The Double Knapsack Negotiation Problem: Modeling Cooperative Agents and Experimenting Negotiation Strategies

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Abstract. This paper presents a novel approach to the well-known Knapsack problem, extending it as a bilateral negotiating problem with default information where each of the two agents has a knapsack and there is a set of items distributed between them. The agents can exchange items in order to reach their goal: fill their knapsacks with items without exceeding their capacity with the aim of maximizing their utility function. Initially the agents do not have any information about their counterpart, e.g. the exact weight of their items and their associated values, so that they consider default assignments for them. This default information can change as the negotiation progresses. A sequential negotiation protocol is proposed, along with different strategies of information exchange and the results obtained when the agents negotiate using them. Information transfer efficiency is assessed in terms of the overall usefulness, quantity of information disclosed and negotiation duration.

Keywords: Automatic negotiation · Bilateral negotiation · Knapsack problem · Default knowledge · Negotiation strategies

1 Introduction

Negotiation is an interaction that happens in multi-agent systems when agents have conflicting objectives and must look for an acceptable agreement. A typical negotiating situation involves two agents that have items to exchange and they are willing to cooperate in order to improve their situations. Therefore, they must start a negotiation dialogue taking into account that they might have incomplete or wrong information about the other agent's goals and items.

Different approaches can be used to model negotiation in multiagent systems. Rahwan et al. [1] distinguish three different kinds of such approaches: those

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which are *game-theoretic*, those which are *heuristic-based*, and finally those based on *argumentation* (*argumentation-based negotiation* or ABN). Game-theoretic approaches are based on studying and developing strategic negotiation models using game-theory precedents [2]. At present, there is no agreed approach to characterize all negotiation frameworks. However, in [3] it has been argued that automated negotiation research can be considered to deal with three broad topics: *a) Negotiation Protocols* (the set of rules that govern the interaction); *b) Negotiation Objects* (the range of issues over which agreement must be reached) and *c) Agents' Decision Making Model* (which accounts for the decision making apparatus the participants employ to act in line with the negotiation protocol in order to achieve their objectives). ABN approaches emphasize the impact of the information exchanged with the proposals in the negotiating process [4]. In this work we address how negotiating agents can select the information exchanged and the impact each selection has in the negotiation process. For this analysis we formalize an extended version of the well-known Knapsack problem.

In the classical Knapsack problem an agent Ag has a knapsack and a set N of items, so that each item $r_i \in N$ has an associated weight ω_i given by the problem definition and a value v_i, representing the benefit the item means for the agent. The problem that the agent faces is to fill *his knapsack* (that supports a maximum weight c, i.e. its capacity) so that the sum of the values of the objects he chooses is maximal. We present a novel, extended version of this problem, modeling it as a bilateral negotiation problem with incomplete information, providing a negotiation model for the analysis and comparison of different strategies. We will assume a scenario with two agents; each of them has a knapsack and a finite set of items. The capacities of their respective knapsacks are known by both agents. The agents can negotiate some exchange of items in order to maximize their own utility function, given by the sum of the values of the items to be put into each knapsack. We assume that initially the agents do not know the weight of the items of their counterpart and the value he has assigned to all the items involved in the problem. Consequently, the agents can compensate this lack of information with default knowledge (possibly inaccurate) about their counterpart. During the dialog, an agent may give an argument to support a claim associated with what he has to offer, revealing some private information which is made available to the other agent.

In this work we propose a negotiation model and a sequential protocol for the agents involved, and we analyze different negotiation strategies, focusing on the selection of the information items the agents reveal in their messages. To compare the proposed strategies we carried out some experiments on different problem instances of the extended version of the Knapsack problem. Then, the information transfer efficiency is empirically assessed in terms of the overall utility, the amount of information disclosed and the negotiation duration. The rest of this paper is structured as follows: next, in Section 2 we provide a generic description of the problem and its underlying formalization. In Section 3 we define the negotiation protocol, and in Section 4 different information concession strategies were proposed. Section 5 summarizes the empirical results obtained, analyzed according to different dimensions. Finally, Section 6 discusses related and future work, and summarizes the main conclusions that have been obtained.

