

UNIVERSITY OF TECHNOLOGY SYDNEY

**An Argumentation System that Builds Trusted
Trading Partnerships**

A dissertation submitted for the degree of
Doctor of Philosophy in Computing Sciences

by

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Sydney, Australia

2010

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate



A handwritten signature in black ink, followed by the date "11-02-2010". The signature is stylized and difficult to read. Below the signature and date is a horizontal line.

Acknowledgement

I would specially like to thank my thesis supervisors Prof. John Debenham and Prof. Simeon Simoff who have worked hard with me in this years, teaching me many important things, among them the most important one is the encouragement throughout the period of my studies. My gratitude goes to the University of Technology Sydney for accepting my scholarship application, funding conference trips, and simply for giving me the opportunity to enjoy being a part of one of the best universities in Australia. Thanks to my colleagues Paul Bogg, Ante Prodan, Anton Bogdanovych, Lei Zhang, and Hooman Homayounfard as well as to other friendly people from e-Market research group, who were always there when I needed to hear a friendly human voice or share one of my new ideas with them. I am thankful to Deborah Turnbull and Sue Felix for proof reading the draft of this dissertation. I would like to thank all the faculty members, and staffs at Faculty of Engineering and Information Technology who have collaborated with me in these years. Last but not least I would like to express my gratitude to my family members who gave me hospitality during this years, and to all friends, relatives, and colleagues who made these years full of love and of happiness.

Submitted by:

Khandaker Shahidul Islam

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Abstract

In e-Commerce, a buying process typically begins with browsing the available products or services, and then selecting the ones that satisfy a given need. The next phase is negotiation to reach an agreement. If an agreement is signed between two parties, they enter into the enactment phase including payment and delivery. After that, they evaluate how well the products or services satisfy their needs. One of the reasons for dissatisfaction is that a trading agent does not know its opponent agent's needs, contract acceptance criteria, or behaviour during their interactions. This dissertation is concerned with the problems and challenges of repeatedly conducted trading activities in e-Commerce applications.

Argumentation is a mode of interaction between agents that enables them to exchange information within messages in the form of arguments to explain their current position and future plans with the intention of increasing the chance of success in the negotiation. How an agent conducts all phases of a buying process through argumentation is an important research query. It becomes difficult to solve this query if an agent has to repeatedly conduct trading activities with its opponent agents. This work describes a novel solution to how an agent builds trusted trading partnerships with its opponent agents.

The requirements of all phases of a buying process are specified by five models: the needs model, the opponent agent selection model, the communication model, the agreement model, and the relationship model. The relationship aware argumentation framework is then proposed. It integrates how the trading agents analyze their interaction history, exchanged information, and any promises made. An agent architecture

is then developed that extends the idea of information based agency. It measures the strength of business relationships and predicts behavioural parameters from the history of interactions.

This dissertation establishes the thesis statement, “*Modelling the strength of relationships between agents and predicting the behaviour of trading partner agents in a multi agent argumentation system enables agents to build trusted trading partnerships*”.

A prototype simulation environment has been developed to conduct the experiments and to validate the thesis statement. The simulated arrival rate obtained by the proposed model is lower than that of an existing model, e.g., the Trust and Honour model. The prototype argumentation system demonstrated a proof of concept. The prototype will be further developed before applying the proposed argumentation system in commercial applications.

Chapter 1

Introduction

My thesis is “*Modelling the strength of relationships between agents and predicting the behaviour of trading partner agents in a multi agent argumentation system enables agents to build trusted trading partnerships*”. In this dissertation, a relationship aware argumentation framework is presented.

In this chapter, the motivation for conducting this work is described, and the research questions, outline of the proposed solution, the contributions and significance, scope of the dissertation, and the structure of the dissertation are introduced.

1.1 Motivation and Aim

The initial motivation was to modelling a general trading process from historical activities between trading parties. Of late, a considerable number of applications have been developed to use the Internet for interaction between parties. A software application for conducting trading activities over the Internet is often referred to as e-Commerce.

Definition 1.1. *E-Commerce* concerns the buying and selling of products or services over electronic systems such as the Internet and computer networks [21].

This work is concerned with the problems and challenges for repeatedly conducted activities in e-Commerce applications especially modelling the strength of relationships between agents and predicting the behaviour of trading partner agents. There are several e-Commerce applications including e-Procurement¹ where the trading activities on related products and services are conducted repeatedly through interactions between two parties. Such application areas include, but are not limited to, interactive shopping for goods and services, attracting customers to revisit a store, predicting customer behaviour, and trading non-standard products and services.

The motivation of this work is to enhance e-Commerce applications in which trading activities are conducted repeatedly. One way to enhance such e-Commerce applications is to ensure that a trading party knows how to predict the future behaviour of other trading parties, to some extent by analyzing their interaction history, exchanged information, and any promises made on related products and services. Such predictions may prove difficult to achieve if the trading parties exchange information about non-standard products and services, or if the environment in which the trading parties interact is dynamic and uncertain. A trading party² may utilize the experiences of any previous trading activities with other trading parties within a trading pact³ on related products and services. *The aim of this work is to develop a system in which a trading party builds trusted trading partnerships⁴ with other trading parties by analyzing their interaction history, exchanged information, and any promises made.*

¹E-Procurement refers to a buying process that conducts business activities to purchase and sell products and services through the Internet or other networking systems.

²A trading party may be a human being or a computer program.

³A trading pact represents a set of trading parties having similar performance or behaviour.

⁴See definition 1.8 on page 8.

1.2 Research Questions

In an e-Commerce application, two trading parties usually interact with each other to perform their assigned activities or to achieve their personal objectives. In a typical buying process, a buyer and a seller interact with each other to satisfy their needs. In order to satisfy a need, a trading party has to perform a sequence of activities. For example, when a new need is observed, a trading party identifies a range of suitable products or services that satisfy this need. A trading party then faces the question of which opponent party should be selected for interaction, hopefully to reach an agreement⁵ that satisfies the need. Subsequently, interaction takes place between two trading parties in order to reach an agreement that consists of a pair of commitments. Finally, both parties enact their commitments, i.e., one party delivers the products or the services, and the other party pays some money. After a reasonable waiting period⁶, both parties evaluate how well these activities have been performed. Similar patterns of behaviour between two complementary roles⁷ (e.g., doctor-patient, teacher-student, or accountant-taxpayer) are also observed in other applications. However, we restrict our scenario to buyer-seller interaction in an e-Commerce application.

In general, a trading party faces some important questions when contemplating how to satisfy a need. These are: how does one specify needs? which products or services properly satisfy the identified needs? which opponent party should one interact with to

⁵An agreement, or a deal, or a contract refers to a pair of commitments between two parties, whereas commitment means that one party commits to bring about a potential state of affairs at some future time. In this work, we use the terms agreement, deal or contract interchangeably. Also, see definition 3.5 on page 85.

⁶The exact waiting period after completing any payment and delivery depends on the nature of products, services, or payment methods. The evaluation should be performed not too early or too late.

⁷A role is a set of connected behaviours, rights and obligations as conceptualized by actors in a social situation [94].

satisfy current needs? how does one interact with the selected opponent party, resulting in mutually beneficial commitments and enactments⁸? and finally, how does one evaluate those enactments of the commitments that satisfy its needs? This generalizes the contribution reported in [74] that describes a general buying process. It consists of the six stages: need identification, product brokering, merchant brokering, negotiation, purchase and delivery, and products and services evaluation. In these six stages, negotiation is used to reach agreements through interactions between trading parties or agents⁹. We define negotiation¹⁰ as:

Definition 1.2. *Negotiation is a form of interaction that enables a group of agents to arrive at a mutual agreement or to achieve their objectives.*

A buying process starts when a need is observed. When a new need that is related to previous needs is observed, the trading parties have some experience or information on how well previous agreements satisfied those needs when the agreements were enacted. Such an experience or information may then indicate how well future agreements might be enacted for the current need. A key question is: how does one analyze the interaction history for the prediction of possible responses from other parties to satisfy the current need in the context of the current negotiation?

To develop a general model, the following research questions will be addressed.

- How does an agent specify needs and which enactments (i.e., products and services) satisfy the specified needs?

⁸An enactment is the observed activities of an opponent party's commitment with (or without) any (pre-approved) variation.

⁹For the time being, a trading agent (or an agent) refers to a computer program that is capable of performing these activities.

¹⁰We rephrase the definition proposed in [10].

- Which opponent agent does an agent select to interact with in an attempt to satisfy a given need?
- How does an agent interact (i.e., negotiate) with an opponent agent hopefully to reach an agreement?
- How does an agent perform the enactment of a signed commitment, and how does an agent evaluate the enactment that satisfies its needs?
- How and when does an agent analyze interaction history, exchanged information and any promises made to predict its opponent agent's behaviour?
- How does one integrate the answers to the above five research questions into a complete system?

1.3 Outline of the Proposed Solution

This work is concerned with the motivation to enhance e-Commerce applications in which trading activities are conducted repeatedly. It is also concerned with uncertain and incomplete information that a trading party might face in repeatedly conducted trading activities; for example, a typical product becomes unavailable from stock, a need is no longer current, the opponent trading party does not have good intentions, or some unforeseen circumstances or special events occur. When a trading party has repeatedly negotiated with his/her opponent trading parties to satisfy a range of similar needs, there is a possibility of coping with such uncertain and incomplete information in a better way by selecting one of the previously selected trading parties rather than an untried trading party¹¹. Our proposed solution addresses the research questions

¹¹A trading party is an untried trading party for another trading party, if they have no previous interaction.

(stated in section 1.2) to enhance e-Commerce applications for repeatedly conducted trading activities.

In a buyer-seller interaction scenario, two trading parties (i.e., a buyer and a seller) negotiate to reach a mutually beneficial agreement that satisfies their needs. In general, a trading party conducts trading activities using incomplete and uncertain information about the behavioural parameters of his/her opponent trading parties. The behavioural parameters (e.g., preferences, needs of other parties, or the degree of cooperation) may be predicted to some extent from their interaction history, exchanged information, and any promises made. The trading party may use such predicted behavioural parameters in repeatedly conducted trading activities. In this work, a trading party (i.e., a buyer or a seller) is represented as an agent where two agents (i.e., a buyer agent and a seller agent) interact to repeatedly conduct trading activities. There are many definitions of an agent found in literature [98, 121, 122, 120, 55, 20, 42]. We use the definition of an agent as follows:

Definition 1.3. *An **Agent** is an encapsulated computer system that is situated in some environment and is capable of flexible, autonomous action in that environment in order to meet its design objectives [55, 122].*

Among the six stages in a buying process, agents use negotiation as a form of interaction to reach mutually beneficial agreements. A trading party may exchange some relevant information during negotiation with other trading parties in explaining how to conduct the other five stages of a buying process. Such an exchange of information may also be related to either a previous negotiation or a future negotiation. One of the negotiation mechanisms that may be applicable in addressing these stages is *argumentation*. In an attempt to simplify the definition proposed by [57], we define argumentation as follows:

Definition 1.4. *Argumentation* is a mode of interaction between agents that enables them to exchange information within the messages in the form of arguments to explain their current position and future plans with an intention of increasing the chance of success in the negotiation.

We have selected argumentation¹² as a way to repeatedly conduct trading activities, because argumentation would provide an opportunity for an agent to construct a model of its opponent agent's behaviour from the exchanged information. The aim of rhetorical argumentation is to alter the beliefs of other agents by using persuasive illocutions, e.g., appeal, reward, and threat¹³. In this work, we are interested in developing a system where an agent predicts its opponent agent's behaviour by analyzing their exchanged arguments and information.

Definition 1.5. An *Argumentation System* is a system in which the agents interact with each other through argumentation.

The argumentation system proposed in chapter 3 specifies the requirements of a general buying process. In this work, an agent analyzes interaction history to measure how well the previous agreements were enacted and to predict how an opponent agent might satisfy a range of related needs in current or future interactions. When an agent interacts with other agents to repeatedly conduct trading activities, one group of opponent agents may have exchanged more relevant information than another. An agent then might have an opportunity to minimize the uncertainty for conducting future

¹²Throughout this dissertation, argumentation is taken in the rhetorical sense and not in the classical sense in which argumentation is concerned with logical proofs that a particular view is valid.

¹³Three persuasive illocutions focus on three main ideas: *appeals*- you should prefer this option over that alternative for this reason; *rewards*- acceptance of this proposal means something positive will happen to you; and *threats*- failure to accept this proposal means something negative will happen to you [108].

trading activities with such a group of agents. In order to repeatedly conduct trading activities, agents in the proposed argumentation system build *business relationships*, *trading partnerships*, and *trusted trading partnerships*. We now define these three terms.

Definition 1.6. A ***Business Relationship***¹⁴ between two agents is defined as a historical sequence of related trades.

Definition 1.7. A ***Trading Partnership*** is a business relationship between two agents such that both agents demonstrate the ability and willingness to repeatedly conduct trading activities for a set of related needs.

Definition 1.8. A ***Trusted Trading Partnership*** is a trading partnership such that both agents have developed a necessary level of trust in conducting trading activities (e.g., product selection, payments and delivery, and products and services evaluation) for a set of related needs.

If an agent is to build a trusted trading partnership through argumentation then the agent requires additional capabilities. The most important ability is to predict an opponent agent's behaviour by analyzing interaction history, exchanged information and any promises made, such as future and/or conditional commitments. We have used several existing methods to summarize the interaction history and proposed a behaviour prediction method. We integrate the methods into a framework, and propose an agent architecture, as discussed in chapter 4. Finally, we develop our argumentation system as a multi-agent system.

Definition 1.9. ***Multi-agent System*** (or MAS) is a system in which several interacting agents pursue a set of goals¹⁵ or perform a set of activities [118, 119].

¹⁴The terms: business relationship and trading relationship are used interchangeably.

¹⁵An agent's goal represents a state that the agent desires to realize by means of actions available to it [22].

Our multi agent argumentation system consists of a set of agents. It contains trading agents that interact with other trading agents. It also contains information-providing agents¹⁶ and an institution agent¹⁷. The latter represents the institution that facilitates the interactions [6]. A simplified model of an argumentation system is shown in figure 1.1 and a detailed model is shown in figure 3.1. The key contribution of this work is the development of a framework for the prediction of an opponent party's behavioural parameters in similar situations by analyzing interaction history, exchanged information, and any promises made.

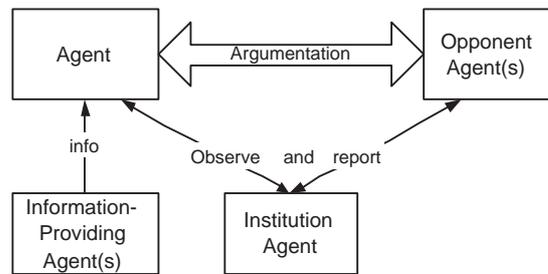


Figure 1.1: The Agents in a Simple Argumentation System

1.3.1 Contributions and Significance

The proposed argumentation system contributes a novel way to solve the set of research questions and to design trusted e-Commerce applications. This work is significant for e-Commerce applications because it enhances the interactions between trading parties

¹⁶An information-providing agent delivers timely information at the right granularity level extracted from the vast amount of information, e.g., news, opinions, comments, white papers, etc., available in electronic form [28].

¹⁷The institution agent plays a number of roles including reporting promptly and honestly what actually occurs after the agents have agreed on the negotiation terms and conditions. It enables software agents that have no sensory perceptive ability to negotiate.

and builds trusted trading partnerships. We have identified five models (i.e., the needs model, the opponent agent selection model, the communication model, the agreement model, and the relationship model) and the relationship aware argumentation framework to assist the agents in building trusted trading partnerships. These models are discussed in chapter 3. The framework is introduced in section 3.7 and further discussed in chapter 4. We now introduce how the identified research questions (see section 1.2) are addressed in this dissertation.

- *How does an agent specify needs and which enactments (i.e., products and services) satisfy the specified needs?* In the proposed argumentation system, a trading agent interacts with its opponent agent to satisfy a set of needs. These needs are represented by the needs model as discussed in section 3.2. Each need in the needs model is represented by a negotiation object as discussed in 3.2.2. A negotiation object has a set of attributes which are categorized as either essential or optional. The proposed agent supports for trading non-standard products and services through the use of optional attributes. The products and services are mapped into a set of hierarchical categories as discussed in 3.4.2. The agent matches its needs with available products or services belonging to the same or similar¹⁸ categories. It then constructs a set of possible agreements in preparing for interaction as described in 3.2.3.
- *Which opponent agent does an agent select to interact with in an attempt to satisfy a given need?* In the proposed argumentation system, the opponent agent selection model (see section 3.3) addresses the second research question. It describes how a trading agent selects its opponent agent for a given need based on their previous performance and behaviour. The agent determines a set of

¹⁸We use semantic distance [62] to measure the similarity between two categories or concepts.

opponent agents with whom there already exists a trusted trading partnership, or with whom there is a possibility of building a trading partnership. It gives priority to the opponent agents with whom there is an existing trusted trading partnership, or any possibility of building a trading partnership. Otherwise, the agent randomly selects its opponent agent. A detailed discussion on the opponent agent selection model is presented in section 3.3.

- *How does an agent interact (i.e., negotiate) with an opponent agent to hopefully reach an agreement?* The communication model (see section 3.4) is used for exchanging arguments and information. The negotiation illocutions include {Offer, Accept, Reject} and the persuasive illocutions include {Reward, Threat, Appeal}. The communication model restricts two agents to use a common language and ontology. The agents also use two languages: an illocutionary based language for exchanging information and arguments, and a probabilistic first order language for internal representation. We discuss the communication model in section 3.4.
- *How does an agent perform the enactment of a signed commitment, and how does an agent evaluate the enactment that satisfies its needs?* We have proposed the agreement model (see section 3.5) to establish, modify and sustain agreements so that a trading agent is able to cope with uncertain events. The agreement model then supports product delivery and payment, and products and services evaluation. We discuss the agreement model in section 3.5.
- *How and when does an agent analyze interaction history, exchanged information and any promises made to predict its opponent agent's behaviour?* The proposed agent builds business relationships and then trusted trading partnerships using the methods described in the relationship model (see section 3.6). It summa-

rizes the relevant interaction history in preparing for future interactions. These measures include a previously described behavioural parameter (i.e., trust [103]), and a proposed performance parameter (see section 3.6.2 for the strength of a relationship). The proposed agent then predicts the behavioural parameters of its opponent agent to some extent by analyzing the exchanged information and any promises made (see section 4.4 for the prediction of need attributes, contract acceptance criteria and behaviour categories). It also extracts the relevant arguments and information from the history of interactions categorized across illocutions, ontology, and semantic distance. We describe the relationship model in section 3.6.

- *How does one integrate the answers to the above five research questions into a complete system?* By integrating all the models proposed to address the above questions, we present the relationship aware argumentation framework (see section 4.1) and also an information based agent architecture (see section 4.5). The proposed agent uses a probabilistic model based on Bayesian inference. Various probability measures such as probability of contract acceptance by an opponent agent, probability of building a trading partnership, or probability of the breakdown of a trading partnership are also discussed. Finally, the proposed relationship aware argumentation framework enables an agent to analyze interaction history, previously exchanged information and any promises made. With the aid of these five models and the framework, the proposed agent demonstrates the ability to build trusted trading partnerships. We discuss the framework and the agent architecture in chapter 4.

1.3.2 Scope

In an e-Commerce application, agents may gather information from both internal¹⁹ and external²⁰ sources. Due to usual constraints of a Ph.D. work, we have not discussed the integration of real time data mining²¹ from the Internet. We assume that a suitable collection of information-providing agents is available²².

1.4 Structure of the Dissertation

This dissertation addresses the problems and solutions as outlined above. The remainder of the dissertation is structured as follows:

Chapter 2 presents a discussion of the related work conducted to solve the identified research questions²³ by the researchers in the field of negotiation and argumentation. It includes relevant background information that helps to provide a detailed understanding of the argumentation system concept. This chapter then identifies the requirements of a relationship aware argumentation system²⁴ that has been developed to build trusted trading partnerships and provides an understanding of the work that has been done.

Chapter 3 describes the components of an argumentation system for building trusted trading partnerships. In the proposed argumentation system, the six research questions are addressed by five models (i.e., the needs model, the opponent agent selection model, the communication model, the agreement model, and the relationship model) and the relationship aware argumentation framework. The five models are dis-

¹⁹Internal information is exchanged in the interaction process.

²⁰External information is gathered from external sources e.g., Internet, news agents, etc.

²¹Data mining is the process of extracting hidden patterns from data [78].

²²See figure 1.1 and also footnote 16.

²³The research questions are identified in section 1.2 on page 3.

²⁴See definition 2.10 on page 52.

cussed in this chapter. This chapter also introduces the requirements of the relationship aware argumentation framework, such as preparing for argumentation (i.e., categorizing, and summarizing the historical interactions), analyzing the exchanged arguments and information, and predicting the selected opponent agent's behavioural parameters.

Chapter 4 presents the relationship aware argumentation framework that enables a trading agent to build trusted trading partnerships through argumentation. It presents how the agent predicts its opponent agent's behaviour by analyzing the responses to the exchanged arguments and information. This chapter also describes how the agent extracts and analyzes the effect of the exchanged arguments and information on its opponent agent. It then describes how the extracted information assists the prediction of the selected opponent agent's behavioural parameters e.g., need attributes, contract acceptance criteria and behaviour categories. We extend information based architecture in [104] that works with uncertain information. Finally, this chapter presents the overall architecture integrating all of these ideas and validates the thesis.

In conclusion, **Chapter 5** describes proposed further work and the strategies to manage it. It concludes with a brief discussion of the achievements that we have made by developing an argumentation system. This chapter presents a summary discussion of the work that has been completed, and relates it to future work. It is hoped that the work presented here is a significant step and a foundation for further research in this area.

Chapter 2

Related Work

In e-Commerce, a buying process typically begins with browsing the available products or services, and then selecting the ones that satisfy a given need. The next step is negotiation to reach an agreement or a contract. If an agreement is signed between two parties, they enter into the enactment phase including payment and delivery. After that, they evaluate how well the products or services satisfy their needs. During this cycle, there may be unforeseen circumstances that need to be taken into account; for example, a need is no longer current, the product becomes unavailable, or special events occur that affect the enactments. When a new need is observed, the trading party will decide to trade with either one of the previously selected opponent parties or an untried opponent party. Such a decision depends on the evaluation of the previous enactments for related needs.

In this work, a trading party has two goals: (i) to satisfy his/her needs and (ii) to build trusted trading partnerships. Six research questions have been identified in section 1.2 in order to develop a general model that builds trusted trading partnerships. To address those identified research questions, a multi-agent argumentation system is shown in figure 1.1 on page 9 (see figure 3.1 in chapter 3 for further details). It is an

open system¹ in which a trading agent interacts with other trading agents to satisfy their needs and also to build trusted trading partnerships. In that argumentation system, a trading agent also interacts with other information-providing agents and the institution agent to gather general information.

This chapter presents a discussion on the research work that has been conducted to solve the identified research questions by researchers in the field of negotiation and argumentation. It includes relevant background information (mainly on negotiation, argumentation, argumentation system and also information based agency) that assists a detailed understanding of the argumentation system concept with the objective of identifying the links between the research areas: argumentation systems and trading partnerships. The requirements of the argumentation system that enable agents to build trusted trading partnerships are then identified in section 2.7. Finally, section 2.8 concludes this chapter.

2.1 How to Reach an Agreement

In a general buying process, a trading agent's activities include: need identification, product brokering, merchant brokering, negotiation, purchase and delivery, and products and services evaluation [74]. Among these trading activities, an agent interacts with other agents through negotiation to reach agreements that satisfy its needs. Argumentation aims to alter the beliefs of other agents by using persuasive illocutions, e.g., threat, reward, and appeal [108, 103]. In addition, argumentation provides an opportunity for an agent to exchange information about any previous or future agreement in the context of the current negotiation. In order to repeatedly conduct trading activi-

¹An open system is a system which continuously interacts with its environment, and its components work independently and autonomously [112].

ties, a trading agent may interact with other agents through argumentation because of the opportunity to exchange information. Sections 2.1.1 and 2.1.2 discuss related work on how an agent negotiates or argues to reach an agreement with other agents.

2.1.1 Negotiation

Negotiation is defined on page 4 as a form of interaction that enables a group of agents to arrive at a mutual agreement to perform their assigned activities or to achieve their objectives². In general, a trading party does not know its opponent agent's requirements (e.g., needs, and acceptance criteria) in advance to make decisions on accepting, rejecting or withdrawing from a negotiation. It requires accurate and timely information in making decisions on potential agreements, but accurate and timely information may not always be available. In other words, an agent has to work with uncertain and incomplete information about its opponent agent's requirements (e.g., needs and acceptance criteria).

In multi-agent systems, negotiation can be categorized as: game theoretic analysis [95, 65, 101], heuristic based approaches [36, 64, 39], and argumentation based negotiation approaches [88, 57, 103]. In this section, overviews of game theory and heuristic based negotiation are presented. Both game theoretic and heuristic approaches describe how agents negotiate on a set of pre-specified requirements, for example, needs, or preferences. By contrast, in argumentation based negotiation, an agent modifies its requirements upon receipt of new information and influences its opponent agents to modify their requirements. Section 2.1.2 describes argumentation based negotiation.

²We rephrase the definition proposed in [10].

Game Theoretic Model of Negotiation

In game theoretic model of negotiation, the interaction between the parties is modelled as a game³. In a game, the parties are usually utility⁴ aware. For example, two trading parties determine an acceptable agreement by analyzing their interaction as a game to maximize their own benefits or expected utilities. [49, 95, 116] discuss how the parties determine their optimum strategies by utilizing game theoretic approaches. In other words, an agent using game theoretic model of negotiation is capable of maximizing its own utility.

Most of the works in game theoretic model of negotiation fall in either competition or competition [11, 113]. In repeatedly conducted trading activities, the nature of the interaction between two agents should be cooperative rather than competitive. An attempt to modelling cooperation among the participants has been achieved by adjusting the rules⁵ of a game that constrain their public behaviour [95]. [72] describes how an agent supports both competition and cooperation by using the notion of persuasion within a negotiation model. However, it is not always possible to resolve inconsistency among the rules in game theoretic model of negotiation.

In this work, a trading agent should adjust its own needs and influence its opponent agents' needs by compensating for previous shortcomings or making future promises in order to hopefully reach an agreement and also to repeatedly conduct trading activities. The next step is the enactment, i.e., payment and delivery, if an agreement is signed.

³A game is a negotiation process to distribute the benefits and burdens in which each agent tries to maximize its own benefits and minimize its own burdens.

⁴The term 'utility' refers to a measure of the relative satisfaction from, or desirability of, consumption of various products and services [115].

⁵The rules of a game determine how the participants should play and when one participant should win.

The evaluation is the last stage in which a trading party evaluates how well the entire buying process has been conducted in satisfying of a given need. The evaluation is conducted in game theoretic model of negotiation in the presence of all possible enactments, although a trading agent does not always know all possible enactments that satisfy its opponent agent's needs. As such, an agent that utilizes game theoretic model of negotiation is not capable of influencing trading parties' needs and also relating any previous compensation or future promise in order to support the entire buying process. Hence, game theoretic model of negotiation is useful, but insufficient to conduct trading activities.

Heuristic Based Negotiation

Heuristics are rules of thumb that produce good enough (or sub-optimal) outcomes by sacrificing the claim of completeness (i.e., optimal outcomes). They are often produced in contexts with simplified assumptions about agents' rationality and resources [88]. Various heuristic functions are used for evaluating and generating offers or proposals in multi-attribute negotiation [37]. For example, [38] applies heuristics to trade off in constructing alternative offers during bargaining using similarity criteria. In order to repeatedly conduct trading activities, heuristic based negotiation may be applied because of its trade off capabilities (e.g., a trial-and-error method may be applied to cope with dynamic and uncertain information), but heuristic models need extensive evaluation through simulation and empirical analysis [88].

Heuristic methods overcome some of the limitations of game theoretic model of negotiation. For example, heuristic approaches may be used to work with unknown parameters, or uncertain events. In order to repeatedly conduct trading activities, agents have to work with uncertain and incomplete information, especially in compen-

sating for previous limitations or satisfying future promises. Heuristic functions may be developed to model such information uncertainty and incompleteness. Nevertheless, heuristic methods still have a number of disadvantages [56], such as generating sub-optimal outcomes, as it becomes difficult to predict the behaviour of a system or its agents.

2.1.2 Argumentation

Argumentation is defined on page 7. It is a mode of interaction between agents that enables them to exchange information within the messages in the form of arguments to explain their current position and future plans with an intention of increasing the chance of success in the negotiation [57]. Argumentation allows agents to alter beliefs and preferences and improves both the likelihood and the quality of deals [89]. For example, a need or acceptance criterion may be modified to match with available products and services. Again, an unsuccessful interaction may promote an alternative acceptable agreement. A trading agent may apply commonsense reasoning⁶ in analyzing the exchanged information to adjust its own needs and to influence its opponent agent's needs by compensating for previous shortcomings or making future promises.

In this work, a trading agent conducts the six stages of a buying process (e.g., need identification, product brokering, merchant brokering, negotiation, purchase and delivery, and products and services evaluation) through argumentation (see section 2.4 for how to conduct trading activities). How a trading agent conducts trading activities through argumentation in the presence of incomplete and uncertain information is an important research query. It becomes difficult to solve this query if an agent has

⁶Common-sense reasoning includes the ability to make a decision with incomplete knowledge and perhaps revise that belief when complete knowledge become available [82].

to repeatedly conduct trading activities (see section 2.5 for how to repeatedly conduct trading activities). The exchanged information assists an agent to minimize uncertainty in conducting trading activities in the current negotiation as well as future negotiations. For example, the payment and delivery mode in an agreement may be decided based on the historical performance of any promises made. If an agent has to repeatedly conduct trading activities with its opponent agents, commonsense reasoning may also be applied on the exchanged information or any promises made in argumentation.

