# Argument-based Decision Making and Negotiation in E-business: Contracting a Land Lease for a Computer Assembly Plant

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**Abstract.** We describe an extensive application of argument-based decision making and negotiation to a real-world scenario in which an investor agent and an estate manager agent negotiate to lease a land for a computer assembly factory. Agents are equipped with beliefs, goals, preferences, and argument-based decision-making mechanisms taking uncertainties into account. Goals are classified as either structural or contractual. The negotiation process is divided into two phases. In the first phase, following a recently proposed framework [8] the investor agent find suitable locations based on its structural goals such as requirements about transportation; the estate manager agent determines favored tenants based on its structural goals such as requirements about resource conservation. In the second phase, we introduce a new novel argument-based negotiation protocol for agents to agree on contract to fulfill their contractual goals such as waste disposal cost.

## 1 Introduction

Argument-based negotiation enables agents to couple their offers with arguments, thus is believed to improve the quality of deals in such contexts as e-business, resource allocation [5]. We describe an extensive application of argument-based decision making and negotiation to a real-world scenario in which an investor agent and an estate manager agent negotiate to lease a land for a computer assembly factory.

Agents are equipped with beliefs, goals, preferences, and argument-based decision-making mechanisms taking uncertainties into account. Beliefs is structured as assumption-based argumentation framework. Goals are classified as structural if they are about static properties of purchased items or services; like a structural goal of an investor for leasing a parcel of land could be that its location is near a sea port. Goals are classified as contractual if they are about features subject to negotiation leading to the agreement of a contract; like a contractual goal for above lease is that the rental cost is lower than $\$.9/m^2/month$. Preferences are given by numerical rankings on goals.

The negotiation process is divided into two phases. In the first phase, following a recently proposed contract negotiation framework [8] the investor agent finds suitable locations based on its structural goals; the estate manager agent determines favored tenants based on its structural goals. In the second phase, agents negotiate to agree upon a contract fulfilling their contractual goals. Agents starts negotiation about a basic item or a main service. As negotiation proceeds, agents may introduce sub-items or new services to accommodate each other's needs for a better deal. For example, the estate manager offers a waste disposal service at low price to make the land lease more attractive for the investor. This kind of reward is very common in daily business. To handle this pattern of negotiation, we develop a reward-based minimal concession negotiation protocol extending the original protocol [8], which does not deal with changes of negotiated items/services during negotiation. Like its predecessor, the new protocol ensures an efficient and stable agreement.

The paper is structured as follows. Section 2.1 gives background on argument-based decision making and section 2.2 presents our new negotiation protocol. Section 3 instantiates the contract negotiation framework [8] to model the decision making of an investor (we omit the estate manager's part due to the lack of space). Section 4 is a design for implementation, and is followed by the conclusions.

## 2 Argument-based decision making and negotiation

### 2.1 Argument-based decision making

An ABA framework,see [4, 7, 6, 8, 13] for details, is defined as a tuple $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{\phantom{x}} \rangle$ where

- $(\mathcal{L}, \mathcal{R})$ is a *deductive system*, consisting of a language $\mathcal{L}$ and a set $\mathcal{R}$ of inference rules,
- $\mathcal{A} \subseteq \mathcal{L}$, referred to as the set of *assumptions*,
- $\overline{\phantom{x}}$ is a (total) mapping from $\mathcal{A}$ into $\mathcal{L}$, where $\overline{x}$ is referred to as the *contrary* of $x$.

We assume that the inference rules in $\mathcal{R}$ have the syntax $l_0 \leftarrow l_1, \ldots l_n$ (for $n \geq 0$) where $l_i \in \mathcal{L}$. Assumptions in $\mathcal{A}$ do not apprear in the heads of rules in $\mathcal{R}$.

A backward deduction of a conclusion $x$ supported by a set of premises $P$ is a sequence of sets $S_1, ..., S_m$, where $S_1 = \{x\}$, $S_m = P$, and for every $i$, where $y$ is the selected sentence in $S_i$: If $y$ is not in $P$ then $S_{i+1} = S_i - \{y\} \cup S$ for some inference rule of the form $y \leftarrow S \in R$. Otherwise $S_{i+1} = S_i$.

An *argument* is a (backward) deduction whose premises are all assumptions.

In order to determine whether a conclusion (set of sentences) should be drawn, a set of assumptions needs to be identified providing an "acceptable" support for the conclusion. Various notions of "acceptable" support can be formalised, using a notion of "attack" amongst sets of assumptions whereby $X$ *attacks* $Y$ iff for some $y \in Y$ there is an argument in favour of $\overline{y}$ supported by (a subset of) $X$. A set of assumptions is deemed

– *admissible*, iff it does not attack itself and it counter-attacks every set of assumptions attacking it;
– *preferred*, iff it is maximally admissible.

We will use the following terminology:

– a preferred set of assumptions is called preferred extension.
– a preferred extension of $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{\phantom{a}} \rangle \cup \{a\}$, for some $a \in \mathcal{A}$, is a preferred extension of $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{\phantom{a}} \rangle$ containing $a$.
– given a preferred extension $E$ and some $l \in \mathcal{L}$, $E \models l$ stands for "there exists a backward deduction for $l$ from some $E' \subseteq E$".

Agents are equipped with beliefs, goals, and preference. Following [8], an agent is defined as a tuple $< G, B, P >$, where

– $G \subseteq \mathcal{L}$ is its goal-base consisting of two disjoint subsets: $G = G^{struct} \cup G^{contr}$, where $G^{struct}$ contains structural goals concerning the attributes of purchased items or services, for example a structural goal for leasing a parcel of land could be that its location is near a sea port; and $G^{contr}$ contains contractual goals concerning the contractual features of purchased items or services, for example a contractual goal for above lease is that the rental cost is lower than $\$.9/m^2/month$.
– $P$ is its preference-base mapping goals from $G$ to the set of natural number, ranking goals according to their importance so that the higher the number assigned to a goal, the more important the goal.
– $B$ is its belief-base represented by an ABA framework $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{\phantom{a}} \rangle$, where
  • $\mathcal{R} = R_i \cup R_n \cup R_c$, where
    ∗ $R_i$ represents information about concrete items or services to be traded, for example the distance from a parcel of land to a sea port is 30 kms.
    ∗ $R_n$ consists of rules representing (defeasible) rules or norms, for example textile industries require only low skilled labour force.
    ∗ $R_c$ represents information related to contractual goals, for example an estate manager often offers rental discount for investors in electronics.
  • $\mathcal{A} = A_d \cup A_c \cup A_u$, where
    ∗ $A_d$ consists of assumptions representing items or services for transactions, for example $location1$, $location2$.
    ∗ $A_c$ represents control assumptions related to defeasible norms.
    ∗ $A_u$ contains assumptions representing the uncertainties about items or services to be traded, for example whether the labour skill available at a location is high.