2 Problem Definition and Modeling

We assume that two agents Ag^0 and Ag^1 have knapsacks with capacities c^0 and c^1, resp. This information is known by both agents. They also know that there is a set of N items distributed between them, such that N^j is the set of items that initially the agent Ag^j has, and that all items are distributed between the two agents, i.e. $N = N^0 \cup N^1$ and $N^0 \cap N^1 = \emptyset$. Each item $r_i \in N^j$ has a weight ω_i; this information is initially known only by the agent Ag^j who owns the item and is estimated with $\widehat{\omega}_i$ by the other agent. Besides, we assume that the item r_i will produce a profit of v_i^j to Ag^j, and he can also estimate that this item produces a profit of $\widehat{v}_i^j$ to its counterpart Ag^{1-j}. These default values are part of an agent's beliefs, and may be updated during the negotiation dialog.

2.1 Agent Model

In what follows, for the sake of simplicity we will only refer to Ag^j (one of the two agents involved). The elements identified can be made extensible to the other agent as well. Let Ag^j be one of the negotiating agents. The mental state of Ag^j represents all the information he has about the knapsack problem: the items he initially has and his beliefs about his counterpart i.e.: Ag^j's mental state will take into account the weight of his items (W^j), his items values (V^j) and his beliefs about his opponent's items values ($\widehat{V}^j$) and weights ($\widehat{W}^j$). Formally:

$$\begin{aligned} W^j &= (\omega_1^j, ..., \omega_{|N^j|}^j) & V^j &= (v_1^j, ..., v_{|N|}^j) \\ \widehat{W}^j &= (\widehat{\omega}_1^j, ..., \widehat{\omega}_{|N^{1-j}|}^j) & \widehat{V}^j &= (\widehat{v}_1^j, ..., \widehat{v}_{|N|}^j) \end{aligned}$$

Notice that V^j and W^j do not change during the negotiation, whereas $\widehat{V}^j$ and $\widehat{W}^j$ contain default information that may change during an agent's updating belief process as the negotiation dialog occurs.

The following sets characterize the agents belief: *Private Information* (I^j), which accounts for that personal information that was not informed yet in the negotiation dialogue; *Public Information* (P^j), which accounts for personal information that has been given out in the negotiation dialogue and *Default Information* ($\widehat{I}^j$), which accounts for information that is unknown, but tentatively assumed. Initially $P^j = \{c^j, c^{1-j}, N^j, N^{1-j}\}$, $I^j = \{\omega_i | r_i \in N^j\} \cup \{v_i^j | r_i \in N\}$ and $\widehat{I}^j = \{\widehat{\omega}_i | r_i \in N^{1-j}\} \cup \{\widehat{v}_i^{1-j} | r_i \in N\}$.

The decision making apparatus an agent employs to decide his negotiation actions depends on his mental state. This apparatus will be in charge of computing those messages the agent will send to the other agent.

The first dialogue message associated with the initial proposal will be singled out by using an initialization function *Init*. A belief revision process and further proposals are computed by another function *Response*. In the following definition we formalize these concepts.

Definition 1 (Agent Model). *An agent* Ag^j *is defined as*
$Ag^j := \langle Ms^j, Init^j, Response^j \rangle$*, where* $Ms^j = \langle W, \widehat{W}, V, \widehat{V}, P, I, \widehat{I} \rangle$[1] *is the agent mental state,* $Init^j : Ms^j \rightarrow Message$ *is the function associated with starting the negotiation and* $Response^j : Ms^j \times Message \rightarrow Ms^j \times Message$ *is the function associated with generating new message.*

For every agent, his aim is to maximize the total utility of their respective knapsacks. In order to do so, they proceed in a negotiation dialogue, exchanging proposals of possible exchanges (which are the items the agent is asking for and what he is willing to offer in return) and some private information they decide to share.