Artificial Intelligence⁷ has long dealt with the challenge of modelling commonsense reasoning [97]. The need for an argumentation model for commonsense reasoning can be traced to the work on truth maintenance systems [30]. That work offered a method that represents beliefs together with the justifications for such beliefs, as well as procedures for dealing with the incorporation of new information. A logical model of commonsense reasoning requires formal principles and criteria in modelling inference [19], but classical logic has been proved to be an inadequate reasoning model [92]. Commonsense reasoning may be applied to cope with incomplete and inconsistent information [76, 77]. As such, in addition to the logical argumentation model [34, 66], several other argumentation approaches (e.g., persuasive [108, 66, 90], interest based [86, 87], preference based [3, 5, 4], and rhetorical [103, 105]) are proposed in the literature to solve different problems. In section 2.3, these argumentation frameworks are discussed in brief.

2.2 What an Agent is Capable of Performing

In general, an agent interacts with its opponent agent by sending and receiving messages. In negotiation, a message usually contains a proposal, or a decision that a

⁷Artificial Intelligence (AI) is the study of agents that receive percepts from the environment and perform actions [96].

proposal is accepted or rejected. As such, an agent must be capable of exchanging proposals. In order to exchange proposals, the agent also decides how effective an incoming proposal is and what an appropriate response is to its opponent agent. In argumentation, a message also contains information or arguments in support of a proposal. In [8, 88], the functional capabilities of the negotiation agent and argumentation agent are discussed.

Definition 2.1. *A **Negotiation Agent** is an agent that is capable of negotiating with other agents.*

Definition 2.2. *An **Argumentation Agent** is a negotiation agent that is capable of exchanging arguments and information with other agents about their current position and future plans with an intention of increasing the chance of success in the negotiation.*

In the following sections 2.2.1 and 2.2.2, the capabilities of these two classes of agents are discussed.

2.2.1 A Negotiation Agent

The main goal of a negotiation agent is to reach a mutually beneficial agreement that satisfies a given need. The primary type of information exchanged in the dialogue between two negotiation agents is a proposal [8]. A negotiation agent is capable of exchanging proposals in the form of utterances, evaluating proposals over a set of issues, and making a decision about whether to accept or reject a proposal; whether to generate a counter proposal or even terminate the negotiation altogether [89, 88].

Definition 2.3. *An **Utterance** is a sentence that is composed of an illocutionary particle and its message content, and a trading agent utters it in the performance of an illocutionary action.*

Definition 2.4. A *Dialogue* between two agents is a sequence of exchanged utterances in which one agent sends an utterance and the opponent agent replies to that utterance and so on with a view to conducting trading activities.

A brief discussion of the major functional capabilities of a negotiation agent is presented below.

Exchanging Proposals. A negotiation agent exchanges proposals with its opponent agent in order to reach an agreement. The agent uses an utterance in representing the proposal to inform its position over a set of issues to its opponent agent.

Proposal Evaluation. A negotiation agent evaluates how effective the incoming proposal is and determines the possible future states that the current negotiation may reach. The agent considers information regarding its opponent agent's model during the proposal evaluation process [8].

Response Generation. A negotiation agent generates a response based on the proposal evaluation [8]. It makes a decision about whether to accept or reject a proposal, to generate a counter proposal, or to terminate the negotiation altogether [8, 88].

All these capabilities of a negotiation agent are concerned with reaching an agreement to satisfy a given need. If a message seems similar to some messages in the completed dialogues, a negotiation agent generally treats that message as a new message. By contrast, an argumentation agent is capable of relating such a message with the exchanged information in historical dialogues. In the absence of such capabilities in a negotiation agent, it becomes difficult to repeatedly conduct trading activities through negotiation (i.e., to achieve the second goal of a trading agent in this work).

2.2.2 An Argumentation Agent

Argumentation extends the capabilities of negotiation with the help of exchanging information within the messages in the form of arguments. An argumentation agent shares many capabilities (e.g., exchanging proposals, proposal evaluation, and proposal generation) with a negotiation agent. In addition to the capabilities of a negotiation agent, an argumentation agent is generally capable of exchanging arguments and information, i.e., evaluating incoming arguments, or generating and selecting outgoing arguments [57, 8, 88]. Such exchanged arguments or information allow an agent to justify its own needs or to influence its opponent agent's needs [57], which may increase the chance of reaching agreement and/or better quality agreements than previous agreements [8].

An argumentation agent is capable of inferring a set of parameters (e.g., need description, acceptance criteria) of its opponent agents from the exchanged information in the form of utterances within a negotiation [106]. Such an inference capability enables an agent to support pre-negotiation activities (e.g., need identification, product selection, and merchant selection) and also post-negotiation activities (e.g., payment and delivery, and evaluation) in the presence of uncertain and incomplete information (see section 2.4 for a further discussion). A brief discussion of the major capabilities of an argumentation agent is presented below.

Incoming Argument Interpretation. An argumentation agent is capable of evaluating agreements proposed by its opponents [88]. It accepts the incoming proposal or argues to overcome the reasons of an unacceptable proposal towards making it acceptable. The capability of an argumentation agent in interpreting the incoming arguments may trigger the revisions of its internal information and also insist to change its negotiation parameters [8].

Argument Generation. An argumentation agent is capable of generating a set of candidate arguments of which one of the arguments is wrapped within a dialogue in order to increase the chance of success in the current negotiation. Such a capability enables an agent either to support a proposal or to exchange an individual piece of information [8]. The generated arguments contain argumentative illocutions from $\{reward, appeal, threat\}$ or information exchange illocutions from $\{query, inform\}$.

Argument Selection. In order to increase the acceptability to the opponents, an argumentation agent utters *reward*, *threat*, or *appeal* illocutions to present justification or supporting information on previous actions. It chooses the most suitable argument from a number of candidate arguments that an agent may utter to its opponent [88]. This selection is usually based on the analysis of the expected influence of the argument, or on the commitments to which it ties the utterer [8].

An argumentation agent achieves its objectives or goals by combining the above capabilities in different orders. It also requires a more specialized capability of generating locution than a negotiation agent. The outgoing locution generator sends the response to the relevant party [88]. It adds some information with the selected argument in order to construct the outgoing utterance. An argumentation agent also utilizes the experience from the history of interactions to evaluate an incoming proposal and to construct the model of its opponent agent. In this work, two agents argue with each other to trade non-standard products and services and to repeatedly conduct trading activities. They also work with dynamic and uncertain information. In section 2.3, the benefits of information based argumentation over other argumentation approaches are discussed. As such, we have chosen information based agency which analyzes the history of inter-

actions while evaluating, generating, or selecting arguments and constructing a model of its opponent agent in order to repeatedly conduct trading activities (see section 2.6).

2.3 Approaches to Argumentation

In an argumentation system, two agents usually interact with each other to achieve their goals through argumentation. In other words, an argumentation system enables agents to achieve their goals through the exchange of information in the form of arguments with an intention of increasing the chance of success in the negotiation. This dissertation describes an argumentation system in which a trading agent has a goal to build trusted trading partnership with its opponent agent in addition to arrive at a mutual agreement or to achieve their objectives. There are many argumentation approaches proposed to solve different problems or reach agreements between agents [88]. In the next subsections, these argumentation frameworks are discussed in brief.

2.3.1 Logical Argumentation

The applicability of a particular logic based argumentation framework to negotiation and argumentation is studied in [83]. These agents share the same architecture and exchange basic information in which the interaction protocol is specified using a finite state machine⁸. [3] describes another logic based argumentation. These agents require complete preferences over knowledge bases; however, it may not always be possible to specify the preferences across two different issues. Dung [31, 32] presents a theory for logical argumentation whose central notion is the acceptability of arguments. [34, 33] further describes a logical argumentation framework in which agents use a set

⁸A finite state machine is a model of behaviour composed of a finite number of states, transition between states and actions.

of arguments related by a binary conflict-based attack relation. Another system of argumentation is introduced in [100]. That work starts from a single-agent proof procedure and tries to split it into multiple disjoint agents while preserving the correctness of the proof theory while using a dialectical version of abductive logic programming⁹. It describes the language, knowledge and reasoning that are required to build negotiation dialogues between two agents in order to obtain resources. In order to repeatedly conduct trading activities, an agent requires a negotiation model that dynamically relates the exchanged arguments and information with historical dialogues, but in logic based argumentation, the negotiation model is usually inspired by a set of logical proof procedures. As such, logic based argumentation seems an inappropriate approach to repeatedly conduct trading activities in a general trading scenario.

2.3.2 Persuasive Argumentation

Persuasive argumentation is concerned with how to influence agents' intentions in order to increase their cooperativeness and reduce disparities and conflicts [66]. It allows the agents having non-cooperative behaviour to negotiate and argue with one another. In [66], persuasion is achieved by using rigid order among argumentative illocutions, starting with appeal, then reward and then threat. A general automated negotiation agent was also implemented in [66]. It is based on the logical model, but not all persuasion based argumentation are based on a logical model. The agent described in [66] plans, acts and resolves conflicts via negotiation in a block world environment. That work adopts a modal logic¹⁰ approach and focuses on the mental states of agents that move

⁹Abductive logic programming [61] extends logic programming with respect to higher level knowledge representation and reasoning tasks based on observations and actions.

¹⁰A modal logic is a system of formal logic that attempts to deal with modalities [70]. Modals qualify the truth of a judgment; for example, if it is true that "X is happy", we might qualify this statement

towards an agreement, often persuading a counterpart in order to foster cooperation along the way. The works [108, 90] also use persuasive arguments, i.e., threat, reward, and appeal illocutions, to negotiate with other agents by passing information. The proposed argumentation system also supports persuasive arguments, i.e., threat, reward, and appeal illocutions (see section 3.4.1) to exchange information that enables agents to repeatedly conduct trading activities.

2.3.3 Interest Based Argumentation

Another argumentation approach reported in [86, 87] is influenced by interest based negotiation among humans [40]. The agents in [86] use comparison criteria for selecting goals based on their support. They then generate the argument based on a list of possible attacks on set goals. [75, 86] describe the types of interaction patterns needed among the agents and makes an attempt to create a dialogue system. These agents do not try to specify how other agents negotiate. Instead, they concentrate on studying the general properties of the dialogue itself or the interesting types of influences. Interest based argumentation may be used by agents to satisfy their needs, but not to repeatedly conduct trading activities. This is because a trading agent may not always be able to generate a complete list of arguments in the presence of dynamic and uncertain information. As such, we do not consider interest based argumentation to be an appropriate option to repeatedly conduct trading activities.

2.3.4 Preference Based Argumentation

[3, 5, 4] describe preference based approaches to argumentation in which classification of dialogue is based on [117]. These agents have complete preferences over knowledge by saying that “X is very happy”, in which case the term “very” would be a modality.

bases, although the preference ordering for two values across two different issues may not always be measured. The arguments are evaluated based on the interaction between arguments and preferences over their content. One argument may be preferred to another one, such as when it is more specific, when its beliefs have higher probability or certainty, or when it promotes a higher value than another [59]. [59] also describes how to use non-monotonic preference reasoning to compute preferences among arguments, and subsequently the acceptable arguments, from the preferences among values. Preference based argumentation appears to be a useful approach to solving the identified research questions. In order to repeatedly conduct trading activities, a trading agent has to adopt the preference ordering based on the failed dialogues so that the chance of success increases in future dialogues, but the changes to the preferences may result in inconsistency in the agent's internal information.

2.3.5 Information Based Argumentation

Information based argumentation enables agents to build their model inferred from the messages they have received and to use information theory and principles in exchanging arguments and information. Here, an agent uses the intrinsic value of information and is also capable of negotiating with its opponent agents having incomplete and uncertain information. In information based argumentation, an agent may use a rhetorical¹¹ approach to change the preferences of its opponent agents, to refine its opponent agent's model, and also to maintain a certain level of trust [102]. [103] utilizes rhetorical particles, i.e., threat, reward, and appeal illocutions, as an information exchange process and summarizes information in historical interactions mainly to build business relation-

¹¹A rhetorical approach [60, 43, 114] refers to the art or technique of effective communication with the goal of persuading the participants to adopt a point of view or perform a particular action.

ships. [105] analyzes the effect of argumentation on the on-going relationship between a pair of agents. Rather than utilizing a logical model, information based argumentation analyzes the effect of utterances on other agents which may include interest, preference, or behaviour. As such, information based argumentation seems more appropriate than logical argumentation in order to address the identified research questions¹².

2.4 How an Agent Conducts Trading Activities

In a general trading scenario, a trading party interacts with other trading parties and negotiates to satisfy a given need. In e-Commerce applications, agents may be used as trading parties where they autonomously buy and sell goods on behalf of users [80, 45]. For example, the trading agent, Nidsia [41] negotiates in an e-Commerce application. In our work, an agent repeatedly conducts trading activities (e.g., need identification, product brokering, merchant brokering, negotiation, purchase and delivery, and products and services evaluation) with its opponent agent by analyzing their interaction history, exchanged information, and any promises made.

Once a need is specified, a trading party conducts two tasks, i.e., product brokering and merchant brokering, before any interaction occurs to reach an agreement. The product brokering activity describes how to identify products and services that match the specified needs. The merchant brokering describes who to interact with to increase the chance of satisfying a given need. Sections 2.4.1 and 2.4.2 present how these activities are addressed in the existing work on negotiation and argumentation. Subsequently, interaction (in this work, information based argumentation) between agents occurs to reach an agreement. If an agreement is signed, the trading parties then conduct payment and delivery and, finally, evaluate the enactments. Sections 2.4.3 and

¹²The research questions are identified in section 1.2 on page 3.

2.4.4 present related work (on information based argumentation) that describes how to interact and how to conduct enactment and evaluation.

2.4.1 How to Specify Needs and Which Enactments (i.e., Products and Services) Satisfy the Specified Needs

When a need arises, an agent specifies its need as a negotiation object¹³. Two agents exchange arguments and information over a range of issues about the negotiation object. A trading agent only discloses a subset of issues or matching criteria that maximizes the chance of reaching an agreement. [57] reported that customers might be interested to dynamically specify the structure of negotiation objects, such as non-standard products and services, in a negotiation. In a general trading scenario, customer's needs and acceptance criteria are dynamic or may be changed without disclosing any prior information. In [44], all issues are negotiated separately and independently in order to learn the possible range of the issues and then optimize the negotiation objects.

In this work, two types of issues, essential and optional are utilized in modeling a negotiation object in order to support non-standard products and services (see section 3.2.1). For example, a car has a default configuration and a customer modifies its default configuration by adding features. A negotiation object for a car is initially constructed from its default features. An agent changes the structure of the negotiation object to include its opponent agent's requirements. The use of such a dynamic structure for the negotiation object may increase the chance of success in repeatedly conducted trading activities. Two trading parties interact to minimize any disagreement on the value of non-standard issues. They then re-construct the negotiation object, incorporating any non-standard issues.

¹³See definition 3.2 on page 66.

Tete-a-Tete [46] includes a product brokering feature through negotiation. It uses multi attribute utility theory¹⁴ to recommend products. [91] merges the product brokering and merchant brokering stages of a consumer buying behaviour model that enables agents to get the best price for a good product from a reputable merchant. It uses a ‘word of mouth’ recommendation, i.e., automated collaborative filtering, that summarizes the recommendation from other parties having a similar buying profile. In order to support non-standard products and services, an agent needs to know how available products and services are filtered by its given need, or how similar products and services are extracted from historical dialogues. Neither of these contributions addresses the dynamic nature of needs (i.e., non-standard products and services) in a buying (negotiation) process, or product selection from historical dialogues.

[103] describes an argumentation model in which products and services are represented in a hierarchy by utilizing the structure of ontology¹⁵. [105] then analyzes historical dialogues categorized by illocutionary categories and the structure of the ontology. In our work, an agent also extracts historical dialogues having similar products and services, and identifies the availability of non-standard products and services. In addition, semantic distance¹⁶ between the concepts in a signed agreement and a subsequent enactment as discussed in [104, 105, 106] refers to the difference between need specification and the selected products. It provides an opportunity for an agent to predict how the selected products and services category might satisfy its given need in the presence of non-standard modification.

¹⁴A Multi attribute utility theory describes a set of techniques that estimates the utility derived from individual attributes and combines the utility from each attribute to measure an overall utility [54]. It ranks and selects the best product or service from a set of possible alternatives.

¹⁵See section 3.4.2 for a further discussion on ontology.

¹⁶We use semantic distance [62] to measure $\text{sim}(c_1, c_2)$ as the similarity between two categories or concepts.

2.4.2 Who to Interact With

The Kasbah system [17] describes an online multi-agent consumer-to-consumer transaction system that automates the merchant brokering and negotiation stages in a buying process. It uses heuristic negotiation and describes how an agent in the marketplace works, and how both parties rate each other's activities after a transaction has been completed [123]. Tete-a-Tete [46] also includes a merchant brokering feature through negotiation. A 'Better Business Bureau' works in the merchant brokering stage of a buying process, and measures trust and reputation using the ratings given to each other from both parties [15, 16]. These ratings may be utilized in determining who to interact with filtered by a threshold value (e.g., trust [79], reputation [99] or both). In information based argumentation, [102] describes trust as the expected deviation of behaviour along a dimension determined by the type of agreement, and [27] describes reputation as a social evaluation of a group about a human or software agent, and [103] introduces honour as the expected integrity of the information and promises exchanged.

In a trading partnership, two agents demonstrate the ability and willingness to conduct trading activities along a dimension in the future (see definition 1.7 in section 1.3). In this work, an agent's ability to conduct trading activities is modelled as how certain the enactment of an agreement is. For a given need, an agent measures trust in modelling its opponent agent's ability to conduct similar trading activities. Again, an agent's willingness to conduct trading activities is represented as an honour. It is measured from any promises made in historical dialogues. In this work, strength of a trading relationship (as a special form of honour, see section 3.6.2) is utilized in modelling the willingness property of a trading partnership. This question is further discussed in an opponent agent selection model (see section 3.3).

2.4.3 How to Interact

The third research question is about how to interact. In argumentation, an agent usually interacts with another agent through the exchange of messages that contain proposals, arguments, or information [88]. In information based argumentation, agents share a communication model to interact with each other through the exchange of arguments and information [104, 106]. [105] describes a communication model that enables an information based agent to exchange information. It utilizes a language and ontology to represent the message contents. In addition, the use of semantic distance also enables those agents to identify similar concepts from the structure of ontology. Agents also require a protocol to represent the structure of dialogues [103]. In general, trading agents exchange information on negotiation terms such as payments and delivery, but if a previous enactment has deviated from the signed commitment, they also claim compensation or make promises. The communication model is further discussed in section 3.4.

2.4.4 How to Enact a Signed Commitment and Evaluate the Enactment (i.e., Payment and Delivery)

The fourth research question relates to how argumentation enables the enactment and the evaluation phase of a buying process after signing an agreement between two agents. If an agreement is reached through the interaction between two trading agents, they sign an agreement that consists of a pair of commitments, $(\varphi_\alpha, \varphi_\beta)$ and then enact the commitments, $(\varphi'_\alpha, \varphi'_\beta)$ and evaluate the enactments, $Eval((\varphi_\alpha, \varphi_\beta), (\varphi'_\alpha, \varphi'_\beta))$ ¹⁷. [104] presents two fundamental primitives in an agent's communication language: *Commit*(α ,

¹⁷The evaluation function, *Eval*(.) to evaluate trading activities for non-standard products and services, and the evaluation database are discussed in sections 3.5.3 and 3.6.2 respectively.

β, φ) to represent, in φ , what in the world α aims to bring about and that β has the right to verify, complain about or claim compensation for any deviations from, and $Done(a)$ to represent the event that a certain action a has taken place. These notions of $Commit(.)$ and $Done(.)$ are useful in signing an agreement and subsequent enactment respectively.

An agreement usually contains negotiation terms about how payment and delivery will be made. An enactment refers to the observed activities of an opponent agent's commitment with or without any variation. A trading agent does not sign an agreement if any anticipated variation in payment or delivery exceeds their threshold values. [23, 103] utilize a probabilistic model, i.e., entropy based inference¹⁸, to cope with uncertain information in negotiating potential agreements or contracts. In this work, a trading agent also utilizes such a probabilistic model in signing, modifying, and sustaining commitments to cope with uncertain and incomplete information about any anticipated variation in the enactments (see section 3.5).

2.5 How an Agent Repeatedly Conducts Trading Activities

In section 2.4, we describe related work on how a trading agent conducts trading activities (six stages of a buying process) to satisfy its given need (i.e., achieving its first goal). In this section, related work on the second goal of a trading agent, or how an agent builds trusted trading partnerships, is discussed. To achieve this goal, a trading agent measures the expectations from its opponent agents in satisfying similar needs through argumentative dialogues that may happen repeatedly. Two related and use-

¹⁸Entropy-based inference is a form of Bayesian inference that is convenient when the data is sparse [18] and encapsulates commonsense reasoning [82].

ful contributions are: [103] proposes the trust and honour model, and [106] describes the prediction of needs, acceptance criteria and disposition¹⁹. The summary measures, trust and honour, are useful in modelling an agent's ability and willingness to conduct trading activities in the future. The predicted parameters - needs, acceptance criteria and disposition - are useful in predicting the behaviour from an existing trading partnership. The proposed agent analyzes historical dialogues, and measures trading partnership parameters (e.g., trust, strength of a trading relationship), and also predicts behavioural parameters (e.g., need attributes, contract acceptance criteria), including the degree of cooperation (i.e., behaviour category). In sections 2.5.1, 2.5.2, 2.5.3 and 2.5.4, brief discussions on valuation, summary measures, rationality, and the degree of cooperation are presented respectively.

2.5.1 The Valuation of Dialogues

The sequence of messages exchanged in a negotiation or argumentation are organized into a dialogue. We restrict that if a sequence of messages, u_1, u_2, \dots, u_n is in a dialogue between two agents (α, β) then u_1, u_3, \dots are the contributions of agent, α and u_2, u_4, \dots are the contributions of agent, β . An argumentation agent generally requires a language (see section 3.4.1) and a protocol (see section 3.4.3) to exchange arguments, and is capable of generating and exchanging the utterances in a dialogue [63]. The value of an utterance in a dialogue is resolved by its contents, namely, an illocution and a message²⁰. In order to repeatedly conduct trading activities, a trading agent also needs to evaluate the utterances in a dialogue in the context of historical dialogues. As such, the value of an utterance should be evaluated with respect to its previous utterance,

¹⁹A disposition represents any difference between what an opponent agent says and what it means.

²⁰A message is constructed from the language as described in section 3.4, and contains a deal with its related information.

the dialogue in which it exists, and any existing trading partnership with the other agents. The agent in [105] evaluates negotiation dialogues in the context of its world model (see definition 2.5 on page 41) and information received from other agents.

In general, the utterances in a dialogue are evaluated using either utilitarian measure or information measure [105, 107]. In this work, a trading agent evaluates an incoming utterance in the context of its world model and available information (e.g., the extracted arguments and information from the dialogue history). That value is then utilized in revising the predicted parameters (e.g., need attributes, contract acceptance criteria and behaviour category).

- **Utilitarian Measure**

The utilitarian measure is applicable in evaluating the utterances in a dialogue when the related information is available. It measures the value of an utterance in the context of a given need and available information. The utilitarian measure of an utterance is expressed in terms of the utility gain obtained from a suitable utility function [69]. In the utilitarian measure, an agent has to know all the relevant future activities with either certainty or a probability distribution expressing the likelihood that they will occur [107]. For a given need, the evaluations of historical enactments are summarized in determining the expectation and are represented as the strength of a business relationship. This parameter is modelled as the utilitarian measure and discussed in section 3.6.2.

- **Information Measure**

The information based measure enables an agent to evaluate the dialogues irrespective of the availability of any related information. An agent usually makes necessary assumptions about unavailable information in the information measure.

The information measure places the intrinsic value on information. This measure reduces the information uncertainty, or increases the information gain, that the dialogue gives to each agent. It is expressed in terms of a decrease in entropy that can always be calculated [105]. In this work, the behavioural parameters (e.g., need attributes, contract acceptance and the degree of cooperation) are modelled as the information measure.

Need for Synthesis of these Two Approaches

In general, a trading agent's activities look like a utility maximizer; that is, maximizing its benefits in a negotiation. This occurs through the use of the utilitarian measure to model the negotiation problem. The agent may not always be aware of all the possible alternatives and works with necessary assumptions about its opponent agent's possible responses. In such cases, the information measure of the dialogue is more appropriate than the utilitarian measure. In other words, a trading agent may utilize the utilitarian measure when data required in conducting its activities is available. It uses the information measure to minimize information uncertainty where a suitable utility function is difficult to define. An approach to synthesizing these two valuations may assist agents in acting as both utility maximizers and uncertainty minimizers. In such a case, negotiation may be viewed as a process of uncertainty minimization and utility optimization through the interaction between two agents.

2.5.2 Summary Measures

In information based argumentation, historical dialogues are summarized into various measures, such as trust [102], honour [103], intimacy [105], and balance [105]. These summary measures are revised after each negotiation round. They also enable agents to

make informed decisions. Among these summary measures, trust and honour measures are utilized in this work. Intimacy and balance are also useful to repeatedly conduct trading activities, and the integration of these two measures with the proposed model is included in our future work. Here, these summary measures are discussed in brief.

Trust. Trust [103] measures the expected deviation of behaviour in the execution of commitments. It represents how an agent is committed to execute an agreement for a given need. Trust simplifies negotiation dialogues, as some negotiation terms and conditions need not be discussed in repeated negotiations [102]. Its values are useful for selecting the next negotiation participant agent or next offer. In this work, the trust measure, $\text{Trust}(\alpha, \beta, \delta)$ ²¹ is utilized to demonstrate an opponent agent's ability to conduct trading activities along a dimension in the future.

Honour. [103] introduces the concepts of honour to measure the expected integrity of the information and promises exchanged. It also presents three different expressions for honour, namely, honour as expected behaviour, honour as expected preferability, and honour as certainty in promise execution. In addition, imposing the structure of ontology and semantic distance makes these expressions useful where sufficient historical dialogues for a given need are not available. We use the strength of a trading relationship as a form of honour (as expected enactment that satisfies a given need) that represents an opponent agent's willingness to conduct trading activities on related products and services in the future negotiation.

Intimacy. Intimacy represents the social closeness of a relationship between two parties that has been developed as a result of experience through repeated interactions [105]. Intimacy between two agents is revised by an update function as each negotiation

²¹The predicate, $\text{Trust}(\alpha, \beta, \delta)$ represents an agent, α 's expectation on its opponent agent, β that the agent, β 's is capable of conducting trading activities along a dimension, δ .

round terminates [105]. The study of any dependency between an intimate relationship and trusted trading partnership is included in our future work.

Balance. Balance of a relationship represents the degree of fairness between two parties, that is, how fair a relationship is between two parties [105]. It depends on the nature of relationships²² between individuals. The balance of a negotiation dialogue is measured as the difference between (i) an agent values a dialogue to itself and (ii) that agent also values the same dialogue to its opponent agent (by assuming that its opponent agent mirrors its own valuation). There is a possibility that if a relationship may be kept balanced up to a certain level then trading partnership will gradually converge towards trusted trading partnerships. This is also included in our future work.

2.5.3 Rationality

Rationality refers to the judgment of an agent as defined by some normative standard²³ [35]. [109] identifies two forms of rationality, constructivist rationality and ecological rationality, which are specifically concerned with human and economic agents. These two forms are also observed in computerized or intelligent agents; for example, game theory and information theory are utilized by agents as constructivist and ecological rationality respectively. In order to repeatedly conduct trading activities, the trading agent should argue in the harmony of previously exchanged information and arguments, and any promises made. A trading agent may construct its world model using both forms of rationalities in order to satisfy a given need. But, the trading agent should construct its social model using ecological rationality in order to build trusted trading partnerships.

²²The nature of relationships are categorized by equity, equality, or need.

²³A normative standard specifies how something ought to be, based on a priori considerations that, if followed, yield success in some dimension [35].

Definition 2.5. *An agent's **World Model** consists of a set of probability distributions that represent how uncertain its states (or necessary information) are to perform the current action (or sequence of actions).*

Definition 2.6. *An agent's **Social Model** consists of a set of probability distributions about the summary of other agents' observed actions that are measured from the history of interactions.*

Constructivist Rationality

In constructivist rationality, an agent's actions are determined by a theory that may be independent of the particular environment in which it is situated. Constructivist rationality is based on game theory, decision theory and the logical model of decision making. Constructivist rationality may be applied to individuals or organizations, and involves the deliberate use of reason in analyzing and selecting actions judged to be better than any alternative feasible actions that might be chosen [109]. In this work, constructivist rationality may be utilized by a trading agent to construct its world model in satisfying a given need, but it is not always the case that a theory that applies in a situation using utility or game theory or logic based approach is available. As such, constructivist rationality does not provide a complete solution in repeatedly conducted trading activities.

Ecological Rationality

Ecological rationality refers to an emergent order. The order takes the form of the practices, norms, and evolving institutional rules governing the actions of individuals that are part of the cultural and biological heritage created by human interactions, but not by conscious human design [109]. In ecological rationality, agents' actions are

derived from their prior interactions and are not predesigned. In information based argumentation, an agent is capable of modelling ecological rationality. For example, in the trust and honour model [103], and the LOGIC model [105], the agents analyze the history of dialogues and decide ecologically. In ecological rationality, rules or actions are adoptive, which is to say that some rules or actions help agents to survive and others do not. The latter are identified through interactions as well as experiences. In order to repeatedly conduct trading activities, ecological rationality may assist a trading agent to construct and/or revise its world model and social model, and then to choose an appropriate action from a set of alternatives by compensating for previous limitations, or by making future promises. As such, a trading agent utilizes ecological rationality in arguing to build trusted trading partnerships.

2.5.4 The Degree of Cooperation

The degree of cooperation indicates how cooperative an opponent agent's behaviour is in a trading partnership. In general, the degree of cooperation varies from cooperative to uncooperative (i.e., competitive or opportunistic) [47]. In order to build trusted trading partnerships, two trading agents should be capable of maintaining cooperation between them, or at least semi-cooperation instead of competition in their interaction. In this work, a trading agent relates the outgoing utterances (i.e., the exchanged arguments and information) to their corresponding incoming responses in predicting the behaviour category (e.g., cooperative, strategic, and opportunistic) of its opponent agent or trading partner agent.

