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Negotiation in Group Decision Support Systems - An Approach based in Argumentation and Satisfaction

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October 20172016

Statement of Integrity

I hereby declare having conducted my thesis with integrity. I confirm that I have not used plagiarism or any form of falsification of results in the process of the thesis elaboration. I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Universidade do Minho, Braga, October 30, 2017

Full Name:

João Miguel Ribeiro Carneiro

Signature:

João Miguel Ribeiro Carneiro

To raise new questions, new possibilities,
to regard old problems from a new angle,
requires creative imagination
and marks real advance in science.

— Albert Einstein

Dedicated to my family...
with love and gratitude

ABSTRACT

Today, in large organizations, most of the decision-making processes (strategic and operational) are carried out in a group. There are several reasons why this is so: if, on the one hand, it is believed that it is possible to make better decisions in a group, on the other hand, the organizational charts of these organizations force to do so. However, in a world that is increasingly global, it is difficult to bring together decision-makers in the same space at the same time, making it impossible to conduct typical face-to-face meetings and benefit from the advantages associated with group decision-making. In order to overcome this impossibility of interaction, Web-based Group Decision Support Systems have been studied. These systems allow decision-makers to participate in the decision-making process anytime, anywhere, by simply having an internet connection. For the most part, these systems use algorithms/models capable of proposing one or more solutions to a given problem, based on the preferences defined by each of the decision-makers. However, with this type of approach, decision-makers interact in a very limited way and the decision-making process is practically non-existent, making it very difficult to present/exchange views, justify opinions and perceive the intentions of each decision-maker.

The work described in this thesis intended to study strategies that allow the support of dispersed groups (through the use of Group Decision Support Systems) in decision-making processes, taking advantage, as far as possible, of the benefits associated with face-to-face group decision-making. To achieve this goal, it was studied if: (1) intelligent agents would be able to act according to a style of behavior assigned to them and thus represent the intentions of the decision-makers; (2) it was possible to predict each decision-maker's perception of the decision quality and to use this indicator in order to enhance it; (3) an automatic negotiation model would be able to create intelligence, involving decision-makers in the process, making it transparent and allowing both decision-makers and intelligent agents to take advantage of the generated knowledge.

For the first objective (1), a model that allowed the decision-makers to represent their intentions regarding the decision-making process was defined. In order to present the set of stances considered to exist in this context, five styles of behavior (dominating, integrating, compromising, avoiding and obliging) that vary according to four dimensions (resistance to change, activity level, concern for self and concern for others) were defined. A case study to understand how decision-makers perceive each behavior style was also conducted. Later, using a prototype, simulations of group decision-making processes were performed (using the values found in the case study), using agents configured with the considered behaviors. For the second objective (2), a model for predicting the decision-makers' perception of the decision quality (called satisfaction model) was formulated. The formulation of the model followed a set of assumptions and premises found in the literature, which allowed to define the points to be considered, as well as the behavior of the model itself in relation to those points. The points considered in this model were: expectations of the decision-makers, evaluation of alternatives, affective aspects, intentions and results. This model was then applied to

other developed algorithms and models in order to study its applicability and potentialities. For the third objective (3), an argumentation-based dialogue model to allow the reflection of the dialogues made by decision-makers in face-to-face group decision-making processes was formulated. In order for the agents' dialogues to be perceptible by decision-makers, a set of illocutions to be used by the agents (appropriate to the context of group decision-making) was defined. A communication model was also defined in order to allow the agents to perform a dialogue sequence/logic similar to that practiced by real decision-makers. In order to allow agents and decision-makers to use arguments to justify opinions and requests, as well as to allow agents to use the knowledge generated in the messages exchanged by the decision-makers, an argumentation framework was developed. In order to have the desired impact on the behavioral styles modeled on the agents, sets of rules and formulas have been defined to establish how the agents participate in the dialogues, as well as their assessment of the incoming requests.

By analyzing the obtained results, it was proved that the proposed behavioral styles model is perceived in a similar way by the decision-makers. In this way, it was possible to find performance values for each of the considered dimensions, which can be used to model agents. In addition, it was also found that the agents were able to correctly exhibit the behaviors with which they were modeled. With respect to the proposed satisfaction model, it has shown to have numerous applications such as: being able to enhance the satisfaction of the decision-makers and of the group, and serving as a metric to evaluate different models of automatic negotiation or decision support systems. It was also proved that agents that use the satisfaction model as a tool to predict the final satisfaction of the decision-makers they represent are able to obtain better and more consensual decisions when compared with agents that do not use it. It was also possible to observe that the argumentation-based dialogue model allows decision-makers to follow/perceive the decision process. In addition, it was found that the model works correctly with multiple agents. It has also been found that the agents are able to use the messages created by the decision-makers in order to make the dialogues more intelligent. It was also possible to prove that the modeling of behavioral styles on agents to represent the intentions of the decision-makers, in the context of group decision-making, significantly helps in obtaining higher quality and more consensual decisions.

To develop systems/models to support dispersed groups is an extremely complex topic. For these systems to achieve better results, special attention should be paid to the interests of the decision-makers and not just focus on the problem. It has been shown that working on communication and representation strategies is extremely relevant in what is the capacity to propose higher quality decisions and to reach consensual decisions more easily.

RESUMO

Atualmente, nas grandes organizações, a maioria dos processos de tomada de decisão (estratégicos e operacionais) são realizados em grupo. Existem vários motivos que levam a que isso aconteça: se por um lado se acredita que em grupo é possível obter melhores decisões, por outro lado, os organogramas destas organizações a isso o obrigam. No entanto, num mundo que é cada vez mais global, torna-se difícil reunir decisores num mesmo espaço ao mesmo tempo, impossibilitando: a realização das típicas reuniões "cara-a-cara" e beneficiar das vantagens associadas à tomada de decisão em grupo. Com o objetivo de ultrapassar esta impossibilidade de interação, têm vindo a ser estudados Sistemas de Apoio à Tomada de Decisão em Grupo baseados na web. Estes sistemas permitem que os decisores participem no processo de decisão em qualquer altura e em qualquer lugar, bastando para isso terem uma ligação à internet. Na sua maioria, estes sistemas utilizam algoritmos/modelos capazes de propor uma ou mais soluções para um determinado problema, com base nas preferências definidas por cada um dos decisores. Contudo, com este tipo de abordagem, os decisores interagem de uma forma extremamente limitada e o processo de decisão é praticamente inexistente, tornando-se muito difícil apresentar/trocar pontos de vista, justificar opiniões e perceber as intenções de cada um dos decisores.

O trabalho que é descrito nesta tese pretendeu estudar estratégias que permitam suportar grupos dispersos (através da utilização de Sistemas de Apoio à Tomada de Decisão em Grupo) em processos de tomada de decisão, tirando partido, tanto quanto possível, dos benefícios associados à tomada de decisão em grupo do tipo presencial. Para alcançar este objetivo, foi estudado se: (1) agentes inteligentes seriam capazes de atuar de acordo com um estilo de comportamento que lhes fosse atribuído e assim representar as intenções dos decisores; (2) era possível prever a perceção da qualidade da decisão de cada decisor e utilizar este indicador de forma a potenciá-la; (3) um modelo de negociação automática seria capaz de criar inteligência, envolvendo os decisores no processo, tornando-o transparente e permitindo que tanto decisores como agentes inteligentes pudessem usufruir do conhecimento gerado.

Para o primeiro objetivo (1), foi definido um modelo que permitisse aos decisores representarem as suas intenções relativamente ao processo de tomada de decisão. Para exibir o conjunto de posturas que se considera existir neste contexto, foram definidos cinco estilos de comportamento (*dominating*, *integrating*, *compromising*, *avoiding* e *obliging*) que variam de acordo com quatro dimensões (*resistance to change*, *activity level*, *concern for self* e *concern for others*). Foi também realizado um caso de estudo para perceber de que forma os decisores percecionavam cada um dos estilos de comportamento. Posteriormente, utilizando um protótipo, foram realizadas simulações (recorrendo aos valores encontrados no caso de estudo) de processos de tomada de decisão em grupo, utilizando agentes configurados com os comportamentos considerados. Para o segundo objetivo (2), foi formulado um modelo de previsão da perceção da qualidade da decisão (denominado de modelo da satisfação) dos decisores relativamente à solução proposta. A formulação do modelo obedeceu a um conjunto de suposições e premis-

sas existentes na literatura, que permitiram definir os pontos a serem considerados, assim como o comportamento do próprio modelo face a esses pontos. Os pontos considerados neste modelo foram: expetativas dos decisores, avaliação das alternativas, aspetos afetivos, intenções e resultados. Este modelo foi depois aplicado a vários outros algoritmos e modelos desenvolvidos de forma a estudar a sua aplicabilidade e as suas potencialidades. Para o terceiro objetivo (3), foi formulado um modelo de diálogo baseado em argumentação que permitisse refletir os diálogos realizados por decisores em processos de tomada de decisão em grupo do tipo presencial. Para que os diálogos realizados pelos agentes fossem percetíveis aos olhos dos decisores, foi definido um conjunto de ilocuções (adequadas ao contexto da tomada de decisão em grupo) para serem utilizadas pelos agentes. Foi ainda definido um modelo de comunicação de forma a permitir que os agentes fossem capazes de realizar uma sequência/lógica de diálogo similar à praticada por decisores reais. Foi também definida uma *framework* de argumentação de forma a permitir aos agentes e decisores a utilização de argumentos para justificar opiniões e pedidos, assim como, para permitir aos agentes utilizar o conhecimento gerado nas mensagens trocadas pelos decisores. Para que os estilos de comportamento modelados nos agentes tivessem o impacto desejável, foram definidos conjuntos de regras e fórmulas para estabelecer a forma como os agentes participam nos diálogos, assim como, a avaliação que fazem dos pedidos recebidos.

Analisando os resultados obtidos, provou-se que o modelo de estilos de comportamento proposto é percecionado de forma semelhante pelos decisores. Desta forma, foi possível encontrar valores de atuação para cada uma das dimensões consideradas, que podem ser utilizados para modelar agentes. Além disto, também se verificou que os agentes foram capazes de exibir corretamente os comportamentos com que foram modelados. Relativamente ao modelo de satisfação proposto, este demonstrou ter inúmeras aplicabilidades, tais como: ser capaz de potenciar a satisfação dos decisores e do grupo, e servir como métrica para avaliar diferentes modelos de negociação automática ou sistemas de apoio à decisão. Provou-se ainda que agentes que utilizam o modelo de satisfação como uma ferramenta de previsão da satisfação final dos decisores que representam, conseguem obter decisões melhores e mais consensuais quando comparados com agentes que não o utilizam. Foi ainda possível observar que o modelo de diálogo baseado em argumentação permite que os decisores acompanhem/percebam o processo de decisão. Além disto, verificou-se que o modelo funciona corretamente com múltiplos agentes. Verificou-se também que os agentes são capazes de utilizar as mensagens criadas pelos decisores de forma a tornar os diálogos mais inteligentes. Foi ainda possível provar que a modelação de estilos de comportamento em agentes, para representar as intenções dos decisores no contexto da tomada de decisão em grupo, também ajuda significativamente na obtenção de decisões de maior qualidade e mais consensuais.

Desenvolver sistemas/modelos para suportar grupos dispersos é um tópico extremamente complexo. Para que estes sistemas alcancem melhores resultados, deve ser dada especial atenção aos interesses dos decisores e não focar apenas o problema. Demonstrou-se que trabalhar estratégias de comunicação e de representação são aspetos extremamente relevantes naquilo que é a capacidade de propor decisões de maior qualidade e de alcançar decisões consensuais mais facilmente.

ACKNOWLEDGEMENTS

I could just follow the protocol, but today I feel like telling a story... mine.

The decision to do a PhD was not something that came up by chance, it was not a second choice and it was not an "escape". The passion for research and science has always existed.

In 2006 I met Professor Ricardo Santos, who quickly became a reference for me. Our talks were quite a few, should have been more, and they will never be enough. His profile as a professor was the trigger I needed for everything that followed. During the following years I focused all my energies on software development. I was never gifted for arts, but I imagine that the need for expression that a painter, writer or composer feels must be quite similar to what I felt in responding to the proposed challenges.

In the second half of 2008 I met Professor Carlos Ramos, a reference in the Artificial Intelligence community – a fact that I was totally unaware of. In fact, I was quite surprised when I found that someone so accessible and pleasant was the holder of such a tremendous curriculum. A certain day, at the end of the presentation of a practical work of the Artificial Intelligence course, he asked me if I would be interested in doing research. I immediately said yes, after all, it was exactly the moment I've been waiting for. At the end of 2008, I joined the GECAD research center (Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development) at ISEP (Instituto Superior de Engenharia do Porto), where I lived the pre, the during and what I now think is the post-crisis period.

In November 28th of 2008 I started another path... the one of love. Patrícia accompanied me throughout all my research path. The availability to help me that she always showed is indescribable. Besides, she always had a fantastic understanding for me, even considering that in the last years, most of the weeks had no weekends and that most of the times when I got home she was already sleeping. From this love, our son João would be born in 2014.

In 2009 I met Professor Goreti Marreiros. She became my Master's and PhD supervisor. We ended up making together more than 40,000 km by plane and a good hundreds by car. As before, I was lucky again. Her profile allowed me to grow as a researcher, to work on my ideas and to pursue a controlled path. She always showed availability to help me, to listen to me, and she always understood me.

In 2011 I met Professor Paulo Novais. He was introduced to me as my PhD supervisor. He is a born leader. He created all the necessary conditions for me to achieve the goals I had set for myself. Always practical and direct, also became a good and concerned adviser. This new relationship led to my entry into the ALGORITMI center at the University of Minho.

At the end of 2012 I started my PhD scholarship funded by FCT - Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) with the reference SFRH/BD/89697/2012.

In 2014 I met my first supervisee, Diogo Martinho and in 2015, the fourth, Luís Conceição, who continue to work with me to this day. For the first time I put into practice the examples that those I mentioned earlier gave me. There were many moments of intensive work, but also of play, of relaxation and companionship. I ended up receiving much more than what I gave.

In 2016 an unexpected reencounter happened. Pedro Saraiva, a former friend from elementary school and currently a PhD student in Psychology, was once again part of my life. The points where our work intersected allowed us to work together again. Pedro ended up having a great contribution in my work.

I'm lucky. Aside from the privilege I had in meeting a number of people who were fundamental in my development as a man and scientist, they also became my friends.

Finally, and since 1986, my parents, Fátima Ribeiro and Carlos Carneiro. My parents gave me everything and created all the conditions for me to be happy. The support they gave me was unimaginable, the dedication shown unquantifiable, and the love immeasurable.

With all my gratitude,
João Carneiro

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ACRONYMS

AA	Abstract Argumentation
ABN	Argumentation-based Negotiation
ADF	Abstract Dialectical Frameworks
AF	Argumentation Framework
AHP	Analytic Hierarchy Process
BAF	Bipolar Argumentation Frameworks
BDI	Belief, Desire, Intention
BFI	Big Five Inventory
CAP	Cognitive Analytic Process
CBR	Case-based Reasoning
DeLP	Defeasible Logic Programming
EAF	Extended Argumentation Frameworks
e-ASA	Aggregation based on Situation Assessment
EIS	Enterprise Information System
FFM	Five Factor Model
GDSS	Group Decision Support Systems
GIS	Geographic Information System
GP	Goal Programming
GRASS	Group Remote Asynchronous Screening Support
MCDA	Multi-Criteria Decision Analysis
NA	Negative Affect
O3A	Open Affective Agent Architecture
OAA	Open Agent Architecture
OCC	Ortony, Clore, Collins
OCEAN	Openness, Conscientiousness, Extraversion, Agreeableness, Neuroticism
PA	Positive Affect

PAD	Pleasure, Arousal, Dominance
PAF	Preference-based Argumentation Framework
PANAS	Positive Affect – Negative Affect
PBA	Proposal-based Approaches
PNGA	Perceived Net Goal Attainment
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
SAT	Satisfaction Attainment Theory
SDSS	Spatial Decision Support System
SWOT	Strength, Weakness, Opportunity, Threat
TNM	Classification of Malignant Tumors
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
VAF	Valued-based Framework
Web-based GDSS	Ubiquitous/Web-based Group Decision Support Systems

1 INTRODUCTION

In order to succeed,
we must first believe that we can.

— Nikos Kazantzakis

This chapter presents an overview of the work that has been developed. For this, a contextualisation of the topics under which work was developed is presented and the existing limitations are exposed, leading the reader to understand the factors that should be considered in a possible solution. The hypotheses are listed based on the limitations identified. The objectives to be achieved are presented next. Finally, the structure of this document is presented. As this thesis is organized according to a format called "Compilation Based" or "Scandinavian model", a summary of each of the publications that are inserted in this document is presented in this chapter.

1.1 OVERVIEW

One of the most important factors that determine the success of an organization is the quality of the decisions made. Making decisions is an intrinsic quality to humans. Each action, more or less significant, conscious or unconsciously, results from a decision. Therefore, we could say we are all natural decision-makers (Saaty, 2008; Saaty and Peniwati, 2013). The decision-making process can be seen as selecting one or more alternatives as the solution for a certain problem (Chen, 2000). It is known that many of the decisions that take place in organizations are made in group (Luthans et al., 2015). Group decision-making is a process in which a group of people, called participants, act collectively to analyze a set of variables, considering and evaluating the available alternatives in order to select one or more solutions. The number of participants involved in the process is variable and all of them may be either at the same place and at the same time or geographically dispersed at different times (Luthans et al., 2015; Palomares et al., 2014). It is a known fact that the number of hours a decision-maker spends in a meeting is not mostly used to make decisions. The time spent on things like social issues is responsible for consuming most of the time of a decision process (Mintzberg, 1973; Argyris and Schon, 1974; Hoffman, 1979). There are several reasons for which decisions are made in group: to improve the quality of the decision, to share workloads, to gain support among stakeholders, to train less experienced group members and due to the majority of organograms existing today (Bell, 1985; Huber, 1984; Kaner, 2014; Griffin and Moorhead, 2011). It has been proven that groups achieve performances that are qualitatively and quantitatively superior to the individual performance (Hill, 1982; Shaw, 1932; **?**). However, in order to take advantage of the benefits behind group decision-making it is necessary to create conditions in which groups can perform certain tasks, such as generating ideas and solutions through group interaction (Hackman and Morris, 1975; Watson et al., 1991). It is considered that with the group decision-making process, members will have their ability to learn enhanced and their cognitive level stimulated (Lamm and Trommsdorff, 1973; Osborn, 1963).

Group Decision Support Systems (GDSS) have been widely studied throughout the last decades to support this type of decisions (Galegher et al., 2014; Dai et al., 2017; DeSanctis and Gallupe, 1984; Desanctis and Gallupe, 1987; Gray, 1987; Marakas, 2003). However, in the last ten/twenty years, we have seen a remarkable change in the context where the decision-making process happens, especially in large organizations (Chen et al., 2007; Grudin, 2002; Novais et al., 2014). With the emergence of global markets, the growth of multinational organizations and a globalist view of the planet, we can easily find decision-makers (chief executive officers, managers and other members of global virtual teams) spreading around the world, in countries with different time zones (Shum et al., 2013). Moreover, to support the group decision-making process in this context is especially complex. This can lead to additional problems: failure to communicate and retain contextual information, unevenly distributed information, difficulty to communicate and to understand the salience of information, differences in the speed of access to information, and difficulty to interpret the meaning of silence (Bjørn et al., 2014); and to deal with temporal issues, which can originate: ambiguity, conflicting temporal interests and constraints, and scarcity of temporal resources (McGrath, 1991; Légaré and Witteman, 2013). To provide an answer and operate correctly in this type of scenarios, the traditional GDSS have evolved to what is known today as Ubiquitous/Web-based Group Decision Support Systems (Web-based GDSS) (Alonso et al., 2010; Kwon et al., 2005; Marreiros et al., 2010; Morente-Molinera et al., 2016). The idea behind the Web-based GDSS is to support the decision-making process "anytime" and "anywhere", and to help dealing with some of the referred problems (Santos et al., 2006; Shim et al., 2002; Palomares et al., 2013).

In a group decision-making process there is a conflict of interests and each of the parties involved may (or may not) have different objectives and needs that intends to satisfy (Lewicki et al., 2011). Two main approaches have been implemented in GDSS to help with group decision-making processes. The classical approaches, based on preferences' aggregation, and the consensus-based approaches. The former consists in an aggregation phase, that combines the experts' preferences, followed by the selection of one alternative (Herrera et al., 2005; Saaty, 1988). The latter extends the former through an iterative process in order to achieve consensus (Fedrizzi and Kacprzyk, 1988; Palomares and Martínez, 2014). They intend to help decision-makers in achieving an agreement (or a consensus) through frameworks and other specific strategies. However, when the decision process involves dispersed decision-makers, many benefits associated to group decision-making process are lost. During the process of a real face-to-face decision-making scenario, the decision-makers interact in many ways (verbal and nonverbal communication) which does not happen when decision-makers are geographically dispersed at different times. These limitations can be the reason why "Computerized Conferences" obtained (in an old study) worst results when compared to face-to-face scenarios (Hiltz et al., 1986). In face-to-face decision-making scenarios, the dialogues can assume different types like: persuasion, information-seeking, inquiry, among others (Walton and Krabbe, 1995). The argumentation-based dialogue models can be a suitable strategy to help overcome the lack of interaction inherent to the decision-making processes in which decision-makers are geographically dispersed (Kakas and Moraitis, 2003; Karacapilidis and Papadias, 2001; Rahwan et al., 2003). They allow the exchange of proposals including justifications and explanations which are essential for the negotiation process (Marey et al., 2014a; Novais et al., 2005)). Furthermore, the arguments can be used to explain to decision-makers the reasons why a certain solution is proposed (Amgoud and Prade, 2006). The most striking approaches were proposed about 2 decades ago (Dung, 1995; Kraus et al., 1998; Sierra et al., 1997). Since then, we have seen different (extensions) approaches to formulate argumentation frameworks, such as: abstract argumentation (Bondarenko et al., 1997; Prakken, 2010), logic-based argumentation (Amgoud, 2014; Besnard and Hunter, 2001), value-based argumentation (Bench-Capon, 2002; D'Avila Garcez et al., 2005), assumption-based argumentation (Dung et al., 2009; Fan et al., 2013), among others (Amgoud and Vesic, 2011b). However, these approaches deal with argumentation as a somewhat one-sided-process "in which a single party merely presents a reasoned justification" (Bench-Capon and Dunne, 2007). In the context of group decision-support, the paradigm is different, the argumentation is "an informed exchange of ideas and positions involving several contributors: in other words, argumentation concerning an issue", which typically, arises as a dialogical process (Bench-Capon and Dunne, 2007). Some strategies have been proposed to deal with dialogical processes (Johnson et al., 2005; McBurney and Parsons, 2001; Parsons et al., 2007), most of which are oriented to be used in multi-agent systems and to formalize some typical aspects, such as: locutions, utterances, rules for dialogue continuation and termination. However, when we search for argumentation-based dialogue models specifically adapted to GDSS, the results are practically inexistent. The few existing results are outdated (Karacapilidis and Papadias, 1996, 2001) and even if some seemed promising in the way they could be adapted to this area (Kraus et al., 1998; Sierra et al., 1997), the works that came next followed (most of the times) another path (despite some of them remain within decision support).

When developing a Web-based GDSS it is necessary to be aware of the benefits inherent to face-to-face meetings. A typical face-to-face meeting allows the decision-makers' interaction, exchange of ideas, work on new knowledge and intelligence generation (Dennis, 1996; Hill, 1982; Huber, 1984). As we had seen, (in an ideal scenario) we can achieve some of these benefits using automatic negotiation models (for instance: argumentation-based dialogue models). However, there is so much more besides the "messages" exchanged by decision-makers, it is necessary to work in the representation of those decision-makers. The representation can range from criteria's evaluation (for instance in a multi-criteria problem (Carneiro et al., 2015b) to a complete representation of the individual (personality, emotions, mood, among others. (Gmytrasiewicz and Lisetti, 2002; Raja and Srivatsa, 2006; Santos et al., 2009)). The group decision-making process benefit from the decision-makers' heterogeneity (Hambrick et al., 1996). This heterogeneity is related to the decision-makers' temperament but also with the decision-makers' intentions. Let us consider a scenario in which a medical team intends to choose a particular course of treatment for a patient whose condition calls for different areas of expertise. As in any other multi-criteria problem, each of the specialists, depending on their own background could have their own preferences over a number of possible alternatives, considering for instance, the order/timing of certain required interventions. However, each team member's opinion may be subject to a different appreciation, being judged for instance in terms of importance, rank, expert level or even based on implicit rules regarding their overall credibility. It is also conceivable that in some authoritative contexts the opinions of the highest graduated specialist may be taken as the rule of law, limiting any further suggestions once they are stated. In order to answer these questions, it is necessary to allow decision-makers to configure not only their preferences (on alternatives and criteria), but also their intentions and other aspects that may be relevant, so that their position can be expressed with the best possible representation.

To model agents with human-like aspects is not new. At the start of the new millennium, some projects dealing with agents' humanization began to appear (André et al., 2000). Nowadays, there are many proposals that intend to model human characteristics in agents, such as: personality (Dimuro et al., 2007; Padgham and Taylor, 1997), emotions (Ball and Breese, 2000; Gmytrasiewicz and Lisetti, 2002), cognitive styles (Frank et al., 2001), among others. There are also some proposals under the topic of GDSS (Palomares et al., 2014, 2013; Recio-García et al., 2013; Santos et al., 2009; Marreiros et al., 2008). All of them share the idea that including cognitive/affective aspects will benefit in some way the decision-making process. However, to the best of our knowledge, most of them are envisaged for use in simulated environments. The usage of such techniques in real systems can bring some disadvantages. "A real me" can be a bad approach if my persona is less persuasive/intelligent/capable than others. An application that mimics one's limitation will be of lesser interest. Moreover, the inclusion of aspects such as personality does not permit to reflect other aspects such as intentions and objectives. For each decision-maker, the objectives and intentions can vary even for the same problem.

Finally, both Web-based GDSS/GDSS and argumentation-based dialogue models present problems related to evaluation. Usually, these systems/models are evaluated through mathematical proofs, number of rounds or seconds to propose (reach) a solution (Marreiros et al., 2010). However, these techniques do not say much in terms of decision quality. It becomes impossible to compare how much more one model is capable of enhancing the quality of the decision in relation to another. Surely, the decision quality cannot be measured in the end of a group decision-making process because the impact resulting from that decision is unknown. What can be measured, or what can be valuable to know in the end of a group decision-making process is the perception of the decision-quality of each decision-maker (or their satisfaction) (Carneiro et al., 2015a). Satisfaction is therefore a strong indicator, not only of the results, but also of the whole decision process (Higgins, 2000). When someone is questioned about the quality of a decision, the answer does not just stem from the assessment of outcomes, but also, even unconsciously, it includes the evaluation process necessary to reach the decision (Higgins, 2000). In literature, satisfaction as a metric has been applied in many different issues like life satisfaction (Schimmack et al., 2004) or job satisfaction (Judge et al., 2002). Satisfaction has also been applied in the GDSS area. However, the existing proposals are not concerned with the perception of the decision quality but instead with the decision-maker's satisfaction regarding the GDSS performance, usability, among others (Briggs et al., 2003a; Tian et al., 2008a; Paul et al., 2004a).

