Flexibility in Negotiation Systems:
An Argumentation-based Approach

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Abstract
Flexible automated negotiation, specially in dynamic, uncertain and unpredictable environments can increase likelihood and quality of agreements and promote agent's properties. For developing flexible negotiation systems, first we should define and formalize flexibility in negotiation. A precise and clear formulation of flexibility in agent-based negotiations has not reported explicitly in the literature. In this paper, we describe the benefits of flexible negotiation and we provide a set of requirements for flexible negotiation in agent-based systems. The main contribution of this paper is an explicit formulation of flexibility in negotiation systems. Based on this formulation a survey and analysis of the existing works in the automated negotiation literature is presented and results are given. Then, according to the proposed formulation, we will show that negotiation systems that are designed and implemented based on argumentation-based approach are flexible and can operate in more dynamic and unpredictable environments.

Keywords: Argumentation-based negotiation, flexible automated negotiation, multiagent system, negotiation

1. Introduction
Multiagent systems are being used in an increasing wide variety of application domains such as industrial, commercial, medical, networking and educational domains. These agent-based software solutions are mainly complex, open and distributed. In these systems, a group of agents interact with each other to solve the problem at hand. In many multiagent solutions to real-world problems, we should design and implement an automated negotiation system that enables agents to negotiate with each other in order to reach an agreement on scare resources, obtain needed resources for performing their task and/or achieving goals, manage task interdependencies and resolve possible conflicts. Various interaction and decision mechanisms for negotiation have been proposed. In [1] Rahwan et al. discuss about three main classes of approaches to negotiation: game-theoretic, heuristic-based and argumentation-based approaches. Each of these approaches operates according to the specific assumptions about participating agents, available resources and environment. These negotiation mechanisms should have some desirable properties. Researchers have defined these properties for game-theoretic (maximizing social welfare, Pareto efficiency, individual rationality, etc.) and argumentation-based approaches (stated dialogue purpose, inclusiveness, transparency, etc.). A discussion about these properties can be found in [3].

Now, mechanism designers try to construct negotiation systems that enable agents to interact efficiently, productively and fairly with each other in certain environmental conditions. We believe that one of the techniques that help a designer to reach to this goal is adding
flexibility to the negotiation system. In human negotiations, having a flexible negotiation style can improve the outcome of negotiation specially in conflict situations. Flexibility is one of the main characteristics of a skilled and effective negotiator. A flexible negotiator has an open attitude and can change his/her beliefs, desires, preferences, actions and strategy in negotiation. Our main claim is that if we consider flexibility in design of negotiation systems, negotiator agents can interact more efficiently, productively and fairly, especially in more dynamic and uncertain environments. But, before justifying this claim, we should specify the requirements of a flexible negotiation system and dimensions of flexibility in negotiation systems.

A precise definition and formulation of flexibility in negotiation between agents has not reported explicitly in the literature [2]. In this paper, we present an explicit formulation of flexibility in negotiation systems. This formulation provides a framework to survey and analyze the existing works on negotiation. Then, we will show that automated negotiation systems that are implemented according to argumentation-based approach are flexible. This work is done as a part of our research to develop a flexible argumentation-based negotiation system.

This paper organizes as follows. In the next section, we define flexibility in negotiation systems and we provide our formulation of flexibility in negotiation systems. In section 3, based on the formulation of flexibility provided in the previous section, we present a survey of existing works in the literature and analyze the approaches to developing flexible negotiation system. In section 4, we justify argumentation-based approach to negotiation as a mechanism for flexible negotiation between agents and we will show how argumentation can provide mechanisms and techniques to add the required dimensions of flexibility. In section 5, we state our evaluation and conclusion.

2. Flexible Negotiation System

Automated negotiation is a form of interaction in which a group of agents with conflicting interests and a desire to cooperate try to come to a mutually acceptable agreement [1]. General goal of negotiation is managing local plans of agents in case of negative interactions. We define a negotiation system as follows [2].

**DEFINITION 1.** A negotiation system $NS$ is a tuple $NS = <Agents, Roles, P, S, FF, Time>$, where:

- $Agents$ is a set of negotiating agents.
- $Roles$ is a set roles that agents play in negotiation.
- $P$: $Agents \times Agents \rightarrow Roles$ is a function that assigns a role to an agent.
- $S$ is a negotiation strategy.
- $FF$ is a formal framework that is used to model negotiation protocol and strategy. This framework can be based on defeasible logic propositional logic, predicate logic or multi-modal BDI logic.
- $Time$ indicates a set of ordered discrete time intervals.

Negotiation protocol specifies, at each stage of negotiation process, who is allowed to say what. Thus, a negotiation protocol is a formal set of conventions governing the interaction among participants [1, 4].

**DEFINITION 2.** Negotiation protocol is defined by a tuple $P = <A, \pi, JS, O, R>$, where:

- $A$ is a set of valid actions that participants can perform in certain situations.
- $\pi: A \rightarrow 2^A$ is a protocol mapping function in which $2^A$ is all subsets of the set of valid actions, $A$.
- $JS$ is a set of negotiation states.
- $O$ is a set of negotiation objects.
- $R$ is a set of negotiation rules.