Definition 2.7. *The **Degree of Cooperation** between two agents represents the level at which one agent interacts in harmony with its opponent agent's requirements and vice versa.*

In this work, the degree of cooperation (i.e., the behaviour category of an opponent agent) is restricted to three categories: cooperative, strategic, and opportunistic (see examples 1, 2, and 3). The degree of cooperation may also fall between cooperative and opportunistic; for example, partially cooperative, strategic, partially opportunistic (see examples 4, 5, and 6). To illustrate how the degree of cooperation is identified, a few examples are presented below.

- **Example 1: Cooperative**

Buyer Agent: I need 10 bags of potatoes today. Do you give me free delivery?

Seller Agent: It is difficult for me to give free delivery, but I will do it for you.

- **Example 2: Strategic**

Buyer Agent: I need 10 bags of potatoes today. Do you give me free delivery?

Seller Agent: You have to wait three days for free delivery, but I can arrange express delivery today with an extra delivery fee.

- **Example 3: Opportunistic**

Buyer Agent: I need 10 bags of potatoes today. Is it possible for you to give me a free delivery?

Seller Agent: Do you need any other items?

Buyer Agent: No, I need only 10 bags of potatoes.

Seller Agent: It is expensive for me to send a delivery van for only 10 bags of potatoes.

- **Example 4: Partially Cooperative**

Buyer Agent: I think this car is not good for elderly people.

Seller Agent: Well, it is comfortable for long journey, but there are some other cars especially suitable for elderly people.

- **Example 5: Strategic**

Buyer Agent: I think this car is not good for elderly people.

Seller Agent: Well, it is comfortable for a long journey.

- **Example 6: Partially Opportunistic**

Buyer Agent: I think this car is not good for elderly people.

Seller Agent: Well, it is comfortable for a long journey and I am offering a special price for a limited time only.

An attempt to develop an argumentation model that takes account of the interest of both parties is reported in [106]. An agent sends a message (i.e., arguments and information), then observes the corresponding response, and aims to model the way its opponent agent reacts. If the selected opponent agent satisfies the values of all the need attributes unconditionally then the degree of cooperation falls into the cooperative category. On the other hand, if the opponent agent advises alternative values of all the need attributes or contract acceptance criteria rather than satisfying previously specified need attributes, the degree of cooperation falls into the competitive (or opportunistic) category. [105] describes balance as a summary measure representing how fair a relationship is, i.e., the degree of fairness. Similarly, the degree of cooperation may be measured as a summary of behaviour categories from the sequence of utterances (i.e., exchanged arguments and information with their corresponding responses). In order to repeatedly conduct trading activities, a trading agent measures the expected degree of cooperation from the selected opponent agent (i.e., predicts the behaviour category) by summarizing the exchanged arguments and information, and interacts in harmony with the predicted behaviour category of its opponent agent. The prediction of behaviour category is further discussed in section 4.4 on page 121.

2.6 Information Based Agency

An information based agent uses the tools from information theory through which it infers the unknown facts from observed information. It aims to make informed decisions, taking into account what has actually been observed. An information based agent models other agents by observing their behaviour [25] and the events in their environment, including what other agents actually do [25, 28]. It evaluates incoming messages, and updates internal information before responding to the sender. In a dialogue, any message from one agent to another discloses information about the sender. The information based agents in [103, 104] summarize relevant information in historical dialogues to measure various expectation models such as trust, honour, and confidence²⁴. They then apply these summary measures in determining how to negotiate with opponent agents. Information based agents are also capable of operating in real-time in response to market information flow [28].

An information based agent architecture is described in [104] that integrates two views of negotiation: cooperative negotiation, in the sense that all interactions involve the exchange of information, and competitive negotiation, in the sense that agents aim at getting the best they can. It uses reactive reasoning in response to any incoming messages or proactive reasoning to negotiate for a given need. The works [102, 28, 104] use entropy based inference which enables an agent to construct complete probability distributions from a small number of observations, but the distributions are not expected to be accurate, and the technique derives the unique distribution that is least biased with respect to what is still unknown. As such, these agents are capable of working with incomplete, uncertain and constantly changing information.

²⁴Confidence measures generalize what are commonly called trust, reliability and reputation measures into a single computational framework that spans the illocution categories in [105].

The information based agents in [102, 28, 104] are capable of constructing complete probability distributions from available information and the distributions are revised on the arrival of new information. They measure performance (e.g., honour) or behavioural (e.g., trust) parameters of their opponent agents by summarizing their history of interactions. The summary measures trust, honour, and confidence [103, 104] indicate how future trading activities with an opponent agent might be conducted for similar products and services. In order to conduct trading activities for non-standard products and services, the probability distributions are initially constructed for the standard range of products and services, and may be revised based on the summary measures, and/or on arrival of any modification request. As such, an information based agent may offer good support for conducting trading activities for non-standard products and services.

Considering the above options, a trading agent may be developed by utilizing the idea of information based agency in order to repeatedly conduct trading activities. Figure 2.1 shows the research work on information based agents that are applied in negotiation and argumentation. These agents summarize behavioural (e.g., trust, intimacy) or performance (e.g., honour, balance) parameters²⁵ from the history of interactions and apply these measures in the current negotiation. In sections 2.6.1 and 2.6.2, two forms of information based agents, a negotiation agent (such as the Trust model) and an argumentation agent (such as the Trust and Honour model) respectively, are discussed in brief. Section 2.7.2 introduces a relationship aware argumentation agent (such as the LOGIC model).

²⁵See section 2.5.2 for a brief discussion on these summary measures.

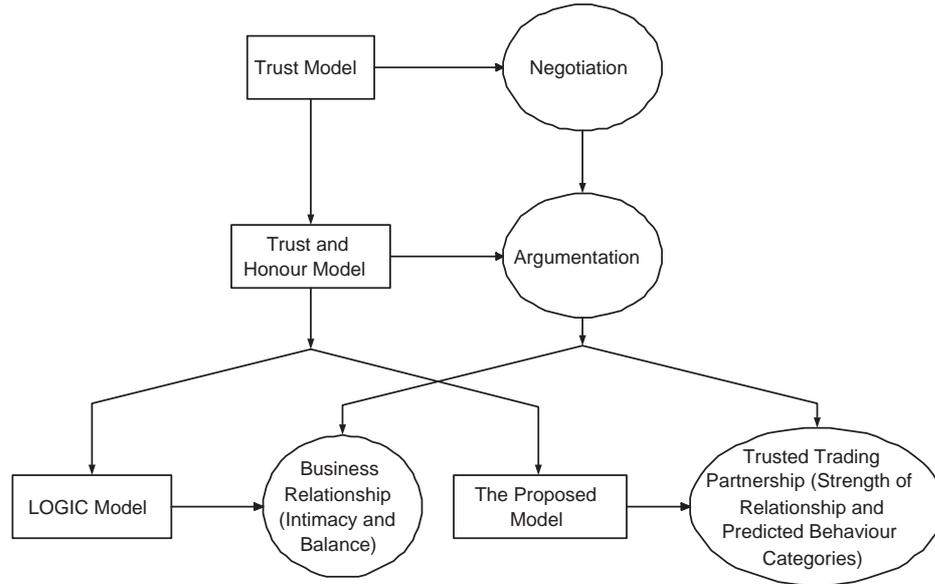


Figure 2.1: Research Work on Information Based Agency

2.6.1 A Negotiation Agent that Satisfies a Given Need

A negotiation agent that uses the idea of information based agency is presented in [25] where it models other agents by observing their behaviour, not by making assumptions concerning their motivations or internal reasoning. [25]’s agent model is shown in figure 2.2²⁶. This agent does two different things in order to support the agreement exchange process: i) it must respond to proposals received from opponent agents, and ii) it must construct and send proposals and possibly information to opponent agents [25]. In information based negotiation, an agent uses ideas from information theory to evaluate its negotiation information [102]. In order to satisfy a given need, the agent in figure 2.2 uses its negotiation strategy in deciding how interactions should take place with respect to its world model.

²⁶In figure 2.2, the symbols \mathcal{N} , \mathcal{X} , and \mathcal{Y} represent needs, in-box, and repository respectively. Again, \mathcal{I} , \mathcal{R} , and \mathcal{A} represent import function, belief revision function and actions sequence respectively. We do not describe the components and the functions here.

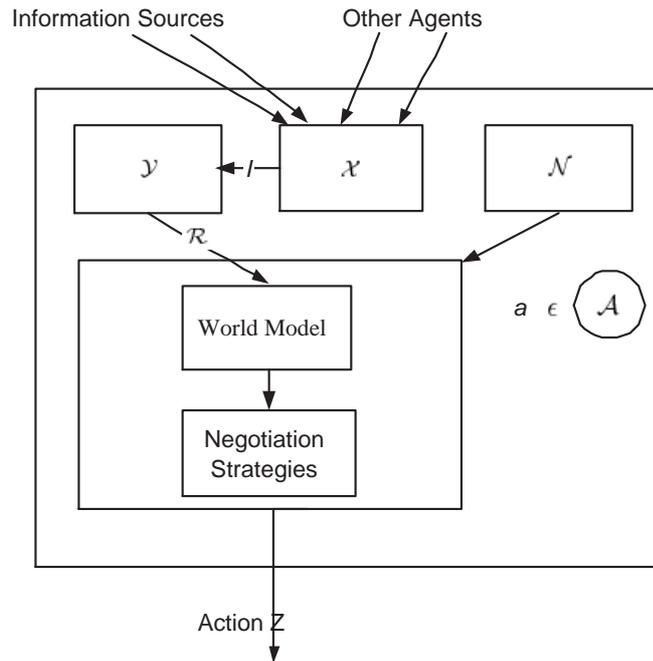


Figure 2.2: A Negotiation Agent that Satisfies a Given Need

Definition 2.8. *An agent's **Negotiation Strategy** is a function that determines the current action or (set of actions) to satisfy a given need.*

The agent shown in figure 2.2 uses entropy based inference and information theory to model other agents on the basis of observations of their actions. The agent supports both single issue and multi-issue negotiations. [23] describes a multi-issue, bilateral bargaining agent that negotiates with an opponent agent to make informed decisions. Such an agent constructs a world model that consists of the probability distributions (e.g., probability of opponent accept, or breakdown) from available information and incoming messages. In the absence of the observed facts, it uses information principle to speculate about what those facts might be [102, 25]. As such, the agent shown in figure 2.2 is capable of conducting trading activities with uncertain and incomplete information.

2.6.2 An Argumentation Agent that Builds Business Relationships

In information based argumentation, an agent uses information theory and principles and extends the capacity of a negotiation agent with the help of argumentation dialogues. [103] describes an argumentation agent that uses threat, reward and appeal illocutions to build business relationships. The agent that uses the idea of information based agency (the Trust and Honour model as described in [103]) and builds business relationships is shown in figure 2.3. Its social model contains trust as the expected deviation of behaviour and honour as the expected integrity of the information and promises exchanged [103]. Here, the agent in [103] is concerned both with future single trades and with trading relationships that encapsulate expectations of future acceptable trades. In order to repeatedly conduct trading activities, a trading agent may be developed by utilizing the ideas from the argumentation agents in [103, 104].

In a general buying process, a trading agent conducts six activities: need identification, product brokering, merchant brokering, negotiation, purchase and delivery, and products and services evaluation. The summary measures (i.e., trust and honour) assists a trading agent having uncertain and incomplete information to model enactments (i.e., payments, delivery) and the evaluation activities of a buying process. Again, the use of ontology and semantic distance simplifies how to specify the customer's requirements in the form of a negotiation object²⁷ (i.e., products and services) that enables an agent to support non-standard products and services during negotiation. The agent in [103] uses threat, reward, and appeal illocutions to build trading relationships with a set of potential trading partners. Such an agent has the short term goal of establishing mutually beneficial deals, and the long term goal of building trading relationships. How the trading relationships will be developed is not detailed in [103].

²⁷See section 3.2.2 for a brief discussion on negotiation object.

Definition 2.9. *An agent's **Relationship Strategy** is a function that determines which opponent agent to negotiate with for a given need, and how to manage its relationships [105].*

In [105], the relationship strategy describes how agents deal with long term business relationships through successive negotiation encounters. The relationship strategy should concern risk management analysis to preserve a strategic set of trading relationships for each mission-critical need [105]. We use relationship strategy to determine how to build trusted trading partnerships (see the opponent agent selection model in section 3.3) in satisfying a set of related needs, and we extend the idea in [103] by utilizing a summary measure, namely the strength of business relationships (see section 3.6.2). In section 2.7, the proposed model is introduced.

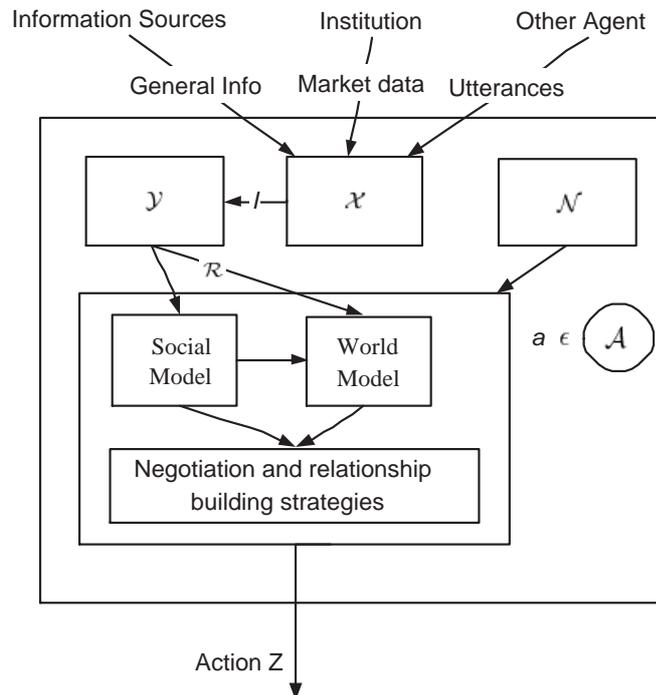


Figure 2.3: An Argumentation Agent that Builds Business Relationships

2.7 Introduction to the Relationship Aware Argumentation System

In recent times, use of the Internet throughout the world has increased significantly [111]. As the number of Internet users continues to increase, there is potentially scope for e-Commerce applications to increase in business transactions. In an e-Commerce application, users visit sites to browse available products or services, and then choose a product or service that matches their needs. Among these users, some purchase the selected products or services and progress to the payment, delivery and evaluation phases. Those users who do not purchase products or services may return to the site at a later time to access previous selections. In order to attract these customers to revisit the store, an argumentation system should include methods for need identification, product brokering and merchant brokering.

Those customers who have completed a purchase now wait for delivery. They then evaluate how well this entire process worked. In general, the evaluation represents how well a product is delivered and how well the product works. Dissatisfaction may arise because of incorrect products or services being delivered, or the customer may have misunderstood when selecting the products or services from the browsing window. In such cases, a trading party should try to keep their existing customers even though they are dissatisfied. They may provide advertisements or free gifts to keep their existing customers long term. On the other hand, a number of customers will not stay with a provider if they are dissatisfied, regardless of what is on offer by way of compensation.

In order to keep existing customers, to attract new customers, and to conduct the other activities of a buying process, the trading agents in e-Commerce applications may use the experiences of their past activities. The ability to reuse such experiences from

the interaction history may assist agents in building trusted trading partnerships. We are interested in developing an argumentation system in which a trading agent builds trusted trading partnerships with other agents.

Definition 2.10. *A **Relationship Aware Argumentation System** is an argumentation system in which the agents are capable of modelling business relationships and then using these models to enrich their argumentation.*

Definition 2.11. *A **Relationship Aware Argumentation Agent** is an argumentation agent which is capable of modelling business relationships and then using these models to enrich its argumentation.*

In the next section, 2.7.1, the necessary components that are required in a relationship aware argumentation system to enable agents to build trusted trading partnerships are introduced. Section 2.7.2 then introduces a relationship aware argumentation agent.

2.7.1 Requirements

This dissertation describes an argumentation system in which the agents repeatedly conduct trading activities through negotiation and argumentation with a view to building trusted trading partnerships. The customers may have need of a group of related products and services that are repetitive in nature. A trading agent argues with them to identify or guess their needs from the available products and services described by a set of attributes. Information based agency has been chosen as an appropriate agent model in building trusted trading partnerships through negotiation and argumentation dialogues that occur repeatedly. The exchanged information and arguments in the historical dialogues are utilized in measuring the parameters to build trusted trading partnerships.

We have already identified the research questions in section 1.2. In order to address these research questions, we have identified five models and a framework to support them. We have discussed the five models in chapter 3 and the framework in chapter 4. Here, we introduce these five models and the relationship aware argumentation framework²⁸.

- *How does an agent specify needs and which enactments (i.e., products and services) satisfy the specified needs?* In order to address the first research question, a trading agent requires the needs model (see section 3.2). [107] describes the needs model as a set of future needs. In addition, a set of need attributes is attached to each need or negotiation object. The attributes are associated with its value type and a set of values. Initially, the negotiation object is constructed with its default values on each need attribute. The relationship aware argumentation framework facilitates how a trading agent identifies or guesses its opponent agent's need attributes through the exchange of arguments and information(see section 4.4.1); for example, a car sales person is interested in identifying the features of a family car that the customer is looking for in terms of a proposal to upgrade. The agent matches its opponent agent's predicted need with the available products and services that are an exact match, or have semantic distance up to a threshold value. As in previous example, the sales person guesses a set of suitable options from the set of available cars depending on the family member's needs, budget or any other constraints. We discuss the needs model in section 3.2.
- *Which opponent agent does an agent select to interact with in an attempt to satisfy a given need?* The second research question concerns how a trading agent selects its opponent agent to interact with for a given need (see section 3.3). [105] address

²⁸See definition 3.10 on page 101.

this issue, but in addition to the work [105], the opponent agent selection model is developed to address this question. In this model, a trading agent summarizes the historic dialogues and measures the behavioural expectation or target from its opponent agent. The relationship aware argumentation framework facilitates how a trading agent predicts its opponent agent's behavior (i.e., cooperative, strategic, or opportunistic) in future dialogues (see section 4.4.3). The agent uses the services offered by other models along with a set of selection criteria to select an opponent agent. We discuss the details in section 3.3.

- *How does an agent interact (i.e., negotiate) with an opponent agent to hopefully reach an agreement?* The third research question is about the communication model (see section 3.4). Two agents interact with each other through the communication model as defined by their language and interaction protocols. In this work, the agents use rhetorical argumentation instead of logical argumentation, utilizing the existing illocutionary communication language described in [103] and the content language described in [105] with necessary minor modification. The communication model should also include the methods to exchange arguments and information with opponent agents. We discuss this model in section 3.4.
- *How does an agent perform the enactment of a signed commitment, and how does an agent evaluate the enactment that satisfies its needs?* The next research question is concerned with signing an agreement to satisfy the specified need, and its enactment and evaluation (see section 3.5). A trading agent requires the agreement model to address this research question. In response to a given need, the agent interacts with its selected opponent agent and reaches a mutually beneficial agreement that satisfies the need. A trading agent estimates the trust on

the enactment of the commitments within the agreements using similar methods to [103]. By using the observed information, the agent then evaluates how well its opponent agent enacted the commitments. The agreement model then supports the delivery, the payment, and the products and services evaluation. We discuss this model in section 3.5.

- *How and when does an agent analyze interaction history, exchanged information and any promises made to predict its opponent agent's behaviour?* In order to deal with the fifth research question, a trading agent uses the relationship model that eases trading activities assigned to the needs model and the agreement model (see 3.6). The needs model and the agreement model describe how the agents accommodate the details of their opponent agent's needs and construct a set of potential agreements or contracts. For example, a home phone service provider offers a phone deal that seems beneficial to customers based on their usage patterns, such as day or evening user, office user, or long distance calls. In other words, based on usage patterns, a trading agent may guess the opponent agent's need attributes. The agent then constructs a set of potential deals (by matching the need attributes with available products) that its opponent agent might sign. In general, a trading agent conducts the activities in the needs model and the agreement model by analyzing interaction history, exchanged information or any promise made. Apart from these, the relationship model should have the necessary components (e.g., the evaluation database) to assist the functions performed by the opponent agent selection model. It should include the necessary summary measures that describe the states of trading partnerships. We discuss the relationship model in section 3.6.

- *How does one integrate the answers to the above five research questions into a complete system?* The last research question is mainly concerned with how to integrate the components identified from the other five research questions (see chapter 4). All the components are integrated into the relationship aware argumentation framework. The argumentation framework analyzes historical dialogues to prepare for argumentation, exchanges arguments and information, and then predicts the behaviour of the selected opponent agent. Such prediction depends on how much information about the selected opponent agent is known before making any decision for argument interpretation, generation or selection. A trading agent also works in an uncertain environment where its selected opponent agent's need attributes, behaviour, and evaluation criteria are not known in advance. We discuss the details in chapter 4.

2.7.2 A Relationship Aware Argumentation Agent

The simplified view of a relationship aware argumentation agent is shown in figure 2.4. It extends the idea in [103]. This agent utilizes two separate strategies, the argumentation strategy and the relationship building strategy. The LOGIC negotiation model proposed in [105] is an example of a relationship aware argumentation agent. It is the first attempt to separate the functionality of argumentation strategies and relationship building strategies. The LOGIC model deals with long term relationships in which negotiators prepare for dialogic exchanges along five dimensions: Legitimacy, Options, Goals, Independence, and Commitment in [105], based on [85]. It categorizes utterances across illocutions and ontology, and estimates a set of summary measures, such as intimacy and balance.

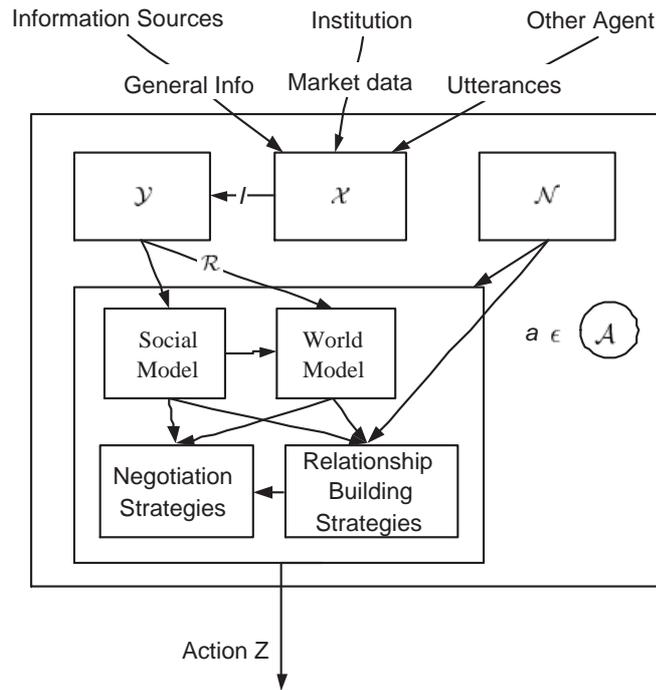


Figure 2.4: A Relationship Aware Argumentation Agent

The agent in figure 2.4 makes an informed decision by constructing a social model and a world model. In this work, the social model includes a set of summary measures and the probability of building or breaking down an existing trading partnership with a set of opponent agents, and the world model contains the probability of accepting or rejecting a possible agreement, or withdrawn from a negotiation. The relationship aware argumentation system is described in chapter 3. A framework (see section 4.1) and an integrated relationship aware argumentation agent (see section 4.5) are then proposed to build trusted trading partnerships.

A relationship aware argumentation agent constructs its social and world model by utilizing a set of summary measures and probability distributions. These parameters are estimated by analyzing the utterances in the history of interactions between agents. The utterances in the history of interactions may be analyzed in three ways:

(i), analyzing and summarizing commitment-observation²⁹ pairs, (ii), categorizing the utterances and measuring relationship parameters such as intimacy and balance, and (iii), analyzing the utterance sequences in the history of interactions. Most of the works reported to date fall into the first two categories; for example, the work [103] describes trust and honour model that falls into the first category, and the LOGIC model describing intimacy and balance in [105] falls into the second category; and the work [106] that introduces the relationship between argumentative utterances falls into the third category. This dissertation proposes a relationship aware argumentation agent as an attempt to integrate the useful models from these three approaches. It contains the models, the strength of a trading relationship (a summary measure), and predicts behavioural parameters (including categorized utterances and the analysis of utterance sequences). Finally, the proposed agent utilizes these models to enrich its argumentation in building trusted trading partnerships with other agents.

2.8 Discussion

In this chapter, the research works that relate to the identified research questions are described. In an argumentation system, an agent interacts with its opponent agent to reach a mutually beneficial agreement through argumentation. In order to conduct trading activities repeatedly, agents should summarize and/or analyze the other phases of a trading process in historical dialogues. The end result is a justification for the requirements of an argumentation system to satisfy a given need and to build trusted trading partnerships in satisfying any related future needs. The requirements of the relationship aware argumentation system are described in section 2.7.1, in which five

²⁹A commitment-observation pair represents what an agent commits and subsequently what enactments are observed.

models and a framework are introduced to address the six identified research questions. The resulting argumentation system should enable agents to build trusted trading partnerships to enhance e-Commerce applications in which the trading activities are conducted repeatedly.

Chapter 3

Argumentation System

In this chapter, an argumentation system is described to address the research questions¹. The first five research questions are addressed and five models are defined. These are: the needs model, the opponent agent selection model, the communication model, the agreement model, and the relationship model. These models describe how to conduct trading activities such as product selection, merchant selection, negotiation, enactment and evaluation, and trading activities conducted repeatedly. The sixth research question is then addressed, in response to which the relationship aware argumentation framework is introduced which integrates the five models. It enables a trading agent to repeatedly conduct trading activities and to build trusted trading partnerships with other agents. The functional components of the framework are also identified.

¹The research questions are identified in section 1.2.

3.1 Conceptual Framework: the five models to support an argumentation system

In this section, the functional components (e.g., the needs model, the opponent agent selection model, the communication model, the agreement model, and the relationship model) of an argumentation system are introduced. With the support of these functional components, a trading agent interacts with other agents to reach mutually beneficial agreements over a set of issues and then builds trusted trading partnerships through repeatedly conducted trading activities. In the proposed argumentation system, the agents share the communication model to exchange arguments and information in a negotiation (see section 3.4). In addition to sharing the communication model, the trading agent utilizes the needs model, the agreement model, and the relationship model (see sections 3.2, 3.5, and 3.6 respectively). The opponent agent selection model is proposed that describes which opponent agent to argue with for a given need (see section 3.3). A conceptual diagram² of the proposed relationship aware argumentation system is shown in figure 3.1.

The specification of a relationship aware argumentation system is described by a tuple $AS=(\mathcal{N},\mathcal{O},\mathcal{C},\mathcal{A},\mathcal{R})$, where \mathcal{N} , \mathcal{O} , \mathcal{C} , \mathcal{A} , and \mathcal{R} , represent a needs model, an opponent agent selection model, a communication model, an agreement model, and a relationship model respectively. For example, a buyer agent wants to buy a car from a trusted seller agent such that the selected car may be replaced if the buyer agent is not satisfied after driving for an initial period and a seller agent has an expectation to continue business long terms; in other words, the seller wants to sell cars to other family members, or hopes that the buyer will recommend other buyer agents to visit the store.

²For simplicity, the opponent agent selection model is not included in figure 3.1, but the opponent agent selection model is shown in figure 3.2.

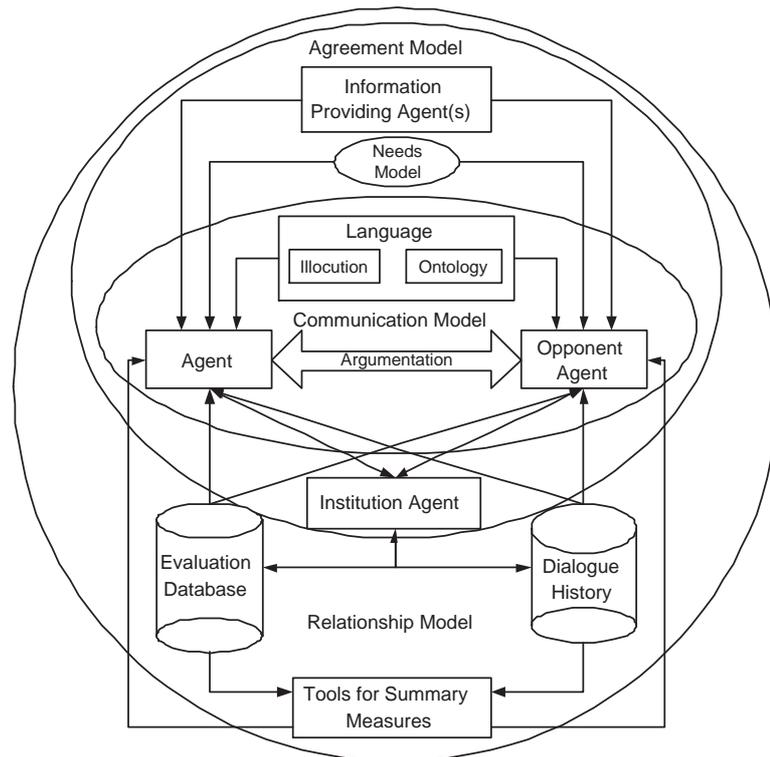


Figure 3.1: Conceptual Framework of the Relationship Aware Argumentation System

In this example, the interaction between a buyer and a seller occurs to conduct trading activities, namely, product selection, negotiation, enactment and evaluation.

A relationship aware argumentation system contains the necessary models capable of supporting similar interaction scenarios as described in the above example. The needs model specifies the buyer agent's need and seller agent's available products. The opponent agent selection model deals with the identification, or selection of a trusted opponent agent. The agreement model specifies the possible options to change the selected products and services (i.e., the selected car) even after an initial evaluation period. The relationship model specifies the buyer agent's expectation to continue future business. Two agents interact using the components specified in the communication model. Finally, all these models are integrated into the relationship aware argumentation framework.

