A Hybrid Model of Electronic Negotiation:

Integration of Negotiation Support and Automated Negotiation Models

by

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Contents

ABSTRACT ---------- **9**

1. INTRODUCTION ---------- **11**
1.1 Motivation ---------- 12
1.2 Research Objectives ---------- 14
1.2.1 Agent Decision Making Model ---------- 16
1.2.2 Hybrid Communication Model and Agent Communication Model ---------- 16
1.2.3 Human-Agent Negotiation and Message Exchange Protocols ---------- 19
1.2.4 Delegation Protocol ---------- 20
1.2.5 Interoperability between NSS and ANS ---------- 20
1.3 Research Scope ---------- 21
1.4 Thesis Outline ---------- 22

2. ELECTRONIC NEGOTIATIONS ---------- **24**
2.1 Electronic Commerce ---------- 24
2.2 Negotiation ---------- 27
2.2.1 Negotiation Decision Approaches ---------- 28
2.2.1.1 Individual Decision Making ---------- 29
2.2.1.2 Normative Decision Approach: A Game-theoretic Approach ---------- 29
2.2.1.3 Negotiation Analysis Approach ---------- 30
2.2.2 Negotiation Agreement Approaches ---------- 31
2.2.2.1 Distributive Negotiations (Win-Lose Negotiations) ---------- 32
2.2.2.2 Integrative Negotiations (Win-Win Negotiations) ---------- 32
2.3 Electronic Negotiations Models ---------- 34
2.3.1 Communication Theories in Electronic Negotiations ---------- 34
2.3.2 Electronic Auction Model ---------- 37
2.3.3 Automated Negotiation Model ---------- 39
2.3.3.1 Software Agents ---------- 40
2.3.3.2 Automated Negotiations ---------- 41
2.3.3.3 Automated Negotiation Methods ---------- 43
2.3.3.4 Characteristics of Negotiation Software Agents ---------- 46
2.3.4 Negotiation Support Model ---------- 47
2.3.4.1 Negotiation Support Systems ---------- 48
2.3.4.2 Decision Support in NSSs ---------- 52
2.3.4.3 Communication Support in NSSs ---------- 53
2.4 Existing Hybrid Negotiation Systems ---------- 59
2.4.1 Aspire: Software Agents in NSS ---------- 59
2.4.2 Hybrid (human-agent) Auction System ---------- 60
2.4.3 Human vs. Agent in multi-issue Negotiation ---------- 61
2.5 Summary ---------- 62

3. REQUIREMENTS OF A HYBRID NEGOTIATION MODEL ---------- **64**
3.1 Human-Agent Negotiation Design Requirements ---------- 65
3.2 Requirement Analysis of Agent Negotiation System ---------- 67

3.2.1 Required Characteristics of Agent Decision Making Behaviour ---- 68
3.2.2 Requirements of Agent Communication Model ---- 70
3.2.3 Components of the Automated Negotiation System ---- 72
3.3 Functional Architecture of Hybrid Negotiation Model ---- 74

4. INTER-AGENT COMMUNICATION AND DECISION MAKING ---- 77
4.1 Inter-agent Communication Model ---- 78
4.1.1 Agent Communication Language (ACL) ---- 79
4.1.1.1 Knowledge Query and Manipulation Language (KQML) ---- 82
4.1.1.2 FIPA ACL ---- 83
4.1.1.3 ACL for Hybrid Negotiation Model ---- 84
4.1.2 Agent Content Languages ---- 85
4.1.2.1 FIPA SL Content Language ---- 88
4.1.2.2 OWL as Content Language ---- 90
4.1.2.3 Content Language for Hybrid Negotiation Model ---- 91
4.1.3 Ontologies in Agent Communication ---- 92
4.2 Decision Making in Automated Negotiations ---- 94
4.2.1 Negotiation Mechanism ---- 94
4.2.2 Decision Making Approaches in Hybrid Model ---- 96
4.3 Computational Automated Negotiation Models ---- 99
4.3.1 The Responsive Mechanism ---- 101
4.3.1.1 Families of Tactics in Responsive Mechanism ---- 101
4.3.1.2 Evaluation of Offers ---- 103
4.3.1.3 Negotiation Strategy for Responsive Mechanism ---- 103
4.3.1.4 Knowledge Required about Counterpart Preferences ---- 104
4.3.2 The Trade-off Mechanism ---- 104
4.3.2.1 Knowledge about Partner Preferences ---- 106
4.3.2.2 Evaluation of Offers ---- 107
4.3.2.3 Meta-Strategy Mechanism ---- 107
4.3.3 Fuzzy Constraint Based Model ---- 107
4.3.3.1 Specification of Negotiation Constraints and Offers ---- 108
4.3.3.2 Decision Making ---- 109
4.3.3.3 Communication Model ---- 111
4.4 Argumentation-Based Automated Negotiation Approach ---- 112
4.4.1 Communication Elements ---- 115
4.4.2 Decision Making Elements ---- 116
4.5 Summary ---- 117

5. THE HYBRID NEGOTIATION MODEL ---- 120
5.1 Analysis and Design ---- 120
5.1.1 A Brief Comparison of Automated and Negotiation Support Models ---- 121
5.1.2 Human-Agent Negotiation Process ---- 122
5.1.3 Human-Agent Negotiation Design ---- 123
5.1.3.1 Roles ---- 125
5.1.3.2 Process Rules ---- 126
5.1.3.3 Offer Specification and Submission ---- 127
5.1.3.4 Information ---- 128
5.1.3.5 Summary ---- 128

5.2 Negotiation Process Protocols ---- 129
5.2.1 Negotiation Protocol ---- 130
5.2.1.1 Negoisst Negotiation Protocol ---- 132
5.2.1.2 Human-Agent Negotiation Protocol ---- 134
5.2.2 Message Exchange Protocol ---- 136
5.2.3 Delegation in the Hybrid Negotiation Model ---- 137
5.3 Human-Agent Communication Model ---- 142
5.3.1 Human-Agent Message Content Representation ---- 143
5.3.1.1 Analysis of Content Categories for Negoisst ---- 145
5.3.1.2 Analysis of Content Categories for Automated Negotiations ---- 150
5.3.1.3 FIPA SL Support for Negotiation Content Categories ---- 152
5.3.1.4 Analysis of Content Categories for Human-Agent Negotiation ---- 155
5.3.1.5 Summary ---- 157
5.3.2 Message Types ---- 158
5.3.2.1 Message Type Request and Communicative Act CFP ---- 161
5.3.2.2 Message Types Offer/Counteroffer and Communicative Act Propose - 163
5.3.2.3 Message Types Accept/Reject and Communicative Acts Accept-/Reject-Proposal ---- 164
5.3.2.4 Discussion ---- 164
5.3.3 Ontologies ---- 165
5.3.3.1 Negotiation Ontology ---- 166
5.3.3.2 Agent Ontology ---- 167
5.3.4 Wrapper Agent ---- 169
5.4 Negotiation Agent Decision Making Model ---- 170
5.4.1 Responsive Mechanism ---- 172
5.4.1.1 Supported Negotiation Behaviour ---- 172
5.4.1.2 Human-Agent Negotiation ---- 172
5.4.1.3 Communication Support ---- 174
5.4.1.4 Initial Setup Requirements ---- 174
5.4.2 Trade-Off Mechanism ---- 175
5.4.2.1 Supported Negotiation Behaviour ---- 175
5.4.2.2 Human-Agent Negotiation ---- 176
5.4.2.3 Communication Support ---- 176
5.4.3 Argumentation-Based Negotiation ---- 177
5.4.3.1 Supported Negotiation Behaviour ---- 177
5.4.3.2 Human-Agent Negotiation ---- 177
5.4.3.3 Communication Support for Argumentation ---- 179
5.4.4 Fuzzy Constraint-based Model ---- 180
5.5 Summary ---- 181

6. EVALUATIVE DISCUSSION ---- 184
6.1 Illustrative Run-Time Evaluation ---- 184
6.2 Negotiation Scenario ---- 187
6.3 Human-Agent Negotiation Examples ---- 189
6.3.1 Example 1 ---- 190
6.3.2 Example 2 ---- 198
6.4 Discussion ---- 201

7. CONCLUSION AND FUTURE WORK ---------- 204
7.1 Review of the Thesis ---------- 204
7.2 Future Work ---------- 207

BIBLIOGRAPHY---------- 209

APPENDIX – INTER-HUMAN NEGOTIATION EXPERIMENT ---------- 217

List of Figures

Figure 2.1: A classification of common auction mechanisms (Wurman et al. 1998) 39

Figure 2.2: Negotiation agreement space (modified from Jennings et al. 2001) 43

Figure 2.3: A three-phase negotiation process 49

Figure 2.4: General structure and components of negotiation messages in NSSs 55

Figure 2.5: Negoisst message window 57

Figure 2.6: An example of a partial offer 58

Figure 3.1: Four main components of the hybrid negotiation model 65

Figure 3.2: Basic negotiation strategies and tactics collected and combined from Pruitt (1981) 69

Figure 3.3: Amount of different types of written communication units in inter-human negotiations (Köszegi et al. 2004) 72

Figure 3.4: Functional architecture of hybrid negotiation model 76

Figure 4.1: Components of Agent Communication Model 79

Figure 4.2: A KQML message 83

Figure 5.1: Negoisst Negotiation Protocol (modified from Schoop et al. (2003)) 134

Figure 5.2: Human-Agent Negotiation Protocol 136

Figure 5.3: Interaction among participants of hybrid Negotiation Model 137

Figure 5.4: An example delegation protocol 140

Figure 5.5: Activities involved in the delegation to a negotiation agent 142

Figure 5.6: Part of agent ontology 168

Figure 5.7: Classes for formality messages 168

Figure 5.8: A wrapper agent converts an agent message into Negoisst message (and vice versa) 170

Figure 6.1: First message from human negotiator in the negotiation workspace of agent's principal 193

Figure 6.2: Conversion of human negotiator's message into an ACL message 193

Figure 6.3: Agent's message for the human negotiator 194

Figure 6.4: Human negotiator receives first message from the negotiation agent..... 194

Figure 6.5: Second message from human negotiator in principal's negotiation workspace 196

Figure 6.6: Human negotiator receives second message from the negotiation agent..... 196

Figure 6.7: Third message received from human negotiator..... 197

Figure 6.8: Human negotiator receives third message (Accept) from the agent 198

Figure 6.9: Two consecutive offers received from the human negotiator of Hurm AG.. 201

List of Tables

Table 4.1: A one-to-one correspondence between Negoisst message elements and ACL message parameters ---------- 85

Table 5.1: A comparison of communication and decision support in NSSs and ANSs --122

Table 5.2: Activities at the side of automated negotiation in the hybrid negotiation model----------123

Table 5.3: General design properties of Negoisst System, Automated Negotiation Models, and Hybrid Negotiation Model----------125

Table 5.4: Negoisst message types and their associated communication type ----------135

Table 5.5: The content types and the illocutions of content categories in Negoisst.------148

Table 5.6: The support of automated negotiation models for content categories and associated communicative acts.----------151

Table 5.7: Equivalent ACL's communicative acts of Negoisst's message types ---------161

Table 6.1: Negotiation agenda and the companies' aspiration levels for each issue------189

Table 6.2: Importance (in percent) of issues for both companies ----------191

Table 6.3: Utilities of offers in an inter-human negotiation thread in Negotiation Phase (Offer=O, Counteroffer=CO, Accept=A) ----------191

Table 6.4: Utilities of offers in an inter-human negotiation thread between Yu26 and Hurm26 (Offer=O, Counteroffer=CO, Accept=A) ----------199

Table 6.5: Importance (in percent) of issues for both companies ----------200

Abbreviations

ABN	Argumentation-Based Negotiation
ACL	Agent Communication Language
ANS	Automated Negotiation System / Agent Negotiation System
BDI	Belief, Desire, and Intention
CFP	Call for Proposal
DAI	Distributed Artificial Intelligence
DSS	Decision Support System
ENS	Electronic Negotiation System
FIPA	Foundation for Intelligent Physical Agents
NSS	Negotiation Support System
OWL	Web Ontology Language
SL	Semantic Language

Abstract

Electronic business negotiations are enabled by different electronic negotiation models: automated negotiation models for software agents, negotiation support models for human negotiators, and auction models for both. To date, there is no electronic negotiation model that enables bilateral multi-issue negotiations between a human negotiator and a negotiation agent—an important task in electronic negotiation research. In this thesis, a model is presented that integrates the automated negotiation model and the negotiation support model. The resulting hybrid negotiation model paves the way for human-agent business negotiations. The integration of two models is realised at the levels of negotiation process, communication support and decision making.

To this end, the negotiation design, negotiation process, negotiation decision making, and negotiation communication in negotiation support systems (NSSs) and agent negotiation systems (ANSs) are studied and analysed. The analyses on these points help in strengthening the motivation behind hybrid negotiation model and setting aims for the integration of an NSS and an ANS in hybrid negotiation model. We mainly propose a human-agent negotiation design, negotiation process protocols to support the design, a hybrid communication model for human-agent interaction, an agent decision-making model for negotiation with human, and a component for interoperability between NSS and ANS. The agent decision-making model is composed of heuristic and argumentation-based negotiation techniques. It is proposed after analysing different automated negotiation models for different human negotiation strategies. The proposed communication model supports human negotiator and negotiation agent to understand and process negotiation messages from each other. This communication model consists of negotiation ontology, a wrapper agent, and a proper selection of an agent communication language (ACL) and a content language. The wrapper agent plays a role for interoperability between agent system and NSS by providing a communication interface along with the negotiation ontology. The negotiation ontology, ACL and agent content language make the communication model of negotiation agent in ANS. The proposed hybrid model is realised by integrating an ANS into NSS Negoisst. The research aim is to

show that a hybrid negotiation system, composed of two heterogeneous negotiation models, can enable human-agent multi-issue integrative negotiations.

1. Introduction

Negotiation is a process by which two or more parties discuss issues of common but competing interests with an aim of reaching a joint decision (Pruitt 1981). The importance of negotiation is obvious in situations from family quarrels to international disputes and from commodities buying to corporate level mergers (Raiffa et al. 2002, Fisher et al. 1983). In recent years, the advancement of the Internet and electronic commerce technologies have developed an interest in conducting negotiations using electronic media, e.g. e-mail, World Wide Web etc. This form of negotiations is called electronic negotiations (Beam & Segev 1997). Electronic negotiations remove the obstacles of space and time between negotiators. They carry less transaction costs than face-to-face negotiations and can take place more frequently in response to the business demands and market dynamics to make new beneficial agreements and new partnerships (Luo et al. 2003).

Research on electronic negotiation is focused on the theories and the systems of three distinct models of electronic negotiations (Schoop et al. 2003), namely, the automated negotiation model (Anthony & Jennings 2003, Jennings et al. 2001, Oliver 1996, Faratin 2000, Chavez & Maes 1996,), the negotiation support model (Schoop et al. 2003, Kersten & Noronha 1999, Lim & Benbasat 1992, Rangaswamy & Shell 1997), and the auction model (Klein 1997, Wurman et al. 1998, McAfee & McMillan 1987). The automated negotiation model aims at automating the negotiations through the employment of intelligent software agents that perform the negotiation tasks autonomously on the behalf of their human principals. The automated negotiation systems (ANSs) based on this model are often designed and developed for particular negotiation problems and they mainly focus on outcome efficiency (Luo et al. 2003, Fatima et al. 2004, Barbuceanu & Lo 2000). The negotiation support model aims at supporting human negotiators and decision-makers to perform themselves their complex negotiation tasks. The NSSs are developed on the concept of the negotiation support model. In contrast to the ANSs, NSSs are developed irrelevant of the negotiation problems in order to provide a prescriptive

support to parties in a negotiation process to avoid humans' behavioural mistakes and to achieve better negotiation outcomes through negotiation analysis (Jelassi & Foroughi 1989, Rangaswamy & Shell 1997). The auction model is a market mechanism for price determination in the case of many market participants (McAfee & McMillan 1987). Auction systems are more flexible than ANSs and NSSs, and can be configured either for manual biddings by the humans or for automatic biddings by the software agents (Wurman et al. 1998). Also, a bidding process can be a combination of manual and automatic bidding. For example, the popular auction system *eBay*[1] enables such hybrid bidding process.

1.1 Motivation

In a bilateral multi-issue negotiation, two parties negotiate with each other on two or more issues such as on price, delivery date etc. (Raiffa 1982). In this thesis, a bilateral negotiation is taken as a one-to-one direct negotiation without the involvement of any third-party (e.g., a mediator) in a negotiation process. Auctions do not come under the definition of bilateral multi-issue negotiations.

Looking at a bilateral multi-issue negotiation, it is possible that one human negotiator conducts the negotiation himself, whereas the second negotiator can prefer an autonomous software agent to perform negotiation on his/her behalf. However, there is no known negotiation system (similar to one that exists for auctions e.g. Wurman et al. 1998) for bilateral multi-issue negotiations that can be configured for human-mediated negotiations as well as agent-mediated negotiations. Likewise, there is no negotiation system, similar to the hybrid auction system (e.g. Das et al. 2001), that enables bilateral multi-issue negotiation between a human negotiator and a software agent. These auction systems (e.g. eBay and one proposed by Das et al. (2001)) can be taken as examples of the system that we are interested in our research. In an auction on eBay, the bidding can be performed manually by all participants or some participants can do bidding manually while the others have set maximum price for automated bidding. The latter case is a scenario of manual bidding against automated bidding. Instead of single-issue (e.g. price)

[1] http://www.ebay.com

auctions like on eBay, the purpose of this research is to deal with the complex negotiation scenario i.e., bilateral multi-issue negotiations.

NSSs and ANSs are based on common negotiation theory i.e., negotiation strategies, negotiation types, negotiation methods (Raiffa 1982, Fisher et al. 1983, Pruitt 1981). Decision making and communication are the main activities that any electronic negotiation system (ENS) should support (Ströbel & Weinhardt 2003). The systems, based on negotiation support model and automated negotiation model, provide these activities (though differently) through decision making and communication components (Lim & Benbasat 1992, Ashri et al. 2003). Further, the architectures of NSSs can be used as starting point to develop automated negotiation systems (Oliver 1996). Regardless of common negotiation theory, similar negotiation activities, and architectural compatibility, the research in one area rarely benefits from research in the other area. The researchers in NSSs and ANSs come from different subject areas[2] and keep their distinct perspectives on electronic negotiations from an application point of view. This problem, until now, has kept two similar research areas at distance. So far there is no study that compares the two models to combine them for the purpose of negotiation between a human negotiator and a software agent.

From the above brief comparison, it can be stated that an NSS and an ANS could create a synergy with their integration in the form of a *hybrid negotiation system* for flexible electronic negotiations. This flexibility can be achieved if a negotiator has an opportunity either to conduct a negotiation manually or to delegate a negotiation task to a software agent, depending on the circumstances (e.g. whether a negotiator has no time for the negotiation then (s)he can delegate negotiation task to a software agent). With a hybrid negotiation system, negotiations that occur between two humans using an NSS can also be conducted (although with limitations) between a human and an autonomous software agent.

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[2] Automated negotiations are studied in computer science and are applications of distributed artificial intelligence (DAI) (Jennings et al. 2001), whereas NSSs are a special class of group decision support systems (GDSS) (Jelassi & Foroughi 1989, Lim & Benbasat 1992) and are studied in the area of information systems (Bichler et al. 2003).

1.2 Research Objectives

The central aim of this research is to present a framework of a hybrid negotiation model that paves the way for conducting negotiations between a human and a software agent. The proposed hybrid negotiation model is a composition of an NSS, an ANS, and the components for interoperability between the two negotiation systems. In a human-agent negotiation, the NSS supports the human negotiator, the ANS supports the negotiation agent, and the interoperability components enable the two heterogeneous negotiation systems to work together. This objective is broadly achieved by aligning the negotiation design (characteristics of negotiation) and the architectural components of the negotiation support model and the automated negotiation model in a hybrid model.

An ANS can be integrated with an NSS, and vice versa. The system that integrates the other system will influence the design of the hybrid negotiation model, i.e., its negotiation design such as negotiation process, negotiation protocol etc., will work as standards in the design of hybrid model. We will integrate an ANS with an existing NSS due to the following reasons. Firstly, an ANS can borrow many design concepts from NSS research (Oliver 1996). Therefore, it is understandable to develop an ANS according to the NSS in a hybrid system. Secondly, an NSS can support a wide variety of negotiation scenarios, whereas an ANS normally implements a particular automated negotiation mechanism that provides a particular negotiation strategy and communication behaviour, and is, therefore, applicable to a specific negotiation problem. From an ANS perspective, an NSS can be considered as supporting or implementing a number of automated negotiation mechanisms. Therefore, an NSS can integrate various automated negotiation mechanisms, which provide different types of negotiation behaviour to the negotiation agent in human-agent negotiations. The first reason is important from the human-agent negotiation design view and the second reason is about the decision-making model of agent. From the implementation point of view there is a third reason, i.e., we want to use one of the existing NSSs. We have selected the Negoisst system (Schoop et al. 2003), due to its unique features of defining negotiation vocabulary and enabling semi-structured messaging. These features make the Negoisst system and the automated negotiation system interoperable (at least at information level).

Bichler et al. (2003) have described negotiations as an iterative communication and decision making process between two or more agents. In this thesis, the main interest is in the components for decision making and communication. The design and implementation of these components are according to the unique objectives of these two models—support or automation. Further, the design of these components, especially in the automated negotiations, is influenced by the supported types of negotiations. For the hybrid negotiation model, we study these two negotiation models, their implemented systems or models, and the components in those systems. For this study, we introduce the research questions that need to be answered for an appropriate ANS and for the interoperability between an ANS and NSS in the hybrid negotiation model. The main research question is:

- *How can human-agent negotiations be enabled*?

To answer the main question, we will have to consider the following questions:

- What is the negotiation design in hybrid negotiation model and how is it realised through a negotiation process, negotiation process protocols and an appropriate ANS for flexible human-agent negotiations?

- What are the differences at the levels of design and support in the decision making and communication support components of two models that should be dealt with to make two models work together for human-agent negotiation? Likewise, what are the similarities in the decision making and communication support components of two models that make the integration of two models realistic?

- What are the possible methods of interoperability between a non-agent-based system (a NSS) and an agent-based system (an ANS) in a hybrid system?

The following elements provide the specifications of the hybrid negotiation model.

1.2.1 Agent Decision Making Model

An agent decision making model provides a negotiating agent with the negotiation decision functions and strategies to create offers. ANSs are developed to solve particular negotiation problems using specific decision functions and strategies. These specific negotiation decision behaviours in automated negotiation are provided through different negotiation approaches that have been categorised in game-theoretic, heuristic and argumentation-based approaches (Jennings et al. 2001).

In the hybrid model, the negotiation agent has to negotiate with a human negotiator therefore the aim is to propose an agent decision making model, which includes common human negotiation behaviour, such as concession making, argumentation, trade-offs etc. For this, the requirement for the agent decision making model will be based on the human negotiation behaviour. Different agent decision making functions and strategies belonging to different approaches (heuristic and argumentation-based) will be analysed and an agent decision making model having the characteristics of human negotiation behaviour will be proposed. Using this decision making model, a negotiation agent will be able to behave according to its negotiation goals and strategy.

1.2.2 Hybrid Communication Model and Agent Communication Model

Communication is an essential part of a negotiation process and it is about exchanging negotiation messages between negotiators. With a hybrid (human-agent) communication model for human-agent negotiation, our aim is to bridge the gap between the communication models of Negoisst and ANS in order to enable two different communicatory entities to communicate their negotiation stance to each other. A communication model in any negotiation system normally defines the structure of negotiation messages and the representation and semantics of contents in messages. The hybrid communication model must thus be based on a thorough analysis of the negotiation communication behaviour and the structure of negotiation messages in NSSs and ANSs. A communication behaviour in a negotiation message can be represented through an offer containing negotiation issues' values with or without text representing the arguments, queries about product or service, clarifications about some negotiation matter, greetings etc. The structure of a negotiation message in NSSs and ANSs is

composed of elements such as meta-data information (information about participants, the topic of the negotiation), a message type[3] describing sender intention, message content etc. The message content element of message structure captures the major portion of communication behaviour[4]. The NSSs and ANSs have similarities in the message structure but they vary greatly in communication behaviour. Human communication behaviour is rich. Human negotiators can send any type of structured/un-structured content during communication, while agents are restricted to some particular types of structured content.

For the compliance of negotiation agent with human communication behaviour, there is a need to study human communication in electronic negotiations and then propose agent communication model accordingly on the basis of communication behaviour supported by different automated negotiation models and the existing agent communication technologies. However, both negotiating entities should be able to understand at least the content containing the offers (issue values). This minimum requirement will be seen as a restriction for human-agent negotiation. Next aim is to present a common message structure that must be realised by the Negoisst system and the ANS in the hybrid negotiation system. The common message structure will capture all the necessary parts of negotiation messages and will enable both systems to process messages from each other. We search for similarities in the communication models of two systems to design the hybrid communication model.

The hybrid or human-agent communication model is designed based on the Negoisst communication model. Therefore, Negoisst message structure and its elements already comply with the hybrid negotiation model. For the agent message structure, message types and negotiation content, the existing agent communication technologies are explored. There are usually specific technologies to represent message structure, content and semantics in an agent communication model. For example, different automated

[3] A message type associates the intention of a sender with the message content such as to request the supply of a product or to promise the delivery of goods.

[4] By communication behaviour we mean the combination of message type and negotiation content expressing some negotiation stance e.g. concession.

negotiation mechanisms[5] require different expressivity levels to represent message content and, therefore, use different agent content languages. It will be studied, which technologies fulfil the requirements of the agent communication model according to the hybrid communication model. These different agent communication technologies are selected according to their ability of representing and expressing business messages.

Selection of Agent Communication Language: An agent communication language (ACL) describes the overall structure of an agent message as well as details of the elements such as participants, message type etc. The hybrid communication model requires an ACL, which can encapsulate all the elements of a hybrid negotiation message. For this purpose, the FIPA ACL will be selected for the agent communication model. FIPA ACL has been designed to support inter-agent communication; however it provides all the required support for the hybrid negotiation model. It can capture all the mandatory elements of a hybrid negotiation message and, therefore, make the human negotiator and software agent communicative. It defines many message types with semantics to be used as the types of negotiation message.

Selection of Agent Content Language: Agent content languages are logic-based languages that are designed to express content in agent messages. Human negotiators using Negoisst are free to write any type of content (free text, arguments, values etc.). Agent communication technology is not yet so sophisticated that negotiation agents can process any type of message content. In the agent communication model, we thus need a content language that is expressive enough to represent different types of content generated or processed by different agent negotiation mechanisms. We select FIPA SL content language for the agent communication model. From the hybrid negotiation model's point of view, it is the most expressive and suitable content language to represent the content of a negotiation message. It is a standard language with FIPA ACL and

[5] For example, heuristic models only need to represent negotiation issues and their values in the message, whereas argumentation-based mechanisms use other logic elements to express tactical statements in messages.

enables different expressions such as representing issues with their values, queries about issues, representing constraints etc. The semantics of the content is defined in ontologies.

Negotiation Ontology: The Negoisst system has a unique feature for unambiguous communication i.e., the negotiation vocabulary (such a negotiation issues) is defined as ontology, called negotiation ontology. Ontologies are also a recommended way in multi-agent systems for defining the semantics of information and then process it accordingly. In the hybrid communication model, we want to use this negotiation ontology for the information level interoperability between the Negoisst system and the ANS. This ontology will provide the meanings to the message content and will serve as the only source of semantic interoperability at content level between agent and human messages.

1.2.3 Human-Agent Negotiation and Message Exchange Protocols

In the hybrid negotiation model, a negotiation protocol specifies the types of negotiation messages and the rules for exchanging these between a human and a software agent. In an NSS or ANS, a negotiation protocol is defined for two participants of the same type—either both humans or both agents. There has to be a different setting in the hybrid negotiation model: firstly, the two negotiators are not of the same type i.e., one negotiator is a human and the counterpart is a software agent; secondly, the agent's principal is a third participant in a negotiation process. For this setting, a hybrid negotiation protocol will be proposed. The hybrid negotiation protocol will be based on the existing negotiation protocol of the Negoisst system according to the different negotiation capabilities of counterparts. In the hybrid negotiation model, the rules of the Negoisst negotiation protocol are changed to accommodate the three participants i.e., a human negotiator at one side and a negotiating agent and its principal as counterparts at the other side of a negotiation table. The benefit of building the hybrid protocol on the Negoisst protocol is that there will be no change required in the Negoisst system at protocol level and the human negotiator will use the same negotiation protocol while negotiating with the negotiation agent or its principal. The negotiation agents keep limited ability of processing negotiation data. Therefore, the negotiating agent will only participate in those messages of a protocol that it can process (understand and generate) such as offers,

counteroffers etc. The remaining messages (which have no impact on contract values) such as queries are answered by the agent's principal. Informally, it can be said that the Negoisst negotiation protocol is divided into two sub-protocols for three participants, namely the human-agent negotiation protocol and the human-principal query protocol.

In the hybrid negotiation system, four human and artificial entities (three are mentioned above and the fourth is the wrapper agent) play an active role in a negotiation process. A message exchange protocol specifies—at high-level—the permissible actions and the messages among these entities. It includes the messages and the entities involved in the negotiation protocol, and it defines the rules for exchanging the messages and carrying out the actions between the wrapper agent and the other entities for interoperability.

1.2.4 Delegation Protocol

A delegation protocol specifies the process of delegating a negotiation task to the negotiation agent. It includes the activities such as setting-up, creating, suspending and terminating the negotiation agent. The delegation to a negotiating agent is different in the hybrid model compared to the fully automated negotiation system due to the fact that the human principal retains the option of carrying out the negotiation manually at any time. In the hybrid model, a principal can delegate and revoke the negotiation task at any time and then perform the negotiation himself/herself, while an agent negotiates from start to end in automated negotiation systems. Additionally, to have more control over the negotiation process, the principal's permission is sought by the agent before finalising or terminating the negotiation process.

1.2.5 Interoperability between NSS and ANS

Negoisst and the ANS in the hybrid negotiation system are not only heterogeneous at information level but they are also heterogeneous at design and architecture level. The information level interoperability between the Negoisst system and an ANS is provided through the hybrid communication model and the negotiation ontology. For the design level as well as for information level interoperability, the hybrid negotiation model introduces the *wrapper agent* approach to make the non-agent Negoisst system interoperable with the ANS. The wrapper agent is used at communication level to

exchange messages between humans and negotiating agents and to transform ACL messages into Negoisst messages and vice versa.

1.3 Research Scope

The following main points define the scope of research in this thesis.

- The research proposes a hybrid negotiation model for carrying out trade negotiations in electronic commerce for the selling and buying of products and services through bargaining. Non-commercial negotiation domains such as political, legal or social disputes as well as negotiations such as voting and group decision making are not taken into account. There is already work on human-agent negotiations (bidding) in auctions, but our focus is on bilateral multi-issue negotiations between a human negotiator and a negotiation agent.

- NSSs are for bilateral multi-issue negotiations. For ANS, we are only interested in those automated negotiation mechanisms, which are for bilateral and multi-issues negotiation scenarios. We concentrate on decision making and communication components of NSSs and ANSs. The decision making and communication components of ANS will only support heuristic-based and argumentation-based negotiation mechanisms.

- A negotiation in all NSSs is a three-phase process: *pre-negotiation*, *negotiation*, and a *settlement* phase. From the perspective of the negotiation process, this research focuses on the activities in the first two phases. The pre-negotiation phase deals with the set-up of the negotiation ontology and the delegation to the negotiation agent. The negotiation phase deals with the implementation of a negotiation protocol—creating, sending and replying to messages. The negotiation agent in human-agent negotiation only supports the negotiation phase, whereas the support in the first and last phases will be provided to the agent's principal by Negoisst.

- We will provide the conceptual model of the hybrid negotiation system and a run-time simulation of a human-agent negotiation. Empirical evaluation of human-agent negotiations using the hybrid negotiation system is not in the scope of this thesis.

1.4 Thesis Outline

The thesis is structured further in five chapters. **Chapter 2** describes the negotiation theory, electronic negotiations and their models. A negotiation theory is based on different decision making approaches and negotiation behaviours adopted by negotiators during bargaining and the resulting types of negotiations. Electronic negotiation is then introduced and the three prominent models (auctions, automated negotiations, negotiation support) of electronic negotiation are discussed and distinguished from one another. The negotiation support model is discussed in detail using some of the existing NSSs. In the end, the existing work on combining software agents and humans in negotiation systems is presented to distinguish our work from them.

Chapter 3 sets the requirements for the design and different components of the hybrid negotiation model, and presents a functional architecture. The hybrid negotiation model consists of a Negoisst system, interoperability component, an ANS, and few interaction protocols. The negotiation design is based on the negotiation scenario and the negotiation process model of the Negoisst system. The requirements for agent's decision making and communication in the hybrid model are set on the human decision making and communication behaviour in inter-human negotiations. The functional architecture shows the components of the hybrid negotiation system and their inter-working.

In **chapter 4**, general agent communication technologies and different automated negotiation mechanisms are evaluated in detail. Current ACLs and agent content languages are analysed for inter-agent communication as well as the roles of speech act theory and ontologies are discussed in agent communication. Based on the analysis, a suitable ACL and a content language are selected for the agent communication model in the hybrid model. To build the decision making model of the negotiation agent, we first compare the automated negotiation approaches (game-theoretic and heuristic) and select one that is suitable for human-agent negotiation design with respect to the Negoisst system. Then existing models/mechanisms of the chosen approach are presented in detail

providing functions to evaluate and generate offers. These different mechanisms can provide different negotiation strategies to a negotiation agent in hybrid model.

Chapter 5 will present the hybrid negotiation model. In the beginning, the design of human-agent negotiation and the hybrid negotiation system will be presented in comparison to the Negoisst system as well as the negotiation activities in human-agent negotiation process are outlined. Three negotiation process protocols are then presented to support the human-agent negotiation design and executing negotiation activities. The agent communication model along within the human-agent communication model will be discussed in detail. This chapter also includes the wrapper agent approach and ontologies for the interoperability between Negoisst and ANS. In the end, the agent decision making model will be discussed in relation to the negotiation strategies provided by automated negotiation models and the support of Negoisst system for expressing and understanding those behaviours by human negotiator.

Chapter 6 provides an evaluative discussion for the hybrid negotiation model to enable human-agent negotiations. The discussion is performed with the help of two illustrative human-agent negotiations.

Chapter 7 concludes the thesis and provides the outlook to future work.

2. Electronic Negotiations

The main topic of this chapter is electronic negotiations and the respective models. In recent years, the advancement in electronic commerce and its business processes has raised the need for electronic business negotiations (section 2.1). In negotiation literature, decision making and communication are the very essence of negotiations. Different decision making approaches and associated negotiation agreement approaches have been presented in the negotiation literature (section 2.2). In electronic negotiation research, decision making perspectives, negotiators' behaviours, formal models and procedures of negotiations etc., have been taken from different negotiation research areas (e.g. law and social sciences, economic sciences and management). However, the fields of computer science and information systems have given negotiations an electronic form so the negotiations can be conducted using computers. These two fields have contributed to the three classes of electronic negotiations, namely, auctions, automated negotiations, and negotiation support (section 2.3). Communication in conventional face-to-face negotiations is flexible but un-structured. Communication in electronic negotiations needs to be structured in order to make communication processes efficient and effective. Two communication theories are also described in section 2.3 that provide the basis for effective electronic communication in electronic negotiations. The negotiation support model is discussed in detail with respect to negotiation decision theories and communication theories. The existing efforts of making software agents work or negotiate with human negotiators are novel ways of conducting electronic negotiations and represent a new research area in electronic negotiations (section 2.4).

2.1 Electronic Commerce

Electronic commerce refers to buying and selling of goods and services, and transfers of cash through public or private digital networks (Beam et al. 1996). Electronic commerce has eliminated the time and space constraints of traditional commerce. Now customers can do buying around the clock by just visiting online shops from any place. Electronic

commerce has reduced the transaction costs and increased the number of potential buyers and sellers (Turban et al. 2006). The earlier electronic commerce systems are simply limited to the buying or selling of well-defined commodities (e.g. books, CDs, toys, etc.) against the fixed price. In these systems, the seller publishes the product and service catalogues on digital markets and the customers buy and pay online. The recent electronic commerce systems are much more flexible and allow customer to build customised products[6]. Electronic commerce systems can be distinguished into consumer-to-consumer (C2C), business-to-consumer (B2C), business-to-business (B2B) electronic commerce systems etc., according to the type(s) and role(s) of buyers and sellers in online transactions (e.g. Kalakota & Winston 1997, Turban et al. 2006).

Electronic commerce supports a complete business cycle such as online marketing, ordering, payment, delivery, after-sales support and evaluation (Timmers 1998). Some of the trading steps in electronic commerce transactions, especially in electronic markets, include the negotiation tasks (Maes et al. 1999, Bakos 1998, Schmid & Lindemann 1998). Maes et al. (1999) have specified the negotiation task as one of the six stages of a buying process (specific to retail markets) in electronic commerce through which the terms of a transaction are agreed. Bakos (1998) has specified three main functions of electronic markets in B2C and C2C, namely matching buyers and sellers, facilitation of transactions, and institutional infrastructure. A negotiation task in such electronic markets determines the price of the product in the matching phase to select a buyer or a seller. Similarly, a market transaction for goods and services in B2B electronic commerce comprises three phases: information phase; agreement phase; and settlement phase (Schmid & Lindemann 1998, Schoop et al. 2001). In the information phase, suppliers and customers search for each other according to their specific needs. In the agreement phase, suppliers and customers negotiate conditions of the transaction such as price, delivery date etc., to make a legally binding contract representing the agreement between them. In the settlement phase, the agreed-upon terms of the negotiated contract are fulfilled, for example, payments are made, and logistics are handled.

Negotiations in electronic commerce are known as electronic negotiations. The advancement of electronic commerce and electronic markets has led to a special interest

[6] e.g. http://www.dell.com

in electronic negotiation research and various web-based electronic negotiation systems have been developed for doing negotiations online (Schoop et al. 2003, Kersten & Noronha 1999, Yuan et al. 1998). Electronic negotiations are argued to be a critical success factor for electronic commerce and electronic markets (Oliver 1996), as they have made it easier to find international partners and have removed the obstacles of space and time between business partners.

Software agents have been employed in electronic commerce and electronic negotiations. They are employed to automate the most time-consuming stages of the buying process in electronic commerce in order to reduce the transaction cost (Maes et al. 1999). According to Guttman et al. (1998), the personalisation, continuous running and semi-autonomous characteristics of software agents make them a desirable technology for the information-rich and process-rich environment of electronic commerce. The use of agent technology in electronic commerce was explored using a framework that consists of six stages of the buying process: need identification, product brokering, merchant brokering, negotiation, payment and delivery, and service and evaluation (Guttman et al. 1998). Agents have been employed in some of the stages.

PersonaLogic, Firefly, Jango, Bargainfinder, Kasbah, and Tête-à-Tête are earlier agent systems developed for the different stages of buying process in electronic commerce (Maes et al. 1999). PersonaLogic and Firefly perform the product brokering to help the customer find the required products. Jango and Bargainfinder perform merchant brokering to show the customer the best available prices. Software agents were developed also for negotiation in electronic commerce. Software agents have been used in business-to-business (e.g. Faratin 2000), business-to-consumer (e.g. Tête-à-Tête, Luo et al. 2003), and consumer-to-consumer negotiations (e.g. Kasbah (Chavez and Maes 1996), eBay). Electronic negotiation has removed the restriction that the negotiators or bidders should be geographically co-located, and hence reduced the transaction costs related with negotiations that may be too high for buyers or sellers. Kasbah and Tête-à-Tête systems provide bilateral negotiations whereas AuctionBot (Wurman et al. 1998) is for online auctions among many participants. Kasbah is an online multi-agent consumer-to-consumer transaction system used by buying and selling agents to negotiate about price (Chavez & Maes 1996). Software agents based on the more advanced shopping assistant Tête-à-Tête perform negotiations bilaterally across multiple dimensions such as

warranties, delivery times, return policies etc. Tête-à-Tête agents also do primitive type of argumentation by exchanging critiques or counterproposal. Faratin (2000) developed an electronic negotiation framework for agent-mediated electronic commerce for multi-dimensional goods called services. The mentioned characteristics of software agents make them well-suited for information filtering and retrieval, personalised evaluations, complex coordination, and time-based interactions, and therefore in the stages of product brokering, merchant brokering, and negotiation of CBB model (Guttman et al. 1998).

2.2 Negotiation

Negotiation is a fact of life and every human being is involved in some sort of negotiations in everyday life to get what he or she wants from others. Negotiations occur in a wide variety of political, economic, and social settings such as from family quarrels to international disputes and from commodities buying to corporate mergers (Lim & Benbasat 1992, Raiffa et al. 2002, Fisher et al. 1983). For example, negotiations between customers and shopkeepers over price, negotiations between two countries on territorial disputes, salary negotiations between employees and bosses. A negotiation situation occurs due to the difference of opinions and interests between people, organisations and countries. Disputes or mutual interests of parties bring them to the negotiation table, where many alternatives are worked out and one is agreed upon mutually by parties as the resolution of dispute. Pruitt (1981) puts negotiation as

> *"a process by which a joint decision is made by two or more parties. The parties first verbalise contradictory demands and then move towards agreement by a process of concession making or search for new alternatives"*

This describes negotiation as a search process in which negotiators jointly search for a single point of agreement. This search process progresses through interaction between parties during which they communicate their interest and make decisions to reach agreement. The communication helps negotiators to understand each other's interests and then to search for new alternatives for joint benefits. It is performed through some channels e.g. face-to-face, on the telephone, in writing, or using electronic media such as

email etc., to exchange offers. The negotiators prepare offers according to their preferences and negotiation objectives. The goal of a negotiator during offer preparation is to satisfy his or her maximum objectives. The offers are created using some of the decision making approaches (Raiffa et al. 2002).

Decision making in negotiations is not only the most important task but also its diversity makes it a difficult task. The negotiators can analyse negotiation decision problems using different approaches and behave differently in different negotiation scenarios and situations that produce different outcomes. The following sub-sections present known negotiation decision approaches used in negotiations and the negotiation strategies that result in different types of outcomes or agreements.

A short negotiation vocabulary follows before going into the details of negotiations and their models. Negotiation outcome, negotiation arena, negotiation agenda or structure, decision making rules, negotiation protocol etc., are the basic elements of a negotiation process (Bichler et al. 2003). *Outcome* is a conclusion reached through a negotiation process. It can be a compromise or a disagreement. *Negotiation arena* is a place where the parties communicate interests and alternatives in the form of offers. The *agenda* specifies the negotiation framework, including the specification of the negotiated issues and format in which they are presented (e.g., sequentially or simultaneously). The purpose of negotiation is to resolve these issues. *Decision making* helps in determining, analysing and selecting decision alternatives, making concessions or arguments etc. A *negotiation protocol* specifies the rules of communication that determine the way offers and messages are exchanged between negotiators. A *negotiation scenario* is a composition of all of these above elements. It is specified as a set of rules (decision making rules, protocol) and a negotiation object (agenda) (Ströbel & Weinhardt 2003). English auction on eBay is an example of a negotiation scenario.

2.2.1 Negotiation Decision Approaches

The negotiation literature differentiates among three decision making perspectives: individual decision making (descriptive and prescriptive approaches), the normative perspective, and the negotiation analysis (Raiffa et al. 2002). Every perspective is not applicable to every negotiation decision problem, neither can all three be combined to provide better analysis of the problem. A skilled negotiator can move back and forth

between different perspectives to analyse the problem from different angles and with different purposes in mind in order to arrive at a well-informed decision. These perspectives help in creating alternative agreements and associated uncertainties, knowing the priorities of other parties, calculating the joint pay-offs, approximating the other side reaction to offers, knowing the trade-offs etc. A description of each perspective is provided below.

2.2.1.1 Individual Decision Making

Individual decision making explains the decision structure in terms of available alternatives and payoffs from a single party perspective, and, therefore, simplifies the decision problem by excluding the explicit information about other party's preferences. Descriptive and prescriptive are two approaches in individual decision making (Raiffa et al. 2002). The *descriptive* decision making is concerned with describing how real people actually make decisions. The analysis of descriptive decision making helps in understanding and predicting the decision making behaviours of negotiators. The *prescriptive* approach describes how real people should make decisions. This approach promotes an understanding of problems before and during negotiations and, therefore, improves confidence in decisions, justification for decisions and satisfaction with consequences. Decision analysis is a practical application of the prescriptive approach, which provides tools and methods to achieve the objectives of the prescriptive approach. The decision analysis deals with decisions under certainty and decisions under uncertainty and risk. Descriptive and normative theories inform negotiation analysis tools and methods. In summary, an individual decision making perspective provides a theoretically well founded methodology to structure a negotiation problem so that, for example, a negotiator can decide with whom to negotiate or can compare the expected benefits of an ongoing negotiation with uncertain benefits of alternatives etc.

2.2.1.2 Normative Decision Approach: A Game-theoretic Approach

The normative decision theory suggests how fully informed, fully rational and super-intelligent people must make decisions to achieve certain decision outcomes (Raiffa et al. 2002). In contrast to individual decision making, this is an interactive decision making approach where the negotiation outcome depends on the choices made by two parties in

the negotiation scenario and the parties must consider carefully the alternatives, interests, aspirations, and behaviours of the other party. The majority of economics and game theory have a normative complexion. In order to realise the normative approach, the standard game theory implies that the negotiator must reason strategically in order to make a decision that optimises the outcome. This strategic reasoning includes that the party must take into account the decisions the other party may make, and must assume that it will act so as to optimise its own outcome. This means, the standard game theory assumes that the negotiators' knowledge is common regarding the valuations of negotiation issues and private deadlines for making a deal, the negotiation alternatives (called strategies in game theory) and associated payoffs are pre-determined, and so on (Jennings et al. 2001). The game theory deals with individual rationality and, therefore, the negotiators are only concerned with their individual high outcomes. For this reason, the normative approach is also known as non-cooperative approach to decision making. The normative theory does not take into account the known cognitive limits of negotiators.