A contract is viewed as a transaction between agents playing different roles, characterized by an item or service package and an assignment of values to item attributes. Formally, a contract between two agents is a tuple $< Buyer, Seller, Item, Features >$ where

- $Buyer, Seller$ are different agents representing the buyer and seller in the contract
- $Item$ is the item or service package to be traded in the transaction
- $Features$ is an assignment of values to item/service attributes

An example contract is $< investor, estate\_manager, location2, rental = \$1.0/m^2/month >$ indicating that the estate $eatate\_manager$ leases $location2$ to the $investor$ at $\$1.0/m^2/month$.

To agree on a contract, agents engage in a two-phase negotiation process. In the first phase, the buyer agent evaluates available items or services to determine how they satisfy its needs. In the second phase, the buyer agent negotiates with the seller for items/services that have passed the first phase. Choices in the first phase are available items or services, and choices in second phase are possible deals. The value of a choice is represented by the set of goals satisfied by the choice.

Let $d \in A_d$ be a choice available to an agent $< G, B, P >$ and $g \in G^{struct}$, we says that

- $g$ is credulously satisfied by $d$ if there is a preferred extension $E$ of $B \cup \{d\}$ such that $E \models g$
- $g$ is skeptically satisfied by $d$ if, for each preferred extension $E$ of $B \cup \{d\}$, $E \models g$

The framework in [8] models risk-averse decision makers who consider *the value of choice* $d$, denoted by $Val(d)$ as the set of goals skeptically satisfied by $d$.

**Definition 1.** *Let $d, d'$ be two choices and $s = Val(d)$,$s' = Val(d')$ be the sets of goals representing the values of $d, d'$ respectively. Then $d$ is preferred to $d'$, denoted by $d \sqsupseteq d'$ iff*

- *there exists a goal $g$ that is satisfied in $s$ but not in $s'$, and*
- *for each goal $g'$, if $P(g') \geq P(g)$ and $g'$ is satisfied in $s'$ than $g'$ is also satisfied in $s$.*

That is, choices enforcing higher-ranked goals are preferred to those enforcing lower-ranked goals.

### 2.2 A Reward-based Minimal Concession Negotiation Protocol

Suppose an investor and an estate manager consider a partnership. The estate manager wants to provide not only land lease but also other estate services such as wastewater treatment. However, at the beginning the estate manager may not have full information about the investor's needs, and the investor may also not have full information about the estate services. They often start negotiation about only land lease. As negotiation proceeds, the estate manager may introduce additional services when he discovers the investor's needs. These services are called *value-added* if their values are lower than that of the main service, however they are offered at significantly lower prices than the prices that could be obtained if purchased separately from different service providers. This kind of reward is very common in business when a service provider offers an extra service at low price to increase the attractiveness of a service package. For example in our scenario the estate manager can offer waste disposal service for some kinds of industrial waste produced from the manufacturing of printed circuits when he discovers this investor's need. The reason the estate manager offers this service at low price is that he collects similar wastes from other tenants as well and then treats them in large scale. Furthermore if the investor contracts with an outside company, he has to pay extra cost for transportation.

To handle this pattern of negotiation, we extend the minimal concession protocol introduced in [8], which is itself inspired by the monotonic concession protocol in [23].

We assume that a buyer agent $\beta$ needs a main service $msr$ and a set $S_\beta$ of (value-added) services. After the first phase, the buyer agent decides to start negotiation to buy $msr$ from a seller $\sigma$ and buys other services in $S_\beta$ from wherever the best offers he gets. The seller $\sigma$ wants to sell the main service $msr$, possibly packaged with other services in $S_\sigma$ possibly different from $S_\beta$. A service package is defined as a set $p = \{msr\} \cup r$, where $r \subseteq S_\sigma \cap S_\beta$.

Agents negotiate to determine a concrete service package for transaction. The value of such transaction is defined by a contractual state.

**Definition 2.** *A contractual state is a pair $\langle p, ass \rangle$ where $p$ is a service package and $ass$ is an assignment of values to contractual attributes(e.g. $\{price = 10K, deliveringTime = 1week\}$). The set of all contractual states is denoted by $CS$ while the set of all contractual states about $p$ is denoted by $CS_p$.*

The preference of an agent $\alpha$ between contractual states can be represented as a total pre-order $\sqsupseteq_\alpha$ where $t \sqsupseteq_\alpha t'$ states that $t$ is preferred to $t'$ (for $\alpha$). $\sqsupseteq_\alpha$ is assumed to be consistent with the partial order obtained from *Definition 1.* We assume that agent knows its preferences between contractual states. Agents are not assumed to know the preferences between contractual states of other agents except if the states have the same package. We say that: $t$ is *strictly preferred* to $t'$ for agent $\alpha$, denoted by $t \sqsupset_\alpha t'$ if $t \sqsupseteq_\alpha t'$ and $t' \not\sqsupseteq_\alpha t$; $t$ is *equally preferred* to $t'$ for agent $\alpha$, denoted by $t =_\alpha t'$ if $t \sqsupseteq_\alpha t'$ and $t' \sqsupseteq_\alpha t$; $t$ *dominates* $t'$, denoted by $t > t'$ if $t$ is preferred to $t'$ for both seller and buyer (i.e. $t \sqsupseteq_\beta t'$ and $t \sqsupseteq_\sigma t'$) and, for at least one of them, $t$ is strictly preferred to $t'$; $t$ is *Pareto-optimal* if it is not dominated by any other contractual state.

We also assume that each agent $\alpha$ possesses an evaluation function $\lambda_\alpha$ that assigns to each package $p$ a contractual state $\lambda_\alpha(p)$ representing the reservation value of $p$ for $\alpha$. For the buyer agent $\beta$ (or the seller $\sigma$, resp.), $\lambda_\beta(p)$ (or $\lambda_\sigma(p)$, resp.) is the maximal (or minimal, resp.) offer it could make (or accept, resp.). The possible deals (contracts) that agent $\alpha$ could accept for a package $p$ is defined by $PD_\alpha(p) = \{t | t \in CS_p \text{ and } t \sqsupseteq_\alpha \lambda_\alpha(p)\}$. Furthermore, agents are rational in the sense that they would not accept a deal that is not Pareto-optimal. We define the *negotiation set* $NS(p)$ (about a package $p$) as the set of all Pareto-optional contractual states in $PD_\beta(p) \cap PD_\sigma(p)$. It is not difficult to see that for $t, t' \in NS_p$, $t' \sqsupset_\sigma t$ iff $t \sqsupset_\beta t'$, $t' \sqsupseteq_\sigma t$ iff $t \sqsupseteq_\beta t'$, and $t' =_\sigma t$ iff $t' =_\beta t$. A package $p$ is said to be *negotiable* if $NS(p)$ is not empty. It follows that $p$ is negotiable iff $\lambda_\beta(p) \sqsupseteq_\sigma \lambda_\sigma(p)$ (or $\lambda_\sigma(p) \sqsupseteq_\beta \lambda_\beta(p)$).