The five models should be integrated with internal³ or external⁴ information received from other agents or the institution. In [28], an e-market framework to identify and integrate information from external sources is discussed. Our work is concerned with the internal information which is observed during argumentation (i.e., the exchanges of arguments and information) between agents. The agent identifies or guesses its opponent agent's internal information during a negotiation for the related models: the needs model, the agreement model or the relationship model. The information based approach is suitable for an agent that works with uncertain and incomplete information [26]. In this work, the information based approach is utilized to cope with uncertain and incomplete information. All the models in the proposed argumentation system are discussed in sections 3.2 to 3.6. An integrated framework for analyzing the exchanged information in historical dialogues, and predicting the opponent agent's behavioural parameters is introduced in section 3.7.

Section 3.2 describes the needs model containing a negotiation object and its need attributes, and the deal space. The needs model also provides a general model for specifying an opponent agent's need details. Section 3.3 describes the opponent agent selection model. The communication model defines the interaction language and protocol between agents as discussed in section 3.4. A brief discussion on the agreement model follows in section 3.5. The agreement model enables agents to establish, modify, and sustain agreements through negotiation and argumentation. It also describes the enactment and evaluation phases of a buying process. The relationship model describes its components (i.e., the dialogue history⁵ and the evaluation database⁶), and

³Internal information is exchanged in the negotiation process.

⁴External information is gathered from external sources.

⁵See section 3.6.1 on page 92.

⁶See section 3.6.2 on page 94.

utilizes them in building trusted trading partnerships (i.e., modeling the strength of business relationships and predicting the selected opponent agent's behavioural parameters). This relationship model is discussed in section 3.6. By using these five models in an integrated framework (see section 3.7 and also chapter 4), the proposed agent (see section 4.5) builds trading relationships and trusted trading partnerships with its opponent agents.

3.2 The Needs Model

A trading agent aims to satisfy a set of needs through argumentation with its opponent agents. The needs model describes how to represent both the agent's needs and its opponent agents' needs. The needs model contains a set of negotiation objects⁷. [107] describes a needs model represented as $v : T \rightarrow \times^n [0, 1]$ where T is time and: $v(t) = (p_1^t, \dots, p_n^t)$ where $p_i^t = \mathbb{P}(\text{need } i \text{ fires at time } t)$ ⁸. When a need fires, the trading agent constructs a negotiation object (see section 3.2.2) having a set of need attributes (see section 3.2.1) that satisfies the need (or requirement) and also constructs a deal space (see section 3.2.3). It then decides which opponent agent to argue with (see the opponent agent selection model in 3.3) and how to argue with the selected opponent agent (see the agreement model in 3.5).

3.2.1 Need Attributes

The negotiation object consists of a set of need attributes, (A_1, A_2, \dots, A_n) . Each attribute is associated with a data type, for example, numeric, range, fuzzy, or boolean. It has a range of values (i.e., $Value_{min} < A_i < Value_{max}$), or a set of numeric values

⁷See definition 3.2 on page 66.

⁸How these needs are activated is not detailed here.

(i.e., $A_i \in \{V_1, V_2, \dots, V_j\}$), or the values from a fuzzy set (i.e., $A_i \in \{F_1, F_2, \dots, F_j\}$). As such, the need attribute is associated with its name, its value types, and its value(s). For example, the attribute quantity may be represented as ($Quantity, Numeric, \{1, 2, 3, 4, 5\}$) in a typical retail business. However, the attribute quantity may also be represented as ($Quantity, Interval, \{100, 200, 300, 400, 500\}$) in the negotiation with a wholesaler.

Definition 3.1. A *Need Attribute* is defined as, ($Name, ValueType, Values$) where $ValueType \in \{numeric, range, fuzzy, boolean\}$ and $Values = \{Value_1[Meaning_1], Value_2[Meaning_2], \dots, Value_n[Meaning_n]\}$.

Here, I present some examples of need attributes. For a typical mechanical device, the speed represents a need attribute and may be defined as ($Speed, Numeric, \{1, 2, 4, 5, 10, 20\}$). Again, the urgent delivery may be represented as ($UrgentDelivery, Boolean\{0[false], 1[true]\}$), the operating mode may be represented as ($Mode, Fuzzy\{1[Local], 2[National], 3[International]\}$) and the years of warranty may be defined as ($Warranty, Numeric, \{1, 2, 3, 4\}$). The negotiation object may be made attractive with the addition of a free item⁹ and represented as a need attribute, e.g., ($FreeItem, Object, \{1[AnyFreeItem], 2[Discount], 3[Delivery], 4[Pineapple], 5[Coupon], 6[Movie], 7[Nothing]\}$).

The need attributes of a negotiation object are categorized into two groups: essential attributes and optional attributes. In this work, a trading agent is allowed to revise the value of an essential attribute in response to a related incoming message. In the case of optional attributes, an extra attribute may be added or removed and values may also be revised. If the agent revises the value of either an essential attribute or an optional attribute, the negotiation object is actually moving from one point to another point

⁹A sample of FreeItem objects (i.e., FreeItem Ontology) is shown in figure A.2 on page 147.

in the deal space¹⁰. When an optional attribute is added or removed, a dimension is added into the deal space or removed from the deal space, and the number of points in the deal space may also increase or decrease respectively. For more on this metaphor for viewing the deal space see [68, 71].

3.2.2 Negotiation Object

In a negotiation, a trading agent describes the details of a given need by a set of attributes. Those attributes refer to the range of issues over which an agreement must be reached [57]. The ability to dynamically specify the structure of a given need provides a wide variety of design choice for inter agent negotiation [57]. A dynamic structure to represent a given need is utilized in this work. Such a dynamic structure of a given need should enable a trading agent to argue with its opponent agents in signing, modifying, or sustaining agreements as discussed in section 3.5. The proposed agent exchanges information with its opponent agents on the attributes of a given need, guesses the values of each attribute of its opponent agent's need, and also predicts the behavioural parameters of its opponent agent.

Definition 3.2. *A **Negotiation Object** specifies the range of issues over which an agreement should be reached for a given need [57].*

In general, a negotiation object is described by a set of need attributes, such as price, quantity, quality, delivery schedule, place of delivery, or a free item. Rather than negotiating for price, a trading agent may also negotiate for a discount on the fixed priced items, e.g., Banana[5K, \$10]+ Discount[10%]. As such, a deal may be represented as Item[essential attributes [,optional attributes]] [+ FreeItem [optional attributes]], e.g., Banana[5K, \$10]+ Movie[1,\$2] represents a deal. In argumentation, a trading

¹⁰See definition 3.3 on page 67.

agent's needs may be modified as an effect of exchanging arguments and information; for example, a new need attribute has been identified, a need attribute is no longer required, or an alternative need has arisen. In order to work with such changing requirements, the proposed agent supports the dynamic structure of a negotiation object.

3.2.3 Deal Space

A deal, or an agreement or contract refers to a pair of commitments between two agents. A trading agent signs an agreement or a deal with its opponent agent that satisfies its need. In a deal or an agreement, two items, x and y are usually exchanged between two agents α and β (i.e., α gives x to β and takes y from β). In a buyer-seller negotiation scenario, such a deal is represented by two commitments, i.e., a seller gives the item, x , and a buyer pays the money, y . For example, a deal consisting of an item[unitprice, quantity] may be represented by two commitments, i.e., a seller gives the specific quantity of items, and a buyer pays the money estimated by unitprice \times quantity.

Definition 3.3. *A Deal Space contains a set of possible deals or agreements that are derived from the specification of a given negotiation object.*

Negotiation can be viewed as a distributed search through a space of potential agreements [57]. A deal space consists of a set of possible agreements or deals from which an agent tries to identify a mutually beneficial deal through negotiation or argumentation with its opponent agent. A deal space is constructed from the chosen negotiation object along with its need attributes and the set of values for each attribute. If two need attributes, A_1 and A_2 have the values $\{u_1, u_2, \dots, u_i\}$ and $\{v_1, v_2, \dots, v_j\}$, then a deal space contains $A_1 \times A_2$ i.e., $\{I(u_1, v_1), I(u_1, v_2), \dots, I(u_i, v_j)\}$ deals. Both essential and optional attributes are used by an argumentation agent while constructing the deal space (see section A.2 and A.6.1 in appendix A).

To illustrate: two essential issues, price and quantity, are utilized in making deals through negotiation dialogues. The deals are constructed from a negotiation object, $\text{Item}[\text{price}, \text{quantity}]$. Let us consider that the possible values for price are \$8, \$10, and \$12 and the possible values of quantity are 1, 5, and 10. A deal space is then constructed that contains $\{\text{Item}[\$8,1], \text{Item}[\$8,5], \text{Item}[\$8,10], \text{Item}[\$10,1], \text{Item}[\$10,5], \text{Item}[\$10,10], \text{Item}[\$12,1], \text{Item}[\$12,5], \text{Item}[\$12,10]\}$. The proposed agent also estimates the probabilities of the opponent agent's contract acceptance, rejection, and breakdown for each deal in the deal space (see section A.6.1 in appendix A for the estimated initial probabilities of an opponent agent's contract acceptance over the deal space). The probabilities of contract acceptance are shown below.

(p, q)	1	5	10
\$8	1	1	1
\$10	1	0.6	0.4
\$12	1	0.4	0.2

If an optional attribute is added, e.g., quality rating $\in \{\text{average}, \text{good}, \text{best}\}$, then the deal space is constructed again. For illustrative purposes only, the modified probabilities of contract acceptance are shown below.

$(p, q,$		$(p, q,$		$(p, q,$							
$r = \text{avg})$	1	5	10	$r = \text{good})$	1	5	10	$r = \text{best})$	1	5	10
\$8	1	0.9	0.8	\$8	1	1	1	\$8	1	1	1
\$10	0.9	0.4	0.3	\$10	1	0.8	0.4	\$10	1	1	0.8
\$12	0.8	0.2	0.1	\$12	1	0.7	0.2	\$12	1	0.9	0.6

3.3 The Opponent Agent Selection Model

When a need is observed, a trading agent determines which opponent agent to argue with. The agent then interacts with the selected opponent agent through argumentation in order to satisfy their needs and also to repeatedly conduct trading activities. It may select an opponent agent randomly from a set of available opponent agents. If an agent is aware of building trading partnerships with its opponent agents then the random selection is not always an appropriate option. A self-interested agent¹¹ evaluates the performance of its opponent agent in the previous commitments and enactments. These two selection methods do not always enable a trading agent to build trading partnerships with its selected opponent agents. For example, there is a possibility that an opponent agent is not selected for a long time using either of these two methods. In order to address the second research question (see section 1.2 for the six research questions), a trading agent should not only consider the performance, but also utilize social factors such as trust, honour, reputation, intimacy, and balance. The agent may utilize these summary measures along with different relationship strategies¹² in selecting its opponent agent for a given need and to repeatedly conduct trading activities.

The opponent agent selection model describes the relevant components and methods in determining which opponent agent to argue with for a given need. In the argumentation system shown in figure 3.1 on page 62, there are two separate histories: the dialogue history and the evaluation database. The dialogue history contains a set of dialogues in the previous interactions between two agents. The evaluation database contains how well trading activities in the historical interactions were conducted in-

¹¹A self interested agent is an agent which mainly considers its own benefits.

¹²See definition 2.9 on page 50.

cluding any deviation between commitments¹³ and their enactments¹⁴. The evaluation database contains the summary of information extracted by the institution agent from the dialogue history. By summarizing the evaluation database and the dialogue history, a trading agent applies different relationship strategies in identifying a suitable opponent agent. Two general approaches in selecting an opponent agent for a given need are identified in addition to the random selection method. The opponent agent selection model is shown in figure 3.2 and these approaches are discussed in sections 3.3.1, 3.3.2, and 3.3.3.

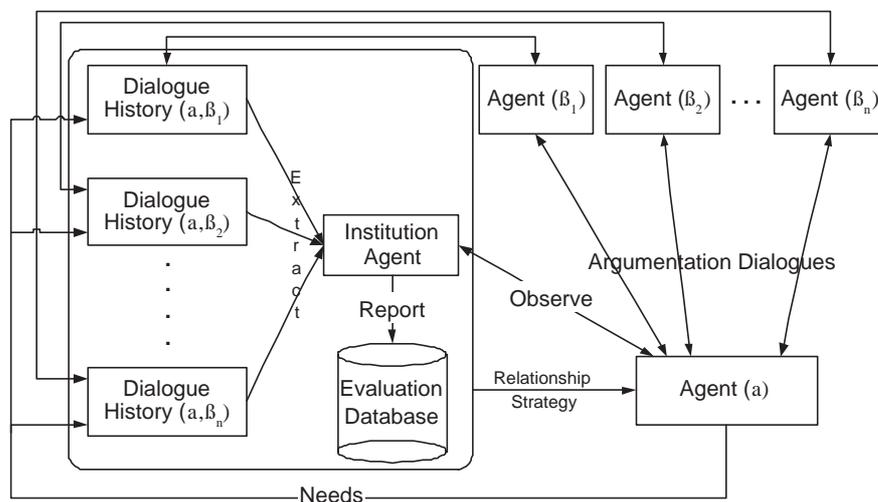


Figure 3.2: The Opponent Agent Selection Model

3.3.1 Random Selection

One simple method is to randomly select an opponent agent with equal probabilities to all available opponent agents i.e., $q_i = \frac{1}{n}$. At the beginning, there is generally insufficient historical dialogue to select the opponent agent. An agent may then consider the random selection as an appropriate option. However, the agent still requires other

¹³See definition 3.4 on page 84.

¹⁴See definition 3.6 on page 88.

methods¹⁵ in deciding which opponent agent to argue with when they have completed a good number of argumentation dialogues. The opponent party (or agent) containing a good history of trades may conduct trading activities better in some dimensions than a new party. A trading agent may give priority to those opponent agents with whom they have observed good experiences in previous interactions. As such, in order to build trusted trading partnerships, the agent should use any experience from the previous interactions and then select an appropriate opponent agent for a given need.

Let us consider that there are n candidate opponent agents, p_i and the corresponding probability to select them in next dialogue is q_i , where $\sum_{i=1}^n q_i = 1$. A trading agent re-generates the distribution, q_i for $i=1,..n$ after completing each dialogue satisfying the constraints $\sum q_i^{new} = 1$. The agent utilizes a revision function to update the probability distribution using an equation inspired by pheromone like model [29]: $q_i = (1 - \tau) \times q_i^{old} + \tau \times q_i^{new}$, where $\tau \in [0, 1]$ is the learning rate. The learning rate depends on the responses received from the selected opponent agent (i.e., its behaviour). Such a revision function assists a trading agent to dynamically select its opponent agent for a given need.

3.3.2 Based on Behavioural Parameters

In the proposed argumentation system, a trading agent aims to satisfy its needs through argumentation and also to build trusted trading partnerships through interactions that happen repeatedly. The result of a successful negotiation is an agreement signed by two parties that satisfies their needs. In this work, a trading agent predicts how the behaviour of its opponent agent might be in the next dialogue by reusing the experience from the related historical dialogues. For example, a failed dialogue with an opponent

¹⁵See section 3.3.2 and section 3.3.3.

agent may still contain a good reason for deciding on a second chance for the selected opponent agent, or a successful dialogue may be a result of a future promise. As such, a trading agent predicts its opponent agent's behavioural parameters, for example, need attributes, contract acceptance criteria, and the degree of cooperation (see section 4.4), by analyzing the historical dialogues.

A trading agent estimates a set of probability distributions (e.g., probability to build and probability to break down) with its possible opponent agents for a given need using a set of summary measures: trust, and honour. In [103], agents estimate these two summary measures from the interaction history. [105] also describes intimacy and balance. These summary measures are discussed in section 2.5.2. In addition, section 2.5.4 introduces the degree of cooperation (i.e., behaviour category of an opponent agent) which may be predicted by analyzing the exchanged arguments and information. The degree of cooperation i.e., behaviour is categorized into three types: opportunistic, strategic, and cooperative behaviour. By analyzing the related dialogues, a trading agent predicts what the future responses of its opponent agent might be, if similar information or arguments are exchanged in the current dialogue. A further discussion on behaviour prediction is presented in chapter 4. The predicted behaviour category (i.e., the degree of cooperation) along with the expected deviations of behaviour (i.e., trust [102, 103]) enable a trading agent to estimate the probabilities to build or breakdown a trading partnership, and then select its opponent agent for a given need (see section 4.2.1). As such, both agents are able to repeatedly conduct trading activities and build trusted trading partnerships.

3.3.3 Based on Performance Parameters

The proposed argumentation system includes the evaluation database (see section 3.6.2 for the structure of the evaluation database). It contains the commitments and subsequent enactments of historical interactions between agents in order to measure a performance parameter. Here, the structure of the evaluation database contains the value of signed commitment and any deviation on its enactment. The institution agent reports the deviation between the signed commitment and subsequent enactment, and updates the evaluation database accordingly. A trading agent then summarizes the performance of similar enactments with a set of available opponent agents and decides which opponent agent to argue with for a given need.

A trading agent summarizes the evaluation database to measure the strength of its business relationship (see definition 3.7 in section 3.6.2) with a set of opponent agents. An opponent agent selection method based on the summary of historical performances such as trading activities categorized across ontology and semantic distance is presented in [52]. That method estimates the strength of business relationships between agents, but does not describe how to improve the strength of business relationship through interactions that happen repeatedly. In order to avoid an unlimited waiting period for an opponent agent, one simple approximation is to choose an opponent agent with the minimum strength of business relationship, when their waiting time exceeds a threshold time limit.

The deviation between a signed commitment and its enactment is measured as a difference between the values of an agreed deal and its enactment. The value of an enactment is also time dependent because a commitment may be enacted over a period of time. The deviation is represented as, $\Delta = V(\textit{commitment}) - V^t(\textit{enactment})$. A transformation function maps the deviation between a signed commitment and its

enactment to a number between $[0,1]$. Usually, less deviation means the transformed value is close to 1 and more deviation means the transformed value is close to 0. One simple approximation may be obtained by, $f(EDB_{\varphi}^{\alpha,\beta_i}.\Delta) = e^{-\lambda\Delta}$, where λ is a decay constant. The institution agent observes and keeps track of $V_{enactment}^t$ and updates any variation in the evaluation database.

The selection of an opponent agent is performed in two steps. First, the list of available opponent agents is narrowed down by a set of eligibility criteria, e.g., select those opponent agents as a set of candidate opponent agents having $Confidence(.)$ ¹⁶ in satisfying need, X is greater than some threshold value, i.e., $Candidate(\alpha, Need(X)) = \{\beta_i \mid \forall_{\varphi \leq Need(X)} Confidence(\alpha, \beta_i, \varphi) > T_c\}$. A trading agent then selects its opponent agent from the set of candidate opponent agents with whom the strength of business relationship has the maximum value, i.e., $Negotiator(\alpha, \rho) = arg \max_i \{strength(\alpha, \beta_i, \{EDB_{item \leq \rho}^{\alpha, \beta_i}\}) \mid \beta_i \in Candidate(\alpha, Need(\rho))\}$. Alternatively, the agent utilizes the predicted behavioural parameters (see section 3.3.2) to select its opponent agent. By using these methods and the relationship aware argumentation framework¹⁷, the proposed agent (see section 4.5) repeatedly conducts trading activities and builds trading partnerships with the selected opponent agent.

¹⁶According to [105], $Confidence(\alpha, \beta_i, \rho)$ is estimated by examining the dialogue history of $\langle reward; accept \rangle$, $\langle threat; \sim accept \rangle$, $\langle inform \rangle$ or any similar sequences from the accepted, rejected, or withdrawn dialogues ranging from an exact item, ontological category, semantic distance of an ontological category or all of the overall items.

¹⁷See section 3.7, for an introduction, and chapter 4 for a further discussion on the relationship aware argumentation framework.

3.4 The Communication Model

In traditional interactions, different communication methods such as letters, fax, telephone, e-mail, or the Internet are supported using a natural language. In an argumentation system, agents restrict their interaction language to two languages: an illocutionary based language for communication, and a probabilistic first-order language for internal representation including the representation of their world model. In this work, a trading agent interacts with its selected opponent agent using a common communication language as discussed in section 3.4.1, and its ontology is discussed in section 3.4.2. Section 3.4.3 then presents a general discussion on protocol, and finally, section 3.4.4 shows how to exchange information within an outgoing utterance and its effect.

3.4.1 Language

A trading agent interacts with its opponent agents by passing information or exchanging proposals and possible agreements. The language is used by the agents to represent the exchanged arguments and information in the dialogues. A general language (\mathcal{L}_S) described here is adapted from the language first reported in [105].

$$u ::= illoc(\alpha, \beta, deal[, info], t) \mid u; u \mid \mathbf{Let} \text{ context } \mathbf{In} \ u \ \mathbf{End}$$

$$deal ::= \text{Item}[\text{essential attributes}[, \text{optional attributes}]] [+ \text{FreeItem}[\text{optional attributes}]]$$

$$\varphi ::= deal \mid term \mid \text{Done}(u) \mid \text{Commit}(\alpha, \beta, \varphi) \mid \varphi \wedge \varphi \mid \varphi \vee \varphi \mid \neg \varphi \mid \varphi = \varphi \mid \forall x. \varphi_x \mid \exists x. \varphi_x$$

$$info ::= \varphi \mid q(\varphi, \varphi) \mid info; info \mid \text{Need}(\varphi) \mid \text{Opponent}(\varphi)$$

$$q ::= \text{“who”} \mid \text{“what”} \mid \text{“why”} \mid \text{“when”} \mid \text{“where”}$$

$$context ::= \varphi \mid id = \varphi \mid prolog_clause \mid context; context$$

Where φ_x is a formula with free variable x , *illoc* is any appropriate set of illocutionary particles, ‘;’ means sequencing, *info* represents any information disclosed or a ques-

tion that describes information yet to be exchanged, *context* represents either previous agreements, previous illocutions, the ontological working context, that is a projection of the ontological trees that represent the focus of the conversation, or code that aligns the ontological differences between the speakers needed to interpret an illocutionary action *u* and *deal* represents an item having a set of essential and optional attributes, and an optional free item with optional attributes. The set *term* contains instances of the ontological concepts and relations.

For example, an offer: “If you buy banana for more than 10K today then I will give you free delivery on any purchase tomorrow” is represented as:

$$\text{Offer}(\alpha, \beta, \text{buy}(\beta, \alpha, \text{Banana}[x, y], y > 10K, \text{today})) \rightarrow \\ \forall z. (\text{Done}(\text{Inform}(\xi, \alpha, \text{buy}(\beta, \alpha, z), \text{tomorrow})) \rightarrow \text{Commit}(\alpha, \beta, \text{Delivery}(z, 0)))$$

In the proposed argumentation system, agents use a set of predefined illocutions. The negotiation illocution particles set as used in [102] are $\{\text{Offer}, \text{Accept}, \text{Reject}, \text{Withdraw}, \text{Inform}\}$. In addition, persuasive illocution particles $\{\text{Reward}, \text{Threat}, \text{Appeal}\}$ are described in [103] for an information based argumentation agent. A few additional illocutions $\{\text{query}, \text{inform}\}$ are also used in [52]. The syntax and semantic meanings of all these illocutions are presented below.

Illocutionary Particles for Basic Negotiation: *Offer-Accept-Reject-Withdraw*

A trading agent exchanges a message with its opponent agent in the form of an illocution(message). A set of illocutions: $\{\text{Offer}, \text{Accept}, \text{Reject}, \text{Withdraw}\}$ are used as basic negotiation illocutions. The agents use these illocutions to make deals without referring to any previous or future dialogue.

- **offer(deal[,info])**. An agent offers a deal to its opponent agent in the form of a proposal. This proposal may be different from the opponent agent’s expected

deal for a given need. The agent may include additional information with the utterance for its opponent agent.

- **accept(deal[,info])**. An agent agrees to its opponent agent's previously offered deal. The agent may include additional feedback information with the utterance for the opponent agent. The feedback contains positive or negative information on the previously offered deal.
- **reject(deal[,info])**. An agent disagrees to its opponent agent's previously offered deal. As with 'accept', the agent may include additional feedback to the opponent agent. The feedback usually contains negative information on the previously offered deal.
- **withdraw(deal[,info])**. By using withdraw illocution, an agent breaks down a negotiation. The agent may also include additional feedback information describing the reason for breakdown, which usually contains negative information on the previously offered deal.

Illocutionary Particles for Argumentation: *Reward-Appeal-Threat*

Argumentation illocutions are used by a trading agent to make deals in a dialogue as well as referring to any previous or future dialogues. In addition to the illocutionary particles used in negotiation, a trading agent utilizes rhetorical illocutionary particles in argumentation.

- **reward(deal[,info])**. A trading agent uses reward with an intention to make its opponent agent accept a proposal with the promise of additional benefits as complements which the opponent agent usually desires. Any additional information in support of the deal can also be given.

- **appeal(deal[,info])**. Appeal illocution is used to make its opponent agent accept a proposal as a consequence of change in belief that the accompanying information might bring about. A trading agent passes additional information in support of a deal. Appeal can be understood as a combination of an offer and an inform.
- **threat(deal[,info])**. By using threat illocution, a trading agent tries to make its opponent agent accept a proposal by committing activities which the opponent agent does not desire. Any additional information in support of the deal can also be exchanged.

Illocutionary Particles for Information Exchange: *Query-Inform*

In order to make an informed decision, a trading agent requires the exchange of information with the selected opponent agent in both negotiation and argumentation. In the proposed argumentation system, agents use illocutionary particles {query,inform} to exchange information (see section 3.4.4 for a further discussion).

- **query(deal[,info])**. A trading agent asks a question to its opponent agent using query illocution. The agent tries to identify detailed information on any previous deal that is offered by either one of them. The agent may also include additional feedback information for the opponent agent. In this instance, the feedback contains positive or negative information on the previous deal.
- **inform(deal,info)**. An agent may respond to any query by using the inform illocution. A trading agent informs its selected opponent agent about any existing interest in making a deal or about any future need.

3.4.2 Ontology

In this work, a trading agent matches its needs having a set of need attributes with the available products and services. The products and services are organized into hierarchical categories that simplify this matching process. In the communication model, the products and services are structured into an ontology. An ontology [62] is a tuple $\rho = (C, R, \leq, \sigma)$ where:

1. C is a finite set of concept symbols (including basic data types);
2. R is a finite set of relationship symbols;
3. \leq is a reflexive, transitive and anti-symmetric relation on C (a partial order)
4. $\sigma: R \rightarrow C^+$ is the function assigning to each relation symbol its arity.

Where \leq is a traditional *is-a* hierarchy, R contains the relations between the concepts in the hierarchy. A number of disjoint *is-a* trees covering different ontological spaces is then required. In this project, two ontologies (i.e., *Item* ontology and *FreeItem* ontology) from [52] are used in different examples and they are also shown in appendix A.1 on page 146.

Semantic Distance

Semantic Distance refers to the notion of the relative or useful distance between concepts. It measures the difference between two concepts within an ontology to evaluate or analyze the exchanged arguments and information in the form of utterances within argumentation dialogues. For example, the deviation between a signed deal and an enacted deal may be measured by utilizing semantic distance. [104, 105, 106] use semantic distance to measure the distance between the concepts in a signed commitment

and its subsequent enactment. [93] defines semantic distance between two concepts in an ontology as:

$$Sim(c_1, c_2) = e^{-k_1 l} \cdot \frac{(e^{k_2 h} - e^{-k_2 h})}{(e^{k_2 h} + e^{-k_2 h})}.$$

Where l is the length of the shortest path between concepts, h is the depth of the subsumed concepts on the shortest path between the two concepts. Here, k_1 and k_2 are parameters scaling the contribution of the shortest path length and depth respectively. This measure of semantic distance is a theoretical and abstract measure of similarity between two concepts. The semantic similarity between two concepts depends on the structure of ontology.

3.4.3 Protocol

A protocol [56] is a formal set of conventions governing the interaction among participants. A trading agent requires a protocol to interact with other agents in an argumentation system. [23] describes an interaction protocol for negotiation to exchange proposals and make deals. In a negotiation, an agent exchanges the proposals with its opponent agent alternatively at successive and discrete times [65]. In a negotiation dialogue, an utterance includes the proposals, exchanged information, accepting a proposal, or rejecting a proposal. In a typical negotiation protocol, agents may exchange proposals using *offer* or exchange information on previous proposals using *query*. Alternatively they inform or make the decision to accept, reject, or withdraw from said negotiation. An agent may try again for alternative deals, if any proposal is rejected in the previous round of interaction. The negotiating agents may use a query-inform cycle which assists them in exchanging information, identifying the need attributes of opponent agents and making a decision to either accept or reject a previously offered

deal¹⁸. If one of them accepts an offer [23], the agents then enter into a commitment. If an offer is rejected, alternative offers are placed in the negotiation or withdrawn from the negotiation.

An argumentation protocol specifies what argumentative illocutions an agent is allowed to say in an argumentation. In the proposed argumentation system, the trading agents communicate using the sentences constructed from the language (see section 3.4.1) and the ontology (see section 3.4.2). In an argumentation dialogue, the utterances contain the exchanged information or arguments related with previous proposals or any future deal. In addition to the functionality supported by a negotiation protocol, the argumentation protocol may refer to any previous illocutions or messages, or a more complex history of messages between agents [88]. A flowchart of an argumentation protocol is shown in figure A.4 on page 150, in which the protocol is used by agents to classify the illocutions into two groups: AIR {accept, inform, reject} and ART {appeal, reward, threat}. A simple strategy is that one agent uses ART illocutions and the opponent agent responds by utilizing AIR illocutions. For example, an agent selects an illocution from the ART group in such a way that the opponent agent accepts, if not informs, and otherwise rejects the deal. The detailed study on argumentation protocol is left for our future work.