2.2.1.3 Negotiation Analysis Approach

Negotiation analysis is a joint decision making approach that examines how groups of individuals can make mutually agreed-upon joint, collaborative decisions. The joint decision making emphasises the opportunities for co-operation between parties and helps them avoiding the trap of individual rationality of normative theory. A co-operative perspective of negotiation analysis measures the rationality of a decision against a group, rather than an individual. Raiffa and colleagues have identified four essential elements of joint decision making: joint decisions, joint payoffs, reciprocal communication, and creativity (Raiffa et al. 2002). These elements have been explained in comparison with the game theory. The joint decisions shift the focus from separate interactive actions of game theory to group actions. The opportunities of joint decisions can be availed throughout the negotiation process such as a joint decision on negotiation issues, a joint decision on post settlements, a joint decision on final agreements etc. In game theory, the separate interactive decisions of negotiators produce the joint payoffs, whereas the joint decision making assumes that the joint decision of parties determines the payoffs for each party. Joint decision making emphasises reciprocal and direct communication of interests,

expectations, persuasive arguments, aspirations, trade-offs, and so forth. The honest communication can result in understanding each other's needs and results in maximising joint gains. This is in contrast with the non-cooperative game-theory where no communication is allowed. From a creativity aspect, in game theory, the set of strategies and associated payoffs are pre-determined and common knowledge. But, in the joint decision making perspective, negotiators can be creative in their actions and decisions. It allows the invention of strategies, new options, creating of new alternatives etc.

The negotiation analysis approach is based on the theoretical models of decision analysis and game-theory, but in contrast to pure game theory, it takes into account the realistic assumptions about the way negotiations are conducted (Rangaswamy & Shell 1997). For example, both parties are not assumed to act in full game-theoretic rationality. Rather, they are expected to act according to the subjective assessment about the preferences of the other party (i.e., imperfect information available to them). Negotiation analysis is an application of decision analysis tools such as the multi-attribute utility assessment tool to help negotiators prepare for negotiations.

2.2.2 Negotiation Agreement Approaches

Raiffa et al. (2002) and Pruitt (1981) have categorised negotiations mainly into distributive and integrative types of negotiations. The categorisation is based on the structure of negotiations (agenda) and negotiation outcomes. Human behaviour plays an important role in the final outcomes. Sometimes a negotiation structure has the potential of reaching an agreement that is good (social welfare) for both parties in negotiation but the behaviour of negotiator(s) can make it good for one and a compromise for the other party. Negotiation behaviour is implemented through a negotiation strategy that a negotiator uses to move towards an agreement. The selection of negotiation strategies highly depends on the negotiation problem and the required outcome. They are used according to the demand level of a negotiator associated with an offer. Three basic strategies are unilateral concession making, competitive behaviour and coordinative behaviour (Pruitt 1981). A *unilateral concession* is a change of offer that reduces the demand level in the other party's favour. Concessions are made in a belief that they will lead to an agreement, prevent the other party from leaving the negotiation, or encourage

the other to make reciprocal concessions. The *competitive* and *coordinative behaviour* are described in the next sub-sections with respect to distributive and integrative negotiations.

2.2.2.1 Distributive Negotiations (Win-Lose Negotiations)

Distributive negotiations are *claiming actions* concerned with obtaining large shares (Raiffa et al. 2002). Such negotiations are one-dimensional settings in which parties negotiate over a single mutually exclusive goal i.e., parties try to maximise their share from the fixed values of issues. These negotiations are called win-lose or zero-sum games i.e., if one party gains some amount, the other party loses the same amount. Such negotiations are common in stock markets and auctions and often occur in single issue negotiations. A distributive negotiation on price only may not be well-suited for retail markets because it hides other value-added services of merchants from the consumer's consideration (Guttman & Maes 1998). Similarly, a merchant also suffers from price only negotiations by not being rewarded for its value-added services. The game-theoretic format of distributive negotiation is highly known.

The negotiation tactics associated with distributive negotiations are collectively called *competitive behaviour*. Since it is not possible for both parties to succeed, they choose competitive behaviour to persuade or force the other party to concede. Competitive behaviour demands unilateral concessions from the other negotiator by means of persuasive arguments, positional commitments, or threats (Pruitt 1981). For example, a persuasive argument by one party can make the offer attractive by identifying its qualitative features, which can encourage the other party to make concession or lower its demand level. Unilateral concession and competitive behaviour are alternative strategies.

2.2.2.2 Integrative Negotiations (Win-Win Negotiations)

Integrative negotiations are the opposite of distributive negotiations and are concerned with making the pie bigger for joint gains (Raiffa et al. 2002). An integrative negotiation is seen as a cooperative process of resolving decision problems. The cooperative process suggests that the negotiators should look wherever possible for new alternatives for mutual gains (Fisher et al. 1983). An agreement is said to be integrative to the extent that "*it reconciles the interests of both parties and thus provides high benefit to them*" (Pruitt

1981). For example, a seller's perspective in an integrative business negotiation is to tailor its offerings according to the needs of customer for better customer satisfaction which results in more benefit for the seller. A buyer perspective in integrative negotiation is the same as the seller perspective to fulfil more demands of the seller in a way that also benefits the buyer (Guttman & Maes 1998).

Negotiation behaviour to enable cooperative negotiation process and to achieve integrative agreement is referred to as *coordinative behaviour* (Pruitt 1981). The coordinative behaviour is normally possible in the presence of multiple independent and inter-dependent issues which are generally mutually non-exclusive. The coordinative behaviour or strategy is based on three bargaining tactics for the development of integrative solutions. In *incorporation* tactic, a negotiator adds to one's own proposal some element of the other negotiator's recent proposal. Incorporation tactic leads to the integrative solutions if the element(s) incorporated in the proposal is of high priority to the other negotiator. *Information exchange* tactic provides insight into the other party's preferences. Information exchange facilitates two types of integrative agreement, namely, *logrolling* and *bridging*. These methods require both parties to change their negotiation positions in an effort to reconcile their interest with one another. Logrolling potential exists when the parties have different priorities among the issues so that it is possible for them to exchange concessions on low priority issues and hence provide considerable benefits to the other party. Bridging occurs when a new option is developed (not previously under consideration) that changes the position of both parties and satisfies their most significant needs. Logrolling is facilitated by the exchange of information about priorities of negotiation issues, whereas bridging requires deeper information about the goals of negotiator and priorities among issues. A *heuristic trial and error* tactic involves frequent variations in one's proposal of a kind that only gradually reduces the level of benefit being sought for oneself. A search model of this tactic is entirely based on the negotiator's own preferences. The search model generates a series of alternatives that are proposed one by one to the partner and if the agreement is still not reached, then the search model is employed again after modification by unlinking and dropping lowest priority goals. The *heuristic trial and error* can also be used to achieve *logrolling* by chance.

2.3 Electronic Negotiations Models

Ströbel and Weinhardt (2003) define electronic negotiation as,

> *"An electronic negotiation in the strict sense is restricted by at least one rule that affects the decision making or communication process, if this rule is enforced by the electronic medium supporting the negotiation, and if this support covers the execution of at least one decision making or communication task".*

The essential aspect of electronic negotiations is that they are supported using the facilities of computer-based electronic media for communication (e.g. e-mail, the Internet etc.) and decision making. The actual contributions to the electronic medium for negotiations are the fields of computer science and information systems (Bichler et al. 2003). Such an electronic medium is referred to as an electronic negotiation system (ENS) (Ströbel & Weinhardt 2003). Neumann et al. (2003) have distinguished ENSs into bargaining systems and auction systems. The authors describe NSSs as bargaining systems, which help human negotiators to overcome problems that lead to inefficient outcomes. The other bargaining systems are automated bargaining systems, where software agents bargain with other software agents on behalf of their user. The auction systems, ANSs, and NSSs are all ENSs and are based on three electronic negotiation models, *electronic auction model* (section 2.3.2), *automated negotiation model* (section 2.3.3), and *negotiation support model* (section 2.3.4), respectively (Schoop et al. 2003). Our focus is on bargaining systems in this research, but for reasons of completeness, we will also discuss electronic auctions as they are also ENSs.

2.3.1 Communication Theories in Electronic Negotiations

Electronic communication in electronic negotiations is enriched with two theories of language and communication. These communication theories are known as the *theory of speech act* (Searle 1969) and the *theory of communicative action* (Habermas 1984). These theories are accepted mechanisms to model explicit and pragmatic communication among

human negotiators (e.g. Schoop et al. 2003) and among software agents (e.g. Faratin 2000) in electronic negotiations.

The *speech act theory* is a high-level theoretical framework influenced by philosophy and linguistics for human communication in social interactions. This theory was developed with John Austin (Austin 1962) who pointed out that every natural language utterance or statement is not meant to be a description of true or false of anything, but such statement performs an action e.g. to request, to assert, or to promise etc. He observed different classes of such utterances. In this theory, a statement, called a *speech act*, is considered to be the minimal unit of communication. A speech act is composed of two components—considered as elementary acts: a locutionary and an illocutionary component. The locutionary component represents a propositional/information content of a speech act, whereas the illocutionary component is characterised as illocutionary force that represents the action in a speech act. For example, in an utterance, 'I want you to close the door', the speaker of this speech act is requesting the listener to close the door. In this example, the information content is the *proposition about the door* and the object of the illocutionary force, whilst the illocutionary component is the illocutionary force of *requesting*. In short, the propositional content describes what an utterance is about, whereas the illocutionary force describes the way it is uttered. Taken together, both components provide the meaning of the communication—the semantics and the pragmatics. The semantics of illocutionary acts in speech act theory can be described as that the speaker is attempting to communicate his or her mental state. And in most cases the listener assumes the speaker is in the required mental state, and the act succeeds (Cohen & Levesque 1995).

Austin's work was extended by Searle (1969) and Habermas (1984) with their own work on speech act theory. Searle identified necessary and sufficient conditions for speech acts and classified speech acts into five classes (Searle 1969). The speaker must comply to necessary and sufficient rules, if (s)he wants to succeed. An utterance or speech act belongs to one of these five classes of speech acts: *assertives* (e.g. informing), *directives* (e.g. requesting), *commisives* (e.g. promising), *declaratives* (e.g. declaring marriage) and *expressives* (e.g. thanking). The classification of speech acts has been explained on three (out of twelve) most important dimensions: *illocutionary point*; *direction-of-fit*; and *psychological state* of speaker (Eriksson 1999). The dimension

"*illocutionary point*" classifies the speech acts from the pragmatic point of view. The illocutionary point determines the main pragmatic function (illocutionary force) of the speech act. According to Searle, there are exactly five illocutionary points which correspond to the five classes of speech acts. The *direction-of-fit* shows how the propositional content of a speech act can be related to the world. With the propositional content, the speaker can either describe the existence (assertion) of certain states of affairs (facts) or express the states of affairs (s)he wants to bring about (promise) or see brought about (request). When a speaker performs a speech act, (s)he expresses some attitude (belief, desire, and intention) to the information content of the speech act. The *psychological state* of the speaker determines this attitude e.g. when a speaker performs an assertion (s)he expresses a belief.

Habermas (1984) developed the Theory of Communicative Action that makes humans to coordinate their action plans with mutual understanding. The communicative action theory uses speech acts for the coordination of social interaction and assumes some validity claims for mutual understanding. A speaker who performs a speech act raises four validity claims that must be comprehended and accepted by the listener if the speech act is to succeed. After that the listener enters into the intended relationship (a communicative intent is expressed by illocutionary force) with the speaker. This relationship implies obligations that drive the social interaction between the speaker and listener. The four implicit validity claims raised by the speaker are *comprehensibility*, *truth*, *sincerity*, and *appropriateness* of the utterance. The claim comprehensibility assumes that the listener can understand the speaker; the claim truth assumes that the utterance represents a fact or belief, and the listener can share the speaker's knowledge; the third claim is about the speaker's sincerity in intentions in utterance so that the listener can trust the speaker; the claim appropriateness assumes that the utterance is appropriate in relation to a given normative context and values so that the listener can agree with the speaker in these values (Schoop 2001). For example, a teacher requesting a student to open the window is a simple example of social interaction (Eriksson 1999). If the student comprehends and accepts the request as valid and opens the window then the social interaction can be characterised as a communicative action. A communicative action includes both the speech act and the material act.

2.3.2 Electronic Auction Model

An auction is a market institution "*with an explicit set of rules determining resource allocation and prices on the basis of bids from the market participants*" (McAfee & McMillan 1987). Auctions are used for products such as artwork items, second hand articles, agricultural products etc., whose values depend on the demand and supply conditions at a specific moment of time. In auctions, products and commodities with standardised descriptions are sold to buyers who pay the highest value. Auctions are considered as a special class of intertwined distributive negotiation involving three or more parties (Raiffa et al. 2002). The emergence of auctions in electronic commerce has produced very successful new business models (e.g. eBay) and enabled auctioneers to reach global customers with very special interests. Electronic auctions provide allocation efficiency for specific product segments such as flight tickets, over-stocks etc., while maintaining the traditional distribution channels and trade forms (Klein 1997). The characteristics of auctions, such as single dimension, price, fit them well for automated negotiations (Beam et al. 1996). Wurman and colleagues (1998) have developed an electronic auction system, called Michigan Internet AuctionBot, for price-based negotiation that supports both software agents and human agents.

McAfee & McMillan (1987) have presented a number of auction mechanisms for determining price. They are distinguished based on the number and type of participants, trading objects, the bidding rules, clearing schedule, closing conditions, revelation of price quotes etc. (Wurman et al. 1998). The selection of a suitable auction mechanism in the given context is done on the basis of economic rationale behind the auction and the motives of the participants. A partial taxonomy of basic auction types is presented in Figure 2.1 below.

In the taxonomy, auctions are classified as *single-sided* or *double-sided*. In *single-sided* auctions, only one side can bid in the auction while the other side has the role of auctioneer. The usual pattern of interaction in *single-sided* auctions is one-to-many, in which an auctioneer initiates an auction and a number of bidders (bidders are uniformly of type buyer or uniformly of type seller) bid in that auction. In *double-sided* auctions, several sellers and buyers submit bids simultaneously. *Double-sided* auctions have the pattern of many-to-many interactions in which there are more than one auctioneer and

more than one bidder. Further distinctions are made whether the bids are *public* (outcry) or *sealed* (SB). The examples of each category of auctions are shown in the figure.

The *English auction* is a single-sided open outcry (all bidders know the current bid) ascending-bid auction. In this auction mechanism, the price of an item is successively raised (i.e., ascending) by the bidders during bidding. The item is sold to the highest bidder at the end of the auction. English auctions are mostly used for the selling of antiques and artwork. The *Dutch auction* is a descending-bid auction and used for selling agricultural products, fish etc. In the Dutch auction, the auctioneer starts at with an initial high price and then incrementally lowers the price (i.e., descending) until one bidder accepts it. The bidding in English and Dutch auctions is outcry, therefore the current bid or price is known to every bidder. The *first-price sealed bid* (FPSB) auction is used for both buying and selling. In this mechanism each bidder submits only one bid to the auctioneer and the contract is awarded to the lowest bidder in the case of a buying auction and to the highest bidder in the case of a selling auction. The bids are sealed i.e., the bidders are not aware of each other's bids. The *Vickrey auction* (also called *second-price sealed bid auction*) is similar to FPSB auction except that in the Vickrey auction the winner pays the second highest price instead of his or her highest bid. A double auction is a commonly proposed symmetric resolution procedure, in which all parties disclose their reservation values simultaneously. The *continuous double auction* (CDA) is the primary institution for trading commodities, equities and derivatives in financial markets such as NASDAQ and the NYSE (Das et al. 2001). In a CDA, a trade is performed immediately after a match between ask price and bid price is detected. The *call markets* (also called clearing house) aggregate bids over time and clear them at scheduled intervals.

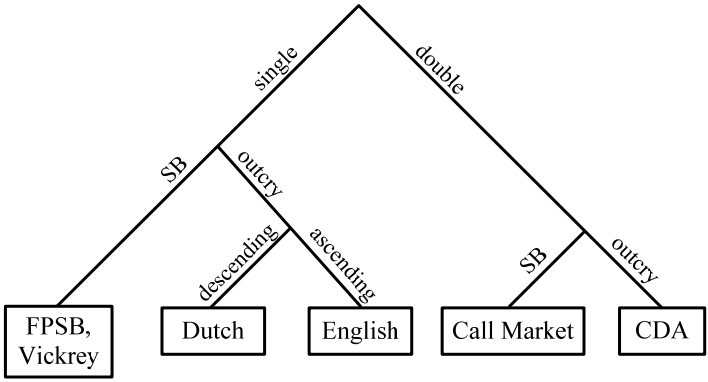

Figure 2.1: A classification of common auction mechanisms (Wurman et al. 1998)

The three core activities, namely receiving bids, submitting bids and clearance of goods against payment, of each auction mechanism require decision making and exchange of different messages. Decision making in these activities can be simple or complex depending on the auction mechanism being used. For example, when a seller receives a bid in an English auction, it is verified against the auction rules i.e., if this bid is higher than the last bid. When a buyer or bidder wants to submit a bid, the current highest bid is increased to some certain level and it is verified whether the newly created bid is within the reservation value. Communication in auctions consists of different messages containing only ask or bid prices.

2.3.3 Automated Negotiation Model

In the automated negotiation model, autonomous software agents perform negotiations on behalf of their human principal. Research on automated negotiations deals with four broad topics: negotiation protocol; negotiation structure; decision making model; and communication model (Jennings et al. 2001, Oliver 1996). Agent decision making model and agent communication model are our main interest and will be discussed later in detail in chapter 4. Here in the sub-sections, we introduce the computational entity called ‘autonomous software agent’ and its growing role in electronic negotiations.

2.3.3.1 Software Agents

Software agents are seen as a next generation model for complex and distributed software systems. A software agent is an artificial entity that works intelligently and proactively to provide solutions to real life problems. Software agents are studied in artificial intelligence (AI), which is concerned with making computers and software systems intelligent and autonomous. The agent paradigm brings together different sub-disciplines of AI such as machine learning, planning, distributed artificial intelligence (DAI) etc., that are essential to develop autonomous and intelligent pieces of software (Jennings et al. 2001). According to Brenner et al (1998),

> *"Intelligent Software Agents are defined as being a software program that can perform specific tasks for a user and possesses a degree of intelligence that permits it to perform part of its task autonomously and to interact with its environment in a useful manner"*

Software agents operate in some environment, which provides a platform to perform valid actions in order to achieve self-defined or user-defined goals. An intelligent software agent is characterised by having the abilities of acting on its own initiatives, working cooperatively and communicating with other agents to accomplish goals using limited information and knowledge. A number of software systems have been developed as complete agent systems or include software agents only for specific tasks (e.g. http://www.aerogility.com, van Aart et al. 2002, Singh et al. 2005, Kersten & Lo 2003). The agent systems range from an operating system demon to highly sensitive multi-agent systems for air-traffic control, from online shopping assistants to multi-attribute automated negotiations, from appointment scheduling assistants to supply chain management, from email filtering to knowledge management etc. (Jennings et al. 1998). For example, in an electronic supply chain, software agents enhance interaction among business partners and reduce their cognitive load (Singh et al. 2005). In negotiation support systems, agents perform an advisory role and guide negotiators through the negotiation process (Kersten & Lo 2003). The appropriateness of using agent technology depends on technology benefits and the characteristics of tasks or processes (Guttman et al. 1998) such as the time or money saved by automating certain process; the ease of

delegating tasks e.g. expressing preferences for task; the risks attached to sub-optimal transaction decision; the consequences for missed opportunities. The agent-based solutions can be used for technical benefits as well as for financial benefits.

2.3.3.2 Automated Negotiations

Automated negotiation is a process in which two or more intelligent software agents bargain for resources autonomously for mutual intended gain, using the tools and techniques from computer science and information systems, and then present solutions to their human principals (Beam & Segev 1997). The need for negotiation among agents arises to solve the problems posed by their interdependence upon one another. "*Negotiation among agents is a form of interaction in which a group of agents, with conflicting interests and a desire to cooperate, try to come to a mutually acceptable agreement on the division of scarce resources*" (Ashri et al. 2003, Jennings 2000). Resources can be anything such as machines or computer resources to carry out tasks, services, commodities etc.

Automated negotiations are argued to exploit the full potential of electronic commerce (Lomuscio et al. 2001). The autonomy and rationality of software negotiation agents make automated negotiation advantageous over face-to-face manual negotiation. The autonomous feature of negotiation agents saves the time of human principals. Das et al. (2001) have argued that people would not entrust software agents in delegating economic decision making in automated negotiations unless agents can obtain on average better financial and performance results than humans without introducing undue risks. Raiffa et al. (2002) have mentioned various human negotiation behaviours (e.g. falling into psychological traps, showing impatience or biases etc.) that are irrational and lead to inefficient negotiation agreements for one party or both. A negotiation agent, unlike a human negotiator, is safe from human sensibilities and always makes rational decisions within its abilities (Greenwald et al. 2003).

Jennings et al. (2001) have defined automated negotiation process as searching for an agreement in a space of potential agreements, as shown in Figure 2.2. In the beginning of a negotiation, each agent has a region of space in which it is willing to make agreements. Each point in this region represents an agreement. The agent uses a utility function to rate each agreement in this region and then uses this rating to determine the

actual agreement it makes. The negotiation proceeds as the participating agents exchange potential agreements to counterparts. The negotiation process terminates when the latest offer lies within the space in which two agents are willing to accept agreement, or when one of the agents has reached its reservation value and rejects the offer. According to this framework, the minimum negotiation capabilities of negotiating agents are to make proposals constructed from one's agreement space and to respond to each incoming proposal indicating whether it is acceptable. Advanced agents can provide feedback to counterparts by sending counter-proposals, critiques, or arguments. Figure 2.2 shows that there exists an agreement possibility between agents A1 and A2, as the parts of their individual regions of acceptability overlap in the negotiation space.

As mentioned before, research on automated negotiations deals with four broad topics: negotiation protocol; negotiation structure; decision making model; and communication model (Jennings et al. 2001, Oliver 1996). These elements make the main components of an ANS. The importance and implementation of a particular element in an ANS depends upon the negotiation scenario and the environment context. Auctions are basically bidding protocols that have prime importance in automated auction systems, while the communication model, decision making model, and negotiation structure are rather simplified. For example, in an English auction scenario, there is only one issue 'price' in the negotiation structure and the agents have simple decision making models i.e., their only dominant strategy is to bid up to their reservation value. The communication is simply sending a bid value to the auctioneer. In the other cases, such as multi-attribute or argumentation-based automated negotiations (e.g. Luo et al. 2003, Sierra et al. 1998, Parsons et al. 1998, Faratin 2000), agents' decision making model, negotiation structure and communication model are the dominant concerns in an ANS. In such negotiations, agents have complex strategic and reasoning behaviour and to communicate issues' values, critiques, arguments etc., agents need a rich communication model.

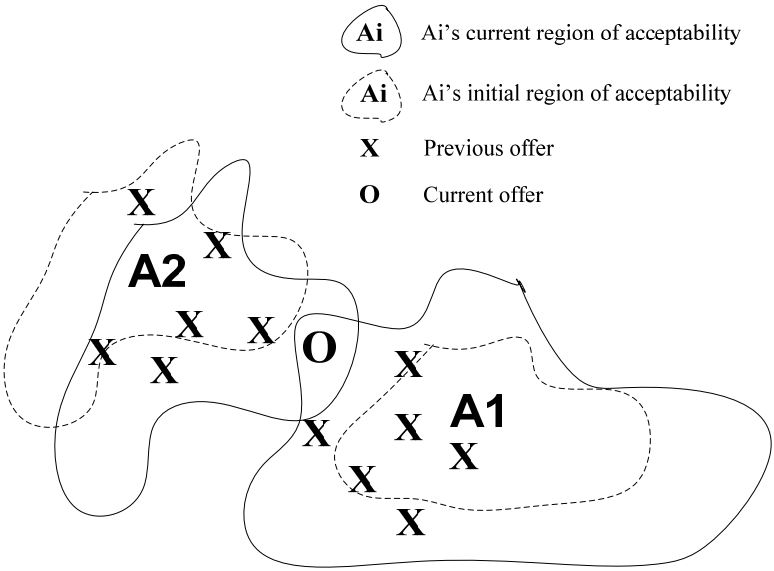

Figure 2.2: Negotiation agreement space (modified from Jennings et al. 2001)

2.3.3.3 Automated Negotiation Methods

The potential of software agents for electronic negotiations can only be realised when they have the means to perform direct party-to-party negotiations, to perform multi-issue negotiations, to conduct negotiations based on incomplete and imprecise information, and to adapt their negotiation strategy (Alem et al. 2000). These negotiation abilities of an agent are realised and used in an ANS according to a negotiation scenario and a negotiation mechanism. Automated negotiation scenarios have been differentiated on the cardinality of issues and participants, characteristics of environment and issues etc., and the mechanisms can be classified according to their certain properties (e.g. computational, communication and outcome efficiency) (Lomuscio et al. 2001). The negotiation mechanism constrains the types of operations on the negotiation object and prescribes the behaviour of the agent's decision making for a particular negotiation scenario (Jennings et al. 2001). The same negotiation scenario can be implemented differently and can produce different outcomes depending on the properties of a mechanism. An agent's negotiation abilities depend actually on the implemented mechanism for the given negotiation

problem. Negotiation mechanisms have been categorised according to three techniques: game-theoretic techniques; heuristic techniques; and argumentation-based techniques.

Game-theoretic Techniques: Game-theoretic techniques (cf. 2.2.1.2) are relevant to the automated negotiation because agents in negotiations are self-interested (e.g. zero-sum games, see 2.2.2.1). The game theory provides tools for the design of multi-agent architectures for automated negotiations where interacting agents try to satisfy only their principal's goals and do not think about global utility (Binmore & Vulkan 1997). These design tools and principles are mainly used to design negotiation protocols and negotiation strategies for automated negotiation mechanisms and negotiation agents (Jennings et al. 2001). A negotiation strategy is decision making behaviour of a negotiating agent that purely depends on the design of an underlying negotiation protocol. The negotiation strategies provided by game theory work best in theory but are unusable by agents in practice due to the high associated computational costs (Faratin 2000).

The success of game theory in automated negotiation is due to its ability to design simple negotiation protocols e.g., monotonic concession protocol with Zeuthen strategy, which show many desirable properties (Rosenschein & Zlotkin 1994). Despite the advantages of game theory, it has several assumptions that restrict its application in many automated negotiation scenarios. For example, game theory assumes that it is possible to define an agent's preferences with respect to possible outcomes. This assumption limits the use of game theoretic models to scenarios in which preferences are obvious such as buying a CD at minimum price. Humans, however, find it hard to consistently define their preferences over outcomes in more complex scenarios such as multi-issue negotiations. Secondly, the theory does not provide a general model governing rational decision in different interdependent negotiation problems. Thirdly, the game theory techniques assume perfect computational rationality i.e., no computation is required to find mutually acceptable solutions, and the space of possible deals is fully known to the participating agents. In practice, however, physical mechanisms take time to process information and agents typically only know their own preferences.

Heuristic Techniques: The heuristic techniques overcome the limitations of game-theoretic techniques and acknowledge the cost associated with computation and decision

making. These techniques are based on realistic assumptions such as that participants have bounded rationality and the negotiation preferences are not common knowledge; hence they can be used in a wider variety of application domains in automated negotiations. The central aim of this approach is to model the agent's decision making heuristically during the course of the negotiation (Faratin 2000, Faratin et al. 2002). These models work within a fairly free negotiation protocol (Jennings et al. 2001). Unlike in the game-theoretic approaches, the chosen negotiation protocol in heuristic approaches does not prescribe an optimal strategy or course of action. In these models, a protocol normatively describes only the orderings of actions and separately decision making mechanisms (responsive, deliberative etc.) describe the possible set of agent strategies. Mostly automated negotiation models or mechanisms (see section 4.3) based on heuristic approach search for joint welfare (cf. section 2.2.2.2).

The heuristic techniques have few disadvantages compared to the game theoretic techniques (Faratin 2000). They do not examine the full space of possible agreements and hence often select outcomes that are sub-optimal. These approaches need extensive evaluation, typically through simulations and empirical analysis, since it is usually impossible to predict precisely the behaviour of system and the constituent agents in a wide variety of circumstances.

Argumentation-Based Techniques: The argumentation-based approach to negotiation is argued to be a more sophisticated form of negotiation than game-theoretic and heuristic-based approaches (Jennings et al. 2001, Parsons et al. 1998). In the game-theoretic and heuristic-based negotiations, the primary negotiation content in offers are the negotiation issues and their values. The argumentation-based negotiation models allow agents to create also meta-information (in addition to simple offers, acceptance and rejection utterances) in form of persuasive arguments (threat, reward etc.) to make negotiation behaviour more explicit. With meta-information, the counterparts try to convey negotiation demands or stance clearly as a strategy to convince their counterpart. Thus using these approaches, an agent can send a critique along with a rejection message explaining why the proposal was unacceptable, or similarly, an agent can accompany a proposal with an argument which explains why the opponent should accept the proposal. In the latter case, for example, a persuasive argument can change the opponent's region of

acceptability by altering its preferences, and also may change the negotiation space itself. Persuasive arguments can be used for both integrative and distributive negotiations. This automated negotiation approach is discussed later in detail (in section 4.4).

2.3.3.4 Characteristics of Negotiation Software Agents

For a given negotiation scenario, the basic negotiation abilities of an agent are implemented according to the underlying automated negotiation mechanism. Ashri et al. (2003) have categorised negotiating agents into basic negotiating agents and argumentative negotiating agents on the basis of information they exchange. The primary type of information exchanged between basic negotiating agents is offers. The negotiation agents implemented for game-theoretic and heuristic type mechanisms can be called basic agents. Agents implementing argumentation-based negotiation models are called argumentative negotiating agents. So, for a given negotiation scenario, the basic negotiation abilities of an agent are designed and implemented according to the underlying automated negotiation mechanism (e.g. functions of generating offers or arguments, available negotiation protocol, expected outcome). However, how these basic negotiation abilities are used strategically to achieve a good outcome is the task of the agent's designer. The following characteristics are attached to agents' decision making behaviour and have been collected from works on software agents and automated negotiations (e.g. Lomuscio et al. 2001, Jennings et al. 2001, and Griss 2001).

Rationality: An agent's rationality might be perfect or bounded. A perfect rational agent needs to perform large computation in constant time, which is, in practical scenarios, not possible due to an agent's limited computational power. Agents with bounded rationality are more realistic.

Knowledge: There can be different degrees to which an agent is capable of reasoning about its goals and knowledge. The agent's knowledge can include domain or business knowledge, implicit or explicit knowledge about private constraints, preferences and utilities of opponent agents etc. Agents cooperating with one another normally have explicit knowledge, whereas in competitive electronic negotiations settings, it is difficult

to assume that agents have explicit and full knowledge about other agents (Alem et al. 2000).

Social behaviour: The agent can be only self-interested or can also think about joint welfare.

Negotiation strategy: This is a mechanism of preparing, accepting and rejecting (counter)-offers. The bidding strategy depends on the agent's rationality, knowledge and the negotiation protocol etc.

Adaptability: The degree to which an agent can adapt itself during the negotiation process in the dynamic environment and changes its behaviour accordingly e.g. its utility function, negotiation strategy etc., determines its adaptability.

Autonomy: In agent-based systems each agent has its own thread of control. Agents have control over their behaviour. They are reactive, proactive and social. Thus, an agent takes actions autonomously without any outside intervention to fulfil given negotiation goals.

2.3.4 Negotiation Support Model

Experiments on negotiation outcomes and negotiators' behaviour have shown that humans do not prepare adequately for negotiations and merely depend on their bargaining experience and expertise (Raiffa et al. 2002). Such experience and expertise are normally based on behavioural intuition rather than rational prescriptions. These behavioural intuitions in decision making may lead to behavioural errors or biases affecting the rational outcomes of negotiations. Moreover, humans are often not clear about issues in the negotiation, their reservation values on issues, possible trade-offs, etc. hence they cannot examine their fundamental interests in negotiation. It is a difficult task for them to order a set of alternative agreements to determine whether one offer is of higher importance than the other offer, especially in multi-issue negotiations (Pruitt 1981).

The complexity of negotiations and behavioural short-comings of human negotiators led to research in negotiation support systems (NSSs) (Jelassi & Foroughi 1989, Rangaswamy & Shell 1997). NSSs are interactive, computer-based systems

intended to support human negotiating parties in reaching an agreement over complex and hard negotiations (Jelassi & Foroughi 1989). NSSs are based on negotiation support approaches, which do not automate the negotiation process but provide IT support for negotiations, leaving the control over the negotiation process with the human negotiators from initial problem setup to final agreement (Schoop et al. 2003). NSSs are different from auction negotiation model in that they are for bilateral multi-issue negotiation problems. These decision and negotiation support tools structure the negotiation process and help focusing on the negotiation issues and searching for a compromise. The maturity of formal methods for decision and negotiation analysis and the use of electronic web-based systems in business transactions play a critical role in the use of NSSs in real negotiations (Kersten & Noronha 1999).

The next sub-sections present the most important (and well-known) existing NSSs and their decision and communication support.

2.3.4.1 Negotiation Support Systems

NSSs are electronic media for business negotiations between human negotiators. An NSS is supposed to provide three main negotiation functionalities, namely, *negotiation requirement analysis*, *strategic analysis*, and *interaction per se* (Lim & Benbasat 1992). These higher-level functionalities are divided into several smaller activities that together make a complete negotiation process. These activities in a negotiation process have been divided among three phases: *pre-negotiation*, conduct of *negotiation*, and *post-settlement* (Kersten & Noronha 1999). Figure 2.3 illustrates the three phases and the activities in each phase. A phase in a negotiation processes is viewed as "organizing the intellectual efforts of the negotiators so that they can think more clearly and can deal efficiently their basic differences" (Pruitt 1981). The pre-negotiation phase is mainly the negotiation requirement analysis phase, which involves activities for understanding the negotiation problem, setting the negotiation issues and available options, and evaluating possible trade-offs. The problem is understood by eliciting preferences on negotiations issues, available options, and possible alternatives. The outcome of pre-negotiation phase is the construction of a utility function that is used to evaluate offers in the next two phases for decision making. The second phase is the strategic analysis and interaction phase. The main activities involved in this phase are to evaluate, create and exchange offers. In the

post-settlement phase, the system plays the role of mediator between parties for an efficient agreement. For this, the efficiency or pareto-optimality of agreement reached so far is checked. The efficient agreements are computed, if possible, and presented to the parties for approval/re-negotiation.

Figure 2.3: A three-phase negotiation process

Not all NSSs support the same three-phase negotiation process. The difference in processes and outcomes of negotiations depends upon the distinct support philosophy by NSSs. NSSs differ in the implemented components, the bandwidth of communication media, and the degree of structure imposed by the systems (Köszegi et al. 2004). NSSs have been classified as preparation and evaluation systems and process support systems (Rangaswamy & Shell 1997). The preparation and evaluation systems operate away from the bargaining table to help negotiators in privately organising information, developing preference representations, refining the pre-negotiation strategies, and evaluating the mid-negotiation offers etc. The process support systems operate at the bargaining table. These systems restructure the dynamics and procedures of the negotiation process in order to make salient the possible gains from integrative bargaining. Thus, these systems are designed not only to assist parties in gaining a subjective representation of the negotiation situation but also to help negotiators to move towards more integrative settlements. According to Neumann et al. (2003), the process support systems meet the definition of trade ENSs as they enable negotiations for the exchange of goods and services. The process support systems are further classified into *mediation systems* and *interactive bargaining systems*. In *mediation systems*, a mediator (computer or human) prompts the

parties towards a joint agreement. All communication between the parties is through a mediator, although the parties remain in control of the outcome. *Interactive bargaining systems* simultaneously support the negotiation processes of all the parties, and enable the parties to communicate directly with each other. A similar but simple classification divides the NSSs in solution-driven and process-driven systems (Köszegi et al. 2004). The solution-driven systems provide only decision analysis support, whereas the process-driven systems support and enhance the complete negotiation process. All three NSSs discussed here are classified as interactive bargaining systems (sub-class of process support systems). These NSSs support the complete negotiation process and meet the definition of trade ENSs. For our purpose, they support bilateral multi-issue bargaining process.

Negoisst: It is a web-based process-oriented negotiation support system proposed for business-to-business negotiations (Schoop et al. 2003). It is based on the DOC.COM framework (Schoop & Quix 2001) for negotiation process support. The DOC.COM framework specifies the communication and document management components of NSSs. The communication management component supports interactive organisational communication by means of electronic messages between negotiators. The document management component prepares contract documents from the exchanged messages and keeps track of the evolution of a business contract. This framework enables monitoring of contractual obligations and the traceability of both documents and messages, and their interrelations. The Negoisst system has been further enhanced with decision support (Schoop 2004) and ontology-based negotiation approach (Schoop & Jertila 2004). It provides *ontology negotiation* activity to specify the negotiation issues/vocabulary explicitly. The negotiation process in Negoisst is implemented on the three-phase model approach (discussed above).

Inspire: Inspire (Kersten & Noronha 1999) is an interactive Web-based NSS that has been used as a research tool, to analyse the effectiveness of computer and communication technologies for conducting cross-cultural negotiations, and to see the impact of different decision making styles on the design of NSSs. It is used as a training tool to help human users in formulating and evaluating offers and to train them in negotiation strategies and

negotiation handlings. The Inspire system provides analytic negotiation support features and a communication platform. The above mentioned negotiation process and the supported activities have been defined for the Inspire system. The communication is done through exchanging offers and counteroffers. For decision support, a negotiation analysis approach has been implemented through the use of negotiation history and negotiation graph. The structure of negotiation issues is fixed in Inspire as the negotiators cannot add or delete issues from a negotiation scenario.

Negotiation Assistant (NA): NA (Rangaswamy & Shell 1997) is another NSS that is based on negotiation analysis concepts (Raiffa et al. 2002). Like Negoisst and Inspire, NA is designed to be more of a facilitator, rather than a mediator and provides three main functions for performing negotiation, namely, preparation for negotiation, structured communication, and post-settlement evaluation.

The use of coordinative behaviour to achieve integrative agreements is concerned with information exchange between negotiators and with calculating new possible agreements (Pruitt 1981). These communication and decision making aspects of negotiation are active through-out the negotiation requirement analysis, strategic analysis, and message exchange through the integration of decision-theoretic approaches with communication support along with different visualisation tools in NSSs (Schoop et al. 2003, Kersten & Noronha 1999, Rangaswamy & Shell 1997). The experiments show that the use of NSS with decision and communication support led to more integrative settlements than without it in face-to-face or over email negotiations (Lim & Benbasat 1992, Rangaswamy & Shell 1997). Lim and Benbasat (1992) present a theory to understand the effects of decision support system (DSS) and communication channel in NSS in a bilateral multi-issues negotiation setting. The theory conceptualises NSSs as consisting of two decision support systems (DSS) interconnected with an electronic communication channel. The hypotheses that were established show that the combination of these two components results in more efficient, confident, quick agreements. Also the experiments have shown that the use of all three functions (preparation, structured communication, post-settlement evaluation) lead to more integrative negotiations than using only a single function, i.e., not only

preparation but also structured communication make trade-offs possible and add value to integrative negotiations (Rangaswamy & Shell 1997).

2.3.4.2 Decision Support in NSSs

Decision support tools in NSSs affect the behaviour of negotiators. Köszegi et al. (2004) have shown that an NSS with decision support features increase the likelihood of agreement as compared to an NSS without decision support. The sophisticated decision support provided by the NSSs is based on the negotiation analysis approach. As discussed before, the negotiation analysis approach (section 2.2.1.3) is a systematic way to help negotiators achieve more integrative outcomes, in contrast to individual decision making (cf. section 2.2.1.1). All three NSSs implement the negotiation analysis approach. In operational terms, negotiation analysis is used for developing methods to achieve integrative settlements by giving negotiators decision-analytic and other tools to help them articulate their own preferences clearly, and to help one or more parties match up their preferences with those of other parties during the negotiation process (Rangaswamy & Shell 1997). Negotiation analysis focuses on subjective perceptions of possible zones of agreement, with the objective of identifying agreements that are "among the best" available to the parties. The concept of decision support in NSSs comes from the decision support systems (DSSs) (Lim & Benbasat 1992). But, decision support in NSSs is different from a DSS, which is a computer-based system that aids managers and professionals in individual decision making in semi-structured decision tasks through direct interaction with data and models.

The applications of negotiation analysis techniques and methods are found in all three phases of negotiation process. The prescriptive or individual decision making element is used for the preparation of negotiation as well for evaluating incoming or outgoing offers. The joint decision making feature of negotiation analysis helps negotiators in searching for trade-offs and contracts that increase both party's welfare during the negotiation and settlement phases.

Pre-negotiation Phase: In the pre-negotiation phase, NSSs provide negotiators with some preference elicitation technique (such as hybrid-conjoint) for analysing the negotiation problem and specifying preferences on issues. The result of this analysis is a construction

of the private utility function for each negotiator. The negotiators use utility functions to rate incoming and outgoing offers. This technique provides the subjective evaluation of offers and counteroffers. It is more likely that the negotiators identify trade-offs using this technique and hence, move toward integrative negotiations.

Negotiation phase: In the negotiation phase, the NSSs offer decision support in the form of a quantitative evaluation of incoming/outgoing offers and the history of a negotiation process i.e., the exchanged offers. The quantitative evaluation of offers tells the level of fulfilled preferences and helps negotiators decide about the acceptance or rejection of an incoming offer, or continuing the negotiation process by sending a counteroffer for better agreement. The negotiation history is viewed using a variety of graphical visualisation tools. The tools help negotiators in doing a strategic analysis of negotiation patterns and adapting the strategy accordingly. Negotiators can analyse the direction of the negotiation. The negotiators can adopt trial and error methods to create trade-offs or they can exchange information with each other to get feedback on exchanged offers. A unique feature of the Negoisst system for decision making is that it allows creation and evaluation of partial offers (see next section 2.3.4.3).

Post-settlement: The decision support based on negotiation analysis in NSSs seeks ways to anticipate the likelihood of post pareto-inefficient agreements, in order to identify ways to help the parties to expand the pie. Once the negotiators have reached the agreement, the NSSs can check the pareto-optimality of the agreement by taking into account the negotiators' utility functions. If the reached agreement is not Pareto optimal, the system calculates efficient solutions and present to both partners for acceptance or re-negotiation. The Inspire system follows such approach.

2.3.4.3 Communication Support in NSSs

The negotiation phase in an electronic negotiation is a communication-intensive phase. The communication includes messages from simple bids to complex offers. In a negotiation analysis approach, communication between negotiators is an essential part of the negotiation (Fisher et al. 1983). Integrative negotiation is a process of communicating back and forth for the purpose of reaching a joint decision. There are many co-operative

negotiation behaviours (e.g. information exchange tactic) that require efficient and structured communication between counterparts (cf. section 2.2.2.2). In other words, by adopting a joint decision perspective, negotiators can better conceive how communication will facilitate the drafting of joint agreements for the benefit of both sides. As mentioned before, the structured communication support combined with decision support leads to more integrative outcomes.

Due to the importance of communication in negotiations, Köhne et al. (2004) have argued for a *communication perspective* on electronic negotiations that is necessary for the design of NSSs. They have defined the communication perspective through a communication process model. The communication process model has been defined at three levels of abstraction: the information level, the communication level, and the media level. The *information* level deals with the content of a message. The *communication* level defines the context of messages and represents the intention of message sender. The *media* level describes the physical characteristics of the communication process. In the following paragraphs, the communication support in NSSs is discussed according to the information and communication levels.

Message Structure in NSSs: Figure 2.4 shows the general structure and the components of electronic negotiation messages in NSSs. The message structure and its components are taken from the Negoisst and Inspire systems. *Message* is the top-level component and consists of two components: *meta-data* and *content*. The meta-data consists of fields to represent, for example, the sender and recipient of a message, the type of message, the date and time associated with message etc. The content part comprises the content of a negotiation message that includes negotiation issues, issues values, information about product or service, comments, arguments, queries etc. The content is the information that is created and exchanged between negotiators and that represents the negotiation position of negotiators.

The Negoisst system and the Inspire system implement the below message structure and its components differently. The aim of Negoisst is to support flexible and unambiguous communication in real business negotiations as well as to extract the partners' obligations from the exchanged messages. For these purposes, the communication support in Negoisst is based on communication theories of speech act and

communicative action, and on the use of structured ontologies. The aim of Inspire system is to study the impact of computer and communication technologies on negotiation outcomes in cross-cultural negotiations rather than providing enhanced communication support for electronic negotiations.