A dialogue between the two agents will be defined as a finite sequence of messages performed alternatively by each of the agents involved in the dialogue, ending with *accept* (there is a deal) or *withdraw* (no deal is possible).

Definition 2 (Message). *A message is defined as:*

$$Message := (x, \Lambda) \mid Accept \mid Withdraw$$

where x *is a proposal to exchange and reallocate items,* Λ *is private information the sender reveals. The Accept and* $Withdraw$ *messages are used to indicate the end of the dialogue.*

A proposal of items exchange and allocation is defined as a tuple where Ag^j proposes the items to be exchanged (X_e^j, X_e^{1-j}) together with its support (X_s^j, X_s^{1-j}). Formally:

Definition 3 (Proposal). *Let* $m^j = (x, \Lambda)$ *be a message sent by* Ag^j*,*

- *A proposal* x *to exchange and reallocate items is defined as* $x = (X_s^j, X_e^j, X_e^{1-j}, X_s^{1-j})$ *where:*

  1. $X_s^j \cup X_e^j \subseteq N^j$
  2. $\sum_{r_i \in X_s^j} W_i^j + \sum_{r_i \in X_e^{1-j}} \widehat{W}_i^j \leq c^j$
  3. $X_s^{1-j} \cup X_e^{1-j} \subseteq N^{1-j}$
  4. $\sum_{r_i \in X_e^j} W_i^j + \sum_{r_i \in X_s^{1-j}} \widehat{W}_i^j \leq c^{1-j}$

  this proposal suggests to exchange the set of items X_e^j *for* X_e^{1-j} *and also suggests to fill* Ag^j*'s knapsack with* $X_s^j \cup X_e^j$*, where* X_s^j *represents the items he already has (i.e the exchange support) and* X_e^j *the items he is asking for exchange.*

- $\Lambda \subseteq I^j$ *stands for the private information that the agent* Ag^j *chooses to disclose.*

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[1] Notice that these sets include redundant information; however this representation helps to make clearer the different negotiation processes involved in our model. When it is understood which is the agent Ag^j the superscript j is omitted.

As the agents initially may have wrong information about their counterpart (i.e. items weight and values), during the negotiation dialog they update their beliefs (and consequently their mental state) according the messages exchanged. Thus, in the context of the ABN framework [5] we will use a belief update approach for the argument interpretation.

Definition 4 (Belief Update). *Let* Ms^0_t *and* Ms^1_t *the agents mental state at time* t*, and* $m^0_{t+1} = (x, \Lambda)$ *a message sent by* Ag^0*. Then the agent* Ag^0 *updates his beliefs transferring the information he has revealed from private to public information set as follows*[2]*:*

1. $Ms^0_{t+1}.P = Ms^0_t.P \ \cup \Lambda$
2. $Ms^0_{t+1}.I = Ms^0_t.I \ - \Lambda$

On the other hand, the agent Ag^1 *updates his beliefs replacing the assumed values by the ones revealed in the message, making as well this information part of the public information set. Formally:*

1. $Ms^1_{t+1}.\widehat{W}_i = \begin{cases} \omega_i & \text{if } \omega^0_i \in \Lambda \\ Ms^1_t.\widehat{W}_i & \text{if } \omega^0_i \notin \Lambda \end{cases}$
2. $Ms^1_{t+1}.P = Ms^1_t.P \ \cup \Lambda$
3. $Ms^1_{t+1}.\widehat{V} = \begin{cases} v^0_i & \text{if } v^0_i \in \Lambda \\ Ms^1_t.\widehat{V}_i & \text{if } v^0_i \notin \Lambda \end{cases}$
4. $Ms^1_{t+1}.\widehat{I} = Ms^1_t.\widehat{I} \ - \Lambda$

When an agent receives a proposal, he computes its expected utility as the maximum of the utility that can be obtained if the exchange is made, considering the different possibilities to fill his backpack according to that proposal.