3.4.4 Exchanging Information

In a traditional business, two trading parties exchange a $\langle \text{query}; \text{inform} \rangle$ messages sequence between them in identifying and exploring detailed information before signing an agreement. In this work, a trading agent also utilizes such a $\langle \text{query}; \text{inform} \rangle$ utterances sequence in exchanging information with other agents to support or explain their

¹⁸A flowchart of a typical negotiation protocol is shown in figure A.3 on page 149.

previous proposals. The proposed agent utilizes a set of simple questions e.g., {*What, Who, Why, When, Where*} and their answers to exchange information. The exchanged information during the argumentation dialogue is then utilized for the prediction of the behavioural parameters such as need attributes, contract acceptance criteria and behaviour category of an opponent agent. A general form of question and answer that may be used in an argumentation dialogue is question(issue,value). The following table 3.1 gives a few examples of exchanging information by using the form of question(issue,value).

Query or Response	Representation
What do you need?	what(need,item)
I need x.	what(need,x)
Where do you want the delivery?	where(delivery,location)
I want the delivery to my home.	where(delivery,home)
When is the best time for delivery?	when(delivery,time)
The best time for delivery is tomorrow.	when(delivery,tomorrow)

Table 3.1: An Example of Exchanging Information

In a typical argumentation dialogue between a buyer agent and a seller agent, a proposal may be rejected for several reasons. For example, a seller agent does not satisfy the needs of a buyer agent, or a seller agent sends a proposal to a buyer agent but the buyer agent's need has already been satisfied or changed. The agents exchange information in the form of question(issue,value) in identifying and informing the relevant information. Two examples of exchanging information in argumentation dialogues are presented below.

Example 1: If an agent appeals for a delivery schedule of banana.

$$\text{appeal}(\alpha, \beta_i, \text{Banana}[10\text{K}] + \text{Delivery}[t] | \text{Need}(\text{Banana}, \text{Urgent}) \wedge \text{when}(t, \text{today}))$$

In response, the agent, β_i informs *why* the delivery schedule is not today. It is because β_i accepted a deal with another agent and that delivery schedule is today.

$$\text{reject}(\beta_i, \alpha, \text{Banana}[10\text{K}] + \text{Delivery}[t] | \text{why}(t \neq \\ \text{today}, \text{Commit}(\beta_i, \alpha, \text{Item}[-] + \text{Delivery}[\text{today}])))$$

In order to increase the chance of acceptance, the buyer agent may disclose the plan to conduct trading activities with a new seller agent, or conduct trading activities for new items with the current seller agent.

- **Case 1:** If you do not give free delivery for 10K of Banana, I will buy banana from another agent.

$$\text{threat}(\alpha, \beta_i, \text{Banana}[10\text{K}] + \text{Delivery}[t] | \text{who}(\text{Opponent}(\alpha, \text{Banana}[10\text{K}]), \beta_j))$$

From this utterance, the agent α identifies *who* is a competitor agent. In response, the seller agent accepts the deal.

$$\text{accept}(\beta_i, \alpha, \text{Banana}[10\text{K}] + \text{Delivery}[\text{now}])$$

- **Case 2:** If an agent appeals for free delivery and informs another need, and in response the opponent agent accepts because *where* to deliver items and *when* to deliver items and *what* other things are needed are contained in the message,

$$\text{appeal}(\alpha, \beta_i, \text{Banana}[10\text{K}] + \text{Delivery}[t, p] | \text{when}(t, \text{today}) \wedge \text{where}(p, \text{home}) \wedge \\ \text{what}(N_f, \text{Potato}[10\text{K}]))$$

and in response, the seller agent accepts the appeal for free delivery and agrees to deliver at any location and also informs a possible deal for potato.

$$\begin{aligned} & \text{accept}(\beta_i, \alpha, \text{Banana}[10\text{K}] + \text{Delivery}[\text{today}, -] | \\ & \text{inform}(\beta_i, \alpha, \text{Potato}[10\text{K}, \text{price}] + \text{Delivery}[\text{today}, \text{home}])) \end{aligned}$$

Example 2: If an agent offers free delivery of banana.

$$\text{offer}(\alpha, \beta_i, \text{Banana}[10\text{K}] + \text{Delivery}[\text{today}])$$

In response, the opponent agent rejects and explains *why* the offer is rejected. The buyer agent informs the seller agent that an agreement has been signed for banana with another agent.

$$\begin{aligned} & \text{reject}(\beta_i, \alpha, \delta = \text{Banana}[10\text{K}] + \text{Delivery}[\text{today}] | \text{why}(\neg \text{sign}(\delta), \\ & \text{Commit}(\beta_i, \alpha, \text{Buy}(\text{Banana}[10\text{K}]))) \end{aligned}$$

3.5 The Agreement Model

A trading agent interacts with its opponent agent by utilizing the language and ontology as discussed in the communication model to reach mutually beneficial agreement or contract (see section 3.4). The agreement model deals with when the agent signs a commitment(φ). It describes how the agent performs the enactment(φ') of any signed commitment and then evaluates that enactment.

3.5.1 Commitment and Agreement

A trading agent interacts with its opponent agent through argumentation dialogues in order to conduct trading activities. Once the agents accept the terms and conditions of negotiation, commitments are signed.

Definition 3.4. *Commitment* is a promise to undertake a specific course of action [58].

[9] describes commitment as a tendency to engage in consistent lines of activity based on the accumulation of investments that would be lost if the line of activity were discontinued. Some commitments, though, are temporal in nature. Such a commitment usually requires a modification before its enactment; otherwise, a trading agent might know how to enact without modifying that commitment so that the agent continues any existing business relationship with its opponent agent. Joint commitments bind the agents involved to achieving goals or executing actions in the pursuit of a shared goal [81]. When two parties agree to respect their commitments, an agreement or a contract is signed.

An agreement usually contains a pair of commitments. In the proposed argumentation system, a trading agent interacts with its opponent agent through argumentation with a view to sign, modify or sustain an agreement.

Definition 3.5. *An **Agreement** (or A **Contract**) is a pair of commitments $(\varphi_\alpha, \varphi_\beta)$ between two agents, α and β such that both parties agree to enact their commitments after the commitments are signed.*

An agreement or a contract describes how the resources, benefits and burdens in a negotiation are distributed between two parties. Such distributions are based on equity, equality, and need [110]. Equity represents the allocation proportional to the effort, equality represents the allocation in equal amounts, and need represents the allocation proportional to the need for the resource [105]. In a general trading scenario, an agreement between two parties is usually signed based on their own contributions, or equity. In order to build trusted trading partnerships, a trading agent should refer to previous or future agreements with its opponent agent that compensate any equity difference in the current agreement between them. Such compensations assist agents to reach an agreement based on their needs in repeated negotiation encounters.

In the proposed argumentation system, a trading agent interacts with its opponent through argumentation to reach an agreement and then sign the commitments. In other words, one of the two agents accepts a proposal or deal that is offered by another. If a negotiation is completed successfully, i.e., a commitment is signed, the agents then enter into enactment, payment and delivery, and the evaluation phases of a buying process. The institution agent observes and extracts any variation during the enactments of a signed agreement or contract, and reports the findings to the evaluation database¹⁹.

Contract Acceptance Criteria

Contract acceptance criteria describes how an agent determines the acceptance of a contract or an agreement. In the proposed argumentation system, a trading agent predicts the contract acceptance criteria of the selected opponent agent for a given need. It analyzes the exchanged arguments and information and uses entropy based inference to guess unknown values from a set of available values. For example, a simple contract acceptance criterion may be specified as $price \leq \$20$. It also specifies the minimum, maximum, preferred, average, or any acceptable values, and then predicts the contract acceptance criteria of the selected opponent agent.

A trading agent may have preference on the values of each need attributes, but the preferences across the attributes are not considered in this work. A deal space is constructed over the set of need attributes (see section 3.2.3). It is narrowed down by filtering through the contract acceptance criteria. The proposed agent estimates the probabilities of an opponent agent's contract acceptance over the deal space from the predicted need attributes and contract acceptance criteria (see section 4.4.2).

¹⁹It is assumed that the institution agent has functional capabilities of observing, evaluating, and reporting the enactments. See the structure of the evaluation database in section 3.6.2.

A trading agent constructs a set of probability distributions by using the predicted contract acceptance criteria. These distributions include: the opponent agent accepts a proposal, rejects a proposal, or withdraws from a negotiation. A general function²⁰ to estimate the probability of contract acceptance is reported in [106], but other functions may also be used and that is an agent's internal decision. The agent estimates $P^t(\text{satisfy}(\alpha, \chi, \delta'))$ by observing an argumentative dialogue and by measuring semantic distance between an agreement in the incoming utterance and its possible enactment that satisfies a given need. This way, an agent forms a view on which of these criteria is important.

3.5.2 Enactment

In the proposed argumentation system, a trading agent exchanges arguments and information with its opponent agents to conduct trading activities by using the communication model. The agent in [103] extends the capability of a negotiation agent in order to sustain trading relationships. When agents use reward or threat illocutions, they refer to a future instance of time where the reward or threat will be applicable, its scope going beyond the current negotiation round [103]. If a negotiation is completed successfully, two trading agents sign an agreement that consists of a pair of commitments. They then enact the commitments (i.e., an enactment of the signed commitment). For example, two agents, α and β sign an agreement $\delta = (\varphi_\alpha, \varphi_\beta)$, where $\varphi_\alpha \in \mathcal{L}_S$ is α 's commitment and $\varphi_\beta \in \mathcal{L}_S$ is β 's commitment, and the enactment is represented as, $\delta' = (\varphi'_\alpha, \varphi'_\beta)$.

²⁰ $P^t(\text{acc}(\alpha, \chi, \delta')) = g(P^t(\text{satisfy}(\alpha, \chi, \delta')), P^t(\text{obj}(\delta')), P^t(\text{sub}(\alpha, \chi, \delta')))$, where χ represents need, and δ' represents the enactment of δ . The distribution, $P^t(\text{obj}(\delta'))$ represents α 's objective valuation, i.e., δ' is a fair deal against the open market. And, $P^t(\text{sub}(\alpha, \chi, \delta'))$ represents α 's subjective valuation, i.e., δ' is acceptable in α 's own terms.

Definition 3.6. *Enactment* is the performed activities of an agent's (or its opponent agent's) commitment including some (pre-approved) variation.

The agreement model enables an agent to cope with uncertain events or states those may arise due to unknown variables during the signing of a commitment. An agent revises the probabilities in its world model and social model due to any uncertain event or state after the agent has signed a commitment. The enactment of that commitment may be deviated. The agent evaluates its opponent agent's activities after the enactment of the signed commitment²¹. An attempt to analyzing any variation in the enactment, [104] describes a relationship between commitment and enactment in the form of a conditional probability distribution. The agent in [104] estimates $\mathbb{P}^t(\text{Observe}(\varphi') | \text{Commit}(\varphi))$ as $\mathbb{P}^t(\varphi' | \varphi) \in \mathcal{M}^t$ and then revises it as observations are made. A trading agent has two options: modify or sustain an existing agreement in the event of any uncertain events or states.

- **Modify Agreement.** A trading agent exchanges information with its opponent agent during argumentation, and identifies or predicts any internal information about the opponent agent. The agent replaces an existing agreement with a new agreement in order to cope with the identified or predicted information.

$$\text{modify}(\delta, \text{info}) : \text{break}(\delta) \wedge \text{sign}(\delta' \mid \delta' \in \{\mathbf{Let } \textit{info} \mathbf{ In } \delta \mathbf{ End}\})$$

For example, a buyer agent prefers delivery or some other value added item, but a seller requires at least 2 days to organize delivery. A seller agent may find an alternative agreement by modifying a previously signed agreement. An existing agreement, $\delta = \text{Banana}[10\text{K}, \$20, \text{quality}=\text{Top}] + \text{Nothing}[1,0]$ may be replaced by either

²¹The institution agent observes what the trading agents actually do after they have committed.

$$\delta' = \text{Banana}[10\text{K}, \$20, \text{quality}=\text{Medium}] + \text{MovieTicket}[1, \$5], \text{ or}$$

$$\delta' = \text{Banana}[10\text{K}, \$20, \text{quality}=\text{Top}] + \text{Delivery}[1, \$5, \text{DeliveryTime}=2 \text{ days}].$$

Where info=“a buyer agent prefers delivery or a free item” is identified by the seller agent and info=“a seller agent requires at least 2 days to organize delivery” is identified by the buyer agent.

- **Sustain Agreement.** In the event of new information arriving, a trading agent sustains an existing agreement by enacting it without any modification. The agent sustains an existing agreement by offering a future promise or signing an additional agreement. For example, a seller agent is unable to enact an agreement, δ , because the price has been increased after signing the agreement, δ . In response, a buyer agent then informs the seller agent that if the agreement, δ is enacted, the buyer agent will revise the price or look after other issues in the next agreement. It is represented by using an appeal illocution to enact the agreement, δ with a promise.

$$\text{sustain}(\delta, \text{info}) : \text{enact}(\delta \mid \text{promise}(\text{sign}(\delta'))) \wedge \delta' \in \{\mathbf{Let} \text{ info } \mathbf{In} \delta \mathbf{End}\}$$

The argumentative illocutions reward, threat or appeal provide an opportunity for the trading agents to enact a signed commitment and sustain business relationships. The agents use these argumentative illocutions and exchange information so that they sustain an existing agreement as well as future possible agreements. For example, a buyer agent requires delivery of a top quality item, but a seller agent offers delivery of a medium quality item. Here, the buyer agent may use a reward illocution for providing a top quality item by passing on some private information and a seller agent then accepts the requirement of providing free delivery of a top quality item. An argument, reward(deal,info) i.e., reward(Banana[10K,\$20,

quality=Top]+ Delivery[1,\$5], Need(Apple[10K,next week]) is used in this situation. It can be generalized as:

$$\text{sustain}(\delta, \text{info}) : \text{enact}(\delta \mid \text{reward}(\text{sign}(\delta')) \wedge \delta' \in \text{info})$$

Again, a seller agent appeals to give a free pineapple instead of offering free delivery i.e., $\text{appeal}(\text{deal}, \text{info})$, where $\text{deal} = \text{Banana}[10\text{K}, \$20, \text{quality} = \text{Top}] + \text{Pineapple}[1, \$5]$ and $\text{info} = \text{Delivery}[1, \$5, \text{DeliveryTime} = 2 \text{ days} \mid \text{delivery van} = \text{full}]$. Sharing private information during the enactment allows an agent to sustain the agreement. It can be generalized as:

$$\text{sustain}(\delta, \text{info}) : \text{enact}(\delta \mid \text{appeal}(\neg \text{sign}(\delta')) \wedge \delta' \in \text{info})$$

As discussed above, an agreement may be enacted including some variation, pre-approved or otherwise. The proposed agent extracts similar historical dialogues and reuses the extracted information in signing and enacting the commitments. It also exchanges information during the enactment, i.e., payment and delivery of a signed agreement. Such reuses of historical dialogues and exchanges of information minimize those variations in the enactments.

3.5.3 Evaluation

In the proposed argumentation system, a trading agent evaluates how well a commitment is enacted. The agent estimates semantic distance, $\Delta = \text{sim}(\delta, \delta')$ (see section 3.4.2) to measure the deviation between a signed commitment and its enactment. The deviation, Δ is then compared with a threshold variation, ϵ . The function of estimating the semantic distance is defined mainly based on the structure of the negotiation object (see section 3.2.2 for details of negotiation object). It has already been asserted that the negotiation object has two types of need attributes: essential and optional

(also see section 3.2.1). In the proposed argumentation system, semantic distance is represented as, $\text{sim}(\delta[e, o], \delta'[e', o'])$ where, essential attributes must be satisfied i.e., $\text{sim}(\delta[e, -], \delta'[e', -])=0$, but optional attributes may be deviated or partially satisfied i.e., $\text{sim}(\delta[e, o], \delta'[e', o']) \leq \epsilon$. However, a trading agent usually does not disclose the entire need attributes at the beginning of a dialogue.

3.6 The Relationship Model

For a given need, a trading agent interacts through negotiation and argumentation with its opponent agent to reach a mutually beneficial agreement or contract and then conducts other trading activities. These other activities include the enactment, payment and delivery, and finally, evaluation of the enactment. In the proposed argumentation system, the first four models {the needs model (see section 3.2), the opponent agent selection model (see section 3.3), the communication model (see section 3.4), and the agreement model (see section 3.5)} describe how a trading agent conducts the six stages of a buying process. In order to repeatedly conduct these trading activities, a trading agent may utilize the experience from the historical trading activities and then conduct the current trading activities with its opponent agent.

When a new need is observed, a trading agent prepares to participate in a dialogue in order to satisfy the identified need. The agent summarizes the evaluation of the previous enactments in estimating the strength of its business relationships (see section 3.6.2 and 3.6.2). This measure describes a performance parameter of a trading partnership between two agents. In the proposed argumentation system, a trading agent summarizes the interaction history of related trades for a given need and then predict the behavioural parameters of its opponent agent by analyzing the exchanged information and arguments. By predicting the behavioural parameters to some ex-

tent, the agent builds trusted trading partnerships with a set of opponent agents for the enhancement of e-Commerce applications in which trading activities are conducted repeatedly.

3.6.1 The Dialogue History

In this work, a trading agent uses the communication model²² to exchange messages with its opponent agents. The exchanged messages contain the related information, arguments, or any promises made in satisfaction of a given need or a set of related needs. They are organized in the form of a dialogue and preserved in the dialogue history. An element in the dialogue history is represented as a tuple of the form $(sender, receiver, A_{ID}, M_{ID}, I, C, R, t)$, where A_{ID} means an argument identifier, M_{ID} means a message identifier, I means an illocution, C means its content, R means the reliability of (I, C) pair, and t represents time stamp (see section A.6.2 in appendix A for sample data from the dialogue history).

For a given need, a trading agent usually initiates a dialogue by a proposal, and exchanges information and arguments in order to satisfy its given need. The agent evaluates incoming proposals, information or arguments in a dialogue²³ during negotiation or argumentation. A trading agent also measures performance parameters (see sections 3.3.3 and 3.6.2) as the utilitarian measure and predicts behavioural parameters (see section 4.4) as the information measure. The ability to predict such behavioural parameters from the completed dialogues and to summarize the entire dialogue history²⁴ may assist an agent to conduct trading activities in the future.

²²We discuss the communication model in section 3.4.

²³See section 2.5.1 that describes two approaches (i.e., utilitarian measures and information measures)

for the evaluation of information in dialogues.

²⁴See section 2.5.2 for summary measures that are related to this work.

Analysis of the Dialogue History

When analyzing the dialogue history, a trading agent extracts a set of related dialogues with its opponent agent from the dialogue history. When the agent receives an incoming argument or information, any similar arguments or information are extracted from the dialogue history inspired by a case based reasoning [1, 13, 14] approach. The extracted arguments and information are utilized in generating possible responses and continuing interactions in such a way that the agent possibly reaches an agreement or contract and then conducts other trading activities. The agent summarizes historical dialogue in estimating a set of behavioural parameters and also extracts similar arguments or information that may be categorized across illocutions, ontology or semantic distance of a given need. The behavioural parameters include: trust and honour [103], and intimacy and balance [105] (see section 2.5.2 on page 38). In this work, a framework for the prediction of the behaviour category is proposed (see section 4.4).

The exchanged arguments and information in the dialogue history may be reused in similar future dialogues. [51] describes how an agent retrieves the relevant information categorized across illocutions, ontology and semantic distance. In this work, two vectors (see the argument response vector and the exchanged information response vector in section 3.6.3) are constructed by relating the extracted outgoing arguments and information, and its opponent agent's corresponding response from the dialogue history. The proposed agent then reuses the extracted arguments and information to predict behavioural parameters of its opponent agent. The predicted behavioural parameters are utilized by the agent to revise the probability for each response from its opponent agent in the current dialogue. In the evaluation phase of a buying process, an incoming response is compared with the expected response and the outcome is also retained in the evaluation database.

Case based reasoning is utilized to solve a wide range of artificial intelligence problems; for example, comparative shopping [67], conference and fair management [7], mobile environment [84]. [7] shows how context-aware information agents gather relevant information based on a model of the specific interests of user to assist a community of attendees in a big conference and fair. Case based reasoning and multi-agent negotiation are used in [67] to develop a context-aware comparative shopping application for automatically estimating user preferences to determine the best purchase between buyer and seller agents. [84] applies a case based reasoning approach to reason about contextual information in a mobile environment. [53] describes a case based reasoning approach to reason on the extracted contextual information in an e-market scenario. The proposed agent utilizes a case based reasoning cycle to extract, categorize and reason on the exchanged arguments and information.

3.6.2 The Evaluation Database

A trading agent enacts its commitment after that commitment is signed with its opponent agent. The institution agent assists the agent in evaluating the enactment. In this work, the signed commitment and the deviation in the enactment are stored in a database. Similar to the impression database in REGRET [99], the evaluation database (EDB) contains a set of evaluation objects. The *EDB* is used to estimate the strength of business relationships (see definition 3.7 on page 96). For example, a buyer agent, α wants to buy one box of tomatoes from a seller agent, β and uses $EDB_{Tomato}^{\alpha,\beta}$ to estimate the strength of a business relationship. One may estimate the strength of trading relationship by utilizing a set of similar evaluation objects instead of $EDB_{Tomato}^{\alpha,\beta}$. For example, an agent uses $EDB_{item \leq \rho \wedge sim(item, Tomato) \leq \epsilon_s}^{\alpha,\beta}$ to estimate the strength of business relationship.

An evaluation object is represented as a tuple of the form $(\alpha, \beta, A_{ID}, deal_{signed}, deal_{enacted}, D_{value}, t, e_s, \Delta)$ where α, β are agents, A_{ID} means argument (possibly a signed agreement) identifier, $deal_{signed}$ is α 's agreed list of items in the deal, $deal_{enacted}$ are the items that actually received by α from β as part of the enacted agreement, D_{value} represents the value of the transaction that occurs between two agents, e_s represents evaluation sequence, and Δ represents the difference between the values of a signed agreement and its enactment (see section A.6.3 in appendix A for sample data from the evaluation database). An evaluation, $\Delta > \epsilon$ has a negative effect on the strength of trading relationship, and an evaluation, $\Delta \leq \epsilon$ has a positive effect on the strength of trading relationship.

The evaluation database $EDB^\alpha \subseteq EDB$ is a set of evaluations containing signed deals by an agent, α with any opponent agent. $EDB_{item}^\alpha \subseteq EDB^\alpha$ contains the set of evaluations in EDB^α such that $item \in deal_{signed}$. A general form of an evaluation object in EDB_{item}^α is $(\alpha, -, -, \{..., item, ..\}, -, -, -, -)$. Again, $EDB^{\alpha, \beta} \subseteq EDB^\alpha$ represents the set of evaluations in EDB^α where the evaluations are the results of enactments between agents α and β . Again, $EDB_{item}^{\alpha, \beta} \subseteq EDB^{\alpha, \beta}$ describes the set of evaluations in $EDB^{\alpha, \beta}$ in which the evaluations are constructed from the enactments between agents α , and β for $item \in deal_{signed}$. A general form of such an evaluation object in $EDB_{item}^{\alpha, \beta}$ is $(\alpha, \beta, -, \{..., item, ..\}, -, -, -, -)$. The set $EDB_{item}^{\alpha, \beta}$ is also a subset or equals to EDB_{item}^α i.e., $EDB_{item}^{\alpha, \beta} \subseteq EDB_{item}^\alpha$. The method to estimate the strength of trading relationship is discussed below.

Strength of Business Relationship

In an argumentation system, the agents develop different levels of understanding through interactions with one another. A relationship strength refers to the ties between re-

lational partners and reflects their ability in both internal and external challenges to the relationship [50]. They also develop a business network through interactions [24], establishing a trading partnership stronger in one dimension than another. As such, a trading partnership may be more effective in achieving joint result than individual result. In this work, the *strength of business relationship* is utilized to represent the expectation of satisfying the needs between two trading parties and is defined below.

Definition 3.7. *Strength of a Business Relationship* *between two agents for a given need represents a trading agent's expectation from its opponent agent's enactment that satisfies the need, and the expectation is estimated from the evaluation of previous enactments in that business relationship.*

A trading agent uses EDB to estimate the strength of a business relationship with its opponent agent for a given need by using the equation,

$$\text{strength}(\alpha, \beta_i, \varphi) = \frac{\sum_{\Delta \leq 0: EDB_{\varphi}^{\alpha, \beta_i} P_{\beta_i}^t(\varphi \in \text{deal}_{\text{signed}})} + \sum_{0 < \Delta \leq \epsilon: EDB_{\varphi}^{\alpha, \beta_i} P_{\beta_i}^t(\varphi \in \text{deal}_{\text{signed}}) \cdot f(EDB_{\varphi}^{\alpha, \beta_i} \cdot \Delta)}{\sum_{\text{deal}_{\text{signed}}: EDB_{\varphi}^{\alpha, \beta_i} P_{\beta_i}^t(\varphi \in \text{deal}_{\text{signed}})}$$

This equation measures the strength of a trading relationship for a given need describing only a single item. By aggregating the values over a class of similar items e.g., the items φ that belongs to an ontology, ρ , the strength of trading relationship may be estimated as:

$$\text{strength}(\alpha, \beta_i, \rho) = \frac{\sum_{\varphi: \varphi \leq \rho} P_{\beta_i}^t(\varphi) \cdot \text{strength}(\alpha, \beta_i, \varphi)}{\sum_{\varphi: \varphi \leq \rho} P_{\beta_i}^t(\varphi)}$$

Similarly, α 's overall estimate of β_i 's strength is

$$\text{strength}(\alpha, \beta_i) = \sum_{\rho} P_{\beta_i}^t(\rho) \cdot \text{strength}(\alpha, \beta_i, \rho)$$

For example, if an agent, α wants to buy 10K of Banana, α computes $\text{strength}(\alpha, \beta_i, \text{Banana}[10K])$ with a set of opponent agents, β_i where $i \in \{1, 2, \dots, n\}$. The agent, α may

narrow down the set of opponent agent filtering by $Confidence(\alpha, \beta_i, Banana[10K])$ greater than a threshold value, T_c . According to [105], $Confidence(\alpha, \beta_i, \rho)$ is estimated by examining the dialogue history of $\langle reward; accept \rangle$, $\langle threat; \sim accept \rangle$, $\langle inform \rangle$ or any similar sequences from the accepted, rejected, or withdrawn dialogues ranging from an exact item, ontological category, semantic distance of an ontological category or all of the overall items. Again, [103] describes $Build(\alpha, \beta, \rho)$ as “agent α considers agent β to be a potential trading partner for deals in a relationship ρ ” and an agent estimates the probabilities to build a trading relationship, $P(Build(\alpha, \beta, \rho))$. This probability represents the certainty that the agent, α has in a proposition to build a trading relationship with its opponent agent, β .

The value of $strength(\alpha, \beta_i, \rho)$ is the summary of entries in the evaluation database (EDB) across an exact item, ontological category, or semantic distance of an ontological category or all of the overall items. The evaluation database entries correspond to an accepted or offered deal with entries existing in the dialogue history and measured against an agent’s willingness to enact an agreement for similar needs. An agent, α may estimate what happened and then estimate the probability to building a new trading partnership²⁵ from the strength of a trading relationship.

$$P(Build(\alpha, \beta_i, \rho)) = strength(\alpha, \beta_i, \rho)$$

For example,

$$P(Build(\alpha, \beta_i, Banana[10K])) =$$

$$\frac{strength(\alpha, \beta_i, \{EDB_{item=Banana}^{\alpha, \beta_i} \cdot deal_{signed} | deal_{signed} \cdot item \cdot quantity \in [9K - 11K]\})}{}$$

²⁵See section 4.2.1 on page 110 for the probability that a trading agent builds a trusted trading partnership with its opponent agent and also the probability that a trading agent breaks down a trading partnership with its opponent agent.

One may become flexible to build trading partnership by extending the range from [9K-11K] to [5K-15K] .

$$P(\text{Build}(\alpha, \beta_i, \text{Banana}[10K])) = \text{strength}(\alpha, \beta_i, \{EDB_{item \leq \text{Fruit}}^{\alpha, \beta_i} \cdot \text{deal}_{signed} \mid \text{deal}_{signed}.item.quantity \in [5K - 15K]\})$$

Again, an agent, α builds a trading partnership from the historical trades for any types of fruits. The agent, α may then use the following equation,

$$P(\text{Build}(\alpha, \beta_i, \text{Fruit})) = \text{strength}(\alpha, \beta_i, \{EDB_{item \leq \text{Fruit}}^{\alpha, \beta_i} \cdot \text{deal}_{signed}\})$$

An agent, α may also build a trading partnership from the historical trades of any ontological category, ρ , using the following equation,

$$P(\text{Build}(\alpha, \beta_i, \rho)) = \text{strength}(\alpha, \beta_i, \{EDB_{item \leq \rho}^{\alpha, \beta_i} \cdot \text{deal}_{signed}\})$$

Finally, an agent, α builds a trading partnership from the historical trades of any items using the following equation,

$$P(\text{Build}(\alpha, \beta_i)) = \text{strength}(\alpha, \beta_i, \{EDB_{all\ item}^{\alpha, \beta_i} \cdot \text{deal}_{signed}\})$$

3.6.3 Analysis of the Exchanged Arguments and Information

In this work, a trading agent predicts the behavioural parameters of its opponent agent (such as need attributes, contract acceptance criteria, and behaviour category) to some extent by analyzing the exchanged information and arguments, and also by using the summary measures. The agent first initializes the behavioural parameters to their default values and then applies a revision function to update its internal models after receiving any argument and information from its opponent agent²⁶. For example, a car sales agent is interested in identifying the features of a car the customer is looking for

²⁶See section 4.4 on page 121.

from the set of available cars based on customer need, budget, or any other constraints. Alternatively, a home phone service provider agent is interested in identifying and advising a customer which phone deal is beneficial to them based on their usage pattern and their need attributes, e.g., home or evening user, office user, or long distance calls. In this work, a trading agent constructs two vectors by relating the exchanged arguments or information with their corresponding incoming responses.

