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Intelligent negotiation model for ubiquitous group decision scenarios*#

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Abstract: Supporting group decision-making in ubiquitous contexts is a complex task that must deal with a large amount of factors to succeed. Here we propose an approach for an intelligent negotiation model to support the group decision-making process specifically designed for ubiquitous contexts. Our approach can be used by researchers that intend to include arguments, complex algorithms, and agents' modeling in a negotiation model. It uses a social networking logic due to the type of communication employed by the agents and it intends to support the ubiquitous group decision-making process in a similar way to the real process, which simultaneously preserves the amount and quality of intelligence generated in face-to-face meetings. We propose a new look into this problem by considering and defining strategies to deal with important points such as the type of attributes in the multi-criterion problems, agents' reasoning, and intelligent dialogues.

Key words: Group decision support systems, Ubiquitous computing, Automatic negotiation, Social networks, Multi-agent systems

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1 Introduction

Many existing group decision support system (GDSS) prototypes use automatic negotiation models as a strategy to support the decision (Maznevski, 1994; Herrera *et al.*, 1997; Moreno-Jiménez *et al.*, 2008; Xu, 2009). Argumentation-based negotiation models are one of the most used and best suited automatic negotiation techniques to support decision making (Rahwan *et al.*, 2003; Marey *et al.*, 2014). It is consensual that the possibility of justifying a request using an argument facilitates reaching an agreement or solution (Bonzon *et al.*, 2012; Marey *et al.*, 2014). Albeit all the recognized advantages in the use of argumentation models in decision making, and the time necessary to study argumentative models in the area of computer science which can be traced back to a few decades, the truth is that such models have not yet been embraced by organizations. The existing models are barely adaptable to the business world reality, have difficulty in reflecting the decision-making natural process, and create a certain discomfort in their use by decision-makers. It is also important to note that the actual evaluation of the argumentation models is not the one an organization would want to use. The fact that an argumentation model gives a solution in lesser rounds or in lesser seconds than another, is not the most relevant point for someone who is concerned about using a mechanism to potentiate the decision quality. Maybe because of that, business intelligence techniques have a

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much higher growth than GDSS.

Looking for studies on argumentation-based negotiation models adapted to GDSS, the results are practically inexistent. The few existing results are old (Karacapilidis and Papadias, 1998; Karacapilidis and Papadias, 2001; Marreiros *et al.*, 2010) and even if some seemed promising in the way they could be adapted to this area (Kraus *et al.*, 1998; Sierra *et al.*, 1998), the works that came next followed most of the time another path (even with some of them remaining within decision support). Forgetting negotiation models for a moment, we found that even the existing argumentation approaches are not oriented to problems that include multiple agents interacting simultaneously. It is even possible to verify that in the most recent argumentation studies, authors with more than one or two decades of work, consider the inclusion of multiple agents as a future expansion for their work (Fan and Toni, 2014; Fan *et al.*, 2014). When agents have 'one-to-one' communication, the process is simple. However, things become more difficult when an agent receives messages from multiple agents. Another important issue is how most authors test their argumentation models. The majority opt for the 'seller-buyer' (Rahwan *et al.*, 2003; Karunatillake and Jennings, 2005; Ramchurn *et al.*, 2007; de Melo *et al.*, 2011; El-Sisi and Mousa, 2012; Marey *et al.*, 2014), which has a type of dialogue much oriented to that kind of problem.

It is a complex task to define a type of adaptable dialogue for use in an argumentation-based negotiation model which has the objective to support group decision making. Walton (1995) believed that dialogues should be classified based on their primary objective, and presented six major dialogue classes for that: inquisition, persuasion, negotiation, deliberation, demand for information, and eristic. However, what is the most adaptable dialogue for a group of people, employees of the same company, whose common objective is not only to solve a certain problem, but at the same time to satisfy their own objectives? Maybe a mixture of several types of dialogue could be the solution, or creating a new class. This makes it very complex to adapt an argumentation theory to this scenario.

We believe that part of the failure of GDSS developed until today is related with the perspective used to analyze the problem and how those systems have been evaluated.

Here we propose an approach for a negotiation model that intends to support the ubiquitous group decision making process similar to a real process, which simultaneously preserves the amount and quality of intelligence generated in face-to-face meetings and is adapted to be used in a ubiquitous context. Our approach is capable of dealing with intelligence because our agents have the possibility to maintain a dialogue about the topic, expressing their opinions, and gather information of what they 'heard'. Our approach is an alternative for researchers that intend to use their specific algorithms, arguments, or models to define agents, for instance, in terms of behaviors of personality.