1.2 RESEARCH HYPOTHESES

Concerning the limitations of GDSS intended for dispersed groups, as well as their low acceptance by organizations (van Hillegersberg and

Koenen, 2014, 2016), we believe that there may be flaws in the way this problem has been considered and interpreted. It is true that sometimes group decision-making is a compulsory process, for example due to most organizational charts of today's organizations. However, there are several benefits associated with the group decision-making process that go well beyond these "policy" issues. So, what would be the interest of a decision-maker in using a GDSS that does not allow him to take advantage of those benefits? What confidence would he take from a proposed solution that discards the existence of a process and everything that a process allows? How frustrating can be a system that does not allow for the insertion of new knowledge? And not less important, how appropriate for a high-level executive or top manager will a system be if, albeit ensuring the best results, requires tens/hundreds of slow configurations?

With the execution of this work we aim to respond to these challenges by using artificial intelligence techniques, to take advantage of the inherent benefits of group decision-making. The research hypotheses for this work are formulated as follows:

1. Computer agents can act according to the style of behavior with which they are defined;
    - It is possible for decision-makers to select a style of behavior to model computer agents in the context of group decision-making so that the behavior of the agents is as expected by the decision-makers;
    - Agents that represent/support decision-makers in the Ubiquitous/Web-based group decision-making process and that use styles of behavior can obtain higher consensus and quality decisions more easily;
    - Agents with a higher level of concern for others obtain higher satisfaction levels;
    - Agents with a higher level of concern for others and a higher level of concern for self obtain higher satisfaction levels;
    - Agents with a low concern for self obtain consensus more easily;
    - Using agents defined with a style of behavior is always advantageous;
    - A cooperative decision system that uses agents modeled with styles of behavior should be able to benefit from this heterogeneity and not present a biased functioning;
2. It is possible to predict the decision-makers' perception of the decision quality;

- If we predict the decision-makers' perception of the decision quality, we can use this prediction in a negotiation model in order to maximize the decision quality;

3. An argumentation-based negotiation model is capable of improving the intelligence (of the agents or entities) and not only to reason about a solution;
    - It is possible for both agents and decision-makers to use a dialogue which is clear to everyone involved in the decision-making process;
    - It is possible for both agents and decision-makers to take advantage of the knowledge which is generated;
    - It is possible to configure the preferences, objectives and intentions of a complex multi-criteria problem without compromising usability and within an acceptable time frame.

1.3 OBJECTIVES

The main objective of this work is to create mechanisms to support disperse groups in the group decision-making process, taking advantage of the benefits inherent to face-to-face scenarios. In other words, these mechanisms should take advantage of the face-to-face group decision-making process, but at the same time be adapted to the needs of the Web-based GDSS target audience (executives and top managers), motivating and encouraging them to use the system, so that the benefits in its use are easily perceived, generating a feeling of comfort and confidence with respect to the proposed solutions.

This main goal is approached in terms of the following objectives:

- To ascertain the state of the art in the following areas: Group Decision-Making, Argumentation, Argumentation-Based Negotiation, and Affective Computing;
- To develop a model that is capable of representing decision-makers according to their intentions in respect to a particular decision process;
- To develop a model capable of predicting the satisfaction or the perception of the decision quality of each decision-maker and the group regarding the proposed solution;
- To develop an automatic negotiation model under the logic of a real decision-making process, involving the decision-makers in the process, allowing them to contribute with new knowledge and to perceive the process and the reason for which a given solution is presented;

- To formalize an argumentation-based dialogue model that considers agents (with behavioral styles) which represent decision-makers, that contemplates affective issues and satisfaction prediction algorithms regarding how agents dialogue and evaluate requests;

- The models developed should not require a large set of configurations, enhancing the usability of a future system and matching the lifestyle and agenda of executives and top managers.

1.4 STRATEGY AND RESEARCH PLAN

To achieve the defined objectives, a methodology called Action-Research was used (Somekh, 2005) . This methodology consists of a set of stages based on continuous development and directed to problem-solving. What distinguishes it from more conventional approaches is that the focus is placed on the scientific study. In this methodology, the researcher systematically studies the problem and his interventions are supported by theoretical considerations. Initially, the problem is identified so that the hypotheses can be formulated. Subsequently, the information is continuously recompiled, organized and analyzed in order to develop a proposal capable of solving the identified problem. Finally, based on the results obtained during the research process, it is possible to draw conclusions. For this methodology to be correctly followed and achieve the stipulated objectives, six complementary stages are defined. Those stages are described below:

- Specification of the problem and its characteristics: this stage consists in the definition of the problem and investigates the reason why it exists/happens, all its characteristics are gathered and the hypotheses are formulated;

- Constant and incremental updating of the state of the art review: the review of the state of the art consists on studying the approaches that relate to current research;

- Development of the solution: the information gathered in the previous stages allows the design/development of a solution to respond to the defined objectives, and consequently will verify or reject the research hypotheses;

- Experimentation and implementation of the solution through the development of a prototype: formalization of a prototype that contains all the resources specified in the solution. Then, its behavior is observed in order to verify its effectiveness;

- Analysis of results and formulation of conclusions: this stage consists on the analysis and validation of the prototype. For this, it is checked if the implementation attains the objectives, which will allow to draw conclusions about the research hypotheses;

- Constant dissemination of the knowledge, results obtained and experiences in the scientific community: dissemination of results in peer-reviewed journals, conferences, workshops, among others.

Based on the last stage of the Action-Research methodology, and considering that it was possible to publish the performed work, it was decided that this thesis would follow the format called "Compilation Based" or "Scandinavian model".

1.5 STRUCTURE OF THESIS

This section presents the structure of the thesis, aiming to make it easier for readers to find the envisioned content and to ease the perception of some aspects related to the structure of the document. This thesis follows a format called "Compilation Based" or "Scandinavian model", which consists of the compilation of several publications that present the methods and the results regarding the hypotheses that were initially defined.

The structure of the four main blocks is as follows:

Chapter 1: Introduction

In this chapter, the context of this work is introduced and it is intended to lead the reader to understand its relevance. Based on the limitations referred in the Overview, research hypothesis and objectives are defined. This chapter ends with the presentation of the structure and contents present in this thesis.

Chapter 2: Background

This chapter addresses each of the relevant topics in the context of the work presented in this thesis. Topics covered are: Group Decision-Making, Affective Computing, Argumentation and Argumentation-Based Negotiation. The state of the art of each of these topics is presented. At first, a contextualization and historical presentation is introduced for each topic, followed by the presentation of the most relevant works. Finally, the limitations of current approaches are discussed.

Chapter 3: Publications Composing the Doctoral Thesis

Chapter 3 presents the set of publications that have been selected to integrate this document. This chapter is composed of 6 publications that cover different parts of the work done. All publications are preceded by a table which presents all the information regarding it.

Section 3.1: Intelligent negotiation model for ubiquitous group decision scenarios (Carneiro et al., 2016c)

This publication proposes a negotiation environment that is based on social networks logic. It presents a set of ideas that can be used in works that intend to develop group decision support systems, argumentation-based negotiation models and agents' modeling. It aims to embody an environment of a face-to-face group-decision process. It proposes two types of communication, Public Communication, which represents in the form of "posts" the existing communications in real group decision-making processes, where all decision-makers listen to the same messages at the same time (avoiding that some agents may act in possession of more knowledge that is public compared to others), and Private Communication, which adds the possibility that the agents can be simultaneously carrying out private "one-to-one" type conversations. A set of illocutions (Statements, Questions or Requests) are also introduced, so that agents can use them to hold a dialogue on the subject under discussion. It is demonstrated that the dialogue carried out by the agents, even considering that they can add new preferences throughout the process, is always finite. A set of attribute types, as well as a possible interaction of the real decision-maker with such an approach, is also proposed.

Section 3.2: Representing decision-makers using styles of behavior: an approach designed for group decision support systems (Carneiro et al., 2017g)

Affective computing is a multidisciplinary field encompassing computer science, engineering, psychology, education, neuroscience, and many other disciplines. As such, it is normal to refer several papers that present solutions and that are developed based on knowledge presented under topics other than computer science. However, this means that sometimes works appear to be developed based on knowledge that underwent adaptations which were themselves not validated. This publication proposes a set of behavioral styles that intends to model the intentions of the decision-makers towards the decision process. Based on existing studies, five styles of behavior were considered: dominating, integrating, compromising, obliging and avoiding. It also proposes the styles to act according to four dimensions: concern for self, concern for others, resistance to change and activity level. This paper presents a study involving 64 participants to find the operating values for these dimensions. The study demonstrates that participants have a homogeneous perception of the level of performance of each style of behavior for the various dimensions, thus allowing to consider the operating values as valid to model agents with those behavioral styles, in the context of group decision-making. In this publication, a communication model to allow agents to have dialogues that mimic the logic of communication present in face-to-face meetings is also proposed. With the work described in this paper, it was possible to conclude that as in reality, decision groups made up of agents with different behavioral styles can benefit from the heterogeneity of their elements when compared to homogeneous groups.

Section 3.3: Evaluating the perception of the decision quality in web-based group decision support systems: a theory of satisfaction (Carneiro et al., 2017f)

In this publication, a formulation of a model to predict the decision-makers' satisfaction (perception of the decision quality) is presented. This work appears in light of the lack of existing mechanisms to predict/study the quality of the decision and consequently it is not possible to evaluate in any way what kind of practical benefits certain systems or models of automatic negotiation can offer (in comparison). In order to predict the perception of the decision-making quality of each decision-maker, and consequently the group, several points are considered: the outcomes, the decision-maker's expectations, style of behavior, emotional changes and mood variation according to a considered set of events. The assumptions and premises used to formulate this model were created according to strong evidences found in the literature under the topics of decision quality, perception of the decision quality and human reasoning (a paper addressing this issue was published in Carneiro et al. (2015a)). In addition to its primary objective, the satisfaction model can be used to evaluate different group support systems or automatic negotiation mechanisms. It is possible to use a short version of this satisfaction model (whenever not all parameters are applicable) as done in (Carneiro et al., 2016a).

Section 3.4: Including cognitive aspects in multiple criteria decision analysis (Carneiro et al., 2016a)

The publication presented in this section introduces a new multi-criteria decision analysis (MCDA) method. Assuming the consideration of affective aspects in computer-based decision-making processes leads to better decisions, we question if the hypothesis can be verified using a purely analytical approach. In this paper, the Cognitive Analytic Process (CAP) is proposed. CAP is a new method of MCDA that contemplates cognitive aspects and allows decision-makers to configure not only their preferences (over criteria and alternatives) but also their intentions. CAP allows each decision-maker to define: a behavior style (to reflect his intentions about the process), his level of expertise and what other decision-makers he considers to be credible. In addition, the CAP considers the evaluation that the decision-makers make of the criteria in an innovative way, the criteria are classified (considering several aspects) as: very important criterion, important criterion, medium criterion, not important criterion or insignificant criterion. The CAP has the advantage of not having compulsory settings, hence all configurations are optional. In addition, the number of configurations to be performed is considerably smaller than in another methods referenced in the literature, as is the case of Analytic Hierarchy Process (AHP) (Saaty, 1988) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Tzeng and Huang, 2011). The CAP proved to obtain more satisfactory results most of the times, when compared to MCDA methods that are referenced in the literature, thus demonstrating the positive impact of the inclusion of affective aspects. This paper used the knowledge published in the paper presented in Section 3.3.

Section 3.5: Dynamic argumentation in UbiGDSS (Carneiro et al., 2017b)

This publication presents what we have called as Dynamic Argumentation. This argumentation model allows disperse decision-making groups to enjoy the known advantages of face-to-face group decision-making, by exchanging messages using exactly the same formulation as that used by agents. These messages are composed (among other things) by a locution and an argument. In that way, attack and reinforcement relationships take place between messages. Also, a mechanism is proposed so that decision-makers can evaluate the messages while being suggested to them if they intend to justify their evaluation. This justification (argument) gives rise to a new message that will be in favor or against the evaluated message. Each decision-maker has his message tree according to his own assessments. In this way, the agent that represents a decision-maker has access to the message tree of his decision-maker "understanding" the actual conversation that he made (regarding the impact of the messages, not the content). All definitions and algorithms that allow agents to navigate the message tree are formulated. With the locutions used by the agents, the decision-makers can also perceive all the dialogues made by the agents, which allows decision-makers to understand the reasons for the proposed solutions as well as to document decisions.

In this work, it was also verified that the agents manage to use the dialogues made by the decision-makers and to create/organize new knowledge that is appreciable for the decision-makers. This approach takes advantage of the benefits of group decision-making because there is a decision-making process that involves decision-makers in the process itself, allowing them to increase their confidence levels with respect to the solutions presented. This approach does not require large configuration costs on the part of the decision-makers and presents a high level of usability. This paper is based upon the knowledge published in the papers presented in Section 3.1, Section 3.2 and Section 3.3.

Section 3.6: Arguing with behavior influence: a model for web-based group decision support systems (Carneiro et al., 2017c)

This publication makes use of the dynamic argumentation model presented in Section 3.5 and proposes an argumentation-based dialogue model. This argumentation-based dialogue model is specifically designed to support dispersed groups in decision-making processes, allowing agents to interact in a way that is very similar to the one of the face-to-face decision-making processes. Decision-makers can model agents with behavioral styles (which act according to the values found in the publication in Section 3.2) that reflect their intentions concerning the decision process. It also proposes a set of arguments that agents can use to make requests, as well as a set of formulas to evaluate such requests, considering the behavioral style of the agent. It also proposes a set of illocutions and utterances that agents can use, as well as all dialogue moves where rationality, dialogue and action rules are specified. This model proves that in a virtual context, higher levels of consensus and satisfaction are achieved when using agents modeled with behavioral styles when compared to agents without any strategy to represent the decision-makers' intentions. This paper uses the knowledge published in the papers presented in Section 3.1, Section 3.2, Section 3.3 and Section 3.5.

Chapter 4: Conclusions

In this chapter, the contributions resulting from the elaboration of the work described in this thesis are presented, as well as the ways by which they validate the research hypotheses previously defined in the introductory chapter. In addition, the activities that permitted the dissemination of results and other related activities occurring during the course of this PhD are described. Finally, final remarks and considerations about future work are described.

2 BACKGROUND

The art and science of asking questions
is the source of all knowledge.
— Thomas Berger

This chapter addresses each of the relevant topics in the context of the work presented in this thesis. Topics covered are: Group Decision-Making, Affective Computing, Argumentation and Argumentation-Based Negotiation. The state of the art of each of these topics is presented. At first, a contextualization and historical presentation is introduced for each topic, followed by the presentation of the most relevant works. Finally, the limitations of current approaches are discussed.

2.1 GROUP DECISION-MAKING

Making decisions is intrinsic to the human being. Each action, more or less significant, conscious or unconsciously, results from a decision. Therefore, one could say we are all natural decision-makers (Saaty, 2008; Saaty and Peniwati, 2013). The decision-making process consists of selecting one or more alternatives to be the solution to a given problem/task (Chen, 2000). Nowadays, many of the decision-making processes that happen in organizations are made in group (Luthans et al., 2015). Group decision-making has been widely studied in the last decades and became the preferred way of making decisions in many organizations (Moon et al., 2003). Group decision-making is a process in which a group of persons, named participants, act collectively to analyze a set of variables, considering and evaluating the available alternatives in order to select one or more solutions. The number of participants involved in the process is variable, and they can all be in the same space at the same time, or geographically dispersed at different times (Luthans et al., 2015; Palomares et al., 2014). When decision-making process is performed in group, the chance to detect a problem is higher, and subsequently, the decision-makers can work together to find a solution for that problem. This turns group decision-making into a more effective and fast process.

In the 50's, researchers saw decision-making groups as a safer way to make decisions (Hilgard et al., 1975). Posterior studies demonstrated that groups tend to be less cautious than individuals and the risk of optimistic analysis increases (Buehler et al., 2005). It is

Table 1: Types of GDSS (adapted from DeSanctis and Gallupe (1984)).

		Duration	
		Limited	Not Limited
Members	Same place	Decision room	Local area decision network
localization	Different place	Teleconference	Remote decision making

known that most of the hours spent by the decision-makers in a meeting are not to make decisions. The time spent on other issues, like social questions, is responsible for consuming most part of a decision process (Mintzberg, 1973; Argyris and Schon, 1974; Hoffman, 1979). Depending on the decision process and group size, decisions made by groups may have better or worse results than those made by individuals (Moon et al., 2003; Fay et al., 2000). There are many reasons to make decisions in group: to improve the quality of the decision, to share workloads, to get support among stakeholders, to train less experienced group members and due to the majority of organizations' organograms existing nowadays (Huber, 1984; Bell, 1985; Kaner, 2014). However, due to the globalization of markets and the firms' internationalization, it is very hard to match the decision-makers' agenda, making it difficult for them to meet at the same place and time (Shum et al., 2013). Therefore, it is no surprise that so many techniques, models, methods and tools that support groups and individuals in the decision-making process are being studied (Carneiro et al., 2016a).

This section describes the evolution of Group Decision Support Systems (GDSS) since their appearance until today. The state of the art regarding GDSS is also presented. Since Multi-Criteria Decision problems are the kind of problems dealt in this thesis, they are also addressed in this section. Finally, a brief summary and discussion are presented.

2.1.1 *The Story of Group Decision Support Systems*

DeSanctis and Gallupe (1984) said that "an exciting new concept was emerging in the decision support area. It involved the development of computer systems for groups of people responsible for making decisions". These systems were called Group Decision Support Systems. These two researchers decided to study GDSS and their technological and functional requirements resulting in one of the first GDSS taxonomic approaches which categorized GDSS in four scenarios. According to this categorization, the purpose and configuration of GDSS vary depending on the duration of the decision-making process and on the degree of physical proximity of the group members. Table 1 shows the GDSS types.

After three years, Desanctis and Gallupe (1987) published a new work. They suggested the formulation of a GDSS should be based on three factors: the group size, if the decision-making is face-to-face or not, and the type of tasks the group must cope with (Figure 1).

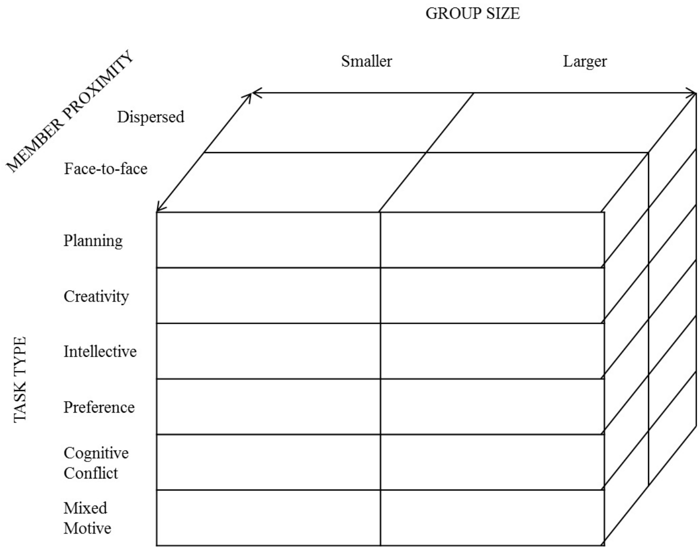

Figure 1: Formulation of GDSS (adapted from Desanctis and Gallupe (1987)).

According to the authors, a decision-making group can be defined by two or more persons that together are responsible for: detecting a problem, finding the problem's origin, generating possible solutions, analyzing possible solutions, and perform strategies to implement the selected solutions. Although the group members may not be physically at the same place, they are aware of the existence of others, realizing they are part of a group that is making a decision. Three different levels of GDSS were defined (Desanctis and Gallupe, 1987), which represent three different possible approaches to support a group in decision-making:

- Level one GDSS: the resources defined for this level can be found in decision rooms, commonly known as "computer supported conference rooms" or "electronic board rooms". These systems enhance the decision process by facilitating the exchange of information among the participants;
- Level two GDSS: these systems can provide automated planning tools, or other features normally found in individual decision support systems, so group members can visualize information simultaneously, also with the use of a large screen. Modeling tools to support analysis that are normally conducted qualitatively, such as social formation analysis, risk analysis, or methods of multi-criteria analysis, can be found at this level;

Table 2: Desanctis and Gallupe's taxonomy of GDSS (adapted from Desanctis and Gallupe (1987)).

		Group size	
		Smaller	Larger
Members	Face-to-face	Decision room	Local area decision network
proximity	Dispersed	Legislative session	Computer-mediated conference

- Level three GDSS: are characterized by inducting knowledge to the group by the system and can include advice from experts, selecting and organizing the set of rules to be applied during a meeting.

The group needs and dynamics vary according to the factors of each situation. Literature on behavior of social sciences groups, as well as the investigation on electronic communication and group decision-making, suggests that the nature of information exchanged and the decision-making results change when groups are extremely large, originating irregular communication (Leduc, 1979). Due to these factors, group size and members' proximity during the meeting are the most critical aspects in the design of a GDSS. Due to the difficulty in characterizing the groups' size, these authors state that groups can be relatively small or relatively large. Marreiros (2008) considers that groups of 3 to 5 elements are considered small, 6 to 12 are medium, and over 12 are large.

Desanctis and Gallupe (1987) also defined a taxonomy that considers four configurable environments according to the group size and the dispersion of its elements. These factors are not mutually exclusive but represent bipolar extremes that influence the meeting dynamics and the selection of functionalities for decision support.

The four environments are characterized in Table 2, and are described as follows:

- The decision room (small and face-to-face group): these group members are all in the same physical space, gathered during a certain period of time to debate a problem or a set of problems. The organization is based in a room with a large display to project the information, and each member has a computer. Communication between members is verbally transmitted or via electronic messaging. The public display is used to show ideas, analysis, polls, group preferences, graphics, etc;

- The local area decision network (small and dispersed): Several system configurations are possible here: group members located at workstations in offices can be connected by a local area network, members who are at home or travelling can be linked by long distance networks, and two or more Decision Rooms can be linked together by teleconference. This kind of meetings can last over a period of days and it is not required that all group members are simultaneously online. A human or electronic facilitator can be present;

- The legislative session (large and face-to-face group): the big difference to the decision room is that in this case only the facilitator can send information to the large display. Individual computers can be shared by groups of 2 or 3 persons. Communication takes place hierarchically, where each member can send messages only to members in his level or to the member responsible for that group;

- Computer-mediated conference (large and dispersed group): when a large number of people is not physically close and need to gather to make decisions, a different GDSS is necessary. Long distance telecommunication networks are needed. Also, there must be a hierarchy of speakers, as happens in legislative sessions.

As most part of technological innovations, GDSS appeared naturally to facilitate the accomplishment of tasks has long practiced by humans. Huber (1984) defined GDSS as a computer-based interactive system that helps solving unstructured problems[1]. According to Straub and Beauclair (1988), a GDSS is any technology used to improve group decision quality. They assume a GDSS can help groups to reach higher quality decisions, stimulating interactions in a more balanced and useful way, and reducing the negative aspects of small decision-making groups. Thus, a GDSS can be seen as a specific decision support system, designed to provide tools and support decision-making. It can be exemplified by systems such as video conference, and interactive software like forums and distributed networks. Throughout the history of development and growth of GDSS, there was a feeling that the quality of the decision made by groups would be better with its use (Straub and Beauclair, 1988; Gallupe, 1987).

In the early 90's, the majority of existing GDSS were of synchronous type (Turban, 1990). However, the interest in systems that do not restrict participants both in terms of decision and meeting time fostered the development and study of asynchronous GDSS. Cao and Burstein (1999) also referred that there was a major concern in investigating computerized support for group decision, where one of the main points of study was to support co-located people in space and time and they considered that there was a need for more research focused in asynchronous group decision support systems.

In the beginning of the new millennium, studies that compare the two forms (synchronous and asynchronous) started to appear, seek-

1 Problems with incomplete or ambiguous information.

ing to understand which one brings more advantages to the decision process (Benbunan-Fich et al., 2003; Shim et al., 2002; Fjermestad, 2004). An asynchronous mean of discussion provides an environment where richer and with greater coordination discussions can occur. This can happen due to the asynchronous interaction self-nature, which allows reflecting and the getting of new ideas, and the discussion of more issues when compared to face-to-face meetings. The effort of asynchronous discussions is superior to the effort in synchronous systems since the participants need to accompany the process for a longer period of time.

The GDSS approaches based on synchronous and asynchronous systems obviously have advantages and disadvantages, but they are not sufficient to fulfill all the needs by themselves. It was found that something more was needed, leading to the appearance of the Web-based and Ubiquitous GDSS (Kwon et al., 2005). These approaches aim to allow participants to interact with the decision process at anytime and anywhere. Ubiquitous computing is the ultimate cleavage of the "here and now" action (Grudin, 2002). Currently, there is a growing interest in developing Ubiquitous GDSS to formalize and design group decision-making processes "at anytime and anywhere" (and through almost any kind of devices), instead of "at the same place and at the same time" (Conceição et al., 2017). This interest arose with the need to gather the best group of potential participants (Marreiros et al., 2010).

Another research line on GDSS is the use of multi-agent systems, especially those with a strong connection to argumentation and negotiation (Rahwan et al., 2003; Marreiros et al., 2007; Hernández et al., 2014; Rossi et al., 2016). Multi-agent systems have been widely used in the last decades (Cao et al., 2013; Jennings et al., 1998). The level of autonomy associated with agents, their abilities to interact/communicate, as well as their capability to exhibit "behaviors" are highly praised features in ever more distributed environments (Ito and Shintani, 1997; Jennings and Wooldridge, 1998; Van der Hoek and Wooldridge, 2008). Many approaches have been put forward in literature, where agents are defined with characteristics that set them apart from each other (Allbeck and Badler, 2002; Badler et al., 2002; Velsquez, 1997; Zamfirescu, 2003). Also under the topic of group decision-making several works with agents have been proposed (Aronson et al., 2005; Olfati-Saber et al., 2007), some of which used agents as a way to represent decision-makers/experts (Carneiro et al., 2017b; Palomares et al., 2014; Santos et al., 2009). This representation of decision-makers allows the systems to become more intelligent and dynamic, given they are capable of dealing with aspects of great relevance in face-to-face type meetings. Also, multi-agent systems have been used to plan meetings (Ephrati et al., 1994; Garrido and Sycara, 1996; Sen and Durfee, 1994; Ramos et al., 2010).

More recently, studies that seek to incorporate typical attributes of affective context in GDSS started to appear (Marreiros et al., 2010; Freitas et al., 2013; Hariharan and Adam, 2015). Attributes such as mood, personality and emotions, are embedded in agents so they operate as most similarly as possible as the participant they represent (Recio-García et al., 2013). Marreiros et al. (2010) conducted experiments that showed agents with emotions can reach a consensus faster than agents without an emotional component. This is one of the most recent research areas in the GDSS world, and is still in an affirmation phase.

2.1.2 *Multi-Criteria Decision Problems*

Multi-criteria decision problems are complex problems. In situations where multiple criteria are involved, confusion can arise if a well-structured and logical decision-making process is not followed. Another difficulty in decision-making is that a consensus in a multidisciplinary group can be very hard to attain. By using Multi-Criteria Decision Analysis, participants do not need to agree in the criteria relative importance or in the alternatives position (Chen, 2000). Each participant inserts his opinions, making a distinct and identifiable contribution to a joint conclusion. Examples of multiple criteria problems are:

- The purchase of a car, in which the criteria can be the price, color, power, brand prestige, design, warranty period, extras, and the engine, among others;
- The purchase of a house, in which the criteria can be the price, areas, construction quality, builder trustworthiness, extras, and the surrounding space, among others.