Definition 3.8. *The **Argument Response Vector** is a vector in which each element is constructed from a dialogue (or a set of related historical dialogues) by relating the outgoing argument with its corresponding incoming response.*

Definition 3.9. *The **Exchanged Information Response Vector** is a vector in which each element is constructed from a dialogue (or a set of related historical dialogues) by relating the exchanged information with its corresponding incoming response.*

In the proposed argumentation system, a trading agent predicts what the possible responses of its opponent agent might be for any similar arguments or information that may be observed in the future. Two vectors, the argument response vector (ARV) and the exchanged information response vector (EIRV), are constructed as part of the analysis of exchanged information and arguments. The analysis of these two vectors is presented in section 4.3 on page 113. Here, few examples are presented to illustrate how the analysis of the exchanged information and arguments is performed by a trading agent.

- **Identification of Need Attributes and Contract Acceptance Criteria from the Incoming Utterance**

A trading agent identifies its opponent agent's need attributes from information within the incoming utterance. For example, a seller agent guesses the need

attributes: quantity=10K as an essential attribute, discount>0 as an optional attribute observed in an incoming utterance=“Is there any discount for 10 K of potatoes?” received from a buyer agent. The seller agent then revises the probabilities, i.e., increases the probability of opponent agent’s contract acceptance, $POppAccept(Potato[10K,-]+Discount[5\%])$ ²⁷ and decreases the probability of opponent agent’s contract acceptance, $POppAccept(Potato[10K,-]+Discount[0])$.

- **Prediction of Behaviour Category from the Argument Response Vector**

An element of the argument response vector (ARV) is represented as ⟨argument; response⟩ pair. For example, ⟨appeal; inform⟩ is an element in the argument response vector. It is constructed from the outgoing utterance=“A buyer appeals to get discount for 10 K of Potatoes” and the incoming utterance=“A seller informs 10% discount for more than 10 K of potatoes, but no discount for 10 K of potatoes”. A seller agent’s response may be utilized in predicting the seller agent’s behaviour. Here, the buyer agent increases the value of $P(\text{behaviour}=\text{“strategic”})$ and $P(\text{behaviour}=\text{“opportunistic”})$ and decreases the value of $P(\text{behaviour}=\text{“cooperative”})$ as an effect of the element in the argument response vector (see section 4.3.2 for a further discussion).

- **Prediction of Behaviour Category from the Exchanged Information Response Vector**

An element of the exchanged information response vector (EIRV) is represented as ⟨information; response⟩ pair. For example, ⟨optional attribute=MovieTicket[\$5];

²⁷The distribution $POppAccept(\alpha, \beta, \delta)$ represents an agent, α ’s estimation on the probability of accepting an agreement, δ by its opponent agent, β . The distribution $POppAccept(\delta)$ is a simplified representation of $POppAccept(\alpha, \beta, \delta)$ between two agents, α and β .

accept) is an element in the exchanged information response vector. It is constructed from the outgoing utterance="A seller offers to give a free movie ticket of value equal to \$5 with a previously offered deal" and incoming utterance="A buyer accepts that deal". A buyer agent's response may be utilized in predicting the buyer agent's behaviour. Here, the seller agent increases the value of $P(\text{behaviour} = \text{"opportunistic"})$ and decreases the value of $P(\text{behaviour} = \text{"strategic"})$ as an effect of the element in the exchanged information response vector and keep unchanged the value of $P(\text{behaviour} = \text{"cooperative"})$ (see section 4.3.3 for a further discussion).

3.7 Introduction to the Relationship Aware Argumentation Framework

The five models of the proposed argumentation system are described in previous sections (from section 3.2 to section 3.6). The relationship aware argumentation framework integrates all the components and their related methods in those models. The framework describes how a trading agent prepares for interactions, analyzes historical dialogues, and predicts behavioural parameters of its opponent agent. The requirements of the relationship aware argumentation framework are identified in section 3.7.1. The framework is further discussed in section 4.1.

Definition 3.10. *A Relationship Aware Argumentation Framework integrates the methods and components in modelling business relationships such that the agent is capable of using these models to enrich its argumentation.*

3.7.1 Requirements

In the proposed argumentation system, a trading agent interacts with its opponent agent to satisfy their needs and to build trusted trading partnerships. The agent analyzes the dialogue history(s) with its opponent agents as part of the preparation for a new dialogue, then signs and enacts the agreements and finally, evaluates the enactments. The information extracted from the dialogue history between the two agents is categorized across illocutions, ontology and semantic distance for a given need. A set of behavioural parameters are then estimated as summary measures from the extracted information. The exchanged information and arguments in the dialogues are utilized for the prediction of how an opponent agent might respond in similar cases. The set of identified components and methods are integrated into the relationship aware argumentation framework (see figure 4.1 on page 108). By utilizing such an argumentation framework, a trading agent repeatedly interacts through negotiation and argumentation with its opponent agent and builds trusted trading partnerships. The functional requirements of the relationship aware argumentation framework are presented below.

- **Preparation.** A trading agent summarizes the dialogue history with a set of available opponent agents, extracts a set of similar dialogues categorized across ontology and semantic distance, and continues the current negotiation in such a way that any existing trading partnership is retained.
- **Analysis.** A trading agent analyzes the effect of the exchanged arguments and information on a new or any ongoing trading partnership. The agent exchanges the arguments and information in such a way that the chance of success in the current negotiation is increased and any existing trading partnership is retained.

- **Prediction.** A trading agent predicts behavioural parameters of its opponent agent in order to minimize uncertainty in conducting trading activities with the selected opponent agent and to build trusted trading partnerships.

3.8 Validation

As described in section 3.1, the proposed argumentation system is defined by a tuple $AS=(\mathcal{N},\mathcal{O},\mathcal{C},\mathcal{A},\mathcal{R})$. To validate the thesis statement, the communication model (\mathcal{C} contains the item and free item ontology (see section A.1 on page 146), protocols (see section A.3 on page 148) has been developed in the prototype argumentation system (see section A.5 on page 151). We then specify the needs model (\mathcal{N} describes the negotiation object and its need attributes), the opponent agent selection model (\mathcal{O} describes the expected performance and behavioural parameters), the agreement model (\mathcal{A} describes how to sign an agreement, when to modify or sustain the signed agreement, and how the evaluation is conducted), and the relationship model (\mathcal{R} contains the dialogue history and the evaluation database, and also estimates the performance and behavioural parameters) of the prototype argumentation system. The prototype argumentation system based on the relationship aware argumentation framework is shown in A.5 on page 151. In the simulation experiments (see section 4.6.1), the trading partnership sets are constructed and their arrival rates are estimated to demonstrate the properties of a trading partnership.

Definition 3.11. *A **Trading Partnership Set** represents a set of opponent agents with whom a trading agent builds a specific form of trading partnership.*

Definition 3.12. *The **Arrival Rate** is defined as the percentage of trading partner agents arrive in (as well as are removed from) a trading partnership set per dialogue.*

In the needs model, an item is randomly selected from Item ontology (see figure A.1) having $\text{unitprice} \in \{1000, 2000, 3000, 4000, 5000\}$ and $\text{quantity} \in \{1, 2, 3, 4, 5\}$ as essential need attributes and $\text{quality} \in \{\text{'good'}, \text{'average'}, \text{'poor'}\}$ as an optional need attribute (see section A.2 on page 147 for the negotiation object and its need attributes). The initial deal space and the probability of an opponent agent's contract acceptance are then estimated and sample estimated values are shown in sections A.6.1 (on page 152) and A.6.1 (on page 152) respectively. In the opponent agent selection model, the threshold values (of strength of relationship, and trust) are chosen from $\{0.2, 0.5, 0.8\}$ to construct the trading partnership sets or trading pacts²⁸ of three sizes i.e., large, medium, and small respectively (see section 4.6 on page 133 for further discussion on validation), and one out of nine opponent agents is then selected. In the agreement model, free items (see figure A.2 on page 147) are used as a promise or a compensation in signing, modifying, or sustaining an agreement, and the difference between the signed deal value and enacted deal value is evaluated. In the relationship model, the probability of building a trading partnership is initially measured from performance (i.e., strength of relationships) and behaviour (i.e., trust) parameters, and then revised by the predicted behaviour categories (i.e., cooperative, strategic, and opportunistic). Finally, the simulation experiments are discussed in section 4.6.1 on page 133.

3.9 Discussion

In this chapter, five models of the proposed argumentation system are discussed and the relationship aware argumentation framework is introduced in order to address the research questions²⁹. The proposed argumentation system makes two significant contri-

²⁸The terms: trading partnership set and trading pact are used interchangeably.

²⁹The research questions are stated in section 1.2.

butions: (i) modelling the strength of relationships; and (ii) predicting the behavioural parameters of the selected opponent agent. In order to build trusted trading partnerships, the methods and components in the five models are integrated into the relationship aware argumentation framework. In the proposed framework, a trading agent summarizes the dialogue history with its opponent agents, extracts and analyzes the exchanged arguments and information, and finally, predicts the behavioural parameters to build trusted trading partnerships (as introduced in section 3.7). Further discussion on the relationship aware argumentation framework is presented in chapter 4.

Chapter 4

Relationship Aware

Argumentation Framework

In chapter 3, an argumentation system is presented that addresses the identified research questions¹. It describes five models (i.e., the needs model, the opponent agent selection model, the communication model, the agreement model, and the relationship model) and introduces the relationship aware argumentation framework. The proposed relationship aware argumentation framework integrates all these models into a complete multi-agent system. By utilizing these models and the framework, a trading agent repeatedly conducts trading activities with a set of opponent agents and builds trusted trading partnerships.

Section 4.1 describes the proposed relationship aware argumentation framework and its functional components (summarizing the history of interactions, analyzing exchanged arguments and information, and predicting behavioural parameters). A detailed discussion of these functional components is then presented in sections 4.2, 4.3, and 4.4. Section 4.5 describes the agent architecture that utilizes the functional compo-

¹The research questions are stated in section 1.2.

nents of the proposed relationship aware argumentation framework and builds trusted trading partnerships with a set of opponent agents. The validation of the thesis is discussed in section 4.6, and finally, section 4.7 concludes this chapter.

4.1 Functional Components of the Relationship Aware Argumentation Framework

In this section, the relationship aware argumentation framework is proposed. It consists of three functional components: preparation for interaction, analysis of the exchanged arguments and information, and prediction of behavioural parameters. As part of the preparation for interaction, a set of summary measures, for example, trust is estimated from the dialogue history and the dialogues are categorized across ontology and semantic distance (within a threshold value) for a given need. Two vectors, the argument response vector and the exchanged information response vector, are then constructed from the completed dialogues. If an existing or new element of the exchanged argument or information is observed in an ongoing dialogue, these vectors are updated. By analyzing the elements of these two vectors, the selected opponent agent's internal parameters (need attributes, contract acceptance criteria and behavioural category) are predicted. In this work, a probabilistic model is utilized for the prediction of behavioural parameters of the selected opponent agent. The proposed framework is shown in figure 4.1.

The proposed relationship aware argumentation framework enables a trading agent² to extract similar arguments and information from the dialogue history, to summarize

²See figure 4.2 of section 4.5 for the integrated agent architecture.

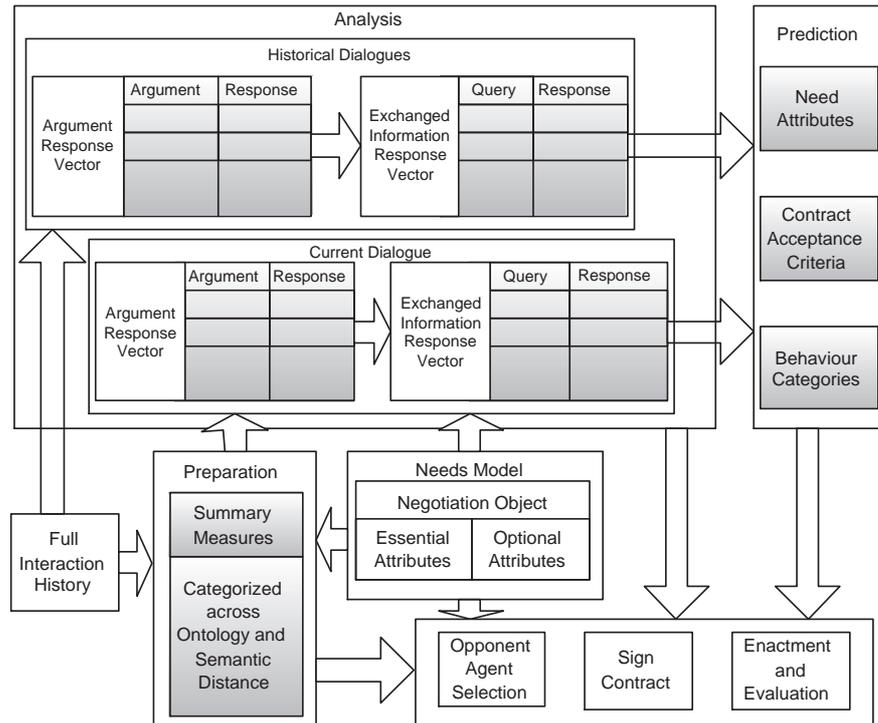


Figure 4.1: The Relationship Aware Argumentation Framework

historical dialogues, and to predict behavioural parameters of the selected opponent agent. The summary measures are utilized for the selection of an opponent agent for a given need. The identification and selection of products and services in satisfying a given need are performed by utilizing the structure of ontology and semantic distance. The framework also supports the prediction of behavioural parameters from the exchanged information and arguments to conduct other trading activities e.g., negotiation to sign an agreement, then the enactment, and its evaluation. By utilizing the functional components of the proposed framework, a generalized solution to the six research questions³ has been achieved.

The proposed relationship aware argumentation framework contains the functional components that are required to build trusted trading partnerships. Figure 4.1 shows

³The research questions are stated in section 1.2.

three functional components of the proposed relationship aware argumentation framework. These components are: preparation, analysis and prediction. By analyzing the dialogue history, the exchanged arguments and information, and any promises made, the proposed framework estimates a set of summary measures, and predicts behavioural parameters of an opponent agent. In this section, a brief discussion of the functional components of the proposed framework is presented. A detailed discussion of these functional components is then presented in section 4.2, 4.3, and 4.4 respectively.

- **Preparing for Interaction.** As part of the preparation, the dialogue history is summarized for a given need. The summary measures include trust and strength of business relationships. A trading agent selects its opponent agent by utilizing these summary measures (see the opponent agent selection model in section 3.3). It then extracts similar experiences from the interaction history across ontology and semantic distance. The need identification, and products and services selection are performed by reusing similar historical experiences. This functional component is further discussed in section 4.2.
- **Analyzing Exchanged Arguments and Information.** In the proposed relationship aware argumentation framework, the arguments and information are exchanged with the selected opponent agent on need attributes, contract acceptance criteria, and also future needs. The framework utilizes a set of questions to exchange information on need attributes and contract acceptance criteria (see section 3.4.4). The exchanged arguments and information with corresponding responses are organized into two vectors, i.e. the argument response vector (ARV) and the exchanged information response vector (EIRV). These two vectors are analyzed for the prediction of need attributes, contract acceptance criteria and

behaviour categories of the selected opponent agent to some extent. This component is further discussed in section 4.3.

- **Predicting Behavioural Parameters.** The probabilities of the selected opponent agent's acceptance or rejection of a proposal, or of withdrawing from a negotiation, or building a trading partnership, are estimated based on the exchanged arguments and information or any promises made, and subsequent observations. This functional component predicts behavioural parameters of the selected opponent agent by analyzing the exchanged arguments and information in similar historical interactions. It enables an agent to work with uncertain and incomplete information where the selected opponent agent's need attributes, behaviour category, and contract acceptance criteria are not known in advance. This functional component is further discussed in section 4.4.

4.2 How to Prepare for Interaction

In the proposed relationship aware argumentation framework, a trading agent prepares for interaction to satisfy a given need by summarizing the historical dialogues. The agent summarizes historical interactions to measure a set of parameters, for example, trust and strength of a trading relationship. It also categorizes the dialogues across ontology and semantic distance. The agent conducts trading activities by utilizing these summary measures and by analyzing the extracted arguments and information categorized across ontology and semantic distance.

4.2.1 Constructing the Social Model

For a given need, the proposed framework describes the construction of the social model before interaction begins. The initial social model is constructed from previous

performances and any opinions⁴ from other agents. Two summary measures, trust and strength of a trading relationship, are initially estimated from the dialogue history and revised if new information is received from the selected opponent agents or other sources. Trust refers to an expected deviation of the other agent's behaviour in a dimension [102, 103], and strength of trading relationship refers to a summary measure of the evaluation of the enactments between two agents [52]. These two summary measures are utilized to construct initial distributions, such as probability to build a trusted trading partnership, and probability to breakdown a trading partnership. They represent the ability and willingness properties of an existing trading partnership. As such, if trust and performance of an opponent agent are high, then the probability to build a trading partnership is high.

$$PBuild(\beta_i, \delta) = k_1 \times Trust(\beta_i, \delta) + (1 - k_1) \times strength(\alpha, \beta_i, \delta)$$

Where, k_1 , and $1 - k_1$ are two constants that represent the weights of trust and the strength of a relationship. If trust is low and performance of an opponent agent is also low, then the probability of the breakdown of a trading partnership is high.

$$PBreakdown(\beta_i, \delta) = k_2 \times [1 - Trust(\beta_i, \delta)] + (1 - k_2) \times [1 - strength(\alpha, \beta_i, \delta)]$$

These summary measures are utilized by the opponent agent selection model (see section 3.3). The opponent agent selection model generates a list of candidate agents and then selects an opponent agent to interact with. The values of trust and strength of a trading relationship provide a general indication of an opponent agent's possible future behaviour. These summary measures also assist the interaction between agents in an environment which is uncertain and dynamic. The estimation of the summary measures across ontology and semantic distance are discussed below.

⁴The summary of other agents' opinions is measured as reputation [27]. We assume that an agent knows how to collect opinions and measure reputation.

Ontology and Semantic Distance

Historical dialogues are categorized across ontology and semantic distance rather than by utilizing the entire dialogue history for the summary measures. It has already been described in the needs model (section 3.2) that the products and services are organized into a hierarchy of ontological categories. For a given need, related historical interactions are extracted based on the current need, an ontological category of the current need, and also semantic distance that is less than a threshold value. The summary measures are applied to construct the probabilities or revise an agent's social and world model.

Ontological category:

$$PBuild(\beta_i, \delta) = k_1 \times Trust(\beta_i, \delta \leq \rho) + (1 - k_1) \times strength(\alpha, \beta_i, \delta \leq \rho)$$

$$PBreakdown(\beta_i, \delta) = k_2 \times [1 - Trust(\beta_i, \delta \leq \rho)] + (1 - k_2) \times [1 - strength(\alpha, \beta_i, \delta \leq \rho)]$$

Ontological category and semantic distance:

$$PBuild(\beta_i, \delta) = k_1 \times Trust(\beta_i, \delta' \leq \rho' \mid \delta \leq \rho \wedge sim(\rho, \rho') \leq \epsilon) +$$

$$(1 - k_1) \times strength(\alpha, \beta_i, \delta' \leq \rho' \mid \delta \leq \rho \wedge sim(\rho, \rho') \leq \epsilon)$$

$$PBreakdown(\beta_i, \delta) = k_2 \times [1 - Trust(\beta_i, \delta' \leq \rho' \mid \delta \leq \rho \wedge sim(\rho, \rho') \leq \epsilon)] +$$

$$(1 - k_2) \times [1 - strength(\alpha, \beta_i, \delta' \leq \rho' \mid \delta \leq \rho \wedge sim(\rho, \rho') \leq \epsilon)]$$

A trading agent prepares for interaction by summarizing and categorizing the historical dialogues and constructing a set of probability distributions, such as the probability to build or breakdown of a trading partnership. The agent having any uncertain and incomplete information performs the product selection by utilizing the extracted arguments and information categorized across ontology and semantic distance. The

probability distributions assist the opponent agent selection model i.e., merchant brokering of a buying process. Once an opponent agent is selected and a range of available products have been identified, the trading agent then identifies any similar arguments and information in order to reuse the experiences from the dialogue history. The agent then negotiates with the selected opponent agent to satisfy a given need from a range of identified products and services. The next section 4.3 analyzes the exchanged arguments and information in utterance sequences in both the dialogue history and the current dialogue.

4.3 How to Analyze the Exchanged Arguments and Information

In the proposed relationship aware argumentation framework, a trading agent constructs two vectors to analyze the exchanged arguments and information. These two vectors are: the argument response vector (ARV) and the exchanged information response vector (EIRV). An element of the ARV is represented as $\langle \text{argument}; \text{response} \rangle^5$. It indicates how the selected opponent agent may behave in related future dialogues. Again, an element in the EIRV is represented as $\langle \text{query}; \text{response} \rangle$ and illustrates the exchanged information about a question⁶ and its corresponding response. It also contains behavioural parameters of the selected opponent agent. By extracting the exchanged arguments and information and their corresponding responses from the dialogue history, the proposed agent constructs the argument response vector (ARV) and the ex-

⁵If a language (see the communication model in section 3.4) for interaction between two agents has m argumentative illocutions out of total n illocutions, then $m \times n$ different $\langle \text{argument}; \text{response} \rangle$ elements are possible to exist in the ARV.

⁶The question tags include who, what, why, when, where, and how.

changed information response vector (EIRV). The proposed framework then predicts behavioural parameters of the selected opponent agent (see section 4.4).

A trading agent exchanges arguments by using a set of illocutions (see section 3.4.1) and also exchanges information by using a set of question tags, such as who, what, why, when, where, and how (see section 3.4.4). An utterance containing an argument describes a need attribute, contract acceptance criteria or behaviour of the selected opponent agent. For example, a buyer agent requires an item, a seller agent needs to obtain payment, a buyer agent requires a specific value regarding a need attribute, a seller agent wants timely payment, a buyer agent wants timely delivery, a seller agent wants to make an extra charge for delivery, and so on. In general, an agent discloses these arguments or information to another agent from which the behavioural parameters may be predicted. In this section, a few examples are presented to illustrate how the proposed agent predicts the need attributes and contract acceptance criteria of its opponent agent, and also predicts the opponent agent's behaviour.

4.3.1 Extracting the Exchanged Arguments and Information

The dialogue history is an internal source of information from which the selected opponent agent's behaviour may be predicted. An incoming utterance usually contains the behavioural parameters e.g., need attributes, and contract acceptance criteria of the opponent agents. An outgoing utterance influences the selected opponent agent to sign an agreement, or to disclose need attributes and contract acceptance criteria.

- **Example 1: Incoming Utterance**

From an incoming utterance, an agent identifies the opponent agent's need attributes. For example, an incoming utterance⁷ *“Is there any discount for 10 bags*

⁷Here, plain English text is used to describe an utterance instead of using the language in section

of potatoes?” assists a seller agent to identify the need attributes of the buyer agent as {quantity=10 bags, Discount, $Y>0$ }. $POppAccept$ (Potato[quantity=10 bags, discount=0]) (i.e., probability of an opponent agent accepts an agreement is decreased due to the incoming utterance.

- **Example 2: Outgoing Utterance**

A seller agent constructs an outgoing utterance describing need attributes or contract acceptance criteria which influences the opponent agent to sign an agreement having those attributes or criteria. For example, an outgoing utterance “*A seller agent gives discount for 10 or more bags of potatoes.*” indicates that the seller agent influences the buyer agent to sign an agreement, δ having need attributes {quantity=10 bags, Discount ($Y>0$)} and estimates $POppAccept(\delta)\approx 1$.

For a given need, a trading agent reuses the experience in constructing an outgoing utterance in response to an incoming utterance. The agent extracts a set of similar utterances from the dialogue history with its opponent agent, e.g., $D_{accepted}(\beta_i, \alpha) = \{\delta | (\beta_i, \alpha, \mu(\text{accept}, \delta)) \in \text{Dialogue History}\}$ and may reuse similar utterances in future dialogues. It may give priority to one of the previously accepted deals that are extracted from the dialogue history. Such reuses of historical information increase the chance of success in an argumentation dialogue and possibly improve the strength of the trading relationship between agents.

In the communication model (see section 3.4 on page 75), an approach to exchanging information such as a set of questions {‘*who*’, ‘*what*’, ‘*why*’, ‘*when*’, ‘*where*’} with two parameters (i.e., issue, value) are discussed. The use of question and answer simplifies how a trading agent extracts the exchanged arguments and information from the dialogue history. For example,

- “*Who* offered a similar deal for a given need?” is extracted from the set, $\{\beta_i | \text{offer}(\delta') \in \mu(\beta_i, \alpha, \dots) \wedge \text{sim}(\delta, \delta') \leq \epsilon \wedge \text{item} \in \delta\}$.
- “*What* were the alternative acceptable deals to the opponent agent?” is extracted from the set, $\{\delta' | \text{accept}(\delta) \in \mu(\beta_i, \alpha, \dots) \wedge \text{sim}(\delta, \delta') \leq \epsilon \wedge P(\beta_i, \alpha, \delta') \approx 1\}$.
- “*Why* was a deal rejected?” is extracted from the set, $\{\text{reason} | \text{reject}(\text{deal}, \text{info}) \in \mu(\beta_i, \alpha, \dots) \wedge \text{why}(\text{reason}) \in \text{info}\}$.
- “*When* was a deal accepted?” is extracted from the set, $\{\text{deadline} | \text{inform}(\text{deal}, \text{info}) \in \mu((\alpha, \beta_i, \dots) \wedge \text{when}(\text{deadline}, \text{time}) \in \text{info} \wedge \text{accept}(\text{deal}) \in \mu'(\beta_i, \alpha, \dots))\}$.
- “*Where* was an item delivered?” is extracted from the set, $\{\text{location} | \text{item} \in \delta \wedge \text{where}(\text{delivery}, \text{location}) \in \mu\}$.

The meaning of an utterance is sometimes related to the previous utterances in a dialogue. In this work, a trading agent realizes the contextual meaning of two consecutive utterances in a dialogue for the prediction of behavioural parameters of its opponent agent. Two vectors i.e., the argument response vector (see section 4.3.2) and the exchanged information response vector (see section 4.3.3) are constructed to modelling the contextual meaning of utterance sequences. The prediction of behavioural parameters from the exchanged arguments and information assist a trading agent to repeatedly conduct trading activities and also to build trusted trading partnerships.

4.3.2 Analyzing the Argument Response Vector

In the proposed framework, a trading agent constructs the argument response vector (ARV) containing a set of outgoing arguments and incoming responses with the selected opponent agent. An element of the ARV is constructed from a sequence of two utterances in the dialogues between two agents. A trading agent utilizes the ARV vector to

predict its selected opponent agent's need attributes, contract acceptance criteria and behaviour.

Example 1: A dialogue between a buyer agent and a seller agent contains an outgoing argument “a buyer agent appeals to get discount for 10 bags of potatoes because it will buy potatoes again” and the incoming response “a seller agent offers to give 10% discount for more than 10 bags of potatoes, but no discount for 10 bags of potatoes”.

The observed parameters are:

- Need Attributes

The predicted need attributes of the seller agent are {price=\$10/bag, quantity=10 bags, Discount[Y=0]}.

- Contract Acceptance Criteria

The predicted contract acceptance criterion of the seller agent is {quantity>10 bags→ Discount[Y=10%]} i.e., the seller agent will give 10% discount for more than 10 bags of Potatoes.

- Behaviour

The seller agent prefers to sign an agreement with a large quantity of potatoes.

The probability of the seller agent's behaviour may be revised as: cooperative(p_1) will decrease, strategic(p_2) will increase and opportunistic(p_3) will increase.

Example 2: A dialogue between a seller agent and a buyer agent contains an outgoing argument “a seller agent gives 10% discount if quantity is more than 10 bags of potatoes, but no discount for 10 bags of potatoes” and the incoming response “a buyer agent rejects, but wants discount for 10 bags of potatoes”. The observed parameters are:

- Need Attributes

The predicted need attributes of the buyer agent are {quantity=10 bags, price=\$10/bag, Discount[Y>0]}.

- Contract Acceptance Criteria

The predicted contract acceptance criterion of the buyer agent is {quantity=10 bags \rightarrow Discount[Y>0]} i.e., buyer agent wants discount for 10 bags of potatoes.

- Behaviour

The buyer agent is trying to get discount for the desired product. The probability estimation for the buyer agent's behaviour may be revised as: if strategic (p_2) will increase then opportunistic(p_3) will decrease and vice versa, but cooperative(p_1) may remain unchanged.

The probability that an element of the argument response vector may be observed in the current negotiation, $p_{x \in ARV}$ is measured from the entire dialogue history or categorized across ontology and semantic distance. The behaviour classification matrix (see section A.4 on page 150) is then consulted in determining the probability distribution of the behaviour categories ($p_{x \in ARV, b}$) for each element in the argument response vector. The opponent agent's behaviour is then measured as a summary (weighted average, $\sum_{all\ x \in ARV} p_x \times p_{x, b}$) of behaviour categories from all the elements of the ARV.

4.3.3 Analyzing the Exchanged Information Response Vector

In the proposed framework, a trading agent constructs the exchanged information response vector containing the exchanged information and corresponding responses. The agent analyzes the exchanged information response vector to predict the selected opponent agent's need attributes, contract acceptance criteria and behaviour.

Example 1: A seller agent exchanges information within an outgoing message “a seller agent gives free movie ticket of value equal to \$5 with the previous deal” and receives the corresponding response “a buyer accepted the deal” from a buyer agent. Assuming that the seller agent’s previous deal was an offer of 5% discount on its price, the observed parameters are:

- Need Attributes

The predicted need attribute of the buyer agent is {Movie Ticket, Value=\$5}. It is an optional need attribute.

- Contract Acceptance Criteria

The predicted contract acceptance criterion of the buyer agent is, ‘Discount is not more important than other optional need attributes, like a movie ticket’.

- Behaviour

The buyer agent accepts the deal with an optional need attribute. The probability estimation for the buyer agent’s behaviour categories is revised. One of the two behaviour categories, $cooperative(p_1)$ and $opportunistic(p_3)$, will increase and another will decrease, but $strategic(p_2)$ may remain unchanged.