2 Proposed model

Much of the existing literature that uses agents for negotiation purposes (Huang and Sycara, 2002; Kakas and Moraitis, 2006; Rahwan *et al.*, 2007) considers mainly scenarios where the agents are fully competitive, in which each agent seeks to achieve its own goals (Santos *et al.*, 2010; Rosaci, 2012), or fully collaborative, where all seek to find a solution that satisfies everyone's needs (Yen *et al.*, 2001; Allen *et al.*, 2002; Reicher *et al.*, 2005). In the case of a GDSS which aims to support an organization's decision group to make decisions, this issue should be looked at differently. Considering a system that will have agents, where each agent will represent a decision-maker, a mixture of competition and collaboration should then be considered. We could acknowledge that while all the agents are part of the same organization, they should be collaborative to achieve the best possible decision for the firm. However, for human nature reasons, that would lose certain existing advantages in the context of meeting. Despite the 'all wear the same sweater' philosophy, in a real context the decision-maker also seeks to achieve his/her own goals. This happens for several reasons, but in this particular situation we are interested only in highlighting the conviction reasons. The decision-maker considers in his/her logic that his/her preferred alternative is the best solution to solve the problem and therefore he/she will defend his/her alternative until arguments that make him/her consider a more beneficial alternative are presented. It is this behavior that enriches the meetings, introduces new knowledge, and allows higher quality decisions to be made. This is the behavior we intend to include in our negotiation model and that we consider to be important to introduce in this kind of system.

The negotiation model here proposed is inspired by the communication logic used in social networks. The main idea follows two main types of communication: (1) public communication (PC) in the form of public posts, and (2) private communication (PrC) in the form of private chat. The visual idea of the communication form is much alike to the one used, for instance, in Facebook. The fact of considering the way of communication used in social networks a good approach to serve as inspiration for this work topic is related to two main factors: the agents communicate in a context similar to the one practiced by the decision-makers in face-to-face meetings and the environment and the agents communication/ interaction is easily understood by the participants (decision-makers).

Fig. 1 shows the two different types of communication. The agent is part of a single PC but can have several PrC simultaneously.

A PC is an open conversation and its functioning reflects the type of dialogue practiced by the decision-makers in a real context. Sometimes public conversations or conversations between multiple agents are mentioned, but in practice what happens is that there is a group of agents that exchange messages where each message has a single receptor. In the case of PC, messages are exchanged as how it happens in real life, where a group of people are seating at a table, and even when a message has only one recipient it can be heard by all. This allows the agents to gather information and create relationships through the messages they listen, even if those messages are not directed towards them. In PC agents can address only one topic at a time. Any agent can propose the closure of a topic, which will be closed if no other agent has anything else to say. Obviously, all agents can participate in a PC and read all the messages.

PrC refers to all the private conversations of each participant agent, and as mentioned, an agent can keep several PrC simultaneously. At most, it can have a PrC with each one of the other agents. An agent can initiate a PrC with any other agent provided that it does not already exist. A PrC can stay open during the entire process without being terminated. The existence of PrC is an advantage over the actual meetings that do not allow simultaneous private conversations during the process.

To the best of our knowledge, in literature in the context of support for group decision making, the agents use requests and questions as a way of communication. The communication allows them to use strategies to persuade the other agents and to gather necessary information to reason about the problem. In addition to questions and requests, in our approach we introduce the concept of statement. The statement is a way of communication which will be used by the agents to demonstrate their points of view. This means agents can share information or perform

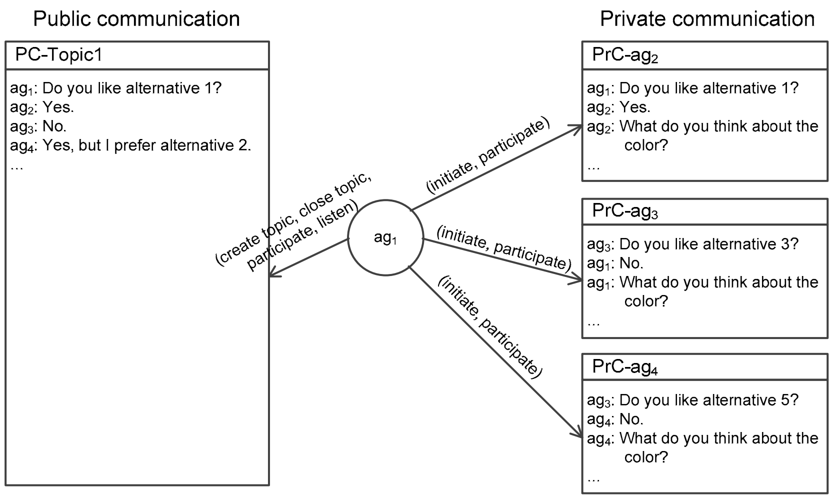

Fig. 1 Two different types of communication

indirect persuasion through statements. For instance, Agent1 can say "to me consumption is the most important attribute". For example, this action can make Agent2, which considers Agent1 the most experienced in the issue that is being discussed, redefine the importance he/she gives to the consumption attribute. As mentioned earlier, it is essential to give prominence to the decision process since strategies that propose solutions based on the problem's initial settings end up losing the process's value existent in real meetings. Negotiation automation should continue to allow the existence of two fundamental points: change of opinion/problem reformulation by the decision-makers when they realize/agree with the arguments presented by other interveners, and learning with the assessment of the process by the decision-makers. Statements, requests, and questions can be used with or without the inclusion of arguments and can be used in PC and PrC. Counter-arguments and acceptance or rejection responses are also made through those three types.