Negotiation strategy plans the action sequences of agents during negotiation.

**DEFINITION 3.** A very simple and abstract definition of negotiation strategy is a function $S: 2^A \rightarrow A$ such that if $A \subseteq T$ then $T \in S(T)$.

Negotiation protocol defines interaction rules, but the negotiation strategy defines the action that should be done in the next step. Negotiation strategy is a set of actions that the agents plan for them during negotiation.

When agents negotiate with each other some problems and conditions may occur. We categorize these problems to the following items:

- **Informational problems**
  - Agent needs certain, valid and correct information for making decision about the best possible action that it should take in negotiation. In some conditions the following problems exist regarding this information:
    - Agents do not have enough information for making decision about the best possible next action.
    - Agents do not have enough resources for acquiring the needed information for decision making.
    - Agents have uncertain information about the environment and negotiation parameters.
    - Agents have inconsistent beliefs (e.g. about the value of a product)

- **Changes in negotiation scenario parameters**
  - Every negotiation scenario is defined by a set of parameters. These parameters can change during run-time of negotiation:
    - Characteristics of negotiation objects change during negotiation
    - New negotiation objects are added to the negotiation
    - Cardinality of interaction changes during negotiation (new agents enter or leave the negotiation)
    - Knowledge of the agents can change during the negotiation

- **Exceptional conditions**
  - No progress in negotiation between agents (deadlock situation)
  - Negotiation time is reaching to the end without any result.

The question is: what are the main causes of these problems? The main reasons for these problems are dynamic, uncertain and unpredictable environment, design of negotiator agents and negotiation process. As characteristics of environment have impact on the negotiation process in the following lines we talk more about the environment and its
specific characteristics that have impact on negotiation system design.

Agents negotiate with each other in various types of environments. Some of these environments such as agent-based manufacturing, agent-based transportation, agent-based e-Marketplace or e-Business, Internet, Grid, traffic control, air-traffic control, Robocup, etc. are open and dynamic, uncertain and unpredictable. The specific characteristics of these environments determine the agent design and mechanisms that will be used in a multiagent system. Dynamic and open environments have the following characteristics:

- In an open environment there is no control at all over the participating agents. In a semi-open environment there is no centralized control, but there may be a form of self-regulation.
- In an open environment, there is no pre-defined structure. Agents can enter and exit the environment in any time so the cardinality parameter of a negotiation scenario can change.
- In an open environment, there may be agents that have been designed by different designers. Agents may be heterogeneous. This heterogeneity can be in their goals, beliefs, architecture, communication languages, etc.
- In a dynamic environment, environment state or environmental variables (e.g. products, price of main products) may change. For example, in Grid computing system resource availability may fluctuate as a result of connection/disconnection of computing resources, human interaction/interruption on the computers, etc. Or in an electronic market environment, market situations such as deadlines, trading options, strategies and competitors may change.
- In uncertain environments information is incomplete and uncertain.

Open and dynamic nature of environment affects negotiation process among agents. In a dynamic environment, changes in environmental variables such as price of main products may affect utilities and preferences in negotiator agents. In these environments, a fixed utility can not lead to an optimal agent behavior.

Agent capabilities and behavior: Another reason for the above mentioned problems during negotiation is design of agents and their capabilities in acquiring the needed information for their decision making. Also some of the exceptional conditions result from the unexpected behaviour of the other agents in negotiation.

Negotiation process: In some cases, negotiation process is not progressing towards a result according to the existing constraints (e.g. negotiation time).

One of the challenges of the negotiation system designers is to design a system that can negotiate under the above mentioned situations and constraints and still preserve its properties and reach to an optimal result. We believe that one good solution to the mentioned problems in negotiation is to introduce flexibility as a property for the negotiation system. In the following lines, first we define a flexible negotiation system and then we describe existing mechanisms for designing these types of systems.

**Definition 4.** A flexible negotiation system is a system that preserves its suitable properties under different environmental conditions or changes.

For example, in open systems, new agents with new goals and strategies enter the environment. In this situation, we should design negotiation mechanisms to preserve stability of negotiation. Another desirable property of negotiation is negotiation time. The negotiation process between agents should terminate in a specified timeframe. Now, consider a negotiation process that dose not have any progress during a certain time period. A flexible negotiator agent can add or remove negotiation objects to remove the deadlock in negotiation process.

According to the reported results and our experience, we can mention the following benefits for flexible negotiation in agent-based systems [2]:

- Accommodating openness and dynamism in environment.
- Increasing the likelihood of an agreement in the negotiation process.
- Increasing expected utility of agents (quality of agreement).
- Ensuring that the agreement better fits its objectives.
- Promoting agent's properties such as autonomy, reactivity, proactiveness, etc. in negotiation.
- Simplifying interactions in negotiation.
- Handling unexpected conditions in negotiation.
- If agreement achieved, possibly reduce the average request for time or computational resources request (negotiation efficiency).

The importance of flexibility in agent communications has also emphasized by Maudet et al. [4]. They mention that flexibility and specification are two main issues that forthcoming generations of interaction protocols must address.