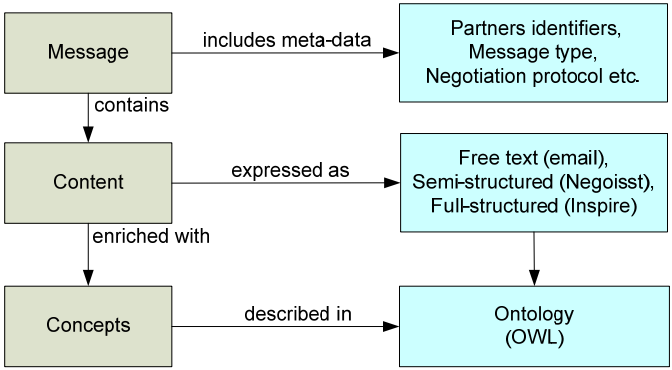

Figure 2.4: General structure and components of negotiation messages in NSSs

Negoisst: The context of the communication support model in the Negoisst system lies in the language-action perspective (LAP) to support the organisational communication (Schoop et al. 2003). The focus of LAP is on the pragmatic aspects of written language (Schoop 2002) and is based on the above mentioned theories of language and communication—the speech act theory and the communicative action theory (cf. section 2.3.1). In the Negoisst system, a message type and the message content are the two main parts of a negotiation message. The speech act theory based communication enables the Negoisst system to separate (structurally) the sender's intention (illocutionary force)—specified by a message type—from the message content (propositional content) for pragmatic communication. With this separation, a message type attached to a message explicitly states the attitude of the sender towards the offer in the message. For example, a new offer with message type 'Counteroffer' shows the sender's disagreement with the previous offer of receiver. This helps the receiver to derive the sender's intention (illocutionary force) directly from the message type instead of from the message content and communication context. The Negoisst system defines seven message types which are considered sufficient to express any intention a negotiator might have during bilateral

business negotiations. These seven message types and their classification are discussed in chapter 5. The use of communicative action theory in the Negoisst system enables the negotiation counterparts to coordinate negotiation actions with mutual understanding. It uses speech acts for the coordination and assumes validity claims on speech acts for mutual understanding. This is done by fulfilling the four validity claims on the message types to avoid communication problem. The Negoisst system provides a (informal) workspace to resolve problematic claims (e.g. incomprehensibility of message etc.) and hence to bring the counterparts into the intended communicative relationship. This relationship implies obligations that drive the coordinated negotiation interaction.

The third element of a negotiation message, i.e., the concept (Figure 2.4), is used to provide a common understanding of vocabulary/words used in message content and the flexibility in contract processing during the negotiation process. The Negoisst system uses semantic web technology (Berners-Lee et al. 2001) for an ontology-based negotiation approach to provide common negotiation vocabulary and its semantics in order to enhance inter-human communication and contract processing. For this purpose, a number of ontologies have been proposed in the Negoisst system (Schoop & Jertila 2004). One of the ontologies is a *negotiation ontology* that defines the structure of the contract to be negotiated. The negotiation ontology characterise only objects of negotiation which form the negotiation message (such as offers, counteroffers). It contains concepts related to negotiation issues, such as product or service description, delivery or payment information etc. This contract structure is not rigid and business partners can add or delete issues from the ontology. This ontology-based negotiation approach is used to create structured offers and to enrich semantically the natural language negotiation text with concepts from the ontology. In the Negoisst system, a message as well as content in the message is *semi-structured* (see Figure 2.5). A semi-structured message is a combination of an *un-structured* natural language free text and a *structured* offer. The structured offer is prepared using the concepts from the negotiation ontology. The offer is stored as an instance of the ontology. This semi-structured message format separates the offer from the text message for independent processing of offers. The message content is also semi-structured as it allows the mixture of un-structured text with the structured offer. This message content format helps to avoid ambiguity by giving flexibility of writing message

contents in natural language which are enriched semantically with concepts from the ontology representing the structured offer.

Figure 2.5 shows a Negoisst message screen used to create a negotiation message. The message window shows all the components of negotiation message, i.e., message type, meta-data, structured offer and semi-structure message content. On the right side, the negotiation issues defined in the negotiation ontology are visible. These issues and their values are making a structured offer. The text area field on the left shows the semi-structured message content composed of natural language text enriched with the issue/value pair from the structured offer. For example, the shown message is a counteroffer. The message content is composed of greeting and a reason for counteroffer, and negotiation issues and their values.

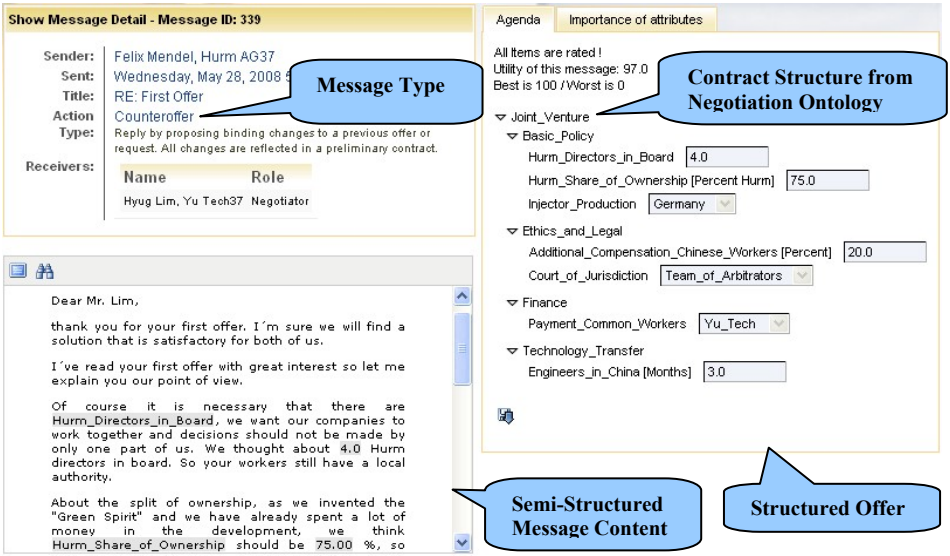

Figure 2.5: Negoisst message window

Figure 2.6 shows a partial offer that the Negoisst system allows negotiators to prepare and exchange. A partial offer does not consist of all negotiation issues and a negotiator does not have to include values for all issues in the offer. As shown in Figure 2.6, the particular negotiator sending that message has indeed not done so. The values of two issues (additional compensation and payment common workers) are missing from the structured

offer. In the case of a partial offer in the Negoisst system, two utilities (minimum and maximum utility) of the incomplete offer are calculated by the utility function. The utility function uses the least preferable options of the missing issues in calculating the minimum utility and the best options of the missing issues in calculating the maximum utility. The preparation and exchange of partial offers allow negotiators to concentrate on negotiation issues one by one based on one's needs and priorities on different issues. Partial offers are used as well in the case of mutual interest on some issues that are then removed from the agenda items after assigning extreme values (Raiffa 1982).

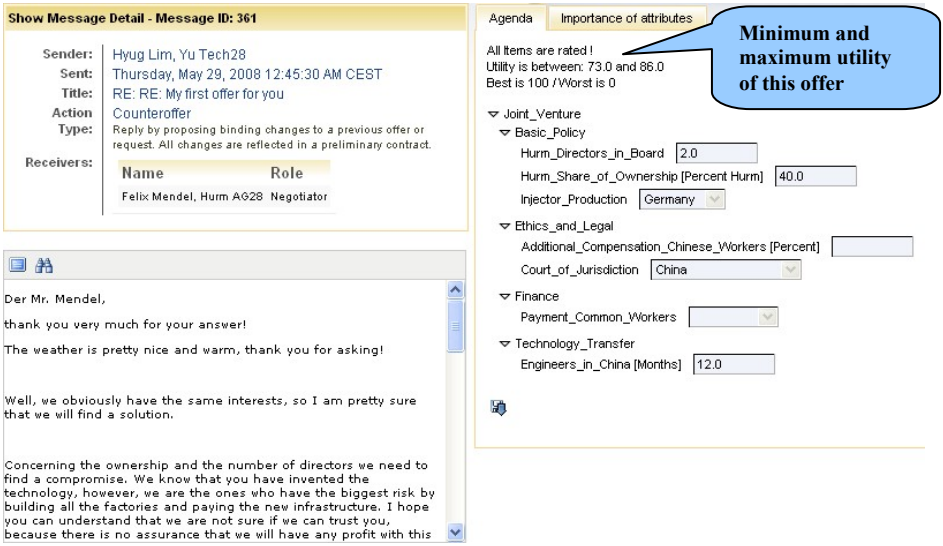

Figure 2.6: An example of a partial offer

Inspire: The communication support in Inspire is basic compared to the Negoisst system. Inspire provides two modes of communication: structured offers and free-text messages. A structured offer contains only the name of issues and their values. Free-text message is for argumentations, clarifications, explanations etc. These two modes can be combined or used independently, for example, a structured offer can be accompanied with free-text message for argumentation and backing. Or, a free-text message can also be sent without offer to set the climate or to request explanations etc. The combination is only done at the sender's discretion, i.e., an offer with a totally unrelated free text could be sent. There is

no conceptual relation between the two. Inspire allows negotiators to exchange complete offers only, i.e., all negotiation issues values to be specified in an offer. In contrast to Negoisst, Inspire offers no support for the enrichment of free-text with concepts from ontologies for more unambiguous and structured communication.

2.4 Existing Hybrid Negotiation Systems

ENSs (bargaining and auction systems) can also be distinguished in negotiation servers and applications (Neumann et al. 2003). A negotiation server (also referred to as a negotiation engine) can typically run multiple negotiation scenarios, while a negotiation application usually runs a single negotiation scenario. The Inspire system (and the ANSs that will be discussed in chapter 4) is an example of negotiation applications as they support only bilateral multi-issue negotiations. The current version of Negoisst and AuctionBot (Wurman et al. 1998) can be taken as the examples of a negotiation server. Negoisst allows potential buyers and sellers to set up either a bilateral negotiation scenario or an auction mechanism depending on the market mechanism. The AuctionBot was developed as an auction system that can be configured for different auction mechanism as well as for manual bidding by humans or for automatic bidding by software agents. In this work, we categorise ENSs according to a new category called *hybrid negotiation system*. In a hybrid negotiation system, a negotiation software agent works together with a human negotiator in an NSS (Kersten & Lo 2003) or negotiates against a human negotiator in a negotiation system (Das et al. 2001, Bosse & Jonker 2005). We are interested in the negotiation applications of this category and describe three hybrid negotiation systems in the following sections. These three systems are negotiation applications as they only support a single negotiation scenario (e.g. continuous double auction or bilateral negotiations). The first system integrates software agents into an NSS, however, the agent has only an advisory role and does not perform the negotiation. The other two systems evaluate the negotiation performance of software agents in human-agent negotiation.

2.4.1 Aspire: Software Agents in NSS

Aspire is an integration of the NSS *Inspire* and a negotiation software agent *Atin* (Kersten & Lo 2003). Atin's integration with Inspire is on the principle that software agents should

only perform well-defined and structured activities in a negotiation process, such as collect information about counter-parts, alert if pre-defined conditions are violated etc., and the ill-defined and ambiguous tasks in negotiations should be left for humans. The role of Atin in Aspire is advisory i.e., it focuses on suggestions and recommendations to user by continuously observing the user's activities and the negotiation process. The suggestions are mainly about the violation of some pre-defined condition, violation of soft and hard constraints (violating reservation values, choices, etc.), and showing pre-defined/pre-written messages to user. It acts independently from the user. The Aspire system does not bind the user to follow all suggestions and recommendations given by Atin. The user can at any time enable or disable Atin. Atin performs only non-negotiation activities received positive user feedback, for example, the warnings from Atin play a significant role in users' decisions and assessment of negotiation strategies, and make negotiations easier.

At architectural level, Inspire and Atin are two standalone systems that are embedded in the application server. Atin interacts with the Inspire system through method calls in application server. The Inspire and Atin systems are loosely coupled and the Aspire architecture allows to replace or update agent system Atin or/and NSS without affecting the other system. All data about user's activities (preference rating, messages, etc.) is stored in a database, and then used by both NSS and Atin for respective tasks. Atin maintains information in a rule-based knowledge base to provide suggestions to users.

2.4.2 Hybrid (human-agent) Auction System

Das et al. (2001) developed a hybrid system for performing real-time, asynchronous experiments on human-agent interaction in continuous double auctions. This hybrid auction system for financial trading is argued to be the first-ever of its kind. The preliminary results based on laboratory experiments show that software bidding agents obtain larger gains from trade than their human counterparts. The bidding agents use strategies based on extensions of the Gjerstad-Dickhaut (GD) and Zero-Intelligence-Plus (ZIP) algorithms. The results suggest further agent-human interactions in electronic markets. The experiments focused on measuring the performance of individual agents instead of global measures of aggregate market behaviour. In experiments, the mixed population of agents and humans was divided evenly between buyers and sellers. In the

experiments, all agents used the same strategy—either ZIP or GD. Human subjects were non-expert, but before the start of each experiment, they received instructions on the auction rules and the profit objective, and were allowed to practice the system. Humans were not provided with any other type of decision support by the system.

As a group, agents out-performed humans in all experiments. Aggregate, agents achieved greater than 100% efficiency by exploiting human errors and weaknesses. Humans, on the other hand scored in the range of 92-96%. Although humans performance tended to improve during the course of experiments as they became more familiar with the system and the market behaviour and got a better idea of how to apply bidding strategies, agents got better results also in the final periods of each experiment.

The hybrid auction system consists of an auction server and separate client programmes for humans and agents. Agent and human bidders use the same set of messages to communicate with the auction server for seamless interaction with one another and to avoid any subtle bias in their treatment by the server. Agent and human bidders communicate with the server using their respective client programme. For humans, it consists of a graphical user interface to view order queue, trade history and to enter bids or asks. Agents participate in an auction using their client programme which transports messages via TCP/IP between server and agents.

2.4.3 Human vs. Agent in multi-issue Negotiation

Bosse and Jonker (2005) conducted experiments to compare the performance of software negotiation agents against humans in multi-issue negotiations. The experiments included all-human, all-agent and human-agent negotiations. The purpose of experiments was to find the weakness of software agents in human-agent negotiations and then improve them accordingly to raise the quality of agents when negotiating with human negotiators in multi-issue negotiations. Comparison between human's behaviour and agent's behaviour was analysed on the basis of their performance in negotiations such as final outcome and number of rounds in reaching agreement, as well as their bidding style such as concession, selfishness etc. In the experiments, agents used a negotiation strategy based on monotonic concession to generate offers. The results of experiments show that fair outcomes in agent-agent negotiations were averagely greater than human-human negotiations which in turn got more fair outcomes than human-agent negotiations. The suspected reason for

more fair outcomes in all agent negotiations could be due to same concession strategy used by both participant agents. In biddings, agents showed more conceding behaviour than human negotiators, but were less diverse in selecting negotiation strategies than human. In the human-agent negotiations, humans got better utility from agreements by playing mixed strategies in offer generation. Agents performed equally well against other agents.

The work does not mention the design and architecture of the system used to carry out experiments on human-agent negotiations or how humans and agents interacted during the negotiation.

2.5 Summary

In this chapter, negotiation theory and three electronic negotiations models have been discussed. Each electronic negotiation model has different support and application areas. The auction model has been discussed briefly to show different auction mechanisms and their application areas (e.g. selling art work or agricultural goods) in electronic commerce. Electronic auctions can be conducted manually as well as automatically. The automated negotiation model has been introduced as an emerging application area of multi-agent systems to perform electronic negotiations autonomously. The division of automated negotiations into three approaches shows that different automated negotiation systems (belonging to different approaches) implement different negotiation behaviour, strategies or protocols for supporting different negotiation scenarios in different domains. This simply means that automated negotiation research is not matured up to the level that a single negotiation agent in an ANS can perform all types of negotiation decision making, negotiation strategies (e.g. coordinative behaviour, tactical behaviour etc.) and communication to solve any type of negotiation problems autonomously. The negotiation support model has been discussed in detail. Though the NSSs differ in the implementation of communication and decision making components, they all can be used by human negotiators for the same negotiation scenarios and they all aim for enabling a negotiation analysis approach for integrative negotiations. The comparison between automated negotiation model and negotiation support model shows that a single NSS can be used for most of the bilateral multi-issue negotiations scenarios, whereas a single ANS can be used for a single negotiation scenario.

Existing hybrid ENSs (specifically negotiation applications) that integrate software agents and humans have also been presented to show the current status of human-agent combination in negotiations. Software agents in such systems either provide advisory support to human principal in negotiation process (Kersten & Lo 2003) or they engage in bidding against a human bidder (Das et al. 2001) or they have been employed in human-agent negotiation to measure their performance against human negotiators (Bosse & Jonker 2005). Neither of the existing hybrid negotiation systems integrates an NSS and ANS in a new system to enable bilateral multi-issue negotiations between a human negotiator and a software agent.

3. Requirements of a Hybrid Negotiation Model

The objective of this research as described in the first chapter is to propose a hybrid negotiation model that combines the negotiation support model for a human negotiator and an automated negotiation model for a negotiation agent to enable bilateral multi-issue human-agent negotiations. None of the existing hybrid negotiation applications presented in the previous chapter (section 2.4) supports such bilateral multi-issue negotiations. To achieve the objective of this research, the main functional and design requirements of the hybrid negotiation model are presented in the following sections. These requirements are based on the research question (section 1.2).

Figure 3.1 shows the four main components of a hybrid negotiation model. The selection of the Negoisst system as the NSS in hybrid model is for the reason that it defines the negotiation agenda (i.e., negotiation issues) formally through a negotiation ontology, which enables a structured representation of offers and semi-structured messaging. These features of Negoisst (as compared to other NSSs) can play an important role in human-agent negotiations. In the figure, there are components such as an interoperability component and negotiation process protocols, which do not belong to Negoisst and to the ANS but are required specifically for the integration of these two different negotiation systems in the hybrid negotiation model. The need for an interoperability component arises as the two electronic negotiation systems are not only heterogeneous but are also based on different software engineering paradigms i.e., a non-agent Negoisst system and an agent-based ANS. The purpose of the interoperability component is to enable communication for exchanging negotiation messages between a negotiation agent and a human negotiator. The requirement for this component is to provide information level as well as system level interoperability. The information level interoperability will enable communication of negotiation stance to the counterpart and the system level interoperability will enable converting negotiation messages to an

appropriate structure so that the messages can be processed by the respective systems (Negoisst or ANS). The negotiation process protocols are part of the hybrid negotiation design. The general design requirements of the hybrid negotiation model are given in section 3.1. The requirements are outlined in relation to the basic development phases of the hybrid negotiation model. The functional requirements for an appropriate ANS as the component of hybrid negotiation model for the automated side of negotiation are presented in section 3.2. The appropriateness of an ANS is measured as the generation of offers using different negotiation strategies and the communication richness and compatibility for the exchange of negotiation behaviour. These requirements are also used for the evaluation of existing agent communication and decision making support in automated negotiations for the human-agent negotiations. Section 3.3 presents the functional architecture of our hybrid negotiation model explaining the high-level functions of each component during human-agent negotiation processes.

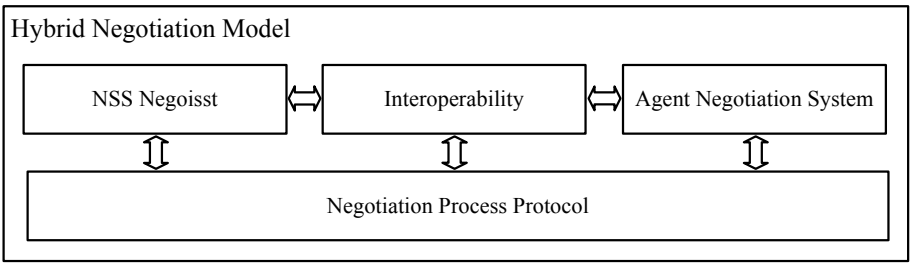

Figure 3.1: Four main components of the hybrid negotiation model

3.1 Human-Agent Negotiation Design Requirements

The creation of an electronic negotiation instance (comprising a negotiation scenario and a medium—a negotiation system) can be structured along the system development phases of analysis, design, and implementation (Ströbel & Weinhardt 2003). The analysis phase identifies the requirements of the negotiation scenario, the design phase specifies the concrete negotiation scenario based on the requirements, and the implementation phase maps the scenario to the architecture of the underlying electronic negotiation medium. A negotiation scenario consists of rules and the object of negotiation. The general properties of negotiation scenarios include numbers and roles of participants, number of negotiation

issues, structure of messages, rules for exchanging offers etc. (Lomuscio et al. 2001, Ströbel & Weinhardt 2003).

In this work, we are interested in the analysis and design phases of human-agent negotiation scenarios. The human-agent negotiation design is intended to be based on the negotiation design of the Negoisst system. The human-agent negotiation design will share the design properties of the Negoisst system and is expected to work in the same domain. Then this design will be mapped to the hybrid negotiation model (Figure 3.1). The analysis phase for getting human-agent design requirements is confined to the analysis of the Negoisst system and its negotiation scenario, and the automated negotiation models. The general properties of the Negoisst system and automated negotiation models should normally be same because both are based on the same negotiation theory. The difference lies only in the realisation of these design characteristics because of the different support models and application areas. The analysis will provide the general properties of the hybrid negotiation system that will actually be the combination of respective negotiation designs of automated negotiation models and the Negoisst system. These design requirements will be used in design phase for the concrete designing of human-agent negotiation scenario and system. The concrete design is about offer exchange rules to support negotiation process (Ströbel & Weinhardt 2003). A detailed analysis and concrete design will be presented in chapter 5 (sections 5.1 and 5.2).

One of the main assumptions or restrictions for the hybrid negotiation design is that the negotiation and system design of the Negoisst system is not changed in order to enable human-agent negotiations. With this assumption, the human negotiator and the principal of the agent will remain able to conduct negotiations according to the three-phase negotiation process of the Negoisst system. This is especially important for the human negotiator's point of view i.e., the delegation of negotiation task to the negotiation agent by the other party should not change the negotiation process for him/her. The execution of the activities depends, among other parameters, on the number of negotiators per side and their roles (e.g. buyer, seller etc.) (Ströbel & Weinhardt 2003). The execution of activities is realised through the interactions between participants. For example, there is one buyer and one seller in Negoisst negotiations. A negotiation either begins with offer by the seller or request by the buyer. There will be different participants in the human-agent negotiation as compared to the Negoisst system, so there will be different

interaction rules to execute the three-phase negotiation process activities. The activities will be assigned to the participants (only at the automated side of negotiation) depending on the role and their capabilities. For example, the agent principal performs the delegation task in the pre-negotiation phase and the agent performs the negotiation in the negotiation phase. The execution of activities in the whole system will depend on the interaction among the different entities at both sides, e.g. interaction of an agent's principal with the agent for the delegation of negotiation activities and interaction between a human negotiator and a negotiation agent to conduct the negotiation etc. These interaction rules will be defined in different protocols according to the requirements of human-agent negotiation design. These protocols are the part of concrete design of the hybrid negotiation model. The three-phase negotiation process has to be extended with activities for delegating the negotiation task to agent.

3.2 Requirement Analysis of Agent Negotiation System

Two main factors can be identified (from this research perspective) that make the communication and decision making for negotiation agents different when negotiating with a human negotiator in human-agent negotiations as compared to when negotiating with another negotiation agent in inter-agent negotiations. The first factor is about the limitation of automated negotiations as compared to the NSSs i.e., an ANS implements a particular automated negotiation mechanism (belonging to a certain automated negotiation approach, cf. 2.3.3.3) that allows only a certain negotiation behaviour leading to certain outcomes whereas using an NSS, human negotiators are completely free to use any negotiation behaviour or to apply any negotiation strategy in reaching agreements. This means, an ANS implementing an automated negotiation mechanism will allow the negotiation agent to demonstrate only particular negotiation behaviours while negotiating with a human negotiator. This is a severe limitation for the principal in order to delegate a negotiation task to an agent. The second factor is opposite to the first one i.e., in some cases, inter-agent negotiations are richer than human-agent negotiations due to different communication modes in NSSs and ANSs (for example, arguments have a structured representation in automated negotiations and free-text representation in the Negoisst system and, therefore, it can be problematic exchanging such information between an agent and a human negotiator). Although decision making and communication models

together enable demonstrating different negotiation behaviours, the first factor is more related to decision efficiency while the second is more towards communication limitation.

In the following sub-sections, the requirements for an ANS are described. The requirements are based on the human negotiation behaviour in decision making and communication. These requirements help in identifying and evaluating the decision making methods and communication technologies in different existing automated negotiation mechanisms and models (chapter 4). The requirements will also be used to analyse the above two factors (decision making and communication) to show the differences between inter-agent and inter-human negotiations and to show the possible solutions for enabling a negotiation agent to demonstrate all possible negotiation behaviours while negotiating with human negotiator (chapter 5).

3.2.1 Required Characteristics of Agent Decision Making Behaviour

The agent's decision making model should integrate informal models of negotiation, inspired by human negotiation problem solving, with AI techniques. We align the requirements of agent's decision making behaviour with respect to the negotiation behaviour and negotiation methods used by human negotiators. Such requirements will make agent's offer generation mechanism dynamic and flexible, and compatible to human counterpart. It can be then applicable to many business negotiation scenarios.

As discussed in chapter 2 human negotiators use three basic strategies for moving towards agreement that are, unilateral concession making, competitive behaviour, and coordinative behaviour (Pruitt 1981). All NSSs neither recommend nor restrict using any strategy. The decision support (e.g. utility function, offers history chart, convergence graph etc.) and communication support (e.g. preparation of free text messages or structured offers, message history etc.) in NSSs help in using all of these negotiation strategies and tactics. Figure 3.2 shows different human strategies and related bargaining tactics, which we want to be part of the agent decision making behaviour.

Concession Making: Concession making is an essential element of negotiation behaviour. Negotiation agents should be equipped with concession making functions. We have to

look, which concession making mechanisms are available for negotiation agents and how they work.

Competitive behaviour: Competitive behaviour demands unilateral concessions from the other negotiator by means of persuasive arguments, positional commitments, or threats. It is desirable for agents to show competitive behaviour where possible while negotiating with human negotiators.

Coordinative behaviour: In a coordinative behaviour, parties collaborate with each other in search of a mutually acceptable solution. Three bargaining tactics have been described for the development of integrative solutions. We look for the following bargaining tactics in the agent decision making model: *incorporation* tactic; *information exchange* tactic; and a *heuristic trial and error* tactic. The information exchange has two tactics: *logrolling* and *bridging*. Coordinative behaviour is also possible by inventing new options to issues or adding new issues to negotiation.

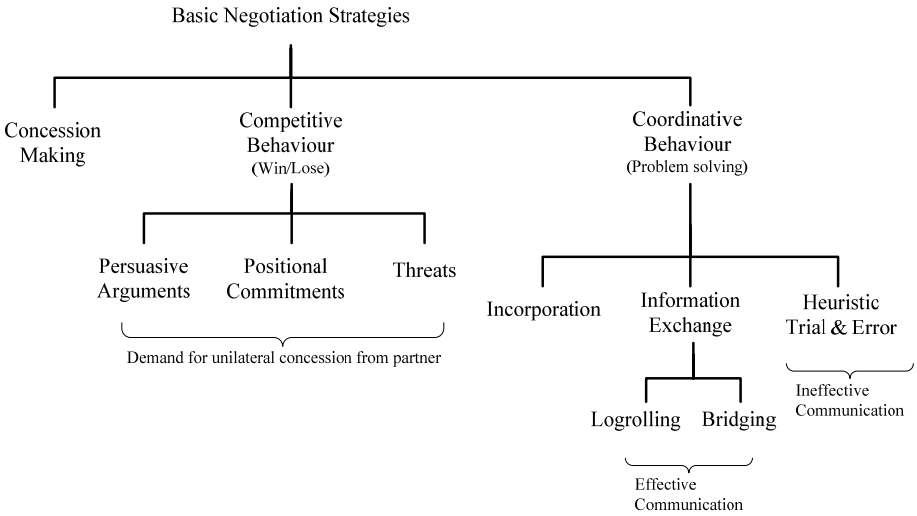

Figure 3.2: Basic negotiation strategies and tactics collected and combined from Pruitt (1981)

3.2.2 Requirements of Agent Communication Model

The requirements for the agent communication model are based on the humans negotiation communication behaviour and the Negoisst message structure and its details. We will see in chapter 4 that the negotiation message structure in automated negotiation is similar to the Negoisst message structure i.e., it has three components: message, content, and concept (see 2.3.4.3). The focus (as we had for the NSSs) is on the information level and communication level of communication process model for the agent communication model. These two levels are captured by the three components of message structure. Out of the three, the content is the major and most crucial component of the agent communication model for human-agent negotiation. We will now discuss the requirements of content components. For the concept and message components, we are simply interested that ANSs also use ontologies for the semantic enrichment of negotiation content and the speech act theory to clearly differentiate between communication and information levels.

Negotiation Content:

To base the agent communication model on the negotiation communication behaviour for the human-agent negotiation, it is necessary to know the content that human negotiators exchange with each other using communication support of NSSs. The listing of such content expressing different negotiation behaviours can be used to evaluate the support of agent communication technology for different contents and the ability and the possibility of negotiation agent to exchange different contents with human counterparts. Köszegi et al. (2004) have conducted content analysis on the collected data from negotiation experiments to observe differences in negotiation behaviour of participants using Inspire and SimpleNS. Content analysis systematically investigates the specified characteristics of communication (cf. Köszegi et al. 2004: Holsti 1969). First the content analysis method identifies data categories from archived negotiation data and then counts the occurrences of each data category in the negotiation data. A data category represents a class of communication units of message content where a communication unit represents a ‘thought’ addressed by the negotiator to the opponent, such as an offer or an argument. Nine categories have been identified from experimental data and each category represents

a particular communication or negotiation behaviour. These nine data categories are also relevant to negotiation content exchanged using the Negoisst system; since Negoisst also offers decision support and communication support. Figure 3.3 shows the distribution of communication acts among nine data categories, which are:

1. *Substantive* communication units constitute fundamental negotiation behaviour such as offers and counteroffers, concessions, logrolling, agreement, rejection.
2. *Task-oriented* communication units facilitate problem solving such as requesting or providing information.
3. *Persuasive* communication units support the negotiation stance of the negotiator such as persuasive arguments.
4. *Tactical* communication units influence the expectations and actions of the opponent. These include threats, commitments, excuses, promises etc.
5. *Affective* communication units are linked to the expression of feelings about the content, the opponent, or the bargaining situation. They depict positive or negative emotions, apology or regret etc.
6. *Private* communication units include statements that are not directly related to the negotiation task itself.
7. *Procedural* communication units facilitate the negotiation process, such as "8:00 am in Taiwan is 1:00 pm in Europe".
8. *Formality communication protocol* contains salutations and units indicating politeness found at the beginning and end of a message.
9. *Text-specific* communication units are particularly linked to written electronic communication. The units include text-specific elements, like fillers "*anyway*", or text structuring elements like "*p.s.*", or "*e.g.*"

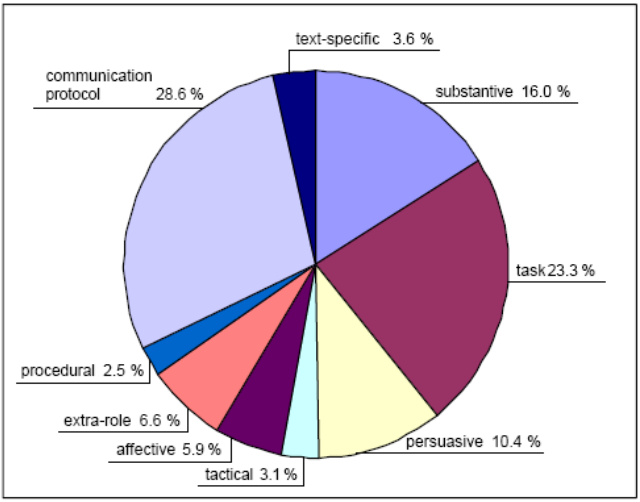

Figure 3.3: Amount of different types of written communication units in inter-human negotiations (Köszegi et al. 2004)

3.2.3 Components of the Automated Negotiation System

To fulfil the requirements for agent decision making and communication behaviour in human-agent negotiation, the analysis of automated negotiation frameworks is required to decide which components of these frameworks are of interest for the agent system in the hybrid negotiation model. The frameworks are based on game-theoretic, heuristic and argumentation-based negotiation approaches and the components in these frameworks are designed and implemented according to the respective negotiation approach (Rahwan et al. 2003, Faratin 2000, Fatima et al. 2004, Barbuceanu & Lo 2000). These frameworks are viewed in terms of negotiating agents and environment in which agents interact (Lomuscio et al. 2001, Ashri et al. 2003, Rahwan et al. 2003). The agent-centric components concentrate on the internal capabilities of agents and are part of an agent's design and implementation. The environmental components provide the communication facilities in terms of negotiation protocol and communication languages for inter-agent interaction.

Faratin's (Faratin 2000) automated negotiation framework is a collection of three main components: communication protocols that define public rules for inter-agent

interaction, services that describes subject of interaction, and the deliberation mechanism for decision making based on heuristic-approach. This is a configurable framework for acquiring services. The configurability is achieved by avoiding the applicability of the framework to a single domain or agent architecture, and dissociating interaction decisions from the interaction protocols (opposite to game-theoretic approach). The agent architecture is composed of mainly the service description and deliberation mechanism components that provide negotiation capabilities to agents. The negotiation capabilities are developed on repositories of an agent's knowledge about itself and about its environment, a coordination model that includes different decision making mechanisms, and a service description—an input to coordination model—which contains the issues involved in the negotiation and preferences over these issues. The environmental components of the framework include middleware services (directory services, security services etc.), a communication protocol and an agent communication language.

Other automated negotiation models implement different negotiation mechanisms with similar components. Fatima et al. (2004) present a game-theoretic agenda-based automated negotiation framework for bilateral multi-issue negotiations. The model comprises of four components, namely negotiation protocol, agents' negotiation strategies, information state of agents, and negotiation equilibrium. This model does not talk explicitly about inter-agent communication but agents obviously need some communication technology for exchanging offers. Luo et al. (2003) present a fuzzy constraint-based model for multi-issue negotiations that consists of conceptual specifications of negotiating agents, the communication protocol, the agent communication and content language, and the negotiation behaviours of agents including negotiation strategies. Barbuceanu and Lo (2000) present a negotiation model based on multi-attribute utility theory (MAUT). The agent's decision making tool consists of a constraint optimization solver and a relaxation protocol. The major elements of communication support, called conversational technology, are conversation plans and agent communication language. The internal design of each component of a framework depends on the negotiation mechanism the frameworks support.

Rahwan et al. (2003) present a conceptual framework of argumentation-based negotiations based on the evaluation of existing work. The framework outlines the core elements and the features required by argumentative agent, as well as the environment

that hosts these agents. The external elements or environment elements of a conceptual framework, like other models, are communication and domain language, a negotiation protocol, and information stores. Domain language (content languages, ontologies) is more prominent as a component of argumentation-based negotiation models than of heuristic negotiation models. The representation of arguments requires richer content languages. The decision making model of argumentative agents contains two components for argumentation, namely, the argument generation component and argument selection component.

From the above discussion, we can conclude that a single heuristic negotiation method or an argumentation-based method cannot fulfil all the above specified requirements of agent decision making and communication behaviour. We have to evaluate different negotiation mechanisms related to different methods to fulfil the maximum possible aspects of the two negotiation approaches. The requirements on the design of the agent negotiation system include a negotiation mechanism suitable for negotiating with human counterpart, an agent architecture, and environment components. The agent architecture will include decision making behaviour, knowledge stores, and service description. The environment components will include negotiation protocol, knowledge base, agent communication model etc.

3.3 Functional Architecture of Hybrid Negotiation Model

The functional architecture shows conceptually a high-level functional view of the hybrid negotiation system and how the various components of hybrid system work together. This includes the structural arrangements of system components and the various inter-relationships among components. The functional architecture, as shown in Figure 3.4, consists of the Negoisst system, the negotiation agent, the negotiation protocol, the delegation protocol, and the wrapper agent. The arrangement shows how these components will work together to enable human-agent negotiations. The detailed functionality and design of not yet existing components and their sub-components will be presented in chapter 5. The negotiation agent performs negotiation tasks on the behalf of the agent's principal with the human negotiator. The delegation protocol defines the rules of interaction between the agent's principal and the negotiation agent for the delegation of

negotiation task as well as for controlling the execution of the negotiation agent. The wrapper agent works as a communication interface between two heterogeneous negotiation systems as the Negoisst message can not be processed by the negotiation agent without conversion to agent message (ACL) and vice versa. When a human negotiator (who is unaware that his counterpart has delegated negotiation task to an agent) sends a message to the human counterpart, the wrapper agent converts the Negoisst message to an agent message (ACL message) by reading the offer (issues values) from the negotiation ontology and forwarding it to the negotiation agent. The agent receives an ACL message, processes this message and generates a new ACL message for the human negotiator. The ACL message is converted to a Negoisst message by the wrapper agent. This way, the communication continues between the agent and the human negotiator. The concrete computational functionality of agent decision making and communication is presented later after the detailed evaluation of these two components. The negotiation protocol is two-part and works between the agent owner, the negotiating agent and the human negotiator. It controls the sequence of message between three entities. The negotiation protocol is designed according to the hybrid negotiation design and makes the hybrid negotiation system to support a variety of message types as in Negoisst.

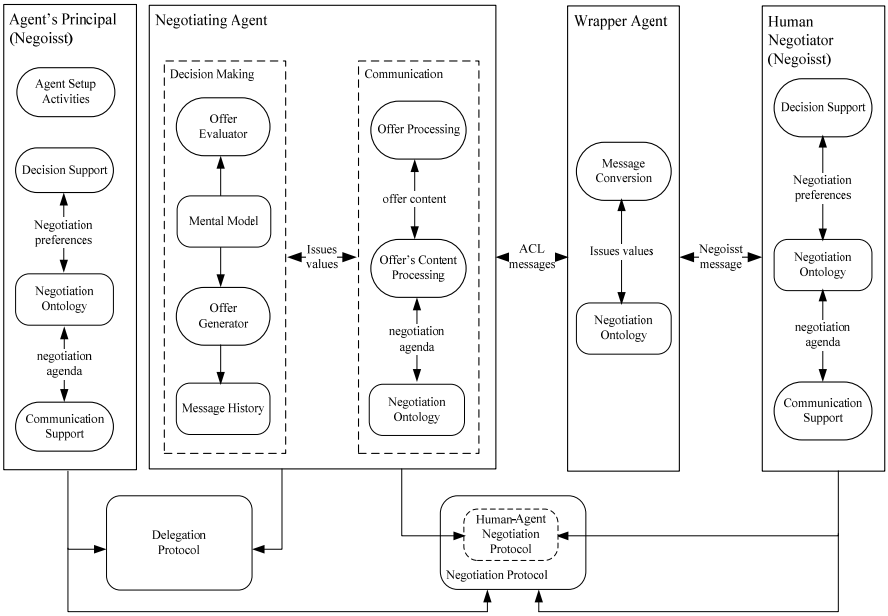

Figure 3.4: Functional architecture of hybrid negotiation model

Having defined the requirements, the question then is whether automated negotiations and agent technology can fulfil those requirements for human-agent negotiations. This is what we will analyse in the following chapters.

4. Inter-Agent Communication and Decision Making

Singh (1998) states that "… *an agent is a persistent computation that can perceive its environment and reason and act both alone and with other agents*". The key concepts mentioned in this definition are *interoperability* and *autonomy*. The interoperability is described as the agent's ability to participate in social interaction with other agents, and the autonomy is the agent's ability to serve a user by executing tasks autonomously during the interaction. The components for decision making (autonomy) and communication (interoperability) are the most important building blocks of an automated negotiation model (cf. section 3.2.3). In this chapter we discuss inter-agent communication and decision making in automated negotiations on which the communication and decision making models of negotiation agents in our hybrid negotiation model can be developed.

There is no negotiation without communication (Fisher et al. 1983). Inter-agent communication is an important research area in multi-agent system research. Different components compose an agent message. We focus on the message structure and its elements (as we did for the communication support in the Negoisst system, see section 2.3.4.3) while studying inter-agent communication. The message composition and its representation are studied in multi-agent systems, especially in the automated negotiation systems. The different components have been associated with the different levels of communication to make the communication effective and efficient. Each component of a message is prepared (i.e., represented or expressed) using some agent communication languages (section 4.1.1) and knowledge representation technologies (sections 4.1.2 and 4.1.3). Based on this study, a suitable communication and representation language for the communication model of negotiation agents will be selected in this chapter.

In studying the agent decision making, our main interest is in the different methods of generating offers, which represent different negotiation behaviour such as concession making, trade-offs, arguments etc., by negotiation agents in automated negotiations. As mentioned in chapter 2, the automated negotiation design space is based on the three automated negotiation approaches. We provide a comparison (section 4.2)

between the game-theoretic approach and the heuristic approach for their benefits and limitations in the hybrid negotiation model, and select the second approach (section 4.3) for negotiation agent's decision making and give reasons for this selection based on the negotiation design. Also the third approach for agent's decision making i.e., argumentation-based negotiation (ABN) is studied (section 4.4).

4.1 Inter-agent Communication Model

Software agents communicate—for cooperation, coordination or negotiation—to achieve certain goals that cannot be achieved working alone. In automated negotiation systems, agents communicate to exchange different kinds of offers in order to reach agreements. Inter-agent communication structures can be described as follows:

"*Communication takes place on several levels. The content of the message is only a part of the communication. Being able to locate and engage the attention of someone you want to communicate with is a part of the process. Packaging your message in a way which makes your purpose in communicating clear is another.*" (Finin et al. 1994)

These communication levels have been arranged into three layers, namely, the content, communication, and message (e.g. Labrou et al. 1999). The content layer deals with the actual content of the message, e.g. negotiation issues values, actions etc., and the associated content representation language. The communication layer encodes the lower level communication parameters, such as sender, recipient, message-id, negotiation-id etc. (known as meta-data in Negoisst). The message layer completes the message encoding. It supplies a speech act that the sender attaches to the message content. According to this three-layer organisation, an agent's negotiation message can be divided into three parts: the content part, the communication part and the message (this organisation is similar to Negoisst).

We specified the requirements for a negotiation agent communication model in the hybrid negotiation model in section 3.2.2. These requirements were based on the different types of communication behaviour of human negotiators and the communication support in Negoisst. Figure 4.1 shows our conceptual communication model for the

representation of an agent's message in the hybrid negotiation model. This model is based on the FIPA standards[7] for inter-agent communication in multi-agent systems and the communication models used in some automated negotiation systems (e.g. Parsons et al. 1998, Luo et al. 2003). The model consists of an agent communication language (ACL), an agent content language and domain ontologies. These three elements correspond to the three layers of inter-agent communication. The structure of this agent communication model is similar to Negoisst and is assumed to be appropriate for achieving efficient and effective communication in human-agent negotiation environments.

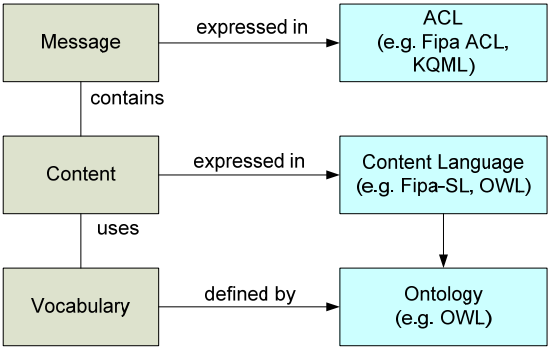

Figure 4.1: Components of Agent Communication Model

In the following sub-sections, we will discuss these three agent communication components in details from an inter-agent communication perspective in order to propose a communication model for negotiation agents in the hybrid negotiation model in the next chapter.

4.1.1 Agent Communication Language (ACL)

Agent communication languages (ACLs) serve the purpose of communication between software agents as natural languages serve for humans. The communication problems between intelligent agents, such as heterogeneity of data format, are addressed by giving

[7] These standards have been developed by the Foundation for Intelligent Physical Agents (FIPA). FIPA is an IEEE Computer Society standards organization that promotes agent-based technology and the interoperability of its standards with other technologies. http://www.fipa.org

them a common ACL so that they share a common syntax, semantics and pragmatics (Finin et al. 1994). An ACL handles propositions, rules and actions with semantics for information and knowledge exchange in inter-agent communication (FIPA 2002b, Labrou et al. 1999). An ACL message represents a desired state of an agent in a declarative knowledge representation language. These languages are suitable for every communication situation in business or other processes. An agent can send an ACL message to another agent, for example to request to perform some task to achieve its goals; to commit or refuse performing actions; to report progress, success, or failure of assigned tasks etc. (Cohen & Levesque 1995). The origin of the first ACL is related to the concept of Knowledge-Sharing Effort to develop a common language for knowledge sharing among computer systems (Finin et al. 1994). For interoperability reasons, communicating agents must adhere to the same ACL to communicate meaningfully.

Some of the desirable requirements for ACLs are *content*, *semantics*, *implementation* and *environment* (Mayfield et al. 1995). These requirements are fulfilled by many ACLs (FIPA 2002b, Finin et al. 1994). The category *content* suggests the two layers of an ACL in order to distinguish between the communication language to express communicative acts (the term communicative act is used for message type in multi-agent systems) and the content language to express application related facts. An ACL should commit to a well defined and extensible set of communicative acts to ensure usability and interoperability across a variety of systems. The purpose and the desired features of a communication language should have a well-defined *semantic* description. Well-defined semantics give agent designers the shared understanding of language primitives and the protocols associated with their use to design interoperable multi-agent systems. An ACL implementation should provide a good fit with existing software technology and the language interface should be easy to use. The language should provide tools for coping with the heterogeneous and dynamic environment of agents, and should support interoperability with other languages and protocols. An ACL message is comprehensible when it contains all necessary components mentioned in language specification.