There are several situations where humans express their preferences aiming to make good decisions (Sedki and Delcroix, 2010), but the major problem in modelling the humans' preferences is that they become increasingly complex (Herrera and Herrera-Viedma, 2000): the considered criteria are generally in conflict and the number of available alternatives is too large. MCDA methods have been developed in order to efficiently solve these complex decision problems.

Many decision problems require reasoning on preferences under uncertainty. In classic decision theory, these problems are formulated in quantitative frameworks where preferences are expressed by a utility function, while uncertainty is represented by a probability distribution (or belief and capacity functions) on a set of alternatives. An alternative with an expected maximum utility value is considered the best. Examples that contemplate these approaches are proposed by Savage (1972) and Von Neumann and Morgenstern (2007).

These approaches require users to express their preferences in a numerical setting. The qualitative representation of preferences has attracted the attention of several Artificial Intelligence approaches (for example: Boutilier (1994); Dubois et al. (2002); Boutilier et al. (2004); Gonzales and Perny (2004)), whose sole requirement is to specify the alternatives order of preference. Even if those qualitative and quantitative approaches are efficient, most of them are not easily applicable. Quantitative representations of preferences are known to be inconsistent and significantly more onerous to the user than qualitative representations. Qualitative representations are often limited to some specific types of preferences, although there are numerous types of preferences (Boolean, conditionals, etc.). The vast majority of existing approaches only consider preferences related to the decision and no other important issues of personal context.

MCDA methods are one of the techniques used to support the decision-making process. MCDA is considered appropriate to deal with conflicting opinions and also qualitative and quantitative objectives (Ram et al., 2011; Golmohammadi and Mellat-Parast, 2012). MCDA provides a framework which deals with complex decision problems. In order to reach a consensus, a MCDA framework allows decision-makers to share information through problem configurations (Dehe and Bamford, 2015; Marreiros et al., 2004; Carneiro et al., 2016a). Throughout the last decades, a wide variety of analytical models have been proposed in literature (Tavana et al., 2010). Some of the most acknowledged MCDA methods in literature are: ER, ELECTRE, PROMETHEE, AHP, ANP, TOPSIS, MACBETH (Greco et al., 2005). Even though there is a very decent amount of work proposed under the topic of MCDA, the issues associated to MCDA are easy to identify. Tavana et al. (2010) have identified certain issues such as: deficiencies when considering objective and subjective criteria, imprecise information due to the lack of the decision-makers' expertise, unavailability of data and time constraint, among others. Besides these issues, we can still include the lack of information about each decision-maker (Nattrass, 2007), the difficulty or impossibility for each decision-maker to express how he intends to face the decision-making process (Rahim and Magner, 1995) and the difficulty (the cost) associated to the problems' configuration (Dehe and Bamford, 2015).

2.1.3 *Group Decision Support Systems Nowadays*

As we have seen, GDSS have been widely studied throughout the last decades to support groups in the decision-making process (DeSanctis and Gallupe, 1984; Desanctis and Gallupe, 1987; Gray, 1987; Marakas, 2003). However, in the last ten/twenty years, we have seen a remarkable change in the context where the decision-making process happens, especially in large organizations (Chen et al., 2007; Grudin, 2002). With the emergence of global markets, the growth of multinational organizations and a globalist view of the planet, we can easily find decision-makers (chief executive officers, managers and other members of global virtual teams) spread around the world, in countries with different time zones (Shum et al., 2013). Moreover, to support the group decision-making process in this context is especially complex due to the decision-makers being geographically dispersed. This can lead to additional problems: failure to communicate and retain contextual information, unevenly distributed information, difficulty to communicate and to understand the salience of information, differences in the speed of access to information, and difficulty to interpret the meaning of silence (Bjørn et al., 2014); and to deal with temporal issues, which can originate: ambiguity, conflicting temporal interests and requirements, and scarcity of temporal resources (McGrath, 1991; Légaré and Witteman, 2013). To provide an answer and operate correctly in this type of scenarios, the traditional GDSS have evolved to what we identify today as Ubiquitous/Web-based GDSS (Alonso et al., 2010; Kwon et al., 2005; Marreiros et al., 2010; Morente-Molinera et al., 2016). The idea behind the Web-based GDSS is to support the decision-making process "anytime" and "anywhere" (Santos et al., 2006; Shim et al., 2002), and to help deal with some of the referred problems. Next are described some recent works under the GDSS:

Choi (2008) published a paper where he introduced a new Aggregation based on Situation Assessment (e-ASA) algorithm. His main objective was to reflect the cultural differences in the GDSS design. He claims that although there are a lot of papers in literature showing the importance of cultural factors, most of them did not address this problem. The algorithm is based on a fuzzy situation assessment model to reflect a decision situation in the aggregation process, making an adaptive aggregation result between the two extremes: min (the most pessimistic opinion) and max (the most optimistic opinion). This result depends on the value of parameter representing a degree of decision situation that is expressed by group members. He considers that his algorithm can be used to reflect cultural differences in GDSS design.

Miranda et al. (2008) presented a scientific work where they developed a simulated medical practice scenario for intelligent decision support in the area of staging of cancer. The decisions were taken in the context of a group meeting in order to facilitate the collaborative work. They used agents that could exchange and store information to reflect the real participants. The system emulated the TNM (Classification of Malignant Tumors) cancer staging system, increasing performance and eliminating paper circulation.

Tavana et al. (2013) brought to us a very relevant and practical work where they proposed a GDSS for the evaluation of alternative pipeline routes to transport oil and natural gas from the Caspian Sea to other distant regions. They decompose the route selection process into manageable steps. They combine Strength, Weakness, Opportunity and Threat (SWOT) analysis with the Delphi method to capture the decision-makers' beliefs. They also used a model called Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) to integrate the decision-makers' beliefs with subjective judgments and identify the most attractive pipeline route. They claim that their system encourages decision-makers to think systematically and carefully consider environmental complexities and uncertainties. They see the incorporation of simulation and optimization methods in the GDSS as future challenges.

Chakraborty et al. (2013) presented a case study of a group decision-making process using the Analytic Hierarchy Process (AHP) to consider the preference intensity of individual voters. This model intends to represent the decision-makers' preferences taking into account the preferences' different intensities. They consider that one of the actual flaws of this approach is that all the alternatives can become unsuitable to a given problem, making it impossible to reach a solution. On the other hand, the fact that this model has a low computational cost is a great advantage.

Efremov and Lotov (2014) recently published a paper where they presented an experimental study of a new Web-based system called Group Remote Asynchronous Screening Support (GRASS). They used interactive decision maps and the reasonable goals method in remote asynchronous group decision-making. They used the reasonable goals method so that an individual could select a small number of alternatives for subsequent ranking. They claim that GRASS produces good results when used by someone familiar with the procedure. However, the non-experienced people failed to use GRASS without the help of an instructor.

Monteban (2014) addressed a very interesting work about how GDSS can facilitate and help the organizations. They performed a good literature review about the thematic and made an experiment to test whether the use of a GDSS increases the quality of a brainstorm session. Although they consider that GDSS promise very potential, they did not find any evidences to assert the GDSS increased the quality of brainstorm sessions.

Oztaysi (2015) proposed the use of an approach that consists on AHP and on interval type-2 fuzzy sets. They consider that the use of interval type-2 fuzzy sets allows a greater flexibility when compared to the type-1 fuzzy set, being more suitable to represent uncertainties. They conducted a case study using an Enterprise Information System (EIS) selection problem which is no more than a Multi-Criteria Problem, since it contains various and conflicting criteria. They consider that the proposed approach allows a better representation of the uncertainties due to the use of the trapezoidal interval type-2 fuzzy sets, leading to the achievement of more reliable results. No information is given regarding the capacity of the approach to enhance the quality of the decision.

Tayyebi et al. (2016) described the SmartScapeTM which is a Spatial Decision Support System (SDSS). SmartScapeTM helps policymakers to evaluate the consequences of crops changes in several ecosystems (agricultural fields). This SDSS has a web-based architecture allowing the typical availability of a web-based application. SmartScapeTM uses spatial and temporal data from a variety of sources to help policymakers make better decisions. Basically, the architecture of this system relies on 3 large pillars which allow: (1) the integration of various open-source software to build a user-friendly web client; (2) the integration of several data (spatial and temporal) and environmental models, creating an interactive environment so that the stakeholders (with different needs and expertise levels) can build crop change scenarios; (3) the stakeholders to identify and assess potential crop change policies by visualizing offsets among the various ecosystems within a reasonable period of time. They concluded the system proved to be an effective tool to demonstrate the possible consequences of crop changes. One of the advantages of this system is that it does not depends on a GIS (Geographic Information System) as most of the existing SDSS.

Morente-Molinera et al. (2016) developed a web platform and an Android application decision support system applied to the problem of choosing a wine. The presented approach allows the decision-makers to contribute to the decision process even if geographically dispersed, and to access expert's information in real time. This approach uses linguistic modelling to facilitate the evaluation of preferences. Several technics were combined to develop the two applications: a fuzzy wine ontology, group decision-making supporting algorithms and the fuzzyDL reasoner. The users only need to be connected to the internet to use the application.

2.1.4 *Summary and Discussion*

A change to the development and conception of GDSS has been verified in the most recent approaches: there is a concern to adapt the new approaches to the needs of the actual decision-makers (as previously referred), and therefore, many of them are Web-based. In addition, there is also a need to work on how the problems are set up, that is, in the last 10 years there has been a need to work the way the decision-maker (user of the system) interacts with the system, namely in the problem's configuration process. Another relevant point is the fact that some (few) approaches already treat the group decision-making process as a continuous process, allowing the decision-makers to mature ideas and consequently make new configurations. There is also a different sensitivity on the part of the researchers, which causes them to increasingly begin to consider cultural and affective/emotional aspects, among others.

Regarding the techniques and algorithms used to support the decision process, it was verified that most of the proposals used MCDA methods, being AHP one of the most used. However, those proposals are restrictive in that they do not allow the addition of new information or justification of positions, as is the case of argumentation-based negotiation models. The number of recent GDSS proposals that use argumentation-based negotiation models is very reduced. Many of them have focused on the use of linguistic models and fuzzy preference relations to facilitate the modeling of uncertainty.

Table 3 presents the result of the bibliographic analysis of a set of GDSS papers published in the last 10 years, including the works described in Section 2.1.3. For each publication it is referred: the type of approach used (e.g.: the MCDA method, automatic negotiation mechanism, or another), if the proposed approach is Web-based or not (W.), if affective or cognitive aspects are contemplated (A.), if attention is given to the cost of configuring the problem (e.g.: ease of expression of preferences and low number of required configurations) (C.), and finally, if the decision is seen as a process or not (P.). For non-applicable situations a "X" is used.

As already mentioned, it is possible to verify in Table 3 that there is a great deal of concern in developing GDSS that support the "anytime" and "anywhere" decision process. However, it also appears that the vast majority of proposals seek to do so using MCDA methods. Although the great advantages of using approaches to justify positions and preferences (such as argumentation-based negotiation models) are consensual, the number of GDSS proposals that include this type of approach is very small. As will be seen in Section 2.3, we can assume that it can be due to its complexity, since there are researchers of argumentation models who point out as future work the expansion of their proposals so that they can be used by more than 2 agents. Among the most used MCDA methods, AHP and TOPSIS have a special emphasis, being the performed case study, presented in Section 3.4, compared to those 2 methods. It is also important to highlight the recent great interest in investigating SDSS, which demonstrate great application potentialities. Increasingly, researchers are focusing on facilitating the problem configuration process. This situation can be analyzed by 2 points of view: first, there is an interest in everything that can affect the usability of the applications, and therefore, it is intended to reduce the cost of configuration in order to avoid saturation by the users of the systems (decision-makers);

Table 3: Publications under the topic of GDSS in the last 10 years.

Publication	Approach	W.	A.	C.	P.
Choi (2008)	Aggregation based on Situation Assessment	X	Yes	No	Yes
Boran et al. (2009)	Intuitionistic fuzzy multi-criteria group decision-making with TOPSIS method	X	No	Yes	No
Eldrandaly (2010)	Integrated GIS with GEP (Gene Expression Programming)	X	No	Yes	Yes
Banias et al. (2011)	MILP (Mixed Integer Linear Programming) model	Yes	No	Yes	X
Ebrahimnejad et al. (2012)	Two-phase group decision making approach (modified ANP and VIKOR)	X	Yes	Yes	No
Lin et al. (2012)	Interactive Meta-Goal Programming (IMGP) and Delphi method	Yes	No	No	Yes
Palomares et al. (2013)	Consensus support system	Yes	Yes	Yes	Yes
Wibowo and Deng (2013)	An interactive consensus building algorithm	X	No	No	Yes
Tavana et al. (2013)	SWOT analysis, Delphi method, PROMETHEE and Geometrical Analysis for Interactive Assistance (GAIA)	No	No	Yes	Yes
Cabrerizo et al. (2014)	Granular fuzzy preference relations	X	No	No	No
He et al. (2014)	Service Oriented GDSS	Yes	No	No	Yes
Li et al. (2014)	Intelligent clustering algorithm (Partitioning Around Medoids) and Particle Swarm Optimization to adjust evaluation values automatically	Yes	No	Yes	Yes
Kar (2015)	Consensus oriented approach using fuzzy set theory, AHP and neural networks	No	No	No	No
Oztaysi (2015)	AHP and Interval type-2 fuzzy sets	X	No	Yes	No
Jelokhani-Niaraki and Malczewski (2015)	GIS and OWA (Ordered Weighted Averaging)	Yes	No	Yes	No
López et al. (2016)	Order-based consensus model for collaborative groups (fuzzy outranking relations to model preferences)	Yes	No	Yes	Yes
Tayyebi et al. (2016)	Spatial Decision Support System	Yes	No	Yes	Yes
Morente-Molinera et al. (2016)	Fuzzy Ontology	Yes	No	Yes	Yes
Tafreshi et al. (2016)	Three MCDM methods (DEMATEL, ANP and VIKOR)	No	No	No	No
Chai and Ngai (2016)	Proposed a conceptual design for argumentation models	Yes	No	No	Yes
Qin et al. (2017)	An extension of TODIM method under interval type-2 fuzzy environment	X	No	Yes	No
Le Pira et al. (2017)	Combination of AHP with Delphi method	Yes	No	Yes	Yes
Urtiga et al. (2017)	Voting procedure	Yes	No	Yes	Yes
Soto et al. (2017)	Fuzzy aggregation algorithm	X	Yes	Yes	Yes

second, there is a concern about whether decision-makers are able to correctly express their preferences through the settings that are asked of them. It was also verified that the number of works under the topic of GDSS that include affective/cognitive issues is still very small, despite the fact that the consideration (in a consensual way) of these aspects is important in the group decision-making process. One of the reasons may be due to the number of models with existing scientific validation is too small.

Finally, it was verified that there is an increasing interest in performing a decision-making process, in the sense that it is necessary to involve the decision-makers in the process, allowing them to reconfigure their preferences and have time to perceive "what is happening". This does not combine very well with the use of MCDA methods, since the type of information reported to decision-makers is poorer when compared to approaches that justify the reason why certain actions and decisions are taken, impoverishing the process.

2.2 AFFECTIVE COMPUTING

Affective computing is a multidisciplinary field encompassing computer science, engineering, psychology, education, neuroscience, and many other disciplines (Calvo et al., 2015). Poria et al. (2017) say, "affective computing is the set of techniques aimed at performing affect recognition from data, in different modalities and at different granularity scales". It expands the interaction between human and computer through the inclusion of emotional communication along with the necessary means to understand the information derived from affectivity (Picard, 1999). It dwells on problems where "computing that relates to, arises from, or influences emotions" (Picard, 1997). The essential role of emotion in both human cognition and perception, as demonstrated by neurological studies, indicates that affective computers should not only provide better performance in assisting humans, but also enhance the computers' abilities to make decisions (Picard, 1995). The most recent studies indicate that emotions play an essential role in decision-making, perception, learning and in a variety of other cognitive functions. The emotional aspects are not limited to art, entertainment and social interaction; they strongly influence the rational thinking mechanisms. The common sense emphasizes that excessive emotions can impair the decision-making process, but other scientific evidences show that the absence of emotions is also prejudicial (Picard, 1999). Due to its great potential in the construction of human-computer interfaces, affective computing has gained a lot of popularity in the last two decades (Picard, 1997; Tao and Tan, 2005). According to Serbedzija and Fairclough (2009), one of the affective computing purposes is to conceive a system that responds, in real time, to changes in the user's affectivity (e.g.: joy, sadness, etc.), cognition (e.g.: frustration, boredom, etc.) and motivation, in a rational and strategical way, such as: voice represented, facial expressions, physiological signs, neurocognitive performance and multimodal combination. Affective computing potential applications include: Learning, Affective Gaming, Robotics, Healthcare and Behavioral Informatics (Wu et al., 2010). It is consensual that affective computing is an emerging field of research capable of enriching systems, making them more and more intelligent and reaching a series of new possibilities that until now were only possible in sci-fi films (Poria et al., 2017). However, for affective computing to be accepted in the consumers' market, it is necessary to be aware of several issues, such as: cross-cultural issues, standardization, ethical, legal and social implications (Schuller, 2017).

This section describes relevant issues in affective computing, addressing topics such as personality traits and styles of behavior (personality, conflict styles, behavior styles), affect (emotion, mood), and decision satisfaction, always from a computational point of view. Existing models are described and analyzed for each topic, and how they have been applied is also considered.

2.2.1 *Personality traits and styles of behavior*

Personality is not the only factor responsible for defining the actuation mode of an individual. There are other factors like motivation and personal interests. In addition, to use an agent to represent a decision-maker such as he is, may not be what a decision-maker really wants. An exact representation can be spectacular in some situations, but not in others. Depending on the context, it may make sense to represent a decision-maker for what he is, for what he is meant to be, or a junction of the two. Therefore, in addition to the topic of personality, this subsection also addresses styles of behavior adaptable to the decision-making context.

2.2.1.1 *Personality*

Personality can be defined as a mark that represents a particular individual, distinguishing him from the others. This mark is composed by a set of characteristics that establish the person's behavior in a personal and social context. The path taken, as well as the surrounding environment during the individual's life, are crucial for the formation of his personality (Allport, 1961). All these variables make a person unique. Therefore, all individuals have their own personality. It is this personality which defines them that is responsible for imposing limitations in social relationships, as well as passing each one's image in interpersonal relationships (Higgins, 1990). The study of personality is defined as the scientific study of behavior and mental processes. Psychologists who study personality aim to characterize it based on the behavior pattern of an individual in order to explain the reactions to his own environment. There are various psychological theories on personality that differ in the importance given to the: past and present, consciousness and unconsciousness, directly and not directly observable. Most personality definitions try to emphasize the unique qualities that distinguish an individual (Li et al., 2007). However, it should be noted that this field is not a consensual matter at all. Many definitions and concepts have appeared throughout history, seeking to impose a terminology capable of defining what personality is and in what it consists. Pasquali (2000) even says that the term "personality" is so wide in its meaning, or rather so vague, that each psychologist practically understands it on his own way. In order to solve this problem, many psychologists choose to denominate personality as temperament, being temperament slightly different from personality but with a less ambiguous definition. Temperament has been considered as a synonym of the individual differences in the humans' behavior (Pasquali, 2000; Chess, 1995). In the temperament area, Jung (1971) developed two psychological dimensions that are still of great utility in psychology today: the dimension of types and the dimension of functions. Jung's theory of psychological types (Jung, 1971) can be characterized by their preference of general attitude: Extraversion and Introversion, both with great relevance in current research studies. Relatively to functions, there are four that stand out and that also have been receiving attention: thinking, feeling, sensing and intuition. Jung characterizes these psychological dimensions as follows:

- Extraversion: libido orientation towards the exterior; positive movement of the individual relatively to the object; the object becomes the individual's active (search for the object) and passive (the object imposes itself) focus of interest;

- Introversion: libido orientation towards the interior; negative movement of the individual relatively to the object; the oneself becomes the individual's active (seeks for reclusion) and negative (becomes unable to reach the object) focus of interest;

- Thinking: conceptual representation of reality (intellectual representation). It can be: active (rational, conscious), called intellect and consists in the search for that representation; or passive (irrational, unconscious), called intellectual intuition and consists in the imposition of that representation even against the individual's will;

- Feeling: to react towards reality as a value, implying acceptance or rejection. It can be seen as active, while seeking to valorize reality, or passive, while imposing it as a positive or negative value. The feeling with organic reactions is called affection;

Table 4: Personality creating factors (adapted from Pasquali (2000)).

Human-being	Cognize	Feel	Act
Physical	Sensation	Emotion	Instinctive act
Psychological	Thought	Feeling	Free acts
Spiritual	Contemplation	Mystical union	Agape

- Sensing: to understand reality in a sensory way (extern and intern). It is the sensory representation of reality; it is an irrational function;
- Intuition: unconscious perception of a global reality; like sensing it is an irrational function.

This psychoanalytic dogma in which Jung invested resulted in a set of interesting distinctions, that even seeming confusing and not very differentiated, are a great contribute to the creation of a typology of temperaments. When seeking to conceptualize temperament, psychologists consider mainly two axes: physical and psychological (some works also consider a spiritual axis). The physical axis follows two lines in the types or temperaments development: the mood-based typologies and the physical body typologies or morphological typologies (Pasquali, 2000). The psychological axis is based on psychological characteristics of the human personality, being the study of definitions on psychological types a growing interest. Table 4 exposes what Pasquali (2000) defends as the factors that create personality.

The study of the psychological axis, which is considered here as personality, is the most relevant to the objectives of this thesis. Some studies show that integrating personality and emotions in intelligent agents will convey a greater credibility to users (Huang et al., 2004). It is starting to become a general opinion, inclusively the one of De Rosis and Castelfranchi (1999), that personality affects the human-machine interaction. This interaction is affected in two ways. On one hand, computers exhibit a personality through their communication style. This personality is perceived by users and can affect usability. On the other hand, even the most superficial manipulations in the interface are sufficient to exhibit personality with powerful effects (Nass et al., 1995). These effects will grow considerably with agent-based interactions (De Rosis and Castelfranchi, 1999).

There are not many personality models in literature, and the acceptance level of most of them is not significantly relevant to be considered here. The two most relevant are presented next. The first model is considered in literature as the personality model main reference. The second model is also of great relevance although not comparable to the first.

The Big Five

While a personality theory that can be universally accepted is not defined, The Big Five or OCEAN (Openness, Conscientiousness, Extraversion, Agreeableness, Neuroticism), also known as the Five Factor Model (FFM), is the model with most acceptance. The FFM is a personality traits type of taxonomy defended by several psychologists (John and Srivastava, 1999) and can capture the essential differences of each individual in terms of personality. This model is composed of five great factors, or dimensions, representing personality (Howard and Howard, 1995) and was developed through lexical analysis. In this model, the most comprehensive empirical form capable of defining an individual's personality is considered.

The FFM was introduced for the first time in 1933, by the president of the American Psychological Association, L.L. Thurstone. The five factors/traits are: Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism, and can be characterized in the following way:

- Openness: adventurer, ideas out of the ordinary, curiosity, variety in experimentations;
- Conscientiousness: tendency to show self-discipline, objectives achievement, schedules;
- Extraversion: energy, positive emotions, tendency to seek the company of others;
- Agreeableness: tendency for compassion and cooperation;
- Neuroticism: tendency to easily express unpleasant emotions such as: anger, anxiety, depression or vulnerability.

Table 5 shows the characteristics of each trait.

Howard and Howard (1995) argue that in modern psychology, personality is specified as a function of thirty attributes where each one is denominated as a personality facet. The personality facets are grouped in five groups: the personality traits. The five personality traits are the ones referred previously in the FFM. The value of each personality trait is determined by the value of its six facets. Each of the five personality groups is referred by a letter: O – Openness; C – Conscientiousness; E – Extraversion; A – Agreeableness; N – Neuroticism. Table 6 presents the six personality facets for each one of the five personality traits. Despite all the acceptance that this Five Factor Model presents in literature, note that it is not perfect. Anyway, it is not a theory, but a very relevant taxonomy in personality description.

Table 5: Most consensual terms to describe the FFM's personality factors.

	Low	High
Extraversion	Quiet, Reserved	Talkative, Assertive
	Shy, Silent	Active, Energetic
	Withdrawn, Retiring	Outgoing, Outspoken
		Dominant, Forceful
		Enthusiastic, Show-off
		Sociable, Spunky
		Adventurous, Noisy
		Bossy
Agreeableness	Fault-finding, Cold	Sympathetic, Kind
	Unfriendly, Quarrelsome	Appreciative, Affectionate
	Hard-hearted, Unkind	Soft-hearted, Warm
	Cruel, Stern	Generous, Trusting
	Thankless, Stingy	Helpful, Forgiving
		Pleasant, Good-natured
		Friendly, Cooperative
		Gentle, Unselfish
		Praising, Sensitive
Conscientiousness	Careless, Disorderly	Organized, Thorough
	Frivolous, Irresponsible	Planful, Efficient
	Slipshot, Undependable	Responsible, Reliable
	Forgetful	Dependable, Conscientious
		Precise, Practical
		Deliberate, Painstaking
		Cautious
Neuroticism	Stable, Calm	Tense, Anxious
	Contented, Unemotional	Nervous, Moody
		Worrying, Touchy
		Fearful, High-strung
		Self-pitying, Temperamental
		Unstable, Self-punishing
		Despondent, Emotional
Openness	Commonplace	Wide interests, Imaginative
	Narrow interests, Simple	Original, Insightful
	Shallow, Unintelligent	Curious, Sophisticated
		Artistic, Clever
		Inventive, Sharp-witted
		Ingenious, Witty
		Resourceful, Wise
		Logical, Civilized
		Foresighted, Polished
		Dignified

Table 6: Professional development Version of the Five Factor Model (adapted from Howard and Howard (1995)).