In a negotiation system, agents negotiate with each other according to a negotiation protocol and a negotiation strategy. Thus, flexibility can be in implemented in agents, negotiation protocols and/or negotiation strategy. In the next section, we will formulate dimensions of flexibility in negotiation systems.

### 2.1 Formulating Flexibility in Negotiation Systems

According to the definition of a negotiation system and existing works in this area, we define the following aspects of flexibility in negotiation systems:

- Flexibility in negotiation protocol (P). This can be: flexibility in protocol specification (formalism), flexibility in protocol implementation, changing structure and content of negotiation object (O), changing negotiation rules (R), changing quantity and variety of possible negotiation actions (A) and changing action sequences.
- Flexibility in negotiation strategy (S).
- Flexibility in negotiating agents (Ag). This means having open attitudes and willingness of agents to change their beliefs, knowledge, desire, goals and/or preferences.

In practice, it may be impossible to consider all the mentioned aspects in a negotiation system. Flexibility will often add to difficulty and complexity of the design and the costs of construction. Infinite flexibility is likely to be technically as well as economically infeasible.
In addition to the usual attributes of negotiation systems, we can consider the following requirements for a flexible negotiation system [4,5]:

- A flexible negotiation system should have a flexible and adjustable formal model.
- A flexible negotiation system should consider agent autonomy. It should allow the agents to use their autonomy for protocol execution and decision making in negotiation process.
- A flexible negotiation system should consider heterogeneity in design of other agents and their negotiation strategies.
- A flexible negotiation system should give this opportunity to the agents to take advantage of opportunities for improving their action selection and simplifying interactions. For example, depending on the existing situation it should be possible for agents to use domain knowledge and discard certain steps in a protocol and go to a specific state.
- A flexible negotiation system should allow agents with incomplete goals or beliefs to negotiate with each other.

If there is a need to design a flexible negotiation system, designers should design the negotiation system in such a way that it satisfies all or some of these objectives.

3. Current Works on Flexible Negotiation Systems

The presented framework for formulating flexibility in negotiation systems can be used to study the current works in this area. Our study shows that the existing works on flexible negotiation fit in this framework. In the following sections, we will examine each work according to our framework.

3.1 Flexible Negotiation Protocols

Negotiation protocol defines the legal actions that agent can do in the course of negotiation. The order of actions and the rules that govern the interaction can be fixed. In this case, agents must adhere to the order of a protocol and cannot recover from deviations and exceptions. A negotiation protocol can be more flexible. This means that autonomous agents can take advantage of their autonomy, goal-directed behavior and reactivity for negotiating with other agents and choose the order of actions based on reasoning about the current state of negotiation process. Agents can identify the unexpected situations and can take advantages of opportunities during negotiation and handle the unexpected conditions or even act proactively to avoid them or use opportunities. This would make using protocols easier and more able to deal with problems caused by having agents coded by two different people/groups, with different goals and beliefs, etc. In turn this should allow agents to negotiate in a variety of environments. In the following lines, we analyze existing works that have focused on developing flexible negotiation protocols. We can categorize these works in protocol specification, protocol operation and protocol implementation.

3.2 Flexible Protocol Specification

Every negotiation protocol has a specification. A variety of formalisms have been used in current works for specifying negotiation protocols. The examples of such formalisms are: Finite state machines [6], Petri Net [7], dialogue games [8, 9], event calculus [10], logic programs [11], Abductive Logic Programs [12], Plans [5] and extended propositional logic [13].

According to the discussions of Maudet et al. in [4], Brewka in [14] and Singh et al. in [15] a flexible formalism for specification of protocols should have the following properties:

- The formalism should be more dependent on the state of negotiation than on the previous action.
- The formalism should not strictly enforce a normative behavior.
- The formalism should represent the protocol declaratively.

According to the above-mentioned properties, some of the existing formalisms such as finite state machine or Petri Net are not flexible because they model protocols in terms of legal sequences of actions. In this way, agents do not compute transitions during negotiation process and follow the formalism. Thus, this kind of formalisms is dependent on the previous action and strictly enforces a certain behavior. We can say that flexibility of the agents in executing these protocols is limited and protocols are over-constrained.

Approaches such as dialogue games provide clear and precise declarative semantics of the interactions by stating the pre- and post-conditions of each locution as well as its effects on agents’ commitments. In this way, agents that follow the protocol, use the action semantics of protocol and reason about the next action.

Yolum and Singh try to introduce flexibility in agent interaction protocols by specifying the intrinsic meaning of actions in protocols through social commitments [10]. They define operations to create and manipulate commitments. In their approach, each action in the protocol is an operation on commitments. In other words, by following the protocol, each agent creates and manipulates commitments, e.g., by fulfilling, canceling, and so on. In addition to providing a protocol specification that defines the actions as operations on commitments, they provide reasoning rules to operationalize the commitments.