Definition 5 (Utility). *Given a proposal* $x = (X^j_s, X^j_e, X^{1-j}_e, X^{1-j}_s)$*, the utility expected for an agent* Ag^j *is defined as:*

$$U^j(x) = \max \sum_{r_i \in X^j_s \cup X^{1-j}_e} V^j_i$$
$$s.t. \sum_{r_i \in X^j_s} W^j_i \ + \sum_{r_i \in X^{1-j}_e} \widehat{W}^j_i \leq c^j$$

whereas Ag^j*'s expected utility wrt his counterpart will be defined as:*

$$\widehat{U}^j(x) = \max \sum_{r_i \in X^j_e \cup X^{1-j}_s} \widehat{V}^j_i$$
$$s.t. \sum_{r_i \in X^j_e} W^j_i \ + \sum_{r_i \in X^{1-j}_s} \widehat{W}^j_i \leq c^{1-j}$$

In negotiation theory, the *Best Alternative to a Negotiated Agreement* (or BATNA for short) is the course of action that will be taken by a party if the current negotiations fail and an agreement cannot be reached [6]. In our scenario, the BATNA is the proposal that maximizes the utility of the agents without exchanging items.

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[2] We use dot notation in order to represent the agent's mental state components, e.g. $Ms^j.P$ represents the private information of Ag^j.

Definition 6 (BATNA). *Each Ag^j believes that the Best Alternative to a Negotiated Agreement is defined as:*

$$bat^j = (X_s^j, X_e^j, X_e^{1-j}, X_s^{1-j}) = \arg\max\{U^j(x) + \widehat{U}^j(x) \mid X_e^j = X_e^{1-j} = \emptyset\}$$

If the negotiation break down the agent Ag^j expect to receive $U^j(bat^j)$, and he expect that his counterpart receives $\widehat{U}^j(bat^j)$. Therefore agents will try to suggest proposal with benefit greater than the BATNA benefit.

3 Negotiation Protocol

The Monotonic Concession Protocol is used in problems with complete information [2] where it is assumed that each agent is fully aware of the utility function of its counterpart. This protocol is performed in rounds such that in each round both agents make simultaneously a proposal; in the first round each agent is free to make any proposal, whereas in the following rounds each agent can make an utility concession, i.e. make the new proposal to improve the usefulness of the counterpart about the latest proposal or stay in the previous proposal.

3.1 Protocol Based on Disclosure of Information/Utility

We focus on incomplete information problems where the negotiating agents have beliefs (probably erroneous) about each other. Based on the Monotonic Concession Protocol, we propose a novel protocol where agents can make a concession either regarding *utility* (making a new proposal that improves the expected usefulness of the counterpart compared to the last proposal made) or regarding *information* (revealing private information not disclosed earlier).

The protocol between the two agents is determined by a finite sequence of messages $[m_1^0, m_2^1, m_3^0, m_4^1, ...]$ sent alternately by each agent[3], where each message m_t^j has the form according Definition 2, we will say that an agent concedes information if a message $m_{t+1}^0 = (x, \Lambda)$ is sent, such that Λ contains information that was not disclosed previously. Formally:

Definition 7 (Concession of Information). *We will say that Ag^0 concedes information in the message $m_{t+1}^0 = (x, \Lambda)$ iff $\Lambda \nsubseteq \Lambda_{t-1} \cup \Lambda_{t-3}..\Lambda_0$. This is denoted as $C_I^0(m_{t+1}^0)$*

Similarly, we will say that an agent concedes utility whenever he believes that the proposal sent in message $m = (x, \Lambda)$ is such that the expected utility for its counterpart represents an improvement compared to the last proposal made. Formally :

Definition 8 (Concession of Utility)

1. *Ag^1 concedes utility to Ag^0 in message m_t^1 iff $U^0(m_t^1.x) > U^0(m_{t-2}^1.x)$. This is denoted as $C_U^0(m_t^1)$*

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[3] Without loss of generality we assume that Ag^0 initiates the negotiation.