Example 2: A seller agent exchanges information within an outgoing message “a seller agent gives free movie ticket of value equal to \$5 with the previous deal” and receives the corresponding response “a buyer agent asks what else may be chosen having the equal value of a movie ticket” from a buyer agent. The observed parameters are:

- Need Attributes

The buyer agent does not consider a movie ticket as an optional need attribute.

- Contract Acceptance Criteria

The predicted contract acceptance criterion of the buyer agent is, ‘There may be some other optional need attributes which are more preferable than a movie ticket’.

- Behaviour

The buyer agent does not accept the deal with an optional need attribute. The probability estimation for the buyer agent’s behaviour is revised as: $\text{cooperative}(p_1)$ and $\text{opportunistic}(p_3)$ will decrease, $\text{strategic}(p_2)$ will increase.

Example 3: A buyer agent exchanges information within an outgoing message “a buyer agent asks what else could be chosen having the equal value of a movie ticket” and receives corresponding response “a seller agent agrees to give 5% discount” from a seller agent. The observed parameters are:

- Need Attributes

The seller agent can give 5% discount.

- Contract Acceptance Criteria

The seller agent’s contract acceptance criteria: Discount can be exchanged with other free items.

- Behaviour

The seller agent accepts the deal with 5% discount. The probability estimation for the seller agent’s behaviour is revised as: $\text{cooperative}(p_1)$ will increase, and $\text{strategic}(p_2)$ and $\text{opportunistic}(p_3)$ will decrease.

The probability that an element of the exchanged information response vector may be observed in the current negotiation, $p_{x \in EIRV}$ is also measured from the entire dialogue history or categorized across ontology and semantic distance. The behaviour

classification matrix (see section A.4 on page 150) is then consulted in determining the probability distribution of the behaviour categories ($p_{x \in EIRV, b}$) for each element in the exchanged information response vector. The opponent agent's behaviour is then measured as a summary (weighted average, $\sum_{all\ x \in EIRV} p_x \times p_{x, b}$) of behaviour categories from all the elements of the EIRV.

4.4 How to Predict the Behavioural Parameters

In the proposed relationship aware argumentation framework, a trading agent predicts the behavioural parameters of its opponent agent. The behavioural parameters include need attributes, contract acceptance criteria, and behaviour categories. Two vectors, the argument response vector and the exchanged information response vector (see section 4.3.2 and 4.3.3), are utilized in modelling the relationship between an outgoing utterance (i.e., argument and exchanged information) and its corresponding incoming utterance. In the previous section 4.3, how to extract the exchanged arguments and information, and how to exploit the two vectors are discussed. The proposed agent sends a message to its opponent agent and then observes what response is received. It observes and measures the variation between the estimated parameters and the observed actions by the selected opponent agent. The behavioural parameters are initially guessed, and then revised as an effect of that variation.

The proposed agent estimates the probability of behaviour categories from a set of pre-defined reasons behind the elements in the ARV and the EIRV (represented as a classification matrix, see section A.4), any existing relationships, and the entire dialogue history. For a given need, if a sufficient number of elements do not exist in the two vectors, the agent constructs the vectors from the related dialogues categorized across ontology and/or semantic distance. The proposed framework utilizes a probabilistic

model such as entropy based inference for the prediction of behavioural parameters of the selected opponent agent. The behaviour prediction method is a significant contribution in argumentation towards repeatedly conducted trading activities and building trusted trading partnerships.

4.4.1 Predicting the Need Attributes of an Opponent Agent

In the proposed argumentation system, a trading agent specifies its given need by utilizing a negotiation object⁸. For example, a typical negotiation object is described by a set of need attributes, such as price, quantity, delivery time, delivery location, and colour. The agent categorizes these need attributes as essential need attributes (e.g., price and quantity) and optional need attributes (e.g., delivery time or location, and colour). An opponent agent may disclose the values of its need attributes in the form of arguments, or related information, but not all the need attributes are necessarily disclosed in a dialogue. The proposed framework analyzes the exchanged arguments and information in predicting a set of acceptable values or ranges for each need attribute.

In this work, a trading agent first guesses the opponent agent's values $N(u, ARV, EIRV)$ of each need attribute, from the first incoming utterance (u), the argument response vector (ARV) and the exchanged information response vector ($EIRV$). It then constructs the deal space⁹ by utilizing the values of each need attribute. The agent also estimates the probability of contract acceptance by its opponent agent (see section 4.4.2). Finally, it revises the uncertainty of those predicted values as the effect of subsequent incoming utterances, or any new element into these vectors. The following example shows that the agent initially guesses, and then revises, the uncertainty of the values of each need attribute from the exchanged arguments and information.

⁸See section 3.2 on page 64.

⁹See section 3.2.3 for a discussion on the deal space.

$$\text{Offer}(\alpha, \beta, \delta[\text{unitprice}=\$10, \text{quantity}>10])$$

$$\text{Query}(\beta, \alpha, \delta[\text{colour} \in \{\text{What are the available colours?}\}])$$

After receiving the above *query*, agent α identifies that agent β gives priority on some specific colour and guesses that β prefers one of {"Red", "Green", "Blue"} colours rather than "White" with uncertainty e.g., $u=0.8$. The agent α then generates a response to the previous query as,

$$\text{Inform}(\alpha, \beta, \delta[\text{colour}=\text{"White"}, \text{unitprice}=\$10] \vee$$

$$\delta[\text{colour} \in \{\text{"Red"}, \text{"Green"}, \text{"Blue"}\}, \text{unitprice}=\$12])$$

And, α received a response from β as,

$$\text{Appeal}(\beta, \alpha, \delta[\text{colour} \in \{\text{"Red"}, \text{"Green"}, \text{"Blue"}\}, \text{unitprice}=\$10] | \text{quantity}=20)$$

Here, agent α identifies that agent β needs the item δ having one of {"Red", "Green", "Blue"} colour, and also needs 20 units of δ . The agent α also identifies that the previous assumptions on the need of β 's colour was appropriate and reduces uncertainty, $u_{new} = \tau \times u_{old}$, where τ is the learning rate (or the uncertainty reduction rate) as an effect of new information, e.g., $u_{old}=0.8$, $\tau=0.75$, and $u_{new}=0.75 \times 0.8=0.6$. Otherwise, the previous assumptions were inappropriate and the uncertainty increases.

4.4.2 Predicting the Contract Acceptance Criteria by an Opponent Agent

In general, a trading agent has incomplete information about its opponent agent's need attributes, contract acceptance criteria, and behaviour category. For example, a buyer agent does not know the minimum acceptable price and product delivery schedule of a seller agent, and a seller agent does not know the behaviour category (i.e., cooperative,

strategic or opportunistic) of a buyer agent. The agents exchange information and arguments to justify their positions, e.g., which need attributes will be partially satisfied, which optional attributes may be exchanged with other optional attributes, or which need attributes will never be satisfied. The proposed framework utilizes a probabilistic model that works with incomplete and uncertain information. It analyzes the incoming utterances (u), the argument response vector (ARV), and the exchanged information response vector ($EIRV$) for the prediction of need attributes, contract acceptance criteria and behaviour (see section 4.3). The prediction of an opponent agent's need attribute is discussed in section 4.4.1. The prediction of contract acceptance criteria, $C(u, ARV, EIRV)$ by an opponent agent is discussed below.

Single Issue

In a dialogue, a trading agent usually starts negotiation with unknown values of its opponent agent's negotiation parameters (e.g., need attributes or contract acceptance criteria). A set of probability distributions (e.g., contract acceptance by an opponent agent, $POppAccept(\cdot)$, or contract rejection by an opponent agent, $POppReject(\cdot)$, or withdrawal from a negotiation, $PWithdraw(\cdot)$) are utilized to guess an opponent agent's need attributes or contract acceptance criteria. The trading agent estimates an initial value by analyzing the similar historical dialogues or guesses an initial value in the case of insufficient historical dialogues. For example, the initial offer may contain the default value of a colour attribute, e.g., Offer(α, β, δ [unitprice=\$10, quantity>10, colour="White"]). The agent α estimates the initial acceptance probabilities by an opponent agent for the four colours {"White", "Red", "Green", "Blue"} are:

$$POppAccept(\alpha, \beta, \delta[\text{colour}=\text{"White"}])=0.8$$

$$POppAccept(\alpha, \beta, \delta[\text{colour}=\text{"Red"}])=0.8$$

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"Green"}])=0.8$$

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"Blue"}])=0.8$$

After receiving the $\text{Query}(\beta, \alpha, \delta[\text{colour} \in \{\text{"What are the available colours?"}\}])$ from β , agent α identifies that agent β gives priority on some specific colour. The agent α guesses that agent β prefers one of $\{\text{"Red"}, \text{"Green"}, \text{"Blue"}\}$ colour over "White" . The agent α revises the probabilities of the four contract acceptance criteria and then sends an outgoing response to β , e.g., $\text{Inform}(\alpha, \beta, \delta | \text{colour} \in \{\text{"Red"}, \text{"Green"}, \text{"Blue"}\} \wedge \text{unitprice}=\$12)$. In this case, the values of the four probabilities are revised by a revision function. A sample revision function inspired by a pheromone like model [29] is: $p_{revised} = \lambda \times p_{old} + (1 - \lambda) \times p_{observed}$, where λ represents the learning rate. The revised values of the contract acceptance probabilities, $C(u, ARV, EIRV)$ are:

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"White"}])=0.4$$

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"Red"}])=0.9$$

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"Green"}])=0.9$$

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"Blue"}])=0.9$$

Multi Issue

Here, a negotiation object is described by two or more issues (e.g., colour and price). In the following example, an agent α has the initial values for the 4 acceptance probabilities of a colour attribute and the 3 acceptance probabilities of a price attribute. These probabilities are:

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"White"}])=0.8$$

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"Red"}])=0.8$$

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"Green"}])=0.8$$

$$\text{POppAccept}(\alpha, \beta, \delta[\text{colour}=\text{"Blue"}])=0.8$$

and

$$POppAccept(\alpha, \beta, \delta[\text{price}=\$8])=0.85$$

$$POppAccept(\alpha, \beta, \delta[\text{price}=\$10])=0.8$$

$$POppAccept(\alpha, \beta, \delta[\text{price}=\$12])=0.7 \text{ respectively.}$$

While estimating the contract acceptance probability of any need attribute, a trading agent utilizes the default values of other need attributes. In this example, price=\$10 is used as the default value for $POppAccept(\alpha, \beta, \delta[\text{colour}=c])$ and colour="White" is used as the default values for $POppAccept(\alpha, \beta, \delta[\text{price}=p])$ probabilities. The agent then estimates the probability, $POppAccept(\alpha, \beta, \delta[\text{price}=p, \text{colour}=c])$ as joint probability i.e.,

$$POppAccept(\alpha, \beta, \delta[\text{colour}=c, \text{price}=p]) = \frac{POppAccept(\alpha, \beta, \delta[c, p_d]) \times POppAccept(\alpha, \beta, \delta[c_d, p])}{POppAccept(\alpha, \beta, \delta[c_d, p_d])}.$$

The agent constructs the initial value of the contract acceptance probabilities as,

Colour vs Price	\$8	\$10	\$12
White	0.85	0.8	0.7
Red	0.85	0.8	0.7
Green	0.85	0.8	0.7
Blue	0.85	0.8	0.7

If agent β asks for an alternative colour, $Query(\beta, \alpha, \delta[\text{What are the available colours?}])$, then the agent α guesses that agent β gives priority on one of {"Red", "Green", "Blue"} colours than "White" and revises

$$POppAccept(\alpha, \beta, \delta[\text{colour}=\text{"White"}])=0.8$$

$$POppAccept(\alpha, \beta, \delta[\text{colour}=\text{"Red"}])=0.9$$

$$POppAccept(\alpha, \beta, \delta[\text{colour}=\text{"Green"}])=0.9$$

$$POppAccept(\alpha, \beta, \delta[\text{colour}=\text{"Blue"}])=0.9$$

The agent then revises the contract acceptance probabilities, $C(u, ARV, EIRV)$ as,

Colour vs Price	\$8	\$10	\$12
White	0.85	0.8	0.7
Red	0.95625	0.9	0.7875
Green	0.95625	0.9	0.7875
Blue	0.95625	0.9	0.7875

The agent revises the contract acceptance probabilities having two or more attributes after exchanging any relevant arguments or information. It uses the following steps in the revision.

1. Revise the element(s) directly affected by an incoming argument or information.
2. If element $p_{i,j}$ is revised in step 1, then revise the elements in the i th row and j th column.
3. Revise all other elements that are related with the revised elements in the previous two steps.

4.4.3 Predicting the Behaviour Category of an Opponent Agent

The proposed framework summarizes the dialogue history by measuring the trust and strength of business relationships, and also categorizes the dialogue history across ontology and semantic distance (see section 4.2). It then analyzes the exchanged argument and information (see section 4.3), and predicts the selected opponent agent's need attributes (see section 4.4.1) and contract acceptance criteria (see section 4.4.2). It may be possible to learn or measure the expected behaviour of the selected opponent agent to some extent from a sequence of utterances between two agents. In this section, a

probabilistic model is discussed that predicts the behaviour category of the selected opponent agent.

In this work, a trading agent utilizes the elements of the argument response vector (ARV) in deciding a set of possible arguments. It also utilizes the exchanged information response vector (EIRV) in deciding similar outgoing utterances. The agent generates a response argument to sign an agreement in the short term and to build trusted trading partnerships in the long term. It observes whether the opponent agent is responding as planned or not. The agent then measures any deviation between the observed response and the estimated response and revises the probability distributions that are related to the deviation.

The proposed agent retrieves the initial probabilities of behaviour categories from the institution agent¹⁰. It revises these probabilities when a related argument or information is received. For example, a trading agent informs its opponent agent about an urgent need. The opponent agent has chosen one from three options i.e., (i) asking for higher price, (ii) informing any hidden defect in the current stock and advising to wait until the next stock becomes available, or (iii) giving priority to a specific deal over a set of alternative deals based on other need attributes. These three options may be classified as opportunistic, cooperative and strategic behaviour categories respectively (see section 2.5.4). The proposed agent revises the probabilities depending on which option the selected opponent agent has applied. We have identified 4 phases in the behaviour prediction method. These are:

- Behaviour prediction from the argument response vector,
- Behaviour prediction from the exchanged information response vector,

¹⁰It is assumed that the institution agent maintains the repository containing an ideal probability distribution for each element in the ARV and the EIRV. See section A.4 on page 150.

- Behaviour prediction from the entire dialogue history, and
- Behaviour prediction from the historical dialogues categorized across ontology and/or semantic distance.

Probability Estimation

- The initial probabilities of behaviour categories may be estimated from uniform distribution. Alternatively, one can use other initial probabilities¹¹ for cooperative(p_1), strategic(p_2), opportunistic(p_3), where $p_1 + p_2 + p_3 = 1$.
- A trading agent predicts the behaviour of its opponent agent from 4 layers. The layers are: exchanged arguments(p^a), exchanged information(p^i), overall(p^o), and categorized across ontology and semantic distance(p^c). In the last two layers, the probability is estimated as a summary of the behaviour categories from the elements in the ARV and the EIRV. If the initial values for these four layers are Strategic(p_2^a), Strategic(p_2^i), Opportunistic(p_3^o), and Cooperative(p_1^c) then the opponent agent's predicted behaviour pattern is represented as *SSOC* along with its probability value, $B(p_2^a, p_2^i, p_3^o, p_1^c)$.
- If n is the number of behaviour types in a layer then n^1 , n^2 , n^3 , and n^4 are the number of behaviour patterns having 1, 2, 3, and 4 layers respectively.

¹¹The maximum entropy inference approach enables an agent to estimate the probability distributions from available information and possibly incomplete information [23].

Probability Revision

- The probabilities of behaviour categories are revised¹² by a classification matrix¹³ of the exchanged arguments and information. For example, if the probability of a behaviour category is increased by X due to the exchange of arguments and information with the selected opponent agent, the probability of two other behaviour categories should be decreased by Y and Z respectively, such that $Y + Z = X$. A simple approximation may be obtained by using $Y = Z = X/2$.
- A set of similar behaviour patterns e.g., *SCOS*, *SSOS*, *SOOS* are revised together as an effect of the exchanged arguments or information on these behaviour patterns. If cooperative behaviour type is observed in the exchanged information response vector, new values for each probability will be: $B(p_2^a, p_1^i[\text{new}], p_3^o, p_2^c) = B(p_2^a, (p_1^i + X), p_3^o, p_2^c)$, $B(p_2^a, p_2^i[\text{new}], p_3^o, p_2^c) = B(p_2^a, (p_2^i - X/2), p_3^o, p_2^c)$, and $B(p_2^a, p_3^i[\text{new}], p_3^o, p_2^c) = B(p_2^a, (p_3^i - X/2), p_3^o, p_2^c)$.

4.5 Agent Architecture

This section presents the proposed relationship aware argumentation agent architecture (see figure 4.2). The proposed agent architecture extends the information based agent in [104]. Similar to the agent in [104], the proposed agent also constructs the social model and the world model by utilizing entropy-based inference¹⁴. Maximum entropy

¹²The principle of minimum relative entropy chooses the revised distribution that has the least relative entropy with respect to a given prior distribution and that satisfies the other constraints [102].

¹³See section A.4 on page 150 for the classification matrix.

¹⁴Entropy-based inference is a form of Bayesian inference that is convenient when the data is sparse [18] and encapsulates commonsense reasoning [82].

inference¹⁵ is used in estimating the initial distribution and minimum relative entropy inference¹⁶ is utilized in revising the probability distributions. The proposed agent (see figure 4.2) is developed by integrating the proposed relationship aware argumentation framework (see figure 4.1) with the simplified view of a relationship aware argumentation agent (see figure 2.4). Figure 4.2 shows the proposed agent architecture¹⁷.

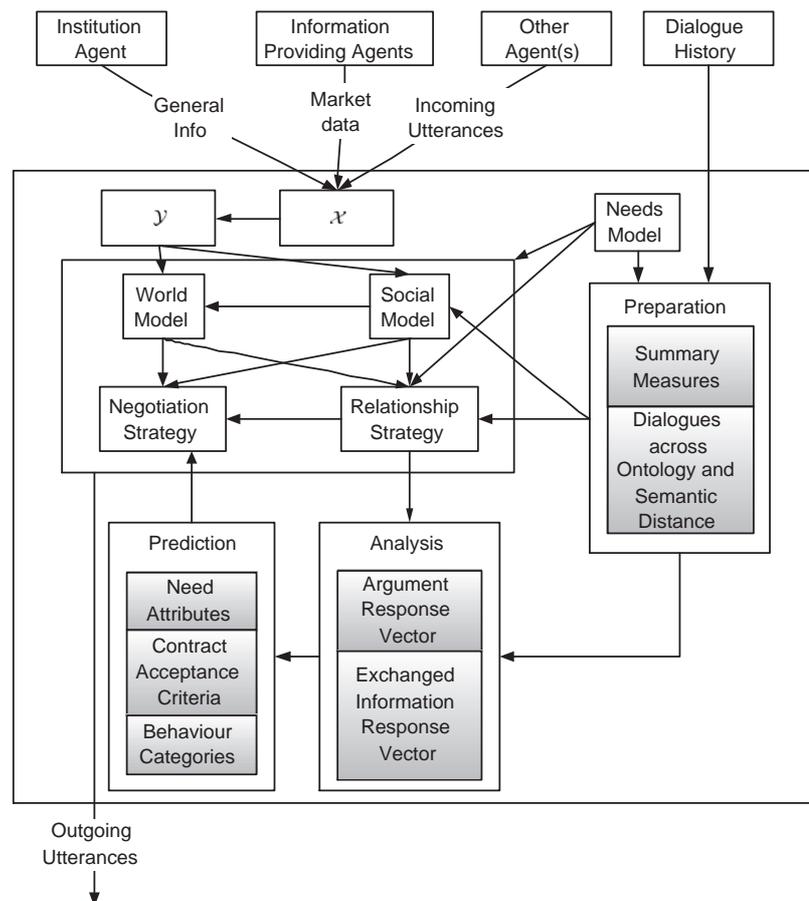


Figure 4.2: The Proposed Relationship Aware Argumentation Agent Architecture

¹⁵Unknown probability distributions are inferred using maximum entropy inference [73] that is based on random worlds [48].

¹⁶The principle of minimum relative entropy is a generalization of the principle of maximum entropy [25].

¹⁷In figure 4.2, the symbols \mathcal{X} , and \mathcal{Y} represent in-box, and repository respectively.

A typical buying process begins when a need is observed. The argumentation system as described in chapter 3 specifies how a trading agent conducts trading activities in satisfying its needs with the support of the five models and the framework. The proposed relationship aware argumentation framework describes how a trading agent extracts, summarizes and estimates a set of performance and behavioural parameters from the dialogue history (see section 4.1). The proposed agent conducts pre-negotiation activities (e.g., product selection and merchant selection) using the summary measures of historical dialogues categorized across ontology and semantic distance¹⁸. It then argues to satisfy a given need by analyzing the exchanged arguments and information, and predicting the behavioural parameters. Finally, the proposed agent conducts the payment and delivery phase, and then evaluates how the payment and delivery phase has been conducted in satisfying a given need.

The framework describes how to predict the behavioural parameters (e.g., need attributes, contract acceptance criteria and behaviour category) of the selected opponent agent. A negotiation strategy utilizes the summary measures (e.g., strength of a trading relationship, $strength(\alpha, \beta_i, \rho_u)$) and the predicted parameters, (i.e., need attributes $N(u, ARV, EIRV)$, contract acceptance criteria $C(u, ARV, EIRV)$, and behaviour category $B(p^a, p^i, p^o, p^c)$) to generate an outgoing utterance (including the expected responses), $u' = \text{Argue}(u, strength(\alpha, \beta_i, \rho_u), N(u, ARV, EIRV), C(u, ARV, EIRV), B(p^a, p^i, p^o, p^c))$ and to reach a mutually beneficial agreement (see e.g., [104] for a related discussion on negotiation strategies), and also to retain the expected behaviour. By integrating the components (the summary measures, extracted and categorized information and

¹⁸For example, the relationship strategy utilizes the estimated parameters in selecting an opponent agent to argue with for a given need and recommends the expected behaviour (similar to negotiation target in [105]).

predicted behavioural parameters) of the relationship aware argumentation framework, the proposed agent is able to maintain a necessary level of trust in an existing trading partnership and repeatedly conducts trading activities with other agents.

4.6 Validation

This section validates the thesis statement, “Modelling the strength of relationships between agents and predicting the behaviour of trading partner agents in a multi agent argumentation system enables agents to build trusted trading partnerships”. Section 4.6.1 describes the experiments that are conducted to validate the thesis. The stability of any trading partnerships is measured by an arrival rate estimator [2]. The prototype argumentation system (see section 3.8 of page 103 for the specification of the five models, and section A.5 of page 151 for a sample interface screen) has been developed to conduct the experiments. A life test on the three sizes (e.g., small, medium, and large) of trading partnership sets is conducted. The arrival rate estimator indicates how stable the life of a trusted trading partnership is. The simulated arrival rate obtained by the proposed model is comparable with an existing model (Trust and Honour model [103]). By utilizing the two parameters (i.e., the strength of business relationships and the predicted behaviour), the proposed agent maintains a trusted trading partnership set¹⁹ containing n out of m trading agents.

4.6.1 Experiments

In the experiments, nine buyer agents interact with a seller agent. The buyer agents are categorized into three groups: cooperative, strategic, and opportunistic. Each

¹⁹If there are m opponent agents from which an agent α maintains a trading partnership of size n then there will be ${}^m C_n = \frac{m!}{n!(m-n)!}$ possible trading partnership sets.

group has three buyer agents. A buyer agent's behaviour is categorized by a probability distribution i.e., $\text{cooperative}(p_1)$, $\text{strategic}(p_2)$, and $\text{opportunistic}(p_3)$, where $p_1+p_2+p_3=1$. For example, an agent shows cooperative behaviour in generating any outgoing response, if the value of $\text{cooperative}(p_1)$ is greater than both $\text{strategic}(p_2)$, and $\text{opportunistic}(p_3)$. The seller agent predicts behavioural parameters of the opponent agents by analyzing the interaction history, exchanged information, and any promises made.

A trading partnership has two properties. These properties are: (i) the opponent agent demonstrates the ability to continue similar trades, and (ii) the opponent agent demonstrates the willingness to continue similar trades. In addition to these two properties, a trusted trading partnership has another property. The third property represents that an agent maintains a necessary level of trust with the opponent agent. The purpose of the experiments is to validate these properties. The experiments are:

- **Experiment 1: Behaviour Prediction.** This experiment is conducted to validate the property (i) of a trading partnership. It also validates the third property of a trusted trading partnership. The proposed trading agent predicts the behavioural parameters of an opponent agent by analyzing their interaction history, exchanged information, and any promises made. It selects those opponent agents whose trust values are at least at the minimum threshold level and having a specific behaviour category. In this test, the trust level indicates that the opponent agents demonstrate the ability to conduct similar trading activities, and the predicted behaviour category indicates that the selected opponent agent has maintained a necessary level of trust in successive negotiation rounds with the proposed agent.

- **Experiment 2: Strength of Relationship.** In this experiment, a trading agent identifies those opponent agents with whom the strength of a trading relationship has reached at least a minimum threshold value. The purpose of this experiment is to validate the property (ii) of a trading partnership. The strength of a trading relationship is measured as the expectation of enactments i.e., any commitments or promises made. The proposed agent continues the existing trading partnership with the opponent agents who demonstrate willingness to conduct trading activities on related products and services in the future negotiation.

Methodology

In this work, a prototype argumentation system has been developed using java programming language. In the prototype system, the simulation of the two experiments has been conducted. One seller agent and nine buyer agents conduct trading activities using the proposed model and also an existing model (trust and honour model [103]). In the experiments, the initial dialogue history contains 100 dialogues²⁰ for each buyer agent with the seller agent. The trust and the strength of a trading relationship are measured from the initial dialogue history. The seller agent and the selected buyer agent then argue with each other in order to satisfy their needs. In each dialogue, the seller agent predicts the behavioural parameters of the selected buyer agent. After the simulation terminating condition has been satisfied, the arrival rate is estimated for each experiment. The arrival rate is also measured for the intersection of the two sets. The arrival rate in the later case represents the average stability of an opponent agent in a trusted trading partnership set. We found that the proposed agent maintains a

²⁰The initial dialogues are generated by using uniform distributions on the item ontology and the deal space over the selected negotiation object.

lower arrival rate in the trading partnership set²¹ than that of an existing trust and honour model [103]. The methodology is shown in figure 4.3.

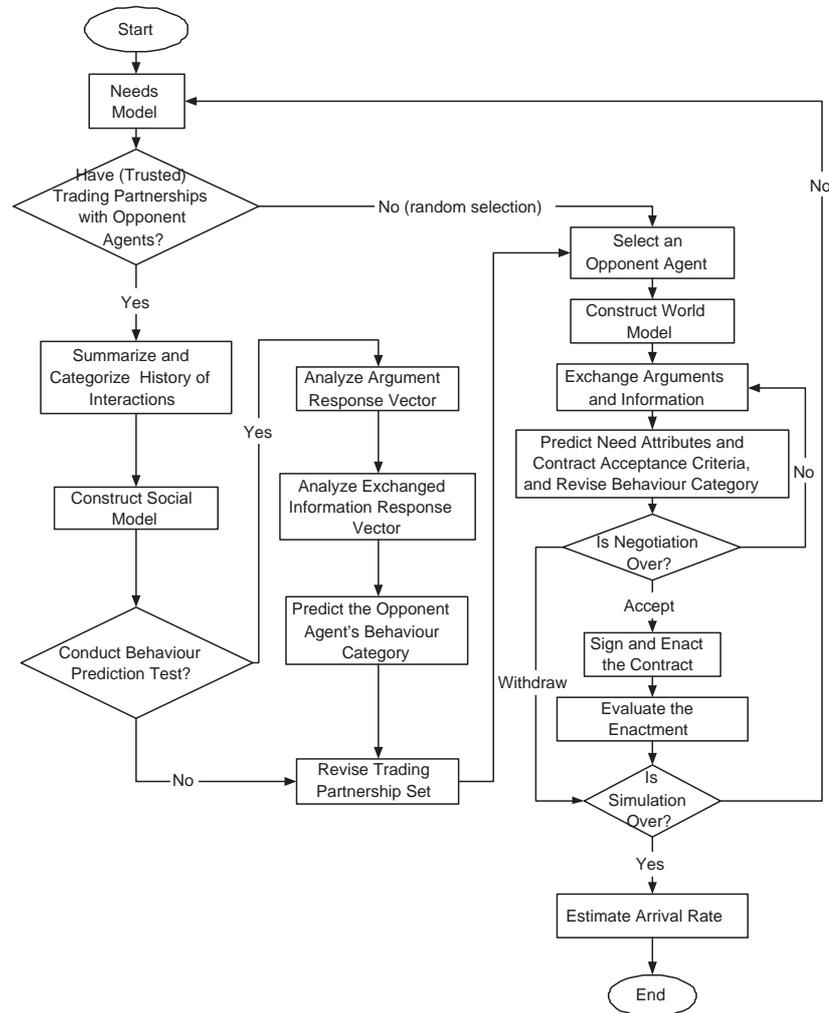


Figure 4.3: The Simulation Methodology

Arrival Rate Test

Each time a dialogue is completed, the proposed agent revises the social model. As an effect, one or more trading partners may be removed from the trading partnership set, and the same number of trading partners may be included in the trading partnership

²¹Two exceptions are observed in the table 4.1 on 137. These are for the size of a trading partnership set equals to one and nine.

set. The arrival rate is defined as how many trading partner agents arrive in (as well as are removed from) a trading partnership set per dialogue. The arrival rate is measured by the equation, $\frac{\sum_{i=1}^L |X_{new}^i \setminus X_{old}^i|}{L \times N} \times 100$, where L represents the number of completed dialogues and N represents the size of a trading partnership set. It generally represents how stable a trading partnership set is. Any change in the partnership set means that a number of agents do not survive the arrival rate test. A higher value means that a trading agent changes the members of a trading partnership set in most of the dialogues. A low value means that a trading agent does not change the trading partnership set frequently, or the trading partnership set is stable²² enough to resist its partner agents' departure. Any change in the partnership set means that a number of agents do not survive the arrival rate test. The arrival rate test results are shown in table 4.1. A sample estimation is shown in section A.6.4 on page 156.