Capturing the intrinsic meaning of the actions and explicitly representing them as part of the protocol brings in flexibility to the protocols, permits the agents to reason about their and others’ behavior during execution of the protocol, and enables them to modify their actions based on the state of interaction and handle unexpected situations during runtime. With this approach agent is not forced to follow a certain sequence of actions. This approach is declarative in that it specifies meaning of actions in the protocol and properties it brings about. Thus, this formalism is a flexible formalism.

In [15] Yolum and Singh propose a concept named commitment machines (CMs) as a formalism to specify and execute protocols. A commitment machine is defined in terms of sets of states and actions that are given a declarative semantic content in terms of commitments. The meaning associated with each state specifies which commitments are in force in that particular state, and the meaning associated with each action defines how the commitments are affected
by that action. Based on the intrinsic meaning of the actions, the new state that is reached by performing an action at a particular state can be logically inferred. Thus, instead of specifying the sequences of actions that can be performed, a CM simply specifies the meanings that are legal in the protocol and, of these, the meanings that are final. Thus, the proposed formalism is more dependent of the state of negotiation than on the previous action. With this in mind, we can come up with different action sequences or paths that accomplish the same goal as the original path, so the formalism is declarative and does not enforce a normative behavior. Commitment machines provide flexibility by capturing the semantic content of the actions in a protocol.

In [8] Dastani et al. propose a method for designing flexible negotiation protocols based on a theory of interaction developed for natural language dialogue systems. A dialogue is a coherent sequence of utterances. An utterance is a single meaningful unit of communication. Interaction patterns in dialogues are frequently occurring sequences of utterance types. A useful metaphor for studying interaction patterns is that of a dialogue game. Each participant plays a role and expects the others to play their respective roles. Each participant makes the moves that are appropriate for its role. The rules and the stages of the game determine which moves are allowed and which are beneficial. Negotiation can be modeled by a particular type of dialogue game, in which each utterance is interpreted as a negotiation act.

Dialogue games define pre-conditions and post-conditions of each action in protocol (dialogue rules) and effects of each action on agent's commitments (dialogue update). The effects of each individual location on the commitments of agent are specified by dialogue update rules. Thus, the protocol is declarative. The dialogue rules specify sequences of valid moves in the protocol. Still we have hard coded the agent behavior but this way of representation does not strictly enforce a normal behavior the agent as finite state machines do. The agents can reason about the next action and the formalism is more dependent on the state of negotiation than on the previous action. In summary, the dialogue game is a flexible formalism for specifying negotiation protocols.

Hutchison and Winikoff attempt to reformulate a protocol in terms of goals and plans to achieve these goals [5]. The goals of the interactions are identified and a set of plans for use by a pair of Belief-Desire-Intention (BDI) agents are designed and implemented. Each plan has a goal, precondition, a body and a post condition. So, the effect of each action in negotiation is specified with this manner and the proposed formalism is declarative. With this approach, a protocol based interaction between agents is linked to their goals. This allows BDI agents to take advantage of their capabilities (such as the ability to achieve goals by multiple means, persistence in achieving a desire or goal, and the ability to choose between goals) in interactions and negotiations. Agents can use their reasoning capability and decide about the next action based on the current situation of negotiation process. Thus, this approach for representing the protocols is flexible. The degree of flexibility added by applying the proposed approach could be: Supporting multiple starting points in a protocol, dealing with agents with incomplete or unclear goals or beliefs, the ability to negotiate in a more intelligent way and resolving conflicting goals between two agents using protocol.

3.2.1 Changing Negotiation Object Set
In a typical negotiation process, agents negotiate over a set of negotiation objects. If agents can change the negotiation object set during negotiation, this may increase the likelihood of an agreement and speed up the process. In this section, we discuss the current works that try to make a flexible negotiation protocol more flexible by changing the negotiation object set.

In [16] Faratin proposes a negotiation strategy named issue manipulation. This issue manipulation mechanism aims to increase the likelihood of an agreement by adding and removing negotiation objects into the negotiation set. The issue manipulation mechanism dynamically alters the structure of the negotiation object, helping to escape local minima in the negotiation dynamics. It does this either by increasing the set of possible outcomes (adding), when negotiation is in deadlock, or, alternatively, removing “noisy” issues that are obstructing the negotiation progress.

In [17] Sierra et al. propose a formal framework for persuasive negotiation in which agents try to change each other’s beliefs and preferences using an expressive communication language. In this framework, illocutions named threats, rewards and appeals for performing argumentation-based negotiation are introduced. Any of these illocutions may introduce new objects in a negotiation process.

3.2.2 Flexibility in Negotiation Protocol Implementation
We can hard code the negotiation protocol in each agent or we can consider a mechanism so that agents can change their negotiation protocol based on the situation of environment. Decision about the implementation mechanism of a negotiation protocol depends on the acceptable level of complexity in negotiation system and benefits that will gain by implementing this flexibility in agents.