ACLs are based on speech act theory—agents interact with each other through performing speech acts wrapped in ACL messages (Labrou et al. 1999, Finin et al. 1994). An ACL message is described as an action or a communicative act that is intended to perform some action by virtue of being sent. The speech act theory has been appealing for

inter-agent communication because, by using it, the ACLs can describe and define speaker's mental state as beliefs, desires, and intentions, which is a common way to model mental state of an agent in the BDI agent architecture[8]. The BDI agent architecture views an agent as having certain mental attitudes of Belief, Desire, and Intention (BDI). These three mental attitudes represent the information, motivational, and deliberative states of the agent, respectively, which determine the agent's behaviour (Rao & Georgeff 1995). The BDI agents have the representation of intentional-level description of speech acts in their mental state which they can use for the communication. These agents communicate their BDI states or attempt to alter the BDI states of their counterparts. The speech act theory enables agents to exchange not only the content but also the intention over content such as assertion, request or some form of query (Labrou & Finin 1998). This intentional level description of speech acts makes them right choice for their application in inter-agent communication, because agents follow intentions to fulfil their desires in BDI agent systems.

Message types of ACLs are speech acts and each ACL defines a certain number of message types that agents can exchange to represent different intentions (FIPA 2002b, Finin et al. 1994). In some ACLs, the semantics (i.e., necessary and sufficient conditions of speech act) of each communicative act is defined in terms of pre-conditions (feasibility) and post-conditions (rational effects) (FIPA 2002b) while others also include completion conditions (Labrou & Finin 1998). These semantics describe the shared intended usage of communicative acts. Thus, an agent will select a communicative act in communication based on the relevance of the act's rational expected outcome (rational effect) to its goals. The agents interpret communicative acts by making reference to their mental state. The representation and reasoning about the state of agent and the world, and

[8] BDI agents are a particular class of agent architecture. The architecture is based on three modalities: B for beliefs to represent the state of the environment, D for desires to represent the motivations of the agent, and I for intentions to represent the ends (or goals) of the agent. The architecture has a separate unit for each modality. The units are given direct interpretation by giving semantics to each modality in terms of possible worlds and the relation between modalities as relations between the associated possible worlds.

how agent's actions change this state is a prerequisite for any semantic interpretation of communicative acts (Labrou & Finin 1998).

4.1.1.1 Knowledge Query and Manipulation Language (KQML)

KQML is an ACL that was developed both as a message format and a message-handling protocol to support run-time knowledge sharing among intelligent software agents (Finin et al. 1994). As a language, KQML specifies wrappers to define messages communicated between knowledge-based systems. As a protocol, KQML facilitates the development of libraries of reusable components (Neches et al. 1991). The intent in developing KQML was that KQML would be to knowledge representation systems what SQL had become to database management systems. KQML provides an extensible set of communicative acts, which represent the permissible "speech acts" to develop higher-level models of inter-agent interaction such as negotiation. KQML has been tested widely in the areas concurrent engineering, intelligent design, and intelligent planning and scheduling. It is independent of the transport mechanism, content languages (e.g., Prolog, first-order logic, SQL etc.) and ontologies.

A KQML message can be organised in three layers: content, communication, and message (Labrou et al. 1999). The content layer bears the actual content of the message expressed in some content representation language. The communication layer describes the lower-level communication parameters, such as the sender and recipient, and a unique identifier associated with the communication. The message layer is the core of the KQML, which encodes a message that an agent transmits to another agent. In addition message layer include optional features that describe the content language, the ontology it assumes etc. The content of a message can be composed in any language, e.g. KIF, LPROLOG etc., of agent's choice and is wrapped inside of a KQML message. Agent systems implementing KQML ignore the content portion of the message, and the individual agents themselves should be able to understand and process contents.

In the following example (Figure 4.2) of a KQML message in s-expression syntax (a balanced-parenthesis list) (Finin et al. 1994), an agent `stock-server` tells the agent `joe` the price of IBM stock.

```
(tell
     :sender    stock-server
     :content   (PRICE IBM 14)
     :receiver  joe
     :language  LPROLOG
     :ontology  NYSE-TICKS)
```

Figure 4.2: A KQML message

The first element of the balanced parenthesis list (i.e., `tell`) is the communicative act and the other elements are the arguments to act. The arguments of the communicative act are represented as keyword/value pairs. Some of the arguments are optional such as ontology and language, but when used, provide the necessary information for the correct processing of the content.

4.1.1.2 FIPA ACL

FIPA ACL has been proposed by the FIPA, which has produced a number of specifications for agent communication and interactions with an emphasis on ACLs and interaction protocols. Specifications exist for message exchange, interaction protocols, communicative acts, and for the content language representations. These specifications collectively make up the agent communication module of FIPA abstract architecture (FIPA 2002a). The syntax of FIPA ACL is identical to KQML except the different names of some of the reserved communicative acts. The message is divided mainly into two parts –the outer part and inner part. The outer part represents the communicative act and defines the intended meaning of the message, whereas the inner part representing the content denotes the expression to which the agents' beliefs, desires, and intentions apply. FIPA ACL message content can be written in any content language. FIPA ACL is primarily intended for purchase negotiations because of the communicative acts it provides. A FIPA ACL message can be encoded in different representations such as XML or in serialised java objects for transportation from one agent to other.

The FIPA communicative act library provides a number of communicative acts of types primitive and macro (FIPA 2002b). Primitive communicative acts such as request, inform etc., are performed directly by an agent, whereas the macro type of acts such as proxy, propagate etc., can be planned by requesting another agent to perform the

act. The specification describes for each communicative act the narrative form and formal semantics based on modal logic in the form of feasibility preconditions and rational effect. The semantics defines the mental state (beliefs, intentions) of agents and links the utterances in the dialogue to the mental states of agents. The feasibility preconditions have to be satisfied before the act is uttered. The set of feasibility preconditions for a communicative act is split into two subsets of preconditions: the ability preconditions define the agent's intrinsic ability to perform the given act; and the context-relevance preconditions specify the relevance of the act to the context in which it is performed. The rational effect represents the motivations for which the act is selected. To achieve a goal, an agent should behave rationally and should select and send an act based on the relevance of the act's expected outcome (rational effect) which satisfies the intention and meets the goal. Sending a message to other agent does not necessarily result in a rational effect, because the other agent is independent in its decision and can refuse to carry out the requested action. An agent implements the FIPA ACL only if it behaves in accordance to the semantics of the acts.

4.1.1.3 ACL for Hybrid Negotiation Model

In our hybrid negotiation model, a standard ACL is used for capturing the common message structure and for providing the standard negotiation message types to the negotiation agent. We need an ACL which not only wraps the agent message but also provides the maximum support to capture the elements of the Negoisst message. Using such an ACL, the conversion from the agent message to the Negoisst message and vice versa will be easier without losing any message component.

The selection of an ACL in our agent communication model depends on the ability to capture the highest number of elements of Negoisst messages. KQML and FIPA ACL both have same syntax i.e., provide all the necessary primitives to compose the agent message from the Negoisst message therefore both are suitable ACLs to be used in our hybrid communication model to represent the agent message. FIPA ACL can be preferred to KQML because of two reasons. The first reason is that the predefined list of communicative acts in KQML does not contain appropriate acts for negotiations (Ferber 1999, page 339). However, this list can be extended with new application specific communicative acts. On the other hand, FIPA communicative act library (used with FIPA

ACL) provides a list of negotiation message types required in human-agent negotiation. Second, FIPA provides a standard content language FIPA SL that is used in conjunction with FIPA ACL. FIPA SL is the most suitable choice (due to its expressivity) among available content languages to represent message content.

The message structure of FIPA ACL (FIPA 2002c) provides all the primitives to capture Negoisst message. The table 4.1 shows the mandatory elements of Negoisst message (as highlighted in Figure 2.5) and the corresponding parameters of FIPA ACL to capture Negoisst elements.

Negoisst Message Elements	**FIPA ACL Message Parameters**
Meta-data:	
Sender	sender
Recipient	receiver
message type	performative
Content:	
structured offer	content, ontology

Table 4.1: A one-to-one correspondence between Negoisst message elements and ACL message parameters

Therefore, the ACL chosen for our hybrid model is FIPA ACL.

4.1.2 Agent Content Languages

An ACL (such as KQML or FIPA ACL) provides communicative acts (with semantics), which capture only the intention of an agent in an ACL message to enable meaningful communication. Understanding a communicative act helps in understanding the purpose of message in communication process and the associated message content (i.e., propositional content) but it does not help in processing this content element semantically and syntactically. The message content is domain specific, captured in some domain or content language, and added as a content element in an ACL message. Content languages are used at the knowledge level and provide a key layer for exchanging and sharing domain-specific and application-relevant data and knowledge among agents (Botelho et al. 2002). The propositional content is a declarative representation of knowledge about the world and is encoded in different declarative knowledge representation languages e.g.,

FIPA SL (FIPA SL 2002), knowledge interchange format (KIF) (Neches et al. 1991, Genesereth & Ketchpel 1994), DAML+OIL (Botelho et al. 2002), web ontology language (OWL) (Zou et al. 2003), and constraint choice language (CCL) (Willmott et al. 2000) etc.

Content languages can be distinguished by targeted application areas[9], expressiveness, complexity, and available support from development/deployment platforms (Botelho et al. 2002). A good content language should be able to express rich contents, could be processed efficiently and should fit well with the existing technology. The expressivity of a content language has been described as the amount and complexity of natural language sentences that may be expressed with a content language. The expressivity tests by Botelho et al. (2002) on different content languages have shown that standard logic-based languages are more expressive than web-based[10] content languages. In the tests, the logic-based languages such as FIPA SL and KIF were able to express more natural language expressions than DAML-OIL and ebXML. The expressions that were tested are propositions about classes of things, action expression, references (to objects), quantification, logical and modal operators. Later, Zou et al. (2003) have evaluated OWL as a content language using the same expressivity test and showed that OWL is suitable to be used by agent in electronic commerce for negotiations.

Until recently, logic-based content languages have been used in automated negotiation systems (Sierra et al. 1998, Parsons et al. 1998, Luo et al. 2003, Barbuceanu & Lo 2000), but now, as mentioned above, web-based content languages are also used in automated negotiation (Zou et al. 2003). A logical content language can be based on different logic or can provide different support in negotiation systems depending on the

[9] Classical propositional logic is used as a negotiation language by the negotiating agents in a domain in which each issue in the negotiation is given value of either "true" or "false". The proposals possible in this kind of language are typically considered in the decision theory (Wooldridge & Parson 2000). The other language, which is based on subset of first-order logic, is used for electronic commerce scenarios, in which agents negotiate to reach agreement with respect to some financial transaction (Noriega & Sierra 1999). In this language, a proposal is represented as a finite set $V = \{v_1,...,v_m\}$ of negotiation issues, where each issue v_i has a natural number value.

[10] Web-based languages are also based on some logics e.g. OWL is partially mapped on description logic (a subset of predicate logic) (Antoniou & Harmelen 2003).

negotiation object and the approach on which the negotiation system is based e.g. heuristic or argumentation based. For example, for a multi-issue negotiation, a content language should be able to at least express the object of negotiation i.e., negotiation issues and values (Sierra et al. 1998). The content language should provide variables to represent negotiation issues, constants to represent values as well as conjunctions operators. These constructs enable agents to prepare full and partial multi-issue proposals. A propositional logic can be used to design such language. Argumentation-based negotiation (ABN) systems define content languages which are problem specific. For example, an ABN system uses BDI based agent architecture for argumentation and, therefore, it defines a content language based on logics of BDI to express goals of agents in terms of beliefs, intentions and desires (Parsons et al. 1998). In constraint-based models (e.g. Luo et al. 2003, Barbuceanu & Lo 2000), a content language is based on CCL (Willmott et al. 2000). In these models, a message from one agent contains constraints representing its requirements and the message from the counterpart represents the solution to the constraints. CCL has been designed for carrying constraints or solutions to constraints satisfaction problems (CSP) (Willmott et al. 2000).

Apart from logical content languages, Cranefield & Purvis (2001) have presented an approach to generate a specialised content language from the given ontology using object-oriented programming and modelling formalisms. The content language enables the use of object-oriented encoding of domain-specific objects in content instead of strings (as in logic-based content languages). This ontology-based content language approach can be a good choice for hybrid negotiation model by using negotiation ontology feature of Negoisst system. The major problem with this approach is that the expressiveness of content language depends on the ontology modelling language and the content language may not work when the ontology changes.

In the following sub-sections, we first present two content languages: a standard logic-based FIPA SL and a standard ontology language OWL, and then select one for the hybrid negotiation model. The two languages are discussed in inter-agent communication for their expressivity and the role they play in automated negotiation to express domain contents. The selected content language should be suitable for expressing content in targeted application area i.e., to express the nine content categories that represent inter-human negotiation behaviours (see section 3.2.2) and its implementation should be

supported by the existing agent development platforms[11]. Although an agent content language is not able (chapter 5) to express all the nine content categories, nevertheless, the study of agent content languages can enable to sort out the categories that can be expressed in some content language.

4.1.2.1 FIPA SL Content Language

FIPA SL (semantic language) is a standard content language by FIPA and often used in conjunction with FIPA ACL. A variety of examples and targeted application areas of FIPA SL have been shown in the communicative act library (FIPA 2002b). A complete specification of FIPA SL provides the syntax, associated semantics, and the lexical definitions of language (FIPA SL 2002). The syntax and semantics of the FIPA SL language are based on the formalism of predicate logic[12].

FIPA SL fulfils maximum requirements related to the language expressivity and, therefore, it is the most expressive logic-based content language among all the standard content languages (Botelho et al. 2002). FIPA SL is expressive in terms of syntax and semantics, and represents propositions, actions and open queries, and allows explicit quantification, logical connectives, action propositions, modal operators and functions. These elements allow supporting many logical languages. For example, FIPA SL is rich enough to fulfil the needs of expressing negotiation objects in existing automated negotiation systems. It provides elements such as variable, constant and binary logical operators to express a negotiation object composed of negotiation issues and values, therefore supporting propositional logic. Similarly, the FIPA SL provides modal operators, unary operator and proposition to express arguments in argumentation-based negotiation model (Parsons et al. 1998).

FIPA SL provides three basic expressions to compose message content: *proposition*, *action expression* and *identifying reference expression* (IRE). Negotiation related communicative acts use propositions to specify conditions and preconditions on

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[11] JADE (Java Agent Development Framework) is one of the popular existing agent development and runtime environments http://jade.tilab.com.

[12] In predicate logic, the formulae contain variables which can be quantified using existential and universal quantifiers.

the action expressions (FIPA 2002b). An action expression represents the action that can be performed in the negotiation (an action expression represents a service or a product, and the action to be performed on it). IRE identifies an object in the domain and is used with action expressions to specify preconditions on the action. Here we describe the elementary constructs of FIPA SL content language, which can be used to construct the propositions, actions expressions and IREs, and to represent the different types of content.

Functional Term: A *functional term* refers to an object via a functional relation with other objects, rather than using the direct name of that object. For example, the functional term `(car :make mercedes :model c-class :year 2008)` refers to a car object. The functional symbol 'car' refers to the object through a list of parameters (name-value pairs). This form of functional term is appropriate to represent content where the functional symbol is interpreted as the constructor of an object and the parameters represent the attributes of the object. The parameters of a functional symbol can be used to describe a service or product. The names of parameter can be specified in an ontology.

Term: In the predicate logic formalism, domain entities are represented by terms, which can be constant symbols, variables, recursively constructed functional terms. The meanings of the symbols used to define terms are determined by the underlying domain representation or domain ontologies.

Proposition: A proposition can be used to state a fact, set conditions on the execution of agreement, or set preconditions on the issues etc. To express rich propositions is the most demanding requirement in content languages, because they are used in all negotiation related acts, such as in queries, assertions, arguments (FIPA 2002b). In FIPA SL, a proposition is prepared through an *atomic formula* or *well-formed formula* (wff). An atomic formula represents an atomic statement, which has a truth value in the language of domain of discourse. An atomic formula can be used to represent a propositional symbol, to show the equality of two terms, or to express assertions using predicate symbols defined over zero or more arguments. A complex proposition can be prepared through wff. A wff is constructed from an atomic formula, by applying logical (unary or binary) connectives, quantifier or modal operators on wffs etc. An atomic formula is itself a wff.

The meanings of terms, predicate or propositional symbols in propositions are domain specific and their meanings can be in the relative domain ontologies.

Referential Operators: As we mentioned above, IRE is used to identify an object in the domain. Three referential operators –*iota*, *any* and *all*—are used to construct IREs and bind free variables in propositions in IREs. The referential operators in IREs are evaluated by applying reasoning mechanism on the agent's knowledge base. The results of evaluation can satisfy the propositions when substituted for the variables. The *iota* operator is used to denote a single object that satisfies the proposition represented by formula, the *any* operator denotes any object that satisfies the proposition, and the *all* operator denotes the set of all objects satisfied by the proposition.

4.1.2.2 OWL as Content Language

The web ontology language OWL (Antoniou & Harmelen 2003) has been used as a content language in a multi-agent system where agents take part in auctions and negotiations (Zou et al. 2003). Besides specifying and publishing underlying common ontologies in system, the OWL has been used as a FIPA-compliant content language for the FIPA ACL messages. The expressivity of OWL has been determined less than logic-based languages such as FIPA SL or KIF, but enough for most of knowledge representation tasks in electronic commerce. The ontology provides basic required classes (e.g., Agent, ACLMessage, Service, etc.), necessary expressive requirement (such as proposition, Action, and Reification), and provides support for expressing rules, queries and responses to queries.

OWL has a well-defined model-theoretic semantics as well as an axiomatic specification that determines the intended interpretations of the language and makes it a counterpart of logic-based content languages. The authors have argued that OWL is a good choice as a content language: for its expressive power as a knowledge representation language that seems to be adequate for many current agent based systems; for its better support for using terms drawn from multiple ontologies than do the current popular agent content languages; as a semantic web language, its design fits into and integrates with web-based information and service systems; and it is fully computer-interpretable, thus ready to agent interoperability and automated reasoning techniques.

4.1.2.3 Content Language for Hybrid Negotiation Model

In practice, all automated negotiation approaches, computational or argumentation-based, use a domain or problem specific content language or a subset of any logic language to represent the negotiation content. These models do not use a standard agent content language (such as FIPA SL or KIF). The purpose of making a standard agent content language the part of the agent communication model in our hybrid model is to support most of the content categories generated in automated negotiations. The above two content languages fulfil the minimum support of expressing negotiation issues with variables, issues values with constants, and conjunction operator for preparing multi-issue offer. But, the choice of content language in the hybrid model for the negotiation agent depends on the agent decision making model. If the agent is using only responsive or trade-off mechanism, then a content language with above elements is enough. But, if agents also perform argumentation then more expressivity is required.

The use of FIPA SL or OWL as a content language in agent communication model depends not only on the language expressivity (as FIPA SL is more expressive than OWL) but also on the targeted application area, ease of implementation and compatibility with existing technology. OWL provides syntax and semantics of a language as well as the meanings of used vocabulary (keywords) in content. It can be used as content language, if

- the expressivity requirements are limited for making statements about types and classes of objects and their instances, and the properties of such types and classes, and for defining the semantics of such statements;

- the complex ontology processing is required or can be performed: multiple ontologies exist, or mapping/translation required from ontology to another etc., or simply, all benefits of owl relating to the modelling, maintaining and sharing of ontologies (Antoniou & Harmelen 2003). OWL provides better support in modelling, maintaining, and sharing ontologies, as compared to FIPA SL, KIF etc.

FIPA SL provides the syntax and the semantics of constructs, but extra ontology language is used to define the domain specific content. FIPA SL should be used, if

- higher expressivity is required to express the negotiation content.

We choose the FIPA SL for hybrid negotiation model and discuss its expressivity in chapter 5 for the negotiation content categories and their possible support in human-agent negotiation. It will be also observed that inter-agent communication is richer than communication between a human counterpart and a negotiation agent in hybrid negotiation model.

4.1.3 Ontologies in Agent Communication

An ontology is described as "*an explicit representation of a conceptualization*" that can be used for communication and interoperability (Uschold & Gruninger 1996). This conceptualisation is a means of sharing domain knowledge among people, databases and applications. To represent a conceptualisation, an ontology formally defines a set of terms and relationships among them. These terms and relationships describe, represent and organise a certain domain i.e., a specific area of knowledge such as medicine (Heflin 2004). In communication, ontologies facilitate shared meaning of communication among people by creating a normative model of the system. The normative model gives a shared understanding of the system and its objectives. For interoperability, ontologies can be developed for enterprise models spanning activities, resources, organisation, goals, products, and services to provide common repository to different software systems or tools to make them work together.

The lack of standard negotiation ontologies is outlined as a key communication and process problem for negotiation agents belonging to different organisations in business negotiations (Tamma et al. 2002, Beam et al. 1996). Ontologies can describe product and business terms as well as negotiation process rules and ensure that all participating agents in a negotiation refer to exactly the same thing. This gives software agents the shared vocabulary as well as the flexibility of learning this shared vocabulary dynamically by acquiring the ontology. In the previous section, we have seen that agent content languages provide syntax to represent the message content and the standard semantics to interpret the message content. The meanings of terms, predicate or propositional symbols building the message content are domain and application specific

and they are defined in common shared ontologies for the meaningful interpretation of content. The existing automated negotiation systems use ontologies for shared vocabulary, along with or without standard content languages. For example, in an automated negotiation system (Luo et al. 2003), agents share a common ontology for the terms they communicate in offers using a standard constraint choice language.

Sycara and Paolucci (2004) have described three contributions of ontologies to agent communication and different use of ontologies in an agent and multi-agent system. The first contribution of ontologies is that they provide concepts and properties to express the content of message and tools to interpret the content according to the defined ontologies. The automated negotiation system presented by Luo et al. (2003) uses ontology in this context. The second contribution of ontologies provides the base for organising the received content (knowledge) in the knowledge base and integrates this knowledge with proof theory so that the agents can derive inferences form the knowledge they gather. The above advantages of using ontologies in agent communication were related to the meanings of content of a message. The next advantage of ontologies is that they provide a way to formalise conversational policies as objects in the domain that can be used by the agents to participate in long conversations. Another automated negotiation system (Sierra et al. 1998) uses an ontology in all three use cases of ontologies in agent communication i.e., the negotiation ontology defines the participating agent's roles, ACL, content language and a dialogue, which help negotiation agents to prepare and exchange arguments during negotiation. Tamma et al. (2002) have presented a negotiation ontology for formalising conversation policies in open environment. The negotiation ontology includes concepts, which are shared across most negotiation protocols, to characterise various different negotiation protocols and their properties. This ontology can be committed partially by agents for interaction purposes only by defining a mapping between their internal knowledge and this ontology.

For a single agent, ontologies serve as the conceptualisation of the domain of the agent and as the knowledge representation to organise agent problem solving and reasoning functionality. The domain can be conceptualised in terms of agent's actions, static facts, vocabulary, inference rules, model of environment etc. In MAS, ontologies can provide the description of the domain of the MAS that is shared across all agents, and the shared vocabulary to understand the content of messages. The MAS description in

ontologies can include the services such as location of registries and conventions such as standard protocols. In the hybrid negotiation model, we will use ontologies for communication between a human counterpart and a negotiation agent, for interoperability between agent negotiation system and Negoisst system, and for conceptualising the knowledge domain of negotiation agent (chapter 5).

4.2 Decision Making in Automated Negotiations

Decision making is the second main issue in developing agent-based systems. There is no single or universal approach to automated negotiation that fits every problem domain. Each approach is based on different assumptions about the environment and the agents involved in the interaction. For example, in simple environments, such as the famous blocks-world scenario, an agent has a complete and correct knowledge about the number of boxes and their position in the world. The decision making simply involves the performance of actions in some sequence to achieve goals without assuming any other entity in the environment. In complex scenarios, such as business negotiations, an agent has to take several factors into account to make good decision. For example, in such environments, agent knowledge is incomplete and uncertain, alternatives to be considered might be large, and decisions depend on other participants in the environment.

A negotiation agent needs to address the following decision problems in a business negotiation (Faratin 2000):

- *What is the range of acceptable agreements?*
- *What initial offers should be sent out?*
- *What counter offers should be generated?*
- *When should a negotiation be abandoned?*
- *When is an agreement reached?*

4.2.1 Negotiation Mechanism

The above negotiation decision problems are handled by a negotiation mechanism (Faratin 2000). A negotiation mechanism is an instance (i.e., an electronic negotiation scenario and the associated medium within the business domain) that supports agents in finding a solution to a particular negotiation problem (Ströbel & Weinhardt 2003). In a

game theory term, a negotiation mechanism consists of a negotiation protocol and negotiation strategies for agents (Fatima et al. 2004). The negotiation strategies include the computational means for offer evaluation and generation. The term mechanism comes from game theory and satisfies certain properties, such as *computation efficiency*, *individual rationality*, *convergence* etc., (Lomuscio et al. 2001, Ströbel & Weinhardt 2003). The properties are desirable in the design of negotiation mechanisms. They are considered explicitly for the game-theoretic mechanisms while implicitly for the computational negotiation mechanisms. Some of these properties are described in this section that will come across later while describing different negotiation mechanisms.

Some properties are more related to the evaluation of mechanisms while the others are more associated with the participating agents. For example, the property *computational efficiency* is related to mechanism. It says that a negotiation mechanism should be computationally efficient i.e., the protocol and strategy that build the mechanism should be manageable in computing offers or reaching agreement. For the hybrid negotiation model, we are more interested in properties that are more related to the negotiation agents. At mechanism level, we are interested in properties, which are associated with the analysis of offer generation functions in mechanisms. Properties such as computational efficiency, makes more sense when we are experimentally evaluating the overall working and performance of hybrid negotiation model. The following properties are directly or indirectly part of a negotiation agent's decision making.

Individual rationality: A mechanism should be individually rational for agents i.e., it should be in an agent's independent interest to participate in negotiation. The negotiation agent should be self-interested. For this, it should be initialised with decision making support consisting of offer generation functions, evaluation function and negotiation strategy, so it can negotiate to maximise the goals of its principal.

Pareto efficiency: Pareto-optimality measures the global goodness of agreements. An agreement is *Pareto efficient* if there is no other agreement that is better for one party without being worse for another party. The quality of a final agreement is measured from individual's satisfaction perspective as well as from joint/group's satisfaction perspective.

Social welfare maximisation: If the negotiation process ensures that every resulting agreement maximises the sum of the utilities of all negotiation participants, the solution is maximising the social welfare. As we are interested in integrative negotiations, we see whether the offer generation methods in automated negotiation mechanisms provide coordinative behaviour.

Convergence: It is important to know whether an electronic negotiation process converges towards a solution. The speed of convergence is the time or number of steps needed until the electronic negotiation process converges towards solution. If the offer generation methods provide negotiation behaviour such as concession making or log rolling, then the negotiation agent's created offers will converge towards a solution.

4.2.2 Decision Making Approaches in Hybrid Model

In chapter 2, we presented a brief introduction to game-theoretic, heuristic and argumentation-based methods to automated negotiations (cf. section 2.3.3.3). These methods are based on different negotiation decision and agreement approaches (cf. sections 2.2.1 and 2.2.2) and, therefore, they are suitable for different negotiation problems and environments. We discuss here on which decision making negotiation approach we are going to model the decision making of negotiation agents in our hybrid negotiation model. Here the selection comparison is between game-theoretic and heuristic approaches. The argumentation-based approach has a completely different purpose in negotiation and will be studied here in any case as a part of the agent's decision making.

Game theory as a formal bargaining approach has been widely applied in the design of rational interaction strategies and negotiation mechanisms for rational agents (Rosenschein & Zlotkin 1994, Sandholm 1999, Binmore & Vulkan 1997, Fatima et al. 2004). The goal of mechanism design in game theory is "*...to generate protocols such that when agents use them according to some stability solution concept—e.g. dominant strategy equilibrium, Nash equilibrium etc. –then desirable social outcomes follow*" (Sandholm 1999). As per the goal, the game-theoretic mechanisms consist of a negotiation protocol and a corresponding negotiation strategy that together aim at the negotiation outcome. For example, Fatima et al. (2004) have presented a game-theoretic automated negotiation framework for generating agreements that are in equilibrium. The

main focus of this framework is on the properties of outcome and the design of stable[13] mechanisms consisting of a negotiation protocol and a negotiation strategy. The strategic behaviours of agents consist of their reservation value, deadline, utility function and a negotiation strategy, as well as the incomplete information or probability distribution about the deadline and reservation values of opponent agent. The model assures equilibrium outcome even in the presence of incomplete information about the opponent.

The main two reasons for game-theory success in negotiations are its ability to conceptualise negotiation problems as games, which are open to experimental analysis, and then explain these games using formal and sound notions, rather then relying on post hoc explanations. However, the game theory's assumptions of knowledge rationality and computational non-boundness are the bottlenecks for the design of negotiation models for real world negotiation problems in dynamic and uncertain environments (Faratin 2000).

We mention here the key reasons for explaining why the game-theoretic negotiation approach is not suitable in hybrid negotiations:

- The main purpose of agent decision making in hybrid negotiation, as presented in chapter 3, is to generate offers showing different negotiation behaviours (negotiation strategies). Game-theoretic negotiation mechanisms are based on the normative decision perspective and, therefore, allow rational behaviour which is competitive behaviour and does not fit in integrative negotiations. They do not provide offer generation methods for concession making or coordinative behaviour. Therefore, we are interested in those automated negotiation approaches that are for integrative negotiations or at least provide methods to generate offers for different negotiation behaviours.

- In a game-theoretic negotiation mechanism, a negotiation strategy is designed according to the negotiation protocol. A software agent is bound to follow the strategy to achieve the established behaviour of mechanism. In the Negoisst system,

[13] A negotiation mechanism is described stable when the strategies of both agents are in equilibrium i.e., agents act strategically and each agent's strategy is a best response to its opponent's strategy.

the negotiation protocol does not restrict a human negotiator to play a certain strategy in some state. The negotiator is free to use any negotiation strategy during negotiation. Therefore, in the hybrid negotiation model, we cannot restrict a negotiation agent to a particular strategy while the human counterpart is free in his or her behaviour.

- The game-theoretic mechanisms are designed by considering the strategic behaviour of both rational self-interested agents. In the hybrid model, an automated negotiation mechanism is being considered for only one player, while the other player is a human negotiator. Who is free in strategic behaviour, rational or irrational, during negotiation.

- In game theory, common knowledge is a usual assumption. But, in the Negoisst system, human negotiators are not normally aware of each other's preferences.

- Game-theoretic negotiation mechanisms are not very flexible and open. Each mechanism is designed to solve a particular negotiation problem whereas, Negoisst is not fixed for particular negotiation problems.

After mentioning the general limitations and the particular problems of the game-theoretic approach for negotiation agents in the hybrid negotiation model, we turn now to the comparable alternative approach to automated negotiations, called heuristic approach. In distributed AI, numerous negotiation models called *computational* models have been developed for this alternative approach (Faratin 2000). These models are the extension of the game-theoretic approach of bargaining. Models based on heuristic methods are examples of computational models. In a computational model, a negotiation agent as a computational entity has all the decision making ability to perform negotiations to achieve negotiation goals, instead of relying on negotiation protocol and strategy implemented by an underlying mechanism. The problems and assumptions of game theory are the main concerns of these computational models. Therefore, they acknowledge the cost associated with computation and decision making. These models, however, use the formal game-theoretic constructs such as protocol, utilities and strategies to build the computational

components, and the solution concepts such as Nash solution, pareto-optimality etc., to empirically evaluate the computational components. These models offer negotiation protocols that are less restrictive and decision making is based on informal and descriptive models of negotiation. A main problem with computational models, also called informal models, is that there are neither formal theories nor strategies that can be used for their evaluation (Faratin 2000). They do not formally analyse the behaviour of agents and the agreement that can be reached during the design phase. Evaluation has to be done through simulations or empirical analyses.

Nevertheless, we use computational models for the agent's decision making model in the hybrid negotiation for the following reasons. The hybrid negotiation model uses the Negoisst negotiation protocol, which just describes the order of actions. Hence, the Negoisst protocol will not bind the negotiation agents to use strategies in accordance to protocol states. An agent's negotiation strategies work independently of the protocol. A flexible decision making behaviour that consists of various negotiation strategies and applicable to variety of negotiation situations can be developed for the negotiation agent. Finally, negotiation strategies, decision functions and protocol are designed in computational models in such a way that have the potentials to lead integrative negotiations or that the solutions are pareto-optimal.

Now a few automated negotiation models based on the heuristic approach (section 4.3) and the argumentation approach (section 4.4) are described in detail to propose the negotiation agent's decision making model for human-agent negotiations.

4.3 Computational Automated Negotiation Models

In the following sub-sections, we discuss in detail computational automated negotiation mechanisms and models[14] for bilateral multi-attribute integrative negotiations. These mechanisms or models are from different negotiation domains, represent and solve negotiation problems differently. However, all generate offers heuristically—a trial-and-error method to reach agreement.

[14] We use term mechanism mainly for offer evaluation and generation functions and negotiation strategy. A model also describes the protocol and communication component for negotiation.

Faratin (2000) presents an automated negotiation framework for service-oriented domains for the provisioning of services among software agents. This negotiation framework implements a complete solution for decision problems for negotiation agents e.g., two offer generation mechanisms, an issue-set manipulation mechanism and a negotiation meta-strategy. For being computational, the mechanisms are applicable in dynamic and uncertain environments. The offer generation mechanisms support competitive and cooperative negotiation behaviour. The issue-set manipulation mechanism enables agents to re-formulate the negotiation problem by changing the negotiation space through the addition or retraction of negotiation issues. The meta-strategy determines the use of suitable offer-generation mechanisms in the given negotiation situation. In the following sub-sections, we present the offer generation mechanisms and the meta-strategy. The responsive mechanism (Faratin 2000) mainly implements the concession making strategy and generates offers and counteroffers by considering some criteria, e.g. remaining time of negotiation, remaining resources, or opponent's behaviour etc. The trade-off mechanism (Faratin et al. 2002) is a heuristic negotiation model for integrative negotiations and generates offers when negotiators are unwilling to decrease their pay-offs in a negotiation. There are also automated negotiation models that solve the negotiation problem as a constraint satisfaction problem (CSP) (e.g., Luo et al. 2003, Barbuceanu & Lo 2000). Luo et al. (2003) propose a fuzzy constraint-based negotiation model and mention the advantages of this model in retail trading environment where buyers do not precisely know their requirements or product details. Barbuceanu & Lo (2000) introduce a negotiation model which integrates/combines multi-attribute utility theory (MAUT) with distributed constraint satisfaction for multi-objective automated negotiations in electronic commerce applications. We discuss the model of Luo et al. (2003) only to show how such models work and how they are different from other computational models (e.g. responsive and trade-off) in evaluating and generating offers.

In discussing each mechanism or model, our focus is on offer evaluation and offer generation techniques, the information required to generate offers, and assumptions about counterpart's preferences. Where necessary, we will also mention protocol, communication support and negotiation strategies associated with a mechanism or model. In offer generation techniques, we are particularly interested in the following information.

- Offer generation is a combination of local reasoning on what an agent has available in its knowledge base such as preferences, knowledge about the counterpart, information about negotiation environments etc., and the interaction with the counterpart, which helps the agent in determining the needs and behaviour of its counterpart. Some offer generation mechanisms do not depend on counterpart information in generating offers, while others assume counterpart preferences in generating offers.

- A search model is a process for discovering alternatives in the negotiation solution space. It is based on the negotiator's own goals, aspirations, and constraints (Pruitt 1981) and is used in the offer generation techniques. A sophisticated search model can also incorporate other party's recent proposal(s).

- We are also interested in whether a mechanism or model allows to process or create partial offers. Through partial offers, agents are not forced to negotiate all issues simultaneously. As mentioned in the previous chapter, Negoisst allows the negotiation of partial offers (cf. section 2.3.4.3).

4.3.1 The Responsive Mechanism

The responsive mechanism provides a set of decision functions called tactics to generate offers and counteroffers (Faratin et al. 1997, Faratin 2000). A decision function computes the value of an issue by considering some criteria e.g. remaining time, remaining resources or opponent's behaviour etc. An agent can use a linear combination of tactics i.e., more than one decision function to compute the value of an issue. In this case, a weighted combination of different tactics is used. The computed values of all negotiation issues are combined to form an offer. The responsive mechanism is mainly for concession making and solves the decision making problems of an agent given its limited information and computational capabilities.

4.3.1.1 Families of Tactics in Responsive Mechanism

The tactics in this service-oriented negotiation model have been divided into time dependent, resource dependent and behaviour dependent tactics, i.e., the concession rate is

a function of the time limits in negotiation, the resources left in negotiation, and the behaviour of the other agents, respectively. The decision mechanism based on these tactics is responsive because the agent reacts to its changing environmental factors (remaining time until the deadline, consumed resources, opponent's behaviour) in making offers/counteroffers. An agent can employ at most one tactic from each of the families to generate value of any issue in the counteroffer. The responsive mechanism is applicable in many types of negotiation scenarios where the time and resources of the negotiation agent and the behaviour of the opponent are key features.

Time-dependent Tactics: Remaining negotiation time is the predominant factor in the time-dependent family of tactics to calculate the issue value to be offered next. Time-dependent tactics can only be used when there is a deadline for an agent to complete the negotiation. The tactics in this family are differentiated on the shape of the concession curve—a function depending on the remaining time. The time-dependent functions are divided into two main families, the *polynomial* functions and the *exponential* functions. Both families are parameterised by a value $\beta \in \Re^+$. For a large value of β, the functions in the polynomial family concede faster at the beginning of negotiation than the exponential functions, and then both behave similarly. For a same small value of β, an exponential function waits longer than the polynomial function before it begins conceding. Three extreme tactics are *linear*, *boulware* and *conceder*. In the linear tactic, the concession rate remains constant from start to end. The boulware tactic is termed as a selfish tactic (Raiffa et al. 2002) and concession is given nearly at the end of negotiation. The conceder tactic is considered as a generous tactic and it concedes nearly the full reservation value in the beginning of a negotiation. Boulware and conceder tactics can be used both in the exponential and the polynomial functions.

Resource-dependent Tactics: These tactics calculate the offers depending on the available quantity of negotiation resources or the environmental resources available to the agent. The negotiation resources can be any type such as available money, remaining product quantity etc., and the environment resources include e.g. the number of participating agents, economic parameters etc. Time-dependent tactics can also be considered as

resource-dependent tactics in which time is taken as resource. In resource-dependent tactics, as the resources become scarce, the agents start conceding fast.

Behaviour-dependent Tactics: Time-dependent and resource-dependent tactics keep agents in constant pressure to complete the negotiation before the time or resources finish. In behaviour-dependent or imitative tactics, the behaviour of the counterpart is taken into account while creating the counter offer. This family of tactics is used in co-operative problem-solving negotiations. Three tactics have been defined in this family: *relative* tit-for-tat; *random absolute* tit-for-tat; and *averaged* tit-for-tat. These tactics differ in their type of imitation, i.e., which aspect and to what degree the behaviour of the counterpart should be imitated in giving concession. The *relative* tactic imitates proportionally; the *random absolute* tactic imitates in absolute term; and *averaged* tactic computes the average of the proportions in a number of previous offers. Unlike time-dependent and resource-dependent tactics, the use of imitative tactics protects the agent from being exploited by partners. Tactics in this family can only be applied when the behaviour of partner agent is known from its previous offers.

4.3.1.2 Evaluation of Offers

When an agent receives an offer from its opponent, it evaluates the offer using its scoring function. If the utility value of an incoming offer is greater than the counter offer an agent is ready to send, then the agent accepts the offer. Otherwise, the counter offer is sent. This process continues until the end time of the negotiation is reached, where the negotiation terminates unsuccessfully. The scoring function is based on additive scoring system (Keeney & Raiffa 1976). The additive scoring function is a model of how an agent can consolidate individual preferences (utilities) over each issue into a single preference (utility). The scoring function used in the responsive mechanism either increases or decreases monotonically.

4.3.1.3 Negotiation Strategy for Responsive Mechanism

A negotiation strategy for the responsive mechanism assigns a weight value to each tactic in case of using more than one tactic in generating the value of an issue. It can be defined as a function which takes an agent's current mental state and current weights of tactics,

and generates new weights of tactics for the next offer. The strategy guides the agent to change its behaviour as the environment changes (resources or opponent's behaviour). The strategy takes into account the changes in the agent's environment and weights of tactics, and determines which combination of tactics should be used at any one time to generate next offers for particular issues. Two types of strategies are possible to change the importance of tactics over time: in the *pure-strategy* case, tactics are assigned a weight value of either 0 or 1 (only one tactic can have value 1 and the rest have value 0), and this value is static throughout the negotiation; in the *strategic* case, tactics can be assigned any weight value in the interval between 0 and 1.

4.3.1.4 Knowledge Required about Counterpart Preferences

In this mechanism, the agent's preferences or reservation values are private. However, an agent takes into account a minimal amount of information about the choices of its partner. Agent decisions are mainly based on the role of the counterpart, the state of environment (time- and resource-dependent tactics) and the choices of the counterpart (behaviour-dependent tactic). The preferences of the counterpart can be known from its role. Normally, negotiators have opposing preferences on all issues (e.g., a seller prefers higher prices to lower ones and the buyer prefers the opposite). The responsive mechanism will not work when both the negotiators have the same preferences (which is unlikely in negotiations) on issues.

4.3.2 The Trade-off Mechanism

We describe now a heuristic offer generation mechanism for generating trade-offs (Faratin et al. 2002, Faratin 2000). A trade-off in negotiations is a sort of compromise where a negotiator lowers his demand on one issue in return of more benefits on other issues to make an offer more acceptable for the counterpart. In creating a trade-off, the negotiator does not decrease his/her own pay-offs. In the model based on the trade-off mechanism, the offer generation reasoning is characterised by a heuristic function that maps the current demand of the opponent and the previous offer of the agent to a new offer to be sent to the opponent. The trade-off mechanism is based on a linear algorithm

that uses the fuzzy[15] similarity notion to approximate the negotiation preferences of the counterpart and then uses the hill-climbing to explore the space of possible deals for the one that is most likely to be acceptable by the partner. This mechanism is argued to be workable for B2B and has been developed taking into considerations that agents are computationally bounded and the negotiation thread is finite (Faratin et al. 2002).

We can formally describe the trade-off mechanism in two steps by assuming that two agents *a* and *b* are negotiating with each other and *a* wants to create a trade-off offer for *b*. It works as follows.

i. Select a set of offers all of which have the same utility as *a*'s previous offer *x* to *b* (agent *a* is indifferent to them)
ii. Select from this set an offer *y* that agent *a* believes is more preferable to *b* than *x*. The more similar the offer *y* is to *b*'s last offer, the higher the chances are of acceptability.

The preferability is based on the preference structure of the partner agent that is approximated on its last received offer. Instead of assigning prior probabilities or guessing subjective expected utilities about opponent's preferences, the trade-off offer generation model employs a heuristic approach to compute a similar offer. This heuristic approach generates a domain model that is then used to induce the likely preferences of the partner agent.

The similarity between two contracts is computed using a fuzzy similarity technique. The fuzzy similarity specifies the concept of closeness between two offers. The similarity is computed for each issue one by one. Then, the individual similarities of issues are added to get the overall similarity between two offers. The similarity represents the closeness between two values of an issue against some evaluation criteria. The evaluation criteria are represented as criteria evaluation functions on a single issue and determine how much a value of that issue matches the criteria. The evaluation criteria are

[15] Fuzzy logic deals with imprecision, information granularity, approximate reasoning and computing with words.

actually the fuzzy similarity constraints on issue. The fuzzy similarity approach copes with the inherent uncertainties in the negotiation process.

The model works for both discrete and continuous negotiation issues. The automated negotiation experiments show that agents using trade-off strategies conclude an agreement which maximises the joint utility of the outcome and hence is beneficial for both agents. The agent using the trade-off strategy gets a higher utility than the agent using the responsive strategy (Faratin 2000). The experimental results of the trade-off mechanism have also shown that the better trade-offs are found if the negotiation space is thoroughly searched. The search is calculated in term of algorithm's iterations (runs) and the number of contracts per iteration.

4.3.2.1 Knowledge about Partner Preferences

To calculate trade-offs, an agent searches the negotiation space for possible deals and such search requires more information about the preferences of partner agent. The trade-off mechanism does not directly model the opponent's actual preferences on issues' value range. Knowledge about preferences of the partner agent is achieved by using a fuzzy similarity technique that models the uncertainty of an agent's beliefs over the preferences of the partner as fuzzy relationships between values of the domain and then use this domain model to induce the possible preferences of the opponent. This technique is used to find similarities for each issue in the negotiation.

To calculate the similarity between a complete generated contract and the opponent's last offer, the opponent's preferences for the importance of each issue is also provided to the algorithm. The experimental results show that the search for a better trade-off is directly affected by how precise the information is the agent has about the opponent's preferences. Four cases have been specified about the opponent's weight preferences for issues (Faratin et al. 2002). In the *perfect* information case, cardinally correct information is provided to the agent. In the *partial* information case, ordinally correct information (correct order of the importance of issues) is provided. In the *imperfect* case, the agent has incorrect information about the opponent's weight preferences. Finally, in the *uncertain* information case, the agent has undifferentiated weights for each issue—all issues have equal importance.

4.3.2.2 Evaluation of Offers

In the trade-off mechanism, when an agent receives an offer from its opponent, it evaluates the offer using its scoring function. If the utility value of a received offer is greater than the previous offer of the agent, then the agent accepts the received offer, otherwise a counter offer (trade-off) is sent. As in the responsive mechanism, offers and counter offers are evaluated using an additive scoring function and the negotiation terminates unsuccessfully when the deadline of the negotiation has been reached.

4.3.2.3 Meta-Strategy Mechanism

The meta-strategy mechanism decides between the responsive or the trade-off mechanism to generate an offer in the course of negotiation (Faratin 2000). The rationale for the use of a meta-strategy is to escape from the local minima of the social welfare function. When both agents use the trade-off mechanism, then they can enter a loop of exchanging the same contract with one another (the distance between the offers does not decrease) i.e., they may remain in local minima. The meta-strategy is a solution to escape such local minima. When an agent observes a deadlock, the meta-strategy switches to the responsive mechanism and the score of the previous offer is reduced by some predetermined amount by lowering the issues' values.