Level	Low	Medium	High
Factor 1: Negative Emotionality	Resilient (N-)	Responsive (N)	Reactive (N+)
Facets:			
N1: Worry	More calm (N1-)	Worried/calm (N1)	More worried (N1+)
N2: Anger	Slow to anger (N2-)	Some anger (N2)	Quick to anger (N2+)
N3: Discouragement	Seldom sad (N3-)	Occasionally sad (N3)	Often sad (N3+)
N4: Self-consciousness	Seldom embarrassed (N4-)	Sometimes embarrassed (N4)	Easily embarrassed (N4+)
N5: Impulsiveness	Seldom yielding (N5-)	Sometimes yielding (N5)	Often yielding (N5+)
N6: Vulnerability	Stress resistant (N6-)	Some stress (N6)	Stress prone (N6+)
Factor 2: Extraversion	Introvert (E-)	Ambivert (E)	Extravert (E+)
Facets:			
E1: Warmth	Aloof (E1-)	Attentive (E1)	Cordial (E1+)
E2: Gregariousness	Prefers alone (E2-)	Alone / others (E2)	Prefers company (E2+)
E3: Assertiveness	In background (E3-)	In foreground (E3)	A leader (E3+)
E4: Activity	Leisurely (E4-)	Average pace (E4)	Vigorous (E4+)
E5: Excitement-seeking	Low need thrills (E5-)	Occasional need for thrills (E5)	Craves thrills (E5+)
E6: Positive emotions	Seldom exuberant (E6-)	Moderate exuberant (E6)	Usually cheerful (E6+)
Factor 3: Openness:	Preserver (O-)	Moderate (O)	Explorer (O+)
Facets:			
O1: Fantasy	Here and now (O1-)	Occasionally imaginative (O1)	A dreamer (O1+)
O2: Aesthetics	Uninterested in art (O2-)	Moderate interest in art (O2)	Major interest in art (O2+)
O3: Feelings	Ignores feelings (O3-)	Accepts feelings (O3)	Values all emotions (O3+)
O4: Actions	The familiar (O4-)	A mixture (O4)	Variety (O4+)
O5: Ideas	Narrow focus (O5-)	Moderate curiosity (O5)	Broad intellectual curiosity (O5+)
O6: Values	Conservative (O6-)	Moderate (O6)	Open to new values (O6+)
Factor 4: Agreeableness	Challenger (A-)	Negotiator (A)	Adapter (A+)
Facets:			
A1: Trust	Skeptical (A1-)	Cautious (A1)	Trusting (A1+)
A2: Straightforwardness	Guarded (A2-)	Tactful (A2)	Frank (A2+)
A3: Altruism	Uninvolved (A3-)	Willing to help others (A3)	Eager to help (A3+)
A4: Compliance	Aggressive (A4-)	Approachable (A4)	Defers (A4-)
A5: Modesty	Superior (A5-)	Equal (A5)	Humble (A5+)
A6: Tender-mindedness	Hardheaded (A6-)	Responsive (A6)	Easily moved (A6+)
Factor 5: Conscientiousness	Flexible (C-)	Balanced (C)	Focused (C+)
Facets:			
C1: Competence	Unprepared (C1-)	Prepared (C1)	Capable (C1+)
C2: Order	Unorganized (C2-)	Half-organized (C2)	Well-organized (C2+)
C3: Dutifulness	Casual about obligations (C3-)	Covers priorities (C3)	Strong conscience (C3+)
C4: Achievement striving	Casual about success (C4-)	Serious about success (C4)	Driven to succeed (C4+)
C5: Self-discipline	Distractible (C5-)	Mix of work and play (C5)	Focused on work (C5+)
C6: Deliberation	Spontaneous (C6-)	Thoughtful (C6)	Careful (C6+)

The Big Five Inventory

The Big Five Inventory (BFI) is a questionnaire, created by John et al. (1991), that allows the quantification of the five personality dimensions, so that they can be studied and identified. Its purpose is to be a short questionnaire that allows the evaluation of the five personality dimensions in an efficient and flexible way, being composed of 44 questions. In order to calculate the personality of a certain user, he/she needs to answer the 44 questions using a five-point Likert scale. The questions are used to calculate each FFM personality trait, Openness (O), Consciousness (C), Extraversion (E), Agreeableness (A) and Neuroticism (N), according to the calculation formula:

$$\forall x \in (O, C, E, A, N) \ f(x) = \begin{cases} \frac{\sum_{i=1}^{n} response_i}{\sum_{i=1}^{n} max_i} \end{cases}$$

Where n is the total questions for each trait, $response$ is the set of possible responses, $response_i$ is the response value given by the user to the question, and max_i is the maximum possible value for that question. Each trait's corresponding questions are:

O: 5; 10; 15; 20; 25; 30; 35R; 40; 41R; 44
C: 3; 8R; 13; 18R; 23R; 28; 33; 38; 43R
E: 1; 6R; 11; 16; 21R; 26; 31R; 36
A: 2R; 7; 12R; 17; 22; 27R; 32; 37R; 42
N: 4; 9R; 14; 19; 24R; 29 34R; 39

The calculation of personality is very simple, by simply adding the responses values for each personality trait. The only exception is when the question number is followed by an "R", which means the score needs to be reverted. Since the responses vary between the minimum value 1 and the maximum 5, for example, if a user scores all questions with the lowest value (1), the result would be:

O: $\frac{1+1+1+1+1+1+1+5+1+5+1}{10*5} = 0,36$
C: $\frac{1+5+1+5+5+1+1+1+5}{9*5} = 0,56$
E: $\frac{1+5+1+1+5+1+5+1}{8*5} = 0,5$
A: $\frac{5+1+5+1+1+5+1+5+1}{9*5} = 0,56$
N: $\frac{1+5+1+1+5+1+5+1}{8*5} = 0,5$

The user's type of personality is found after calculating the personality traits value (O: 0,36; C: 0,56; E: 0,5; A: 0,56; N: 0,5).

There are other approaches (not many) that allows the quantification of the five personality dimensions using questionnaires with less questions (Gosling et al., 2003; Rammstedt and John, 2007). These approaches proved to achieve acceptable results, however, the studies demonstrated substantial losses in comparison to the full-scale BFI.

PEN Model

This model also presents some relevance in literature, albeit not comparable to the FFM. It was developed by Eysenck (1991), who was a great opponent to the FFM. Eysenck claims that the FFM model presents dimensions that overlap. So, he proposed the use of only three super factors (dimensions) in his model. In the FFM, all dimensions are at the same hierarchical level as opposed to what happens in the PEN model. In his model, Eysenck considers Psychoticism, Extraversion and Neuroticism as super factors, being at the top of the hierarchy, followed by traits or factors, which in turn are followed by habits, and finally, by behaviors. The Psychoticism trait, which does not appear in the FFM, is associated with psychotic episodes and aggressive behaviors, being the remaining traits compatible with the ones of the FFM (Extraversion and Negative Emotionality).

2.2.1.2 *Models to define conflict and behavior styles*

In this subsection, we put forward some models that can be used by computer scientists to model anthropomorphic agents. A current problem in the humanization of agents is related to the lack of knowledge that still exists about human psychological functioning, and perhaps even more so regarding the formalization of such knowledge. This problem often leaves computer scientists prone to devise strategies that still lack solid scientific validation. In this regard, a greater investment in multidisciplinary teams becomes of uppermost importance. Next, we advance some models that, in our view, show the potential of the adaptation to computational systems, regardless of whether they are simulators or real systems.

Kilmann and Thomas (1975) suggested a model for interpersonal conflict-handling behavior, based on Jung's studies and a conflict-handling mode proposed by Blake and Mouton (1964), that defines five modes: competing, collaborating, compromising, avoiding and accommodating, according to two dimensions: assertiveness and cooperativeness.

As seen in Figure 2, both the dimensions of assertiveness and cooperativeness are related to the integrative and distributive dimensions as discussed by Walton and McKersie (1965). Integrative dimensions refer to the overall satisfaction of the group involved in the discussion while the distributive dimension refers to the individual's satisfaction within the group. It is possible to see that the thinking-feeling dimension maps onto the distributive dimension while the introversion-extraversion dimension maps onto the integrative dimension. This association becomes more evident if we conceive competitors as the ones who seek the highest individual satisfaction and collaborators as the ones who prefer the highest satisfaction of the entire group. On the other hand, avoiders, do not worry about group satisfaction and

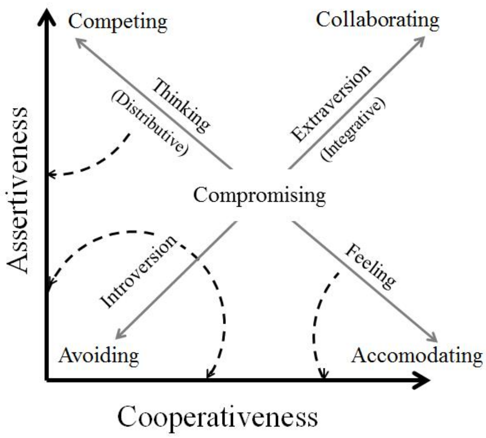

Figure 2: Thomas and Kilmann's model for interpersonal conflict-handling behavior (adapted from Kilmann and Thomas (1975)).

accommodators do not worry about individual satisfaction. They also concluded that the thinking-feeling dimension did not move towards the integrative dimension, and that the introversion-extraversion did not overlap with the distributive dimension.

McCrae and John (1992) proposed a set of thirty traits extending the five-factor model of personality which included six facets for each of the factors. These traits were used in a study made by Howard and Howard (1995) in order to help them separate different kinds of behavior styles and identify corresponding themes. They defined a theme as "a trait which is attributable to the combined effect of two or more separate traits" (Howard and Howard, 1995). Those styles and themes are based on common sense and general research, and can be inferred as the conflict styles that were proposed, (Negotiator, Aggressor, Submissive and Avoider). It is also important to refer other suggested relevant styles, such as the Decision and Learning styles. Decision style includes the Autocratic, Bureaucratic, Diplomat and Consensus themes while Learning style includes the Classroom, Tutorial, Correspondence and Independent themes.

Rahim (1983) created a meta-model of possible styles for handling interpersonal conflict based on two dimensions: concern for self and concern for the other. Later, Rahim and Magner (1995) performed a study to assess the construct validity of the five subscales of the Rahim Organizational Conflict Inventory (Rahim, 1983). The styles defined by Rahim (1983) are presented in Figure 3 and have been adapted to our problem. Rahim (1983) acknowledges the existence of 5 types of conflict styles: integrating, obliging, dominating, avoiding and compromising. In this work, he suggested these styles as means to describe different possible ways of behaving in conflicting situations. The proposed styles are defined according to the level of concern an individual shows for achieving one's own goal or following through on other people's objectives.

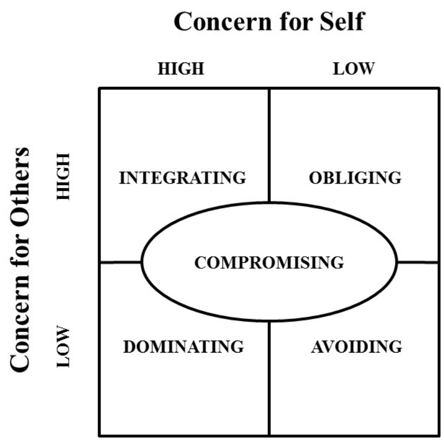

Figure 3: Rahim's proposal of conflict styles (adapted from Rahim and Magner (1995)).

The model proposed by Rahim (1983) also relates to the themes identified by Howard and Howard (1995) to a certain extent. The Aggressor theme resembles the Dominating style; the Negotiator theme resembles the Integrating style; the Avoiding theme resembles the Avoider style; and the Submissive theme resembles the Obliging style. The main difference is the existence of the Compromising style in the model proposed by Rahim (1983) which does not relate to a specific theme. In theory, the Compromising style is an intermediate state between the other styles that were identified. It is worth noting that in psychological literature, depending on its scope, even the mere definition of single behavior styles is often not consensual. For example, what we conceive as "avoidance" for the sake of the present work may not reflect the subtleties of the concept as proposed elsewhere. For instance, when it is presented as an attachment style and therefore rendered as multifold. We would then have to consider avoidants that do not care and also the anxious, preoccupied avoidants that do care but won't engage, for regarding their actions as not useful or even as detrimental to the task in hand (Fraley and Shaver, 2000). Certainly, these examples and possible ramifications abound for all other behavior styles. Nonetheless, we commit to Rahim's formulation as a basis for our work because, more than any other model, it has been largely grounded in organizational contexts, from which a great part of his data has sprout. This too is our target of application.

2.2.2 *Affect*

In this subsection, the topics of emotion and mood are addressed. Models that allow the computer science researchers to computerize human affects are presented. According to the Cambridge Dictionary, affect is defined as "to have an influence on someone or something, or to cause a change in someone or something". Affect is the experience of feeling or emotion. "It is a prepersonal intensity corresponding to the passage from one experiential state of the body to another and implying an augmentation or diminution in that body's capacity to act" (Shouse, 2005).

2.2.2.1 *Emotion*

Emotion, in a general definition, is a neural impulse that moves an organism towards action. Emotion differentiates from feeling because, as observed by Freitas-magalhães (2013), it is a neuropsycophysiological state. Emotions are caused by the interaction of a human-being with the environment and the others, affecting the decisions and actions. There are several types of emotions, being the cognitive emotion the most important for this work. Cognitive emotion is related to knowledge, being actions such as: learning, memorizing, motivating and planning, considered cognitive processes. It is possible to learn to control a certain emotion through cognitive evaluation. An individual is under the effect of a certain emotion during a short period.

It is well known and considered for a long time that emotions play a fundamental role in humans, and only recently psychologists began studying emotions as a component that positively affects intelligence and cognitive aspects (Ekman, 1992). A great set of evidences has demonstrated that emotions have impact on reasoning, memory and judging (Li et al., 2007). Damasio (2006) showed that people with deficiencies at the level of the emotional response, generally adopt weak decisions, severely limiting their interpersonal relationships and their place in society. Gardner (1987) proposed the concept of "multiple intelligences", considering personal intelligence as a specific kind of intelligence that deals with the interaction and emotions. Later, Goleman (1995) used the term "emotional intelligence", recognizing the current point of view that emotion is really an important part of the human intelligence.

Lately, the modelling of emotions has had a very strong growth with respect to their computational representation. The incorporation of emotions in games and applications enables a more natural interaction with the user. Nass et al. (1995) showed in their work that humans like to communicate with computers in a similar way to that used to interact with other people. With respect to the application area of emotions, Kessler et al. (2008) identified three:

- Artificial emotions: can be used to improve problem solving in complex environments;
- Emotional models: can be used to perform experiments of psychological theories using controlled scenarios;
- Emotions: are fundamental to make computer agents more credible. Emotional models that are able to synthetize and express

emotions are needed to make artificial intelligence characters look more human.

Next, two models that describe emotional processes are presented. Although the second model is of great relevance, the first model is the greatest reference to computer science researchers.

OCC (Ortony, Clore and Collins) Model

Many psychologists have proposed models to describe emotional processes. One of the most popular is the OCC model, developed by Ortony, Clore and Collins, deriving its name from their initials, a model that is widely used to analyze emotions (Ortony et al., 1990). According to this model, an emotion is triggered as a reaction to: consequences of events, actions of agents, or aspects of objects. Thus, emotional perceptions appear related to the objectives, patterns and preferences of an individual. To calculate the intensity of an emotion, global variables are considered, such as the sense of reality and proximity, as well as local variables, such as the probability of an event to occur, the effort to achieve a goal and the possibility to fulfill an objective. The structure of OCC model is illustrated in Figure 4.

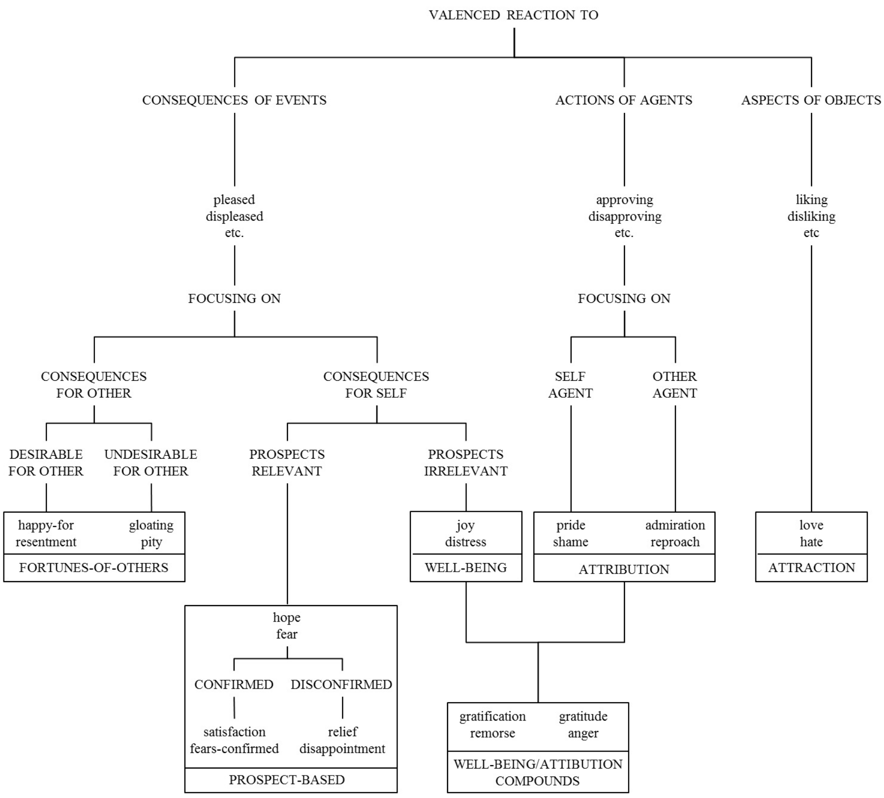

Figure 4: The structure of emotions of the OCC model (adapted from Ortony et al. (1990)).

The OCC model also evaluates the preferences and patterns of the agent. The emotions are generated by the interpretation of the agent to the reactions to the consequences of the events, actions of other agents and aspects of the objects. Agents can be people, animals, inanimate objects, or abstractions as institutions. Events are how agents perceive what happens. There are three kinds of value structures underlying the perception of goodness and badness: objectives, norms and attitudes. Patterns are used to assess the actions of an agent. The actions of an agent are evaluated according to his obedience to social norms, morals, or behaviors. Finally, the objects are evaluated as attractive, depending on the compatibility with taste and attitudes of their attributes.

One of the many practical implementations of the OCC model was developed by Staller and Petta (1998), who constructed a virtual agent whose emotional architecture related categories of discrete emotions to 14 categories of action-response, covering a wide range of individual actions. The OCC model is also partially congruent with the renowned theory of Frijda (1986).

Ira Roseman's Emotional Model

According to this model, emotions are generated based on an event association procedure (Roseman et al., 1990). Events are divided into events with consistent motifs and events with inconsistent motifs. The former are defined as being consistent with the objectives of the individual, while the latter, the inconsistent, are events that threaten one of the objectives that the individual proposes to achieve. Events are further classified according to the cause of the event, and can be caused by third parties, by the own individual or by circumstance. Another way to differentiate emotions is that an event was motivated because the subject wanted a reward or wanted to avoid a punishment. A certainty measure was also used as another way to classify events: an event may be declared in an unexpected, certain, or uncertain manner, i.e., subject to a valuation.

2.2.2.2 *Mood*

Mood is a psychological state of an individual that indicates the degree of his mood and well-being (Mehrabian, 1996), being a way of representing the emotions felt and the individual's personality. A mood is maintained over a period of time until something, such as the emotions felt, awakens a new mood. A person's mood influences his/her decisions and is important in the way he/she analyzes the received information. There are several models developed to analyze an individual's mood, being PAD (Pleasure, Arousal and Dominance), developed by Mehrabian (1995), one of the most popular. Another model also well cited is PANAS, developed by Watson et al.

(1988).

PAD (Pleasure-Arousal-Dominance) Model

PAD (Pleasure, Arousal and Dominance) is a model that allows the integration of personality and emotions in order to know the mood generated (Mehrabian, 1996). This model defines three dimensions which describe the emotional state (mood/temperament) of an individual: pleasant, arousable and dominant (Mehrabian and O'reilly, 1980). These three dimensions define a three-dimensional space where individuals are represented as points, personality types as regions and personality scales as straight lines that cross the intersection point of the three axes. By using +P, +A, and +D, Mehrabian (1995) refers to pleasure, arousable, and dominant temperament, respectively, and -P, -A, and –D, to unpleasant, unarousable, and submissive temperament (Table 7):

- Pleasure (Pleasure (+P) versus Displeasure (-P)): predisposition towards positive versus negative affective states;
- Arousal (Arousability, +A versus -A): physical alertness versus mental alertness;
- Dominance (Dominance (+D) versus Submissiveness (-D)): control versus lack of control.

Table 7 presents the labels that can be used to describe the resulting octants of temperament space.

Table 7: Description of various mood states (adapted from Mehrabian (1996)).

Positive	Negative
Exuberant (+P+A+D)	Bored (-P-A-D)
Dependent (+P+A-D)	Disdainful (-P-A+D)
Relaxed (+P-A+D)	Anxious (-P+A-D)
Docile (+P-A-D)	Hostile (-P+A+D)

PANAS (Positive Affect – Negative Affect)

PANAS is a model often mentioned in literature capable of measuring mood, and is used in many research works. Positive Affect (PA) and Negative Affect (NA) are the scales used in this model. It is composed by two of ten items of psychometric scales that measure positive affect (the extent to which individual feels attentive, interested, alert, excited, enthusiastic, inspired, proud, determined, strong, and active) and negative affect (the extent to which individual feels anguished, angry, hostile, irritated, scared, afraid, ashamed, guilty, nervous, and easily perturbable). PANAS has been demonstrated to be very reliable and easy to apply (Watson et al., 1988), being an instrument frequently used in psychology and other areas (Crawford and Henry, 2004; Mackinnon et al., 1999). Numerical answers are given on a 5-point Likert scale for the ten items of Positive Affect and for the ten items of Negative Affect, which are added to obtain a single score for PA and NA, comprised between 10 and 50.

2.2.3 *Decision Satisfaction*

Higgins (2000) says that "a good decision has high outcome benefits (it is worthwhile) and low outcome costs (it is worth it)", and that "independent of outcomes or value from worth, people experience a regulatory fit when they use goal pursuit means that fit their regulatory orientation, and this regulatory fit increases the value of what they are doing". With this, it is possible to understand that decision quality, in the perspective of each participant, is related to what he considers relevant. Satisfaction is therefore a strong indicator, not only of the results, but also of the whole decision process. When someone is questioned about the quality of a decision, the answer does not reflect only the assessment of outcomes, but also, even unconsciously, it includes the evaluation process necessary to reach the decision. To understand how suitable a decision is, it is necessary to understand and analyze the means to reach that decision (Beach, 1990; March, 1994). Thus, one should give prominence to the process when drawing conclusions about the results. There is a great variety of factors affecting the satisfaction of a decision-maker with the decision made in a meeting: emotional variables (affective components) (Liljander and Strandvik, 1997; Oliver et al., 1997; Wirtz and Bateson, 1999), the process (Simon, 1955, 1967), the outcomes (Higgins, 2000), factors that affect the situation (Bailey and Pearson, 1983) and expectations (Hovland et al., 1957; del Bosque et al., 2006). Satisfaction with a decision resulting from a decision process needs a complex analysis and involves multiple variables. Obviously, satisfaction is related to what we think a good decision is. But what is a good decision? As previously referred, in the common sense a decision is considered good because of the analogy made with the obtained results. However, psychologically, the results are not enough to make a participant consider a decision as good. Higgins (2000) says that "psychologically, then, a decision is perceived as good when its expected value or utility of outcomes is judged to be more beneficial than the alternatives. The benefits include the social benefits of a decision, such as those received from a 'politically correct' or ingratiating decision. The costs of attaining the outcomes can also influence whether a decision is perceived as good. The outcome benefits have to be weighed against the costs of attaining the outcomes. The costs include not only the goods or services one must give in exchange for receiving the benefits but also the costs of the decision-making process itself. The decision-making process that would optimize outcomes might not be used because the costs in cognitive effort or time are too high". Therefore, it is clear that there is much more than knowing if the chosen alternative is the participant's favorite in order to evaluate his satisfaction with the decision. It has been suggested that a purely cognitive approach may be inadequate in modeling satisfaction ratings, so it is particularly important to include emotional variables (Liljander and Strandvik, 1997; Oliver et al., 1997; Wirtz and Bateson, 1999). The research made in the field of satisfaction has recognized that there is a need to incorporate the emotional and affective components in regulating the consumer's satisfaction (Wirtz et al., 2000). Therefore, the final results and the decisions made are not the only responsible for determining the quality and the satisfaction of the decision. In his work, Higgins (2000) says: "We are all familiar with the idea expressed in the maxim of the late-19th-century British statesman John Morley, 'It is not enough to do good; one must do it the right way' or the coaching classic, 'What counts is not whether you win or lose but how you play the game'. Such maxims reflect a moral position: Achievements should be evaluated not only in terms of outcomes but also in terms of the means by which they were attained. 'The ends do not justify the means.'". Using the reasoning present in this approach and the moral objective of these famous maxims, the process relevance in performing a certain action is easily understood. We can also conclude that the impact of the decision-making process can drastically change the participant's satisfaction regardless of the results. Higgins (2000) also refers that "this insight concerns how the goodness of a decision depends not only on its relation to ends or outcomes but also on whether the means used to make it were suitable. Suitability here refers only to what is morally proper. By considering proper the more general meaning of suitable as 'fit', a new perspective on what makes good decisions good is possible". The consideration of several factors is therefore necessary to obtain a correct approach in the decision-maker's satisfaction analysis regarding the decision made. The studies addressed in this subsection show the importance of analyzing the whole decision-making process, and the whole set of actions that involve and influence the participant during the process. We also verified that it is necessary to analyze a set of emotional factors in that process, and that emotional changes mean situations that affect the participant. It is obvious that this brings new challenges, such as to better know the participant in order to better understand the impact of each situation in each kind of person. Thus, the emotional cost has a relevant impact on satisfaction. Another important factor in satisfaction analysis are the (different) expectations, and therefore the satisfaction with the same outcome may be completely different.

2.2.3.1 *Expectations*

The expectation levels are the reason why two organizations in the same sector can offer such distinct levels of service while keeping consumers equally satisfied (Zeithaml et al., 1993). That is why McDonald's can enlarge an industrialized service of excellence, with few employees per consumer, while an expensive restaurant with employees dressed in tuxedos may not do it so well from the costumer's perspective (Davidow and Uttal, 1989). A costumer's expectations are pre-conceived beliefs about a particular product (Olson and Dover, 1979) that serve as benchmarks against which the product is evaluated. Parasuraman et al. (2002) state that the evaluation of the service quality made by the customer results from comparing the existing expectations with the actual performance. Anyway, despite the importance of expectations being recognized in several works as the service quality (Gronroos, 1983) and customer satisfaction (Oliver, 1985), many questions related to the role of expectations have been considered in research and need to be answered. Consumer expectations have been studied in several research environments (Oliver and Winer, 1987), with a greater emphasis in the analysis of the consumer's satisfaction/dissatisfaction and service quality. In literature, there is a consensus on expectations to serve as standards against which subsequent experiences are compared, resulting in assessments of satisfaction and quality. Consensus on other issues such as: the expectation's specific nature, the number of standards used, and the sources or antecedents of expectations, have not yet been met. Research in the expectations area is mostly related to the service quality, but the principles addressed are perfectly applicable in decision group processes. Naturally, decision-makers create expectations regarding the process (for instance, if it will be more or less litigious) and the possibility of reaching their objectives. Several expectations patterns have been proposed:

- Expectations as standard predictions: Expectations are seen as predictions made by consumers on what is likely to happen during the process. According to Oliver (1985), it is a general agreement that expectations are considered by the consumer as probabilities of the occurrence of positive and negative events when he is involved in something. Miller (1977) called this pattern as the expected pattern, defining it as a performance probability calculation. Swan and Trawick (1980) and Prakash (1984) named this pattern as predictable expectations, defining them as estimates of the expected performance level;

- Expectations as the ideal pattern: A normative expectations pattern has been proposed by a large number of researchers. Miller (1977) proposed ideal expectations, designating them as the desired performance level. Swan and Trawick (1980) indicated a pattern which they called desired expectations, defining it as the level at which the costumer wants the process to be executed. Prakash (1984) designated them as normative expectations, i.e., how a brand should work so that the consumer is fully satisfied. In a more comprehensive way, several researchers (Woodruff et al., 1983; Cadotte et al., 1987; Sirgy, 1984) argued that the consumer's satisfaction and dissatisfaction is more likely to be determined by how well a service/process/product fulfills the consumer's needs or desires, contrary to a prediction pattern;

- Others expectations patterns: Woodruff et al. (1983) proposed that costumers expect certain patterns that reflect what the process should provide, being these expectations based on the past experience. These expectations are called expectations of experience based in standards because they are composed by what would be ideal to happen plus the expectations' real aspects. Miller (1977) also proposed tolerable minimum expectations, defining them as the lowest performance level acceptable by the consumer, and deserved expectations, reflecting the subjective evaluation of the consumer's investment in the product. Finally, Prakash (1984) proposed a pattern called comparative expectations, where the consumers' expectations are created by comparing similar products of different brands.