Tamma and Wooldridge propose an approach in which agents can choose the negotiation protocol which is most suitable to the type of interaction they participate in [18]. In their approach, agents do not commit to a specific negotiation protocol and their interaction is regulated by a shared ontology of protocols. The shared ontology defines the most general concepts that are used to describe a negotiation protocol and it is populated by the particular protocols available. In this approach, negotiation protocols can be learned dynamically by acquiring the part of ontology modeling them. With this approach, the negotiation is not hard-coded within the agent, but is should be acquired from where interoperation takes place. With current approaches, agents can participate only to the kinds of negotiation governed by the protocols already coded within themselves. The commitment to the same high level concepts can facilitate the communication of negotiation rules among agents, thus improving flexibility.

3.3 Flexible Negotiation Strategy
Researchers believe that fixed negotiation strategy in automated negotiation agents has some problems. First, agents are not as flexible and adaptive to different negotiation environments as desired. Second, a fixed strategy or a static group of strategies may become known by competing agents as a result of negotiation processes, after
3.4.1 Changing Preferences of Agents
In [16] Sierra et al. mention that preferences also evolve. This may be because negotiation object set evolves or because the agent is persuaded to change its preferences. Any illocution may introduce new objects in a negotiation, while the persuasive argument, appeals, may in addition modify preference relationships and the agent's theory. However, the actual effect of an illocution depends on the agent's interpretation of the utterances.

If agent preferences remain fixed during negotiation and their beliefs are inaccurate they can not reach to an agreement that maximizes their utility. Agents can acquire and modify their preferences as a result of interaction with other agents.

3.4.2 Changing Beliefs in Negotiation
When agents with a specific set of beliefs negotiate with each other they may change their beliefs. Meyer et al. consider negotiation as a mutual belief revision in agents. They compare adaptation and concession in negotiation with revision and contradiction in belief revision [25].

Another mechanism to change beliefs of other agents in negotiation is argumentation. This approach allows agents to argue about their beliefs during negotiation process. When agents argue about their beliefs, an agent must accept a proposition if it fails to provide an argument for the negation of the proposition. We will talk about changing beliefs with argumentation in section 4.

3.4.3 Changing Goals of Agent
Agents can change their goals in the course of negotiation after receiving new information from other agents. Argumentation can be a mechanism through which agents try to argue about their goals. We will talk about changing goals with argumentation in section 4.

4. Argumentation Based Negotiation as a Mechanism to Design Flexible Negotiation Systems
Current approaches to automated negotiation have some limitations. Some of these limitations make the existing approaches inflexible. In conventional approaches, agents can not exchange additional information about the proposals during negotiation. So it is hard to persuade the participants to change their beliefs, preferences and intentions during negotiation process by giving them new information in form of justifications and facts. Agent’s preferences are usually assumed to be completely known prior to negotiation and this preference is fixed during the negotiation process. One agent can not influence another agent’s preferences or any of its mental attitudes.

In argumentation-based negotiation, agents try to argue about their beliefs or other mental attitudes by exchanging meta-information and/or persuasive arguments (threaten, promise, appeal) in negotiation process. This can help make negotiations more efficient and flexible. Agents form their preferences based on information available to them. As a result, they acquire and modify their preferences as a result of interaction with environment and other agents. In

which those agents can potentially exploit this knowledge in future negotiations. Third, negotiation strategies of agents seldom examine the trade-off between the benefit of accepting a suboptimal proposal to reach a consensus more quickly (or with more certainty) and the benefit of postponing an agreement in search of an optimal outcome [19,20,21]. For solving these kinds of problems, many existing research works on negotiation strategy try to develop adaptive negotiation strategies.

In [19] Zhang et al. propose a hybrid negotiation strategy mechanism using a strategy pool framework that allows negotiation agents more flexibility and robustness in an automated negotiation system. The strategy pool framework dynamically assigns an appropriate negotiation strategy to a negotiation agent according to the current negotiation environment by using a Feed Forward Back propagation (FFBP) classifier. The framework also creates new negotiation rules by learning from past negotiations based on multidimensional inter-transaction association rules mining technique.

In [20] Sim et al. propose market driven agents that react to changing market situations by adjusting rates of concession. In determining the amount of concession for each trading cycle, market-driven agents in this research are guided by four mathematical functions of eagerness, remaining trading time, trading opportunity, and competition. At different stages of trading, agents may adopt different negotiation strategies, and make different rates of concession.

In [21] Shen et al. propose adaptive negotiation strategies for agent-based load balancing and Grid computing. The proposed approach is to implement multiple negotiation strategies that can be selected by the system automatically to adapt to computation needs as well as changing computing resource environment. The agent learns negotiation strategies based on previous experiences by using case-based reasoning technique.

In [22] Opera proposes an adaptive negotiation strategy for agent-based electronic commerce. In this approach, the seller tries to adjust its negotiation strategy to the buyer’s negotiation strategy by using the artificial neural network forecasts. The learning capability of the seller agent will give information about the overall negotiation style (e.g. the other agent is tough or compliant) and will provide some heuristic information regarding the buyer’s reservation price. As a result of learning, the seller is expected to gain more accurate expectation of the buyer’s payoff structure and therefore make more advantageous offers.