4.3.3 Fuzzy Constraint Based Model

Luo et al. (2003) present a fuzzy constraint based model for bilateral multi-issue negotiations over products and services in retail markets. In this negotiation model, a buyer agent negotiates its requirements, expressed through prioritised fuzzy constraints, with the seller agent, who in response generates offers satisfying these constraints. The negotiation continues to find agreement by submitting new constraints or relaxing already submitted constraints by the buyer agent and generating new alternatives by the seller agent. The negotiation strategies and protocol in this model ensure that agents reach a fair deal (pareto-optimal) by revealing constraints and preferences gradually. In this model, the buyer's payoff is the satisfaction with the bought product and the seller's payoff is the profit it earns from the sold product.

Two main advantages of the constraint-based models have been mentioned over non constraint-based models: first, buyers normally do not precisely know all product

details or what they want, but by using constraints, they can at least express their requirements precisely over multiple issues; second, a seller's offer rarely violates completely the buyer's constraints. It satisfies usually some of the constraints and this partial satisfaction motivates both partners in searching for a solution.

The fuzzy constraint-based model is different from the responsive and trade-off negotiation models in the specification of the negotiation problem, negotiation behaviour, and protocol. This model consists of conceptual specifications of negotiation agents, the communication protocol, and the negotiation behaviours of agents. The design of the model supports negotiations in retail markets where buyers are normally not clear about their requirements, therefore, the focus of the model is mainly on the buyer side of negotiation.

4.3.3.1 Specification of Negotiation Constraints and Offers

The buyer's requirement model consists of a set of product attributes called negotiation issues and their associated domains, a set of fuzzy constraints on attributes, the buyer's profile model and the offer acceptability threshold. The set of constraints (this set of constraint is pre-calculated before the negotiation starts), crisp or fuzzy, captures the negotiation or product requirements of the buyer. Expressing the buyer's product requirements as fuzzy constraints helps the seller agent to explore more negotiation space than a single point as in the responsive and the trade-off mechanisms. Each fuzzy constraint has an associated priority, which specifies the relative importance of constraint. The crisp[16] constraints specify the buyer's requirements that cannot be relaxed during negotiation. A crisp constraint is normally defined on a single attribute. The fuzzy[17] constraints specify the requirements that can be relaxed during the negotiation. A fuzzy constraint can be defined on a combination of attributes and it captures the buyer's preference order on the alternative trade-offs between composing negotiation issues. Each

[16] In a standard constraint satisfaction problem (CSP) a constraint either admits a value(s) to the variable(s) or not. This is called crisp constraint. The satisfaction degree of crisp constraint is either 1 or 0, there is no intermediary situation.

[17] A fuzzy constraint admits value(s) to the variable(s) to some degree between 0 and 1. Given values can satisfy a constraint between fully acceptable and fully violated.

alternative is assigned a satisfaction degree, which represents the buyer's preference level for the values of attributes in that alternative. A fuzzy constraint composed of alternatives and their associated satisfaction degrees, is prepared by the principal of buyer agent at the start of negotiation. A fuzzy constraint is relaxed using a cut-level[18] technique to some defined relaxing threshold. An acceptability threshold in buyer's requirement model represents the minimum utility the buyer will accept during negotiation. A profile model of a buyer represents facts about the buyer and is specific to a business domain. These facts are not a part of negotiation issues on which fuzzy constraints are defined.

The seller agent's product offerings are stored in a product model. A product model consists of a set of products the seller holds. Each product is composed of a restriction (if any), a reward (if any), a profit and product's attributes. A restriction represents a condition on the buyer in order to obtain the product. A reward is an incentive that is attached to product to increase its acceptability for the buyer. The profit represents the seller's payoff for that product. The attributes characterise the product and represent the negotiation issues. Restriction and reward that are attached to a product are not a part of negotiation issues. A reward in offer works as a trade-off, i.e., its existence or absence does not change the profit of that product but can change the acceptability of offer for the buyer. The product model is a complete set of solution and is pre-calculated before the negotiation starts.

4.3.3.2 Decision Making

The decision making of agents primarily consists of a negotiation strategy to reveal constraints or to select offers from the existing requirement model of the buyer and the product model of the seller agent, respectively. The decision making component does not generate offers from attributes' domains as in the responsive or the trade-off mechanism. Using one's respective strategy, the aim of the seller agent is to maximise profit, whereas the aim of buyer agent is to satisfy most of the high priority constraints. The basic idea

[18] Intuitively, a cut-level for a fuzzy constraint is a kind of threshold. If the satisfaction degree to which a value of attributes satisfies a fuzzy constraint is less than the threshold, the values are regarded as unsatisfactory with respect to the constraint, otherwise, they are regarded as satisfactory. A fuzzy constraint can be relaxed if the cut level is not less than the relaxing threshold.

behind the negotiation strategies of both agents is to reveal as few of the preferences as possible to get a fair deal.

The negotiation strategy of a buyer agent guides it when to reveal which constraint from the set of constraints. The constraints are submitted in proposals. The constraints (crisp or fuzzy) are submitted one after the other in the order of highest to lowest priorities. Submitting a constraint can be understood as concession making from buyer to seller, which is performed at two levels, namely, submitting a new constraint or relaxing an already submitted constraint. The buyer agent reveals a new next highest priority constraint to the seller agent when the buyer finds that the seller's recent offer is violating some of its constraints in the constraints set. If a fuzzy constraint has been already submitted, a buyer agent can give concession by relaxing constraint to a minimum value i.e., the agent selects the next highest satisfaction degree trade-off (constraint) from the list (a fuzzy constraint consists of number of trade-offs) and submits it to the seller agent. Only fuzzy constraints can be relaxed up to their associated relaxing threshold. A buyer agent does not reveal facts in its profile to the seller, because they are not part of the negotiation issues.

Each time a buyer receives an offer from a seller agent, it checks its acceptability against the acceptability threshold. The seller offer consists of product attributes, possibly a reward and a restriction. The acceptability of a received offer is calculated by evaluating that offer against the agent's requirement model. The evaluation of offer includes: the overall satisfaction to which the attributes values in the offer satisfy all buyer constraints; the degree to which the buyer can obey the restriction (if any present in the offer); and the degree to which the reward (if any present in offer) is valuable for the buyer agent. If the acceptability threshold is still not reached, then the buyer agent can submit a new constraint or ask the seller agent to re-find the offer for the already submitted constraints. Although the restriction and reward are not negotiation issues, their presence in the offer can greatly affect the evaluation of received offer, depending on the kind of restriction and reward. For a successful termination of negotiation, all the submitted constraints must be satisfied as well as acceptability threshold must be reached.

The negotiation strategy of a seller agent is to select an offer from its available list of offers. An offer is selected, which satisfies the buyer's constraints as well as maximises the seller's profit. The seller offer consists of product attributes, possibly a

reward and a restriction. If more than one solution satisfies the buyer's constraints, the seller agent sends solutions one after the other in profit descending order. When a seller cannot find a new solution satisfying the requirements, it can either add a reward to the previous offer to increase the chance of it acceptability or can ask the buyer to relax the constraints. Addition of a reward in an offer does not decrease the profit level of that offer for the seller, but this reward can increase the acceptability of the offer for the buyer.

This minimum information revelation mechanism in this negotiation model enables a compromise agreement that is considered equally acceptable for self-interested agents. The information should be revealed only to the counterpart when it is necessary to break the impasse and to continue negotiation to an agreement. For example, if one of the agents reveals all its private information at the beginning, then the other agent will use this information to maximise its payoff and this outcome may not be fair from first the agent's point of view.

4.3.3.3 Communication Model

The communication model in this fuzzy constraint-based negotiation model is based on the ACL KQML and a content language, called constraint choice language (CCL), to prepare offers, and an alternating offer protocol to exchange messages. KQML has been extended with new message types according to the requirements of negotiation protocol and agents' internal reasoning. CCL is suitable in this model as it expresses the offer content in form of constraints and choices (values of attributes). A message type in this model does not simply represent an action such as offer or counteroffer as in other models (e.g. responsive, trade-off), but it specifies clearly what the sending agent wants from the counterpart, e.g. a seller agent can ask explicitly the buyer agent to check the satisfiability of a current offer or to relax the constraints using *check* and *relax* performatives, respectively. Similarly, the buyer agent can ask the seller agent to find a new product while submitting a new constraint with performative *find* or to re-find a new product with performative *re-find* while revealing no new information to the seller. In this protocol, only a buyer agent can complete the negotiation process by accepting or rejecting the last offer.

The communication difference between this model and the first two models is that the first two models (responsive and trade-off) have only one message type (for

counter offer) to attach with the heuristically generated offers in order to continue the negotiation process. In this constraint-based model, the seller or buyer can not only send pre-calculated offers or constraints (as counter offer), respectively, but can also send other message types such as re-find or relax to seek concessions.

4.4 Argumentation-Based Automated Negotiation Approach

Many argumentation-based frameworks for automated negotiation have been proposed in literature (e.g. Sierra et al. 1998, Parsons et al. 1998, Kakas & Moraitis 2003, Amgoud et al. 2000). Our purpose in this section is not to discuss all of these frameworks; rather we will discuss the negotiation behaviours supported and the main components of a*rgumentation-based negotiation* (ABN) frameworks. We are mainly interested in the communication and decision making components of ABN frameworks in order to study how this negotiation approach can be used by a negotiation agent in our hybrid negotiation model. The discussion is based on an ABN framework for the business process management (Sierra et al. 1998) and an ABN framework in the domain of planning resources for executing tasks (Parsons et al. 1998). We will describe the purpose of argumentation in these frameworks, the types of arguments generated and the required communication support. The details of logical reasoning, based on the inference and formal systems, for the evaluation and generation of arguments in not provided here.

Argumentation is negotiation behaviour (Köszegi et al. 2004, Pruitt 1981). A negotiation process proceeds not only with counteroffers but also with justifications, critiques, threats and meta-information on these counteroffers (Parsons & Jennings 1996). All these negotiation behaviours represent a negotiation position of a negotiator. A counteroffer is a way to reject partially or completely the counterpart's offer by amending or extending the received offer. A counteroffer can contain justifications for one's actions or critiques for the counterpart's actions. A negotiator can also make a threat or promise a reward to exert pressure on the counterpart to accept an offer. A meta-information is additional information to reveal information that is not directly associated with the issues such as expressing one's preferences. These different contents in a negotiation message provide a sort of feedback to understand why a particular offer is not acceptable or to convince the partner of acceptance. This feedback is necessary for a rational negotiator

who would not change his/her beliefs or preferences unless being provided with enough reasons. Argumentation in negotiations is a form of reasoning to convince the other party. For example, justification and persuasion make offers more attractive for the opponent (Jennings et al. 2001). The justification helps the opponent to understand the sender's constraints and behaviour, for example, “a particular item may be out of stock and the next delivery might not be until the following month”. Persuasion leads the opponent agent to look favourably upon a sender’s proposal and as a result, it may change its agreement space or its rating over that space, for example, “a car salesman throws in a stereo with a car to increase the value of the good” or “a car salesman gets the buyer to change its rating function (changing issues importance) by convincing him that security is more important than high speed” (Jennings et al. 2001).

In automated negotiation, an ABN approach allows more sophisticated forms of interaction than their game-theoretic and heuristic counterparts. In game-theoretic and heuristic automated negotiation models, the scope of offers (or counteroffers) are confined to the structure of the negotiation object i.e., the content in offers are just negotiation issues and their values (Faratin et al. 2002, Guttman & Maes 1998, Faratin 2000). The negotiation agents are not able to justify and persuade their negotiation stances to the counterparts. The absence of argumentation diminishes some of the potential of the negotiation technology in these models and makes the automated negotiations inefficient (Jennings et al. 2001, Sycara 1989). The ABN frameworks gain increasing popularity for their potential ability to overcome the limitations of more conventional approaches to automated negotiation, however, such models are typically more complex (Rahwan et al. 2003). The ABN frameworks facilitate the exchange of justification, persuasive arguments, meta-information etc. that help agents to communicate clearly their negotiation position and argue about their beliefs and other mental attitudes during the negotiation process.

“Using argumentation in real agents means handling the complexities of the agents’ mental attitudes, communication between agents, and the integration of the argumentation mechanisms into a complex agent architecture” (Jennings et al. 2001). The emphasis of ABN research is in providing the frameworks with their key components, rather than showing the formalisation of all argument types (Sierra et al. 1998, Parsons et al. 1998). Rahwan et al. (2003) provide an abstract framework for ABN which outlines

the core elements and features required by agents engaged in argumentation-based negotiation as well as of the environment that hosts these agents. For each element of the abstract framework, existing ABN frameworks have been evaluated and the major challenges have been highlighted. The environment or external elements make the interaction environment of argumentation-based negotiations. Before describing the basic requirements for communication technology and a process of decision making in ABN frameworks in the following sub-sections, we provide a short description of two ABN frameworks.

Sierra et al. (1998) developed an ABN framework for business process management. The persuasive argumentation is composed of three argument types—*threat*, *reward*, and *appeal*. The authority relations (peer-to-peer/boss-to-subordinate) and organisational relationships (two negotiating agents belong to either different organisations or different departments of same organisation) between agents are two of the main factors in the modelling of the argument types. These social relations have the main impact upon the persuasion and argumentation process in this model. The agents exchange arguments depending on their individual needs and goals which are set from one's preferences on negotiation issues, domain knowledge and negotiations history. Most of the negotiations are inter-departmental and, therefore, result in cooperative behaviour. Threats can be exchanged between the agents of different organisations for breaking off the negotiations, or from a boss to a subordinate to exercise its authority etc. A reward type argument is made between agents of the same organisation to indicate a positive effect of some action on the organisation, or it is used between agents of two different organisations in making a promise for accepting future bids. Appeals can be made between agents of the same organisation for telling a prevailing practice or revealing new information, or an appeal is used as to recall the precedent between agents of different organisations. In the framework, the act type appeal is the basic building block of persuasive argumentation through which a sender appeals to the receiver to change its preference relationship(s) on issue(s) with supporting arguments for the appeal.

Parsons et al. (1998) presented an ABN framework for BDI agents who argue to plan resources in order to fulfil their objectives. This model assumes that agents trust each other and have each other's private information. In this framework, an agent engages in argumentation with another agent to get the necessary external resource(s) to satisfy its

intention(s). The agent prepares a message and passes it to the owner of resource(s). The message is an argument that contains the proposal containing the requirements for the resource(s) required and the justification (meta-information) for the proposal. If the other agent detects any objection on the incoming proposal, it can reply with another type of argument called critique. To create arguments, an agent uses its beliefs as well as the beliefs of its counterpart.

4.4.1 Communication Elements

For ABN frameworks, agents need rich communication and content languages to be able to exchange arguments. The computational automated negotiation mechanisms require communicative acts for making offers, counteroffers, acceptance or rejections etc. Such communicative acts are available in existing standard ACLs (FIPA 2002b, Finin et al. 1994). But, ABN requires more acts as provided by ACLs to capture threats, rewards or meta-information. ABN frameworks distinguish between negotiation acts (e.g. offer) and argumentation acts (e.g. threat). As mentioned before, a communicative act has a unique semantics which gives a unique meaning to a statement expressed in some content language. The use of the same communicative act such as offer or counteroffer to represent an argument can lead to misunderstanding between agents and negotiation can finish abruptly, because the semantics of these additional statements (e.g. argument) fall outside the boundaries of the semantics of communicative act or communication language.

For such reasons, the ABN framework (Sierra et al. 1998) has a communication language that divides the communicative acts into negotiation related acts (offer, request, accept, reject, withdraw) for making offers and counteroffers and argumentation related acts (appeal, threaten, reward) for persuasive argumentation. An offer in this framework can be accompanied by persuasive arguments. The *proposal* and *critique* are two acts which carry arguments during resource planning (Parsons et al. 1998). In ABN, a negotiation protocol is usually more complex than those in non-ABN, because the protocol has a larger number of communicative acts for negotiation as well as argumentation purpose and hence a larger number of interaction rules.

ABN frameworks need to express content for proposals as well as meta-information about the world, agent's beliefs, preferences, goals, etc. (Rahwan et al. 2003).

ABN frameworks use an application specific content language developed from logical language and meta-language. For example, Sierra et al. (1998) use single-order logical language to express negotiation issues and their values, and a meta-language expressing arguments such as to express preferences between two values of an issue. This framework avoids the use of a higher-order logical language to express arguments due to the associated computational problems of such logics. The other ABN framework (Parsons et al. 1998) uses a content language based on logics of BDI (Rao & Georgeff 1995) to express plans and resources in argumentation statements to justify their position.

The following example of a persuasive argument has been prepared using the communicative acts and supported content language in ABN framework (Sierra et al. 1998). In the example, an agent `a` threatens agent `b` of terminating the negotiation if `b` does not accept the issues values represented in a propositional logic language.

```
threaten (a, b, not accept (b, a, price=100 and time=10), withdraw(a,b) )
```

4.4.2 Decision Making Elements

Argumentation-based negotiation decision making requires logical reasoning on beliefs, desires and intentions (Parsons et al. 1998), whereas decision making in computational mechanisms requires mathematical and search functions for searching new values for issues. The differences in the conceptual models, representing the features of a simple agent (non-ABN agent) and an ABN agent, have been presented in the work on architectures for negotiating agents (Ashri et al. 2003). The decision making model of non-ABN agents is composed of only the *proposal evaluation and generation component*[19], whereas the decision making model of ABN agents contains in addition, the *argument evaluation*, *generation*, and *selection components* (Rahwan et al. 2003). ABN agents are equipped with argumentation mechanisms for evaluating arguments (and updating the mental state accordingly) and for generating and selecting arguments. The *argument evaluation component* evaluates incoming arguments and updates the agent's mental state accordingly about the agent itself, about its environment and its counterpart.

[19] A proposal contains only negotiation issues and their values.

The *argument generation component* generates outgoing candidate arguments that could accompany the proposal (response). For example, the *proposal evaluation and generation* component might decide that a proposal is not acceptable and the *argument generation* mechanism might accompany the rejection with a critique describing the reasons behind the rejection and generates one or more arguments expressing critique. The *argument selection component* decides which argument should be sent from a number of potential arguments and selects one of the many critique arguments. The detail for each component in an ABN framework is specific to the type of argumentation supported. An argument can also be sent stand-alone, i.e., not in conjunction with a proposal, acceptance or rejection.

In (Sierra et al. 1998), the decision making during argumentation is greatly influenced by the social relations between agents. A received argument from a peer can be rejected (if the receiver can prepare an attacking argument from its preferences), but the autonomous nature of subordinate agent is limited due to its lesser social power and therefore it cannot reject an argument from its boss, even if it can attack the boss's arguments using its preferences. The other ABN framework (Parsons et al. 1998) provides a formal model of argumentation-based reasoning at the level of an agent's internal reasoning and at the level of negotiation between agents. The decision making begins when an agent prepares an argument and sends it to the owner of resource. During the creation of the argument, the agent uses its belief about the counterpart that the counterpart has this resource and then the agent makes a new belief (by using the theory of planning) that the counterpart also has an intention to give the demanded resource to the agent. When the requirements or meta-information in the argument of the agent conflict with the objectives or beliefs/desires/intentions, respectively, of the counterpart, then the counterpart will inform the agent of its objection by sending back an argument (a critique). The agents can reach an agreement as long as the agent can either find an alternative way of achieving its original objective, or a way of persuading its counterpart to drop its objections.

4.5 Summary

We discussed in this chapter the agent message structure and the related technologies, and the different negotiation mechanisms for generating offers in automated negotiations. This

study of the inter-agent communication model and decision making functions will be used to model components of negotiation agents in our hybrid negotiation model.

We can observe that the structure of an agent message is similar to the message structure in the Negoisst system. An agent message is composed of a communicative act from ACL, content language expressions and concepts from domain ontologies. We have seen that many implemented agent negotiation systems use the same message structure for communication; however, they may be using different implementations of languages. The speech act theory plays a crucial role in the interpretation of intentions of communicating agents. The logic-based content languages are more expressive than web-based content languages. The negotiation systems use a content language in relation to the negotiation object. Ontologies have various contributions in inter-agent communication in negotiation systems. For example, they provide the negotiation vocabulary, the knowledge base of agents, and can be used for the definition of negotiation rules and protocols. The study of inter-agent communication has given the details of its components and their purpose and use. These details are used to build the communication model of negotiation agent that is interoperable with the Negoisst communication model for communicating with the human negotiator. The FIPA ACL and FIPA SL were selected as a suitable choice for the agent communication model.

There are certain decision making tasks that agents have to perform during negotiations, among them are the offer evaluation and offer generation. We have shown that the game-theoretic approach is not suitable in the hybrid negotiation model due to the limitations and assumptions of this approach. In addition, we have shown that an automated negotiation mechanism for the negotiation agent is required that works independent of the human counterpart. The automated negotiation models based on the computational approach are better suited to the decision making behaviour of negotiation agents because they generate offers independent of the protocol and the counterpart's strategies. We have described two computational mechanisms for generating offers and one model for constraint-based negotiations. The computational mechanisms provide the negotiation behaviour for concession making and generating trade-offs. The argumentation-based negotiation framework was also discussed. The computational and argumentation-based models together represent the three main types of negotiation behaviour found in human negotiations, i.e., concession making strategy, competitive

strategy and coordinative strategy. These mechanisms will be analysed in detail in the next chapter for their supported negotiation strategies to the negotiation agent and their compatibility with the Negoisst decision making and communication components to enable human-agent negotiation.

5. The Hybrid Negotiation Model

The hybrid negotiation model and its components are the subject of this chapter. The model is based on the objectives of human-agent negotiation (cf. section 1.2), the Negoisst system, the requirement analysis (cf. chapter 3), and the automated negotiation models (cf. chapter 4). The hybrid negotiation model consists of components specified in chapter 3 while describing the requirements. It is an integrated negotiation model that takes into account the aspects of the two hitherto distinct electronic negotiation models (negotiation support and automated negotiation) and aligns their characteristics to enable electronic negotiations between a human negotiator and a negotiation agent. For the hybrid negotiation model, an ANS is integrated into the NSS Negoisst. The integration is performed at the architectural level, the process level and the communication level. The Negoisst system already exists (according to the components of the hybrid negotiation model in Figure 3.1), so the focus of this chapter is on the components for communication between the human negotiator and the negotiation agent, the components of the agent's architecture, the negotiation process protocols to regulate the human-agent negotiation process, and the interoperability between the Negoisst system and an ANS.

The hybrid negotiation model is discussed in four parts. First, the human-agent negotiation design is presented in section 5.1. The negotiation process protocols to support the design and the human-agent communication are discussed in sections 5.2 and 5.3, respectively. These two sections make up the environmental components of the hybrid negotiation model. A negotiation agent's decision making model is discussed in section 5.4. The negotiation design and each component of the hybrid model are discussed as a comparison between the Negoisst system and automated negotiations to provide suitable solutions for human-agent negotiations.

5.1 Analysis and Design

One of the specified design goals of the hybrid negotiation model is not to change the negotiation design and negotiation process of human-mediated negotiations supported by

the Negoisst system while combining an ANS with it for human-agent negotiation (see section 3.1). With this approach, the human-human negotiation process using the Negoisst system will remain unaffected for the principal of an agent if (s)he decides to resume the negotiation manually during a human-agent negotiation process. The discussion on our hybrid negotiation model starts with a high level architectural comparison between NSSs and ANSs (section 5.1.1). The analysis and design scope for the hybrid negotiation model is confined to the particular phases and activities in the three-phase negotiation process (section 5.1.2). Then the detailed analysis and conceptual design of the hybrid negotiation model is discussed using an electronic negotiation classification scheme (section 5.1.3).

5.1.1 A Brief Comparison of Automated and Negotiation Support Models

A summary of the main components of NSSs and ANSs taken from the previous chapters is provided in Table 5.1 (Rehman & Schoop 2007). The table compares the communication and decision support in the two models. The level of support or the sophistication of the sub-components depends on the negotiation scenario, the system design and the implementation of the negotiation systems (cf. section 2.3.4 and chapter 4).

As can be seen in table 5.1, the components in NSSs and ANSs can be classified according to the same categories but their implementation is different. Hence, many of these components are not interoperable for human-agent negotiations. From a communication point of view, a text area is usually provided to write free natural language text to compose negotiation content in NSSs. The Negoisst system provides in addition the opportunity to enrich the natural language text with structured values of issues (cf. section 2.3.4.3). The ANSs allows only structured content which is expressed in logic-based languages and automatically generated by the agent. The decision support in NSSs is for generating offers manually through negotiation analysis, e.g. evaluation of incoming and outgoing offers, negotiation history etc. The software agents perform the entire decision making autonomously using different negotiation strategies.

		NSSs	Agent Negotiation Systems
Communication Support	**Message representation**	No standards	Structured using ACL (e.g. FIPA ACL, KQML)
	Content representation	Free text, semi-structured, fully-structured	Structured using content languages (e.g. FIPA SL, OWL)
	Negotiation Vocabulary	Natural language, Ontologies	Domain languages, Ontologies
	Message exchange	Protocols are flexible	Protocols implement strict sequencing
Decision Support	**Offer evaluation**	Additive utility functions, hybrid conjoint analysis method	Linear additive utility functions
	Offer creation	Using the help of visualization tools e.g. history graph etc.	Autonomously using automated negotiation mechanisms e.g. responsive, trade-off etc.
	Support type	Prescriptive	Normative, Prescriptive

Table 5.1: A comparison of communication and decision support in NSSs and ANSs

5.1.2 Human-Agent Negotiation Process

A negotiation process defines the different types of negotiation activities that are performed by the negotiator using an ENS. The human-agent negotiation process supports also the three-phase electronic negotiation process (like the Negoisst system as discussed in section 2.3.4.1). However, the focus in human-agent negotiations is on the negotiation setup activities in the *pre-negotiation* phase and bargaining activities in the *negotiation* phase. Table 5.2 introduces the focused activities and the system participant that executes those activities on the agent side. The negotiation setup activities are performed by the principal of negotiation agent. The bargaining activities will be primarily performed by the negotiation agent. To prepare the negotiation agent for bargaining activities, the *pre-negotiation* phase is extended with new activities. These new activities are about delegating negotiation tasks to the agent and defining the decision making model of the agent. The bargaining activities in the *negotiation* phase remain the same in the hybrid system with the exception that at the agent side, these will be performed by the negotiation agent as well as by the agent's principal.

Pre-Negotiation Phase **(Negotiation Setup Activities)** ***Agent Principal***	**Negotiation Phase** **(Bargaining Activities)** ***Negotiation Agent***
-Ontology negotiation (agenda setting) -Preference elicitation -Utility function construction **Delegation Related Activities:** -Creation/Termination of agent -Specify agent offer creation functions -Specify agent negotiation strategy	-Offer evaluation, creation -Offer exchange -Offer analysis

Table 5.2: Activities at the side of automated negotiation in the hybrid negotiation model

5.1.3 Human-Agent Negotiation Design

The correct design of the hybrid negotiation system can play an important role for the success of human-agent negotiations. At higher level, the human-agent negotiation design can be classified as supporting bilateral multi-issue negotiations similar to the Negoisst system. However, as we will see, the integration of two different types of ENSs (namely ANS and Negoisst) and their users make the design of the hybrid negotiation system different from the Negoisst system. Like any ordinary design process, an electronic negotiation design process comprises of two fundamental tasks: an analysis and a synthesis (Neumann et al. 2003). The analysis task is about investigating the negotiation settings, e.g. number of participants, negotiation goals etc. The synthesis task is about selecting a negotiation scenario (rules and the object of the negotiation) that matches the analysed requirements.

Only a few electronic negotiation classification schemes have been proposed to characterise electronic negotiation designs (negotiation scenarios) and systems (media), as well as to provide structured approaches for the design of electronic negotiations (Lomuscio et al. 2001, Wurman et al. 2001, Ströbel & Weinhardt 2003). A classification scheme is described as a parameterisation of the negotiation design space. The classification schemes provide well-defined sets of classification criteria/parameters to describe and classify electronic negotiations. The sets of classification criteria support the selection of the right electronic negotiation scenario and an appropriate electronic

negotiation system—from auctions to bilateral negotiations—automated or manual. There are schemes specifically for the auction design space (Wurman et al. 2001) or automated negotiations (Lomuscio et al. 2001) or for a complete electronic negotiation design space (Ströbel & Weinhardt 2003). We use the negotiation classification scheme '*Montreal taxonomy*' of Ströbel and Weinhardt (2003) for the structured analysis and design of a human-agent negotiation instance (a combination of human-agent negotiation scenario and hybrid negotiation system).

The Montreal taxonomy has been mainly used here for the design analysis of the Negoisst system and the automated negotiation models. The purpose of the following analysis is to obtain important design characteristics of these two different negotiation models. The automated negotiation models were selected from the same negotiation domain as the Negoisst system, i.e., business negotiation for the buying and selling of products and services. Both types of negotiation models share the same characteristics and their integration into the hybrid negotiation model will support the new human-agent negotiation scenario that is expected to work in the same domain as of two models (i.e., the same negotiations are supported by the hybrid negotiation model). The result of this analysis is the conceptual design, i.e., general properties, of the hybrid negotiation model. These properties can be used as requirements for the concrete design of the human-agent negotiation process such as offer exchange rules etc. (section 5.2).

We classify the Negoisst system and automated negotiation models using the explicit endogenous criteria and then this classification is used in parallel to analyse the hybrid negotiation model. The explicit endogenous category provides the sets of criteria to be used by the negotiation system designers to classify the existing negotiation designs and systems, and to define new negotiation designs and systems. A criterion represents a distinctive property of electronic negotiation and is associated with one or more values. The sum of all criteria values assigned to a negotiation scenario or system constitutes its type. Table 5.3 shows the sets of criteria for which the human-agent negotiation design will be discussed in the following sub-sections.

The characteristics of the Negoisst system and automated negotiation models are presented in the second column of table. Most of the properties are shared between two models. The hybrid negotiation model is an integration of Negoisst and automated negotiation scenarios. Therefore, it inherits many characteristics of existing scenarios. The

characteristics of the hybrid negotiation model is shown only from the agent's side of a human-agent negotiation while keeping in mind the presence of the agent's principal in negotiation.

Sets of Criteria	**Negoisst / Automated Negotiation Models**	**Hybrid Negotiation Model** (from agent's side of negotiation)
Roles:		
Participation	Bilateral	Bilateral
Agents	One	Two
Identity	Exposed	Hidden
Process Rules:		
Variation	Fixed	Flexible
Concurrency	Allowed / Prohibited	Prohibited
Offer specification:		
Cardinality of Issues	Multiple	Multiple
Structure	Flexible / Fixed, Flexible	Fixed, Flexible
Offer submission:		
Sides	Multiple	Multiple
Activity	Unrestricted / Restricted	Restricted
Information:		
Communication	Offer-extended, Free-form / Offer-restricted, Offer-extended	Offer-restricted, Offer-extended
Negotiation History	Logged	Logged

Table 5.3: General design properties of Negoisst System, Automated Negotiation Models, and Hybrid Negotiation Model

5.1.3.1 Roles

This set of criteria examines the roles defined for an electronic negotiation. *Participation* or cardinality of interaction in the hybrid negotiation system is *bilateral* i.e., two sides are involved in the negotiation, e.g. a customer and a supplier. At one side is a manual negotiation i.e., a human negotiator negotiates using the Negoisst system, and at the other side is an automated negotiation i.e., a software agent negotiates using an ANS (or when required the principal of the agent participates in the negotiation using the Negoisst system). Only one participant, namely the negotiation agent or its principal, will be active

in the negotiation process at any particular time. There is one type of agent, namely a human negotiator, at the side of manual negotiation and two types of agent, namely a software agent and its principal, at the side of automated negotiation. The task of the agent's principal in the human-agent negotiation process is to perform the negotiation setup and delegation activities as well as the activities for which an agent is not eligible (as will be discussed in detail later). In the Negoisst system, the negotiators have unique *exposed identities*. With exposed identities, a negotiator knows with whom (s)he is negotiating. In the hybrid negotiation system, the negotiation agent uses the identity of its principal, so that the identity of the current counterpart (i.e., human or agent) will not be explicitly transferred to the human negotiator.

5.1.3.2 Process Rules

The process rules specify the execution order of individual actions during a negotiation activity. There are different sets of rules for executing negotiation activities during the whole negotiation process in the Negoisst system. For example, there is a set of rules for creating the negotiation ontology and another set of negotiation rules for exchanging messages (Schoop et al. 2003, Schoop & Jertila 2004). The set of rules for exchanging messages is called the *negotiation protocol*. The difference in roles between the Negoisst system and the hybrid negotiation model makes the negotiation protocol (negotiation rules) different in both systems.

The negotiation rules are *fixed* in the Negoisst system i.e., the interaction sequence to exchange offers between human negotiators is fixed through the negotiation protocol. In contrast, the negotiation rules should be *flexible* in the hybrid negotiation system to accommodate the execution of activities either in an ANS by the software agent or in the Negoisst system by the principal. The flexibility of rules means that the set of negotiation rules is predefined and then the active negotiation rules are selected from the predefined set depending on the type of participant at the side of the automated negotiation. For example, when an agent negotiates with a human negotiator, then the message conversion is performed through the wrapper agent according to rules before sending the message to the human negotiator; otherwise the message is exchanged between the two human negotiators as usual. Concurrency is *allowed* in the Negoisst system for human negotiators i.e., they can run parallel multiple-bilateral negotiation

sessions. A negotiation agent is created only for one negotiation scenario, so concurrency should be *prohibited* for software agents.

5.1.3.3 Offer Specification and Submission

The Montreal taxonomy provides sets of criteria for offer specification, submission, acceptance etc. We categorise these sets into communication, process, and decision making related sets. The communication and process related sets are general to electronic negotiations, whereas the decision making sets such as offer evaluation, matching, allocation etc., are more specific to auctions. Here we present the relevant criteria for *offer specification* to characterise the offer design in both the Negoisst system and the hybrid negotiation system and the relevant criteria for *offer submission* to characterise the submission of offers in both systems.

The human-agent negotiation scenario is for *multiple* issues, which are fixed by human counterparts in the pre-negotiation phase. The Negoisst system allows a *flexible* structure of an offer i.e., a human negotiator can create an offer (partial offer) which does not contain values of all issues (section 2.3.4.3). We aim for a human-agent negotiation design that is compatible with the negotiation design of Negoisst in the flexibility of structure, but the existing agent systems do not generate partial offers. However, we will see in section 5.4 on agent decision making model, that it is possible to generate partial offers by agents. The hybrid system supports bilateral negotiation, so *multiple* (both) sides can submit offers. On the agent side of a negotiation, an offer can be submitted by either software agent or its principal. In Negoisst, the negotiation process allows *unrestricted* activity i.e., human counterparts can exchange any number of offers without time restriction. The negotiation completion time is not part of the negotiation setup and, therefore, no deadline is enforced from the system to complete the negotiation task. In the hybrid system, the offer submission activity can be *restricted* at the agent side of the negotiation. Some automated negotiation mechanisms generate and submit offers until the preset negotiation deadline or the maximum message limit has been reached, while in other mechanisms the negotiation strategy is defined so that the offer generation algorithms or protocols converge to a solution in infinite iterations.

5.1.3.4 Information

The communication in the Negoisst system can be characterised as either *offer-extended* or *free-form*, whereas in automated negotiations and in the hybrid negotiation model it is either *offer-restricted* or *offer-extended*. In the case of offer-restricted communication, a negotiator can only exchange offers (issues values); in an offer-extended case, a negotiator can exchange remarks, inquiries etc., along with an offer; and a free-form communication allows to exchange any sort of content in a message e.g., offer, comments, any natural language text etc. The Negoisst communication support for semi-structured messaging (structured offer, free text, and free text content enriched with ontology concepts) corresponds exactly to the offer-extended communication. However, this semi-structured messaging can also be used for offer-restricted communication by ignoring the free text from the negotiation messages as well as for free-form communication by carrying only free text into the messages. In the Negoisst system, the formal contract negotiation is through offer-extended communication, while informal discussions during negotiation are supported through free-form communication (details in section 5.2.1.1). The communication in the hybrid negotiation system at the agent's side of negotiation is *offer-restricted or offer-extended*. The negotiation agent can use offer-restricted or offer-extended communication depending on its decision making model. The principal takes part only in discussions using free-form communication. The negotiation communication in human-agent negotiation is discussed in detail in sections 5.2.1 and 5.3. In the Negoisst system, the negotiation history of an ongoing negotiation process is available to the human negotiators. The same negotiation history is also made available to negotiation agent in the hybrid negotiation system, because an agent needs the past offers in a negotiation process for decision making.

5.1.3.5 Summary

The above discussion on the characterisation of the Negoisst system and automated negotiation models provides the conceptual design of the hybrid negotiation model. It shows the differences and similarities among the three relevant models of electronic negotiations i.e., negotiation support, automated, and hybrid. The concrete design of the hybrid negotiation system is supported through negotiation process protocols (section 5.2) and the human-agent communication model (section 5.3). The sets of criteria such as

roles, process rules and offer submission provide the design requirements of different negotiation process protocols. The sets of criteria such as offer specification and communication provide the information for the structured design of communication in our hybrid negotiation model. The criteria in the negotiation history are used for decision making tasks. The negotiation agent's decision making model is only part of its own architecture and not of the whole negotiation system.

5.2 Negotiation Process Protocols

A negotiation process is enforced by a negotiation protocol. Bichler et al. (2003) describe a negotiation protocol as:

> *"A negotiation protocol includes all rules that define the negotiation arena (communication medium), agenda and permissible decision making and communication activities of the negotiators. The protocol may specify possible actions and their sequence, allowable offers and messages, timing of offers and messages. It may also specify the syntax and semantics of the messages, and mechanisms in which alternatives are determined and assessed, offers are constructed, and concessions are made. The electronic negotiation protocol may be complex and with many rules governing the parties as they move through different stages and phases of the negotiation process".*

Bartolini et al. (2005) describe a negotiation protocol as the interaction of roles for the execution of all activities in a negotiation process. Protocols are important in any negotiation scenario but their importance is obvious in the hybrid negotiation model due to the participation of many different types of agents (human negotiator, negotiation agent, principal, and wrapper agent) performing specific tasks in the different stages and phases of the negotiation process. Instead of confining the negotiation rules for the hybrid negotiation model to a single negotiation protocol, they are defined through different protocols for different phases in the human-agent negotiation process according to the conceptual design of the hybrid negotiation model. In some electronic negotiation systems, a negotiation process is composed of only a *negotiation* or *bargaining* phase to

exchange offers and counteroffers, and a negotiation protocol regulates only the communication activities between negotiators (Ströbel & Weinhardt 2003, Luo et al. 2003). However, there are other systems in which the single-phase negotiation process can consist of other protocols besides the negotiation protocol. For example, a negotiation phase in an automated negotiation model is supported by two interaction protocols: the issue manipulation protocol for adding/removing negotiation issues and the negotiation protocol for integrative negotiations (Faratin 2000).

In chapter 3, the need for three interaction protocols to support the activities in the human-agent negotiation process was discussed. These protocols explicitly specify the permissible actions of each participant in these activities as well as the sequence of actions. These protocols are part of the concrete design of a system and mainly specify the rules for the communicative activities and the delegation activities in the hybrid negotiation model. The permissible decision making actions are not part of these protocols, as the hybrid negotiation model is neither for auctions nor based on some non-cooperative game-theory approach.

- The *human-agent negotiation protocol* specifies the rules of exchanging negotiation messages between a human negotiator and a negotiation agent in the negotiation phase.

- The *message exchange protocol* specifies the communication activity rules for interaction among all the participants in the negotiation process.

- The *delegation protocol* specifies the rules of interaction between the negotiation agent and its principal for different purposes e.g. initialising or terminating the agent during the life cycle of the negotiation agent.

5.2.1 Negotiation Protocol

A negotiation protocol will define the rules for the *exchange of messages* to facilitate the communication activities in the hybrid negotiation model. From this point of view of interaction in the electronic negotiation literature (Schoop et al. 2003, Jennings et al. 2001, Rosenschein & Zlotkin 1994), a negotiation protocol implements a code of correct

social conduct during the negotiation phase by defining the rules of interaction for exchanging negotiation messages between negotiation counterparts. It constrains the use of message types or communicative acts for the negotiation messages (Schoop et al. 2003, Parsons et al. 1998, Luo et al. 2003). The rules of encounter include the permissible number and types of participants, negotiation states, events that change negotiation states, and permissible actions in a certain state (Schoop et al. 2003). A negotiation protocol can support an iterative negotiation process in which the offers and counteroffers are revised in consequent iterations either to reach agreement or to optimise the potential agreement (Ströbel & Weinhardt 2003). In automated negotiation models, interactions follow the rules of an alternating sequential protocol in which the agents take turn to make offers and counteroffers. The rules in a negotiation protocol can be used as negotiation strategy or/and communication. For example, in game theory an interaction protocol is not a communication protocol but a negotiation protocol which determines the possible strategic actions that agents can take at different points of the interaction (Sandholm 1999). On the other hand, in computational automated negotiation models and NSSs, the primary purpose of the negotiation protocol is to regulate the exchange of messages between the negotiators. Such negotiation protocols are for *semi-structured negotiations* (Bichler et al. 2003), because they provide flexibility to negotiators in their decision making and information exchange activities.

The Negoisst system (similar to other NSSs) is not based on the normative approach of decision making and, therefore, the negotiation protocol is not used to define the possible strategic actions of human negotiators. The prescriptive support to negotiators, communication and the calculation of pareto-efficient agreements are those parts of the negotiation analysis approach that aim at achieving joint welfare. The suitable negotiation behaviour or negotiation strategies for integrative negotiations in the negotiation analysis approach are independent of negotiation protocols. A negotiation protocol in NSSs determines only the types and order of messages for iterative negotiation process. This is also the case in automated negotiations. In section 4.2.2, the computational and game-theoretic models of automated negotiation were compared for their suitability for the hybrid model and the former was chosen because it offers a less restrictive negotiation protocol i.e., the negotiation protocol does not prescribe an agent's

negotiation behaviour, and the decision making is based on informal and descriptive models of negotiation for integrative negotiations (Faratin 2000, Luo et al. 2003).

Depending on the negotiation behaviour of the human negotiator and the negotiation agent, the purpose of hybrid negotiation model is also to enable human-agent integrative negotiations. Thus in the hybrid negotiation model, a negotiation protocol is required for semi-structured negotiations i.e., the protocol does not prescribe negotiators' behaviour, but simply defines the normative rules of interaction. These rules temporally order communication utterances by specifying who can say what and when according to the negotiators' roles.

5.2.1.1 Negoisst Negotiation Protocol

The Negoisst negotiation protocol organises the process of conducting negotiations between two human negotiators (e.g. buyer and supplier). The Negoisst provides a *formal* area for exchanging messages which lead to legally binding contract, and an *informal* area for messages which are important for the progression of negotiation but are not considered legally binding (Schoop et al. 2003). The informal area is used for discussions such as questions and clarifications to fulfil the validity claims of communicative action theory (cf. section 2.3.4.3). The negotiation protocol is shown in Figure 5.1. It is composed of seven types of messages or actions that a human negotiator can use during negotiation:

- `Request`: A customer can begin a negotiation with a request. It expresses interest in buying a product or service.

- `Offer`: A seller can begin a negotiation with an offer. It is used to present some product or service to a customer.

- `Counteroffer`: The negotiation proceeds with a counteroffer that is used as a reply to a request, an offer or another counteroffer when the recipient is not yet satisfied but wants to continue the negotiation.

- `Accept`: The negotiation ends successfully with an accept message type.

- `Reject`: The negotiation ends in disagreement with a reject message type.

- `Question & Clarification`: If the need for a discussion arises between counterparts, the question and clarification message types can be used. These message types are communicated in informal area. A clarification is the reply to a question.

These message types are used according to the sequence given in Figure 5.1 to develop a contract. A negotiation message communicates one of these message types (illocutions) with only issues values and/or free text message. A messages based on first five message types contain an offer (structured) and free text supporting the offer. The combination of structured offer and text make these messages semi-structured. For the human-agent negotiation design, messages based on these five message types can be categorised as *offer-extended* communication (cf. section 5.1.3.4). The last two message types, `question` and `clarification`, are for exchanging information such as queries and clarifications. The purpose of these message types is that they should contain only free text message. These messages are exchanged in the informal area and do not contain the negotiation agenda values, and thus do not make any direct change in the negotiating contract. In human-agent negotiation design, these messages can be categorised as *free-form* communication. Although the free-form communication defined in (Ströbel & Weinhardt 2003) means that a message can contain anything e.g. offer, comments etc., in our case a free-form communication is assumed to contain only free text content without any offer.

In Figure 5.1, a party `a` represents the initiator of negotiation and a party `b` represents the counterpart. The negotiation phase starts in state `0`. In this state, the negotiator `a` can start negotiation with a `request` or an `offer` message type depending on its role (buyer or seller). In state `1`, the counterpart `b` can continue the negotiation by sending an `offer` or `counteroffer` message, or can terminate negotiation phase by sending a `reject` or `accept` message. The `offer` or `counteroffer` message is

sent in response to `request` or `offer` message, respectively. In state `1`, the negotiator `b` can also send a `question` to `a` who replies it with a `clarification` message type in state `5`. In state `2`, the negotiator `a` replies to `b`'s `offer` or `counteroffer` with a `counteroffer` or with an `accept` or a `reject`. Furthermore, in state `2`, the negotiator `a` can send a `question`. The states `3` and `4` are final states. This protocol has been implemented in the Negoisst system as an alternating protocol. It is possible for a recipient to reply to an earlier message of the sender.