Given this descriptive definition and the underlying motivations of our approach, we now formulate these notions to develop a notational representation of the schema.

Definition 1 Let p be a multi-criterion problem (p=(C, A, A_g)), where C is the set of considered criteria (C={c_1, c_2, …, c_n}), A is the set of considered alternatives (A={a_1, a_2, …, a_m}), and A_g is the set of all participant agents (A_g={ag_1, ag_2, …, ag_k}).

Rule 1 Each alternative is related with each criterion. There cannot be an existing alternative with values for a criterion that is not considered in the problem.

Example 1.1 Let us consider, as an example, the multi-criterion problem of purchasing a new car. In this problem three criteria and three alternatives will be discussed. Three agents will participate in the discussion. Therefore, p is defined as p=({c_1, c_2, c_3}, {a_1, a_2, a_3}, {ag_1, ag_2, ag_3}).

Definition 2 Let c_i be a criterion ($c_i=\{n_{c_i}, v_{c_i}, m_{c_i}\}$), where $\forall c_i \in C$, $i \in \{1, 2, \ldots, n\}$, n_{c_i} is the name of a particular criterion, v_{c_i} is the value of a particular criterion (Numeric, Boolean, or Classificatory), and m_{c_i} is the greatness associated with the criterion (Maximization, Minimization, Positivity, Negativity, or Without Value).

Example 1.2 For the previous example, let us consider three criteria: Price, Transmission, and Air Conditioning. Each criterion is defined as follows:

c_1={Price, Numeric, Minimization},
c_2={Transmission, Classificatory, Without Value},
c_3={Air Conditioning, Boolean, Positivity}.

Definition 3 Let a_i be an alternative ($a_i=\{n_{a_i}, [c_{1_{a_i}}, c_{2_{a_i}}, \ldots, c_{n_{a_i}}]\}$), where $\forall a_i \in A$, $i \in \{1, 2, \ldots, m\}$, n_{a_i} is the name of a particular alternative and $[c_{1_{a_i}}, c_{2_{a_i}}, \ldots, c_{n_{a_i}}]$ is the instantiation of every criterion.

Example 1.3 For the previous example, let us consider three alternatives. Each alternative is defined as follows:

a_1={Car1, [10 000€, Automatic, No]},
a_2={Car2, [15 000€, Manual, Yes]},
a_3={Car3, [12 500€, Manual, No]}.

Definition 4 Let l_i be a locution ($l_i=\{\text{type}_{l_i}, \text{id}_{l_i}, \text{text}_{l_i}, \text{context}_{l_i}, \text{Var}_{l_i}, g_{l_i}\}$), where $i \in \{1, 2, \ldots\}$, type_{l_i} is the locution's type (Question, Statement, or Request), id_{l_i} is the locution's identification, text_{l_i} is the text associated to the locution, context_{l_i} is the locution's context (Alternative, Criterion, or Without Context), Var_{l_i} is the set of variables associated to the locution (Alternative or Criterion), and g_{l_i} is the locution's domain (General or Specific).

The proposed locutions to be considered are specified in Table 1.

Definition 4.1 Let L be the set of all locutions. For a domain g assigned to locution l_i, the set of locutions L_g is associated if $L_g \subset L$ and $\forall l_i \in L_g$, $g_{l_i}=g$.

Definition 4.2 Let L be the set of all locutions. For a particular type t assigned to locution l_i, the set of locutions L_t is associated if $L_t \subset L$ and $\forall l_i \in L_t$, $\text{type}_{l_i}=t$.

Definition 4.3 Let L be the set of all locutions. For a particular criterion c_i, the set of specific locutions $L_{s_{c_i}}$ is associated if $L_{s_{c_i}} \subset L$, $\forall l_j \in L_{s_{c_i}}$, $g_{l_j}=\text{Specific}$, $\forall l_j \in L_{s_{c_i}}$, $c_i \subset \text{Var}_{l_j}$, and $\forall l_j \notin L_{s_{c_i}}$, $c_i \not\subset \text{Var}_{l_j}$.

Rule 2 For any locution $l_j \in L_{s_{c_i}}$ and $c_i \subset \text{Var}_{l_j}$, there

Table 1 Considered locutions

Locution	Type	id	Text	Context	Variables	Domain
Criteria general preference	Statement	1	"For me the most important criterion/a is/are 1, 2, …, *n*"	Criterion	Criteria 1, 2, …, *n*	General
Alternatives general preference	Statement	2	"For me the most important alternative/s is/are 1, 2, …, *n*"	Alternative	Alternatives 1, 2, …, *n*	General
Criteria general preference	Question	3	"Which criterion/a you consider most important?"	Criterion	–	General
Alternatives general preference	Question	4	"Which alternative/s you prefer?"	Alternative	–	General
Criteria individual preference	Question	5	"Who considers the criterion/a as the most important?"	Criterion	Criteria 1, 2, …, *n*	Specific
Alternatives individual preference	Question	6	"Who prefers the alternative *n*?"	Alternative	Alternatives 1, 2, …, *n*	Specific
Agreement	Statement	7	"I agree."	Without Context	–	Specific/ General
Disagreement	Statement	8	"I disagree."	Without Context	–	Specific/ General
No information	Statement	9	"I do not have that information."	Without Context	–	Specific/ General
End of participation	Statement	10	"I have nothing more to say."	Without Context	–	General
Alternative request	Request	11				
Accept	Statement	10	"I accept."	Alternative	Alternatives 1, 2, …, *n*	Specific
Refuse	Statement	11	"I do not accept."	Alternative	Alternatives 1, 2, …, *n*	Specific

cannot be another locution l_k where $c_i \subset \mathrm{Var}_{l_k}$ and $l_k \notin L_{\mathrm{s}_{c_i}}$.