We represent a state of a negotiation as a tuple $\langle(\sigma, v_\sigma), (\beta, v_\beta)\rangle$ where $v_\sigma$, $v_\beta$ are the lastest offers of the seller agent and the buyer agent respectively. Offers are represented by contractual states. Agent starts negotiation by putting forwards its most preferred offer from the initial negotiation set $NS(\{msr\})$. That is, the seller agent offers to sell $msr$ at $\lambda_\beta(\{msr\})$ and the buyer agent offers to buy it at $\lambda_\sigma(\{msr\})$. The negotiation state after these moves is $\langle(\sigma, \langle\{msr\}, \lambda_\beta(\{msr\})\rangle), (\beta, \langle\{msr\}, \lambda_\sigma(\{msr\})\rangle)\rangle$.

Suppose now that agents are negotiating about a package $p$ and the current negotiation state is $\langle(\sigma, v_\sigma), (\beta, v_\beta)\rangle$. If agent $\alpha \in \{\beta, \sigma\}$ taking its turn to move next puts an offer $v$ about the package $p$ then $v$ should be an element of $NS(p)$ such that $v \sqsupseteq_{\overline{\alpha}} v_\alpha$ because when an agent makes a new offer, it should be at least as preferred for its opponents (denoted by $\overline{\alpha}$) as the one it has made previously.

Instead of making new offer for package $p$, the agent could introduce or request a set of new services $r$ to be included in the negotiation. To determine the asking price for the new package from the current stage of negotiation, we assume that each agent $\alpha$ possesses a function $f^\alpha_{p,r} : CS_p \rightarrow CS_{p\cup r}$ computing its first offer for $p \cup r$ from an offer about $p$, where $r \cap p = \emptyset$. It is sensible to assume that $f^\alpha_{p,r}$ satisfies following constraints

1. *Lossless.* The new offer is strictly preferred (or preferred, resp.) to its previous offer for agent $\alpha$ (or $\overline{\alpha}$, resp.), who introduces/requests (or who replies, resp.) $f^\alpha_{p,r}(v) \sqsupset_\alpha v$ and $f^\alpha_{p,r}(v) \sqsupseteq_{\overline{\alpha}} v$
2. *Reward.* The seller offers $r$ additional to $p$ at price cheaper than the price the buyer could get $r$ from other vendors.
   $f^\sigma_{p,r}(v) \sqsupset_\beta f_{p,r}(v) \sqsupseteq_\beta v$, where $f_{p,r}$ is a function returning the minimal possible cost of $p \cup r$ if the buyer purchases $p$ at $v$ from the seller and then purchases $r$ from other vendors.
3. *Monotonicity.* Service inclusion retains preference order.
   If $v_2 \sqsupset_\alpha v_1$ then $f^\alpha_{p,r}(v_2) \sqsupset_\alpha f^\alpha_{p,r}(v_1)$. If $v_2 =_\alpha v_1$ then $f^\alpha_{p,r}(v_2) =_\alpha f^\alpha_{p,r}(v_1)$.
4. *Value-added.* Service inclusion expands negotiation space.
   $f^\alpha_{p,r}(v) \sqsupset_\alpha f^{\overline{\alpha}}_{p,r}(v)$.
5. *Flatten.* The inclusion of a set $r$ of services can be substituted by the inclusions of individual services in $r$ consecutively.
   $\forall asr \in r$, $f^\alpha_{p,r}(v) = f^\alpha_{p\cup\{asr\},r-\{asr\}}(f^\alpha_{p,\{asr\}}(v))$; and $f^\alpha_{p,\emptyset}(v) = v$

*Example 1.* To motivate and explain the above constraints, let's consider a simple case where cost (say in US$) is the only contractual attribute. A contractual state is defined by a pair $\langle p, v\rangle$ where $v$ a natural number representing a cost of package $p$. So $\lambda_\alpha(p) = \langle p, \Gamma_\alpha(p)\rangle$, where $\Gamma_\alpha(p)$ is a natural number representing the reservation cost of $p$ for $\alpha$. It is reasonable to assume that $\Gamma_\beta(p \cup r) = \Gamma_\beta(p) + \Gamma_\beta(r)$ since $\beta$ may have to buy each services separately from different vendors. Suppose the lowest price the seller is willing to offer $r$ is $d(r)$, which could be considered as a fixed effective reservation price of $r$. Hence $\Gamma_\sigma(p \cup r) = \Gamma_\sigma(p) + d(r)$. So it is sensible for the buyer to set $f^\beta_{p,r}(\langle p, n\rangle) = \langle p\cup r, n+d(r)\rangle$; and for the seller to set $f^\sigma_{p,r}(\langle p, n\rangle) = \langle p\cup r, n+\Gamma(r)\rangle$ where $\Gamma(r)$ is smaller than $\Gamma_0(r)$ which is the minimal possible amount the buyer has to pay for getting $r$ on the market from other vendors (i.e. the minimal possible sum of market price of $r$ and cost for packaging $p$, $r$ together). It is sensible to expect $\Gamma_\beta(r) \geq \Gamma_0(r)$ (since $\beta$ has to pay at least the minimal market price of $r$ and packaging cost in order to obtain $r$ from other vendors), and $\Gamma(r) > d(r)$ and $f_{p,r}(\langle p, n\rangle) = \langle p \cup r, n + \Gamma_0(r)\rangle$. It is easy to see the satisfaction of above constraints when written in simplified forms belows