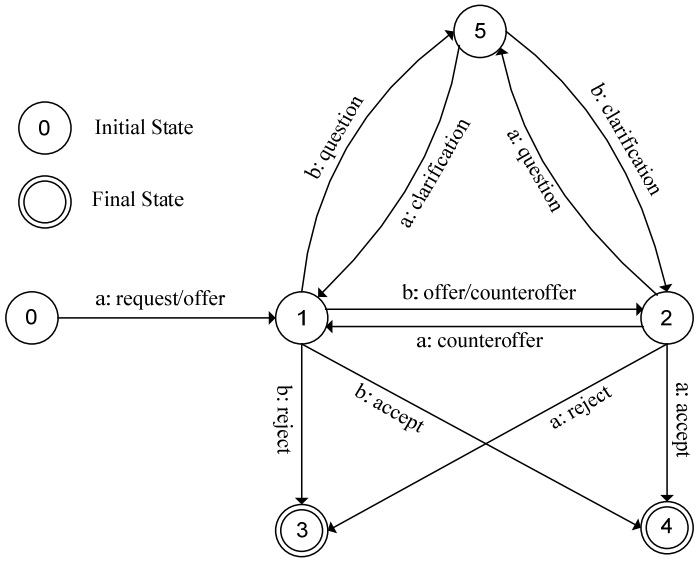

Figure 5.1: Negoisst Negotiation Protocol (modified from Schoop et al. (2003))

5.2.1.2 Human-Agent Negotiation Protocol

The interaction process between the human negotiator and the negotiation agent is established by a *human-agent* negotiation protocol. The Negoisst negotiation protocol is a general protocol that is adapted for a human-agent negotiation in the hybrid negotiation model. The protocol is adapted on the bases of the message types in it and the abilities of participants in processing the messages. Table 5.4 shows how the seven message types of Negoisst protocol have been categorised into *offer-extended* and *free-form* communication. This categorisation is used to identify the negotiation capabilities of the

negotiation agent from decision making and communication view. As we have seen in the previous chapter, the computational models of automated negotiation deal with the evaluation and generation of values of negotiation issues i.e., the communication in those models is *offer-restricted*. This means the negotiation capability of a negotiation agent using computational models is limited to *offer-restricted* communication i.e., it can generate and communication only values of negotiation issues without any comments or remarks.

Message Types	Communication Category
Request, Offer, Counteroffer, Accept, Reject	Offer-extended
Question, Clarification	Free-form

Table 5.4: Negoisst message types and their associated communication type

The two communication categories of message types (in Table 5.4) separate the bargaining related actions from information exchange actions and enable us to specify a human-agent negotiation protocol. If the comments or remarks are removed from offer-extended messages, then they become offer-restricted message. Thus an offer-extended message in Negoisst system is compatible to the same offer-restricted message in the automated negotiation model. In the human-agent negotiation case, at the agent side of negotiation the offer-extended message types are assigned to the negotiation agent and free-form message types are assigned to the agent's principal. The Negoisst negotiation protocol remains unchanged at the human side of negotiation. Figure 5.2 shows the human-agent negotiation protocol in which the human-agent negotiation consists of only *offer-extended* message types. It is the same protocol as the Negoisst protocol except that state 5 and the transitions to it have been removed. These five message types can communicate any type of negotiation behaviour or action to develop a contract in bilateral multi-issue negotiations, and thus make the negotiation protocol complete in a human-agent negotiation, as in other electronic negotiation systems (Kersten & Noronha 1999, Rangaswamy & Shell 1997, Faratin 2000). The negotiation agent can have the role of buyer or seller as an initiator or a participant in the protocol. The negotiation agent uses

the FIPA ACL and its message types in the negotiation. The ACL message types which are equivalent to the Negoisst five message types will be discussed in section 5.3.2. The *free-form* message types are outside the ability of the negotiation agent. Although these message types do not have any formal role in building a negotiation contract, they are used to avoid communication problems in negotiations by making the communication more comprehensive, truthful etc. These two message types however can be handled by the principal of the agent to fulfil the validity claims.

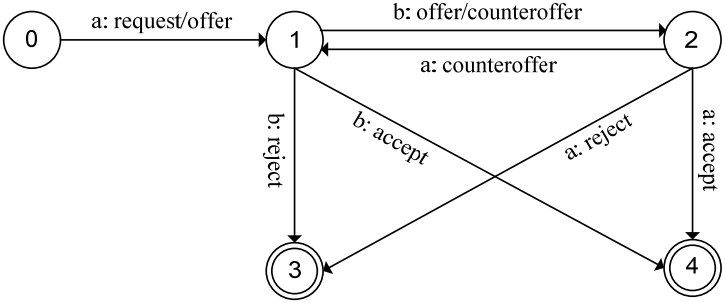

Figure 5.2: Human-Agent Negotiation Protocol

5.2.2 Message Exchange Protocol

The message exchange protocol can simply be described as a combination of all protocols in the hybrid model. As shown in Figure 5.3, the message exchange protocol defines the interaction of all the different participants during the execution of all activities in the pre-negotiation and negotiation phases of a human-agent negotiation process. The contract negotiation between a negotiation agent and a human negotiator, discussed in the previous section, has been represented with a dashed line in the figure. This dashed line indicates that the message exchange between the human negotiator and the negotiation agent is indirect. This indirect interaction is due to the different technologies to represent negotiation messages (i.e., the negotiation agent uses an ACL language to represent messages, whereas the Negoisst system has its own interface for message representation). This indirect message exchange between human and agent is performed through a *wrapper agent*. The wrapper agent provides the communication interface between the Negoisst system and the ANS by converting messages from a Negoisst message to an

ACL message, and vice versa (see section 5.3.4). The scope of the wrapper agent is confined to the negotiation phase.

In the two-phase process model, the principal has three main tasks in the human-agent negotiation process: negotiation setup and preference elicitation, delegation to agent, and negotiation. In the pre-negotiation phase, the principal sets the negotiation agenda with human counterpart and elicits preferences on negotiation issues, and then delegates negotiation tasks to the negotiation agent. In the negotiation phase, the principal, if required, takes part in the negotiation such as for providing a reply to free-form message types.

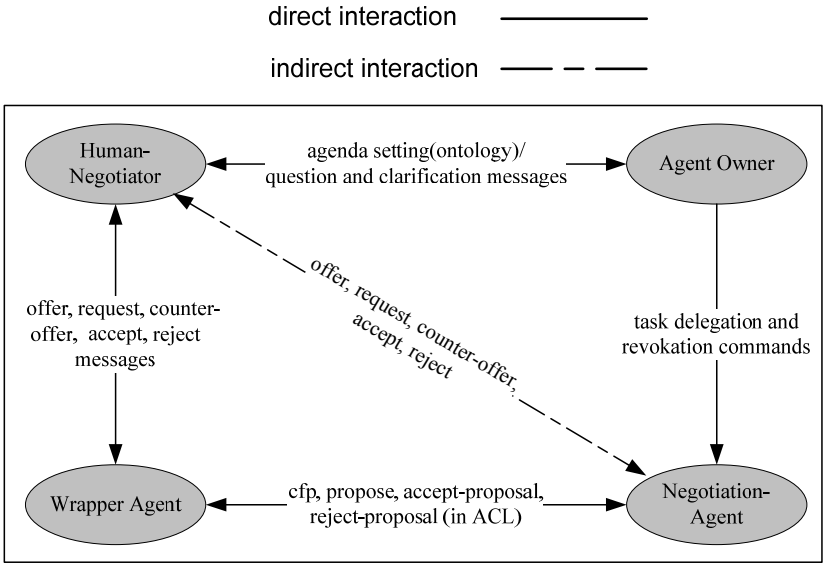

Figure 5.3: Interaction among participants of hybrid Negotiation Model

5.2.3 Delegation in the Hybrid Negotiation Model

The process of assigning a task to an agent is called delegation. Delegation is a central idea underlying agent-oriented technology and described by Papazoglou (2001) as "*the owner or user of an agent delegates a task to the agent and the agent autonomously performs the task on behalf of the user*". In automated negotiations, the principal of an

agent has normally a high-level control over the agent's mental state and its behaviour (Chavez & Maes 1996). This high-level control is a delegation that specifies the task (e.g. multi-issue negotiation) that the agent should perform and the data (e.g. principal preferences, automated negotiation functions and strategies) that defines the goal and is required to perform the negotiation task. How to perform that task solely depends on the agent's internal behaviour. For example, in the case of a selling agent, the user creates an agent with a deadline to sell the item, a desired price and a reservation price for the item, and the concession rate. The agent uses this information to make its internal negotiation bidding model.

Thus, through delegation, the principal delegates not only the task but also the negotiation goals to the agent. In this section, the purpose is not to provide a complete solution for delegation in the hybrid negotiation model. We only describe the meaning of delegation to agents, its importance in the hybrid negotiation model, and then discuss briefly according to the Negoisst system.

There are several factors that should be considered while delegating a task to an agent (Milewski & Lewis 1997, Crastelfranchi & Falcone 1998). It is argued that the cost of delegation (e.g. monitoring of agent work and progress, communication of desired goals etc.) should be considered before delegation, that the tasks and principal's goals should be precisely communicated to the agent, that the principal should have access to an agent's behavioural data to have more trust on the agent (Milewski & Lewis 1997). Castelfranchi and Falcone (1998) discuss different kinds and levels of delegation on which the autonomy of agents is based. They describe that the full autonomy 'open delegation' means that the agent takes care of the interests or goals of the principal in performing the delegated task autonomously without the monitoring and intervention (control) from its principal. For this level of autonomy, the agent is supposed to use its knowledge (this knowledge can be provided by the principal), its intelligence, its ability, and has a full degree of authority on its decisions. They also argue that more intelligence and autonomy of an agent make it less quick and passive obedient.

Unlike the automated negotiation systems, we think an explicit and comprehensive delegation process is necessary in the hybrid negotiation system due to its objective and architecture, and the design of human-agent negotiations. The main focus here is on the kind of delegated autonomy. The open delegation, in which the negotiation

agent is given full autonomy from beginning to finalising the agreement, is not required in the hybrid negotiation model due to the following reasons:

- The purpose of the hybrid negotiation model is not to evaluate the performance of the negotiation agent against the human negotiator for which the agent must perform the negotiation completely autonomously.

- With the presence of Negoisst and the ANS in the hybrid system, the principal can either perform the negotiation manually or delegate it completely to negotiation agent. The principal delegates because the cost of delegation might be less than the cost of performing the task oneself (Milewski & Lewis 1997). The third possibility in the hybrid negotiation systems is to delegate the negotiation task to agent but to restrict the agent's autonomy. In this option, the principal can have control over the decision making of the negotiation agent. For example, the principal can rule that the negotiation agent will not accept or reject an incoming offer without the principal's approval.

The delegation which controls the autonomy of negotiation agent can be described as 'bound delegation'. The bound delegation restricts the autonomous execution of an agent's actions during human-agent negotiation. However, in bound delegation, the agent is autonomous in its communication and decision making behaviour for creating the content of offers such as values of issues in an offer. The benefits of this delegation can be that the principal uses the computational and negotiation abilities of the negotiation agent in generating offers. However, the exchange of such offers is under the principal's authority. The communication and trust can also be handled as part of the delegation in the hybrid negotiation model. The precise communication between principal and agent is a necessary part of delegation (Milewski & Lewis 1997, Papazoglou 2001). The guidelines and approaches of communication for the purpose of delegation have been proposed in the literature (e.g. Cohen & Levesque 1995, Barbuceanu & Lo 2000) and can also be used in the hybrid negotiation model. The principal's trust in an agent can be maintained by giving the principal access to the agent's behavioural data. The principal can change behavioural data (e.g. strategy) when necessary and has access to all negotiation messages sent or received by the agent.

Delegation Protocol:

According to the above discussion on delegation to the negotiation agent, a comprehensive delegation protocol can be defined for the hybrid negotiation model. Here a prototype delegation protocol is presented that defines the delegation and revocation activities during the pre-negotiation and negotiation phases. Figure 5.4 presents the delegation protocol and Figure 5.5 presents the activities involved in the delegation. The protocol's instruction set includes the instructions for the bound autonomy other than the instructions for preferences, goals etc. The delegation protocol consists of states and transitions to define the life cycle of a negotiation agent. The states are used to specify the necessary delegation data (e.g. preferences, strategy etc.) and regulate the execution of an agent's actions. In the example delegation protocol, the letter A and P represent the negotiation agent and its principal, respectively.

In state `1`, the principal elicits preferences for the negotiation issues and specifies the agent's decision making model (e.g. automated negotiation mechanism, negotiation strategy etc.). The principal can also specify instructions such as seeking the principal's approval before accepting or rejecting an offer. After this automated negotiation setup in the pre-negotiation phase, the principal can create and start the negotiation agent. With its creation, all the components (e.g. knowledge base, decision making and communication components etc.) of the agent's architecture are initialised with the necessary information. This information makes up the agent's internal negotiation bargaining model.

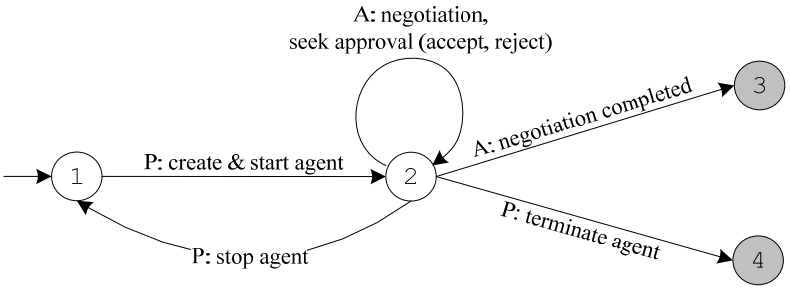

Figure 5.4: An example delegation protocol

In state 2, the agent is ready to conduct an automated negotiation with a human negotiator. The agent creates and exchanges messages following the human-agent negotiation protocol. Depending on the delegation tasks setting, negotiation agent can communicate with its principal for taking approval for actions such as sending final messages (e.g. accept or reject) to the counterpart. During the automated negotiation state, principal can stop the execution of agent to perform activities which are not part of human-agent negotiation protocol such as add/remove issues, change preferences, change the agent's decision making model, handling question and clarification message types. In this case, the state 1 of delegation is reached again. The principal can also terminate the agent to conduct the negotiation himself/herself or the agent reaches the final state 4 after completing the negotiation. States 3 and 4 represent the agent's completed life cycle.

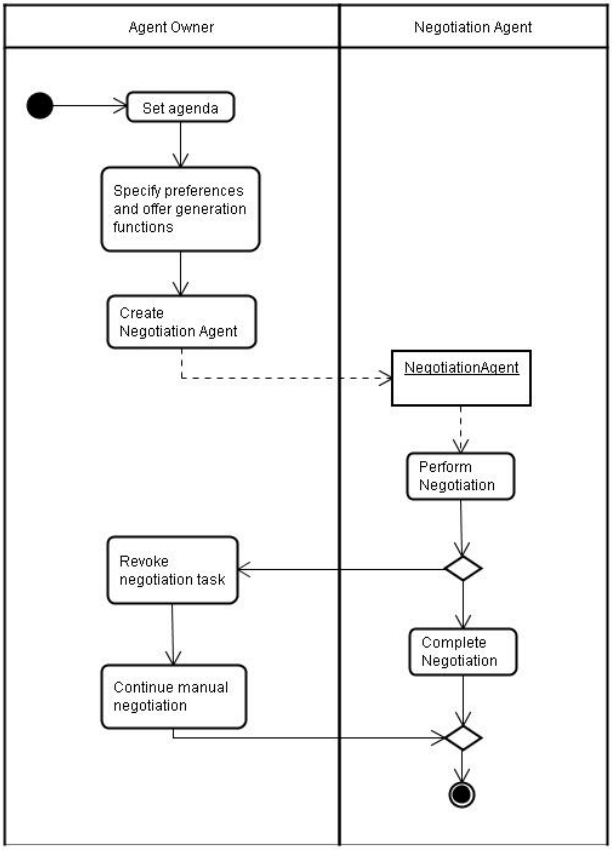

Figure 5.5: Activities involved in the delegation to a negotiation agent

5.3 Human-Agent Communication Model

An electronic negotiation framework is viewed as an environment, which provides communication facilities for composing and exchanging negotiation messages. For the hybrid negotiation model, some of the relevant components (e.g. negotiation process protocols) building these communication facilities have been presented in the previous section. In this section, the remaining components of environment are presented that complete the human-agent (hybrid) communication model. These components are based

on a message structure that is similar to both the one in the Negoisst system and in agent technology, on ontologies that play an important role in inter-human as well as inter-agent communication, on the features of the Negoisst system such as structured representation of offers, and on interoperability between the Negoisst system and the ANS for offer exchange.

If a component in the agent communication model provides the same support as the corresponding component in the Negoisst system, then a more effective human-agent negotiation communication can be supported. We have seen the message structure of the Negoisst system and the ANSs in chapter 2 and chapter 4, respectively. With respect to the information and communication levels of the communication process model (cf. section 2.3.4.3), the message structures in two types of systems are similar i.e., they are composed of three components: *message*, *content* and *vocabulary*. In the following sub-sections, these three components for the negotiation agent communication model in relation to the Negoisst system for human-agent communication are discussed. In contrast to the vocabulary, the message and content components are expressed differently in the Negoisst and in agent systems. To provide compatibility for the message element between the two systems, the FIPA ACL has been selected (see section 4.1.1.3) for the agent communication model due to its ability of capturing all the components of the Negoisst message as well as providing an extensive set of negotiation related communicative acts (section 5.3.2). The content level communication and the role of vocabulary in human-agent communication are discussed in sections 5.3.1 and 5.3.3, respectively.

5.3.1 Human-Agent Message Content Representation

Content level communication between a negotiation agent and a human negotiator is discussed in this section. The content element of a negotiation message structure is the most dynamic and rich element in human-mediated as well as in multi-issue automated negotiations. However, there is a great variance between inter-human communication and inter-agent communication in electronic negotiations at content level (see sections 5.3.1.1 and 5.3.1.2, respectively). The inter-human communication is rich due to natural language communication, whereas the computer processable content languages have comparatively limited flexibility and expressivity. This difference is a hindrance for efficient and effective human-agent communication.

Natural language text processing is considered unsuitable for this purpose. Kemke (2006) has developed a framework that enables a human user to delegate tasks to artificial agents using natural language task description (the architecture and implementation of this work is not presented here). The system takes domain specific natural language commands and questions from the human user and maps them onto actions understandable for an agent system. In the case of ambiguity or when the system cannot interpret some word from the natural language input, a clarification dialogue with the human user is initiated to resolve these problems. This approach of converting natural language sentences into agent's actions is argued as a base work for the development of adaptable speech and language interfaces for a variety of agent systems. We argue that such a natural language processing technique may not be suitable for human-agent negotiation communication for many reasons. In Kemke's system, the natural language processing is for delegation and, therefore, communication is in one direction i.e., only humans can communicate in natural language commands to software agents. In contrast, human-agent negotiation is two-way interactive communication i.e., a negotiation agent should be able to understand the human negotiator, and vice versa. The above system deals only with certain types of natural language sentences with certain structures, e.g. commands or questions, and the application domain contains a small number of objects and actions, whereas the natural language sentences written by a human negotiator could have any structure and contain any negotiation behaviour as well as any written communication content. An effective parsing of such natural language content would be difficult in a negotiation scenario. The clarification dialogue between human and agent makes sense in the above system because the task cannot be delegated correctly in case of ambiguous content. However, in case of ambiguous message structures and text, a negotiation agent cannot ask for the clarification of words from the human negotiator. Due to these factors, processing natural language text is inadequate for the hybrid negotiation system and is thus not considered in this work.

We are going to analyse the content level difference between inter-agent communication and inter-human communication using the nine content categories which we set as content level communication requirements for human-agent negotiations (cf. section 3.2.2). As mentioned before, these nine content categories have been identified by Köszegi et al. (2004) after a content analysis on experimental negotiation data collected

from different NSSs. This content level requirement is used in analysing the several different communication behaviours in the Negoisst system and automated negotiation models:

- What is the support for these nine content categories and their sub-categories in the Negoisst system and in automated negotiations?

- What does agent communication technology offer to represent and exchange different content categories in automated negotiations?

- Which of the content categories can a negotiation agent and a human negotiator exchange and process in a human-agent negotiation?

The first question from the Negoisst point of view is answered by analysing the preparation and representation of these content categories during inter-human communication, and from the automated negotiations view, the question is about which of the content belonging to these categories is generated by automated negotiation models. Also the associated message types or communicative acts along content categories are mentioned. For the second question, FIPA SL content language is analysed for its support for content categories supported by the automated negotiation models. The third question helps in identifying what a negotiation agent can actually exchange with the human counterpart (for example argumentation, inter-agent communication is richer than communication with human negotiators).

5.3.1.1 Analysis of Content Categories for Negoisst

The negotiation data, on which the nine categories have been identified, has been collected from the Inspire system and SimpleNS (Köszegi et al. 2004). The support of the Negoisst system for preparing negotiation messages is comparable to NSSs Inspire and SimpleNS. As discussed in section 2.3.4, the Inspire system provides a decision support tool for decision making and two communication modes for supporting structured offers and optional free text messages (e.g. clarifications, arguments etc.). The optional free text message can be sent separately or along with an offer. SimpleNS provides merely

communication support. The communication support consists of a message box and an offer box for separating messages from offers. However, a user can embed offers within the messages without using the offer box. The Negoisst system has similar communication functionalities of both Inspire and SimpleNS for preparing negotiation messages. Like in Inspire, it is compulsory to provide values of issues in the offer box for preparing an offer in Negoisst (however, unlike Inspire, Negoisst allows to create partial offers). Having communication and decision support, the negotiation data created and exchanged in the Negoisst system by human negotiators can also be categorised into nine content categories.

The nine content categories and their sub-categories have been identified from the negotiation data analysis only. These nine content categories can be further distinguished: first from the speech act theory point of view by identifying higher level relationships between content categories (propositional content) and the message types (illocutions) i.e., what content (e.g. offer, free text) is exchanged in an offer or counteroffer message types etc.; secondly the division of content categories according to their content type (structured or un-structured as well as bargaining-related or non-bargaining). The above two tasks on nine content categories are performed using the seven message types in the Negoisst negotiation protocol and the Negoisst semi-structured communication support, respectively. This evaluation helps in comparing the support for the nine categories in the Negoisst system and automated negotiations for human-agent negotiation.

In section 5.2.1, the message types in the negotiation protocol have been divided into offer-extended and free-form communication to specify human-agent negotiation protocol. In free-form communication only those message types have been added that only contain free-text. The offer-extended message types are a full representation of semi-structured messages, whereas free-form message types are only one part of semi-structured messages i.e., free-text. As mentioned above, a semi-structured message becomes offer-restricted if the free-text is deleted from the message and only the offer (issues values) related content is left in the message, otherwise it is an offer-extended message. We divide the un-structured free-text content of semi-structured messages into *bargaining-related* and *non-bargaining* content. These two content types distinguish the purpose of any free-text in negotiation. Thus, the nine content categories can be

distinguished into offer-restricted content, bargaining-related content and non-bargaining content categories. A structured message is prepared using keywords representing issues (or specifying the attributes of products or services) as well as numerical and categorical values representing the values of keywords. An un-structured message is a combination of keywords, numerical and categorical values, and free text.

Table 5.5 shows a relationship between nine content categories and the Negoisst communication support and message types. It specifies the content type and message type(s) for each negotiation content category. A numeric value written in the front of each content category represents the data amount (in percent) of that category in all experimental negotiation data collected from several negotiations. It means that the amount of a particular content category can vary in negotiations. Each content category—representing specific negotiation behaviour—is assigned to one content type. A content type identifies that a content category contains either structured content or un-structured content as well as whether the content category has contribution in developing agreement. For example, *log-rolling* in substantive negotiation behaviour is represented using semi-structured content in NSSs i.e., content consists of issues values (offer) and free-text (e.g. persuasive arguments). The persuasive arguments are sent to make the negotiation stance clear but they are not a mandatory part of log-rolling behaviour. To express the log-rolling behaviour, only the issue values are mandatory. Therefore, the log-rolling substantive negotiation behaviour has been categorised as structured bargaining content. Only substantive behaviour belongs to the structured bargaining communication. In the Negoisst system, substantive negotiation behaviour can be exchanged using all message types except *question* and *clarification*. Substantive behaviour or in other words structured content amounts to 16 % of all negotiation data.

Content Type		Content Categories* (Amount %)	Examples*	Message Type in Negoisst (illocution)
Structured Bargaining Content (16%)		**Substantive behaviour (16):** Acceptance; rejection; log-rolling; full and partial offer.	Issues and their values, for example: '*Price: $3.71, delivery: 30 days, payment: upon delivery, return: 75% refund with 5% spoilage*'	Request, Offer, Counteroffer, Accept, Reject
Un-Structured Content	**Bargaining-related (42.7%)**	**Task-oriented behaviour (23.3):** Request/provide information; express understanding etc.	'*I truly see the problems you have to face through these elements*' '*We know that quality is the most important factor for you*'	Any
		Persuasive argumentation (10.4): Self/other supporting statements/information etc.	'*I must reaffirm that we gave you the best offer*' '*I think that full return policy is not necessary because defects won't happen*'	Counteroffer
		Tactical behaviour (3.1): Commitment; exert pressure; authority-related tactics etc.	'*This is my last offer*' '*To be competitive in the market the highest price we are willing to pay is $ 3.98*' '*I have clear instructions of our finance department…*'	
		Affective behaviour (5.9): Positive/negative emotions; apology; thanking etc.	'*I feel that my suggestions where I really try to find solutions acceptable to both of us are not really appreciated*' '*I admire your sense of responsibility*'	Any
	Non-Bargaining (41.3 %)	**Private (Extra-role) behaviour (6.6):** Any information	'*Yes, Vienna is a cool town*' '*When you have the chance to come to Taiwan, I can take you wherever you want to go*'	
		Procedural (2.5): Time-related/technical/ Negotiation-process coordination.	'*For example 8:00 am in Taiwan is 1:00 pm in Europe*' '*Because of the possible problems in your email-system I will notify you on your personal address '*	
		Communication Protocol (28.6): Formal/informal address/close/signature	'*Thank you for your message*' '*I am looking forward to hearing from you soon*'	
		Text-Specific (3.6)	'*anyway*' or '*p.s.*' or '*offer no. 1.*'	
* Content categories, % values and the related examples are taken from (Köszegi et al. 2004)				

Table 5.5: The content types and the illocutions of content categories in Negoisst.

The content categories task-oriented, persuasive argumentation, tactical and affective behaviours are associated to un-structured bargaining-related contents. The statements belonging to these four content categories are natural language text that is written to support offers. These content categories add supporting negotiation behaviour to content belonging to substantive negotiation behaviour. The examples could be the statements that support offers or disclose negotiation preferences etc. The persuasive argumentation and tactical behaviour normally occur in counteroffers in order to move towards agreement, while the statements of the other two behaviours may occur in any message. For example, content belonging to tactical behaviour is not sent alone in a message but along with some values of issues and together they show e.g. commitment or promise on values. These content categories amount to 43 % of all experimental negotiation data.

In the un-structured non-bargaining category, those content categories have been included that do not represent any sort of negotiation behaviour i.e., they do not represent any negotiation stance and hence have no effect on the contract. The content in these content categories belongs to written or/and electronic communication and represents social relationships. Examples in table 5.5 show that content belonging to the communication protocol category expresses mere salutations and politeness, and such comments are exchanged in almost every message. Communication protocol, text-specific, and procedural categories are classified as specific characteristics of electronic written communication. These units tie in with previous and upcoming events and keep up a continuous flow of written communication. The extra-role behaviour contains statements that are not related to the negotiation task at all. Such statements are disclosure of private information that can be used, for example, to establish a positive relationship with the counterpart. The content categories that have been included in non-bargaining communication amount to 41 % of all communication units.

From a message type point of view, some categories belong to only one particular message type, such as persuasive behaviour or log-rolling is usually expressed with the message type counteroffer. Some content categories can appear in messages of any types such as communication protocol statements.

5.3.1.2 Analysis of Content Categories for Automated Negotiations

The content categories have been identified from the negotiation data collected from NSSs. Therefore, these categories do not truly represent negotiation data in automated negotiations and cannot be analysed like in the Negoisst system in Table 5.5. As mentioned before, the main reason for this is the difference between the written natural languages used in the Negoisst system for expressing content and the computer processable content languages used in the automated negotiations. The logic-based content languages represent only structured content (as compared to structured and un-structured content in the Negoisst system) and for this reason the automated negotiation models only generate bargaining related content (no written communication related content like in NSSs).

The automated negotiation models generate negotiation content for both offer-restricted and offer-extended communication. For example, the computational models (e.g. trade-off mechanism) generate offers which only include issues values, whereas the argumentation-based negotiation model also generates persuasive arguments in support of offers. The automated negotiations as a whole can be categorised as structured offer-extended communication. Here we discuss those content categories from Table 5.5 that are supported by automated negotiation models. This support means that these models generate and represent content that expresses the behaviour attached to these content categories. All the components of an automated negotiation model contribute to generate a particular negotiation behaviour. The decision making functions generate the content, the communication model expresses the content, and the protocol attaches the illocution to the content. Only the support for the main content categories is analysed in automated negotiation models. Sub-categories are not discussed. Table 5.6 shows the automated negotiation models support for content categories and the associated communicative acts.

The substantive behaviour is supported by the computational automated negotiation mechanisms. Each computational mechanism provides a decision making model and a protocol for preparing, proposing, accepting, and rejecting offers, and communication support for expressing offers. The trade-off, responsive, and constraint-based mechanisms generate and exchange the content or an offer belonging to sub-categories of substantive behaviour such as accepting, rejecting, log-rolling, offer etc. The argumentation-based automated negotiation (ABN) models support the next three content

strategies i.e., task-oriented, persuasive argumentation, and tactical. The ABN frameworks have been developed to make the automated negotiation efficient to support negotiation behaviours such as persuasive argumentation besides substantive behaviour. The framework by Sierra et al. (1998) supports three types of arguments: *threaten*, *reward*, and *appeal*. An appeal can be of different types such as appeal to an authority, a prevailing practice, or a self-interest. Threat and reward have narrower ranges of interpretations. The examples given for these three argument types in the work show that the three content categories (i.e., task-oriented, persuasive argumentation, and tactical) can be supported by this ABN framework. The examples, which have been given for threat and reward, show the tactical behaviour and the examples for appeal show the task-oriented and persuasive argumentation behaviour. The ABN model presented by Parsons et al. (1998) is for cooperative resource planning in order to satisfy intentions. This model creates *justification* and *critique* types arguments on an offer, i.e., a proposal contains an offer representing resources and associated justification or critique on offer. With this justification and critique types of meta-information, this model can support content categories such as task-oriented and persuasive argumentation. These two ABN models support offer-extended communication in automated negotiations. As mentioned before, ABN models use extra communicative acts to represent arguments in order to avoid any ambiguity between an argument and an offer. For example, the arguments in the work of Sierra et al. (1998) are supported through three communicative acts threat, appeal and reward. The four content categories supported by automated negotiation models roughly amount to half of all communication units.

	Content Categories	**Communicative Acts**
Computational Models	Substantive behaviour	Propose, trade-off, accept, withdraw
ABN Models	Task-oriented, Persuasive argumentation, Tactical	threaten, appeal, reward (Sierra et al. 1998); proposal, critique (Parsons et al. 1998)

Table 5.6: The support of automated negotiation models for content categories and associated communicative acts.

The content categories that have been included in non-bargaining category in Table 5.5 are not supported by automated negotiation models. Statements or content belonging to these categories occur in written electronic communication or for establishing business relationships between counterparts. Although these communication units are essential part of messages, but they do not show any kind of negotiation stance or behaviour nor help directly in reaching agreement. Also the affective behaviour in bargaining-related category is not supported by the automated negotiation models. It can be concluded that half of the communication units are not supported by automated negotiations.

These nine content categories have been distinguished as strategy categories (substantive, task-oriented, persuasive, and tactical), relationship categories (affective, private communication) and communication categories (procedural, formality, text-specific) (Köszegi et al. 2004). The strategy categories represent core negotiation behaviour and especially task-oriented behaviour is associated with the integrative negotiation style. Automated negotiation models support only strategy categories. Relationship categories are until now not supported by automated negotiation models and except the procedural category, the other two communication categories (communication protocol and text-specific) do not make sense for agent-mediated negotiations or multi-agent systems.

5.3.1.3 FIPA SL Support for Negotiation Content Categories

From the expressivity of FIPA SL and the examples given in (FIPA 2002b), it can be argued that this content language can be used alone to express statements belonging to many content categories in automated negotiations instead of using different content languages for different contents. In this section we evaluate the support of FIPA SL for the substantive, persuasive, tactical and task-oriented content categories.

Substantive Behaviour:

The minimum requirement for an agent content language is that it can express offers (Sierra et al. 1998)—in other words the content of a substantive behaviour. For this a content language must contain variables to represent issues, contents for issues values, and a conjunction operator to form multi-issue offer. The FIPA SL fulfils these minimum

requirements by providing different elements (see 4.1.3.1) to express substantive behaviour.

Example 1:

```
(Structured-Offer (offer :price 25000 :delivery-date 12-08-2009
:quantity 30) )
```

The above example is an instance of a FIPA SL proposition consisting of a predicate symbol and a functional term. The functional term element can be used to represent an instance of an offer or a product/service etc. In the example, a functional term consists of three parameters (key-value pairs) and a functional symbol. The first element of a parameter is a key and the second element is a value of the key. Suppose there are three negotiation issues in a negotiation agenda and these three parameters represent the three negotiation issues `price`, `delivery-date`, and `quantity` and their values `25000`, `12-08-2009` and `30`, respectively. The units and types of the values can be defined in an ontology. These three issues and their corresponding values represent an offer in FIPA SL. The predicate symbol `Structured-Offer` indicates the type of content that has been represented by the functional term. The above example thus specifies an offer consisting of `price` 25000, `delivery-date` 12-08-2009 and `quantity` 30.

Example 2:

```
(any (sequence ?x ?y) (and (price ?x) (delivery-date ?y) ) )
```

The second example can be used in conjunction with the first example to make a query on the negotiation issues. In the example 2, an identifying reference expression (IRE) is used to describe a query about `price` and `delivery-date`. A referential operator `any`, a list operator `sequence`, a binary logical operator `and`, two predicate symbols `price` and `delivery-date`, and two variables `?x` and `?y` make this query. The predicate `price` is related to the variable `?x` and the predicate symbol `delivery-date` is related to the variable `?y`. The sender of this content is asking the receiver agent for the values of price and deliver-date. The receiver is supposed to provide the values of variables which represent the values of issues. The example 3 represents an answer to

query in example 2 and it is a combination of a proposition and IRE. The receiver has extended the original query with a proposition that tells the values of issues i.e., `price` is `20000` and `delivery-date` is `31-08-2008`.

Example 3:

```
(= (any (sequence ?x ?y) (and (price ?x) (delivery-date ?y)))(sequence 20000 31-08-2008) )
```

So, with the language constructs of FIPA SL, negotiation issues, products, services or queries can be represented in different forms. The sub-categories such as offers, counteroffers, logrolling, acceptance, rejection etc., of substantive behaviour can be represented using functional terms, IREs, propositions etc.

Persuasive, Task-oriented and Tactical behaviours:

For representing arguments, some more logical language elements such as atomic formulae (*true*/*false*) and the unary logical operator *not* (besides the variables, constants and the conjunction operator) as well as a meta-language are used (Sierra et al. 1998). The meta-language is defined to express preferences between offers. The minimum requirement for a meta-language is to represent statements of logical language as terms in the meta-language and to have a preference meta-predicate to express preferences between statements of the logical language. The FIPA SL is based on predicate logic and contains the elements of a logical language, and fulfils the requirements of a meta-language. Using FIPA SL, a predicate symbol with two terms can express a preference between two offers.

In the FIPA communicative act library, examples have been given for expressing content in FIPA SL. The examples show that conditions (pre- or post conditions) can be set on the performance of actions. These conditions can be used as preparing persuasive, tactical or task-oriented statements. Example 4 shows that an `agentA` will stream a `file123` on channel `19` when it believes ('B') that the `customer78` is ready.

Example 4:

```
((action (agent-identifier :name agentA) (stream-content file123
19))
    (B (action (agent-identifier :name agentA) (ready customer78))
```

The FIPA SL language also provides modal operators; therefore, it can express plans and resources in argumentation statements as in the ABN framework (Parsons et al. 1998).

5.3.1.4 Analysis of Content Categories for Human-Agent Negotiation

The human-agent negotiation protocol (cf. section 5.2.1.2) consists of the message types that belong to the category of offer-extended communication. All the content categories in Negoisst belong to offer-extended communication (i.e., structured offer for substantive behaviour and un-structured text message for all other behaviours). The commonality between the Negoisst system and automated negotiations is the support of strategy categories that include substantive, persuasive, tactical and task-oriented behaviours. The strategy categories are considered to be core negotiation behaviour and amount to approximately half of the all communication units (Figure 3.3).

The difference between NSSs and automated negotiation models is the structure of content to support offer-extended communication. Except substantive behaviour, the Negoisst system and automated negotiations differ on the content type of other three content categories (persuasive, tactical, and task-oriented). Persuasive, tactical and task-oriented behaviour in automated negotiations are expressed with structured content, while in Negoisst system such content is un-structured. The offer-restricted communication between a human negotiator and a negotiation agent is even possible due to the support for structured offers in Negoisst. For example, if the offers are embedded into the un-structured text like in SimpleNS, then even the exchange of offers or substantive behaviour could not be possible in human-agent negotiation. The difference of structured and un-structured content restricts the communication of persuasive, tactical and task-oriented behaviours. A negotiation agent can create and send structured statements belonging to three categories but the human negotiator will not be able to understand this structured content in the Negoisst system, and similarly, if the human negotiator sends

such content in natural language, the negotiation agent will not be able to process that free text content.

The next difference between Negoisst and automated negotiation is from the illocution point of view. The electronic negotiations based on the speech act theory assume that the propositional content in a negotiation message should be according to the illocution. In the Negoisst system, the relationship between illocution and propositional content is very broad i.e., a message type can represent content of many content categories. For example, a counteroffer message type tells explicitly that the content of a message is a bargaining stance; however the bargaining content could be of substantive behaviour (e.g. log-rolling), argumentation behaviour (e.g. arguments), or task-oriented behaviour (e.g. preferences information exchange etc.). But in automated negotiation models the propositional content is fixed depending on the communicative acts. For example in the trade-off mechanism, a trade-off illocution allows only an offer as the propositional content and in an ABN framework, a threat act contains only threat content. So, it would be incorrect for the negotiation agent in human-agent negotiation to assume the propositional content in a message to be only according to the semantics or purpose of the communicative acts, as it is assumed in automated negotiations.

Except the substantive content category, all other content categories cannot be supported in the same way in human-agent negotiations as in inter-human negotiations. Nevertheless some of the bargaining and non-bargaining categories can be supported in human-agent negotiation. For example, the non-bargaining communication protocol statements are not required in automated negotiations and, therefore, no automated model exists to generate them. The communication protocols are simply the static opening and closing statements (see examples in Table 5.5), which are written in nearly every message and have a large contribution in all communicative acts, namely 28%. These fixed statements (e.g. greetings, salutations etc.) can be added to the beginning and ending of each message that is sent by an agent to the human counterpart. These communication protocol statements are for only one-way communication. A negotiation agent can generate and send them to its human counterpart, but does not need to process when it receives such statements. These formality statements can be defined in an ontology and stored in the knowledge base of the agent. These messages can be distinguished according to the message types (for example, the greetings at the start and end of negotiations are

normally different than those in the middle). The same one way content communication can be used for tactical behaviour. For example, an agent can generate a threat using fixed sentences, e.g. “this is my last offer”. Unlike in communication protocol statements, the negotiation agent will use its decision making model to decide when such a threat statement can be sent to a human counterpart. Such statements can make the agent messages look more formal and natural as if they were prepared by the human counterpart.

From the above analysis it is obvious that with the current implementation of the Negoisst system and using only existing automated negotiation mechanisms, the human-agent negotiation is possible only at offer-restricted communication level i.e., substantive behaviour. The substantive behaviour is argued to increase the agreement probability, however, it amounts only 16% of all communicative units. With the additional support, for example, for communication protocol and tactical behaviour statements, the negotiation agent message content can be made richer and more realistic.

5.3.1.5 Summary

The main nine content categories that were identified on written natural language text have been used for analysing the human-agent negotiation communication. The human-agent communication has been proved even less rich than inter-agent communication. The agent content languages play the same role in the automated negotiation that natural languages play in the human-mediated negotiations. From the analysis it can be seen that the communication between two counterparts using the same language (natural language or artificial content language) is richer than both using different languages (natural language vs. content language) for communication. For example, negotiation agents are able to communicate arguments in some content language, but the argumentation is not possible between an agent and a human counterpart due to heterogeneous languages.

Although the negotiation agent is able to process all strategy categories, the human-agent communication in the hybrid negotiation model is restricted to substantive behaviour. It has been mentioned that substantive behaviour alone increases the agreement probability, while the task oriented behaviour, persuasive behaviour, and tactical behaviour do not have significant effects on agreement (Köszegi et al. 2004). However, we have no evidence that substantive negotiation behaviour alone will lead to

successful human-agent negotiations. The fixed formality and tactical statements can make communication more realistic and richer in human-agent negotiation.

We can think of different possibilities for increasing content level communication between a negotiation agent and a human negotiator by adding new features to the Negoisst system. For example, other strategy categories can be supported in a similar way to substantive behaviour in the Negoisst system i.e., by representing and storing content of these categories structurally and showing them graphically to the human negotiator. To show offers graphically to human negotiators helps them understand and analyse offers in a better way. Adding support for all strategy categories seems possible because for preparing such behaviour the required information is already available in the system such as negotiation preferences, negotiation history etc. For example, for task-oriented behaviour an agent or human negotiator can disclose preferences for integrative negotiation such as issue priorities. Here the solution is recommended for those content categories for which the automated negotiation model exists and the negotiation agent is able to create and process content.

5.3.2 Message Types

The analyses in the previous sections have shown similarities and differences in the message structure and the message content between negotiation support and automated negotiation models. The similarities take towards enabling the human-agent negotiation communication. Now the communication models of both negotiation models are compared and discussed with respect to the communication level of communication process. As mentioned in section 2.3.4.3, the communication level defines the context of message and represents the intention of the sender. The message types in the Negoisst system (section 2.3.4.3) and in multi-agent systems (section 4.1.2) are based on speech act theory for enabling pragmatic communication. These message types realise the communication level by defining the context of messages and represent the intention of the message sender. The speech act based communication in both negotiation models is an important common factor that makes interoperability possible also at communication level between two different communication models. However, the theory of speech acts is used more formally in the multi-agent systems compared to the Negoisst system.

In the human-agent negotiation protocol, five message types have been specified, which formulate the negotiation contract (section 5.2.1.2). Although these message types are based on speech act theory, they are handled differently in the communication model of the Negoisst system and agent systems. In the Negoisst system, the message types describe the intentions of sender without any formal semantics (which the human negotiator has to fulfil in order to send or process a negotiation message). The absence of an explicit semantics allows a human negotiator to attach any propositional content to the message type. On the other hand, a negotiation agent claiming to conform to the FIPA ACL must implement the communicative acts according to the defined semantics. The negotiation agent selects or processes a message type according to its mental state and, therefore, the propositional content is according to the semantics of a communicative act. Here, we discuss the five message types from the negotiation agent point of view in human-agent negotiation. FIPA provides a library of communicative acts required in different inter-agent communication situations (FIPA 2002b). Some of the communicative acts are particular for electronic negotiations and can be selected for the negotiation agent in hybrid model.

In the Negoisst system, the main purpose or intention of communication is provided by the message types instead of communication context and message content. The message content is added according to this intention. This relationship between message type and message content is broad in the Negoisst system. As observed in the previous section, a message type represents an explicit attitude to a structured offer in the message content and an implicit understanding towards the rest of the un-structured natural language content in the message content. For example, a counteroffer message type clearly indicates a new offer, but this message type does not tell explicitly what else could be in the message content. Besides the offer, the rest of the content is understood from the bargaining or communication context. This content may consist of further utterances (speech acts) with explicit, implicit, or missing illocutionary force. In such cases, the missing and implicit illocutionary force is understood from the context in which the communication is taking place and from the message contents. The inter-human negotiation communication is rich and dynamic and, therefore, it is not possible to provide a separate message type for all possible negotiation behaviours.

Using FIPA ACL, an agent message is considered valid only if it contains an illocutionary force represented by a communicative act and if that communicative act is implemented according to the defined semantics. Otherwise, the agent message could not be processed properly by the receiving agent and the communication would fail. The semantics of a communicative act is an intentional-level description which represents an agent's internal beliefs about the domain and the intention to be fulfilled by sending the message. Thus a communicative act is implemented by adding propositional content according to this intentional-level description of the agent. A communicative act is usually used to represent a single intention i.e., for each communication behaviour a separate communication act is used in automated negotiation. For example, a communicative act for counteroffer in the automated negotiation models (trade-off, propose) contains only the offer content (substantive behaviour), similarly a communicative act for threat includes only the tactical behaviour content. The agent systems add content in communicative acts from four content categories (substantive, tactical, persuasive and task-oriented) according to the defined semantics of the acts. All systems use proprietary communication models so that the semantics is defined for the particular negotiation problem. The defined semantics is according to the inter-agent communication, but such semantics may need to be revised for human-agent negotiation.