Definition 4.4 Let L be the set of all locutions. For a particular alternative a_i, the set of specific locutions $L_{\mathrm{s}_{a_i}}$ is associated if $L_{\mathrm{s}_{a_i}} \subset L$, $\forall l_j \in L_{\mathrm{s}_{a_i}}$, g_{l_j}=Specific, $\forall l_j \in L_{\mathrm{s}_{a_i}}$, $a_i \subset \mathrm{Var}_{l_j}$, and $\forall l_j \notin L_{\mathrm{s}_{a_i}}$, $a_i \not\subset \mathrm{Var}_{l_j}$.

Rule 3 For any locution $l_j \in L_{\mathrm{s}_{c_i}}$ and $a_i \subset \mathrm{Var}_{l_j}$, there cannot be another locution l_k where $a_i \subset \mathrm{Var}_{l_k}$ and $l_k \notin L_{\mathrm{s}_{a_i}}$.

Definition 4.5 Let L be the set of all locutions. For a particular context, Context, the set of general locutions $L_{\mathrm{ge}_{\mathrm{Context}}}$ is associated if $L_{\mathrm{ge}_{\mathrm{Context}}} \subset L$, $\forall l_j \in L_{\mathrm{ge}_{\mathrm{Context}}}$, g_{l_j}=General and $\forall l_j \in L_{\mathrm{ge}_{\mathrm{Context}}}$, $\mathrm{context}_{l_j} = \mathrm{Context}$.

Definition 5 Let msg$_i$ be a message (msg$_i$={l_{msg_i}, $\mathrm{Arg}_{\mathrm{msg}_i}$, $\mathrm{idch}_{\mathrm{msg}_i}$, $\mathrm{ag}_{\mathrm{e}_{\mathrm{msg}_i}}$, $\mathrm{ag}_{\mathrm{r}_{\mathrm{msg}_i}}$}), where $i \in \{1, 2, \ldots, n\}$, l_{msg_i} is the locution sent in the message, $\mathrm{Arg}_{\mathrm{msg}_i}$ is the justification associated to the locution (can be an argument or null), $\mathrm{idch}_{\mathrm{msg}_i}$ is the conversation code (the post for PC or the private chat for PrC), $\mathrm{ag}_{\mathrm{e}_{\mathrm{msg}_i}}$ is the identification of the agent who sent the message, and $\mathrm{ag}_{\mathrm{r}_{\mathrm{msg}_i}}$ is the set of the agents who will receive the message (can be 1 or *).

Definition 6 Let Arg$_i$ be an argument (Arg$_i$={$\mathrm{id}_{\mathrm{Arg}_i}$, $\mathrm{text}_{\mathrm{Arg}_i}$, $\mathrm{Var}_{\mathrm{Arg}_i}$}), where $i \in \{1, 2, \ldots, n\}$, $\mathrm{id}_{\mathrm{Arg}_i}$ is the identification of a particular argument, $\mathrm{text}_{\mathrm{Arg}_i}$ is the text associated to a particular argument, and $\mathrm{Var}_{\mathrm{Arg}_i}$ is the set of variables associated to a particular argument (can contain alternatives and criteria).

The criteria included in the set of the agent's preferred criteria will also be included in the set of the agent's updated and preferred criteria. Therefore, the size of the set of the agent's updated and preferred criteria will always be at least the same as or larger than that of the set of the agent's preferred criteria that is not updated. Likewise, the alternatives included in the set of the agent's preferred alternatives will also be included in the set of the agent's updated and preferred alternatives. This means that the size of the set of the agent's updated and preferred alternatives will always be at least the same as or larger than that of the set of the agent's preferred alternatives that is not updated.

Proposition 1 The system is finite.

Proof One agent ag_j that has preferred criteria $n_{c_{\text{ag}_j}}$ belonging to C_{ag_j} and alternatives $n_{a_{\text{ag}_j}}$ belonging to A_{ag_j} can initially use $n_{l_{\text{ag}_j}}$ locutions where

$$n_{l_{\text{ag}_j}} = \sum_{i=0}^{n_{c_{\text{ag}_j}}} L_{\text{s}_{c_i}} + \sum_{i=0}^{n_{a_{\text{ag}_j}}} L_{\text{s}_{a_i}} + L_{\text{ge}_{\text{Criterion}}} + L_{\text{ge}_{\text{Alternative}}} + L_{\text{ge}_{\text{Without Context}}},$$

and n_l is the sum of all the locutions related to each criterion and alternative preferred by the agent.