2.2.3.2 *Satisfaction Models*

The literature is very poor in terms of satisfaction analysis as an indicator of the perceived decision's quality. The results related to the evaluation of the satisfaction of the decision-makers with the decision made (in group), with the perception of the quality of the decision or with the quality of the decision obtained with the use of a GDSS are practically nonexistent. There are works that study the satisfaction with the use of a GDSS (or of a software in general) and the satisfaction of the decision-maker in the decision process using surveys.

Briggs et al. (2003b) presented a theory of meeting satisfaction, which explains the causes of conflicting research results on meeting satisfaction, as these results have never been fully explained in the group support systems literature. Therefore, their theory tries to contribute to a possible development of systems and methodologies that increase group efficiency and group effectiveness, without decreasing meeting satisfaction. The authors proposed and tested the Satisfaction Attainment Theory (SAT) – a causal model of meeting satisfaction. Taking into account the SAT assumptions, satisfaction, i.e., the affective arousal with a positive valance a participant felt after a meeting, would be a function of the perception that, balancing conflicting and mutually exclusive goals, the value of one's goals increased, or the likelihood of their success increased because of the meeting. Meetings that produce positive Perceived Net Goal Attainment (PNGA) should also produce high levels of meeting satisfaction, and meetings that produce negative PNGA should also produce low levels of meeting satisfaction. However, other researchers may choose to define meeting satisfaction according to other factors, such as the degree to which a meeting has fulfilled certain requirements. The difficulty to provide a clear definition of meeting satisfaction reduces the degree to which research on meeting satisfaction can be generalized.

In their work, Paul et al. (2004b) explore how the performance of a GDSS affects the different satisfaction dimensions. They focus on three indicators of group performance, namely: the decision time, the efficiency in decision-making and the number of iterations in the group decision-making process. For each one of these indicators hypotheses that affect satisfaction were created. Example: "H1a – In a GDSS-supported group decision, the higher the decision time, the lower is the satisfaction of a group with the system used by its members." This model is based on hypotheses and is illustrated in Figure 5.

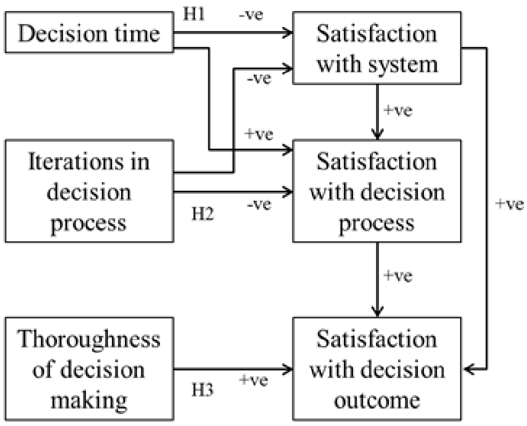

Figure 5: Paul et al. (2004b) research model based on hypotheses.

Some of the conclusions obtained from this work demonstrated that the performance of GDSS influences the group members' satisfaction. When decision time increases, the system appears to be unproductive and the group members' satisfaction with the system decreases. However, when GDSS meetings end quickly, members may perceive that they are rushed through the process and different alternatives of the decision situation are not adequately evaluated. This is evinced in the positive relationship between decision time and the members' satisfaction with the process. The authors found a positive relationship between the thoroughness of decision-making and the group members' satisfaction with the decision outcome.

Tian et al. (2008b) conducted a study on how to measure satisfaction based on the emotional space. The satisfaction measured sought to understand the users' acceptance of a product by testing its usability. In order to analyze the emotional space, they used the PAD (Pleasure, Arousal and Dominance) model proposed by Mehrabian (1995). To find out his initial emotional state the user must answer to the Big Five Inventory questionnaire, and with the obtained personality he is given a standard emotional state. The emotions generated during the test are detected by observing the user's behavior. His emotions decay through the process, getting closer to the initial state, as can be seen in Figure 6.

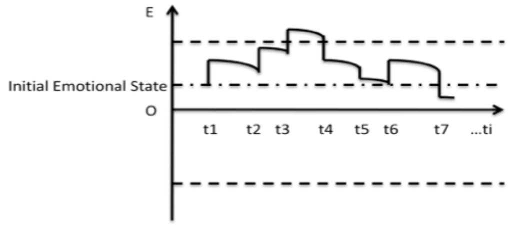

Figure 6: Changes of single dimension in PAD model (adapted from Tian et al. (2008b)).

After performing the test and building the emotional map, the emotional changes are registered and their sum is calculated. With the emotional values, interesting conclusions are attained. The authors claim that "with a good pleasure emotional state, users can have a smooth thinking and judgment to choose the most effective method to finish the task, so the pleasure state of the users can reflect the affinity and usability of the product in the testing. The arousal degree has a positive effect on usability, but the high level of arousal means that users are in a highly concentrated spirit and get tired easily; on the other hand, also means that users may be thinking about a way to solve the problems. So a lower level of positive arousal degree reflects the usability of the software operations. The improvement of the user domination means that users are in an intense state, and that has a negative effect on usability. High usability products should be consistent with the users' traditional habits, without the need to consider the controllable process and solutions of the product. Therefore, the domination degree indirectly reflects the extent of the ease of using the product."

Husain (2012) presented a paper where he included a satisfaction tool to help solve problems in GDSS. The tool is based on linear goal programming (GP) in order to assist GDSS participants in performing group decision-making for problems that have multiple and conflicting alternatives. His objective is to achieve a higher satisfaction for the group using this technique. Some theoretical ideas in this paper are very similar to the ideas described in this thesis: (1) the consideration of satisfaction in group decision-making process, (2) the use of satisfaction to achieve better results and (3) the consideration of the classification of the alternatives by the decision-makers to find the optimal solution. The author claims that with this approach it is possible to improve the participants' satisfaction by reducing the deviation by 29%. However, this work does not include all the necessary variables to measure satisfaction, as is possible to verify in the literature (for instance, decision-makers' expectations and the consideration of decision process). In addition, the decision-making process faces some limitations when using the GP strategy, such as: reconfiguration of the problem, impossibility of the decision-maker to add new information during the process, and some limitations related to human-interaction and psychological issues.

2.2.4 *Recent Works*

In this subsection, we present some works in the field of computer science, which somehow deal with cognitive and/or emotional aspects.

André et al. (2000) presented a paper where they describe the functioning of three projects that integrate lifelike characters. They considered that the growth in the number of research projects related to humanization with the goal of making human-computer interaction more enjoyable has become noticeable. To make the psychological modeling of the agents, they used the OCC model to model the emotions, and the Five Factor Model to model the personality. They stressed the importance of taking into account affective issues in user-agent interactions. However, they did not present any type of data to quantify how the proposed models would allow the obtention of more satisfactory utilization processes.

Gmytrasiewicz and Lisetti (2002) presented a research work where they included a formal definition of emotional states and personality in a typical rational agent design based on decision theory. This work is especially relevant due to the hypothesis put forward by the authors: "the main hypothesis of our work is that notions of personality and emotions are useful in designing competent artificial agents that are to operate within complex uncertain environments populated by other artificial and human agents". The authors used the OCC model to define the emotional states of the agents and correlated them with different modes of decision-making. This means that each emotional state is associated with a decision-making situation. They also considered the personality of the agent, but did not use any specific personality model. They considered the personality of the agents as a set of emotional states the agents are capable of being in. Basically, the agents can vary their personality according to the three considered emotional states: cooperative, slightly annoyed and angry. The transitions that can occur between these states happen due to environmental inputs that they divided into 2 categories: cooperative and uncooperative. Although the authors point to a number of advantages and possible uses of the proposal, one cannot really say that there is a true verification of the research hypothesis. This can be read in the conclusions, by their own words: "we believe, will significantly enhance the applications of intelligent systems ...".

Becker et al. (2004) presented an emotion system that takes into account/works with the emotions and mood of a conversational agent. Like most works since then, they use the OCC model to deal with emotions. The emotions are represented in an "emotion axis" and the mood in an "orthogonal axis" that stands for an undirected, longer lasting system state. In addition, they consider "boredom" in order to deal with the absence of stimulus that the agent may face. In this way, they get the agents to express their emotional state according to the content of the conversation. They presented an experience in which the agent leaves the scene when it begins to feel insulted.

Lorini and Falcone (2005) presented work in which they deal with the expectations of pro-active agents. They point out that one of the aspects that most characterize/most distinctive aspects of intelligent agents is that they are proactive, meaning that they have to be able to deal with the future and to represent that future or the possible future effects. For this, the authors provide a precise characterization of anticipatory mental states in order to analyze their role in the generation of surprise, relief and disappointment. This allows the agents to have a clear comprehension of the surprise phenomenon. In addition, the proposed approach allows an $Agent_i$ that expects an $Agent_j$ to take an action that is negative for it, develops a negative strong expectation, causing it to persuade the $Agent_j$ to stop doing this action.

Santos et al. (2009) presented a scientific work where they proposed a multi-agent architecture model designed to support groups in the decision-making process. The novelty of their work is the possibility to model the agent's personality. The idea is to humanize agents and with that, facilitate the negotiation process. They used four personality types, negotiator, aggressor, submissive and avoider, based on the Five Factor Model to define the agents' personalities. To select the agent's personality, each decision-maker needs to answer a Big Five Inventory questionnaire. The authors also proposed a simple negotiation model where the agents use the personalities to choose which kind of requests they should send and to process the received requests. The publication does not include any case study; however, the content is very interesting because the proposed model is based in strong assumptions existent in the literature.

Marreiros et al. (2010) developed a GDSS model that uses intelligent agents to represent the meeting participants and the facilitator. However, the agents are not intended to replace the meeting members in the decision-making, but to support them. Since the authors consider emotions play an important role in the negotiation process, agents are endowed with an emotional component, based in the OCC model. The participant agent's architecture is comprised of three layers: knowledge, reasoning and interaction (Figure 7).

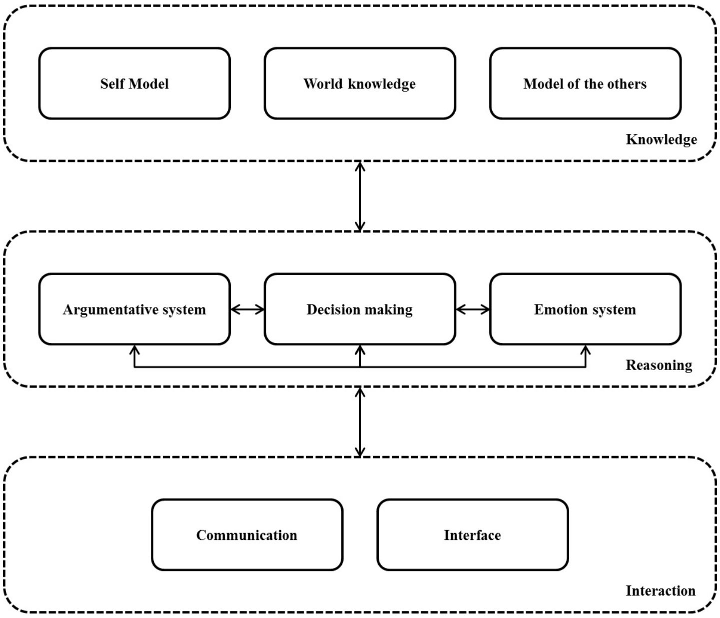

Figure 7: Participant agent's architecture in an emotion-based GDSS model (adapted from Marreiros et al. (2010)).

In the knowledge layer, the agent has information about the world and about the other participant agents' profiles, their preferences and goals. The reasoning layer has three modules: the argumentative system, decision-making module, and the emotional system. The argumentative system is responsible for generating explanatory and persuasion arguments. The decision-making module helps the agent to classify alternatives in three classes: preferred, indifferent, and inadmissible; and to choose the preferred one. The emotional module generates the participant agents' emotions and moods, affecting the choice of the arguments that are sent to other participant agents, the analysis of the received arguments, and the final decision. The interaction layer is responsible for communicating with the other agents and acts as an interface for the GDSS simulator users. The developed emotional system includes three main components: evaluation, selection, and decay. Evaluation is concerned with the process that triggers emotions. When $Agent_y$ sends a certain argument to $Agent_x$, $Agent_x$ will generate an emotion based on the received argument. Each generated emotion has different intensities depending on the situation it was generated. The agent expresses emotions according to the intensity of other triggered emotions. The selection component is responsible for selecting the dominant emotion, i.e., the emotion chosen by an agent in a certain moment that has a larger difference between intensity and the activation limit. In turn, decay is a component that appeases the emotions state. Emotions have a short duration, but they do not disappear instantly, they dissipate with time.

Decay allows the emotion to gradually disappear after being generated, and the agent's emotional state to move back to normal. One criticism that has been pointed to the OCC model is that it does not contemplates interactions performed by agents in previous scenarios and past emotions. However, the researchers in this study believe that their GDSS model allows overcoming this problem as the developed model considers the agents' mood.

Palomares et al. (2013) presented a Web-based consensus support system that allows for/permits the integration of the decision-makers' attitudes regarding consensus. They study the importance that decision-makers place in reaching consensus in respect to the possibility of modifying their own preferences. Decision-makers can/adopt pessimistic, indifferent and optimistic attitudes. For example, a decision-maker who adopts an optimistic attitude means that to reach the agreement is more important to him than his own preferences. In this way, the group's opinions will be given more importance. They argue that (as may be expected) optimistic attitudes help to reach consensus while pessimistic attitudes hamper the achievement of consensus.

Recio-García et al. (2013) presented a group decision support system where each decision-maker is represented by an agent who/that argues with the other agents in order to achieve the best alternative for the group. The presented negotiation model includes the users' social factors, personality and trust in the argumentative process. The personality of the decision-makers is represented by a number ranging from $[0, 1]$ where 0 means a very cooperative person and 1 the reflection of a very selfish one. To study the trust, they use the interaction of the decision-makers in social networks through a set of 10 factors. For the argumentation model, they used D^2ISCO, which is a platform for the design and implementation of deliberative and collaborative case-based reasoning (CBR) applications. They concluded that the proposed model allows the achievement of better satisfaction rates when compared to the standard "fully connected" group recommender.

Rodrigues et al. (2016) proposed a model of personality-based agents to produce different emotional responses. The assumption is that "emotional responses can vary according to differences in personality traits". Hence, they proposed a model where agents defined with different "personalities" (extroverted and introverted) have a distinct emotional reaction to the same scenarios. In the proposed model, they considered the 6 emotions proposed by Paul Ekman (sadness, happiness, fear, anger, surprise and disgust). To deal with personality they used the Five Factor Model (The Big Five Inventory was used to measure the value of each personality trait). In the performed experiment they collected data from social networks and each participant had to associate an emotion with the text. Then, the agents were "trained" according to the proposed model. The authors concluded that the inclusion of personality traits is relevant/important for producing emotional agents.

Alfonso et al. (2017) presented the Open Affective Agent Architecture (O3A). The O3A consists in a modification of the BDI (Belief–Desire–Intention) agent language AgentSpeak. They extended the traditional BDI reasoning cycle to incorporate affective components. They used the OCC model to represent emotions in Agents, the PAD model for mood and the FFM to deal with personality. Their work is still in process and their intention is to reach agents' behaviors closer to the humans' behavior.

2.2.5 *Summary and Discussion*

To rephrase Doyle (1991), AI is the discipline aimed at understanding intelligent beings by constructing intelligent systems. In 1998, Castelfranchi (1998) said "AI is the science of possible forms of intelligence, both individual and collective". It is therefore absolutely necessary to first know the human being (its functioning) before using that knowledge in the development of intelligent systems. To model agents with human beings' aspects is not new. At the beginning of the new millennium, some projects related to the agents' humanization began to appear (André et al., 2000; Ball and Breese, 2000; Franklin et al., 1998).

Nowadays, there are many proposals that intend to model human beings' aspects in agents, such as: personality (Dimuro et al., 2007; Padgham and Taylor, 1997), emotions (Ball and Breese, 2000; Gmytrasiewicz and Lisetti, 2002; Dias and Paiva, 2005), cognitive styles (Frank et al., 2001), etc (Paiva et al., 2005; Dias et al., 2014; Preuveneers and Novais, 2012; Novais and Carneiro, 2016). There are also some proposals under the topic of GDSS (Palomares et al., 2014, 2013; Recio-García et al., 2013; Santos et al., 2009). All of them share the idea that the inclusion of cognitive/affective aspects may somehow help the decision-making process. However (to the best of our knowledge), most of them are to be used in simulated environments. We believe the usage of such techniques in real systems can bring some disadvantages. "A real me" can be a bad approach if my persona is less persuasive/intelligent/capable than others.

The interest that computer science scientists have been showing for the field of Affective Computing is considerable. However, it is also noticeable that it is a recent field with much to explore, where tools are needed but sometimes not yet available. It can be verified that the models most used by the community and that can be adapted to Affective Computing are the FFM, OCC and PAD. However, these models may not satisfy all the needs of future computational models. The need to carry out multidisciplinary work is becoming more and more visible, which is still infrequent today.

In the context of the Group Decision Support Systems there are some that consider affective aspects, yet at a very embryonic stage. Regarding the topics of satisfaction and perception of decision quality in the use of GDSS, the results are practically non-existent, perhaps due to the number of variables that need to be considered, and because there is a lack of knowledge on what strategies to use in order to deal with some of those variables. From the decision quality point of view, it remains a challenge to classify or compare GDSS or negotiation models.

2.3 ARGUMENTATION-BASED NEGOTIATION

Rahwan et al. (2003) defined negotiation as "a form of interaction in which a group of agents, with conflicting interests and a desire to cooperate, try to come to a mutually acceptable agreement on the division of scarce resources"; Hadidi et al. (2010) defined negotiation as "the process of looking for an agreement between two or several agents on one or more issues"; and El-Sisi and Mousa (2012) defined it as "a process of reaching an agreement on the terms of a transaction such as price, quantity, for two or more parties in multi-agent systems such as E-Commerce. It tries to maximize the benefits for all parties". Taking these definitions into account, in this thesis we propose the following definition:

Negotiation is a process between two or more parties seeking for an agreement.

In literature, it is possible to verify a consensus regarding the main approaches that deal with negotiation: game theory, heuristics and argumentation (Rahwan et al., 2003; Hadidi et al., 2010; El-Sisi and Mousa, 2012). From the computational point of view, argumentation is a key topic of this doctoral work and this section gives special attention to it.

Game-theoretic approaches to negotiation

Game theory is a branch of economics that studies interactions between self-interested agents. Myerson (2013) defined game theory as "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers". For him, the term "game" is not the most appropriate to describe what game theory actually is. He considered that the purpose of this approach would be better described as "conflict analysis" or "interactive decision theory". The paper proposed by Von Neumann and Morgenster in 1944, "The Theory of Games and Economic Behavior", is considered one of the most important works in the field (Von Neumann and

Morgenstern, 2007). The main idea behind game-theoretic analysis is to determine the optimal strategy by analyzing the interaction as a game between the agents and look for equilibrium (Rahwan et al., 2003). Most of the classical game-theoretic approaches have some limitations, for instance, computational limitations (Dash et al., 2003). The range of application is also limited, for example, if we try to apply the game-theoretic techniques to a chess game, the number of solutions will be exponential.

Heuristic-based approaches to negotiation

To overcome some of the limitations related to game-theoretic approaches, some heuristic-based approaches have emerged. Contrary to game-theoretic approaches, heuristics intend to seek or produce a good enough solution. This purpose turns heuristics faster and overcomes the computational limitations. Jennings et al. (2001) identified two main advantages of the heuristic approaches: the models are based on realistic assumptions and the designers of agents, who are not wedded to game theory, can use alternative, and less constrained, models of rationality to develop different agent architectures. They also identified two main disadvantages: the models often select outcomes (deals) that are sub-optimal and they need an extensive evaluation through simulations and empirical analysis. Faratin et al. (1998) introduced three negotiation tactics based on heuristics: time-dependent tactics (where the predominant factor used to decide which value to offer next is time), resource-dependent tactics (very similar to the previous one but considers different resources) and resource estimation tactics (generates counter-offers depending on how a particular resource is being consumed).

Argumentation-based approaches to negotiation

It is a known fact that game theoretic and heuristic-based approaches evolved and became more complex. With this development, they have been used in a wide range of applications. However, they share some limitations in addition to those already referred. In most game-theoretic and heuristic models, agents exchange proposals, but those proposals are limited. Agents are not allowed to exchange any additional information other than what is expressed in the proposal itself. This can be problematic, for example, in situations where agents have limited information about the environment, or where their rational choices depend on those of other agents. Another important limitation is that agent's utilities or preferences are usually assumed to be completely characterized prior to the interaction.

Thus, to overcome those limitations, argumentation-based negotiation appeared and became one of the most popular approaches for negotiation (Marey et al., 2014a), being extensively investigated and studied, as witnessed by many publications (Mbarki et al., 2006; Amgoud and Vesic, 2011a; Bonzon et al., 2012). The main idea of argumentation-based negotiation is the ability to support offers with justifications and explanations, which play a key role in the negotiation settings. So, it allows the participants not only to exchange offers during the negotiation, but also reasons and justifications that support those offers in order to mutually influence their preferences regarding the set of offers, and consequently, the outcome of the dialogue.

It is simple to understand the parallelism between this approach and group decision-making. The idea of a group of agents exchanging arguments in order to achieve, for instance, a consensus, to support groups in the decision-making process, is easy to understand.

2.3.1 *Argumentation*

The theory of argumentation is a complex and interdisciplinary area of research lying across philosophy, communication studies, linguistics, and psychology (Van Eemeren et al., 2013). Its techniques have been applied to a large range of applications in both theoretical and practical branches of artificial intelligence and computer science (Maudet et al., 2006). The interest to research about argumentation in artificial intelligence appeared about two decades ago (Dung, 1995; Kraus et al., 1998; Sierra et al., 1997). The connection between argumentation and some other subfields of artificial intelligence as knowledge representation, nonmonotonic reasoning, and multi-agent systems is strong and highly beneficial. Furthermore, the argumentation has been successfully applied and it has proved to be valuable in legal reasoning, decision support for resolving conflicts between different opinions and in the context of dialogues and persuasion. Argumentation techniques can also be found in expert systems applied to a wide range of different areas, for instance, medicine and eGovernment. Brewka et al. (2014) consider there are two major lines of research regarding argumentation: logic-based and abstract approaches. For them, the logic-based approaches are the responsible for defining notions such as: attack, undercut and defensibility. The abstract approaches are more concerned about the relations between arguments, where arguments are considered as atomic items.

Argumentation is used by human beings in their daily life. We all use argumentation in order to evaluate information or support an opinion. The beauty of argumentation is that we use it even in our introspection. Thus, the arguments can be used to: evaluate information in order to support the decision, perform a debate and for persuasion purposes. Argumentation can be characterized into two types: monological argumentation and dialogical argumentation (Asterhan and Schwarz, 2007; Linell and Markovä, 1993). The former is for individual analysis or presentation of information (for instance, political speech before elections) and the latter is for exchange of information between agents. The argumentation process has a logic evolution, usually an argument that supports a case of interest is used, then, counter-arguments to that argument are presented, and after, counter-counter arguments, and so on. Therefore, considering all this knowledge, we can say automated negotiation is useful because it: simulates human reasoning, provides a way of handling uncertainty and helps in the decision support process. For being able to model argumentation is necessary to perform some mandatory tasks such as: to define structures to represent arguments, to formalize counter-argument relations between arguments, to define formal criteria for comparing arguments and identify which are the winning ones and, of course, automate all of them.

Due to his work in formal deductive reasoning and rhetoric, Aristotle is considered one of the great proponents of argumentation (Billig, 1996). But it was in the last century that the work responsible for computationally defining argumentation has appeared. In 1953, Toulmin (2003) considered that arguments are pronounced according to a certain "field" and are related to a certain "modal". The "field" can be seen as the domain or context in which the argument is pronounced. "modal" represents the initial attempt to perceive the argument's semantic (to classify the arguments as "acceptable" or not). Toulmin's layout of arguments is presented in Figure 8, where D stands for Data, Q stands for Qualifier, C stands for Claim, W stands for Warrant, B stands for Backing, and R stands for Rebuttal (Toulmin, 2003). The model proposed by Toulmin is well known in literature (his book has thousands of quotations) and recognized in later works, such as Dung (1995).

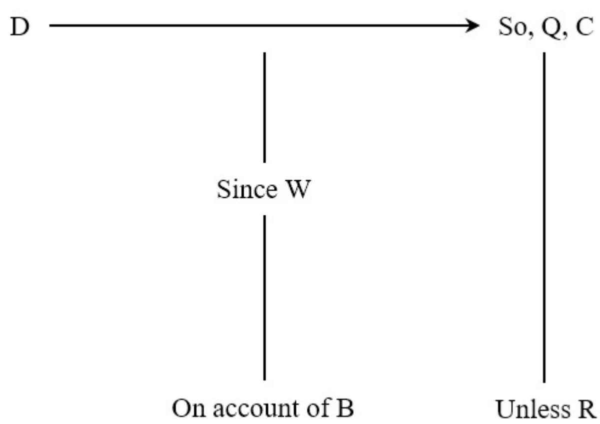

Figure 8: Toulmin's layout of arguments (adapted from Toulmin (2003)).

Pollock was also one of the responsible for relevant developments in the topic of argumentation (Pollock, 1991, 1994, 1995). He devel-

oped one of the first formal systems for argumentation-based inference, and was one of the first to study important argumentation topics such as: argument structure, the nature of defeasible reasons, the interplay between deductive and defeasible reasons, rebutting versus undercutting defeat, argument strength, argument labelling, self-defeat, and resource-bounded argumentation (Prakken and Horty, 2012). Pollock (1995) considers that defeasible reasoning is, a fortiori, reasoning. The reasoning advances as new arguments are being constructed, where the reasons administer the atomic links in arguments. Obviously, conclusive reasons allow to reach the conclusions and thus the defeasibility arises from the fact that not all reasons are conclusive. Pollock considers arguments as inference trees, where nodes are statements, leaf nodes are the premises and the branches (links) are the applications of "reasons". Pollock considers sequences of lines from an argument. Each line from an argument is a tuple (φ, r, l, s), where φ is a proposition, r is the reason applied to infer φ, l is the set of preceding lines from which φ is inferred, and s is the line's strength (a number). A sequence of such lines is a (linear) argument if each line is such that its proposition is either inferred from earlier lines or taken from the knowledge base (Prakken and Horty, 2012).
With his definition of arguments, Pollock defines defeat as follows:

- An argument line (φ, r, l, s) defeats another argument line (φ', r', l', s') if and only if:
  - r' is a defeasible rule, and
  - $s \geqslant s'$, and
  - $\varphi = \neg\varphi'$ or $\varphi = \neg r'$ (r' is the shorthand for saying that the antecedents of rule r do not support its consequent);
- An argument A defeats an argument B if and only if a line of A defeats a line of B.