Table 5.7 shows the Negoisst message types and their equivalent FIPA communicative acts as well as the sender's role and illocutionary point of each message type. The FIPA communicative acts have been taken from the FIPA communicative acts library (FIPA 2002b). The conversion of a FIPA communicative act to a Negoisst message type and vice versa will be demonstrated in section 5.3.4. An illocutionary point is one of the five classes (see section 2.3.1) of speech acts and expresses the pragmatic function of a message type. Here we compare and explain FIPA communicative acts with Negoisst message types on three classification dimensions (illocutionary point, propositional content, psychological state) of speech acts (cf. section 2.3.1). The three dimensions for communicative acts are explained according to their semantic definitions.

While discussing the propositional content part of Negoisst message types and ACL communication acts, only a structured offer is considered as a propositional content[20].

Negoisst message types	Sender role	Illocutionary point	FIPA ACL Comm. Acts	Remarks
Request	Purchaser	Directive	CFP	starts negotiation
Offer	Supplier	Commisive	Propose	starts negotiation
Counteroffer	purchaser/ supplier	Directive/ Commisive	Propose	continues negotiation with new offer
Accept	Any	Declarative	Accept-proposal	terminates negotiation successfully
Reject	Any	Declarative	Reject-proposal	terminates negotiation unsuccessfully

Table 5.7: Equivalent ACL's communicative acts of Negoisst's message types

5.3.2.1 Message Type Request and Communicative Act CFP

Request (Negoisst):

The message type *Request* is a *directives* type of speech act. The pragmatic function (illocutionary force) of this message type is that the buyer starts negotiation with supplier in an attempt to make the supplier carry out selling or delivery of a product or a service. The direction-of-fit shows how the propositional content of this message type relates to the negotiation. In this regard, the content of request expresses the values of negotiation issues and associated message (free text) for the product/service wanted from the supplier. The psychological state of the buyer determines the attitude when performing the message type. So, the buyer is in the psychological state of intention to purchase specified product from the supplier through the negotiation to fulfil some of the goals.

[20] In the Negoisst system, the product or service attributes that make the negotiation issues are defined in the pre-negotiation phase. A structured offer contains only these negotiation issues and their values.

CFP (ACL):

The communicative act *CFP* (call for proposal) is also a *directives* type of speech act. CFP is a general-purpose action to initiate a negotiation process by an agent by making a call for proposal to perform an action. The purpose of this communicative act can be explained through its semantics provided by FIPA. The formal semantics describes that the sender intends the receiver to perform an action. The sender sends the action and asks the receiver about the preconditions on which the receiver will perform the action. The feasibility preconditions state that the sender neither knows nor is uncertain about preconditions. Furthermore, the sender does not know the intention of receiver if it informs the precondition to sender. The rational effect of this act is that the receiver will inform the sender about the preconditions for performing the action. The propositional content of this act should contain (according to the semantics) the specification of action and the variables for preconditions. So, the content consists of an action expression and one or more referential expression(s). The action expression denotes an action the sender is willing to have performed by the message receiver. A referential expression defines a single-parameter proposition specifying the preconditions on the performance of action. The agent responding to a CFP answers with a proposition giving the value of the parameter in the original precondition expression. In negotiation terminology, we can take a precondition as a negotiation issue. One referential expression is used to specify one precondition on action. In case of many issues or multiple parameters, we can have a separate identifying expression to set preconditions on each issue in an offer.

Use in Human-Agent Negotiation:

The CFP communicative act can be used by the negotiation agent for the same purpose as the Request will be used by the human negotiator in human-agent negotiation. From an illocutionary point of view, both (Request and CFP) express interest in purchasing and determine the role of sender as buyer. The agent adds an action (to be performed by the receiver) in the content of CFP. This action expression is not required in human-agent negotiation. In inter-human negotiations, the performance of action is not meant for the receiver only. The human negotiators have their respective actions to perform. The actions are the duties on negotiation issues such as the price will be paid by the buyer and the

product will be delivered by the supplier etc. The structured offer part of a Request message will be taken as the preconditions part of CFP and vice versa. The action part from CFP can be ignored in human-agent negotiation.

5.3.2.2 Message Types Offer/Counteroffer and Communicative Act Propose

Offer and Counteroffer (Negoisst): A supplier can begin a negotiation with an *Offer* message type by presenting some products or services to a potential customer. An Offer is a *commisive* act i.e., the supplier is intended to perform an action represented in the propositional content. The pragmatic function of Offer is that the supplier starts a negotiation with a buyer in an attempt to sell products. While sending an offer the supplier is in psychological state of intention to sell a specified product or service to buyer in order to fulfil his goals. The Counteroffer message type provides the pragmatic function of preceding the negotiation process. It is a directive act when issued by the buyer and commisive act when sent by the supplier. Besides free-text, the Offer and Counteroffer messages contain the values for issues.

Propose (ACL): The communicative act *Propose* is to make a proposal or respond to an existing proposal during a negotiation process by proposing to perform an action by the sender when the preconditions become true. The semantics of this communicative act describes that the sender informs the receiver that, once the receiver informs (with accept-proposal) the sender that the receiver has adopted the intention for the sender to perform action, and the preconditions for the sender performing the action have been established, the sender will adopt the intention to perform the action. The feasibility preconditions state that the sender believes that the receiver has the intention for the sender to perform the action under the preconditions sent by the sender. The rational effect of this communicative act will be that the receiver also believes in what the sender believes. The propositional content contains an action expression and a proposition. The action expression is out of scope for the hybrid negotiation model. A proposition represents the precondition on the performance of the action.

Use in Human-Agent Negotiation:

The Propose act can be used as a replacement of Offer and Counteroffer message types for the negotiation agent in the hybrid model. The agent can use the Propose act to start a negotiation in the role of seller (in the same way as the human negotiator uses the Offer). The agent can use this act as a counter offer act in response to message types Request, Offer, and Counteroffer from the human-negotiator. The structured content of Offer and Counteroffer can be converted to preconditions of the Propose act (and represented as proposition) and vice versa.

5.3.2.3 Message Types Accept/Reject and Communicative Acts Accept-/Reject-Proposal

The *accept-proposal* and *reject-proposal* communicative acts are the replacements for *Accept* and *Reject* message types, respectively, in the agent communication model. Alike Accept message type, the accept-proposal act is performed to accept a previously submitted proposal. The agent agrees with the last received proposal of the opponent and finalises the deal by sending this message. This message terminates the negotiation successfully and leads to a legally binding contract. Likewise, the reject-proposal act is performed to reject a previously submitted proposal. The sender agent does not agree with the last received proposal of the opponent and has no intention to continue the negotiation. This message terminates the negotiation unsuccessfully without providing a contract.

5.3.2.4 Discussion

In the case of human-agent negotiation, it is not critical if the negotiation agent does not implement an act according to the given semantics because the human negotiator or the Negoisst system does not process the received message type according to some semantics. Similarly the agent can process received messages without using any semantics. In the hybrid negotiation model, instead of using the standard semantics, communicative acts can simply be defined on the basis of the negotiation protocol and the negotiation strategy. The feasibility preconditions and rational effects of communicative acts are met when the negotiation agent exchanges messages according to the negotiation protocol and their negotiation preferences. The communicative acts are implemented on the basis of the

conceptual model of the agent's knowledge, goals, and commitments making the negotiation agent's decision making model.

A message type in the Negoisst system expresses a single intention but the message contains content represents many negotiation behaviours whereas content in an agent message is restricted to the intention of a communicative act. The difference at propositional content level is handled by assuming only structured offers in the Negoisst message type and preconditions/conditions representing negotiation issues in agent system.

5.3.3 Ontologies

Ontologies have a role in facilitating the sharing of information between humans (Schoop & Jertila 2004), between software agents (Pokraev et al. 2004), and between human and agent (Kemke 2006). The use of ontologies in the Negoisst system has been discussed in section 2.3.4.3 and the use in agent communication in section 4.1.3. In this section, the role of ontologies in facilitating the human-agent negotiation in the hybrid negotiation model is discussed. In the hybrid negotiation model, ontologies can play the role as the negotiation agent's knowledge base, or facilitating communication between a human negotiator and negotiation agent, and as interoperability between an ANS and the Negoisst system.

Following the ways presented by Sycara and Paolucci (2004) for using ontologies in the single agent system and in agent communication, the ontologies can contribute in the following three ways for the negotiation agent in the hybrid model: ontologies serve as a conceptualisation of the negotiation domain of a negotiation agent for communication and as a knowledge base for decision making. The negotiation domain of a negotiation agent can contain communicative acts, static facts (e.g. communication protocol statements), negotiation protocol, negotiation issues, partner info etc.; the ontologies provide concepts and properties to semantically express and interpret the content of message, and they work as an agent's internal knowledge. As a knowledge base, the ontologies organise and store the received content (knowledge) that can be used by the agent's decision making model for evaluating and generating offers. Ontologies formalise the conversation by defining a negotiation protocol and the message types. The first two advantages of using ontologies in agent communication are related to the

meanings of content of a message, which we can achieve through negotiation and agent ontologies (see next sub-sections). The last advantage can be achieved through the agent ontology. Ontologies enable communication between a human negotiator and a negotiation agent by providing a shared meaning of communication (vocabulary) to understand the content of the negotiation message. For interoperability, ontologies provide the negotiation data and negotiation protocol message types as a common repository to the ANS and Negoisst system to make them work together.

The Negoisst system's information and process infrastructure is based on various different ontologies, which work as main data sources during negotiation (Schoop & Jertila 2004). The *application* ontology describes workflow of negotiation by defining elements such as negotiation protocol, possible number of participants and their roles. The *contract* ontology contains a set of general concepts such as goods, payment, delivery etc. that are required normally in every negotiation and they build the initial structure of each business contract. The *domain* ontology contains concepts specific to some business domain e.g. tourism, construction etc. The *user* ontology is a collection of concepts that are defined during negotiations where a user is one of the negotiation participants. The *negotiation* ontology is a collection of concepts from user, contract and domain ontologies, as well as concepts defined during negotiation.

In the sub-sections, we mention negotiation ontology and agent ontology, which have an important role in hybrid negotiation model at communication level.

5.3.3.1 Negotiation Ontology

The purpose and construction of the negotiation ontology can be seen in detail in the original work (Schoop & Jertila 2004). The development process of a negotiation ontology follows the approach proposed by Uschold et al (Uschold & Gruninger 1996). Now the aspects of negotiation ontology, which are relevant in this work, are mentioned. The negotiation ontology serves as an Interlingua between the negotiation agent and the human negotiator as well as between the ANS and the Negoisst system. Initially the negotiation ontology is a replica of the contract ontology. It contains a set of general concepts that are required in the contract negotiation and build the main structure of business contract. These general concepts are contract partners, good, payment, delivery, order etc. The negotiation ontology is extended with negotiation issues in the pre-

negotiation phase. The offers on the negotiation agenda (negotiation issues) are stored as instances in the ontology. The negotiation ontology is associated with a single negotiation and is the only reference to offers.

The negotiation ontology can provide a structural and semantic interoperability between two heterogeneous communication models in the hybrid model by defining all the negotiation vocabulary and storing negotiation data at a single place independent of any system. The purpose of the negotiation ontology in the Negoisst system is to enable unambiguous inter-human communication, but in the hybrid negotiation model, the negotiation ontology is the source of communication of offers (substantive behaviour) between a human and a negotiation agent. These offers are structured and generally processable by the negotiation agent.

As mentioned before, FIPA SL provides only syntax and semantics to represent and interpret the message content, whereas ontologies are a general method of providing semantics to domain and application specific symbols or terms in message content. For example, in a functional term of FIPA SL (shown in section 5.3.1.3), the parameter names specifying the issues and the parameter values specifying the values are application specific and can be taken from the negotiation ontology to prepare an offer. The negotiation ontology stores the offers in a structured way for agent system therefore the data for substantive behaviour is at least available to the negotiation agent for decision making.

5.3.3.2 Agent Ontology

As the negotiation ontology has been defined for the Negoisst system, we can define a new ontology '*agent ontology*'. The reason for the agent ontology is to keep the negotiation ontology independent of the automated negotiation model. The agent ontology can be designed in accordance with the agent communication model and decision making model. This ontology, for example, conceptualises the communicative acts, provides mappings between Negoisst message types and agent communicative acts, and stores offers that are exchanged between agent and human negotiator. This ontology at first can be a replica of the negotiation ontology and then it is extended with new concepts for the agent's negotiation vocabulary. The agent adopts the agent ontology in its internal knowledge.

The following concepts can be added to the agent ontology for the agent's activities during the automated negotiation process. All negotiation issues are extracted from the defined contract points (product or service description). These negotiation issues are the agent's negotiation object and make the content of an agent message. A negotiation message and all its parts can be defined in the ontology. The rules of the human-agent negotiation protocol and associated communicative acts can also be defined. For example, *offer* is a concept in the agent ontology, which is an aggregation of negotiation issues concepts (see Figure 5.6). An offer can contain some or all negotiation issues. An offer is associated with one of the communicative acts in accordance to the negotiation protocol and agent decision making model.

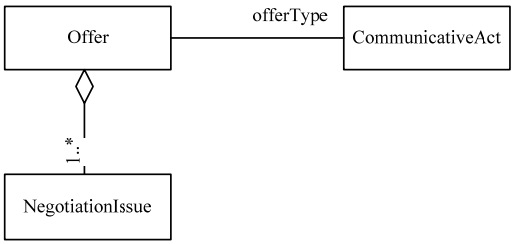

Figure 5.6: Part of agent ontology

Classes can also be added in the agent ontology to represent the formality messages or tactical statements (see Figure 5.7). These messages may differ for different communicative acts.

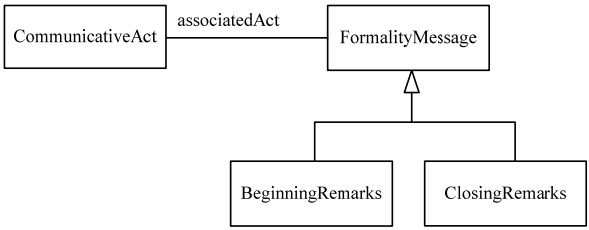

Figure 5.7: Classes for formality messages

5.3.4 Wrapper Agent

The negotiation ontology and agent ontology presented in the previous section provide the semantic and information i.e., content (offer) level and message structure level as well as, interoperability between the heterogeneous communication models of the negotiation agent and the Negoisst system. The information level interoperability helps the human negotiator and the negotiation agent to understand the different components (e.g. content, message type) in messages, but it does not provide the representational or system level interoperability between a non-agent system and an agent system. An ACL message cannot be processed by the Negoisst system and vice versa. Genesereth and Ketchpel (1994) have presented a number of different standard approaches and techniques to convert existing applications into software agents or at least to communicate with these applications. One of the techniques is wrapper agent that provides interoperability between agent and non-agent based systems.

In a wrapper approach, the existing or non-agent application is wrapped with code so that it can communicate in ACL. The wrapper can examine and modify existing application data. In our framework, we use a wrapper agent that will work as the interface between the Negoisst system and the automated negotiation system for communication between the human negotiator and the negotiation agent. As shown in Figure 5.8, the wrapper agent's main function is to translate ACL messages into Negoisst messages and vice versa. For example, to convert a Negoisst message into an ACL message, the wrapper agent reads the message type and the values of issues from the negotiation ontology and converts them into FIPA communicative acts using the agent ontology and FIPA SL representation, respectively. For this conversion, it is assumed that the human negotiator always uses the structured offer window (Figure 2.5) to prepare an offer.

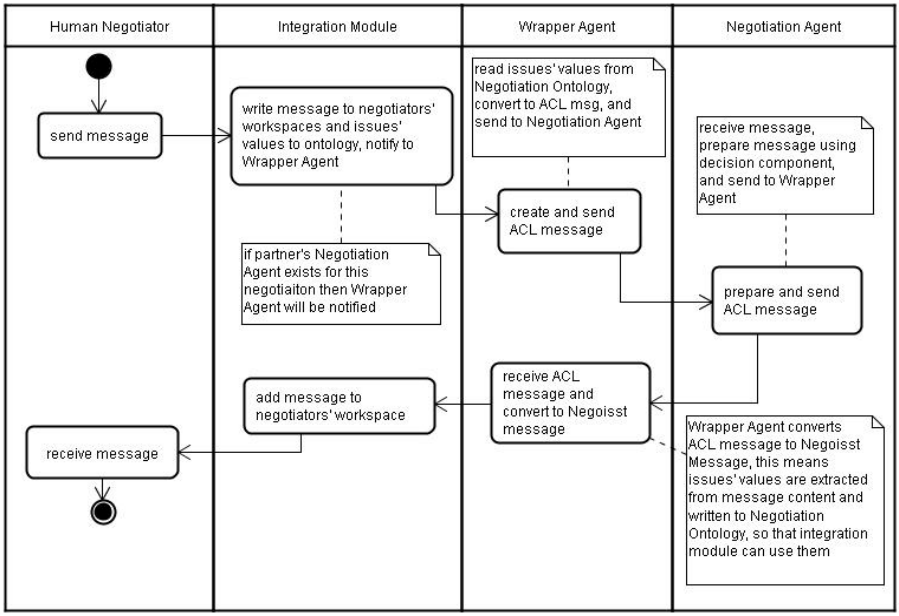

Figure 5.8: A wrapper agent converts an agent message into Negoisst message (and vice versa)

5.4 Negotiation Agent Decision Making Model

The aim of a negotiation agent decision making model is to provide offer evaluation and offer generation decisions during negotiations with a human negotiator. For this, the model should include the autonomous decision making apparatus similar to the one provided by the automated negotiation mechanisms/models (chapter 4). The apparatus includes the utility function for offer evaluation, decision functions and algorithms for offer generation, and strategies for adopting the best path. Instead of proposing a new automated negotiation mechanism that is composed of this apparatus, the conceptual usage of existing mechanisms in consistence with the Negoisst system is shown for the evaluation and generation of offers.

The working of the agent decision making model is focused on Pruitt's *strategic choice model* (Pruitt 1981) that consists of three basic negotiation strategies for moving towards agreement (cf. sections 2.2.2 and 3.2.1). The first strategy is to concede

unilaterally to reduce the distance between the demands of the two parties. The second strategy, namely competitive behaviour, is to stand firm and employ pressure tactics in an effort to persuade the other party to concede unilaterally and thus also to reduce the distance between demands (distributive agreement). The third strategy is to collaborate with the other party in search of a mutually acceptable solution in integrative negotiations. This working is achieved through the existing automated negotiation mechanisms providing different negotiation behaviours and the representation of these behaviours using the already presented agent communication model.

The aim—providing offer evaluation and offer generation methods—and the functional working—generation and representation of different negotiation behaviours—of an agent's conceptual decision making model is discussed in the following sub-sections with respect to the following aspects. The focus of discussion is on how the existing negotiation mechanism can fit into human-agent negotiations.

- Negotiation Strategies: We discuss the support of human negotiation behaviour i.e., strategies and tactics (see section 3.2.1), by each automated negotiation mechanism.

- Human-Agent Negotiation: A discussion on the use of automated negotiation mechanisms in human-agent negotiation according to the offer design (e.g. partial offers) and communication design (e.g. semi-structured message support) in Negoisst is provided. Partial offers help to build up an agreement with a succession of compromises on individual issues or subgroups of issues (Raiffa et al. 2002). This support of Negoisst will be evaluated in automated negotiation mechanisms. The second aspect is the design of the Negoisst system that has an important role in the implementation of automated negotiation mechanisms. The features of the Negoisst system make the offers generated by an automated negotiation mechanism understandable for the human counterpart. Problems are also discussed that may arise due to the use of automated negotiation mechanism against a human negotiator. Some recommendations are presented for the successful implementation of automated negotiation mechanism in hybrid model.

- Communication: The support and limitations of the agent communication model for the representation and exchange of offers generated by the automated negotiation mechanisms is discussed.

- Delegation: We present the delegation of any negotiation mechanism to an agent i.e., which initialisation information is required to build functions and algorithms in agent's decision making model.

5.4.1 Responsive Mechanism

The responsive automated negotiation mechanism provides various families of tactics for several concession making behaviours (Faratin et al. 1997, Faratin 2000).

5.4.1.1 Supported Negotiation Behaviour

The decision functions of the responsive mechanism can be used not only for concession making but also for competitive and coordinative behaviour. Time-dependent and resource-dependent tactics can be used for concession making and competitive behaviour depending on the *conceder* or *boulware* concession strategy, respectively. The family of behaviour-dependent tactics is basically a cooperative problem solving strategy by giving concessions in response to the counterpart. Behaviour-dependent tactics can also be used for *heuristic trial and error* tactics of coordinative negotiation behaviour, which gradually reduces the level of benefit being sought for oneself. For example, if the negotiation agent receives concession on one high weight (important) issue, it can reciprocate concession on any other less important issue using the behaviour-dependent tactics. This less important issue from the agent's point of view might be very important for the human negotiator. The behaviour-dependent decision functions are also *logrolling* (a coordinative behaviour under *information exchange* tactic) by chance. These decision functions do not assume or guess the preferences of opponent to execute any strategy.

5.4.1.2 Human-Agent Negotiation

There might be many issues to be dealt with when a negotiation agent is using the responsive mechanism in human-agent negotiation.

The responsive mechanism does not provide an explicit support for generating partial offers. In this mechanism, a tactic(s) is specified individually for each issue and therefore, the value of each issue is generated independent of other issues. The values of all issues are then combined to make a complete offer, which is then evaluated using the linear additive utility function. The way in which the value for each issue is generated makes it possible to generate partial offers using this mechanism. For the responsive mechanism, an algorithm can be designed for the evaluation and generation of partial offers in the agent's decision making model. For example, Negoisst system's technique can be used for the evaluation of an incoming or outgoing partial offer. The partial offers can be prepared by generating the values of required issues only. The exact description and behaviour of such an algorithm requires a proper formalisation and evaluation.

The time-dependent tactics require the maximum negotiation time to be specified. At this maximum time the negotiation agent either concedes its reservation value (if generating an offer) or abandons the negotiation (if the incoming offer is not acceptable). In the Negoisst system, no explicit time deadline is specified as a part of the process for the completion of negotiation (time deadline is normally the private knowledge of each human negotiator and can be fixed during negotiation). For the negotiation agent, the principal can set the negotiation completion time for the time-dependent tactic(s) according to his/her preferences at the start of negotiation.

The evaluation function of the responsive mechanism terminates the negotiation either once the maximum negotiation time is reached or an incoming offer is accepted. An incoming offer is accepted if the utility of that offer is greater that the utility of the offer to be sent next. Using any tactic in the responsive mechanism, both agents concede in each round, therefore the utility of latest received offer is always greater than the previous received offer (monotonically increasing). However, it is not the case in human-mediated negotiations that the utility of received offers always increases monotonically for the receiver and similarly, the utility of sent offers always decreases monotonically for the sender. Humans use various negotiation strategies randomly. It means, in the case of human-agent negotiation, that it is not certain that the utility of every received offer from the human counterpart is monotonically increasing for the negotiation agent, and the agent should just accept the offer if it has greater utility than the offer it will send next. It might well be the case that some of the previously received offers have a greater utility than the

latest received offer whose utility in turn, is greater than the agent's latest offer to be sent next. Thus, the agent should not simply accept the last received offer if its utility is greater than the next offer to be sent out. Rather, the agent should check all previously received offers in the thread and try to re-negotiate an offer with maximum utility with the human negotiator.

5.4.1.3 Communication Support

From the communication point of view, with the existing support or implementation of the Negoisst system, the negotiation agent is able to use the responsive mechanism for concession making strategies in human-agent negotiation. The tactics only generate substantive negotiation behaviour that can be expressed using suitable elements of FIPA SL (cf. section 5.3.1.3). Through an interoperability component, this substantive behaviour is shown to the human counterpart as a structured offer in the Negoisst message window.

5.4.1.4 Initial Setup Requirements

Setup requirements for each tactic are different in the responsive mechanism. A time-dependent tactic requires the maximum negotiation time and the concession making rate (e.g. linear, conceder or boulware). The setup of the resource-dependent tactic requires the amount of resources which the negotiation agent takes into account while making concessions. For a behaviour-dependent tactic, the extent to which the negotiation agent imitates the human-negotiator to make concession is specified during setup. The imitation extent could be calculated from two or more previous offers of the counterpart from the offer history.

If the agent principal wants to use more than one tactic (combining tactics) of the responsive mechanism to generate a value of an issue, then (s)he has to mention the relative importance of each tactic by providing the weights for each tactic. As mentioned in chapter 4, a negotiation strategy on the responsive mechanism generates new weights for issues. If the agent's principal wants to define this negotiation strategy, the settings for generating new weights have to be defined. For example, for a single issue under no time pressure, the agent's strategy could be defined to give full weight 1 to the boulware tactic and 0 to the conceder tactic. But with the passage of time or under time pressure it will

start reducing importance of boulware tactic and increasing the importance of conceder to reach an agreement. A simplest setting (and therefore a strategy) could be specified for using a fixed single tactic for each issue through out the negotiation process.

5.4.2 Trade-Off Mechanism

The trade-off mechanism (cf. section 4.3.2) is for generating offers while keeping one's aspirational level unchanged (such offers are called trade-offs).

5.4.2.1 Supported Negotiation Behaviour

The trade-off mechanism is for non-zero sum games where each agent assigns different priorities to issues. Experiments have shown that this mechanism is for integrative negotiation that increases the joint welfare of both agents through trading off between negotiation issues (Faratin 2000). However, this mechanism can also represent different negotiation behaviours implicitly, such as concession making, competitive, and coordinative behaviour.

The trade-off mechanism generates trade-offs using a similarity criteria technique that is a way to compute a counteroffer that is similar to the received offer of the counterpart. This way of generating offers can be resembled with the *incorporation tactic* of coordinative negotiation behaviour (section 2.2.2.2). The incorporation tactic (a sort of compromise) adds some element of the counterpart's last received offer to the sender's current offer. So, trade-off mechanism is a method of creating offers by incorporating some element of the counterpart's offer in the trade-off. If the incorporated element is of high priority, then it can be considered a concession and a trade-off can lead to an integrative solution. Using the meta-strategy mechanism (section 4.3.2.3), a combination of responsive and trade-off mechanisms can be used to support another coordinative behaviour tactic called *heuristic trial and error* tactic. The heuristic trial and error tactic involves the gradual decrease in benefit being sought. The use of the responsive mechanism in the meta-strategy mechanism to break deadlock by giving concession can be compared to the modification of heuristic trial and error tactic's search model by unlinking and dropping lowest priority goals (cf. section 2.2.2.2). The heuristic trial and error tactic can also be used to achieve *logrolling* by chance. It can be hence concluded that an agent's decision making model consisting of trade-off mechanism and a

responsive mechanism (for meta-strategy mechanism) can support all three coordinative tactics used by humans to reach integrative agreements while negotiating with a human negotiator.

5.4.2.2 Human-Agent Negotiation

The trade-off mechanism cannot start a negotiation process by creating a first offer. This mechanism requires the last sent offer of the agent and the last received offer of the counterpart to generate a trade-off. In a human-agent negotiation, the negotiation agent can use the responsive mechanism to create the first offer to start a negotiation.

The trade-off algorithm uses the counterpart's preferences on the importance of issues. The four cases have been mentioned to provide this information (see section 4.3.2.1). In human-agent negotiation, the information about preferences might be provided more accurately compared to inter-agent negotiation as the principal has the chance to know the counterpart's preferences using the information exchange strategy by exchanging question/clarification message types or the principal can guess preferences during the negotiation and then input them into the mechanism.

The trade-off mechanism only deals with complete offers (i.e., no built-in support for partial offers). The algorithm, however, creates the value of each issue one by one and, therefore, could be used for assembling partial offers. The agent's decision making model in human-agent negotiation can include only those issues in preparing a partial counteroffer which it received in a partial offer from the human negotiator.

5.4.2.3 Communication Support

The communication support of the negotiation agent is able to support negotiation behaviours related to the trade-off mechanism. As with the responsive mechanism, the trade-off mechanism only generates the values of negotiation issues. These values can be represented as ACL message content using suitable constructs. By the interoperability component, this content is converted to the instances of the negotiation ontology from where they can be displayed in the Negoisst message window as a structured offer.

5.4.3 Argumentation-Based Negotiation

The heuristic methods implement concession making and coordinative negotiation behaviour in a negotiation agent. Now the argumentation-based negotiation approach is discussed in the hybrid model to make human-agent negotiations more efficient. As with the heuristic models, the ABN approach is analysed for negotiation behaviours in the agent's decision making model, as well as the Negoisst's communication support is analysed to communicate the supported behaviour with a human negotiator. In the analysis, instead of showing a complete list of arguments that can or cannot be implemented by the negotiation agent, the emphasis is on the overall possibility of implementing this decision making approach in the negotiation agent.

5.4.3.1 Supported Negotiation Behaviour

We show here some of the argument types that are implemented by the ABN frameworks for persuasive argumentation and that can be implemented by the negotiation agent in a hybrid negotiation system. The competitive negotiation strategy consists of persuasive arguments, threats and positional commitment types of tactics (section 3.2.1). The ABN framework (Sierra et al. 1998) supports persuasive negotiation using *threat*, *reward* and *appeal* communicative acts (see section 4.4). So, we have a one-to-one relation between competitive tactics and ABN arguments types. The *appeal* act is used for revealing information or appealing to the precedent, therefore it is best suitable for persuasive arguments tactic. The *reward* and *threat* acts can be used for positional commitment and threat tactics, respectively. The appeal act can also be used as an information exchange tactic for an integrative negotiation between agent and human counterpart. The other ABN framework (Parsons et al. 1998) provides components for generating persuasive arguments in favour of or against proposals. This justification and critique argumentation mechanism can be used for persuasive arguments by the negotiation agent.

5.4.3.2 Human-Agent Negotiation

Argumentation in human-agent negotiations can be differentiated from argumentation between two agents mainly based on agent's knowledge base and agent's communication model.

In the Negoisst system, only negotiation issues have a structured representation. Human negotiators exchange arguments in natural language text. A negotiation agent cannot interpret free text arguments and hence cannot learn about human negotiator's preferences. This is obviously a communication limitation of an agent (section 5.3.1.2). This means that the Negoisst system should support a structured representation of arguments in order to enable argumentation between a human negotiator and an agent. Nevertheless, with the existing implementation of the Negoisst system, single-sided argumentation can be implemented in the hybrid negotiation model i.e., the negotiation agent can send a persuasive argument to the human counterpart, but it has no ability to process the received arguments. The usefulness of this single-sided argumentation is shown later with the help of examples.

In the Negoisst system, the human negotiators have knowledge about negotiation issues, their preferences and the negotiation thread (negotiation history). The same knowledge is available to the negotiation agent for negotiation and argumentation. In ABN frameworks, power and organisational relations between agents (Sierra et al. 1998) and the availability of the counterpart's private information and trust (Parsons et al. 1998) play a major role in the evaluation, generation and acceptance of arguments (see section 4.4). In the first system, the agents create arguments on common knowledge and the organisational relations make the argumentation process successful. ABN frameworks have been implemented for cooperative domains. For example, if an agent possesses an extra resource that cannot be exchanged with other resources, then the agent will give it to the other agent (if the other agent has requested it) without compromising the utility. In the hybrid negotiation model, there are no such explicit organisational relations between a human negotiator and an agent, preferences are private to negotiators and environment is competitive. Therefore, in the hybrid model, the agent's decision making behaviour in creating arguments has to be restricted to the formal representation of negotiation issues, principal's preferences and the negotiation thread. For example, the negotiation agent can create a justification from its preferences such as revealing reservation values of some issue; using the negotiation thread in memory, the negotiation agent can recall the counterpart of some previous offer as some proof; with previous negotiation histories, the negotiation agent can try to persuade by referencing to some previous agreements.

Here are some examples of persuasive arguments that a negotiation agent can send to the human counterpart using its existing capabilities of decision making and communication. These arguments can at least help the human counterpart to understand the sender's constraints and behaviour.

- If the agent finds no utility gain in the currently received offer then it can send a critique complaining that the last offer of the human counterpart did not carry any benefit for the agent, or some offer before the last offer was more attractive than the last offer or the partner agent is deviating from the promise made in the previous offer.

- As a justification, for example, a negotiation agent has reached its reservation value for some issue and now wants to inform the human counterpart. The agent can prepare a justification and inform the human counterpart that it cannot give more concession because the reservation value has been reached. If the agent does not send this justification to counterpart, the counterpart can never understand the agent's stance of not conceding.

- An agent might also make a threat to the human counterpart. For example, a threat can be used when the agent cannot give more concession to the human counterpart and wants to terminate the negotiation, but before terminating the negotiation, it can inform the human counterpart of this fact.

5.4.3.3 Communication Support for Argumentation

In Negoisst, arguments are inserted within free content. As mentioned in section 4.4.1, the ABN frameworks distinguish between negotiation communicative acts and argumentation communicative acts. There is no such distinction between message types in the human-agent negotiation protocol i.e., arguments will not be sent to a human counterpart using separate message types, rather only the available message types in the protocol will be used to send any type of negotiation behaviour—offers, arguments etc.

In hybrid negotiation model, we can use FIPA ACL's acts according to the defined semantics or we can ignore defined semantics and use according to the

requirements of human-agent negotiation to represent offers as well as arguments. In the later case, for example, a FIPA act *proposal* can be used to represent an offer as well as an argument expressed through a proposition. In the former case, to use the act in accordance to the FIPA ACL as well as fulfilling the requirements of Negoisst to represent different contents in single message, we can use multiple acts to form a message in hybrid model. For example, *proposal* act for offer and '*critique*' for argument (similarly '*complement*' for some sort of complements). The two acts are prepared by negotiation agent and wrapped in a single message. This single message is sent to the wrapper agent who can convert it to a human readable Negoisst message. For example, an argument to a human counterpart can be wrapped in a proposition that become part of free text after message conversion.

5.4.4 Fuzzy Constraint-based Model

The fuzzy constraint-based model (section 4.3.3) is discussed here as a different approach to agent's decision making and communication in human-agent negotiation as compared to other computational models (e.g., responsive and trade-off mechanisms). The representation of negotiation problem in constraints and profile make the implementation of this model incompatible with the implementation of Negoisst system. If this model is to be used in hybrid negotiation system then the preference elicitation component, message editor and protocol of the Negoisst system has to be modified. Here a brief overview is given to use this model in hybrid model.

There are number of negotiation strategies that can be applied using this constraint-based mechanism as compared to other two computational mechanisms. The buyer's requirement model and the way constraints are submitted can be used for information exchange tactic for coordinative behaviour. Addition of reward in an offer from seller can be seen as tactical behaviour to persuade buyer. This reward does not decrease the seller's profit, but can increase the utility of offer for buyer. Restriction on offer from seller can be taken as task-oriented behaviour, because seller is providing crucial information related to the contract that is not part of negotiation issues. Human negotiators exchange constraints on issues through task-oriented behaviour in free text. The task-oriented behaviour can be enabled through this fuzzy constraint model in

human-agent negotiation. If the fuzzy constraints are used to send buyer's offer, then substantive as well as task-oriented behaviour can be enabled in human-agent negotiation.

Buyer's negotiation problem representation is composed of pre-defined fuzzy constraints and personal profile. This representation is incompatible with respect to the preference elicitation as well as communication with the Negoisst system. To implement this model for agent, a new preference elicitation model has to be developed to capture the principal requirement in the form of constraints instead of using the existing preference elicitation model provided by the Negoisst system. The personal profile is extra information as compared to the Negoisst system. The information in profile is not communicated to the counterpart. It is only used to evaluate the seller's offer. The evaluation function is not based on the linear additive utility function. From communication point of view, the buyer agent sends constraints in its offer. Negoisst message window should be able to represent these constraints to the receiving human negotiator. However, the structured representation of content is limited to offer; therefore the communication of constraints is not possible with the existing implementation of Negoisst system.

5.5 Summary

In this chapter, a hybrid negotiation model has been presented for a novel approach of conducting bilateral multi-issue human-agent negotiations. The model has been proposed with a negotiation design and several components to realise the design. The design and the components have been thoroughly analysed and discussed according to the capabilities of a negotiation agent and the design of the Negoisst system. The analyses have shown that a hybrid negotiation system based on these components can implement flexible and successful negotiations between an agent and a human.

The conceptual design of the hybrid negotiation model has been obtained by synthesising the design properties of the Negoisst system and automated negotiation models (section 5.1.3). The design shares many properties (e.g., participation, number of issues, offer-restricted communication etc., see Table 5.3) of the Negoisst system and automated negotiation models as the two are the constituent components of the hybrid negotiation model. The differences in some design criteria (e.g., number of agents at any side of process, rules variation) from the other two models are due to the presence of

several negotiation participants with different negotiation capabilities in a human-agent negotiation process (section 5.1.2). The hybrid negotiation design and the human-agent negotiation process have been supported through several negotiation process protocols (section 5.2). The need for several protocols is due to the four participants in the negotiation process to execute their respective negotiation, delegation, and message conversion activities in the negotiation process. The protocols enable all the participants in the negotiation process to execute activities according to their abilities, as well as have defined rules for interoperability between two different negotiation models. For example, the human-agent negotiation protocol has been adopted from the Negoisst negotiation protocol according to the negotiation and communication abilities of a negotiation agent and its principal.

The human-agent communication model (section 5.3) has been discussed and compared in detail regarding the message structure, message content and message types to enable negotiation communication between a human negotiator and an agent. Several compatibilities (e.g., offer-restricted communication, equivalence between message types and communicative acts etc.) at all levels have been shown for successful communication as well as an approach has been shown to make two different negotiation systems interoperable (e.g., ontologies, wrapper agent) for communication. The negotiation agent is able to communicate safely at content level the substantive negotiation behaviour with the human negotiator and this behaviour is considered alone as increasing agreement probability as compared to other negotiation behaviours represented through other content categories. The human-agent communication of substantive behaviour is possible due to the Negoisst feature of preparing and storing structured offers in a negotiation ontology and showing these offers separately from the free-text to the human negotiator. It has also been seen that communication of some behaviours such as persuasive argumentation and tactical behaviour etc., is possible in inter-agent communication but has limited applicability in human-agent communication. The human-agent communication for negotiation also misses private communication, affective and task-oriented behaviour etc. that lead to friendly communication and increase the chances of agreement.

Negotiation with a human counterpart requires a negotiating agent to have a dynamic decision making model consisting of various negotiation strategies and tactics. Therefore, relevant automated negotiation mechanisms have been discussed in this

chapter for their supported strategies such as concession making, coordinative, and competitive for making the agent's decision making model sophisticated. Furthermore, the communication compatibility of these negotiation strategies and tactics has been analysed in comparison with the communication support (e.g., structured offers) of the Negoisst system (section 5.4). The analyses have shown that most of these strategies and tactics are usable by the negotiation agent while negotiating with a human negotiator. Not only the agent can make concessions or trade-offs with a human, but it can also play a competitive strategy using ABN mechanisms. The discussion on the agent's decision making model has also shown the support of generating partial offers in response to human's partial offers.

The usefulness of a hybrid negotiation system implemented based on the novel negotiation model will have to be evaluated and this will be done in the following chapter.

6. Evaluative Discussion

The main topic of this chapter is the evaluation of the hybrid negotiation model. The purpose of this evaluation is to show that we have achieved our aim, namely to enable human-agent electronic negotiations and thus to show the effectiveness of our approach. Future work will have to show the efficiency of the approach, namely to investigate how human-agent negotiations compare with agent-agent or human-human negotiations. However, this is beyond the scope of the present thesis.

The use of the hybrid negotiation model and the results of human-agent negotiations cannot be predicted until an evaluation of an implemented hybrid negotiation system is carried out in different human-agent negotiation contexts. This is particularly true for the agent's decision making and communication models to generate and represent different negotiation behaviours while negotiating with a human negotiator. The evaluation below is not based on a simulation technique for generating automated offers and counteroffers (negotiation behaviours) in response to offers of human negotiators but on an ongoing implementation of the hybrid negotiation model that we have developed. In the current chapter, we will illustrate our approach and perform an evaluative discussion.

Inter-human negotiations conducted using the Negoisst system are the basis for evaluating the hybrid negotiation model. Our evaluation approach is further detailed in section 6.1. The negotiation scenario on which the inter-human negotiation experiment has been conducted is presented in section 6.2. The negotiation scenario and agenda show possibilities of the applicability of the proposed agent's decision making model and the human-agent communication model for reaching agreements. Some examples of human-agent negotiations using the components of the hybrid negotiation model are discussed in section 6.3.

6.1 Illustrative Run-Time Evaluation

The operation and results of a hybrid negotiation system could be evaluated on the basis of an experiment. However, since the purpose of the thesis is to *enable* human-agent

negotiation, the evaluation criterion must be whether such a negotiation can be conducted based on our model. In particular, we will show that a negotiation support system for the human negotiator, an automated negotiation system for automated negotiation (see sections 5.3 and 5.4), negotiation process protocols (see sections 5.1 and 5.2) for supporting human-agent negotiation process, and an interoperability component (see section 5.3.4) connecting two heterogeneous negotiation system can enable bilateral multi-issue human-agent negotiations.

As it has been discussed in section 2.2 for human negotiations, not every negotiation decision approach is applicable to every negotiation problem and likewise not all approaches can be combined for a better solution of the negotiation problem. Similarly, it can be concluded that an agent's negotiation decision making model can include different automated negotiation mechanisms relevant to the negotiation problem in hand. It can be argued that an agent's decision making model can be designed for the specific negotiation problem and domain. It means, depending on the negotiation problem, the agent principal can use a single or multiple mechanisms to solve the negotiation problem.

Here we discuss the suitability of two offer generation mechanisms and their tuning configuration according to the principal's needs and the agent environment to get the required results. The responsive and trade-off mechanisms can be developed as a library of decision making strategies and can be made available to the agent principal in the hybrid negotiation system. The principal can then implement and configure these mechanisms in the agent for negotiation according to the negotiation objectives (such as increasing social welfare or striving for more personal objectives). Faratin (2000) has called this a descriptive design approach as the principal is free to implement and configure the negotiation agent according to the objectives.

The principal can use both of the mechanisms in all those negotiation scenarios where the principal's interests are in the conflict with the counterpart i.e., they give different importance to issues. The principal can use the responsive mechanism when (s)he wants to play a concessionary behaviour in response to the changes in environment i.e., remaining negotiation resources (e.g. remaining negotiation time, money etc.), and to the concession behaviour of the human counterpart. Secondly, the principal can use this mechanism when participating in the role of either a buyer or a seller and being unaware

of the choices of the counterpart (i.e., importance weights of all issues). The responsive mechanism does not require information about the choices of the counterpart to generate offers. It simply assumes that the counterpart is participating in the opposite role (buyer or seller) and has opposing preferences; therefore any concession will be a true concession from the counterpart's point of view. The principal can configure the responsive mechanism from no concession to full concession depending on the available resources. The trade-off mechanism is computationally more complex than the responsive mechanism. The principal can use the trade-off mechanism when (s)he is motivated to increase the social welfare along with the current aspiration level over his/her preferences. The principal can implement the selfish, concessionary and cooperative in the agent's decision making model by implementing meta-strategy. For example, when the agent has enough resources it can be selfish or cooperative and, on the other hand, in the case of minimum resource, it can play concessionary behaviour. Therefore, the agent needs to be supplied with both types of decision making facilities.

The run-time evaluation described in this chapter is carried out using the NSS Negoisst. The evaluation is based on an existing inter-human negotiation experiment that has been conducted in May 2008 with around 80 participants from the University of Hohenheim, Germany and the Radboud University Nijmegen, Netherlands. The purpose of the experiment was to evaluate the communication and decision support in the three-phase negotiation process in Negoisst. The negotiation case and the preferences that were specified for that experiment are used for our evaluation. As the hybrid negotiation model is a novel way to conduct bilateral multi-issue negotiations, the inter-human negotiation experiment is a reasonable basis and workable option for evaluating the hybrid negotiation model. Different negotiation cases are taken from the inter-human experiment in order to show how the hybrid negotiation model would work in these negotiations.

In our run-time evaluation, a negotiation agent simulates one of the two human negotiators using the Negoisst system in an electronic negotiation. This is a sort of mapping of negotiation behaviours of a human negotiator to the negotiation behaviours of a negotiation agent. This evaluation concerns the negotiation agent's decision making and communication models to generate and express negotiation behaviour while negotiating with a human negotiator. From a decision making point of view, it is shown how offers are evaluated and generated representing different negotiation behaviours. From a

communication point of view, it is shown how offers are converted and exchanged between an agent and a human negotiator.

The evaluation measures instances in which the negotiation agent is able to simulate the offers of a human negotiator. The simulation means that the agent is able to generate the negotiation behaviours of humans using its communication and decision-making components. This measurement provides a qualitative evaluation of the hybrid negotiation model. It shows for example whether an outcome was achieved or whether particular features were observed while the negotiation agent was simulating its human principal.

6.2 Negotiation Scenario

The negotiation scenario used in the Negoisst negotiation experiment is about a joint venture between a German car manufacturer called *Hurm AG* and a Chinese manufacturer called *Yu Tech* for producing car engines in China. The representative of each company negotiates over a number of issues to finalise the agreement for the joint venture. This negotiation scenario ranges over a number of numerical (quantitative) and categorical (qualitative) issues (cf. Table 6.1). There are opposite interests of the companies for each issue. Therefore, both negotiators have different aspiration levels for the options of each issue. As the negotiators give different importance to different issues in negotiations, there is a chance of integrative negotiations maximising joint welfare. In such negotiation scenario, concession making and trade-off seems essential to reach agreements.