Whenever C_{ag_j} and A_{ag_j} are updated, with $n_{c_{\text{new}_{\text{ag}_j}}}$ belonging to $C_{\text{new}_{\text{ag}_j}}$ and $n_{a_{\text{new}_{\text{ag}_j}}}$ belonging to $A_{\text{new}_{\text{ag}_j}}$. $n_{l_{\text{new}_{\text{ag}_j}}}$ will be

$$n_{l_{\text{new}_{\text{ag}_j}}} = \sum_{i=0}^{n_{c_{\text{new}_{\text{ag}_j}}}} L_{\text{s}_{c_i}} + \sum_{i=0}^{n_{a_{\text{new}_{\text{ag}_j}}}} L_{\text{s}_{a_i}} + L_{\text{ge}_{\text{Criterion}}} + L_{\text{ge}_{\text{Alternative}}} + L_{\text{ge}_{\text{Without Context}}}.$$

This process is repeated until agent ag_j prefers all the criteria and alternatives and $n_{c_{\max_{\text{ag}_j}}} \in C_{\max_{\text{ag}_j}}$ and $n_{a_{\max_{\text{ag}_j}}} \in A_{\max_{\text{ag}_j}}$. $n_{l_{\max_{\text{ag}_j}}}$ will be

$$n_{l_{\max_{\text{ag}_j}}} = \sum_{i=0}^{n_{c_{\max_{\text{ag}_j}}}} L_{\text{s}_{c_i}} + \sum_{i=0}^{n_{a_{\max_{\text{ag}_j}}}} L_{\text{s}_{a_i}} + L_{\text{ge}_{\text{Criterion}}} + L_{\text{ge}_{\text{Alternative}}} + L_{\text{ge}_{\text{Without Context}}}.$$

It is possible to verify that the model is finite as the agent will be able to use, at most, a number of locutions corresponding to the total of criteria and alternatives considered for the multi-criterion problem, and the remaining locutions that do not have a specific context.

The set of locutions defined by each agent will depend on the algorithms used and in each specification of our model. However, each agent will have his/her particular set of locutions regarding the issues considered by the algorithm. An agent can generate his/her set of locutions based on, for instance, the interests configured by the real participant, real participant personality, agent's conflict style, etc.

To better understand the process flow of our model, we are going to present some data flow diagrams for each of the main entities of our model.

3 Real participant (decision-maker)

When develop models and applications that will be used in real scenarios, we have to pay special attention to the end users. The end users of our research will be the decision-makers. Considering we are dealing with ubiquitous scenarios, we assume our end users are people with a very busy schedule, that's why we also have been working with techniques to configure multi-criterion problems (Carneiro *et al.*, 2015). In our proposal, the decision-maker is represented in the 'system' by a participant agent. Usually, this agent is seen as someone capable of defending the interests of the decision-maker. In our case, we consider (to develop a successful system) this agent as someone who seeks and understands data (and the environment) and other people's perspectives, capable of organizing that data, and present more intelligent information to the decision-maker so that he/she can perform better decisions. A successful ubiquitous group decision support system (UbiGDSS) cannot be one that only presents possible solutions, even when the presented solutions are the best possible. It needs to be capable of presenting information that provides confidence to the decision-maker so that he/she can reason and make decisions. The decision-maker should be capable of understanding other people's motives. Our model intends to follow the decision-makers during the decision making process. We believe the best approach would be an iterative process, where the participants can (re)configure the problem whenever they want and also understand all the processes and other people's perspectives through the interaction with their agents. An interesting fact is that we do not find in the literature any research regarding the kind of information that should be available to support the decision-maker during the process. The lack of these 'intelligent reports' is a huge disadvantage when comparing UbiGDSS with business intelligence techniques. Fig. 2 presents our perspective on how the real participant's data should flow.

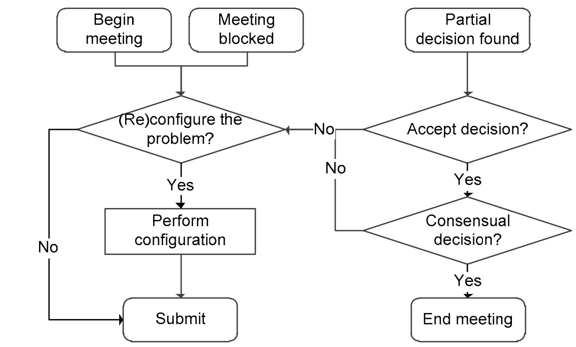

Fig. 2 Flowchart of a real participant (decision-maker)

4 Facilitator agent

In this kind of proposals it is very common to use a facilitator agent. We also consider important to use a facilitator agent; however, in our case the facilitator is responsible only for managing the beginning and the end of the meeting. All the dialogue and the messages exchange are on the participant agent side. Fig. 3 presents our perspective of how the facilitator agent's data should flow.