- Lossless: $f^\beta_{p,r}(\langle p, n\rangle) = \langle p\cup r, n+d(r)\rangle \sqsupset_\beta \langle p, n\rangle$ and $f^\sigma_{p,r}(\langle p, n\rangle) = \langle p\cup r, n+\Gamma(r)\rangle \sqsupset_\sigma \langle p, n\rangle$.
- Reward: $f^\sigma_{p,r}(\langle p, n\rangle) = \langle p\cup r, n+\Gamma(r)\rangle \sqsupset_\beta f_{p,r}(\langle p, n\rangle) = \langle p\cup r, n+\Gamma_0(r)\rangle \sqsupseteq_\beta \langle p, n\rangle$
- Monotonicity: If $n_1 < n_2$ then $\langle p \cup r, n_1 + d(r)\rangle \sqsupset_\beta \langle p \cup r, n_2 + d(r)\rangle$ and $\langle p \cup r, n_2 + \Gamma(r)\rangle \sqsupset_\sigma \langle p \cup r, n_1 + \Gamma(r)\rangle$
- Value-added: $\langle p \cup r, n + d(r)\rangle \sqsupset_\beta \langle p \cup r, n + \Gamma(r)\rangle$
- Flatten: $d(r) = \sum_{asr\in r} d(\{asr\})$ and $\Gamma(r) = \sum_{asr\in r} \Gamma(\{asr\})$

After the inclusion of new services $r$ to the current package $p$, the current negotiation state is changed to $\langle(\sigma, f^\sigma_{p,r}(v_\sigma)), (\beta, f^\beta_{p,r}(v_\beta))\rangle$. From the above constraints, it follows that

- The negotiation space is changed from $\{v|v_\sigma \sqsupseteq_\sigma v \sqsupseteq_\sigma v_\beta\}$ to $\{v|f^\sigma_{p,r}(v_\sigma) \sqsupseteq_\sigma v \sqsupseteq_\sigma f^\beta_{p,r}(v_\beta)\}$, which is not empty since $f^\sigma_{p,r}(v_\sigma) \sqsupset_\sigma f^\sigma_{p,r}(v_\beta) \sqsupset_\sigma f^\beta_{p,r}(v_\beta)$.
- $\forall v \in NS(p)$, $f^\sigma_{p,r}(v) \sqsupset_\sigma f^\beta_{p,r}(v) \sqsupseteq_\sigma v$ and $f^\beta_{p,r}(v) \sqsupset_\beta f^\sigma_{p,r}(v) \sqsupset_\beta v$. Thus if agents could reach a deal about $p$ then they could reach a new deal about $p \cup r$ that *dominates* the other.
- the size of $\{t|f^\sigma_{p,r}(v) \sqsupseteq_\beta t \sqsupset_\beta f_{p,r}(v)\}$ (or $\Gamma_0(r) - \Gamma(r)$ as in example 1) could be considered as part of a reward from the seller to the buyer.

We define reward-based monotonic concession negotiation as an interleaving sequence of concession negotiation about the package already accepted for negotiation and negotiation for service inclusion. Concession negotiation is an alternating sequence of moves between the seller agent and the buyer agent. Suppose that agents are negotiating about a current package $p$ with the negotiation state $\langle(\sigma, v_\sigma), (\beta, v_\beta)\rangle$. A move is represented by a tuple $\langle type, \alpha, v\rangle$, where *type* is type of the move, $\alpha$ is the agent making the move, and $v$ is an element of the current negotiation space $NS(p)$. If $v$ is strictly preferred to the agent's previous offer for its opponent ($v \sqsupset_{\overline{\alpha}} v_\alpha$), then *type* is *concede*; otherwise, it is *standstill*. After a buyer's (or seller's, resp.) concession move $\langle concede, \beta, v\rangle$ (or $\langle concede, \sigma, v\rangle$, resp.) the current negotiation state is changed to $\langle(\sigma, v_\sigma), (\beta, v)\rangle$ (or $\langle(\sigma, v), (\beta, v_\beta)\rangle$, resp.). Negotiation about the inclusion of a set $r$ of new services can be initiated with an introduction move for $r$ of the seller agent or a request move for $r$ of the buyer agent. An introduction move is represented by a tuple $\langle introduce, \sigma, f^\sigma_{p,r}(v_\sigma)\rangle$. A request move is represented by a tuple

$\langle request, \beta, \langle p \cup r, \bot \rangle \rangle$ where $\bot$ means that the buyer is asking the seller to state its price. The buyer (or seller, resp.) will reply to the introduction (or request, resp.) move by making a reply move. If the buyer agent needs a subset $r' = r \cap S_\beta$ of introduced services, it will reply positively by making a positive reply move, represented by a tuple $\langle reply, \beta, f^{\beta}_{p,r'}(v_\beta) \rangle$. Similarly, if the seller agent provides a subset $r' = r \cap S_\sigma$ of requested services, it will make a positive reply move, represented by a tuple $\langle reply, \sigma, f^{\sigma}_{p,r'}(v_\sigma) \rangle$. A positive reply move will change the current negotiation state to $\langle (\sigma, f^{\sigma}_{p,r'}(v_\sigma)), (\beta, f^{\beta}_{p,r'}(v_\beta)) \rangle$. Agents could reply negatively by repeating its last offer to indicate that the proposal for service inclusion fails and the negotiation state remains unchanged.

Formally, a reward-based monotonic concession negotiation is a sequence $m_1, m_2, \ldots, m_n$ of alternative moves of the form $m_i =< type_i, \alpha_i, v_i >$ between a buyer agent and a seller agent where the seller agent starts the negotiation by offering to sell the main package at the buyer's reservation value, and the buyer agent replies by offering to buy it at the seller's reservation value.

Suppose now that the current negotiation state is $\langle (\sigma, v_\sigma), (\beta, v_\beta) \rangle$. Subsequent moves $m_n$, $n \geq 3$ could be of one of the types *introduction, request, reply, standstill, or concession*, where