Size of Trading Partnership Set	The Proposed Model	The Trust and Honour model
1	88%	81%
2	69%	72%
3	47%	51%
6	43%	49%
9	0%	0%

Table 4.1: The Arrival Rate Test Results

Graphical Interpretation

In the experiments, the opponent agents are moving in the trading partnership set or moving out from the trading partnership set. The average amount of time, an opponent

²²Here, the stability of a trading partnership set = (100 - The arrival rate)%.

agent resides in the trading partnership set is measured by the arrival rate estimator. By modelling the strength of relationships and predicting the behaviour of opponent agents, the proposed agent maintains two sets of opponent agents. The opponent agents in one set demonstrate the ability and also have developed a necessary level of trust as indicated by the trust measure (initially) and predicted behaviour category (in successive negotiation rounds). The opponent agents in another set demonstrate the willingness to conduct similar trading activities as indicated by the strength of a business relationship.

The proposed relationship aware argumentation framework maintains a trading pact at an intersection of the above two sets. The strength of relationship test enables the proposed agent to construct different sizes (from 1 up to 9) of trading partnership sets. The predicted behaviour category enables the proposed agent to construct a trading partnership set of size equal and up to the actual number of available opponent agents having the same behaviour category. Two trading partnership sets and their intersection are graphically shown in figure 4.4.

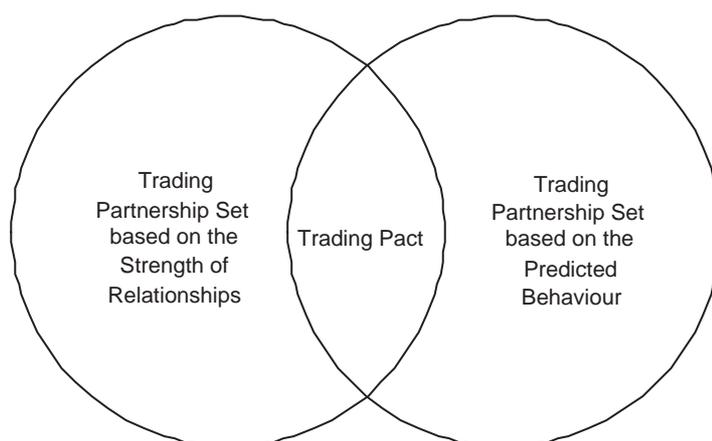


Figure 4.4: The Trusted Trading Partnership Test

In the experiments, a number of opponent agents (1, 2, or 3 agents) have been removed from the trading partnership set and also the same number of opponent agents have been added to the trading partnership set. The proposed agent ecologically increases the value of trust with its opponent agent on the related dimensions as an effect of a successful dialogue. In the case of insufficient historical dialogues (at the system starting time, i.e., the size of initial dialogue history ≤ 100), a trading agent may use reputation measures in generating a short list of opponent agents and then select an opponent agent randomly. In conclusion, the proposed agent builds a trusted trading partnerships with a set of opponent agents because it is possible to manage a trading partnership set by controlling the threshold values of the strength of relationships or behavioural parameters.

4.7 Discussion

In the proposed argumentation system, a trading agent conducts trading activities through the exchanges of arguments and information in order to satisfy its given need. When a buyer agent satisfies the terms of an agreement (e.g., payment on time, or ignoring minor defects), the seller agent evaluates that buyer agent as a candidate member of a trading partnership set and vice versa. In other word, the relationship aware argumentation framework facilitates the trading agent in conducting all phases of a general buying process. The proposed agent repeatedly interacts with other agents, measures performance parameters and predicts behavioural parameters of its opponent agent, and finally, builds trusted trading partnerships.

This chapter has described the components of the proposed relationship aware argumentation framework. Two major contributions, namely, the strength of a business relationship and the prediction of behavioural parameters are integrated into the pro-

posed framework. The framework summarizes interaction histories, analyzes the exchanged arguments and information, and any promises made. The integrated agent architecture is proposed based on information based agency [104]. Finally, this chapter validates the thesis.

Chapter 5

Conclusion and Future Work

This dissertation establishes the thesis statement, “Modelling the strength of relationships between agents and predicting the behaviour of trading partner agents in a multi agent argumentation system enables agents to build trusted trading partnerships”. The proposed (multi agent) argumentation system describes the five models and the relationship aware argumentation framework by analyzing the dialogue history, exchanged information, and any promises made. In the proposed argumentation system, a trading agent interacts with a set of opponent trading agents to conduct trading activities (e.g., negotiation, sign and enact agreements for a set of related products and services, payment and delivery, and evaluation) and builds trusted trading partnerships. This dissertation makes the following contributions in the research area of argumentation systems.

- The five models (i.e., the needs model, the opponent agent selection model, the communication model, the agreement model, and the relationship model) of the proposed argumentation system specify the general requirements of an e-Commerce application to conduct trading activities (e.g., need identification, product selection, merchant brokering, negotiation, payment and delivery, and

evaluation). By integrating these models, the relationship aware argumentation framework describes how a trading agent builds trusted trading partnerships.

- The relationship aware argumentation framework analyzes the history of interactions, the exchanged information and arguments, and any promises made. It describes how a trading agent predicts the selected opponent agent's behaviour categories (i.e., cooperative, strategic, and opportunistic) from the exchanged arguments and information. The prediction of behaviour categories assists a trading agent to cope with uncertain and incomplete information in building trusted trading partnerships.
- The relationship aware argumentation framework is integrated with information based agency. The proposed agent maintains two sets of trading partner agents by utilizing the strength of business relationships and the predicted behaviour. The stability of a trading partnership set is measured by the arrival rate estimator.
- The idea of constructing two vectors (i.e., the argument response vector and the exchanged information response vector) significantly extends the fields of argumentation and data mining. These two vectors supply timely and relevant information at the right granularity level to the proposed agent. They extend the field of information supply and discovery technologies.
- The proposed agent uses simple mathematical equations (a simplified version of entropy based inference) for the prediction of behavioural parameters e.g., need attributes, contract acceptance criteria, and the degree of cooperation (i.e., behaviour categories) and ecological emulation. Maximum entropy inference is utilized for the estimation of the initial distributions, and minimum entropy distribution is used for the revision of those distributions.

- A prototype simulation environment has been developed to conduct a set of experiments and to validate the thesis statement. The simulation experiments for the validation of the thesis statement show that the calculated arrival rate of the trading partnership set constructed by the proposed agent is less than that of an existing model (Trust and Honour Model [103]). By modelling the strength of trading relationships and predicting the behavioural parameters (e.g., need attributes, contract acceptance criteria and behaviour categories) from the exchanged arguments and information, the proposed agent builds trusted trading partnerships. The proposed argumentation system is a unique and significant contribution that enables a trading agent to repeatedly conduct trading activities and build trusted trading partnerships. The prototype system is a useful tool for conducting further experiments as introduced in section 5.1.

In this work, an argumentation system is proposed that addresses the identified research questions¹. This work presents the relationship aware argumentation framework that enables the proposed agent to build trusted trading partnerships. The need for further work to be carried out is introduced in section 5.1.

5.1 Future Work

In order to build trusted trading partnerships, the five models and the framework are described in this dissertation. The proposed framework analyzes the dialogue history, exchanged information, and any promises made. The proposed agent evaluates the historical performance, and predicts the behavioural parameters in conducting trading activities with the selected opponent agent. Due to the usual constraints of a Ph.D. project, some important application issues have been left for future work. These are:

¹The research questions are identified in section 1.2.

- The proposed argumentation system describes the five models in an attempt to conduct trading activities of a general buying process. The general requirements of an argumentation system is specified by the five models. The proposed argumentation system utilizes both the existing parameters (e.g., trust) and the proposed parameters (strength of a relationship and predicted behaviour of an opponent agent). In future, we will continue our work on other related research questions, such as applying different argumentation protocols, formal approach to signing an agreement, enactment and evaluation and the feasibility of applying the predicted behavioural parameters to commercial applications.
- The proposed agent negotiates with the selected opponent agent by utilizing the predicted behavioural parameters. The behaviour category of an opponent agent is determined as the degree of cooperation, i.e., cooperative(1), strategic(0.5), and competitive(0) by utilizing entropy based inference. We will conduct further work to compare the results obtained from entropy based inference with the same of empirical method, and also how to converge the behaviour category of an opponent agent from competitive towards cooperative. An opponent agent's behavioural parameters may be changed by the exchanged arguments and information. The strategies for exchanging arguments and information that enable a trading agent to show dynamic behaviour will be investigated.
- In the prototype argumentation system, the summary measures - trust, and strength of business relationship - are initially utilized as a behavioural parameter and a performance parameter respectively. Other available measures (e.g., intimacy and balance [105], and reputation [27]) will be integrated with the prototype to conduct trading activities (e.g., the dependency between intimacy and

trusted trading partnerships, and the effect of balance in developing trusted trading partnerships) before application to commercial systems.

- The prototype argumentation system demonstrated a proof of concept. The prototype will be further developed for an e-Commerce application domain before applying the proposed argumentation system in commercial applications. We will further integrate the proposed argumentation system with 3-D virtual institutions [12] which will enhance the user experience in repeatedly conducted trading activities.
- The models are presented in the conceptual level. The models will be further developed formally by providing mathematical definitions and their properties. The formally defined models will facilitate to mathematically validate the thesis statement.
- The thesis statement is validated by simulation instead of using empirical evidence. The feasibility of the proposed argumentation system for commercial applications will be investigated. We will also apply the proposed model to an e-Commerce application where such a model is applicable and any empirical evidence is available.

Appendix A

Miscellaneous

Here, a few examples of ontology, negotiation object, sample protocols, a behaviour classification matrix, a snapshot of the simulation environment, and also sample outputs are presented.

A.1 Ontology

Item Ontology (see figure A.1) is represented by its vocabulary, concepts and relationships.

Vocabulary of ItemOntology={Item, Fruit, Vegetable, Apple, Banana, Tomato, Potato}

Concepts: Item(Name,Type), Fruit(Name), and Vegetable(Name)

Relationships: isa(Banana, Fruit), isa(Apple, Fruit), isa(Tomato, Vegetable), isa(Potato, Vegetable), isa(Fruit, Item), and isa(Vegetable, Item)

FreeItem Ontology (see figure A.2) is represented by its vocabulary, concepts and relationships.

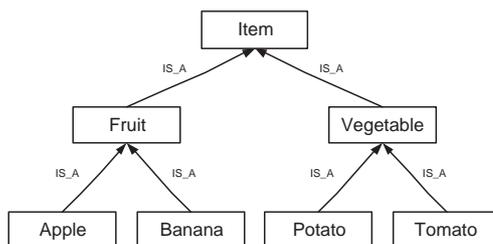


Figure A.1: An Item Ontology

Vocabulary of FreeItemOntology={Discount, Delivery, Coupon, Pineapple, Movie, Nothing}

Concepts: Discount(ItemName, Value), Delivery(ItemName, Value), Coupon (ItemName,Value), Movie(ItemName,Value), Pineapple(-,Value), and Nothing(-,0)

Relationships: isa(Discount,FreeItem), isa(Delivery,FreeItem), isa(Coupon,FreeItem), isa(Movie,FreeItem), isa(Pineapple,FreeItem), and isa(Nothing,FreeItem).

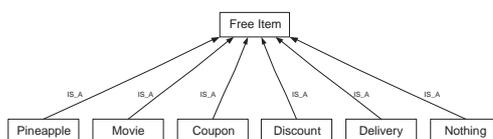


Figure A.2: A Free Item Ontology

A.2 Negotiation Object

In this work, the negotiation object is represented as Item[quantity,unitprice,quality] + FreeItem[name,value], where Item and FreeItem are instances of Item ontology in figure A.1 and FreeItem ontology in figure A.2 respectively. For example,

Banana[5,-,-]+Discount[10]

Apple[5,-,-]+Delivery[10]

Tomato[1,-,-]+Nothing[0]

Fruit[5,-,-]+Delivery[10]

Vegetable[3,-,-]+Movie[5]

A.2.1 Need Attributes

As described in section 3.2.1, a need attribute is represented as $(Name, ValueType, Values = \{Value_1[Meaning_1], Value_2[Meaning_2], \dots, Value_n[Meaning_n]\})$. For example,

- **Essential Attribute**

Quantity Numeric {1, 2, 3, 4, 5}

UnitPrice Interval {1000, 2000, 3000, 4000, 5000}

- **Optional Attribute**

Quality Fuzzy {(1,Good), (3,Average), (5,Poor)}

A.3 Flowcharts

Here, we present two flowcharts in section A.3.1 and A.3.2. These flowcharts have been used in the prototype argumentation system.

A.3.1 A Negotiation Protocol

We are using alternate offer generation protocol. In the negotiation protocol (see figure A.3), a negotiation agent uses *Offer*, *Accept*, *Reject* illocutions to exchange proposals. Along with exchanging proposals, this protocol uses a *query-inform* sequence to exchange information. It terminates by an accept, or withdraw illocution.

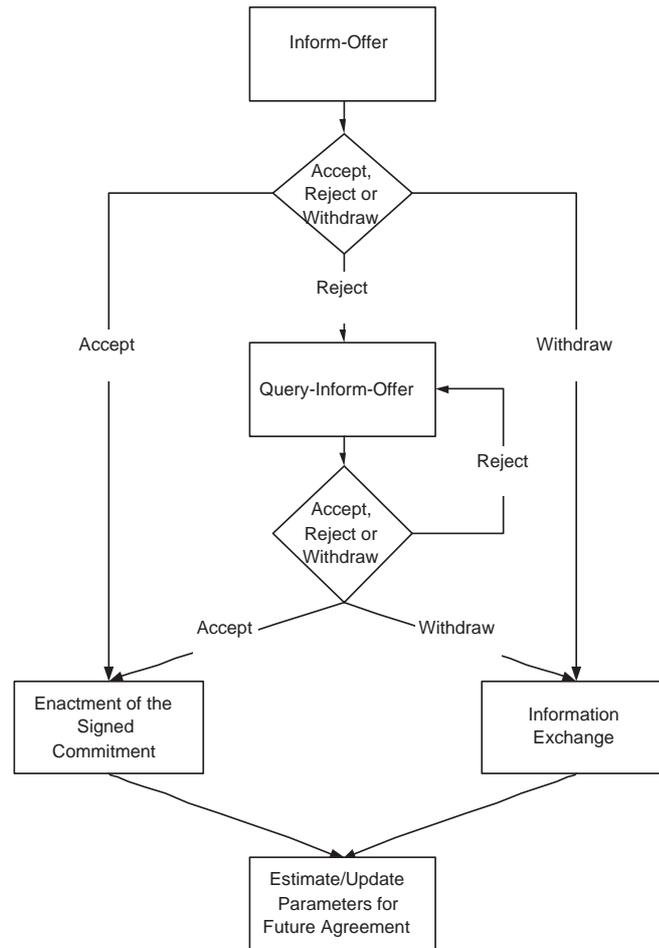


Figure A.3: A Negotiation Protocol

A.3.2 An Argumentation Protocol

The following argumentation protocol (see figure A.4) presents how an argumentation agent uses *Reward*, *Threat*, *Appeal* illocutions. The exchanged arguments and information are utilized to estimate the behavioural and performance parameters.

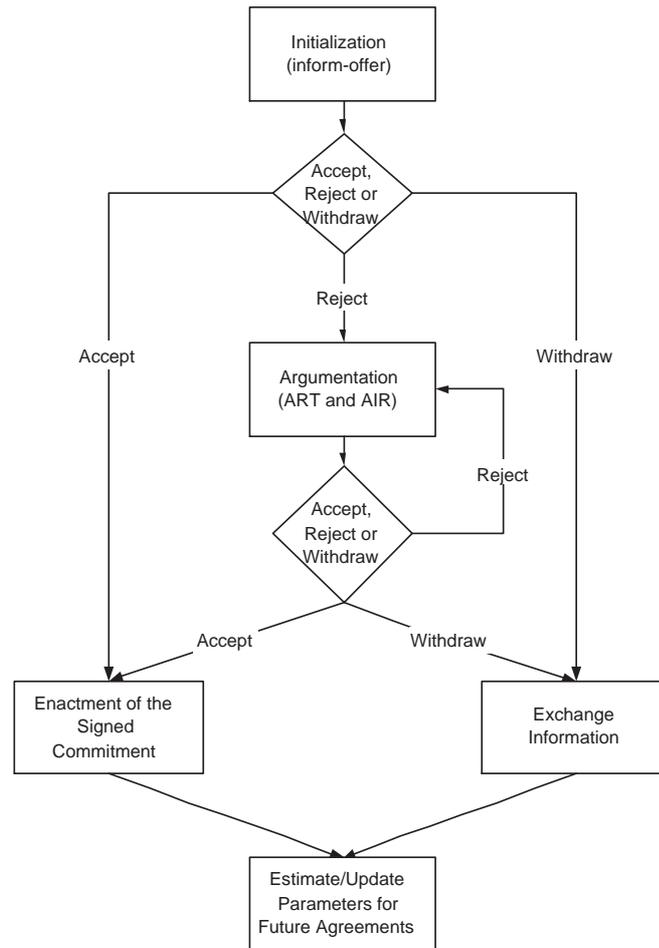


Figure A.4: An Argumentation Protocol

A.4 The Behaviour Classification Matrix

The behaviour classification matrix shows the relationships from the exchanged arguments and information to the behaviour categories of an opponent agent. It maps an element of the argument response vector (ARV) or the exchanged information response vector (EIRV) into behaviour categories in terms of a probability distribution. A trading agent retrieves the initial behaviour categories (i.e., probability distribution) from the behaviour classification matrix, if a new element in the ARV or the EIRV is constructed. It is assumed that the institution agent maintains the repository containing

an ideal probability distribution¹ for each row in the behaviour classification matrix. We have left the construction of such a matrix for our future work. A sample behaviour classification matrix is shown below.

ARV/EIRV Element vs

Behaviour Category	Cooperative	Strategic	Opportunistic
<i>ARV</i> ₁	0.1	0.6	0.3
<i>ARV</i> ₂	0.7	0.1	0.2
<i>ARV</i> ₃	0.2	0.4	0.4
<i>EIRV</i> ₁	0.5	0.4	0.1
<i>EIRV</i> ₂	0.3	0.2	0.5

A.5 The Simulation Environment

A prototype of the proposed argumentation system has been developed using Java programming language. It supports some of the functionalities discussed in this dissertation and is used to validate the thesis. An interface screen of the prototype system is shown in figure A.5.

¹The institution agent constructs the matrix from the dialogue history.

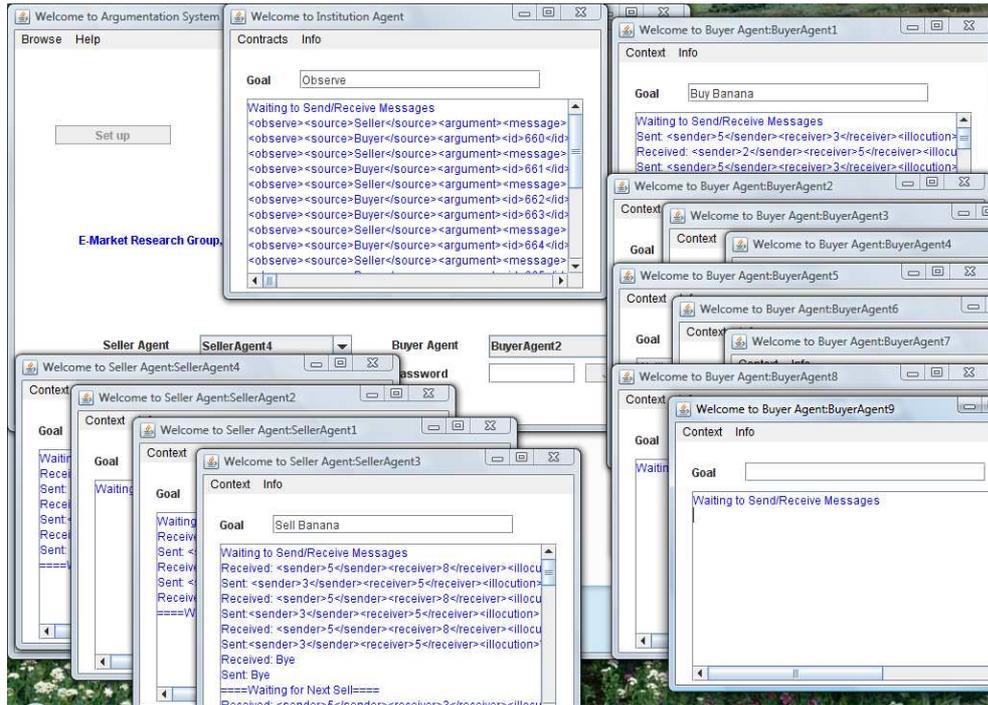


Figure A.5: A Sample Interface Screen of the Prototype Argumentation System

A.6 Sample Outputs

Here, the initial deal space, the probability of contract acceptance by an opponent agent, sample data from the dialogue history and the evaluation database, and an example of the arrival rate estimation are presented.

A.6.1 The Initial Deal Space and Probability of Contract Acceptance

The negotiation object consists of three attributes: quantity, unit price, and quality, having 5, 5, and 3 different values respectively (see section A.2). It means that the initial deal space contains $5 \times 5 \times 3 = 75$ possible deals. If the optional attribute ‘quality’ is removed from the negotiation object, then the deal space contains $5 \times 5 = 25$ deals, i.e., the size of the deal space is reduced. The deal space is constructed for the negotiation object having three above need attributes. It contains the following deals.

0: Item[1000,1,1]

1: Item[1000,1,3]

2: Item[1000,1,5]

3: Item[1000,2,1]

4: Item[1000,2,3]

5: Item[1000,2,5]

6: Item[1000,3,1]

7: Item[1000,3,3]

8: Item[1000,3,5]

and so on

The proposed agent estimates the initial probabilities of contract acceptance by an opponent agent over the above deal space. The estimated probabilities are shown below.

$P(\text{deal}[1000,1,1])=0.013333333333333334$

$P(\text{deal}[1000,1,3])=0.026666666666666667$

$P(\text{deal}[1000,1,5])=0.04$

$P(\text{deal}[1000,2,1])=0.026666666666666667$

$P(\text{deal}[1000,2,3])=0.053333333333333334$

$P(\text{deal}[1000,2,5])=0.08$

$P(\text{deal}[1000,3,1])=0.040000000000000001$

$P(\text{deal}[1000,3,3])=0.080000000000000002$

$P(\text{deal}[1000,3,5])=0.120000000000000004$

and so on

A.6.2 A Sample of the Dialogue history

Here, a subset of dialogues from the dialogue history is presented in figure A.6 for illustration purposes only.

SenderId	ReceiverId	ArgumentId	MessageId	Illocution	MessageContent	Reliability	TimeStamp
2	5	503	2	Offer	Buy(Banana[5000]	0.34	008 2:13:45
5	2	503	3	Accept	Buy(AnyItem[0.001]	0.92	008 2:13:45
2	5	503	4	Sold	Pay(AnyItem[0.001]	0.31	008 2:13:45
5	2	503	5	Paid	0	0.85	008 2:13:45
5	2	504	1	Inform	Need(Apple)[1000]	0.36	008 2:13:45
2	5	504	2	Offer	Buy(Apple[5000]	0.34	008 2:13:45
5	2	504	3	Reject	Buy(AnyItem[0.001]	0.68	008 2:13:45
5	2	605	1	Inform	Need(Tomato)[1000]	0.15	009 3:17:05
2	5	605	2	Offer	Buy(Tomato[5000]	0.89	009 3:17:05
5	2	605	3	Reject	Buy(AnyItem[0.001]	0.74	009 3:17:05
2	5	605	4	Reward	Buy(AnyItem[0.001]	0.22	009 3:17:05
5	2	605	5	Inform	Buy(AnyItem[4000]	0.88	009 3:17:05
2	5	605	6	Threat	Buy(AnyItem[0.001]	0.28	009 3:17:05
5	2	605	7	Inform	Buy(AnyItem[4000]	0.39	009 3:17:05
2	5	605	8	Reward	Buy(AnyItem[0.001]	0.53	009 3:17:05
5	2	605	9	Reject	Buy(AnyItem[4000]	0.43	009 3:17:05
2	5	605	10	Withdraw	Buy(AnyItem[0.001]	0.45	009 3:17:05
5	2	605	11	Others	Bye	0.46	009 3:17:05
2	5	605	12	Others	Bye	0.35	009 3:17:05
5	2	606	1	Inform	Need(Tomato)[1000]	0.45	009 3:17:06
2	5	606	2	Offer	Buy(Tomato[5000]	0.33	009 3:17:06
5	2	606	3	Reject	Buy(AnyItem[0.001]	0.4	009 3:17:06
2	5	606	4	Withdraw	Buy(AnyItem[0.001]	0.13	009 3:17:06
5	2	606	5	Others	Bye	0.19	009 3:17:06
2	5	606	6	Others	Bye	0.98	009 3:17:06

Figure A.6: A Portion of the Dialogue History

A.6.3 A Sample of the Evaluation Database

Here, a subset of evaluation objects from the evaluation database is presented in figure A.7 for illustration purposes only.

BuyerAgentId	SellerAgentID	ArgumentID	DealExpected	DealActual	DealAmo	EvaluationTime	EvaluationS	Deviation
5	3	2568				0 008 5:49:51 PM	1	
5	3	2569	Buy(Apple)+Get	Pay(Apple)+Fre		0 008 5:49:54 PM	1	<delivery>too
5	3	2570				0 008 5:49:56 PM	1	
5	3	2571	Buy(Potato)+Ge	Pay(Potato)+Fr		0 008 5:49:58 PM	1	<delivery>too
5	3	2572				0 008 5:50:00 PM	1	
5	8	2573	Buy(Banana)+G	Pay(Banana)+F		0 008 5:50:02 PM	1	<delivery>late
5	8	2574				0 008 5:50:04 PM	1	
5	3	2575				0 008 5:50:06 PM	1	
5	3	2576				0 008 5:50:08 PM	1	
5	3	2577	Buy(Apple)+Get	Pay(Apple)+Fre		0 008 5:50:10 PM	1	<delivery>late
5	3	2578	Buy(Apple)+Get	Pay(Apple)+Fre		0 008 5:50:12 PM	1	<delivery>late
5	8	2579				0 008 5:50:14 PM	1	
5	8	2580				0 008 5:50:16 PM	1	
5	7	2581				0 008 5:55:43 PM	1	
5	8	2582	Buy(Banana)+G	Pay(Banana)+F		0 008 5:55:46 PM	1	<delivery>late
5	8	2587	Buy(Banana)+G	Pay(Banana)+F		0 008 5:58:07 PM	1	<delivery>late
5	7	2588				0 008 5:58:09 PM	1	
5	7	2589	Buy(Apple)+Get	Pay(Apple)+Fre		0 008 5:58:11 PM	1	<delivery>late
5	7	2590				0 008 5:58:13 PM	1	
5	8	2591				0 008 5:58:15 PM	1	
5	7	2592	Buy(Potato)+Ge	Pay(Potato)+Fr		0 008 5:58:17 PM	1	<delivery>too
5	8	2593				0 008 5:58:21 PM	1	
5	7	2594	Buy(Apple)+Get	Pay(Apple)+Fre		0 008 5:58:23 PM	1	<delivery>too

Figure A.7: A Portion of the Evaluation Database

A.6.4 An Example of the Arrival Rate Estimation

Here, table A.1 shows sample data for the arrival rate estimation and is presented for an illustration purpose only. The terms: C_1 , C_2 , and C_3 represent three cooperative agents, S_1 , S_2 , and S_3 represent three strategic agents, and O_1 , O_2 , and O_3 represent three opportunistic agents. An entry, (\checkmark) at the i th row and the j th column in the table A.1 represents that a trading agent selects the opponent agent in the j th column as one of the trading partners in the i th simulation run. The symbol, (\setminus) represents the set difference operator.

Simulation	C_1	C_2	C_3	S_1	S_2	S_3	O_1	O_2	O_3	$ X_{new}^i \setminus X_{old}^i $
Run vs Agents										
1	\checkmark	\checkmark			\checkmark					-
2	\checkmark			\checkmark		\checkmark				2
3	\checkmark				\checkmark		\checkmark			2
4	\checkmark	\checkmark			\checkmark					1
5					\checkmark	\checkmark	\checkmark			2
6	\checkmark			\checkmark	\checkmark					2
7		\checkmark		\checkmark	\checkmark					1
8	\checkmark	\checkmark		\checkmark						1
9			\checkmark	\checkmark	\checkmark					2
10		\checkmark	\checkmark	\checkmark						1

Table A.1: A Sample Data for the Arrival Rate Estimation

$$\sum_{i=1}^L |X_{new}^i \setminus X_{old}^i| = 2 + 2 + 1 + 2 + 2 + 1 + 1 + 2 + 1 = 14$$

And the arrival rate = $\frac{\sum_{i=1}^L |X_{new}^i \setminus X_{old}^i|}{L \times 3} \times 100\% = \frac{14}{10 \times 3} \times 100\% = \frac{1.4}{3} \times 100\% = 46.67\%$.

In the above example, 1.4 out of 3 opponent agents² are new or rejoined in the trading partnership set. The small value of arrival rate means that a trading agent does not change its trading partnerships frequently. In other words, $(3 - 1.4) = 1.6$ out of 3 trading partner agents remain unchanged on average in the trading partnership set. It means that the trading partnership set is $\frac{1.6}{3} \times 100 = 53.33\%$ stable. The simulated arrival rate obtained by the proposed model is lower than that of the existing Trust and Honour [103] model. However, the Trust and Honour [103] model does not support the entire buying process to build trusted trading partnerships, whereas the proposed model does.

²The actual number of new or rejoined opponent agents are either 0, 1, or 2. Here, the value 1.4 represents their arrival per dialogue.

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