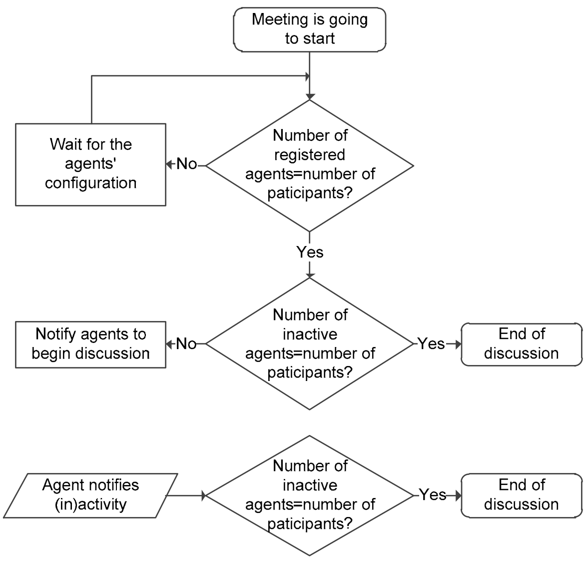

Fig. 3 Facilitator agent's flowchart

5 Participant agent

The participant agent plays an essential role in our model. He/She is the virtual representation of the decision-maker. What it does and when it does will depend on the complexity of the algorithms that are used. What differentiates our model is the capability of those agents to create free dialogues. Usually most of the proposed models are rigid, when defining the order of the events. In our model the agents are free to act according to their intentions. Fig. 4a shows the participant agent's data flow regarding the public conversations and Fig. 4b shows the participant agent's data flow regarding the private conversations. The participant agent reports only his/her inactivity to the facilitator when the 'report my inactivity' status in both PC and PrC is verified.

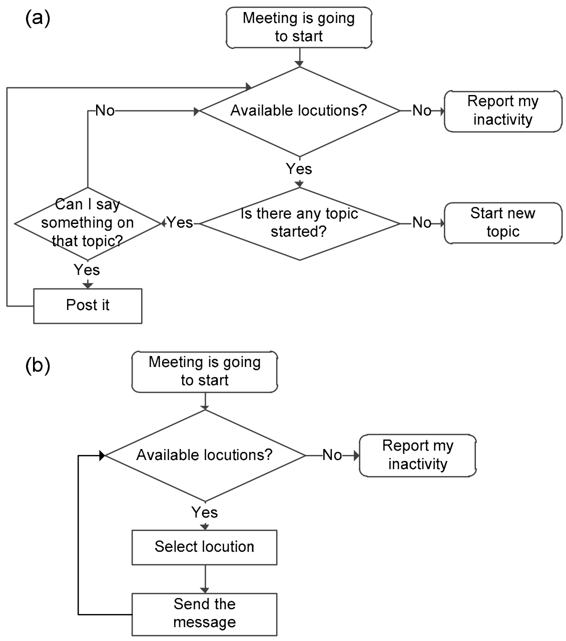

Fig. 4 Participant agent's flowchart for public conversations (a) and private conversations (b)

6 Attribute types

Our model is specifically designed to handle multi-criterion problems. It is not our goal to include any type of natural language mechanism in our prototype. However, we believe it is possible and essential that the agents can understand what is happening in the 'conversation'. For that, it is necessary to make a proper definition of the type of attribute that can be used.

Considering our example of purchasing a new car, one of the attributes was the car's consumption and that attribute was defined as a minimization numerical attribute. If Agent1 says "for me the most important decision factor is consumption" it will allow other agents to argue with Agent1 saying "accept alternative *C* because it has the lowest consumption". It is possible to understand that this strategy allows the agents to have the ability to perceive a lot of different information. Another major advantage of this approach is the easiness in which an agent will generate perceptible reports for the real participant. Besides being able to present data that supports the decision (for instance, charts, tables, statistics), it is possible to present the argumentation between the agents and the reason that led the agents to propose a certain decision in a more perceptible way.

The types of attributes considered can be visualized in Fig. 5. Two main types of attributes can be considered:

1. Objective: objective attributes are comparable with each other. This means that in the case of the car consumption, if car1 has a lower consumption than car2 and the consumption is a minimization numerical attribute, car1's consumption is invariably better than car2's consumption. The values of the objective attributes are always absolutely true. For instance, if the air conditioning attribute of an alternative is true then the possibility of that car not having air conditioning cannot be considered. There are three types of objective attributes:

(1) Boolean: this type of attribute is used in situations where the attribute can be classified by only two values, e.g., on/off, yes/no, 0/1, true/false; in this case the most advantageous situation must be specified (true or false). However, this specification is not mandatory. The situation that offers a greater value is considered to be advantageous even if that value does not solve the problem. Considering that the same car with or without air conditioning costs exactly the same price, the fact of having air conditioning is an advantage, even assuming that for health reasons it will not be used.

(2) Numerical: the numerical type attributes are used to define measurable attributes, for example, consumption, height, width, and distance. This type of attribute is defined as the maximization or minimization attribute. However, this specification is not mandatory. For instance, we 'always' want to minimize costs, but on the other hand, we always want to maximize the profits. However, we may not be interested in minimizing or maximizing the height of an employer.

