her colleagues [18], where both of them were built based on Dung's abstract argumentation framework [42]. We extended Mbarki's framework by incorporating a new important parameter, *agent's uncertainty degree*, to come up with a practical and yet effective argumentation framework that allows the negotiators to explicitly influence each others' preferences and reason about the selection of their moves during negotiation when uncertainty matters. More precisely, we presented the agent theory in a more abstract way to include the negotiation constraints, the arguments owned by the agent, a preference relation over arguments, an attack relation among those arguments, a set of offers, a preference relation over offers, a function that specifies the arguments that support each offer, and a function that returns a real number representing the agents' uncertainty about the selection of their moves. By doing so, we guarantee that each agent can interpret correctly the received arguments and compare them with its own arguments. We also allow each agent to recognize whether the received argument is in conflict or not within its own arguments. Moreover, we proposed a new mechanism for selecting the most appropriate (relevant) argument based on three selection criteria and analyzed the computational complexity of this selection mechanism. Finally, we proposed two reasoning mechanisms namely, strategic and tactic reasoning. These reasoning capabilities allow negotiating parties to reason about and decide on the selection of the most appropriate (relevant) argument locally at each dialogue step (using tactic reasoning), and decide about the global communication plan (using strategic reasoning) to achieve their goal (the agreement) according to the adopted strategy.

In Chapter 4, we have presented an efficient method to assess agents' uncertainty about the exchanged moves (offers/arguments) and their acceptance in argumentation-based agent negotiation (ABAN). The main issue we have investigated is the agent's uncertainty about selecting its moves during the negotiation process from not only the perspective of the agent itself, but also from its beliefs about the acceptance criteria of the opponent. In particular, we used Shannon entropy —a well-known technique for quantifying information on the randomness degree —to measure the uncertainty degree of each move at each dialogue step first, and then, to measure this uncertainty for the whole dialogue. The probability of each possible move reflects its degree of uncertainty. Thus, in order to be able to calculate this uncertainty, we have defined a function called *Move's Probability Function*. This function assigns a probability value between [0,1] to each move, such that the summation of all moves' probabilities at each dialogue step is equal to 1. Moreover, in order to facilitate the selection process we have defined a function called *Probability Ordering Relation* that order the moves based on their probability (i.e., based on their acceptability sequence). Now that we know how to assess the uncertainty degree for the move, we can measure he uncertainty degree of the dialogue in three methods: in the first method, we simply take the average of uncertainty degrees of all dialogue moves. Whereas, in the second method, we calculate the number of all possible dialogues that can be generated from all possible moves, which can be obtained by taking the Cartesian product of all possible moves at each dialogue step, and then, we compute the probability of each possible dialogue by multiplying the probabilities of its moves. Finally, we measure the uncertainty degree of the dialogue using the general formula of Shannon entropy. In the third method, we used a hypothesis testing approach. In particular, instead of going through the process of calculating the uncertainty of all dialogue moves one by one, we simply calculate agents' uncertainty for sample of moves, take the average of uncertainty of these moves and assume that it equals to the uncertainty of the dialogue, then apply the hypothesis technique to see whether this assumption is true or not.

Further, we have presented a novel classification for the set of potential arguments based on their uncertainty degree, and we used this classification for designing a new set of negotiation strategies in Chapter 5. Furthermore, an attractive discussion of some special cases of arguments' uncertainly based on the available number of arguments and their relative classes at each dialogue step is presented. To validate our work, we implemented the proposed technique by applying it on a real case study (Buyer/Seller) scenario from the business domain. The obtained experimental results confirmed the effectiveness of using our uncertainty-aware techniques in reaching agreements compared to those who assume typical negotiation settings, which do not consider uncertainty.

In Chapter 5, an efficient and flexible negotiation mechanism for automated bilateral argumentation-based negotiation has been proposed. The main purpose of this mechanism is to help negotiating parties make their decisions about whether to make concessions or not and whether to accept or reject other's proposals during the negotiation process. This can be done through the adaptation of the right negotiation strategy which considers agents' uncertainty about their proposals. Therefore, to design such strategies, we started by addressing the needed parameters such as the negotiation constraints, concession mechanism, and defining some metrics related to the negotiation outcome. And then, we introduced a new classification and evaluation for the set of potential offers that assists the agents to decide about the acceptance of other's proposals. Having all the design parameters ready, we then proposed two main sets of negotiation strategies namely; *concession* and *acceptance* strategies, each of which is composed of three subsets. The combinations of all possible strategies resulted in nine agent profiles (AP1 to AP9). In any negotiation session, each agent has to select its profile that consists of one concession and acceptance strategy using what we called *Strategy Selection Function*. Furthermore, we discussed two important outcome properties, completeness and Nash equilibrium, corresponding to the adopted strategy (i.e., agent profile). Finally, we validated our work by implementing the proposed approach using a Java-based tool developed mainly for this purpose. We tested the ABAN framework in the e-commerce environment with the used car trading problem, and we analyzed the dialogue outcome for the different agent profiles in two different scenarios. In the first scenario, we tested non-argumentative agent profiles (i.e., we neglected the impact of the supporting arguments and their respective classes), while in the second scenario, we provided the negotiating agents with a set of supporting arguments associated to different classes for each potential offer, and tested the impact of these arguments and their respective classes on the agents' decisions.