2. *Ag^1 believes that he has conceded utility to Ag^0 in message m^1_t iff $\widehat{U}^1(m^1_t.x) > \widehat{U}^1(m^1_{t-2}.x)$ This is denoted as $\widehat{C}^1_U(m^1_t)$*

We will define a protocol based on concession of information and concession of utility as follows:

Definition 9 (Protocol). *Let $[...m^0_{t-3}, m^1_{t-2}, m^0_{t-1}, m^1_t, m^0_{t+1}]$ be the last part of a dialogue between the two agents. Then m^0_{t+1} is defined as follows:*

1. *accept iff $U^0_t(m^1_t.x) \geq U^0_t(m^0_{t-1}.x)$.*
2. *withdraw iff*
   $\neg C^0_I(m^0_{t-3}) \wedge \neg C^1_I(m^1_{t-2}) \wedge \neg C^0_I(m^0_{t-1}) \wedge \neg C^1_I(m^1_t) \wedge \neg \widehat{C}^0_U(m^0_{t-1}) \wedge \neg C^0_U(m^1_t)$
3. *(x, Λ) such that $U^j(x) \geq U^j(bat^j)$ and $\widehat{U}^j(x) \geq \widehat{U}^j(bat^j)$ Otherwise.*

Note that (1) indicates that Ag^j will accept those proposals whose utility is the same or better than the last proposal advanced by the agent itself; (2) indicates that the agent will abandon the negotiation if there was no information concession in the last four messages, nor utility concession in the last two messages; and (3) another proposal will be presented if the previous cases do not hold. Such proposal must better than the BATNA.

4 Negotiation Strategies Based on Information Concession

In this paper, we explore the results of the bilateral negotiation in the Knapsack problem according to different strategies the agents use to disclose information in their messages. Thus, the information that an agent reveals with a proposed exchange can be considered as a *justification* of the current proposal or a *critique* to the last received proposal. An agent can also give private information on items that are considered more or less valuable for him, or information about a random item, among other alternatives. Below, we formalize some of these strategies, analyzing then the results obtained in different experiments we conducted with negotiating agents. For the The Double Knapsack Negotiation Problem, we propose different negotiation strategies in which the agents choose a set Λ containing information's items to reveal.

We assume that in all the alternatives the information an agent communicates is private (i.e. it is fully accurate and associated with his own beliefs) and has not been made public previously in the negotiation process. In our context, the following information concession strategies are defined:

1. **Random:** the agent selects a random item r_i. If $r_i \in N^j$ then he reveals v^j_i and ω_i; otherwise he only communicates v^j_i.
2. **Max:** the intuition behind the Max strategy is that the agent reveals the information of the item that has *the maximum relative value* for him. He first selects $r_i \in N$ such that it maximizes v^j_i/ω_i and reveals v^j_i. Then, he chooses $r_i \in N^j$, maximizing v^j_i/ω_i, and reveals ω_i.

3. **Min:** in analogous way than in the previous strategy, the agent communicates the information of the item that has *the minimum relative value.* Firstly, he selects $r_i \in N$ such that he minimizes υ_i^j/ω_i and reveals υ_i^j. Then, he chooses $r_i \in N^j$, minimizing υ_i^j/ω_i, and communicates ω_i.
4. **Dissimilar:** in this strategy the agent communicates the information related to items r_i such that his current proposal differs from the last received proposal. It can be seen as a justification of his counterproposal based on the differences. Formally, let $x = (X_s^0, X_e^0, X_e^1, X_s^1)$ be the proposal made by Ag^{1-j} and $Y = (Y_s^0, Y_e^0, Y_e^1, Y_s^1)$ the current proposal of Ag^j then, Ag^j does not reveal ω_i, υ_i^j if $r_i \in (X_s^0 \cap Y_s^0) \cup (X_e^0 \cap Y_e^0) \cup (X_e^1 \cap Y_e^1) \cup (X_s^1 \cap Y_s^1)$
5. **Similar:** this approach is complementary to the previous one, since it communicates all items where there is an overlap between the counterproposal and the last received proposal. Formally let $x = (X_s^0, X_e^0, X_e^1, X_s^1)$ be the proposal made by Ag^{1-j} and $Y = (Y_s^0, Y_e^0, Y_e^1, Y_s^1)$ the Ag^j current proposal then, Ag^j revels ω_i, υ_i^j if $r_i \in (X_s^0 \cap Y_s^0) \cup (X_e^0 \cap Y_e^0) \cup (X_e^1 \cap Y_e^1) \cup (X_s^1 \cap Y_s^1)$