- If $m_n$ is an introduction move of the seller agent (or a request move of the buyer agent, resp.) for a set $r$ of new services, then $m_n = \langle introduce, \sigma, f^{\sigma}_{p,r}(v_\sigma) \rangle$ (or $m_n = \langle request, \beta, \langle p \cup r, \bot \rangle \rangle$, resp.) where $p \cap r = \emptyset$. The current state of negotiation remains unchanged.
- If $m_n$ is a positive reply move of the seller (or buyer, resp.) agent then the previous move is a request move of the buyer agent (or introduction move of the seller agent, resp.) for a set $r$ of new services and $m_n = \langle reply, \sigma, f^{\sigma}_{p,r'}(v_\sigma) \rangle$ (or $m_n = \langle reply, \beta, f^{\beta}_{p,r'}(v_\beta) \rangle$, resp.) where $r' = r \cap S_\sigma$ (or $r' = r \cap S_\beta$, reps.) and $r' \neq \emptyset$. The new negotiation state is $\langle (\sigma, f^{\sigma}_{p,r'}(v_\sigma)), (\beta, f^{\beta}_{p,r'}(v_\beta)) \rangle$.
- If $m_n$ is a negative reply move of the seller (or buyer, resp.) agent then the previous move is a request move of the buyer (or an introduction move of the seller, resp.) agent for a set $r$ of new services and $r \cap S_\sigma = \emptyset$ (or $r \cap S_\beta = \emptyset$, resp.) and $m_n, m_{n-2}$ coincide with exception of their types. The current negotiation state remains unchanged.
- If $m_n$ is a standstill move then the previous move $m_{n-1}$ is not an introduction/request move and $m_n = \langle standstill, \alpha_n, v_\alpha \rangle$
- If $m_n$ is a concession move then $m_n = \langle concede, \alpha_n, v_n \rangle$ and the previous move $m_{n-1}$ is not an introduce/request move, and
  - if $\alpha_n$ is the seller agent then $v_n \sqsupset_\beta v_\sigma$ and the new negotiation state is $\langle (\sigma, v_n), (\beta, v_\beta) \rangle$
  - if $\alpha_n$ is the buyer agent then $v_n \sqsupset_\sigma v_\beta$ and the negotiation state is $\langle (\sigma, v_\sigma), (\beta, v_n) \rangle$
- A service should not be requested or introduced twice.

A seller's positive reply move or introduction move for a set $r$ of new services where $r \cap S_\beta \neq \emptyset$ is basically an argument about a reward for the buyer agent represented in a short form. However, the move is not seen as a seller's concession since it does not suffer any loss in comparison with its previous offer.

A negotiation terminates successfully if one of the agents accepts an offer. The seller (or buyer, resp.) agent accepts an offer made in a concession move $m_n = \langle concede, \alpha_n, v_n \rangle$ by the buyer agent (or seller agent, resp.) if $v_n \sqsupseteq_\sigma v_\sigma$ (or if $v_n \sqsupseteq_\beta v_\beta$, resp.) where $\langle (\sigma, v_\sigma), (\beta, v_\beta) \rangle$ is the negotiation state after $m_{n-1}$.

A negotiation terminates with failure if the agents make three standstill moves consecutively. Two standstills are said to be consecutive if moves between them are only introduction, request, and negative reply moves.

**Definition 3.** *If a concession move leads to a successful termination, then the move is called a* finishing *move.*

**Definition 4.** *A contractual state $t'$ is said to be a* minimal concession of agent *$\alpha$ wrt $t$ about a package $p$ if $t, t' \in NS(p)$ and $t'$ is strictly preferred to $t$ for $\overline{\alpha}$ and for each contractual state $r \in NS(p)$, if $r$ is strictly preferred to $t$ for $\overline{\alpha}$ then $t'$ is preferred to $r$ for $\alpha$.*

**Definition 5.** *A contractual state $t'$ is said to be a* hasty concession of agent *$\alpha$ wrt $t$ about a package $p$ if $t'$ is a minimal concession of $\alpha$ wrt $t$ about $p$ and there exists a service $asr \notin p$ such that a minimal concession of $\alpha$ wrt $f^{\alpha}_{p,\{asr\}}(t)$ (about $p \cup \{asr\}$) is strictly preferred to $f^{\alpha}_{p,\{asr\}}(t')$ for $\alpha$.*

So if agent $\alpha$ makes a minimal concession move following an introduce/request move for *asr*, then it will reach a state which is preferred for it to the state if it makes the introduce/request move for *asr* following a minimal but hasty concession move.

**Definition 6.** *Reward-based minimal concession negotiation is a reward-based monotonic concession negotiation where each agent only makes a minimal concession in a concession move and no agent makes a hasty concession move or a finishing move if it can make a request or introduction move. Furthermore agent standstills only if its opponent standstills in previous step.*

The following proposition shows that request and introduction moves represent a simple but effective information-seeking dialogs (for honest agents).

**Proposition 1.** *If both seller agent $\sigma$ and buyer agent $\beta$ negotiate using the reward-based minimal concession strategy, then negotiation terminates successfully by a deal containing all services in $S_\sigma \cap S_\beta$.*

Let $deal(st_\sigma, st_\beta)$ denote the deal of negotiation if $\sigma, \beta$ use reward-based monotonic concession strategies $st_\sigma$, $st_\beta$ respectively. If the negotiation terminates in failure then $deal(st_\sigma, st_\beta)$ is assigned a special value $\perp$, which is less preferred to any deal for both agents.

**Proposition 2.** *For any reward-based minimal concession strategy $st_\sigma$ (or $st_\beta$, resp.) and any reward-based monotonic concession strategy $st_\beta$ (or $st_\sigma$, resp.), there exists a reward-based minimal concession strategy $st'_\beta$ (or $st'_\sigma$, resp.)such that $deal(st_\sigma, st'_\beta) \sqsupseteq_\beta deal(st_\sigma, st_\beta)$ (or $deal(st'_\sigma, st_\beta) \sqsupseteq_\sigma deal(st_\sigma, st_\beta)$,resp.).*

The following proposition shows that reward-based minimal concession strategies are equivalent.

**Proposition 3.** *If $st_\sigma, st_\beta, st'_\sigma, st'_\beta$ are reward-based minimal concession strategies then $deal(st_\sigma, st_\beta) = deal(st'_\sigma, st'_\beta)$*

A strategy is said to be in *symmetric Nash equilibrium* [14] if under the assumption that if one agent uses this strategy the other agent can not do better by not using this strategy. A strategy is said to be in *symmetric subgame perfect equilibrium* [15] if for each history of negotiation h, under the assumption that one agent uses this strategy starting from h, the other agent can not do better by not using this strategy starting from h.

It is not difficult to see:

**Theorem 1.** *The reward-based minimal concession strategy is in symmetric Nash equilibrium and symmetric subgame perfect equilibrium.*

## 3 Investor's decision making

Foreign investors often lease serviced land plots inside industrial estate to set up factories [1, 20, 18]. In this session we examine how an investor in computer assembly selects a location from Vietnam industrial property market.