There are some formalizations for modelling argumentation, some of the most important are abstract argumentation, assumption-based argumentation, argumentation-based on defeasible logic and argumentation-based on classical logic. In this thesis, we describe abstract argumentation in terms of purpose and semantics, and we explain the purpose of the other formalizations.

Abstract argumentation

Abstract Argumentation is a simple, yet illustrative way for formalizing the mechanism of argumentation (Dung, 1995). It is a simple structural way for representing binary attack relations in a given set of arguments. However, abstract argumentation has a limited expression and presents no method to deduce individual arguments from some knowledgebase.

In Abstract Argumentation (AA), an Argumentation Framework (AF) is simply a pair $AF = \langle A, R \rangle$, consisting of a set of arguments, A, and a binary attack relation, R.

Example:

$$AF = \langle \{A, B, C\}, \{(A, B), (B, A), (B, C), (C, C)\} \rangle.$$

In AA arguments are evaluated given the relation of attack. The objective is to determine which arguments are "acceptable". In a logical way, we can see that arguments that are not attacked should be considered "acceptable". On the other hand, arguments that are attacked and cannot counteract these attacks should not be considered "acceptable". AA is normally represented by directed graphs. Figure 9 presents the graph related to the presented example (arguments are represented as nodes and attacks are represented as directed links in those graphs).

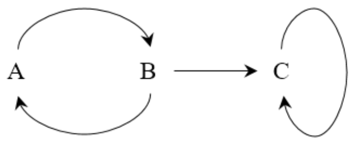

Figure 9: An Abstract Argumentation graph example.

As can be seen in Figure 9, arguments can attack each other (arguments A and B) and an argument can attack itself (argument C).

In order for the arguments to be evaluated, argumentation semantics are used. There are two main styles of argumentation semantics: extension-based and labelling-based (Bench-Capon and Dunne, 2007). Extension-based is described next in order to illustrate how the semantics work.

A subset of arguments is called an "extension" (Bench-Capon and Dunne, 2007). In this way, we can say that an acceptable extension E is a set of arguments able to withstand the attacks it receives from other arguments. In order for the extension to be conflict-free, arguments cannot attack each other. Formally, we can say that given an argumentation framework $AF = \langle A, R \rangle$, a set $S \subseteq A$ is conflict-free if and only if $\nexists a, b \in S$ such that $(a, b) \in R$. The set of "extensions" prescribed by a semantics S in an abstract framework $AF = \langle A, R \rangle$, is denoted as $E_S(AF)$.

In order for an extension E to be acceptable, it must be able to counteract the attacks it receives. Formally, we can say that given an argumentation framework $AF = \langle A, R \rangle$, an argument $a \in A$ is acceptable with respect to a set $S \subseteq A$ if and only if $\forall b \in A : (b, a) \in R \Rightarrow (\exists c \in S : (c, b) \in R)$. In addition, the set of arguments is only acceptable if and only if all of its elements jointly defend the set by issuing counterattacks. Formally, we can say that a set $S \subseteq A$ is acceptable if and only if $\forall x \in A, \forall b \in S : (x, b) \in R \Rightarrow \exists c \in S(c, x) \in R$.

After defining the concepts of conflict-freeness and acceptability, we can now define admissibility. Formally, we can say that given an argumentation framework $AF = \langle A, R \rangle$, an extension E is admissible if and only if E is conflict-free and acceptable (Table 8 presents the semantics for extension-based argumentation).

Table 8: Extension-based argumentation semantics.

Semantics	Sets
Conflict-free	$\{\}, \{A\}, \{B\}$
Admissible	$\{\}, \{A\}, \{B\}$
Complete	$\{\}, \{A\}, \{B\}$
Grounded	$\{\}$
Preferred	$\{A\}, \{B\}$
Ideal	$\{\}$
Stable	$\{B\}$

We can also find a set of other semantics in literature (Bench-Capon and Dunne, 2007):

- Complete: Given an argumentation framework $AF = \langle A, R \rangle$, an extension E is complete if and only if E is admissible and every argument of A which is acceptable with respect to E belongs to E;
- Grounded: The grounded extension of an argumentation framework $AF = \langle A, R \rangle$, denoted as $GE(AF)$, is the smallest set of arguments which is complete, with respect to set inclusion;
- Preferred: Given an argumentation framework $AF = \langle A, R \rangle$, a set $E \subseteq A$ is a preferred extension of AF if and only if it is a maximal set of arguments which are admissible, with respect to set inclusion;
- Ideal: Given an argumentation framework $AF = \langle A, R \rangle$ an extension is ideal if and only if it is a maximal set of arguments which are admissible and a subset of all preferred extensions, with respect to set inclusion;
- Stable: Given an argumentation framework $AF = \langle A, R \rangle$, a set $E \subseteq A$ is a stable extension if and only if it is conflict-free and attacks all arguments that are not in it.

Assumption-based argumentation

Assumption-based argumentation is a more expressive formalism for modelling argumentation (Bondarenko et al., 1997). It is an instantiation of abstract argumentation and it is based on logic and incorporates deduction. The idea of assumption-based argumentation is the possibility to generate arguments from assumptions and rules. Thus, it is possible to represent knowledge in a more detailed and expressive way. In an assumption-based argumentation framework, an argument is a deduction supported by a set of assumptions and obtained along with the rules available. An argument B attacks another argument B' if the conclusion of B is the contrary of one of the assumptions supporting B'. However, assumption-based argumentation still has a restricted language syntax and proof theory compared to classical logic.

Contrary to abstract argumentation (in which the arguments are represented through the use of graphs), in assumption-based argumentation arguments are trees. The tree's root is the claim of the arguments, and leaves are either assumptions or facts. All the semantics presented in abstract argumentation are also defined in assumption-based argumentation.

Argumentation-based on defeasible logic

Defeasible logic incorporates two kinds of rules: defeasible rules, that represent weak information (notation: $\prec$); and strict rules, that represent sound information (notation: $\leftarrow$). This approach is also based in logic and provides mechanisms for deducing arguments (Nute, 2001). Defeasible rules capture the way humans tend to make inferences through observations and withdraw some conclusions in the presence of new information. This approach permits to define priorities on rules. Like the assumption-based argumentation, argumentation-based on defeasible logic is limited compared to classical logic approaches.

Argumentation-based on classical logic

The big difference between argumentation-based on classical logic and the previous ones is that this one is very expressive (Besnard and Hunter, 2001, 2009). Argumentation-based on classical logic allows a detailed knowledge representation and inference mechanisms. It is an approach that introduces a sophisticated way for defining counter-arguments. In addition, it is a powerful language with a simple and intuitive syntax. Has a well-established proof theory and extensive foundational results and a concise representation of the most meaningful counter-arguments. However, one of the main disadvantages of argumentation-based on classic logic is the inherent complexity.

Final considerations

Argumentation is a cognitive process employed by human beings when trying to make decisions; especially when dealing with conflicting information. Computational argumentation can be used by decision support systems, particularly useful for conflict resolution. Various frameworks have been proposed for modelling argumentation-based on different underlying logics, and some are presented in this document (Amgoud and Cayrol, 2002; Bench-Capon, 2003; Prakken, 2010). Several theories extend these frameworks and a number of tools have been implemented (some are presented in this document) to support the various applications of argumentation. There are many practical challenges to overcome.

2.3.2 *Dialogue*

Dialogue theory was first addressed in modern philosophy by Paul Grice (Grice et al., 1975). For him, an argument is seen as a contribution that is given in a collaborative conversation. In his perspective, an argument must be evaluated from the point of view of its collaborative value taking into account the time it is spoken (Grice et al., 1975).

There are several types of dialogues. Each of them is characterized by having different objectives, and different sets of rules that make it easier to achieve those objectives (Walton, 1989). One of the most recognized dialogue taxonomy was proposed by Walton and Krabbe (1995). They divided dialogues into six types (see Table 9):

- Persuasion: In this type of dialogue, the proposer tries to persuade the other party that a certain fact is true and vice versa. Basically, both parties try, by using arguments, to convince the other party to change its opinion;

- Negotiation: The goal of negotiation is to reach an agreement. In this type of dialogue, both parties seek to maximize their benefits while achieving a consensus that is, at the same time, acceptable to both;

- Inquiry: This type of dialogue arises from the need to establish or prove propositions. It aims to achieve general agreement on the subject that is on the table. Here, the objective is not to satisfy interests as it happens in negotiation, since there is no conflict of opinions but an open problem;

Table 9: Dialogue types (adapted from Walton and Krabbe (1995)).

Type	Initial situation	Main goal	Participants' aim
Persuasion	Conflicting point of view	Resolution of such conflicts by verbal means	Persuade the other(s)
Negotiation	Conflict of interests and need	Making a deal	Get the best out of it for oneself
Inquiry	General ignorance	Growth of knowledge and agreement	Find a "proof" or destroy one
Deliberation	Need for action	Reach a decision	Influence outcome
Information seeking	Personal ignorance	Spreading Knowledge and revealing positions	Gain, pass on, show or hide personal knowledge
Eristic	Conflict and antagonism	Reaching (provisional) a accommodation in a relationship	Strike the others party and win in the onlookers

- Deliberation: As in the inquiry, this type of dialogue is about an open problem. However, the goal here is to decide how to act. In this way, it is also intended to achieve an agreement, but the agreement does not have to be obligatorily general;

- Information-seeking: This type of dialogue concerns to the search for information by the participants. This search for information happens through requests to an expert, where the goal is to spread knowledge. Here it is not intended to prove anything but to retrieve a piece of knowledge;

- Eristic: This kind of dialogue is a bit different in that its purpose is to seek conflict instead of seeking to resolve the conflict. The idea is to go against the opponent regardless of what he says.

Dialogue systems have also been studied by computer science scientists (Prakken, 2000; McBurney and Parsons, 2002; Prakken, 2006). In these systems, agents exchange messages with a certain objective, e.g., negotiation, persuasion, seeking information, etc. The use of arguments allows agents to justify their positions, actions or preferences when carrying out any of those dialogues (Rahwan et al., 2003).

According to Prakken (2006), a dialogue system should include the following elements:

- Topic language: The language that designates the meaning of each utterance;

- Communication language: The language that enables the discussion;

- Dialogue purpose: Purpose of the dialogue;
- Participants: The participants involved in the process (at least 2), who may have several roles, objectives and beliefs;
- Context: The type of dialogue;
- Logic: The logic used in the dialogue, which may or may not be monotonic and which may or may not be argument-based;
- Effect rules: Defines the effect of utterances;
- Protocol: Specifies which movements are possible to be performed during the dialog;
- Outcome rules: The set of rules that define the outcome of the dialogue.

Black and Hunter (2009) presented a framework for representing dialogues of the type inquiry. Their argumentative system is based in Defeasible Logic Programming (DeLP). In their work, they consider two types of inquiry dialogues: argument inquiry and warrant inquiry. The former intends that agents can jointly construct arguments to support a particular claim that would not be possible if done separately (alone). The latter intends that agents can share arguments in order to construct a dialectical tree that they could not do alone with their own beliefs. In these two types of inquiry dialogues, agents jointly seek to inquire about topics. However, the argument inquiry dialogue does not allow to determine the acceptability of the constructed arguments, and in warranty inquiry dialogue the agents work together to determine the acceptability of the arguments. The authors named the communicative acts as "moves". They considered the existence of three different moves: open, assert and close. A move is represented as $\langle Agent, Act, Content\rangle$, where $Agent$ is the agent generating the move, Act is the type of the move and $Content$ contains information about the details of the move. The dialogue is always performed by exactly two agents and always starts by an "open" move. They represent the first move as $\langle x, open, dialogue(\theta, \gamma)\rangle$, where θ is the type of the dialogue and γ is the topic of the dialogue. So, the type and the topic of the dialogue are defined in the content of the first move. The dialogue ends when both agents make the "close" move.

Prakken (2005) proposed a formal framework of argumentation dialogues for persuasion. In his work, he presents an example of a persuasion dialogue, which we present below:

1. ag_1: My car is very safe. *(making a claim)*;
2. ag_2: Why is your car safe? *(asking grounds for a claim)*;

Table 10: Speech acts for liberal dialogues (adapted from Prakken (2005)).

Acts	Attacks	Surrenders
claim φ	why φ	concede φ
why φ	argue A ($conc(A) = \varphi$)	retract φ
argue A	why φ ($\varphi \in prem(A)$)	concede φ ($\varphi \in prem(A)$
	argue B (B defeats A)	or $\varphi = conc(A)$)
concede φ		
retract φ		

3. ag_1: Since it has an airbag. *(offering alternative grounds for a claim)*;

4. ag_2: That is true, *(persuasion: conceding a claim)* but I disagree that this makes your car safe: the newspapers recently reported on airbags expanding without cause. *(stating a counterargument)*;

5. ag_1: Yes, that is what newspapers say *(conceding a claim)* but that does not prove anything, since newspaper reports are very unreliable sources of technological information. *(undercutting a counterargument)*;

6. ag_2: Still your car is still not safe, since its maximum speed is very high. *(alternative counterargument)*.

This example demonstrates the complexity of the persuasion dialogues. As we can see, during a dialogue of this type, an individual/agent can refer back to previous choices in the same dialogue, as well as justify a certain point of view in different ways.

In his work, Prakken introduced the "liberal" and "relevant" dialogue systems. Table 10 presents the moves for liberal dialogues.

As in the work of Black and Hunter (2009), Prakken's liberal dialogues are represented as trees and the arguments of a tree are always relative to only one topic. An argument is a deduction with a conclusion ($conc$) and premises ($prem$), and "An argument B extends an argument A if $conc(B) = \varphi$ and $\varphi \in prem(A)$". The author also defined a turn-taking function that specifies which agent does the next move, which basically guarantees the existence of a "ping-pong" dialogue, where the first move is responsible for specifying the dialogue's topic. One of the most relevant parts of this work is the way Prakken determines the outcome of a dialogue by defining an in/out labelling. Theoretically, what happens is that a node is in if it withstands its attacks, otherwise it is out. So, considering that the root of a dialogue is responsible for defining the topic, the proponent wins the dialogue if the root node is in.

Parsons et al. (2003) presented a study about argumentation-based dialogues between agents. They have defined locutions from which agents can exchange arguments. In addition, agents may adopt different attitudes which will condition the arguments that they can build and what locutions they can make. They also defined a set of protocols which determine the entire functioning of the dialogue (termination, dialogue outcomes and complexity). In this work, they deal with three types of dialogues: information seeking, inquiry and persuasion. They assume the dialogues are always performed by only two agents, which can use several utterances, such as: assert, accept, challenge, question, etc. One of the most fascinating points of this work is the relation defined between the agents' attitudes and their way of acting. For instance, an agent can have three different assertion attitudes: confident, careful and thoughtful, and three acceptance attitudes: credulous, cautious and skeptical. Next, an example of a possible information seeking dialogue is presented, using the protocol proposed by the authors:

1. ag_1 asks $question(p)$;
2. ag_2 replies either $assert(p)$ or $assert(\neg p)$ if it can, and $assert(U)$ if it cannot. Which response is given will depend upon the contents of its knowledge base and its assertion attitude. U indicates that, for whatever reason, B cannot give an answer;
3. ag_1 either accepts B's response, if its acceptance attitude allows, or challenges. U cannot be challenged and as soon as it is asserted, the dialogue terminates without the question being resolved;
4. ag_2 replies to a challenge with an $assert(S)$, where S is the support of an argument for the last proposition challenged by ag_1;
5. Go to 3 for each proposition in S in turn;
6. ag_1 accepts p if its acceptance attitude allows.

There is a large number of applications of dialogue systems in literature (Mackenzie, 1990; Woods and Walton, 1978) covering various topics, such as: resource-bounded reasoning (Loui, 1998; Brewka, 2001), legal reasoning (Gordon, 1993; Hage et al., 1993; Bench-Capon, 1998; Prakken, 2001), to support agent interaction (Parsons et al., 1998; Amgoud et al., 2000; Parsons et al., 2003; Kraus et al., 1998), among others.

2.3.3 *Important Foundational Works*

This section resumes some of the best works that influenced Argumentation and Argumentation-Based Negotiation.

Dung (1995) ***"On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games"***

In 1995, a paper from Dung was published (Dung, 1995), becoming one of the highest references in the argumentation field. The goal of this paper was very simple, compute the expression "The one who has the last word laughs best". The logic behind this old saying is easy to understand. Let's imagine two people are arguing about something. Person $P1$ uses argument $A1$ to support his position; if person $P2$ cannot justify or counterargue $A1$, $P1$ can claim "victory"; otherwise, if $P2$ justifies $A2$, $P1$ cannot claim victory and the argumentation proceeds; if $P2$ counterargues and $P1$ cannot justify or counterargue then $P2$ can claim victory, else the argumentation proceeds.

Considering this scenario and the intention to compute this behavior, "The understanding of the structure and the acceptability of arguments are essential for a computer system to be able to engage in exchanges of arguments." Dung refers that, on one hand, significant work has been made to analyze the structure of arguments, but on the other hand, the acceptability of arguments is not a consistent thematic. In this paper, Dung intends to enlighten the "semantical relations between argumentation and nonmonotonic reasoning".

To better understand Dung's work, it is important to understand what monotonic and nonmonotonic reasoning is in the context of argumentation. In a simple perspective, a reasoning is monotonic if a conclusion is true and continues to be true regardless of the knowledge added. Reasoning is nonmonotonic if a conclusion can be invalidated by adding more knowledge.

Dung claims and demonstrates as nonmonotonic reasoning in AI and logic programming can be both considered different forms of argumentation. A conclusion or even a simple argument can only be considered true if there isn't any other argument or evidence that contraries it. For Dung, argumentation can be viewed as logic programming with negation as failure.

The analogy made by Dung to transform logic programming theory into a "framework" is very clear. Fundamentally, the basis of Dung's Argumentation Framework (AF) is composed by a pair $AF = \langle AR, attacks \rangle$, where AR is a set of arguments, and $attacks$ is a binary relation on AR. So, in practice this means $attack \subseteq AR * AR$. If we consider two arguments $A1$ and $A2$, $attacks(A1, A2)$ represents an attack of $A1$ against $A2$.

The argumentation theory proposed by Dung is very interesting and seems to be a very rational way of turning the real world into a mathematical world. Implementing real systems with argumentation-based on this theory can, be a success in some contexts. However, Dung's theory seems to have some difficulty in dealing with vague knowledge or arguments, which can be considered more difficult to deal with incomplete or uncertain information.

Kraus et al. (1998) ***"Reaching agreements through argumentation: a logical model and implementation"***

This paper came in sequence of the work developed by Sarit Kraus where she argues about the importance of interdisciplinary approaches in argumentation models (Kraus, 1997). This perspective is one of the factors that distinguished the work developed by Sarit Kraus and her team in the last 2 decades.

In this paper, Sarit Kraus and her colleagues present a logical model on the mental states of the agents in order to make them capable of reaching an agreement through argumentation in an automated negotiation process. The work presented in this paper is a huge reference in this field and inspired a large number of works.

To reach the agreement through argumentation, they proposed an agent with a structure that allows the designer to define some specific issues influencing the agent's general behavior. The structure of each agent consists in three different parts: mental state, characteristics and inference rules. The mental state is composed by the agent's beliefs, desires, goals and intentions. The activities performed by the agent intend to fulfill the agent's desires. The goals of an agent at a certain moment are a consistent subset of its desires. The intentions can be considered the way how the agent plans to act during the process. Concerning to beliefs, they divided the agent's beliefs into beliefs concerning the world and beliefs concerning the mental states of the other agents. The other parts are described below.

In this work, the authors intended to have agents with what they call of different "character". So, to achieve this goal, they defined different kinds of agents with some additional conditions in their models. They considered important to have the following agents: bounded, omniscient, knowledgeable, unforgetful, memoryless, non-observer and cooperative.

The title of this work reflects exactly what we found during the reading of this paper. The term "consensus" is not used during the whole document, but it is clear what "reaching agreements" and "persuade each other" means. So, to try to get a consensus, agents exchange arguments between them. The arguments proposed by the authors are: threats, future reward, appeal to past reward, appeal to precedents as counterexamples, appeal to prevailing practice and appeal to self-interest. They claim that, as these arguments work in human negotiations, they may also work in automated agents' negotiations. They chose these particular arguments due to some very interesting factors. They intended to make these agents capable of

negotiating with humans and to allow the designers to follow and understand the negotiation process between the agents.
The three previous paragraphs constitute the core of the general structure of an agent:

- Mental state (beliefs, desires, goals, intentions);
- Characteristics (agent type, capabilities, belief verification);
- Inference rules (mental state update, argument generation, argument selection, request evaluation).

The whole structure of an agent is used during the argumentation process and its parts influence each other in the process. This process permits the agents to reason about argumentation, influence the others' beliefs, evaluate arguments and update data. Based on this, we can conclude that this work tries to humanize the agents.

This publication (Kraus et al., 1998) was a tremendous scientific contribution. Of course, there are lot of questions that arise. For us, one of the most important is: "How to evaluate a prototype based in a model like this?" Anyway, this question continues to be pertinent in most of the group decision support systems proposed these days.

Sierra et al. (1997) ***"A framework for argumentation-based negotiation"***

Sierra et al. (1997) presented a "novel framework for describing persuasive negotiations between autonomous agents". This work was conducted by a group of strong researchers in this area, which claim persuasive argumentation is the only way to influence another's behavior. They consider argumentation-based negotiations as one of the most elaborated forms of negotiations. For them, argumentation-based negotiation consists in allowing the parties to send justifications or arguments indicating why they should be accepted. Moreover, the parties should be able to send counter proposals according to the proposals received. As in (Kraus et al., 1998), one of the greatest sources of inspiration for this work was the work published by Karlins and Abelson (1970).

The authors consider 3 different types of illocutions: threats, rewards and appeals. For them, the main focus is not to provide "an exhaustive formalization of all the argument types", but to withdraw "a framework in which the key components of argumentation can be described". In order for the agents to exchange the illocutions they defined 4 conventions shared by the agents:

- "The elements that are relevant for the negotiation of a deal – in the form of issues and values that may evolve as negotiation proceeds";

- "The rationality of the participating agents – in terms of some form of preference relationships or utility functions which enable the agents to evaluate and compare different proposals";
- "The deliberation capability of the participating agents – in the form an internal state in which the agent may register the history of the negotiation as well as the evolution of its own theoretical elements on which its decisions are founded";
- "The minimal shared meaning of the acceptable illocutions – this is captured in the way that a received illocution should be interpreted when heard by an agent, and by making explicit the conditions that enable an agent to use (or 'generate') a given illocution at a given time".

They consider the social relationship of each agent as a form of creating impact in the persuasion and argumentation process. They suggest that this relation can be defined as a binary function over a set of social roles. For them the logical language shared by the agents is not important in the context of their work. However, they consider mandatory to contain at least variables, constants, equality and conjunction. These features are needed to express the kind of sentences intended by the authors. For instance, a sentence is:

$$(Price = 10) \cap (Quality = High) \cap (Penalty = ?)$$

where $Price$, $Quality$ and $Penalty$ are the issues under negotiation and so are represented as variables; 10, $High$ and ? are values for those issues and therefore are constants; $=$ denotes equality; and $\cap$ denotes conjunction.

The illocutions used by the agents are according to the negotiation protocol defined by the authors and are illustrated in Figure 10:

- "A negotiation always starts with a deal proposal, i.e. an offer or request";
- "This is followed by an exchange of possibly many counter proposals (that agents may reject) and many persuasive illocutions";
- "Finally, a closing illocution is uttered, i.e. an accept or withdraw".

This work is very well grounded and our conclusions about this work are very similar to the ones presented before in the review of Kraus et al. (1998) paper. The introduction of some concepts captured from social sciences are priceless and open a wide of different possibilities to the present and future research. As mentioned before, there are a number of issues which need investigation in order to be validated. Although these authors applied their model to a framework, the model is not properly validated nor compared to others. The authors themselves considered and pointed some issues such as: how expressive communication language is required to be and how to better manage the agent's preferences.

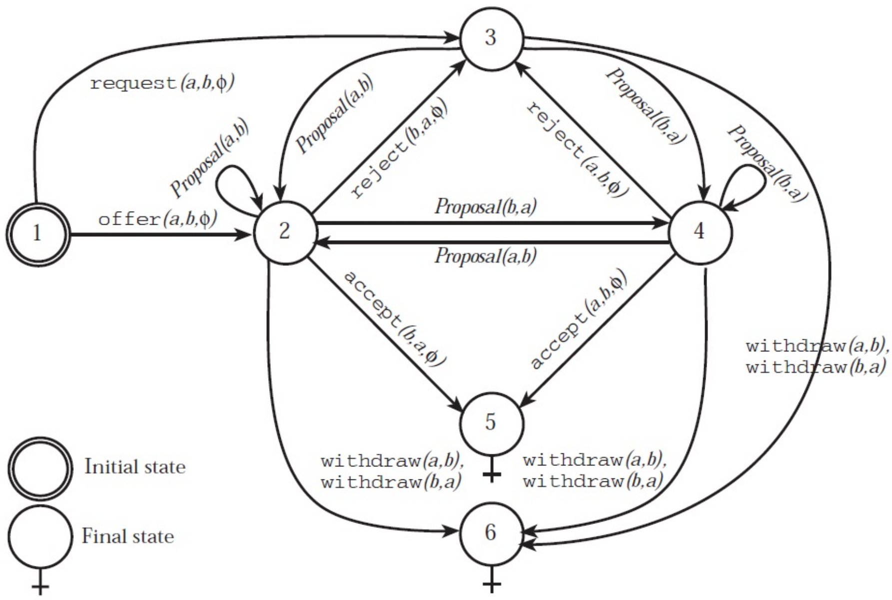

Figure 10: Negotiation Protocol (adapted from Sierra et al. (1997)).

2.3.4 *Argumentation and Argumentation-based Negotiation Trends Nowadays*

Heras et al. (2010) analyzed how Argumentation Schemes Theory can be used to formalize and structure on-line discussions and user opinions. They considered a social network to be an abstraction of social structures that connects individuals or organizations. They distinguished implicit and explicit social networks and presented several features that could be used to define those networks (such as purpose, nodes, roles, etc.). They also identified three main advantages of applying argumentation schemes to the social network business (to provide a formal structure for opinions and recommendations, to provide a way of evaluating user opinions and recommendations, and to provide a formal structure for the dialogue). As a final remark, they believe that argumentation can enhance business driven social networking.

Sánchez-Anguix et al. (2011) proposed and studied the performance of several intra-team strategies that could be used by negotiation teams. These strategies define how the communication is carried out between team members and how decisions can be made (which requests are sent to the opponent and what mechanisms are used for the opponent to accept or refuse the request). They concluded that the negotiation environment (diversity, negotiation on time, concession strategy) greatly affects the performance of the intra-strategy that is chosen. They also referred to the fact that their approach is new to the literature and that they could further improve its performance by considering more environmental conditions (opponent strategies, non-static team memberships, etc.).

van der Weide et al. (2011) published a scientific work where they proposed a formalism to argue on a meta-level about what argument an agent should select in a given persuasion dialogue. For the authors, the approaches that exist in literature do not combine different criteria in the argument selection. They were inspired by decision analysis techniques and they decomposed into criteria and sub-criteria what matters for an agent. The criteria and sub-criteria are structured hierarchically into a value tree. They claim this approach is easier for a designer than a purely quantitative approach, it allows the use of criteria that are partial and/or incommensurable and it allows the agent to explain why a certain argument was selected.