It must be remarked that every negotiation process using some of the above strategies concedes information, since agents are allowed to concede pieces of knowledge until all possible individual knowledge has been disclosed. If such is the case, then both agents will accept the resulting solution to the problem.

5 Experiments and Results

We have implemented different kinds of negotiating agents following the proposed model and selecting –in each case– one of the five strategies we have defined in the previous Section 4. We have conducted a number of experiments, where both agents use the same strategy, with the aim of comparing the results of the negotiation process in terms of the total utility gained, information revealed and duration of the negotiation. Next, we present the experiments that were carried out and the results obtained.

Experiments Design: We have run 30 negotiating simulations for problems of size N (i.e. number of items), experimenting with $N = 6 \ldots 40$. In all the negotiation problems the two agents have been assigned $N/2$ items and each knapsack was assumed to support a maximum weight of 550. The items weight ω_i were generated randomly in the range [50..100] and the items value υ_i^j were also random values in the range [30..80]. The default knowledge each agent initially was also set randomly with an accuracy of ±30.

We assume as well that both agents are trustworthy (no false information is communicated on purpose). The agents send messages (x, Λ) where x is the proposal for exchanging items and Λ accounts for information that the agent is willing to reveal according to the strategy selected.

The generated proposal x corresponds to the assignment that maximizes $\lambda U^j(x) + (1-\lambda)\widehat{U^j}(x)$, where $\lambda \in [0,1]$ is a parameter that allows to weigh his own estimated utility and the estimated utility for its counterpart. Different values for λ can represent how "collaborative" the agent is when generating proposals (i.e. different agent personalities). If $\lambda = 1$ then, the agent is assessing only his own utility (selfish agent), whereas $\lambda = 0$ stands for a totally generous agent. An intermediate value, i.e. $\lambda = 0.5$, can be assumed to represent equitable agents which combine both utilities with the same weight. For our experiments we have considered that both agents are equitable ($\lambda = 0.5$).

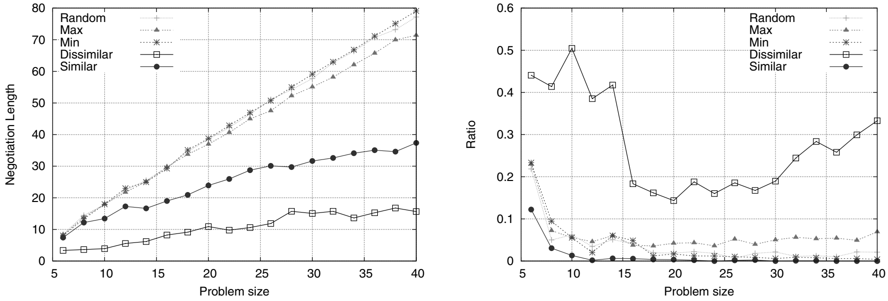
The aim of the experiments is to analyze the outcomes of the negotiating agents using the five strategies. The results to be analyzed are:

- *The negotiation length:* number of messages exchanged during the negotiating process.
- *The hiding of information:* the ratio of information items that were not revealed in the negotiation process respect to the total of private items in the problem.
- *Expected-Real Efficiency ratio:* the rate of the expected utility value of the reached agreement, with respect to the utility obtained after carrying out the exchange of items.
- *Expected-Optimal Efficiency ratio:* the rate of the expected utility value of the reached agreement, with respect to the utility obtained in the outcome of the same negotiation problem under complete information.