### 3.1 The investor

Suppose an investor has analyzed computer market demand and decided to invest in assembly of low-end computers. To set up a computer assembly plant, the investor has to make decisions about technologies to be used in the plant, and location of the plant.
**Goals of the investor.** The investor wants to achieve

- structural goals related to technology choices, for example
  - ($g_1$) capacity of the plant could be easily adjusted to adapt to market demand
  - ($g_2$) enhancing the dynamics of assembly line (see $norm_2$ below)
- structural goals related to the location of the plant, for example
  - ($g_3$) qualified labour force is available at the location
  - ($g_4$) average wage does not exceed some threshold, e.g. \$1.3/*hour*
  - ($g_5$) the location is near a sea port
  - ($g_6$) the location is eligible for sufficient government investment incentives
- contractual goals related to industrial estate services
  - ($g_7$) reservation price for land lease is $\$.9m^2/month$
  - ($g_8$) reservation price for waste disposal is $\$.3m^2/month$

The investor determines the preferences over goals by ordering them according to their importance, for example, $g_3 \sqsupseteq g_1 \sqsupseteq g_6 \sqsupseteq g_2, g_5, g_9, h_3 \sqsupseteq g_4$, and encodes the order by numerical rankings such as $P(g_1) = 5$, $P(g_2) = 3$, $P(g_3) = 6$, $P(g_4) = 1$, $P(g_5) = 3$, $P(g_6) = 4$, $P(g_7) = 3$, $P(g_8) = 3$. High ranked goals include labour and capacity adjustment. This is because computer assembly mainly concerns manual operation, so labour takes important role. Capacity needs to be adjusted according to very high expected demand variability. Lower ranked goals include wage and sea port. This is because average wage in Vietnam is very low and transportation cost is not big in comparison with the computer price.

**Knowledge about technology choices.** Knowledge about technologies demonstrates the technical know-how of the investor. The most important decision about technology in computer assembly concerns the structure of the assembly process. There are two kinds of assembly lines[10]. In *parallel* line, the whole assembly process is completed by a small group of workers at one workstation. In *serial* line, the assembly process is divided into sub-processes which are completed at different workstations in a specific order. The investor should know the influence of a technology choice on his goals. For example, to decide between parallel or serial lines, he should be aware of the relations between different factors:

- $norm_1$ related to $g_1$(capacity adjustment). If market demand changes rapidly, the investor needs to be able to *adjust production capacity* quickly. In parallel line, increasing capacity requires a duplication of *workstations*. In serial line, increasing capacity requires adding more workers to assembly line. Hence, capacity adjustment in parallel line incurs the cost of redundant workstations while in serial line it incurs the cost of modifying *working procedures*
- $norm_2$ related to $g_2$(line dynamics). In serial line, workers in a workstation work under pressure from workers in other workstations of the same line. Workers at a workstation may work faster if they know that the next workstation is idle or they have just taken longer time completing the last unit, for fear that they are holding up the line. The effect of this behavior is that the line speed is maintained by workstations pushing and pulling material through the line, possibly enabling higher throughput than parallel line where no such inter-workstation pressure exists. This advantage of serial line is referred to as the *line dynamics*.
- $norm_3$ related to $g_3$(labour availability). Parallel line requires *higher labour force skill* than serial line. In parallel line, a worker is responsible for the assembly of the whole unit while in serial line, he is just responsible for completing tasks assigned to his workstation.
  - ($norm_{3.a}$) The investor classifies labour force skill of a location into *low* or *high*. Parallel line requires *high skill* labour force while serial line just requires *low skill* labour force [1]

[1] We assume a two-level classification for simplicity. The classification could be more than two.

  - ($norm_{3.b}$) The investor could improve labour force skill by organizing *training programs* in electronics.
- $rule_1$(uncertainties about labour skill). If there is no information about labour skill of a location, the investor can assume that it could be *either high or low.*

The investor should know factual information about technology, for example

- $fact_1$ related to $norm_1$
  - ($fact_{1.a}$) computer assembly only requires manual tools and inexpensive general purpose workstations. The cost for factory floor for redundant workstations is not significant. Thus the cost of redundant workstations for a capacity buffer can be *ignored*.
  - ($fact_{1.b}$) changing working procedure when workers are added or removed from serial line incurs a *significant throughput loss* because the line takes sometime to stabilize.

It follows from $norm_1$ and $fact_1$ that the investor can easily adjust the capacity of the plant if he selects parallel line. However, it is costly to do so if he selects serial line.
**Knowledge about locations.** The investor develops a set of criteria to evaluate suitability of a location as follows

- $norm_4$ related to $g_3$ (labour availability). Labour availability of a location is assessed by its *population*, e.g. greater than 40K, and its labour force qualification. Labour force is qualified when its *labour force skills* meets the requirements posed by selected technology.
- $norm_5$ related to $g_5$ (sea port accessibility). Location should be connected to a sea port by national roads with *distance smaller than*, e.g. 35km to reduce transportation cost because some computer components need to be imported by sea.
- $norm_6$ related to $g_6$ (incentives). Tax reduction for at least five years is considered as an attractive incentive.

Information of land plots for lease could be as follows

- *location*1: population is 45K; distance to sea port is 30km by national road; average wage is $\$1/hour$; tax reduction in the first three years of any investment; there is an on-site electronics training center.
- *location*2: population is 46K; distance to sea port is 35km by national road; average wage is $\$1.5/hour$; tax reduction in the first eight years of any investment; the estate manager is considering building either a training center in electronics or a mansion on site; IT industry is encouraged by rental cost reduction.
- $rule_2$ (uncertainties about estate facilities). If there is no information about whether the estate manager (of *location*2) is going to develop a mansion or a training center, the investor assumes that he could develop either facility.

**Decision analysis.**With two candidate locations and a technology choice between serial and parallel, the investor has four options as follows: $(location1, serial)$, $(location1, parallel)$, $(location2, serial)$, $(location2, parallel)$. The satisfaction of goals wrt the above four options are summarized in Table 1. Option $(location1, parallel)$ satisfies goal $g_1$ because of $norm_1$ and $fact_1$; and dissatisfies $g_2$ because of $norm_2$. Option $(location2, parallel)$ neither satisfies nor dissatisfied goal $g_3$. This is because there is no information about labour skill, nor a planing to build training center or mansion of *location2*. By $rule_2$, the investor infers that estate management could build either facility. By $rule_1$, the investor can assume that the labour skill is either high or low. If the investor believes the labour skill is high, or a training center will be built, then by $norm_3$ and $norm_4$, goal $g_3$ will be satisfied; otherwise, $g_3$ will be dissatisfied. Thus, for a risk-averse agent, option

**Table 1.** Investor's goal satisfaction

| Goals | Rank | Location 1 | | Location 2 | |
|---|---|---|---|---|---|
| | | Serial | Parallel | Serial | Parallel |
| ($g_1$): Capacity adjustment | 5 | No | Yes | No | Yes |
| ($g_2$): Line dynamics | 3 | Yes | No | Yes | No |
| ($g_3$): Labor | 6 | Yes | Yes | Yes | Undetermined |
| ($g_4$): Wage | 1 | Yes | | No | |
| ($g_5$): Sea port | 3 | Yes | | Yes | |
| ($g_6$): Incentives | 4 | No | | Yes | |

$(location1, parallel)$ is the most favoured.