3.4 Flexible Agents in Negotiation
Negotiating agents are the most important elements of every negotiation system. So, when we talk about flexibility in negotiation, agents themselves play an important role. In every real world negotiation process that takes place among humans, flexibility or rigidity of participants will affect the negotiation result and speed of negotiation. Negotiating agents have their own mental attitudes, internal motivations, decision mechanisms, knowledge bases and other necessary components. We can have flexible negotiators in multiagent negotiations. In this section, we discuss about flexibility dimensions in negotiating agents.
argumentation-based negotiation, agents argue with one another and discuss each other’s interests. This enables them to jointly discover new possibilities and correct misconceptions.

Existing works on argumentation-based negotiation can be classified into two major categories: i) embedding negotiation concepts within defeasible argumentation based on dialectical logic; and ii) extending bargaining-based frameworks by allowing agents to exchange rhetorical arguments. A good survey of argumentation-based negotiation can be found in [1].

According to the definition given in [10,23], in the following definitions, we formally define argument and argumentation system. Based on this formal definition, designer can design construct building blocks of an arguer agent.

Definition 4 (Argument). An Argument is a pair \((H,h)\) where \(h\) is a formula of \(L\) and \(H\) a subset of \(E\) such that i) \(H\) is consistent, ii) \(H \vdash h\) and iii) \(H\) is minimal, so no subset of \(H\) satisfying both i) and ii) exists. \(H\) is called the support of the argument and \(h\) its conclusion.

Definition 5 (Undercut). Let \((H_1,h_1)\) and \((H_2,h_2)\) be two arguments of \(A(E)\). \((H_1,h_1)\) undercuts \((H_2,h_2)\) iff \(\exists h \in H_2\) such that \(h = \neg h_1\).

In other words, an argument is undercut iff there exist an argument for the negation of an element of its support.

Definition 6 (Argumentation System). An argumentation system is a triple \((A(E), \text{Undercut})\) such that \(A(E)\) is a set of arguments built from \(E\), Undercut is a binary relationship representing defeat relationship between arguments, \(\text{Undercut} \subseteq A(E) \times A(E)\).

In an argumentation-based negotiation system we need an argumentation protocol and an argumentation strategy (argument interpretation, argument selection and argument generation).

Definition 7 (Argumentation Protocol). Argumentation protocol is a structured discourse to probe or challenge the statements of others. An argumentation protocol can be defined by a tuple \(AP = (L, \pi, R)\) in which:

- \(L\) is a set of valid locutions that participants can perform in certain situations. These locutions enable utterances to be questioned or contested and appropriate response generated.
- \(\pi: A \rightarrow 2^A\) is the protocol mapping function.
- \(R\) is a set of argumentation rules that determine what locutions should be said in the argumentation process.

By using the argumentation protocol an agent acquires the new information in a dialogue and after receiving new information the agent decides to change its beliefs or preferences.

Definition 3 (Argumentation strategy). Argumentation strategy is a guide for decision making about which argument to actually send. This argument can be selected among candidate ongoing arguments. If \(A\) is a set of arguments, argumentation strategy can be defined as a function \(S: 2^A \rightarrow A\) such that if \(A \subseteq T\) then \(T \in S(T)\).

In this section, we try to justify argumentation-based negotiation as a mechanism to design and implement flexible negotiation systems. Based on the presented formulation of flexibility in section 3 and analysis of existing works in the literature, in the following lines, we will show how an argumentation-based approach to negotiation can provide the flexibility in negotiation protocol and negotiation strategy.

4.1 Flexibility in Argumentation Protocol Specification

Argumentation protocols can be represented by using a formal specification such as finite state machine (FSM). In [17] Sierra et al. model their proposed argumentation protocol by a FSM. According to this machine, in the initial state, an agent can issue an offer or request. In the next state, the other agent can do a reject, accept, withdraw or a proposal that is constructed with offer, threaten, reward or appeal illocutions. This formalism fixes the sequence of legal actions that agents can perform. In this way we develop an argumentation protocol that is fixed.

Another way of representing argumentation protocol is using dialogue games [9, 26]. Dialogue games define pre-conditions and post-conditions of each action in protocol (dialogue rules) and effects of each action on agent's commitments (dialogue update). The effects of each individual locution on the commitments of agent are specified by dialogue update rules. Thus, based on the definition presented in section 3.2, the protocol is declarative. The dialogue rules specify sequences of valid moves in the protocol. Still we have hard coded the agent behavior but this way of representation does not strictly enforce a normal behavior the agent as finite state machines do. The agents can reason about the next action and the formalism is more dependent on the state of negotiation than on the previous action. In summary, the dialogue game is a more flexible formalism for specifying argumentation protocols.

4.1.1 Changing Negotiation Actions

In argumentation-based negotiation it is possible to change the available actions. Brewka has proposed a dynamic multi-level argument system in which the available actions may differ from level to level. Even if actions like claiming, conceding or retracting often appear in all levels, their proposition arguments will differ from level to level [14].

4.1.2 Changing Negotiation Rules

Agents can argue about the negotiation and/or argumentation rules. By this means, rules may be changed and new rules invented until agreement about the rules is reached. Loui says that locutions pertain not only to the substance of dispute, but also to the protocol. Arguments can advance claims about how to define or alter the protocol [27].