El-Sisi and Mousa (2012) presented a paper where they analyzed the benefits of argumentation-based negotiation (ABN) against proposal-based approaches (PBA). They considered the possibility to exchange additional information as the greatest advantage of ABN. In their work, they classified the game theoretic, heuristic and argumentation-based as the three different existing approaches to one-to-one automated negotiation. Furthermore, for them, negotiation can be characterized into three different forms: bidding, auctioning and bargaining. They also described some relevant information about the implementation techniques used in their work. To achieve their goals, they performed an empirical comparison of ABN to PBA in a strategic two-player scenario. They configured 2 agents (seller and buyer) with the goal to achieve an agreement in a negotiation process. They ran 12 examples for each one, ABN and PBA. They concluded that the argumentation increased the quality of the agreements. Another very important fact was that all the failed examples in PBA were accepted in ABN. They stated ABN is much better than PBA in terms of the quality of the agreements and the quantity of unsuccessful negotiations.

Booth et al. (2012) addressed a work where they proposed a way to measure and quantify the disagreement in argument-based reasoning. To illustrate the problem, they presented a scenario where three scientists intended to reach a collective position regarding a problem considering three different positions: A, B and C. Two scientists support position A and the other supports position B. They want to reach the collective position closest to their respective individual positions. To attain this, some questions arose: should all of them change to position C? Or should the third scientist change to position A, ensuring the first two stick to their point view? For the authors, these examples highlight the need for an approach to measure the distance between the different positions. To achieve this objective, they presented several distance functions. As for future work, their goal is to continue studying the issue and apply it to the problems of revision and judgment aggregation in argumentation.

Müller and Hunter (2012) published a work proposing the use of argumentation to satisfy the needs to support the decision-maker and to document the reasons behind decisions. For them, it is an advantage to solve both tasks using the same method. In their work, they presented a system "able to generate decisions for analysis, instead of relying on predefined input of options." They also presented an argumentation-based method for the decision-making process. The ability to generate decisions was inspired in the work proposed by Amgoud and Prade (2009) and the decision-making framework was created based on the work proposed by Dung (1995) (already described in this thesis). They considered a set of possible decisions and goals and, using argumentation, they created arguments in favor and against each decision. So, the best decision is the one that satisfies the most goals. Their collaboration with a company to carry out this work was without any doubt a great advantage, but, although their work has a strong relationship to industry, they did not present any validation.

Bonzon et al. (2012) presented in 2012 an extended abstract where they proposed a reasoning mechanism "that allows negotiating agents to take into account information about their counterparts." For them, there are many papers in literature related to agents that negotiate exchanging arguments, but only a few include knowledge about the opponents in the reasoning. They adapted a negotiation strategy used in a previous work to implement the new reasoning mechanism. Their approach is very simple: basically, each agent uses the partial knowledge it has on his opponents in order to find the best argument considering the opponent's argumentation theory. To validate their approach, the authors ran a great amount of experiments, where they compared the negotiation strategy with and without their approach. They concluded that the new approach improved the performance of the system (namely the length of the negotiation and the quality of the agreements).

Heras et al. (2013) proposed an argumentation framework for Multi-Agent Systems using case-based reasoning. In their framework, the agents use arguments to reach an agreement. During the dialogue, the arguments can be classified as acceptable, unacceptable, or undecided. They evaluated their system in terms of the knowledge the agents have about the social context of their partners, performance, percentage of agreement, and influence on the amount of argumentation knowledge of each agent. They concluded that arguments used by experts are usually preferred; agents using their argumentation framework usually provide more accurate solutions and achieve higher percentages of agreement compared to agents who do not use it; and the more knowledge an agent possesses about the context of the argumentation process, more number of agreements and of agreeing agents occurs. However, they also pointed to the fact that achieving a consensus could be difficult if the agents had the same amount of knowledge and therefore had the same persuasive power.

Fan and Toni (2013) introduced very interesting notions of dominant decisions: strongly dominant, dominant and weakly dominant. In this work, they presented two different frameworks for representing decision-making. In one of their frameworks they included the possibility to define preferences over goals. For them, the definition of preferences is important for the cases where a decision framework has only weakly dominant decisions but no dominant or strongly dominant decision. The main advantage of their work is the possibility to explain the selected decisions through argumentation-based justification. However, they considered important to continue the studies of decision-making with preferences. Another important conclusion to remember in the future is the necessity to study "decision-making in the context of multiple agents, in which agents sharing potentially conflicting knowledge and preferences".

Fan et al. (2013) published a scientific work about assumption-based argumentation for decision-making including preferences over goals. One of the most interesting features of this work is the possibility to define preferences over combined goals. For instance, it may be that A is preferred by both B and C, but C and B together are more preferred than A. Another important feature of this work is the easiness how it gives an argumentative justification for the selected decisions. The authors applied their approach to a case study in medical research and they obtained satisfactory results. They claim that their approach is easy to apply to other domains. In the future, they plan to develop a decision-making model to select the most suitable treatment for a patient, which in can bring important conclusive results to literature.

Fan et al. (2014) addressed another work about assumption-based argumentation. They consider that the majority of works related to argumentation-based decision-making found in literature do not pay attention to the decision-making amongst multiple agents. The main contribute of this paper is the way how it covers all the process: decision frameworks, argumentation-based computation, dialogues and a real-world application with implementation. The authors presented a two-agent decision-making model with argumentation dialogues, where the agents try to make informed decisions by using information provided by both agents. During the decision-making process, each agent constructs an assumption-based argumentation framework. This framework is created according to their particular decision framework. A decision framework is what describes the agent's own decisions, attributes, goals and relationships. After that, an assumption-based argumentation dialogue is performed between the two agents. The authors concluded that successful dialogues generate good decisions. As for future work, they remark the intention to study: the agents' preferences; a different way to represent the knowledge, making it more flexible; the decision-making in the context of game theoretical, considering non cooperative agents; and finally, they intend to expand their dialogue model in order to support more agents.

Marey et al. (2014a) published a paper where they included the uncertainty in argumentation-based negotiation. This work came in the sequence of the one presented in Marey et al. (2014b), where they introduced two types of agents' uncertainty: Type I and Type II. Type I is the "agent's uncertainty about selecting the right moves during the dialogue" and Type II is "the agent's uncertainty that the selected move will be accepted by the addressee". In Marey et al. (2014a), they studied the agents' uncertainty about the moves exchanged in a dialogue game and their acceptance. They conducted a case study (buyer/seller scenario) based on their proposed approach and concluded that with their techniques the negotiating agents achieve better results than the others. They claim that this work was the first in literature to deal with the agents' uncertainty in the context of argumentation-based negotiation.

Brewka et al. (2014) presented a fairly recent paper that discusses the generalizations currently available in Dung's framework. As was referred before in this document, also for them, "Phan Minh Dung introduced what are currently the most prominent abstract systems for argumentation". Their work is very complete and interesting, describing the frameworks and adding some very important opinions in the middle. Although the purpose of this work is not to present or extend a new framework, their analysis of existing frameworks is very relevant to the state of the art here presented. They described the preference-based argumentation framework (PAF) and they claim that this framework, including the preferences, permits to more accurately model the problem. They also described the valued-based framework (VAF) which is related to PAF. They even affirm that the Trevor Bench-Capon's valued-based argumentation frameworks are based in similar ideas (Bench-Capon, 2002). They considered important to have frameworks that allow arguing about preferences and not just with preferences (PAF and VAF). For them, this knowledge led to the appearance of extended argumentation frameworks (EAF). The EAF permits an argument to attack not only other arguments but also other attacks. They also described the bipolar argumentation frameworks (BAF). While the previous frameworks only consider a single relationship between arguments, in BAF both relations are modeled. Finally, they described the abstract dialectical frameworks (ADF). The big difference of ADF is to allow not only abstract arguments, but also abstract relations. As for future work, they considered important to continue the research on ADF semantics and start exploring the possibility to switch the language of the acceptance conditions.

Sklar et al. (2016) conducted a study in order to evaluate the effectiveness of "ArgTrust". The "ArgTrust" is an interactive application developed to help human users in the decision-making process (Parsons et al., 2013). In this work, they tested the "ArgTrust" in an ambiguous and complex scenario, where participants completed pre-, mid- and post-surveys based in their understanding about a certain scenario, before and after using "ArgTrust". The major conclusion is that "ArgTrust" has contributed to help users "consider their decisions more carefully".

Wyner (2016) presented a notable work about abstract argumentation and argumentation schemes. The idea was to integrate the argumentation schemes with abstract argumentation through a functional language. In order to contextualize this work, let's consider argumentation schemes as forms of argument that capture stereotypical patterns of human reasoning and abstract argumentation as a group of atomic arguments used by argumentation frameworks to formalize relationships between arguments. He developed a functional language for the computational analysis of argumentation schemes that is compatible with his argumentation framework. However, he did not run any tests yet but they intend to "implement argumentation schemes in a database for web-based applications and Functional or Logic Programs that instantiate the argumentation schemes, as well as to generate arguments, calculate attacks, and determine extensions". They also want to expand their research to relate argumentation schemes to semantic models, critiques and dialogue.

2.3.5 *Summary and Discussion*

There are several negotiation models adapted to group decision-making in literature (Ito and Shintani, 1997; Karacapilidis and Papadias, 1996, 2001; Marreiros et al., 2010). However, the existing models are limited to very specific contexts. Looking for studies on argumentation-based negotiation models adapted to group decision support systems, the results are practically inexistent. The few existing results are old and if some seemed promising in the way they could be adapted to this area (Kraus et al., 1998; Sierra et al., 1997), the works that came next followed most of the times another path (even with some of them remaining within decision support). Forgetting negotiation models for a moment, we find that even some of the existing argumentation approaches are not oriented to problems that include multiple agents simultaneously. It is even possible to verify that in the most recent argumentation studies, authors with some decades of work, point the inclusion of multiple agents as a future expansion for their work (Fan et al., 2014). When agents have "one-to-one" communication the process is simpler. However, things become more difficult when an agent receives messages from multiple agents. Another important issue is how authors test their argumentation models, the majority opt for the "seller-buyer" example (Rahwan et al., 2003; Karunatillake and Jennings, 2004; Ramchurn et al., 2006; de Melo et al., 2011; El-Sisi and Mousa, 2012; Marey et al., 2014a), which has a type of dialogue much oriented to that kind of problem.

Defining a type of adaptable dialogue for use in an argumentation-based negotiation model which has the objective to support group decision-making is a complex task. Walton and Krabbe (1995) believes that dialogues should be classified based in their primary objective, and presents 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 to solve a certain problem, but at the same time satisfy their own objectives? Maybe a mix of several types of dialogues or the creation of a new class could be the solution. This makes the adaptation of argumentation theory to this scenario a very complex task.

Another key issue in the inclusion of automated intelligent negotiation mechanisms in the context of group decision-making is related to the ability of an agent to understand or not the preferences of other agents. The ability to understand the context and the arguments are not (in this case) related to natural language. The idea is to have an agent intelligent enough to understand why a participant prefers a certain alternative and associate it with the criteria evaluation performed by him.

As already mentioned in this thesis, most of the decisions made nowadays are in groups. Contrary to what may seem in this section, decisions are made in group with the objective of adding knowledge and cognitive capabilities to problem solving (the number of decision-makers does not have the objective of generating confusion). A participant (a company employee) in a complex process of group decision-making, even initiating the meeting with his convictions and seeking to defend his interests, during the process tries to understand the choices and preferences made by other participants. The possibility to destroy his own arguments with the arguments used by other participants, causes the participant to change his preferences or create new arguments based in the new information.

3 PUBLICATIONS COMPOSING THE DOCTORAL THESIS

If I have seen further than others,
it is by standing upon the shoulders of giants.

— Isaac Newton

This chapter presents the set of publications that have been selected to integrate this document. This chapter is composed of 6 publications that cover different parts of the work done. All publications are preceded by a table which presents all the information regarding it.

3.1 INTELLIGENT NEGOTIATION MODEL FOR UBIQUITOUS GROUP DECISION SCENARIOS

Title	Intelligent negotiation model for ubiquitous group decision scenarios
Authors	João Carneiro, Diogo Martinho, Goreti Marreiros, and Paulo Novais
Publication Type	Journal
Publication Name	Frontiers of Information Technology & Electronic Engineering
Publisher	Springer
Volume	17
Number	4
Pages	296-308
Year	2016
Month	April
Online ISSN	2095-9230
Print ISSN	2095-9184
URL	https://link.springer.com/article/10.1631/FITEE.1500344
State	Published
Scimago journal rank (2016)	0.232, Computer Networks and Communications (Q3), Electrical and Electronic Engineering (Q3), Hardware and Architecture (Q3), Signal Processing (Q3)
JCR impact factor (2016)	0.622, Information Systems (Q4), Software Engineering (Q4), Engineering - Electrical & Electronic (Q4)

Contribution of the doctoral candidate

The doctoral candidate, João Miguel Ribeiro Carneiro, declares to be the main author and the major contributor of the paper *Intelligent negotiation model for ubiquitous group decision scenarios*.

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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

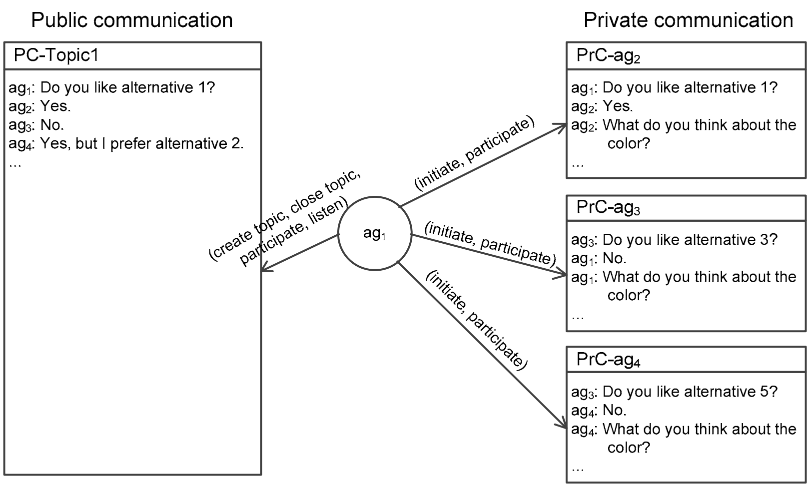

Fig. 1 Two different types of communication

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 $\forall c_i \in C$, $i \in \{1, 2, \dots, n\}$, 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 ($a_i=\{n_{a_i}, [c_{1_{a_i}}, c_{2_{a_i}}, \dots, c_{n_{a_i}}]\}$), where $\forall a_i \in A$, $i \in \{1, 2, \dots, m\}$ n_{a_i} is the name of a particular alternative and $[c_{1_{a_i}}, c_{2_{a_i}}, \dots, c_{n_{a_i}}]$ 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 $i \in \{1, 2, \dots\}$, 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 $c_i \subset \text{Var}_{l_i}$, 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 $n_{c_{\mathrm{ag}_j}}$ belonging to C_{ag_j} and alternatives $n_{a_{\mathrm{ag}_j}}$ belonging to A_{ag_j} can initially use $n_{l_{\mathrm{ag}_j}}$ locutions where

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

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 $n_{c_{\mathrm{new}_{\mathrm{ag}_j}}}$ belonging to $C_{\mathrm{new}_{\mathrm{ag}_j}}$ and $n_{a_{\mathrm{new}_{\mathrm{ag}_j}}}$ belonging to $A_{\mathrm{new}_{\mathrm{ag}_j}}$. $n_{l_{\mathrm{new}_{\mathrm{ag}_j}}}$ will be

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

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

$$\begin{aligned} n_{l_{\mathrm{max}_{\mathrm{ag}_j}}} = & \sum_{i=0}^{n_{c_{\mathrm{max}_{\mathrm{ag}_j}}}} L_{\mathrm{s}_{c_i}} + \sum_{i=0}^{n_{a_{\mathrm{max}_{\mathrm{ag}_j}}}} L_{\mathrm{s}_{a_i}} \\ & + L_{\mathrm{ge}_{\mathrm{Criterion}}} + L_{\mathrm{ge}_{\mathrm{Alternative}}} + L_{\mathrm{ge}_{\mathrm{Without\ Context}}}. \end{aligned}$$

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.

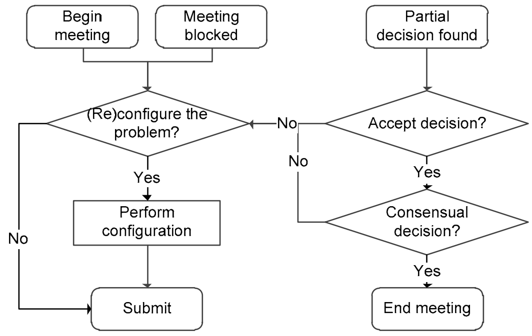

Fig. 2 Flowchart of a real participant (decision-maker)

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.

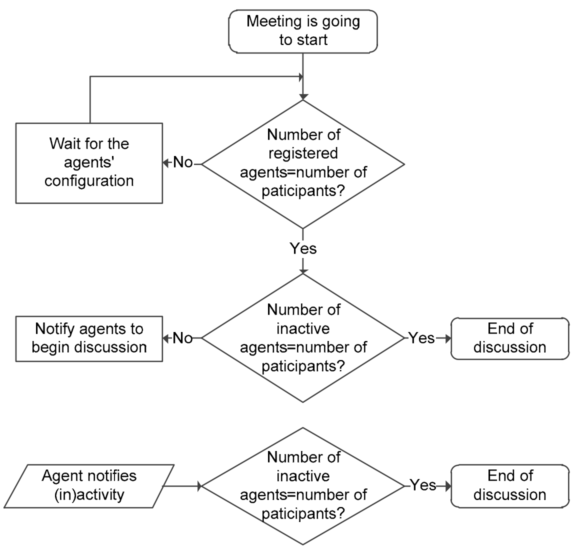

Fig. 3 Facilitator agent's flowchart

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.

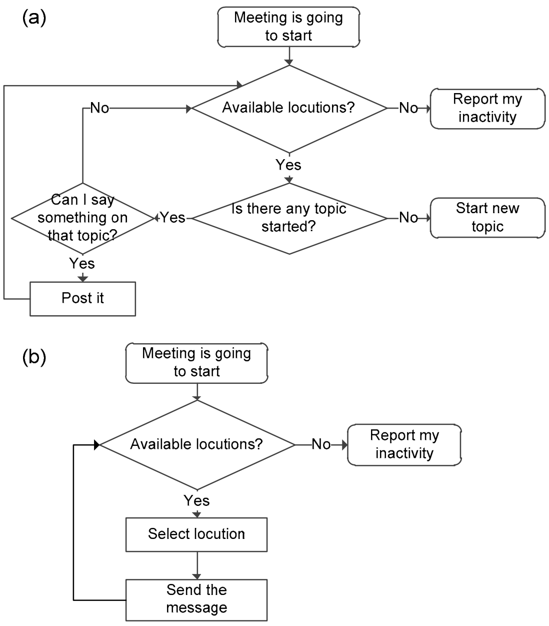

Fig. 4 Participant agent's flowchart for public conversations (a) and private conversations (b)

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.

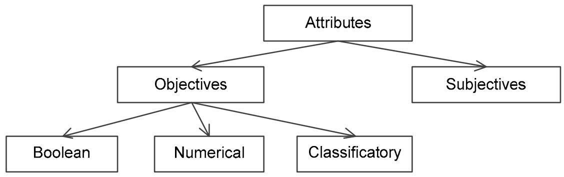

Fig. 5 Attribute types

(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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3.2 REPRESENTING DECISION-MAKERS USING STYLES OF BEHAVIOR: AN APPROACH DESIGNED FOR GROUP DECISION SUPPORT SYSTEMS

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Representing decision-makers using styles of behavior: An approach designed for group decision support systems

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Abstract

Supporting decision-making processes when the elements of a group are geographically dispersed and on a tight schedule is a complex task. Aiming to support decision-makers anytime and anywhere, Web-based group decision support systems have been studied. However, the limitations in the decision-makers' interactions associated to this scenario bring new challenges. In this work, we propose a set of behavioral styles from which decision-makers' intentions can be modelled into agents. The goal is that, besides having agents represent typical preferences of the decision-makers (towards alternatives and criteria), they can also represent their intentions. To do so, we conducted a survey with 64 participants in order to find homogeneous operating values so as to numerically define the proposed behavioral styles in four dimensions. In addition, we also propose a communication model that simulates the dialogues made by decision-makers in face-to-face meetings. We developed a prototype to simulate decision scenarios and found that agents are capable of acting according to the decision-makers' intentions and fundamentally benefit from different possible behavioral styles, just as a face-to-face meeting benefits from the heterogeneity of its participants.

Keywords: Group decision support systems; Styles of behavior; Cognitive agents; Affective computing

1. Introduction

It is a given that in organizations most decisions are group decisions (Lunenburg, 2011). There are 2 main reasons: on the one hand, most of the current organizations organigrams involve several decision-makers (Luthans, 2010), both at the strategic (Eisenhardt & Zbaracki, 1992) and at the technical level (Montoya-Weiss, Massey, & Song, 2001), and on the other hand, deciding as a group can potentiate the decision quality (Dennis, 1996; Hill, 1982; Huber, 1984). Group Decision Support Systems (GDSS) have been widely studied throughout the last decades (DeSanctis & Gallupe, 1984, 1987; Gray, 1987; Marakas, 2003) to support this type of decisions. However, in the last ten/twenty years, we have seen a remarkable change in the context where the decision-making process happens, particularly in large organizations (Chen, Liou, Wang, Fan, & Chi, 2007; Grudin, 2002). With the

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emergence of global markets, the growth of multinational organizations and a globalist view of the planet, we can easily have decision-makers (chief executive officers, managers and other members of global virtual teams) spreading around the world, across countries with different time zones (Shum, Cannavacciuolo, De Liddo, Iandoli, & Quinto, 2013). Moreover, to support the group decision-making process in this context is particularly complex, due to the decision-makers being geographically dispersed. This can lead to additional problems: failure to communicate and retain contextual information, unevenly distributed information, difficulty to communicate and to understand the salience of information, differences in the speed of access to information, and difficulty to interpret the meaning of silence (Bjørn, Esbensen, Jensen, & Matthiesen, 2014); and to deal with temporal issues, which can originate: ambiguity, conflicting temporal interests and requirements, and scarcity of temporal resources (McGrath, 1991). To provide an answer and operate correctly in this type of scenarios, the traditional GDSS have evolved to what we identify today as Web-based GDSS (Alonso, Herrera-Viedma, Chiclana, & Herrera, 2010; Kwon, Yoo, & Suh, 2005; Marreiros, Santos, Ramos, & Neves, 2010). The idea behind the Web-based GDSS is to support the decision-making process "anytime" and "anywhere" (Santos, Marreiros, Ramos, Neves, & Bulas-Cruz, 2006; Shim et al., 2002), and to help deal with some of the referred problems. Two main approaches have been implemented in GDSS to help with group decision-making processes. The classical approaches, based on preferences' aggregation, and the consensus-based approaches. The former consists in an aggregation phase, that combines the experts' preferences, followed by the selection of one alternative (Herrera, Martınez, & Sánchez, 2005; Saaty, 1988). The latter extends the former through an iterative process in order to achieve consensus (Fedrizzi & Kacprzyk, 1988; Iván Palomares & Martínez, 2014b).

When developing a Web-based GDSS it is necessary to be aware of the benefits inherent to group decision-making. A typical face-to-face meeting allows the decision-makers' interaction, exchange of ideas, work on new knowledge and intelligence generation (Dennis, 1996; Hill, 1982; Huber, 1984). In an ideal scenario, we can achieve some of these benefits using automatic negotiation models (for instance: argumentation-based negotiation models). However, there is much more besides the "messages" exchanged by decision-makers. It is necessary to work in the representation of those decision-makers. The representation can range from criteria's evaluation (for instance in a multi-criteria problem (Carneiro, Martinho, Marreiros, & Novais, 2015)) to a complete representation of the individual (personality, emotions, mood, etc. (Gmytrasiewicz & Lisetti, 2002; Raja & Srivatsa, 2006; Santos, Marreiros, Ramos, Neves, & Bulas-Cruz, 2009b)). The face-to-face meetings benefit from the decision-makers' heterogeneity (Hambrick, Cho, & Chen, 1996). This heterogeneity is related with the decision-makers' temperament but also with the decision-makers' intentions. Let us consider a scenario in which a medical team intends to choose a particular course of treatment for a patient whose condition calls for different areas of expertise. As in any other multi-criteria problem, each of the specialists, depending on their own background could have their own preferences over a number of possible alternatives, considering for instance, the order/timing of certain required interventions. However, each team member's opinion may be subject to a different appreciation, being judged for instance in terms of importance, rank, expert level or even based on implicit rules regarding their overall credibility. It is also conceivable that in some authoritative contexts the opinions of the highest graduated specialist may be taken as the rule of law, limiting any further suggestions once they are stated.

To model agents with human-like aspects is not new. At the start of the new millennium, some projects dealing with agents' humanization began to appear (André, Klesen, Gebhard, Allen, & Rist, 2000). Nowadays, there are many proposals that intend to model human characteristics in agents, such as: personality (Dimuro, da Rocha Costa, Gonçalves, & Hübner, 2007; Padgham & Taylor, 1997), emotions (Ball & Breese, 2000; Gmytrasiewicz & Lisetti, 2002), cognitive styles (Frank, Bittner, & Raubal, 2001), etc. There are also some few proposals under the topic of GDSS (Palomares, Martinez, & Herrera, 2014; Palomares, Rodríguez, & Martínez, 2013; Recio-García, Quijano, & Díaz-Agudo, 2013; Santos et al., 2009b). All of them share the idea that the inclusion of cognitive/affective aspects helps in some way the decision-making process. However, (to the best of our knowledge) most of them are oriented to be used in simulated environments. The usage of such techniques in real systems can bring some disadvantages. "A real me" can be a bad approach if my persona is less persuasive/intelligent/capable than others. An application that mimics one's limitation will be of lesser interest. Moreover, the inclusion of aspects such as personality, do not permit to reflect other aspects such as intentions and objectives. For each decision-maker the objectives and intentions can vary even for the same problem.

In this article, we propose a set of behavioral styles (Dominating, Integrating, Compromising, Obliging and Avoiding) to model agents that represent decision-makers in a group decision-making process. An agent modelled with each of these behavior styles is able to act following the intentions of the decision-maker it represents; The intentions may be for instance "preferring to please a group of other decision-makers", "preferring to dominate the course of the decision", "let people better positioned to lead the decision process", etc. The proposed behavioral styles act according to four dimensions deemed relevant in the context of group decision-making (Concern for self, Concern for others, Resistance to change and Activity level). Moreover, we introduce a communication model that allows agents to have dialogues that mimic the logic of communication existing in face-to-face meetings. Our research hypotheses are: (h1) it is possible for decision-makers to select behavioral styles to model computer agents in the context of group decision-making so that the behavior of the agents is as expected by the decision-makers; (h2) computer agents can act according to the style of behavior with which they are defined; (h3) a cooperative decision system that uses agents modelled with behavioral styles should be able to benefit from this heterogeneity and not present a biased functioning. In order to study h1, we carried out a survey with 64 participants to understand if the definition of the proposed behaviors has a homogeneous understanding on the part of the users and more importantly to find a homogeneous classification (numeric) of the behavioral styles in the proposed dimensions. To study h2 and h3, we have developed a prototype of a multi-agent system that includes a previously proposed argumentation-based negotiation (ABN) model for running simulations. In the developed prototype, the agents try to achieve the consensus through an iterative process (the ABN model used is fully described in Carneiro, Martinho, Marreiros, Jimenez, and Novais (2017)). We created different simulation environments with different numbers of agents in order to study the hypotheses. The proposed behavioral styles, as well as the proposed definitions, allowed us to find homogeneous operating values in the proposed dimensions. In turn, the agents have been able to represent the intentions associated with each style of behavior and to take advantage of their style of behavior just as face-to-face meetings take advantage from the heterogeneity of their participants.