From the obtained results, it can be observed that agents' uncertainty about the selection of their moves is a very important factor that should be considered during the negotiation process, especially when the agents do not have enough information about each other. Also, it can be noticed that as long as an agent is highly or moderately certain about its choice, it will not need to concede and move to the next offer. However, if the agent is not sure or there is no more supporting arguments for its current best offer, it can easily do so. In fact, considering agents' uncertainty about their moves' selection based on their profiles in the design and development phases of agents are of great importance since they contribute in automating the negotiation process in such a way that enables each negotiating agent to choose its partner to achieve a better outcome.

6.2 Critical Assessment of Our Framework

In this thesis, we have successfully met all the objectives that we intended to address through answering all the research questions raised in Chapter 1. However, dealing with argumentation-based negotiation in uncertain setting is undoubtedly a complex task. Therefore, in order to tackle this problem, we limited our selves to bilateral argumentation-based negotiation, which considers only two parties negotiate over some issue(s) (i.e., bilateral multi-issues negotiation). Even though this topic is a very active area of research in automated negotiation, considering multi-party multi-issues negotiation is another important direction of this research that we did not investigate.

Another point that we have not explored is the complexity of the whole system. Indeed, we analyzed the complexity of the arguments selection mechanism presented in Chapter 3, but not for the whole system. In fact, our framework is very complicated and involves many interacting components, so analyzing the complexity of such a system is not a trivial task, especially when uncertainty issues matter.

Another limitation in the assessment of our framework is the lack of using public data sets which are missing in this research area.

6.3 Future Research Directions

This thesis has drawn its own direction in the area of argumentation-based negotiation in uncertain settings. However, the work presented here is a step forward towards investigating some other open issues for dialogues prone to uncertainty. Therefore, this work can be improved or extended in many different ways. In what follows, we list some of them.

- We intend to improve the proposed framework by applying our results on multi-party argumentation-based negotiation, i.e., many-to-one or many-to-many, where new concepts need to be introduced such as group and coalition arguments. However, extending the proposed approach to this type of dialogues is not straightforward. For instance, defining the rules of a multi-party negotiation is much more complicated than a two-party dialogue.

- Investigating some game-theoretic strategies such as Tit-for-Tat is another possible improvement to this work.

- We plan to apply the proposed uncertainty assessment technique for other types of dialogue games such as persuasion, deliberation, inquiry and information seeking.

- Another possible extension of this work is to analyze argumentation-based dialogues from the optimization perspective and analyze the computational complexity of such optimization problems. Also, studying the computational complexity of converging towards Pareto optimality depending on the adopted agent profiles is an important point to be considered in future research.

- We are also interesting in calculating some metrics on different parameters, such as the competence of each agent relatively to the selection of its arguments, and considering different agent profiles and their degree of trust.

- Providing the negotiating parties with a reasoning capability to self-adapt their profiles according to the opponent's profile during the negotiation process is another important point to be addressed in future research.

- We also plan to formalize the two types of agents' uncertainty (Type I: uncertainty about the selection of the right move, and Type II: uncertainty about the selected move to be accepted by the address) discussed in our ABAN framework as a Markov Decision Process (MDP). By doing so, the problem of achieving an agreement, which satisfies both agents, become the problem of finding a joint policy that specifies which move an agent should choose at each dialogue step.

- Finally, investigating model checking techniques for verifying argumentation-based negotiation dialogues and their protocols using, for instance, the methodology proposed in [116] is an important point for future research we plan to target.

Publications in refereed journals and conferences

Journals

- Omar Marey, Jamal Bentahar, Ehsan Khosrowshahi Asl, Khalid Sultan, Rachida Dssouli: Decision making under subjective uncertainty in argumentation-based agent negotiation. J. Ambient Intelligence and Humanized Computing 6(3): 307-323 (2015)

- Omar Marey, Jamal Bentahar, Rachida Dssouli, Mohamed Mbarki: Measuring and analyzing agents' uncertainty in argumentation-based negotiation dialogue games. Expert Systems with Applications. 41(2): 306-320 (2014)

- Omar Marey, Jamal Bentahar, Mohamed Mbarki, Ehsan Khosrowshahi Asl, Rachida Dssouli: Uncertainty-Aware Mechanism for Automated Bilateral Agent Negotiation Using Argumentation. Group Decision and Negotiation. (Submitted)

Conferences

- Omar Marey, Jamal Bentahar, Ehsan Khosrowshahi Asl, Mohamed Mbarki, Rachida Dssouli: Agents' Uncertainty in Argumentation-based Negotiation: Classification and Implementation. ANT/SEIT 2014: 61-68

- Mohamed Mbarki, Omar Marey, Jamal Bentahar, Khalid Sultan: Agent Types and Adaptive Negotiation Strategies in Argumentation-Based Negotiation. ICTAI 2014: 485-492

- K. Sultan, J. Bentahar, O. Marey: A Probabilistic Logic to Reason about the Interaction between Knowledge and Social Commitments in MASs. In the Proc. of The 13th International Conference on Intelligent Software Methodologies, Tools, and Techniques (SOMET_14), Langkawi, Malaysia, 2014.

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