In [14] Brewka defines an argument system with different argumentation level. Each level has an argumentation context. For modeling potential disagreement about the rules of order as well as dynamic changes of these rules an argumentation record is defined for each level to keep track of the state of argumentation. This record is used to keep track of the current state of argumentation at each level and
to determine whether performing an action \( a \) in state \( r \) at level \( i \).

### 4.1.3 Changing Negotiation Objects
Agents may also exchange information that results in changing the negotiation object itself, by introducing new attributes (or dimensions) to the negotiation object. For example, the manager might modify the negotiation object such that the negotiation involves not only the salary amount, but also the number of working hours. In this way, the manager might be able to offer reduced working hours instead of a salary increase.

Sierra and his colleagues believe that one of the main ways in which an agent may persuade another about the desirability of a particular proposal is to introduce new objects in the negotiation process [17]. This can be done by using the illocutions that have been designed for argumentation and negotiation.

### 4.2 Flexibility in Arguer Agents
One of the key elements of any negotiation setting is negotiating agents that participate in negotiation interactions. Rahwan et al. provide a discussion of the general features of an argumentation-based negotiation agent [1]. In their framework an agent that negotiates based on argumentation must at least be able to:

- interpret incoming locutions
- evaluate incoming proposals
- generate outgoing proposals
- generate outgoing locutions
- evaluate incoming arguments and update its mental state accordingly
- generate candidate outgoing arguments
- select an argument from the set of available arguments

For performing the above functions, the agent should have the following components:

- Location interpretation to parse incoming messages.
- Proposal database for storing proposals.
- Proposal evaluation and generation to make a decision about whether to accept, reject or generate counterproposal or even terminate the negotiation.
- Location generation to send response to the relevant party or parties.
- Knowledge base of mental attitudes (beliefs, desires, preferences, …)
- Argument evaluation or interpretation to update agent's mental attitudes.
- Argument generation to decide what arguments should accompany the response.
- Argument selection to select the appropriate argument among the generated arguments.

Based on the above conceptual model of agent architecture, we believe that flexibility mechanisms can be implemented in the "Argument Evaluation and Interpretation", "Argument Generation" and "Argument Selection" components. In the following lines we will talk about these aspects of flexibility in arguing agents.

### 4.2.1 Flexible Argument Interpretation
As mentioned above, one of the steps of argumentation process is valuation of relative strength of the arguments. Then, in another step, the most acceptable arguments are selected. Thus, on receiving an argument an agent should decide how to interpret this argument and update its mental state (beliefs, goals, preferences, …) accordingly. We define a **flexible arguer agent** as an agent that adapts or changes itself by willingness to change and adapt its mental states (beliefs, intentions, and goals) and preferences during argumentation-based negotiation.

In [1] two argument evaluation strategies are specified: objective and subjective. In objective strategy, an agent may evaluate an argument based on some objective that defines how the quality of a proof for a conclusion is established. In subjective evaluation an agent may choose to consider its own preferences and motivations in evaluating arguments. Thus, the flexible arguer agent changes its beliefs or current theory based on its objective and subjective evaluation strategies. We can define a range of flexibility in agents according to their argument evaluation strategy or acceptance attitude. A **rigid agent** is an agent that has decided to never change its mental states and preferences. It seems that argumentation-based negotiation with this agent will not reach to a suitable agreement. A desirable participant agent in argumentation-based negotiation is one who is "receptive" or open-minded in displaying a willingness to listen to other's normative claims and impartial or fair-minded in his judgment or decision. The flexibility of arguer agents depends on their reasoning about the arguments in order to determine the most acceptable argument.

### 4.2.2 Changing Beliefs with Argumentation
Argumentation approach allows agents to argue about their beliefs during negotiation process. When agents argue about their beliefs, an agent must accept a proposition if it fails to provide an argument for the negation of the proposition.

Parsons et al. [6] provides a detail description about how an agent can argue about the beliefs of other agents. In their framework they define argument and attack relationships between arguments. The attack notion is defined in the BDI architecture. In this architecture conflict arises when agent tries to change a particular mental state in another agent. In other words the agent intends to persuade another agent to believe or desire or intend the negation of one of its current beliefs, respectively desires or intentions.

### 4.2.3 Changing Goals with Argumentation
Agents can argue about goals and can change their goals after receiving new information from other agents. Rahwan et al. argue that systems of argumentation designed for arguing about beliefs are not readily suitable for argumentation over goals, particularly due to the different ways conflict resolution among arguments must be dealt with. For example, there is a difference between attacking a goal by demonstrating that it is not achievable and attacking it by demonstrating that it is not useful. Rahwan et al. demonstrate different ways in which goals may relate to their sub-goals, their super-goals and the agent’s beliefs. This allows one to characterize different types of arguments that may be provided against a particular goal, and how they can, if successful, affect the agents’ mental states [28].
4.2.4 Changing Preferences with Argumentation

In argumentation-based negotiation, we can consider illocutions for introducing new objects in the negotiation. Arguments such as “appeal” in addition to introducing new objects may modify the preference relationships and the agent's theory. However, here we can say that the exchanged illocutions or information during the argumentation process provides mechanisms for flexible negotiation and the actual effect of an illocution depends on the agent's interpretation of the utterances.