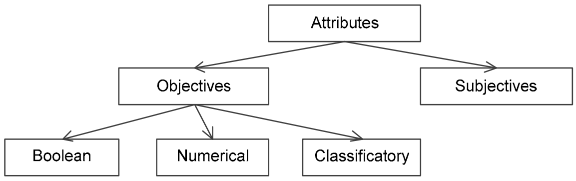

Fig. 5 Attribute types

(3) Classificatory: this type of attribute is used to specify attributes with a defined and recognized classification. For instance, we can use this type of attribute to specify a car's safety. However, this classification should not be made by someone without credentials. An expert or a classification that has been published in a reference location can be used to make this classification. The classification will function as a scale.

2. Subjective: subjective attributes allow agents to perceive what issues do not make sense to argue. For example, it will not make sense to argue that a car is better than another because of the color. The fact an agent prefers a certain color (in a certain context) is considered by this type of attribute as a personal taste which cannot be argued. Other examples of subjective attributes (always depend on the context) include car design, food taste, beauty, and sound quality.

We believe this proposal on the types of attributes for the multi-criterion problem is simple but effective. In this way it is possible to set a wide number of problems with a strategy that allows agents to understand about what they are arguing. We believe this approach makes the agents as well as the dialogues more intelligent allowing richer and more perceptible outputs.

7 Discussion

To Jennings and Wooldridge an intelligent agent can make flexible autonomous actions to meet its design objectives. To them, an intelligent agent needs to be responsive, proactive, or social. For further information about these definitions see Wooldridge and Jennings (1995). To Wooldridge (2000) what makes a rational agent is its autonomy. In the last decades we have seen many examples in the literature in which the topic of intelligent agents is addressed

(Müller, 1996; Sycara *et al.*, 1996; Jennings and Wooldridge, 1998). It is also known that there are agents that perform the same task with more intelligence than others. However, it is known that in the case of humans, the reactive decision is processed by the brain in a different location of the proactive decision. In the case of agents or computational systems the proactive decision can exist but always in a simulated way.

On the subject of intelligent and rational agents, there is a relevant point that deserves attention regarding group decision-making support systems. Suppose we have a system that can rapidly propose a solution to a certain problem according to the decision-makers' preferences. It is obvious that this indicator is not enough to know whether the system is good or bad. The proposed solutions can always be unacceptable for the decision-makers, making the system useless. However, let us consider that the system can always propose acceptable solutions for the decision-makers, ending up having a great impact on a particular organization. Taking into account these details it would be hypothetically possible to say this system had quality. However, this may not be true. When someone wants to develop a negotiation model to adapt to a group decision-making support system, there is an important factor, which is often forgotten, to take into account. In the case of face-to-face meetings the decision-makers have time to think over the subject during the process, and usually they start the meeting with certain beliefs which are then changed after hearing others' opinions and argumentations. Sometimes our opinion changes when new knowledge is shared with us or when the arguments used invalidate our logic. This fact is what makes face-to-face meetings the preferred choice to make important decisions, and no system is still prepared to deal with such a situation. The way models and systems are designed makes this crucial part of a real meeting be lost. We think that research on negotiation models for group decision-making support systems needs to start concerning about such a fact. It is important for the agent to have the capability to seek to understand why other agents have other preferences, and not only to seek information that allows him/her to achieve his/her goals while forgetting that on the other side there may be an agent who changes opinion even if he/she did not share his/her initial convictions with the group.

In the approach here presented, and as already explained, it is intended that the agents communicate in public and private conversations. Public communication is visible by all agents even if it is not directed towards a specific agent. As such, an agent will be listening to a public conversation even if he/she is not part of it. The agent shall gather information on the messages exchanged publicly and then process that information. The idea here is that the agent studies the relationships that are being created as the information is exchanged. In a real meeting, if one of the decision-makers shows his/her preference for a certain alternative or an attribute that is also another decision-maker's favorite, in that instant a connection between them is created because they share that in common.

Another topic that will also be part of the agents' reasoning and whose advantages have already been previously addressed is the capability to seek to understand the reason behind other agents' preferences. If we think clearly, this agents' reasoning is very similar to what happens in reality: a decision-maker seeks to understand other decision-makers' opinions. Again, this will allow to generate a richer argumentation as well as more useful and elaborated reports to be analyzed by the decision-maker. The agent will have the ability to understand other agents' opinions by analyzing and questioning them on the evaluation and importance given to the attributes. In the example of buying a car, if an agent gives much importance to the consumption and that agent has a preferred car which is the one with the lowest consumption, another agent can deduce that this is why he/she chooses that alternative. A very interesting interaction would be requesting that agent to accept a much cheaper alternative at the cost of just a small increase in the consumption.

Finally, the agents should have the ability to analyze the prediction they make on their satisfaction, that is, the prediction on their perception of the decision quality at a given moment, taking into account the outcome they are predicting. For that, they will use our model on satisfaction analysis. For further information see Carneiro *et al.* (2014a; 2014b). The fact that they have the ability to analyze the final satisfaction of the decision-maker, whom they represent, makes them more intelligent. This allows them to know when to stop defending their favorite alternative and bet on another which is also preferred (although less). This fact will give them a greater final satisfaction that another alternative had been chosen. The model should also predict the group final satisfaction when their goal is a decision that brings high satisfaction for all the elements. Satisfaction analysis will also be useful for blocked situations and will help the agents better understand whether or not to accept requests from other agents.