Results: Figure 1a shows the average over the number of messages per negotiation for different sizes of negotiating problems. As the strategies *Dissimilar* and *Similar* can exchange more information items in each message, they tend to reach faster a negotiation agreement than the other ones, requiring consequently less duration. From both of them, *Dissimilar* has the best performance concerning duration.

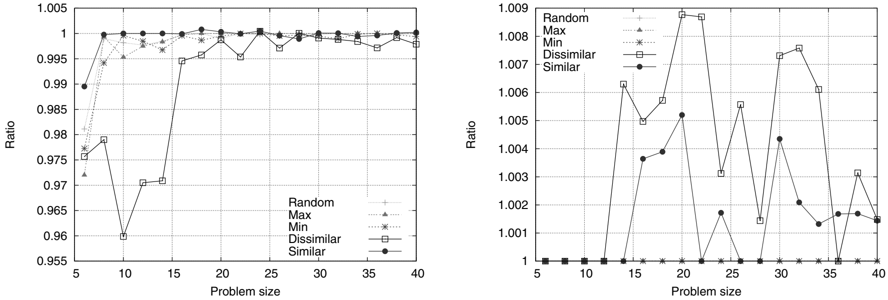
Figure 1b shows the percentage of private information non disclosed during the negotiation processes. We can observe that the strategy that allows agents to share less private information is the *Dissimilar*. The results of the rest of the strategies have a similar behavior. They are under the 10% of concealment for problems of size 10 or greater, i.e. reveal almost all the information until the negotiation process concludes. We can notice the behavior change in the graphics around problems size 15. In our experiments, the item's weights and the knapsacks capacities used allow a maximum amount of items for each knapsack closer to 7 items in average, thus we consider that it is the reason the strategies behave differently when the problem's size is less than 15.

In Figure 1c we present the average results of the *Expected-Optimal Efficiency* (i.e the ratio of the total expected utility obtained respect to the utility associated with the problem under complete information). We can observe that the performance obtained with the strategy *Dissimilar* has a ratio between 96% and 100%. This percentage is less than the one obtained with the other ones because this is the strategy that allow the agents to reach an agreement with less information exchange. Even so, we notice that for problems size greater than 15, the obtained ratio is over 99.5%. Thus, we can conclude that the *Dissimilar* strategy allows the agents to obtain total utility results closer to the ones



(a) Negotiation Length

(b) The hiding information



(c) Expected-Optimal Efficiency ratio

(d) Expected-Real Efficiency ratio

Fig. 1. Experiment's Results

obtained in the problems under complete information, but with less information exchange and in fewer iterations.

Because the negotiating agents may reach an agreement with incomplete information, after carrying out the exchange of items, the accepted proposal expected utility may be not equal to the utility received after exchanging the items, we call this the "real" utility. Figure 1d shows the *Expected-Real Efficiency ratio* obtained after the negotiation wrt the expected one. The strategies that reveal more information are the ones with ratio nearest to 1.

6 Related Work and Conclusions

In recent years, there have been several approaches concerned with formalizing negotiation in multiagent environments. ABN-based approaches emphasize the impact of the information exchanged with the proposals in the negotiating process [4]. To the best of our knowledge, there are no previous studies addressing how negotiating agents can select the information to exchange and the impact the different strategies have in the negotiation process. Next, we will briefly discuss some recent research related to our proposal.

In [7] the authors explore how exchanging information about the agents underlying goals can help improve the negotiation process, formalizing so-called "interest-based negotiation" (IBN). An empirical assessment of this approach is then presented in [8]. Our work shares some aspects with IBN (e.g. notion of deal, utility, information exchange), but differs in that the agents in IBN communicate information only when this is required. Another distinguishing contribution of our approach is the formalization of a "cannonical problem" (Double Knapsack Negotiation Problem) in order to compare and assess alternative strategies. In [9], an algorithm based on Branch and Bound to search for good proposals is introduced, analyzing its performance in a problem called the *Negotiating Salesmen Problem*. In contrast with our approach, the Salesmen agents have complete information about the environment. Pilotti et al. in [5] present a formalization for bilateral negotiation based on belief revision. In contrast with the present proposal, this approach is based on belief revision operators (including an incision function). Besides, they neither consider agents strategies for selecting proposals nor concession information strategies, as we have done in this work.