This negotiation scenario is used here to evaluate the theoretical working of our hybrid negotiation model by taking inter-human negotiation instances from the experiment. These instances are then simulated for human-agent negotiations by replacing one of the two negotiators in inter-human negotiation with a negotiation agent i.e., a negotiation agent negotiates on behalf of Hurm AG or Yu Tech with the human representative of the other company. In this negotiation scenario, the employment of negotiation agent is possible with responsive and trade-off mechanisms.

The human-agent negotiations follow the negotiation process presented for the hybrid model. In the pre-negotiation phase, the principal delegates the negotiation task to his/her negotiation agent. Delegation includes the setup and creation of the negotiation agent with its knowledgebase (cf. Figure 5.5). The knowledge of the negotiation agent

consists of a set of negotiation issues, the principal's preferences for each issue (reservation values, importance), the role of agent in the negotiation, and the negotiation history (thread of offers and counteroffers). A contract in the Negoisst system contains of both an identification part (meta-data information e.g. negotiation-id, partners etc.) and a negotiation part (actual negotiation issues counterparts negotiate over). In this evaluation, we consider only the negotiation part of a contract. As mentioned before, the ambiguity over the meaning and values of negotiation issues is resolved in the pre-negotiation phase of a negotiation process, and these issues and the related preferences are stored in the negotiation ontology. In the negotiation phase, the message exchange is carried out according to the human-agent negotiation protocol and the messages are given the appropriate format by the wrapper agent so that the respective receiving entity (negotiation agent or human negotiator) can process it. The human-agent negotiation protocol specifies an alternate sequence of offers and counteroffers of values for the negotiation issues.

Agenda for Hurm AG / Yu Tech

Attribute	Worst Case	Options	Best Case
Hurm share of ownership	25% / 75%	0-100%	80% / 20%
Hurm directors in board	1 member / 5 members	1-5 members	4 members / 1 member
Injector production	China / Germany	Germany vs. China	Germany / China
Engineers in China	Additional 12 months / 0 month	0 – 12 months	0 months / additional 12 months
Payment of "common workers"	Hurm AG / Yu Tech	Common workers paid by Hurm AG, Yu Tech, or half-half	Yu Tech / Hurm AG
Additional compensation Chinese workers	10% additional compensation / 20% additional compensation	0-20% additional compensation	20% additional compensation / 0% additional compensation
Court of jurisdiction	China / Germany	China, independent arbitrators, Germany	Germany / China

Table 6.1: Negotiation agenda and the companies' aspiration levels for each issue

6.3 Human-Agent Negotiation Examples

By looking at the utilities of offers in all the negotiation threads in the Negoisst experiment (see appendix), we can observe the combination of all three main negotiation behaviours or strategies: concession making, coordinative behaviour (making offers attractive for a counterpart while keeping one's aspiration/gain same or increased), and competitive behaviour (one's welfare is increased at the cost of counterpart's welfare). To evaluate the hybrid negotiation model, we have selected two examples from the Negoisst experiment to exhibit the first two negotiation behaviours by the negotiation agent when

negotiating with a human negotiator. The examples discuss the working of all the components of hybrid model to enable human-agent negotiations and thus help in evaluating the effectiveness of this novel negotiation model. The efficiency related variables of the human-agent negotiations such as number of messages in reaching agreement, the social welfare of the outcome, text messages exchanged for argumentation or task-oriented behaviour etc., are not part of the evaluative discussion.

The first example shows that a negotiation agent having only a responsive mechanism implemented can reach an agreement while negotiating with a human negotiator (section 6.3.1). The second example shows that the implementation of responsive and trade-off mechanisms can also lead the negotiation agent to reach an agreement (section 6.3.2). The examples discuss the complete message exchange process between a human negotiator and negotiation agent.

The figures in the examples show the messages exchanged between two human negotiators taken from the original scenarios as well as the ACL messages in human-agent negotiations. As explained in section 2.3.4.3 (see Figure 2.5), the right hand side of figures 6.1 and 6.4 - 6.8 shows the offer (issues with values) and the left hand side shows the semi-structured message (free-text with issues values). Some of these original screen shots have been modified for the human-agent negotiations e.g. the original semi-structured contents in figures 6.4 and 6.6 has been replaced with the agent generated free text.

6.3.1 Example 1

The inter-human negotiation between Yu1 and Hurm1 (see appendix) is simulated in the example 1. The importance (weight) for each issue in the negotiation agenda (cf. Table 6.1) and the utilities of offers exchanged between two human negotiators have been shown in Table 6.2 and Table 6.3, respectively. To simulate this inter-human negotiation instance as a human-agent negotiation, the human negotiator (Smith with user name Hurm1) representing Hurm AG is replaced by a negotiation agent that then negotiates with the representative (Li with the user name Yu1) of Yu Tech. For the human-agent negotiation example, the messages sent by Yu Tech to Hurm AG are shown as they were originally sent, whereas the messages sent to Yu Tech are modified to represent the involvement of a negotiation agent. As the messages being sent to Yu Tech are generated

by the negotiation agent, the original free-text message is replaced by the agent's generated free text (containing greetings, fixed sentences etc.). The offer part of the original message remains unchanged.

The utilities of the received offers are monotonically increased (cf. Table 6.3). This shows that both human negotiators used a concession strategy in moving towards an agreement. The negotiation agent can use the responsive mechanism to give concession on one or more criteria. So, in this example the agent's decision making model is only built on the responsive mechanism. The mechanism contains an evaluation function based on the preferences of its human principal (cf. Table 6.1 and Table 6.2) and the offer generating tactics for making concession. In the human-agent negotiation process, the presence of the negotiation agent is not explicitly exposed to the human negotiator.

Issues	**Li (Yu Tech)**	**Smith (Hurm AG)**
Hurm Share of Ownership	30	20
Hurm Directors in Board	20	15
Injector Production	15	30
Engineers in China	10	5
Payment Common Workers	5	10
Additional Compensation Chinese Workers	5	5
Court of Jurisdiction	15	15

Table 6.2: Importance (in percent) of issues for both companies

	1st msg	**2nd msg**	**3rd msg**	**4th msg**	**5th msg**	**6th msg**
Yu1 (Initiator)	75 (O)	19	58 (CO)	32	44 (CO)	44
Hurm1 (Responder)	23	88 (CO)	52	72 (CO)	63	63 (A)

Table 6.3: Utilities of offers in an inter-human negotiation thread in Negotiation Phase (Offer=O, Counteroffer=CO, Accept=A)

1st offer from Agent

The representative of Hurm AG receives the first offer from the Yu Tech human negotiator (Figure 6.1). The negotiation agent is negotiating on behalf of Hurm AG, so the

received Negoisst message is converted to the ACL message (cf. Figure 6.2) by the wrapper agent (see section 5.3.4). The wrapper agent prepares the ACL message by reading the structured offer from the negotiation ontology and a corresponding communication act *Propose* for the message type *Offer* from the agent ontology. The ACL message is then forwarded to the negotiation agent by the wrapper agent.

On receiving the first offer (an ACL message) from the human negotiator, the agent checks whether the negotiation deadline has been reached. If that is not the case, it generates a counteroffer in the form of an ACL message (Figure 6.3). This counteroffer is the first offer of the negotiation agent. To generate a first offer in the responsive mechanism, an individual predefined constant is used to calculate the values of issues instead of using any tactic. The respective constant is multiplied by the size of the issue interval to determine the value of the issue. Values of all issues are calculated this way and combined to make the first offer (a counteroffer) to be sent to the human negotiator. The following offers in a negotiation thread are generated using some tactics (e.g. time-dependent, resource-dependent, or behaviour-dependent) provided by the responsive mechanism. The utility of the counteroffer created by the agent is 88 and the utility of the received offer from the human negotiator is 23. The agent is rational, therefore, it will send a counteroffer to the human negotiator. Figure 6.3 shows the agent's message to be sent to the human negotiator. The message consists of two propositions—the first one is the structured counteroffer and the second one is the free text. Agents can prepare free texts by combining salutations, greetings, and some fixed sentences from the agent ontology. The structured offer is a compulsory part of all ACL messages received or sent. The negotiation agent then sends the ACL message to the wrapper agent. The wrapper agent will convert the ACL message into a Negoisst message by creating an offer instance and free text in the negotiation ontology with an appropriate message type *Counteroffer*. Then the prepared message will be added to the negotiation space of the human negotiator, who will see the message as shown in Figure 6.4.

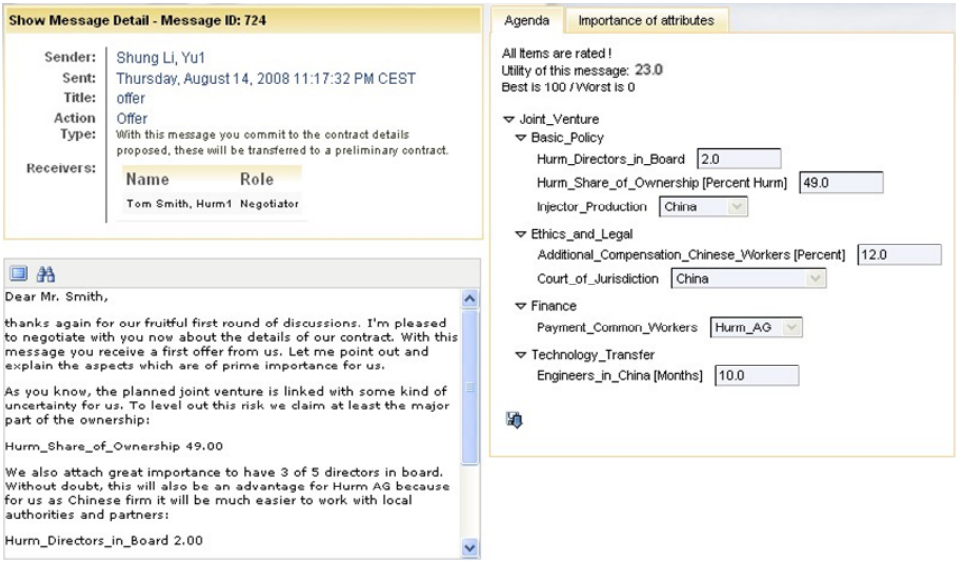

Figure 6.1: First message from human negotiator in the negotiation workspace of agent's principal

```
(propose
  :sender (agent-identifier :name wrapperAgent)
  :receiver (set (agent-identifier :name hurm-agent))
  :content
    "(structured-offer
       (offer
       :Hurm_Directors_in_Board 2.0
       :Hurm_Share_of_Ownership 49.0
       :Injector_Production "China"
       :Additional_Compensation_Chinese_Workers 12.0
       :Court_of_Jurisdiction "China"
       :Payment_Common_Workers "Hurm_AG"
       :Engineers_in_China 10.0 ))"
  :ontology negotiation-ontology, agent-ontology
  :language fipa-sl)
```

Figure 6.2: Conversion of human negotiator's message into an ACL message

```
(propose
  :sender (agent-identifier :name hurm-agent)
  :receiver (set (agent-identifier :name wrapperAgent))
  :content
   "( (structured-offer
        (offer
        :Hurm_Directors_in_Board 4.0
        :Hurm_Share_of_Ownership 70.0
        :Injector_Production "Germany"
        :Additional_Compensation_Chinese_Workers 18.0
        :Court_of_Jurisdiction "Germany"
        :Payment_Common_Workers "halfhalf"
        :Engineers_in_China 6.0 ) )

      (fixed-text ("Dear Mr. Li, Thanks for your first Offer.
              We have made some changes in your offer, which
              we think will be acceptable for you. Looking
              forward for your cooperation. Regards, Smith" ))
    )"
  :ontology negotiation-ontology, agent-ontology
  :language fipa-sl)
```

Figure 6.3: Agent's message for the human negotiator

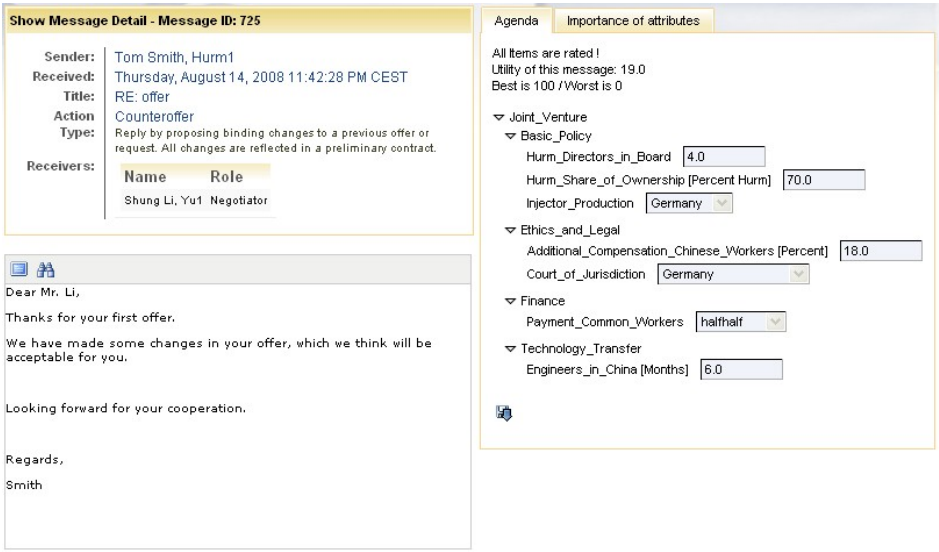

Figure 6.4: Human negotiator receives first message from the negotiation agent

2nd offer from Agent

Figure 6.5 shows the message (counteroffer) which the human negotiator has sent to his human counterpart in response to the agent's first offer. Again, by following the human-agent process protocols and communication support, the Negoisst message is converted to an ACL message by the wrapper agent and forwarded to the negotiation agent. The utility of the received counteroffer is 52 for the agent. The negotiation deadline is not yet reached so the agent generates a new counteroffer which has the utility of 72 that is greater than 52. The agent will send (through the wrapper agent) the counteroffer with utility 72 to the human negotiator. The counteroffer received by the human negotiator is shown in Figure 6.6. An offer from the agent is usually generated using a single tactic or a combination of tactics. This counteroffer can be taken as an example of using a tit-for-tat tactic, because the agent can observe that the human negotiator has conceded from his last stance and the agent has gained utility from the current received offer, i.e., from 23 to 52. So, using a tit-for-tat tactic, the agent can imitate the human negotiator's behaviour and can give concession, in this case by lowering its aspiration from 88 to 72. As the counterparts have different aspiration levels for each issue, the human counterpart will certainly gain some utility from the current counteroffer. Figures 6.4 and 6.6 show that the human negotiator has gained utility from the agent's current counteroffer, i.e., from 19 to 32.

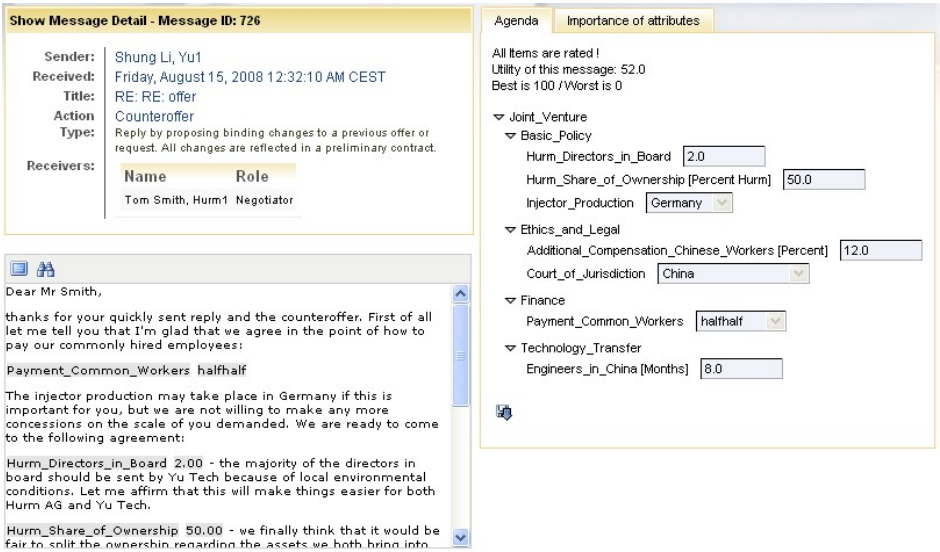

Figure 6.5: Second message from human negotiator in principal's negotiation workspace

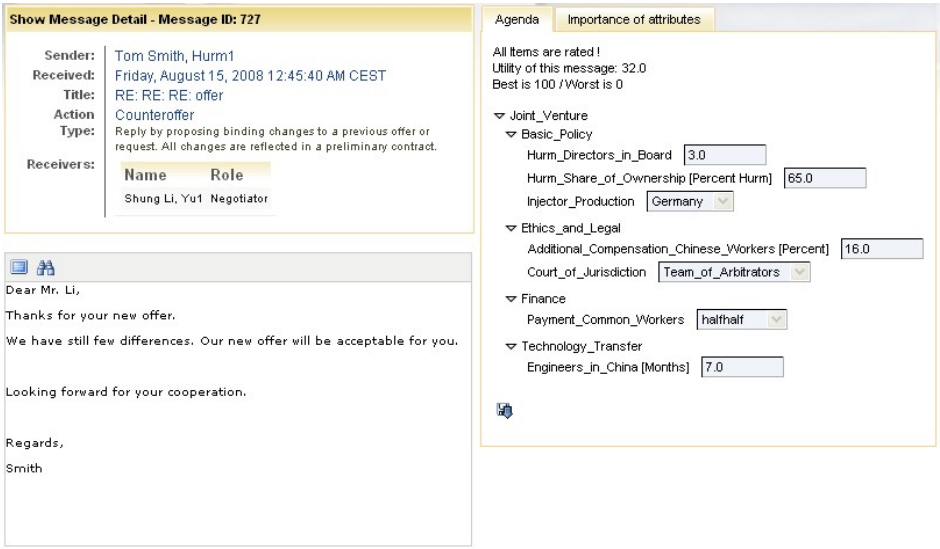

Figure 6.6: Human negotiator receives second message from the negotiation agent

3rd offer from Agent

The negotiation agent can accept the next incoming counteroffer of the human negotiator (Figure 6.7) by sending an *Accept* message (Figure 6.8). In the responsive mechanism, the reason for accepting the incoming counteroffer is that the utility of the generated counteroffer to be sent next is less than the utility of the received counteroffer from the human negotiator.

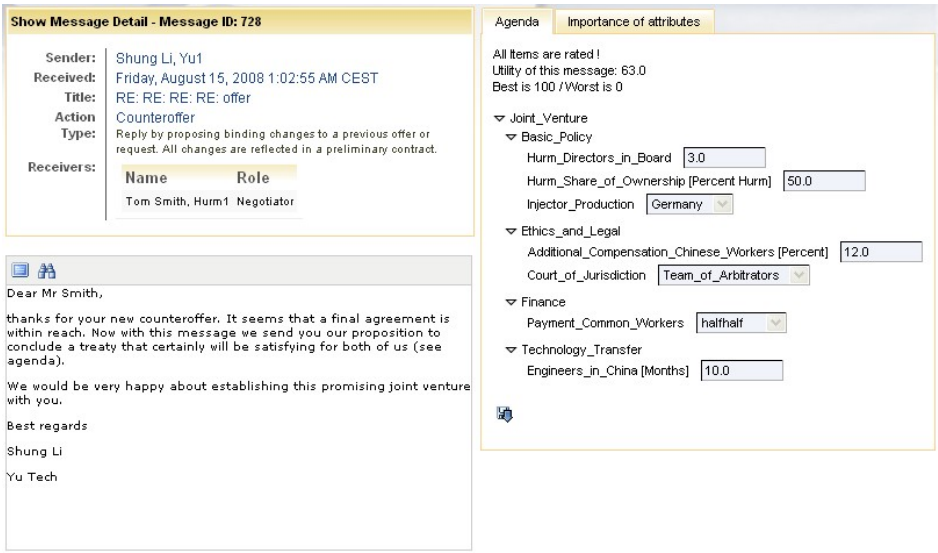

Figure 6.7: Third message received from human negotiator

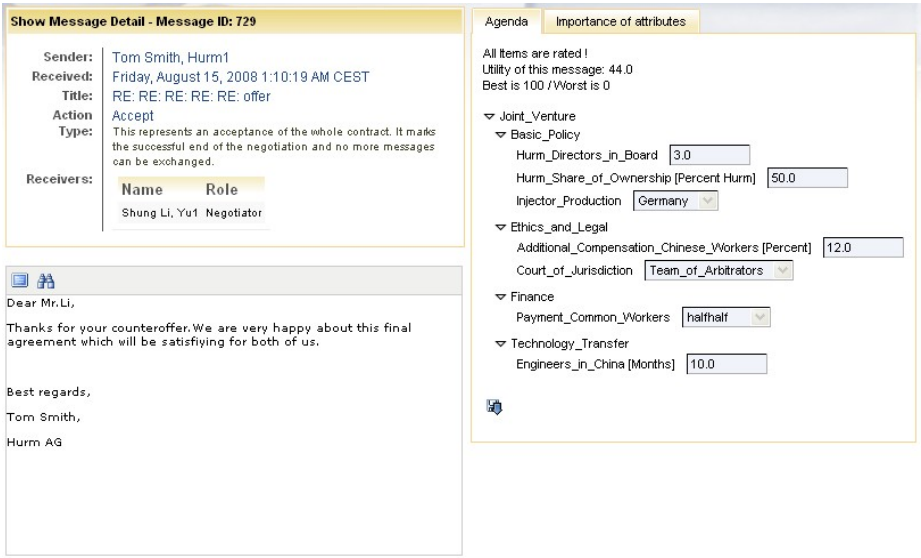

Figure 6.8: Human negotiator receives third message (Accept) from the agent

6.3.2 Example 2

Now an inter-human negotiation instance (between Yu26 and Hurm26) is taken in which one of the human negotiators has used a combination of concession and coordinative behaviours to reach agreement. This negotiation thread is used to show that a negotiation agent can simulate the offers of that human negotiator (Hurm26, the representative of Hurm AG) using a combination of responsive and trade-off mechanisms. Here, instead of describing the whole process of negotiation (e.g. message conversion etc.), only the agent's decision making to generate offers using the combination of two mechanisms is discussed. The responsive mechanism is used to generate the first offer (in the role of initiator or responder) and for concession making and the trade-off mechanism is used to generate trade-offs (see meta-strategy mechanism in section 4.3.2.3). Table 6.4 shows the utilities of offers exchanged in the inter-human negotiation thread and Table 6.5 shows the importance of each issue for both human counterparts.

	1st msg	2nd msg	3rd msg	4th msg	5th msg	6th msg	7th msg	8th msg	9th msg
Yu26 (Initiator)	90 (O)	5	85 (CO)	16	67 (CO)	50	57 (CO)	56	56 (A)
Hurm26 (Responder)	0	98 (CO)	3	84 (CO)	52	63 (CO)	60	63 (CO)	63

Table 6.4: Utilities of offers in an inter-human negotiation thread between Yu26 and Hurm26 (Offer=O, Counteroffer=CO, Accept=A)

The second and third offers of Hurm26 to Yu26 are simply the concession making by decreasing own gains. The fourth offer to Yu Tech is some sort of trade-off while Hurm26 has kept own level of aspiration same, i.e., 63. The third and fourth offers of Hurm AG are shown in Figure 6.9 from the perspective of Yu Tech (6th and 8th message in Table 6.4). For Yu Tech, the utility of the fourth offer (a) is greater than that of the third offer (b) and it is approximately the same as of his last offer to Hurm AG (i.e., 57 in 7th message), so the Yu Tech's representative has accepted the fourth offer. As both human negotiators had specified different importance to negotiation issues (see Table 6.5), this trade-off was possible. Looking at the third and fourth offers closely, it can be stated that the human negotiator from Hurm AG provides the trade-off offer by giving concessions in two issues (namely ownership share and engineers in China) and by increasing the utility for one issue (namely directors in board). This trade-off was possible because Yu Tech has given a high level of importance to the issue 'engineers in China' while Hurm AG has given relatively more importance to the issue 'directors in board', while the importance for 'Hurm share of ownership' is approximately the same for both counterparts. Without going into the details of all offers and the information exchanged or argumentation made in the free text in this negotiation between two human counterparts, we can assume that counterparts have used either the incorporation tactic or performed logrolling using the information tactic (section 2.2.2.2) in the 7th and 8th messages.

The negotiation agent can simulate the offer generation behaviour of Hurm26 by generating all his four offers in response to Yu26 offers using the combination of responsive and trade-off mechanisms. The first offer can be created by the responsive mechanism in the similar way as in Example 1, i.e., by multiplying the constants with issues' intervals. The next two offers can be generated either using the time-dependent

tactic or tit-for-tat tactic of the responsive mechanism. The behaviour-dependent tactic is possible because the human negotiator at Yu Tech has given concessions in his second and third offers (i.e., 3 and 52, respectively). The agent can imitate the conceding behaviour of the human negotiator using the behaviour-dependent (tit-for-tat) tactic. The time-dependent tactic is also possible to make concessions because with passing time, an agent becomes more conciliatory. The fourth offer can be generated using the trade-off mechanism. We have seen in the trade-off mechanism that an agent keeps its aspiration the same while generating the next offer that can be more attractive for the opponent (section 4.3.2). As discussed in section 5.4.2, an agent cannot use the information exchange tactic required for logrolling with the human negotiator, however the negotiation agent could generate the fourth offer by the *incorporation* tactic or *logrolling by chance* using the heuristic *trial and error* tactic.

Issues	**YU Tech**	**Hurm AG**
Engineers in China	14	1
Payment Common Workers	8	4
Hurm Share of Ownership	29	30
Hurm Directors in Board	18	25
Injector Production	10	32
Additional Compensation Chinese Workers	7	6
Court of Jurisdiction	14	2

Table 6.5: Importance (in percent) of issues for both companies

(a) (b)

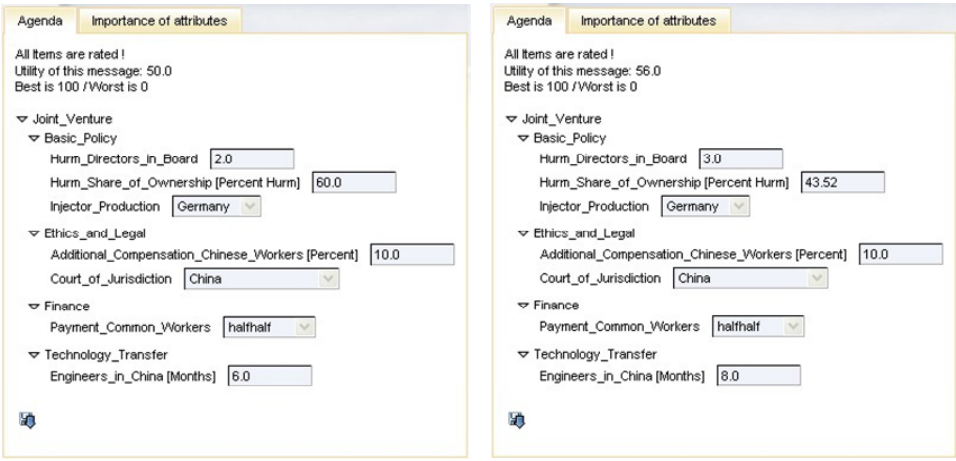

Figure 6.9: Two consecutive offers received from the human negotiator of Hurm AG

6.4 Discussion

The above two examples have shown the effectiveness of the hybrid negotiation model for enabling the human-agent negotiations. A negotiation agent implementing different negotiation mechanisms and communication model can exhibit negotiation behaviours compatible to human negotiation behaviours and hence can negotiate on behalf of a human principal. The above evaluation shows that a negotiation agent and a human negotiator can reach agreements by exchanging complete offers with or without free-text for argumentation or explanations. From the agent's decision making point of view, the example 1 has shown that an agent can reach agreement by giving concessions. The second example shows that coordinative behaviour is possible in human-agent negotiations even without using information exchange tactics (e.g. logrolling and bridging for exchanging preferences and priorities of issues) for reaching integrative outcomes. As we can see in the appendix on the basis of utilities of offers that these two negotiation behaviours (e.g. concession making and trade-offs) are frequent in most of the inter-human negotiations of the experiment described. However merely the combination of responsive and trade-off mechanisms does not provide the negotiation agent with the

same dynamic negotiation behaviour as humans have shown in several negotiations. There are apparent limitations in the decision making behaviour of the negotiation agent in the above human-agent negotiations. For example, the negotiation agent cannot perform competitive behaviour in the negotiations. The competitive behaviour is also visible in inter-human negotiations. From the point of view of negotiation content categories, the negotiation agent has created approximately 45% (substantive 16% and communication protocol 28.6%) of all message content (according to the content categorisation given by Köszegi et al (2004) for inter-human negotiations). Rangaswamy and Shell (1997) have analysed that the human negotiators mainly take decisions on the bases of utilities of incoming and outgoing offers. Also, Köszegi et al (2004) have argued that the substantive behaviour alone increases the chances of agreements.

In chapter 5, we have discussed two features of the Negoisst system and have shown that an agent will not be able to use these features in performing negotiations. However, the Negoisst experiment results reveal that these two features are not used frequently by the human negotiators. Therefore, it can be assumed that a negotiation agent will not loose much by not being able to use these two features. In section 5.2.1.2, we have specified that an agent will take part in only offer-extended communication category message types while the principal of agent engages in free-form communication message types (i.e., question and clarification). This is a limitation of the negotiation agent that it cannot answer all of the messages of the human negotiator; however, the experimental data show that out of 37 successful negotiations, the questions and clarification messages were exchanged only in 12 negotiations (see appendix). The Negoisst's negotiations simulated in the above two examples did not have the free-form communication message types (i.e., question and clarification). It also seems that these two message types do not have much influence in negotiations. The average joint utility reached in these 12 negotiations is 125 as compared to 123 for the other 25 negotiations without question/clarification messages. We also see in the results that the use of the other feature of exchanging partial offers between human negotiators is not very common i.e., in only one third negotiations, partial offers were exchanged and almost in all cases they happened in the starting phase of negotiations by the initiator of negotiations. A brief discussion to provide solution for generating partial offers by the negotiation agent in response to partial offers from the human negotiator has been given in the agent's

decision making model in section 5.4. The Negoisst negotiation results and our partial solution solve the limitation of exchanging partial offers in human-agent negotiations.

With our approach, human-agent electronic negotiations are enabled and thus we have achieved our research aim. Furthermore, the human negotiator can negotiate as before using Negoisst, i.e., the human negotiator will not have to use another system, software, protocol or tactic if the counterpart is a negotiation agent.

7. Conclusion and Future Work

In this final chapter we present the review of our work for enabling human-agent negotiations (section 7.1). The chapter ends with a summary of the future work (section 7.2).

7.1 Review of the Thesis

Negotiation support systems are meant to provide prescriptive support (by allowing preference elicitation, showing utilities of incoming and outgoing offers, providing graphs to negotiation analysis, and offering pareto optimal solution etc.) and structured communication to human negotiators for deliberated decision making. However, negotiators are free in their decisions during negotiations. They can show irrational behaviour and come to agreements, which are neither good for themselves nor for the partners. Automated negotiations are the counterpart of human performed manual negotiations. Automated negotiations are being advocated for reasons of efficiency, rationality, and autonomous nature of negotiation agents. A third option, which we have introduced in this thesis, can be developed by combining the benefits of two former negotiation models for more flexible negotiations. In our hybrid negotiation model, agents will conduct the negotiations autonomously and rationally and where the flexibility is required, humans will jump in. Even in an automated negotiation, two thirds (namely agenda setting, preference elicitation) of the negotiation are done manually and the other third (creating and exchanging offers) but time consuming part is performed by the agents.

This thesis has presented a novel negotiation model for enabling bilateral multi-issue human-agent negotiations. The central aim of the research is to provide a framework consisting of an automated negotiation system appropriate for automated negotiations with a human negotiator, a human-agent negotiation process, protocols and a communication model, and an interoperability component between an ANS and an NSS

(section 1.2). The ANS provides a communication and a decision making model to the negotiation agent according to its abilities for negotiating with the human negotiator.

The NSS Negoisst provides negotiation support irrespective of any particular negotiation behaviour from the decision making and communication point of view, whereas the automated negotiation models implement a particular negotiation behaviour and communication support for solving particular negotiation problems. Therefore, different automated negotiation models have been presented to be combined in an ANS to minimise the difference between the negotiation behaviours of an agent and a human negotiator, especially from the decision making point of view.

The design of the hybrid negotiation model aligns the characteristics of the automated negotiation model and the negotiation support model and thus enables a negotiation agent and a human negotiator to negotiate a contract. The human-agent negotiation design provides a conceptual classification of the hybrid negotiation model for describing the concrete human-agent negotiation process rules. The human-agent negotiation process concentrates on setting up a negotiation agent and flexible message exchange activities between a human negotiator and a negotiation agent for performing their part of negotiations in reaching agreements. The human-agent negotiation protocol defines the rules for interaction between two different counterparts according to the communication capabilities of the negotiation agent.

We have analysed that the negotiation behaviour (from the communication and decision making point of view) of a human negotiator is rich and dynamic compared to that of the negotiation agent. The agent's communication model allows representing offers and arguments and fulfils some of the communication requirements set for the negotiation agent. The exchange of offers in human-agent negotiations is possible as the Negoisst system stores the offers structurally in an ontology separate from the free-text. The exchange of complex argumentation is not possible in the human-agent negotiations as the arguments are expressed differently by the human negotiator and the negotiation agent. However, simple tactical statements can be sent to the human negotiator by the negotiation agent. The analysis has also shown that the communication between negotiation agents is richer than communication between a human counterpart and a negotiation agent in the hybrid negotiation model. For, example, the communication of arguments between a human counterpart and a negotiation agent is not possible on the

same level as it is in inter-agent negotiations. In our hybrid negotiation model, agents will not be able to transmit social cues. Some of such social behaviours lead to integrative negotiations. The FIPA ACL and FIPA SL have been argued to be the most suitable agent communication and content languages, respectively, developing the agent communication model in the hybrid negotiation model. The FIPA ACL provides compatibility at message structure and message types levels with the Negoisst system.

Negotiation with a human counterpart demands a sophisticated decision making model consisting of various negotiation strategies and tactics which are used by human negotiators. However, not a single automated negotiation mechanism or model exhibits all the human negotiation strategies. Each mechanism or model implements particular negotiation strategy and its tactic(s). Therefore, a few existing automated negotiation mechanisms have been discussed and proposed for the agent's decision making model. These mechanisms generate offers representing substantive behaviour as well as arguments. The aim of presenting an agent's decision making model is not to enable a negotiation agent to solve all negotiation decision problems during human-agent negotiations; rather we have shown that different automated negotiation mechanisms can be used alone or in combination to generate different types of negotiation behaviour by the negotiation agent. The responsive and trade-off mechanisms represent plenty of human negotiation strategies and are compatible with the Negoisst system in order to enable the negotiation agent to generate offers. The communication support in the Negoisst system for preparing and representing offers is compatible to represent the different substantive behaviours generated by these two mechanisms. Also the offer evaluation model (i.e., linear additive utility function) used by these two mechanisms is consistent with the Negoisst system. The principal can use the same preference elicitation process to specify the offer evaluation function of the agent's decision making model or to conduct negotiations manually. The only limitation in the responsive and trade-off mechanisms in comparison to the Negoisst system is that the Negoisst system allows generation of partial offers whereas these two mechanisms do not. The other limitation in the human-agent negotiation is the absence of persuasive argumentation in decision making process. This limitation is only due to the communication incompatibility between agent and human negotiator. The negotiation agent expresses an argument in some logical language which is not meaningful to the human and, similarly, humans write arguments in

free text which is not understood by the agent. However, simple tactical statements can be generated and communicated by the negotiation agent to the human negotiator.

The evaluative discussion on the hybrid negotiation model has shown its effectiveness for human-agent negotiations. The negotiation agent can use the proposed communication model and decision making to generate offers, which resembles the human's offer. Two illustrative examples have shown the participation of all the different components of the hybrid negotiation model in making the human-agent negotiation process successful.

7.2 Future Work

Future work on the empirical (exploratory and experimental) evaluation of the hybrid negotiation model will provide a more accurate account of the effectiveness and efficiency of the human-agent negotiations. The empirical evaluation will help us analysing in depth the negotiation behaviour of the negotiation agent and the human negotiator as well as the delegation behaviour of the principal. The evaluative discussion in chapter 6 has provided a sufficient satisfaction with the hybrid negotiation model by enabling human-agent negotiations. This evaluation can be used as the basis for formulating precise experimental questions for the future empirical evaluation.

The future human-agent negotiation experiments will measure the efficiency of human-agent negotiations in comparison to inter-human negotiations. The experiments will study the efficiency not only with respect to the abilities of the negotiation agent and the features used in the chapter 6 for enabling the human-agent negotiations (i.e., exchange of structured offers, greeting messages, responsive and trade-off mechanisms) but also using the abilities of the negotiation agent presented in chapter 5 for human-agent negotiations (i.e., partial offers, simple argumentations).

In the previous chapter it has been shown that the negotiation agent can create message content for substantive behaviour (a strategic behaviour) and formality communication behaviour (greeting, salutations etc.) that make approximately 45% of all communication units in inter-human negotiations. A next step would be to analyse the negotiation experience of the human negotiators and the efficiency of negotiation outcomes in human-agent negotiations when the substantive behaviour (offers) are the only strategic negotiation content that both negotiators can exchange with each other in

reaching agreements. In chapter 5, we have identified content categories (e.g. tactical and persuasive behaviour) which can be supported by the agent and the hybrid communication model in human-agent negotiation. In the future experiments also the tactical and persuasive content will be added into the agent message for richer communication. For example, the effectiveness of simple tactical fixed sentences such as “this is my last offer” from the negotiation agent can be measured. The effects of missed communication and decision making behaviours in human-agent negotiations will also be evaluated. For example, how can the absence of social communication (that leads to friendly communication) from the negotiation agent affect the negotiation outcomes, especially when the human counterpart is sending such content? From the agent’s decision making point of view, it will be evaluated which strategy (e.g. concession making, selfish, coordinative, or their combinations) of the agent is more successful in human-agent negotiations to reach agreements, as the configuration of these strategies is under the control of agent’s principal. For example, the principal can configure the responsive mechanism for linear, boulware or conceder tactics.

Besides efficiency analysis of human-agent negotiations, also a different way of using the negotiation agent in human-agent negotiations can be tested. For example, instead of making the negotiation agent independent in creating and responding offers and adding free-text, the agent is used to create the offers only and the principal adds the free-text. The purpose of using a negotiation agent in this way is to use the agent's decision-making capabilities for generating offers and making communication richer for the receiver by adding natural language text. The text can include the persuasive arguments, affective and task-oriented communication behaviour. The use of automated negotiation mechanisms to generate offers has the benefits that the principal can explicitly use the particular mechanism to generate a particular offer (concession making, selfish or trade-off) and then adds the text accordingly. This way of using the negotiation agent can reduce the cognitive load of principal in creating offers according to the utility.

Finally, it would be interesting to investigate whether and how a human negotiator notices that the negotiation partner is a software agent and not another human. We have discussed that the agent simulates human behaviour by sending salutation, simple arguments etc. but we have also shown the limitations of agent argumentative behaviour. Thus, the above question needs to be analysed in real-life negotiations.

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Appendix – Inter-Human Negotiation Experiment

The following two tables show the results of the 2008 inter-human negotiation experiment conducted using the Negoisst system. Two negotiations from this experiment have been used in the evaluative discussion of the hybrid negotiation model (cf. chapter 6). The tables show the utilities of offers (including the end utilities of agreements) exchanged during the negotiation process. For each exchanged offer the sender's and receiver's utilities are shown. The rows marked with the letter 'Y' represent the negotiations in which the human negotiators exchanged the *question* and *clarification* message types.

		Offers' Utilities in Negotiations																									
	End Utility	Msg 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Question/Clarification
Yu1	44	75	19	58	32	44	44																				
Hurm1	63	23	88	52	72	63	63																				
Yu2	51	50/73	10	60	31	57	42	51	51	51	51																Y
Hurm2	60	5/24	94	50	72	55	67	60	60	60	60																
Yu3	75	83	22	-	37	76	37	37	56	83	57	77	70	75	71	75	75	75									Y
Hurm3	53	0	100	-	71	5	71	71	61	40	61	53	53	53	53	53	53	53									
Yu4	75	86	23	91	57	87	67	78	75	75	75																
Hurm4	51	2	99	38	69	37	61	48	52	51	51																
Yu5	52	100	6	95	22	69	39	59	46	56	52	52															
Hurm5	58	5	100	11	86	43	67	50	68	56	58	58															
Yu6	61	100	15	87	30	80	61	61																			Y
Hurm6	57	0	81	35	72	46	57	57																			
Yu7	54	90	8	18	13	20	16	19	18	75	35	64	36	66	48	54	54	65	49	63	48	60	47	59	54	54	
Hurm7	56	0	99	89	94	90	93	90	91	11	75	19	77	45	64	29	59	46	62	46	57	46	56	55	56	56	
Yu9	50	76	76	76	20	60	40	58	45	56	46	52	45	50	50												Y
Hurm9	57	3	3	3	93	39	63	41	62	46	60	55	60	57	57												
Yu10	63	15/32	67/77	27	75	49	61	53	63	63	63	63															
Hurm10	59	21/51	66/96	21/46	94	47	76	60	70	58	59	59															
Yu11	70	96	96	96	53	74	67	69	70	70																	Y
Hurm11	61	0	0	0	72	47	65	41	61	61																	
Yu12	73	0/100	0/100	61	34	48	61	72	70	73	73																Y
Hurm12	55	0/100	0/100	4	96	4	65	55	55	55	55																
Yu13	66	71	49	70	37	75	64	71	66	66																	
Hurm13	63	10	36	12	75	49	64	59	63	63																	
Yu14	69	46/84	39	84	62	70	69	69																			
Hurm14	63	5/35	90	51	67	31	63	63																			
Yu15	66	80	25	65	53	65	51	59	66	66																	
Hurm15	84	54	76	62	71	57	67	65	84	84																	
Yu16	70	0/100	0/100	77	90	59/64	59	74	66	70	70																Y
Hurm16	69	0/100	0/100	5	50	26/31	86	66	76	69	69																
Yu17	60	90	42	76	27	69	40	64	64	64	64	64	64	63	64	63	50	60	60								Y
Hurm17	40	5	51	28	67	34	52	37	37	37	37	37	37	39	37	39	54	40	40								
Yu18	60	100	44	67	0/100	0/100	47	51	0/100	0/100	52	65	46	69	69	60	60	60									Y
Hurm18	52	0	72	42	0/100	0/100	72	62	0/100	0/100	62	51	64	33	33	52	52	52									

Yu19	54	0/100	5	77	22	60	23	58	55	54	46	56	54	54						
Hurm19	60	0/100	100	21	89	51	83	56	59	59	67	58	60	60						
Yu21	61	77	63	63	58	61	61													
Hurm21	64	4	11	11	66	64	64													
Yu22	72	80	47	55	58	74	72	72												
Hurm22	41	0	77	18	58	39	41	41												
Yu23	74	77/80	28/31	92/95	37/40	77/80	51	76	69	74	74									
Hurm23	52	0/5	95/100	22/38	82/87	47/52	77	51	59	52	52									
Yu25	60	87	87	76	30	71	59	60	60	60										
Hurm25	57	0	35	11	78	48	60	57	57	57										
Yu26	56	90	5	85	16	67	50	57	56	56										
Hurm26	63	0	98	3	84	52	63	60	63	63										
Yu27	73	81	41	59	53	81	54	77	66	73	73									
Hurm27	60	2	94	65	76	50	73	58	64	60	60									
Yu28	68	48/69	36/57	73/86	44	56	51	70	56	68	58	68	68							
Hurm28	62	14/34	69/89	44/59	82	72	75	60	70	62	68	62	62							
Yu29	54	54	14/44	26/56	43	57	52	54	54											
Hurm29	41	24	57/82	16/41	47	41	40	41	41											
Yu30	55	22/100	22/100	37/95	20/55	28/78	31/66	70	45	55	55									Y
Hurm30	69	0/80	0/80	6/68	57/100	30/85	56/86	55	84	69	69									
Yu31	72	0/100	1/96	100	48	91	29	87	39	81	65	78	70	78	69	77	67	72	72	Y
Hurm31	57	0/100	5/99	25	75	32	79	37	76	48	62	46	58	46	59	47	54	57	57	
Yu32	66	33/85	22/62	52/72	45/50	64/69	64	60	55	67	48	66	66							
Hurm32	52	15/75	31/81	22/57	54/69	45/60	60	55	70	45	60	52	52							
Yu33	63	79	79	73	73	70	59	63	63											
Hurm33	64	5	5	9	9	57	67	64	64											
Yu34	65	81	58	80	37	57	55	65	65											
Hurm34	57	1	76	47	80	23	65	57	57											
Yu35	73	30/84	46/100	54	58	53	63	73	73											
Hurm35	52	0/75	20/95	52	87	43	71	52	52											
Yu36	68	75	75	75	75	71	45	69	65	71	68	68								
Hurm36	67	0	0	0	0	7	90	65	67	60	67	67								
Yu37	64	85	29	90	51	81	62	67	62	67	64	64								
Hurm37	68	0	97	44	77	51	69	68	69	65	68	68								
Yu38	94	0/100	22/95	12/85	66/89	22/95	72	71	86	63	65	65	94	94						Y
Hurm38	83	0/100	11/97	6/92	65/91	11/97	76	54	67	59	59	59	83	83						
Yu39	86	0/100	0/100	65	23	58	35	52	86	86										
Hurm39	59	0/100	0/100	0	93	9	65	30	59	59										
Yu40	56	23/98	23/98	48/98	48/98	54/64	56	56												
Hurm40	56	0/76	0/76	30/76	30/76	48/56	56	56												