Our work brings a new refreshing perspective in the context of GDSS. To the best of our knowledge, the type of communication performed by agents has never been suggested in the literature. We believe that our work has similarities with the one proposed by Marreiros *et al.* (2010), but our approach has the great advantage to offer an easy understanding of the dialogues conducted by agents. Besides, in most of the work about GDSS in the literature in the last decade, fuzzy logic was used as a mechanism to achieve a solution (Bashiri and Hosseininezhad, 2009; Zhang *et al.*, 2009; Kar, 2014). This makes it impossible to justify preferences and becomes a very non-interactive process performed by decision-makers. Our approach takes advantage of the benefits inherent to the use of argumentation (for example, it is possible to justify requests and statements) and allows introducing new knowledge (Rahwan *et al.*, 2003; El-Sisi and Mousa, 2012). It is also important to mention that in ubiquitous contexts most proposed systems will not take advantage of the benefits inherent to group decision making (Huber, 1984; Dennis, 1996). This issue affects decision-makers that cannot gather at the same place and time and that can interact with each other only by using the GDSS. The result will be an increase of frustration of decision-makers, which will lead to most of them giving up on using the system (Paul *et al.*, 2004). Another important point of our approach is that it takes advantage of group decision making by creating a process (Dean and Sharfman, 1996). Some researchers used mechanisms that search immediately for a solution preventing any further reasoning of decision-makers (Gorsevski *et al.*, 2013). Our approach allows decision-makers to keep changing their preferences and understand what is happening throughout the process. This leads to a reflected and justified change of opinion. In addition, many existing studies in the literature did not follow the advantages of group decision making simply because they cannot promote interaction between decision-makers (Tavana *et al.*, 1993; Alonso *et al.*, 2010). The approach here presented has been defined in a way that allows agents to understand the entire decision-making process and to be able to express their opinions through a problem reconfiguration. Besides, the type of communication is much more explicit due to the proposed attributes' definition. Alonso *et al.* (2010) have presented a very interesting work using Delphi's method (which is common for this type of context, see Burke and Chidambaram (2003), Guo *et al.* (2005), and Smits *et al.* (2013)). The great advantage of our work compared to this approach is that it motivates the interaction and the interest to understand why other decision-makers have different opinions. In their approach, there is no such thing as interaction between 'experts'. This problem is also common to all of other works in which Delphi's method was used in the GDSS context.

8 Conclusions and future work

The group decision support systems have been studied in the last three decades. However, after all this time, they are still not being accepted by the industry. Regardless of the amount of artificial intelligence techniques applied, they still have too many limitations, especially in situations with time/space constraints. Furthermore, there are big challenges regarding the processes used to evaluate and validate these systems. The processes' evaluation used allows saving good scientific results in certain cases but does not transmit enough confidence so that the industry can understand all the potential of these systems.

To support the group decision making in situations with time/space constraints, the GDSS evolved for the so-called ubiquitous GDSS (UbiGDSS). They are the ultimate cleavage of GDSS. With the appearance of UbiGDSS some other problems appeared, for instance, how to overcome the lack of human-interaction, understand the decision quality perception in the perspective of each decision-maker, and overcome the communication issues.

One of the usual techniques in UbiGDSS is automated negotiation. The idea behind automated negotiation, for instance, argumentation, is allowing agents to find a solution through an intelligent dialogue. However, there are no specifically defined dialogues for these situations, plus there are only a few argumentation-based negotiation models proposed in the literature where the majority was defined before the appearance of UbiGDSS. Going deeply, we can also verify that even the argumentation theories have difficulty in adapting to this scenario.

Here we propose a theoretical negotiation model specifically planned for UbiGDSS. More particularly, we propose new approaches on topics such as the type of attributes and dialogues. In addition to these specific proposals, this topic is addressed under a new look and approach. Multiple reflections are shared, and the most important issues are analyzed which, in the opinion of authors, have been the cause of the GDSS problems.

The model proposed in this paper uses a social networking logic due to the type of communication employed by the agents. Our approach intends to support the ubiquitous group decision-making process, in a similar way to a real process, while simultaneously preserving the quantity and quality of intelligence generated in face-to-face meetings, and is adapted to be used in a ubiquitous context. Agents are capable of performing dialogues about the problem, understanding the messages of others agents, and using arguments in any kind of used locution. The kind of knowledge created by agents in our model can be used to bring UbiGDSS to a higher level.

As for future work there are still a lot of things that need to be done. We will work on the creation of an argumentation framework to be included in our model. Also, we will develop a new prototype that includes all the topics addressed here and others previously published. We believe that in the end we can draw strong conclusions on the results obtained from this new look over automatic negotiation in group decision-making support systems.

As a final remark, we can say that there is a lot of work to do to adapt GDSS to this new era. This is a very complex area and involves so many other different areas, but working in this field is very exciting and can result in outstanding results.

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