### 3.2 Formal representation of the investor agent

The investor agent is represented by a triple $< G, P, B >$ where,

- goal-base $G = G^{struct}_{location} \cup G^{struct}_{tech} \cup G^{contr}$, where
  - $G^{struct}_{tech}$ consists of structural goals related to technology choices: $(g_1)$ $capacityAdjustment$; $(g_2)$ $lineDynamics$.
  - $G^{struct}_{location}$ consists of structural goals related to location: $(g_3)$ $labourAvailability$; $(g_4)$ $wage < \$1.3/hour$; $(g_5)$ $seaPortAccessibility$; $(g_6)$ $incentives$.
  - $G^{contr}$ consists of contractual goals: $(g_7)$ $rental \leq \$.9/m^2/month$; $(g_8)$ $wasteDisposal \leq \$.3/m^2/month$.
- preference-base : $P(g_1) = 5$, $P(g_2) = 3$, $P(g_3) = 6$, $P(g_4) = 1$, $P(g_5) = 3$, $P(g_6) = 4$, $P(g_7) = 3$, $P(g_8) = 3$.
- the belief-base $B$ is an ABA framework $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{\phantom{x}} \rangle$, where
  - $\mathcal{R} = R_i \cup R_n \cup R_c \cup R_f$,where
    - $R_i$ represents information about locations

      **Representation of information about location 1:**

$pop = 45K \leftarrow location1$; $distanceToSeaPort = 30km \leftarrow location1$;
$nationalRoad \leftarrow location1$; $wage = \$1/hour \leftarrow location1$;
$yearsOfTaxReduction(3) \leftarrow location1; trainingCenter \leftarrow location1$.
**Representation of information about location 2:**
$pop = 46K \leftarrow location2$; $distanceToSeaPort = 35km \leftarrow location2$;
$nationalRoad \leftarrow location2$; $wage = \$1.5/hour \leftarrow location2$;
$yearsOfTaxReduction(8) \leftarrow location2$.

- ∗ $R_n = R_n^{tech} \cup R_n^{location}$, where
  - · $R_n^{tech}$ consists of representation of norms about technologies as well as rules representing uncertainties
    **Representation of** $norm_1$**:**
    $capacityAdjustment \leftarrow parallel, asm1$;
    $difficultToAddWorkstations \leftarrow highCostForRedundantWorkstations$;
    $capacityAdjustment \leftarrow serial, asm2$;
    $difficultToAddWorkers \leftarrow expensiveToChangeProcedure$.
    **Representation of (the conclusion in)** $norm_2$**:**
    $lineDynamics \leftarrow serial$.
    **Representation of** $norm_3$**:**
    $qualification \leftarrow parallel, highSkill$; $qualification \leftarrow serial$;
    $highSkill \leftarrow trainingCenter$.
    **Representation of** $rule_1$**:**
    $lowSkill \leftarrow notHighSkill$; $highSkill \leftarrow notLowSkill$.
    **Representation of** $rule_2$**:**
    $mansion \leftarrow notTrainingCenter, location2$;
    $trainingCenter \leftarrow notMansion, location2$.
  - · $R_n^{location}$ consists of representation of norms about location
    **Representation of** $norm_4$**:**
    $labourAvailability \leftarrow pop > 40K, qualification$.
    **Representation of** $norm_5$**:**
    $seaPortAccessibility \leftarrow distanceToseaPort < 35km, nationalRoad$.
    **Representation of** $norm_6$**:**
    $incentives \leftarrow yearsOfTaxReduction(X), X \geq 5$.

- ∗ $R_f$ consists of
  **Representation of** $fact_1$:
  $lowCostForRedundantWorkstations \leftarrow; expensiveToChangeProcedure \leftarrow$.

- $\mathcal{A} = A_d \cup A_c \cup A_u$, where
  - ∗ $A_d = A_d^{tech} \cup A_d^{location}$, where
    - · $A_d^{tech} = \{serial, parallel\}$ are assumptions representing technology choices
      $\overline{serial} = parallel$; $\overline{parallel} = serial$.
    - · $A_d^{location} = \{location1, location2\}$ are assumptions representing location choices
      $\overline{location1} = location2$; $\overline{location2} = location1$.
  - ∗ $A_c = \{asm1, asm2\}$ are control assumptions related to norms
    $\overline{asm1} = difficultToAddWorkstations$; $\overline{asm2} = difficultToAddWorkers$.

* $A_u = \{notLowSkill, notHighSkill, notTrainingCenter, notMansion\}$ are assumptions representing uncertainties about locations. $\overline{notHighSkill} = highSkill$; $\overline{notLowSkill} = lowSkill$; $\overline{notTrainingCenter} = trainingCenter$; $\overline{notMansion} = mansion$.

**The investor agent's decision analysis**. Table 2 shows structural goal states and their min satisfied by the composite decision. For example, $g_2$ is credulously satisfied by option $(location1, serial)$ -assumptions contained in the preferred extension $\{location1, serial, asm1, notLowSkill\}$. As a risk-averse decision maker, the value of an option is the min of all its goal states. So, he considers the value of option $(location2, parallel)$ is $\{g_1, g_5, g_6\}$.

**Table 2.** Investor's preferred extensions

| Decisions | Preferred extensions | | Goal states | Min |
|---|---|---|---|---|
| | Control asm. | Uncertainties | | |
| (Location1,serial) | asm1 | notLowSkill | $g_2, g_3, g_4, g_5$ | $g_2, g_3, g_4, g_5$ |
| (Location1,parallel) | asm1 | notLowSkill | $g_1, g_3, g_4, g_5$ | $g_1, g_3, g_4, g_5$ |
| (Location2,serial) | asm1 | notLowSkill,notTrainingCenter | $g_2, g_3, g_5, g_6$ | $g_2, g_3, g_5, g_6$ |
| | | notLowSkill,notMansion | | |
| | | notHighSkill,notTrainingCenter | | |
| | | notHighSkill,notMansion | | |
| (Location2,parallel) | asm1 | notLowSkill,notTrainingCenter | $g_1, g_3, g_5, g_6$ | $g_1, g_5, g_6$ |
| | | notLowSkill,notMansion | $g_1, g_3, g_5, g_6$ | |
| | | notHighSkill,notTrainingCenter | $g_1, g_5, g_6$ | |
| | | notHighSkill,notMansion | $g_1, g_3, g_5, g_6$ | |

## 4 Design for implementation

An agent could be implemented by two separate modules. The first module is for internal decision making and the second is for bargaining. The first module is the direct translation of the agent formal representation into CaSAPI [2] and MARGO [3]. The second module is the implementation of the reward-based minimal concession strategy. A sample fragment of the seller agent's second module is as follows. We assume the agent possesses a function $f_{concede}$ to compute its next minimally conceded offer, function *noOfStandstills*() to return the number of consecutive standstills in the negotiation, and function $notHasty(S_\sigma, p, v_\sigma, f_{concede})$ defined as $\forall asr \in S_\sigma . f^{\sigma}_{p,\{asr\}}(f_{concede}(v_\sigma)) =_\sigma f_{concede}(f^{\sigma}_{p,\{asr\}}(v_\sigma))$ to check if a concession is not hasty.