In this paper we have presented a novel approach to the traditional Knapsack problem, adapting it to represent a bilateral negotiating problem with default information. Also, a protocol based on utility and information concession was proposed. As discussed in the introduction, the focus of our work was to provide a suitable model for capturing different negotiation strategies in agent dialogues. We have implemented this negotiation model in C++ and using the solver Scip (http://scip.zib.de/). The agents using this solver are capable to deal with big knapsack problems. As the illocutions the agents exchange in the proposed model are very simple, we did not consider it necessary to use an agent communication platform (e.g. JADE).

Besides, we have developed different kinds of negotiating agents following the proposed model and selecting –in each case– one of the five strategies we have defined. The experiments allow us to compare the results of the negotiation process in terms of the total utility gained, information revealed and duration of the negotiation. As result, we can conclude that *Dissimilar* gives good results considering a balance between the three analyzed aspects. The intuition behind this strategy is that the agent reveals information supporting a counter-proposal from the point of view of the differences with the previous proposal.

Part of our future work involves the study and analysis of alternative strategies and their impact for reaching agreements. Also, we want to compare the individual results of negotiating agents modeled using different strategies and varying the accuracy level of their initial beliefs. The resulting protocol can be enriched by including additional considerations (e.g. costs associated with making some particular proposal, etc.) and moreover, another protocol can be experienced. Another issue which deserves particular consideration is a full-fledged model with a group of different agents, where two or more agents can get involved in a negotiation dialogue using extended notions of information and utility (e.g. some information or utility could be disclosed only for the other agent in the dialogue, or to all the other agents in the group). Research in these directions is currently underway.

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References

1. Rahwan, I., Ramchurn, S.D., Jennings, N.R., Mcburney, P., Parsons, S., Sonenberg, L.: Argumentation-based negotiation. Knowl. Eng. Rev. **18**, 343–375 (2003)
2. Rosenschein, J.S., Zlotkin, G.: Rules of Encounter - Designing Conventions for Automated Negotiation among Computers. MIT Press (1994)
3. Jennings, N.R., Faratin, P., Lomuscio, A.R., Parsons, S., Sierra, C., Wooldridge, M.: Automated negotiation: Prospects, methods and challenges. International Journal of Group Decision and Negotiation **10**(2), 199–215 (2001)
4. Amgoud, L., Dimopoulos, Y., Moraitis, P.: A unified and general framework for argumentation-based negotiation. In: Proceedings of the 6th International Joint Conference on Autonomous Agents and Multiagent Systems, AAMAS 2007 (2007)
5. Pilotti, P., Casali, A., Chesñevar, C.: A belief revision approach for argumentation-based negotiation with cooperative agents. In: McBurney, P., Parsons, S., Rahwan, I., (eds.) Post-Proceedings of the 9th International Workshop on Argumentation in Multi-Agent Systems (ArgMAS 2013) (2013)
6. Fisher, R., Ury, W.L.: Getting to Yes: Negotiating Agreement Without Giving, 2nd edn. Penguin (Non-Classics) (December 1991)
7. Rahwan, I., Pasquier, P., Sonenberg, L., Dignum, F.: On the benefits of exploiting underlying goals in argument-based negotiation. In: Twenty-Second Conference on Artificial Intelligence (AAAI), Vancouver, pp. 116–121 (2007)
8. Pasquier, P., Hollands, R., Rahwan, I., Dignum, F., Sonenberg, L.: An empirical study of interest-based negotiation. Autonomous Agents and Multi-Agent Systems **22**(2), 249–288 (2011)
9. Jonge, D.D., Sierra, C.: Branch and bound for negotiations in large agreement spaces. In: van der Hoek, W., Padgham, L., Conitzer, V., Winikoff, M., (eds.) AAMAS, IFAAMAS, pp. 1415–1416 (2012)