In [17] authors propose persuasive illocutions such as appeal, threaten and reward that can be used in argumentation for modifying preferences of agents.

According to the above mentioned discussions, we can say that argumentation theory, exchanged meta-information and or persuasive argumentation primitives such as threat, promise and appeal provide necessary mechanisms for flexible negotiation. Argumentation can provide flexibility in negotiation protocol, negotiation strategy and negotiator agents. In the next section, when we discuss about the results and conclusions, we provide a discussion about how flexibility is implemented by using an argumentation approach and how we can compare effectiveness of this approach with other proposed approaches to flexible negotiation.

5. Conclusion

In this paper, we presented the first formulation of flexibility in negotiation systems. We showed that a flexible negotiation system is a system that its elements, negotiation protocol, negotiation strategy and mental attitudes of agents can change according to what have been perceived from environment and other agents. A flexible negotiation system should preserve its suitable properties in case of changes in the negotiation environment. Based on the proposed formulation of flexibility in negotiation systems and existing works in literature[4,5,6,8,10,13,14], we justified that argumentation-based approach to negotiation can provide needed mechanisms and techniques to add flexibility to negotiation protocols, strategies and negotiator agents. Agents that negotiate based on argumentation approach are capable to operate in more dynamic, uncertain and unpredictable environments.

Many formal frameworks have been developed for argumentation-based negotiation [6,9,11,12,17,26,28,29]. These frameworks provide components for constructing a computational and implementable agent-based system in which agents negotiate with each other based on the argumentation construct. There is a formal theory underlying the specification of each framework (e.g. decision theory, argumentation theory, dialogue games, etc.) that provides the main idea for developing that framework.

These frameworks try to construct generic models of argumentation-based negotiation and study their applicability. In these frameworks properties of decision making components of arguer agents and argumentation protocols necessary for facilitating argumentation-based negotiation are discussed. Also, Rahwan et al. propose a conceptual framework that outlines the core elements and features required by agents engaged in argumentation-based negotiation [1]. The framework provides a good basis for implementing negotiation systems based on argumentation approach.

One of the main ideas of this paper is that argumentation-based negotiation provides necessary techniques for building more sophisticated, flexible and robust agent-based systems that can negotiate in more dynamic, uncertain, and unpredictable environments. This idea is supported by the research that has been done in our laboratory for justifying and evaluating argumentation-based approach as an effective way for constructing flexible negotiation systems [3]. For evaluation of this approach we considered likelihood and quality of agreements as two evaluation criteria. We considered a classic distributed bargaining scenario and based on this scenario we compared a conventional approach to negotiation with fixed strategy and protocol, a conventional approach to negotiation with flexible strategy and/or protocol and an argumentation-based approach to negotiation with each other by tracing the scenarios. It should be mentioned that it is the common approach for evaluating the proposed approaches in this domain. Results show that in more dynamic and uncertain environments particularly when the agents have incomplete and inaccurate beliefs, argumentation-based approach could increase likelihood and quality of agreements.

In argumentation-based approach to negotiation rational agents exchange information about their proposal and counter proposals in form of justifications, proofs and reasons. A rational and flexible agent should only change its beliefs and desires by receiving new information. Preferences and actions of agents can change as a result of belief and desire change. So, the argumentation approach is considered as a means of utility and action change. These changes let the agents to be flexible and react to the changing conditions of its negotiation environment. If the preferences and actions of agent remains fixed during negotiation and their beliefs are inaccurate, then an agent may fail to reach to an agreement or maximize its utility in an agreement. Previous empirical results show that in general, more flexible negotiation agents outperform fixed agents negotiator agents in many situations [16,20,30].

The philosophy of exchanging information in form of justification and proofs for persuading the other agent to change its beliefs and desires is an appropriate tool for flexible negotiation. Also, as shown in this paper, argumentation approach to negotiation covers all the mentioned aspects of flexibility in our formulation.

Also, it is possible to design an argumentation-based negotiation system that can reach to the same level of flexibility that is available in existing flexible negotiation settings. For example, Hutchison et al. has reformulated an interaction protocol, defined as a rigid sequence of interactions/messages, in terms of goals and plans that achieve these goals and has shown that the degree of flexibility added by applying the proposed approach could be quite great. For assessing the robustness and flexibility of the reformulated they have defined some simple scenarios that could occur in using the protocol. One of these scenarios is “Incomplete Goals and Beliefs of Agents”. The main question of this test scenario is: “Can two agents still use a protocol, if an agent did not know how to evaluate an attribute of a negotiation object?” One way to communicate a lack of beliefs over some aspect of negotiation would be
appropriate additions to the plan sets of both agents to allow them to communicate if they had a lack of beliefs or goals on a particular topic. This condition in negotiation can be handled in a more effective and efficient way in argumentation-based negotiation by communicating lack of beliefs in the arguments that are exchanged between agents. Also agents can initiate an information seeking dialogue to acquire needed information from other agents or their environments.

References


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