[2] www.doc.ic.ac.uk/ dg00/casapi.html

[3] http://margo.sourceforge.net/

1. The seller opens the negotiation by offering to sell the main service at the buyer's reservation value.
   $O(1, start, \beta, \{msr\}, \lambda_\sigma(s)) \leftarrow$
2. The buyer replies by offering to buy it at the seller's reservation value.
   $O(2, start, \sigma, \{msr\}, \lambda_\beta(s)) \leftarrow$
3. Suppose now that the seller has its turn at the $n^{th}$ move in the negotiation, $S_\sigma$ contains only value-added services not introduced yet, and the negotiation after state $m_{n-1}$ is $\langle p, (\sigma, v_\sigma), (\beta, v_\beta)\rangle$.
   (a) If the buyer standstills then the seller also standstills.
   $O(n, standstill, \sigma, p, v_\sigma) \leftarrow O(n-1, standstill, \beta, \_, \_)$
   (b) If the buyer requests a set $r$ of services then the seller replies
      i. positively if he can provide
      $O(n, reply, \sigma, p \cup r', V) \leftarrow O(n-1, request, \beta, p \cup r, \_), r' = r \cap S_\sigma, r' \neq \{\}, V = f^{\sigma}_{p,r'}(v_\sigma)$
      ii. negatively otherwise.
      $O(n, reply, \sigma, p, v_\sigma) \leftarrow O(n-1, request, \beta, p \cup r, \_), r \cap S_\sigma = \{\}$
   (c) If the buyer replies or concedes then
      i. if the seller has services then
         A. he either introduces
         $O(n, introduce, \sigma, p \cup r, V) \leftarrow O(n-1, t, \beta, p, v_\beta), t \in \{reply, concede\}, r \subseteq S_\sigma, V = f^{\sigma}_{p,r}(v_\sigma)$
         B. or concedes provided that this is not a finishing or hasty concession move
         $O(n, concede, \sigma, p, V) \leftarrow O(n-1, t, \beta, p, v_\beta), t \in \{reply, concede\}, V = f_{concede}(v_\sigma), v_\beta \sqsupset_\beta V, notHasty(S_\sigma, p, v_\sigma, f_{concede})$
      ii. else, the seller concedes.
      $O(n, concede, \sigma, p, V) \leftarrow O(n-1, t, \beta, p, v_\beta), t \in \{reply, concede\}, S_\sigma = \{\}, V = f_{concede}(v_\sigma)$
   (d) The seller accepts an offer made in a concession move $m_{n-1}$ of the buyer if $v_{n-1} \sqsupseteq_\sigma v_\sigma$
   $StopAndAccept \leftarrow O(n-1, concede, \beta, p, v_{n-1}), v_{n-1} \sqsupseteq_\sigma v_\sigma$
   (e) The negotiation terminates in failure if there are three consecutive standstills.
   $StopInFailure \leftarrow noOfStandstills() = 3$

The design of the module for bargaining of the buyer is similar.

## 5 Conclusion

We have extended the two-phase contract negotiation framework[8] where by in the first phase a buyer agent decides on items fulfilling its structural goals, and in the second phase it negotiates with the agent selling the item determined in the first phase to agree on a contract. The new framework improves on its predecessor by allowing agents to exchange information about each other's needs and capabilities during negotiation to change negotiated items. It also drops the assumption that the seller has no structural goals (we do not present the seller's part due to the lack of space). Our new framework, like its predecessor, allows agents to achieve Nash and subgame perfect equilibria.

The first phase is supported by a decision-making mechanism using argumentation and preferences. A number of such decision-making mechanisms exist, e.g. [11, 16, 12, 3]. This argument-based framework can deal with decision making, uncertainties and negotiation. However, we have restricted ourself only to a simple and ideal case where we assume that the agents are honest and open to each other, and ignore the need of information-seeking in the first phase. The second phase is also supported by argumentation with only reward-based arguments. We plan to explore other types of arguments and define a communication machinery to support information-seeking in the future.

We have illustrated our approach using a scenario studied in the ARGUGRID project [4]. We believe that our approach could be fruitfully applied to scenarios where a buyer negotiates for a current item and plans possible subsequent encounters with the same seller for additional items. For example, negotiation between a car seller and buyer may cover possible after-sale services.

Several works exist on argumentation-based negotiation [17]. For example, [21] propose a protocol and a communication language for dealing with refusals in negotiation. It would be useful to see how this protocol and communication language may be used to support the two-phase negotiation framework we have defined. Also, [2] presents an abstract negotiation framework whereby agents use abstract argumentation internally and with each other. Our framework instead is tailored to the very common case in business and assumes a very concrete and structured underlying argumentation framework.

Our reward-based monotonic minimal concession strategy for fair agents is inspired by the monotonic concession protocol of [23], though it differs from it in significant ways. In our framework the agent moves alternatively where in [23] they move simultaneously. The condition for terminating the negotiation is also different. As a result, the minimal concession strategy is in symmetric subgame perfect equilibrium in our framework while the corresponding strategy in [23] is not even in symmetric Nash equilibrium. We do not use an explicit function of utilities to calculate a notion of risk to determine the player who should make the next concession as in [23] as research into practical negotiation behavior [19] shows that a strategy of making a large concession and then expects the other player to match is not a sound practical negotiation strategy as the other player often then discounts such concession as not important to the player who made it.

In this paper we have considered just two agents, not within multi-agent systems as in other existing works, e.g. [9, 22] and focused instead on the full negotiation process, from the identification of issues to bargain about to the actual bargaining, thus linking argumentation-based decision making to the monotonic concession protocol.

[4] `www.argugrid.eu`

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