The rest of the paper is organized in the following order: in the next section, we present several models (under the topic of psychology) that can be used by computer science scientists to model computer agents with human' characteristics/features. In Section 3, we expose the related work and in Section 4 we introduce the considered behavior styles and the dimensions in which they are defined. The study of operating values for behavior dimensions and their homogeneity is addressed in Section 5 and in Section 6 the agents are modelled with the proposed behavior styles and several experiments are performed. In Section 7 the discussion is presented. Finally, some conclusions are taken in Section 8, along with the work to be done hereafter.

2. Literature review

In this section, we put forward some models that can be used by computer scientists to model agents with typically human characteristics. A current problem in the humanization of agents is related to the lack of knowledge there still is about human psychological functioning, and perhaps ever more so regarding the formalization of such knowledge. This problem often leaves computer scientists prone to devise strategies that would still benefit from stronger scientific validation. In this regard, a greater investment in multidisciplinary teams becomes of uppermost importance. Next, we advance some models that, in our view, show the potential of being adapted to computational systems, regardless of whether they are simulators or real systems.

Kilmann and Thomas (1975) based on Jung's studies and a conflict-handling mode proposed by Blake and Mouton (1964), suggested a model for interpersonal conflict-handling behavior, defining five modes: competing, collaborating, compromising, avoiding and accommodating, according to two dimensions: assertiveness and cooperativeness.

As seen in Fig. 1, both the dimensions of assertiveness and cooperativeness are related to the integrative and distributive dimensions as discussed by Walton and McKersie (1965). Integrative dimensions refer to the overall satisfaction of the group involved in the discussion while the distributive dimension refers to the individual's satisfaction within the group. It is possible to see that the thinking-feeling dimension maps onto the distributive dimension while the introversion-extraversion dimension maps onto the integrative dimension. This association becomes more evident if we conceive competitors as the ones who seek the highest individual satisfaction and collaborators as the ones who prefer the highest satisfaction of the entire group. On the other hand, avoiders, do not worry about group satisfaction and accommodators do not worry about individual satisfaction. They also concluded that the thinking-feeling dimension did not move towards the integrative dimension, and that the introversion-extraversion did not overlap with the distributive dimension.

McCrae and John (1992) proposed a set of thirty traits extending the five-factor model of personality (OCEAN model). Based on the most commonly accepted Big Five "buckets of traits", Costa and McCrae (1992) presented a model that comprises the dimensions of: (a) Negative Emotionality: as an individual's susceptibility to negative

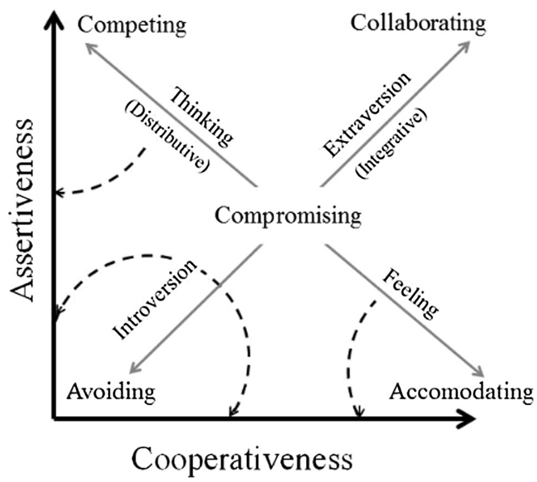

Fig. 1. Thomas and Kilmann's model for interpersonal conflict-handling behavior, adapted from Kilmann and Thomas (1975).

emotions and a general discontent with life; (b) Extraversion: broadly taken as the number of relationships with which one is comfortable; (c) Openness: referring to the number of interests, i.e., the variety and depth of information one is to prone to explore; (d) Agreeableness: measured by the one's willingness to takes norms for behavior while deferring to figures of authority; and (e) Conscientiousness: resulting from the number of goals on which one is focused, where an high consciousness level means to be able to focus on a limited number of goals and to exhibit a high self-discipline. The traits then included six facets for each of the factors described above. These traits were used in a study made by Howard and Howard (1995) in order to help them separate different kinds of behavior styles and identify corresponding themes. A theme is defined as "a trait which is attributable to the combined effect of two or more separate traits". Those styles and themes are based on common sense and general research, and can be inferred such as the conflict styles that were proposed, (Negotiator, Aggressor, Submissive and Avoider), however it is also important to refer other relevant styles that were suggested such as the Decision and Learning styles. Decision style includes the Autocratic, Bureaucratic, Diplomat and Consensus themes while Learning style includes the Classroom, Tutorial, Correspondence and Independent themes.

Rahim (1983) created a meta-model of possible styles for handling interpersonal conflict based on two dimensions: Concern for self and Concern for the other. Later, Rahim and Magner (1995) performed a study to assess the construct validity of the five subscales of the Rahim Organizational Conflict Inventory (Rahim, 1983). The styles defined by Rahim (1983) are presented in Fig. 2 and have been adapted to our problem. Rahim (1983) acknowledge the existence of 5 types of conflict styles: Integrating, Obliging, Dominating, Avoiding and Compromising. In this work, they suggested these styles as means to

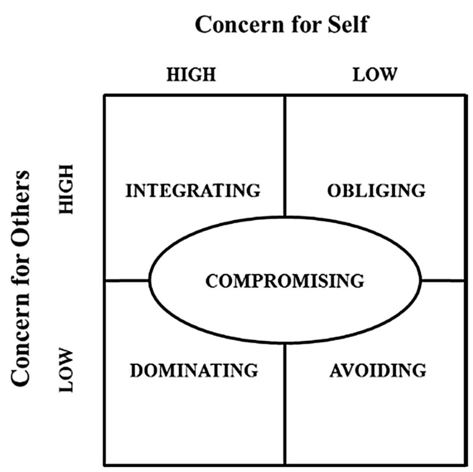

Fig. 2. Conflict Styles, adapted from Rahim and Magner (1995).

describe different possible ways of behaving in conflict situations. Their proposed styles are defined according to the level of concern an individual shows for achieving one's own goal or follow other people's objectives.

The model proposed by Rahim (1983) also relates to the themes identified by Howard and Howard (1995) to a certain extent. The Aggressor theme resembles the Dominating style; the Negotiator theme resembles the Integrating style; the Avoiding theme resembles the Avoider style; and the Submissive theme resembles the Obliging style. The main difference is the existence of the Compromising style in the model proposed by Rahim (1983) which does not relate to a specific theme. In theory, the Compromising style is an intermediate state between the other styles that were identified. It is worth noting that in psychological literature, depending on its scope, it is often not consensual even the mere definition of single behavior styles. For example, what we conceive as "avoidance" for the sake of the present study may not reflect the subtleties of the concept as proposed elsewhere. For instance, when it is presented as an attachment style and therefore rendered as multifold. We would then have to consider avoiders that do not care and also the anxious, preoccupied avoiders that do care but won't engage, for regarding their actions as not useful or even as detrimental to the task in hand (Fraley & Shaver, 2000). Certainly, these examples and possible ramifications abound for all other behavior styles. Nonetheless we commit to Rahim's formulation as a basis for our work because, more than any other model, it has been largely grounded in organizational contexts, from which a great deal of his data has sprout. This too is our target of application.

3. Related work

In this section, we present some works in the field of computer science, which somehow deal with cognitive and/or affective aspects. We began by taking a more general approach and later focus on work in the area of decision support or recommendation systems.

To rephrase Doyle, Cummins, and Pollock (1991), AI is the discipline aimed at understanding intelligent beings by constructing intelligent systems. In 1998, Castelfranchi (1998) said "AI is the science of possible forms of intelligence, both individual and collective". In order to build intelligent systems, it is therefore absolutely necessary to first know the human being (its functioning) in order to later be able to use this knowledge in the development of systems. Multi-agent systems have been widely used in the last decades (Cao, Yu, Ren, & Chen, 2013; Jennings, Sycara, & Wooldridge, 1998). The level of autonomy associated with agents, their abilities to interact/communicate, as well as their capability to exhibit "behaviors" are highly praised features in ever more distributed environments (Ito & Shintani, 1997; Jennings & Wooldridge, 1998; Van der Hoek & Wooldridge, 2008). Many approaches have been put forward in literature, where agents are defined with characteristics that set them apart from each other (Allbeck & Badler, 2002; Badler, Allbeck, Zhao, & Byun, 2002; Velsquez, 1997; Zamfirescu, 2003). Also under the topic of group decision-making several works with agents have been proposed (Aronson, Liang, & Turban, 2005; Olfati-Saber, Fax, & Murray, 2007), some of which used agents as a way to represent decision-makers/experts (Carneiro, Martinho et al., 2017; Palomares & Martínez, 2014b; Santos, Marreiros, Ramos, Neves, & Bulas-Cruz, 2009b). This representation of decision-makers allows the systems to become more intelligent and dynamic, given they are capable of dealing with aspects of great relevance in face-to-face type meetings. Zamfirescu (2003) proposed a model with two kinds of agents: interface agents and resources agents. Interface agents support each member that takes part in the meeting, including the group facilitator. Resources agents provide services for the rest of the system (communication services, decision support system services, and information recovery services). Iván Palomares and Martínez (2014b) used agents to represent experts. To minimize the needed interactions with the system, the experts can model the agent that represents them according to 1 of 3 profiles: sure profile, unsure profile and neutral profile (see below for a more detailed description). Santos, Marreiros, Ramos, Neves, and Bulas-Cruz (2009a) used agents to represent decision-makers and used the Five Factor Model to model the agents with different personalities: Aggressor, Submissive, Negotiator and Avoiding.

To model agents with human-like' aspects is not new. At the beginning of the new millennium, some projects related to the agents' humanization began to appear (André et al., 2000; Ball & Breese, 2000; Franklin, Kelemen, & McCauley, 1998).

Becker, Kopp, and Wachsmuth (2004) presented system that takes into account the emotions and mood of a conversational agent. Like most works since then, they use the OCC model by Ortony, Clore, and Collins (1990) to deal with emotions. The emotions are represented in an "emotion axis" and the mood in an "orthogonal axis" that stands for an undirected, longer lasting system state. In addition, they ponder "boredom" in order to deal with the absence of stimulus that the agent may face. In this way, they get the agent to express their emotional state according to the content of the conversation. They presented an experience in which the agent leaves the scene when it begins to feel insulted.

André et al. (2000) presented a paper where they describe the functioning of three projects that integrate life-like characters. They considered that the growth in the number of research projects related to humanization with the goal of make human-computer interaction more enjoyable had become noticeable. To make the psychological modeling of the agents they also used the OCC model (to model the emotions) (Ortony et al., 1990) and the Five Factor Model (FFM) (to model the personality) (McCrae & John, 1992). They stressed the importance of taking into account affective issues in user-agent interactions. However, they did not present any type of data that quantified how the models proposed by them allow to obtain more satisfactory utilization processes.

Gmytrasiewicz and Lisetti (2002) presented a research work where they included a formal definition of emotional states and personality in a typical rational agent design based on decision theory. This work is especially relevant due to the hypothesis put forward by the authors: "the main hypothesis of our work is that notions of personality and emotions are useful in designing competent artificial agents that are to operate within complex uncertain environments populated by other artificial and human agents". The authors used the OCC model (Ortony et al., 1990) to define the emotional states of the agents. Thus, they correlated these emotional states with different modes of decision-making. This means that each emotional state is associated with a decision-making situation. They also consider the personality of the agent, but do not use any specific personality model. They consider the personality of the agents as a set of emotional states the agent is capable of being in. Basically, the agents can vary their personality according to the three emotional states considered by them: cooperative, slightly annoyed and angry. The transitions that can occur between these states happen due to environmental inputs that they divided into 2 categories: cooperative and uncooperative. Although they point to several advantages and possible uses of the proposal, one cannot really say that there is a true verification of the research hypothesis. This can be seen in their own word, in the conclusions "we believe, will significantly enhance the applications of intelligent systems ...".

Lorini and Falcone (2005) presented work in which they deal with the expectations of pro-active agents. They point out that one of the most distinctive aspects of intelligent agents is that they are proactive, meaning that they have to be able to deal with the future and to represent that future or the possible future effects. For this, in this work they provide a precise characterization of anticipatory mental states, to analyze their role in the generation of Surprise, Relief and Disappointment. This allows the agents to have a clear comprehension of the surprise phenomenon. In addition, the proposed approach allows an $Agent_i$ that expects an $Agent_j$ to take an action that is negative for it, develops a negative strong expectation, causing it to persuade the $Agent_j$ to stop doing this action.

Nowadays, there are many proposals that intend to model human-beings' aspects in agents, such as: personality (Dimuro et al., 2007; Padgham & Taylor, 1997), emotions (Ball & Breese, 2000; Gmytrasiewicz & Lisetti, 2002), cognitive styles (Frank et al., 2001), etc. There are also some few proposals under the topic of GDSS (Ivan Palomares et al., 2014, 2013; Recio-García et al., 2013; Santos et al., 2009b). All of them share the idea that the inclusion of cognitive/affective aspects may somehow help the decision-making process. However, (to the best of our knowledge) most of them are oriented to be used in simulated environments. The usage of such techniques in real systems can bring some disadvantages. "A real me" can be a bad approach if my persona is less persuasive/intelligent/capable than others. No one will be interested in using an application that harms oneself. We will now present some recent proposals under the topic of decision-making that include agents and other important technical issues.

Miranda, Abelha, Santos, Machado, and Neves (2008) presented a scientific work where they developed a simulated medical practice scenario for intelligent decision support in the area of staging of cancer. The decisions were taken in the context of a group meeting in order to facilitate the collaborative work. They used agents that could exchange and store information to mirror real participants. The system emulated the TNM (Classification of Malignant Tumors) cancer staging system, increasing performance and eliminating paper circulation.

Santos et al. (2009b) presented a scientific work where they proposed a multi-agent architecture model designed to support groups in the decision-making process. The novelty of their work is the possibility to model the agent's personality. The idea is to humanize agents and with that, facilitate the negotiation process. They used four personality types (Negotiator, Aggressor, Submissive and Avoider) based on the Five Factor Model (McCrae & John, 1992) to define the agents' personalities. To select the agent's personality, each decision-maker needs to answer a questionnaire named Big Five Inventory (John, Donahue, & Kentle, 1991). They also proposed a simple negotiation model where the agents use the personalities to choose which kind of requests they should send and to process the received requests. The publication does not include any case study; however, the content is very interesting because the proposed model is based in strong assumptions existent in the literature.

Vallejo, Albusac, Castro-Schez, Glez-Morcillo, and Jiménez (2011) proposed a multi-agent architecture for supporting distributed intelligent surveillance based on a scalable normality analysis model. This scalable formal model, allows to define and identify the normality of an environment based in different issues (object speed, proximity relationships, etc). The proposed architecture is composed by three levels: reactive level, deliberative level and user level. The researchers implemented a prototype based on the proposed architecture to monitor a real urban traffic environment. The objective was to analyze the trajectories and speed of moving objects. They concluded that the use of normality analysis improves the flexibility of the proposed approach. In addition, they claimed that future systems based on this architecture can be easily extended when it is needed. They also stated that the proposed architecture meets some important surveillance requirements, such as scalability and robustness. Finally, the prototype was proven to work well when the number of situations is higher and the environments are tougher.

Palomares et al. (2013) presented a Web-based consensus support system that permits the integration of the decision-makers' attitude regarding consensus. They study the importance that decision-makers place in reaching consensus regarding the possibility of modifying their own preferences. Decision-makers can/adopt three attitudes: pessimistic, indifferent and optimistic. For example, a decision-maker who adopts an optimistic attitude, means that for him to reach the agreement is more important than his own preferences. In this way, the group's options will be given more importance. They argue that (as might be expected) optimistic attitudes help to reach consensus while pessimistic attitudes hamper the achievement of consensus.

Recio-García et al. (2013) presented a group decision support system where each decision-maker is represented by an agent who argues with the other agents in order to achieve the best alternative for the group. The presented negotiation model includes the users' social factors, personality and trust in the argumentative process. The personality of decision-makers is represented by a number ranging from [0,1] where 0 means a very cooperative person and the reflection of a very selfish one. To study the trust, they use the interaction of decision-makers in social networks through a set of 10 factors. For the argumentation model, they used D^{2}ISCO, which is a platform for the design and implementation of deliberative and collaborative CBR applications. They concluded that the proposed model allows to achieve better satisfaction rates when compared to the standard "fully connected" group recommender.

Abraham, Flager, Macedo, Gerber, and Lepech (2014) performed a study on the impact of using a Multi-attribute decision-making (MADM) techniques and data visualization methods in group decision-making processes as a way to help reaching consensus. The authors refer that despite the benefits of using this type of techniques being generally recognized, their true impact had never been previously discussed. In this study they performed four charrettes, in each of them participants were divided in teams ranging from 3 to 5 elements and the teams were divided into 4 groups. The 1st group had no access to MADM techniques nor to visualization methods, the 2nd group had access to MADM techniques but had no access to visualization methods, the 3rd group had no access to MADM techniques but had access to visualization methods and the 4th group had access to both. They concluded that the use of MADM methods helps the group to reach consensus, but more important they managed to understand that the use of visualization techniques helps decision-makers to show the clients the reasons for which a certain proposal is made.

Palomares and Martínez (2014b) presented a semisupervised consensus support system (CSS) based on the multiagent system paradigm. The main purposes are to overcome the difficulties associated with managing large groups of experts and the need for constant human supervision. In order to minimize the need for experts' interactions with the system, they defined a strategy that allows the experts to express their individual concerns. To do so, they defined three different profiles: sure profile, unsure profile and neutral profile. The first, intends to represent experts that are very confident about their preferences. Therefore, they do not intend to change them. The second, represents experts that want to achieve a consensus but are unsure about their opinions. The third, represent the experts that want to achieve a consensus and are moderately sure about their opinions. They conducted a case study made up by a set of experiments with the intent of understanding the different evolution of the degree of consensus between the proposed semisupervised CSS and a full-supervised CSS. They concluded that through the proposed system it was possible to minimize the need for expert human supervision and more importantly, they concluded that their proposal helps to achieve high levels of consensus faster than the full-supervised CSS.

Palomares and Martínez (2014a) published a very interesting work about a tool that aims to help the decision-makers to reach consensual decisions in urgent situations. To do so, they put forward a visual decision support tool that can represent the experts' preferences. This tool is based on Self-Organizing Maps and consists in a two-dimensional visual representation that allows to perceive the existing levels of agreement/disagreement. The preferences are visually represented based on their similarities. They developed an experiment to demonstrate the usefulness of the proposed tool, succeeding to demonstrate that the proposed tool may help decision-makers reach consensus more easily, as well as to have a better perception of the current status of the decision process.

4. Styles of behavior in the context of group decision-making

In order for decision-makers to choose a style of behavior that mirrors their intentions (to model the agent that represents them), first and foremost it is necessary to define the mode of action of each of the styles considered. The approach proposed in this work was based on the model proposed by Rahim (1983) and subsequently studied more thoroughly in Rahim and Magner (1995), for being the one we consider to be the most appropriate for the context of this work. As we saw earlier (Section 2), Rahim (1983) proposed 5 styles of handling interpersonal conflict (Dominating, Integrating, Compromising, Obliging and Avoiding). He differentiated the styles of handling interpersonal conflict along two basic dimensions: Concern for self and Concern for others. The Concern for self explains the degree (high or low) to which a person attempts to satisfy his or her own concerns. The Concern for others explains the degree (high or low) to which a person wants to satisfy the concerns of others (Rahim & Magner, 1995). These dimensions were considered to represent the motivational orientations of a given individual during conflict (Rahim & Magner, 1995).

In this work, as a first step, we take on the conflict styles proposed by Rahim (1983) and we call them behavior styles. The designation of behavior styles is preferred for expressing something more comprehensive that serves for example to define the activity level of the agent. In addition, the idea is that a decision-maker can select a behavior style for the agent that represents him/her in a context of group decision-making. This behavior may vary throughout the process, i.e., the decision-maker must be able to change the behavior of the agent whenever he/she sees fit. Also, we define each behavior style specifically for the context of group decision-making:

- **Dominating:** An individual functioning according to a Dominating style feels that he/she holds the key to the problem. The individual actively engages in the decision-making process and seeks to impose his opinion on others.
- **Obliging:** An Obliging functioning easily tends to yield his position to follow the interests of the group, choosing to follow the opinions of others instead of sharing his own.
- **Avoiding:** An Avoiding functioning is related to disengagement. Such an individual seeks not to be involved in decision-making, devaluing both the process and the opinion of all stakeholders.
- **Compromising:** A Compromising functioning privileges a collaborative style. It seeks to reach consensual decisions, valuing both their own opinions and those of others in the group. Here, the individual is moderately involved in the decision-making process.
- **Integrating:** An Integrating functioning privileges a collaborative style. It seeks to achieve consensual decisions, valuing both their own opinions and those of others very much. The individual prefers to manage the entire decision process in a highly committed manner.

As we mentioned earlier, Rahim (1983) used two dimensions (Concern for self and Concern for others) to differentiate conflict styles. Each style was rated in these dimensions according to 2 levels (Low or Mid). Later, in Rahim and Magner (1995), "there are 3 levels", since they consider "Compromising" as a style that "involves moderate concern for self as well as the other party involved in conflict".

In this work, we also consider the two dimensions proposed by Rahim (1983) to define agent behavior due to its high relevance in the context of group decision-making. However, to properly define the mode of action of each of the behavior styles in this context, these 2 dimensions are not sufficient. For this, we correlated the conflict styles proposed by Rahim (1983) with conflict styles proposed by Howard and Howard (1995) (see Table 1).

The conflict styles proposed by Howard and Howard (1995) are defined using 4 of the 5 factors of the Five Factor Model (McCrae & Costa, 1995). The factors used are: Negative Emotionality (N), Extraversion (E), Agreeableness (A) and Conscientiousness (C). Table 2 presents the classification of the conflict styles proposed by Howard and Howard (1995). A plus sign (+) indicates a score above 55; a minus sign (−) indicates a score below 45, and a letter with no plus or minus indicates a score in the 45–55 range.

Table 1
Proposed correspondence between Rahim's and Howard and Howard's conflict styles.

Rahim (1983)	Howard and Howard (1995)
Dominating	Aggressor
Integrating	Negotiator
Compromising	–
Obliging	Submissive
Avoiding	Avoider

Table 2
Conflict styles proposed by Howard and Howard (1995).

Theme	Components
Negotiator	N, E(+), A, C(−)
Aggressor	N+, E+, A−, C+
Submissive	N−, E−, A+, C−
Avoider	N+, E−, C−

The 45–55 range comprises one standard deviation in the middle/from the mean of the population.

Because Howard and Howard's conflict styles are classified in this way, it becomes possible to perceive/describe them through the facets that Costa and McCrae (1992) defined for each factor. Table 3 presents a small example of some of the facets related to the "Extraversion" factor. We can see that the conflict style "Aggressor" (see Table 2) can be described as: "prefers company", "a leader" and vigorous. On the other hand, the "Submissive" can be described as: "prefers alone", "in background" and "leisurely".

We use the facets proposed by Costa and McCrae (1992) to identify the remaining dimensions necessary to define our behavioral styles. The first dimension is that of "Resistance to change" which is related to the facets identified in the "Agreeableness" factor. The second dimension is that of "Activity Level" which has to do with the facets identified as the "Extraversion" factor. With our dimensions already identified we are now in position to describe them in this context of group decision-making.

- **Concern for self:** This dimension is concerned with how much the decision-maker values achieving his or her own goals. It directly influences the number of requests that will be made by the agent. An agent with a higher concern for self makes more requests to achieve his/her goals faster.

Table 3
Example of some of the facets related to the "Extraversion" factor.

Extraversion	Introvert (E−)	Ambivert (E)	Extravert (E+)
Gregariousness	Prefers alone	Alone/others	Prefers company
Assertiveness	In background	In foreground	A leader
Activity	Leisurely	Average pace	Vigorous
...	...	...	...

- **Concern for others:** This dimension is related to the extent to which the decision-maker values achieving the objectives of the group, or of a subgroup of decision-makers that he considers important/credible. An agent with a high degree of concern for others has a wider ability to accept certain types of requests.
- **Resistance to change:** This dimension is related to the ease with which the agent accepts requests. This means that an agent with a high resistance to change is much less able to accept requests than an agent with a low resistance to change.
- **Activity level:** This dimension is related to the level of participation of the agent in the process. An agent with a high level of activity level engages more in the process, carrying out more questions and affirmations/statements. On the other hand, an agent with a low activity level is less interventive, limiting himself to responding rather than starting new dialogue topics.

We present in Table 4 the classification of each of our behavioral styles in each of the dimensions identified. This classification is completely theoretical, based on the data found in the literature.

Seen that there is no conflict style in Howard and Howard (1995) equivalent to the "Compromising" conflict style in Rahim (1983), we assume that this behavior style in the dimensions of "Resistance to change" and "Activity Level" has a Moderate level. It is important to note that in this work and contrary to what happens in other works (Howard & Howard, 1995; Kilmann & Thomas, 1975; Rahim, 1983), we are not evaluating individuals themselves. We are grounding our study in already existing models to define behaviors in agents that represent people. This means that the important thing is for people to be able to understand a certain style of behavior in the same way when the style is to be selected. This means that if the population homogeneously considered the "Dominating" as having a low "Activity Level" low, it would not be problematic, as long as this understanding was identical.

5. Study 1

In this section, we intend to determine the operating values that can later be used to model our agents according to four dimensions: Concern for self, Concern for others, Resistance to change and Activity level. Based on these dimensions, we will be able to configure five behavior styles: Dominating, Integrating, Obliging, Compromising and Avoiding. In order to achieve this, first, as previously put forward in (h1) we needed to empirically validate the values that would correspond to each style of functioning. So, the step that follows implies asking a group of participants how do they perceive what is expected in terms of the behavior that each style would present in the context of group decision-making.

Table 4
Classification of behavioral styles in the considered dimensions (Low, Mid, High).

Styles of behavior	Concern for self	Concern for others	Resistance to change	Activity level
Dominating	High	Low	High	High
Integrating	High	High	Mid	Mid/High
Obliging	Low	High	Low	Low
Compromising	Mid	Mid	Mid	Mid
Avoiding	Low	Low	Low	Low

5.1. Method

5.1.1. Participants

In this study participants were 64 adults, 39 men and 25 women, aged between 19 and 68 years old ($M = 33.56$; $SD = 10.84$) all of which either had higher education degrees or were undergraduate students (10%). In respect to their fields of expertise, respondents were professionals from a wide variety of backgrounds, ranging from technology to social sciences. In Fig. 3 we present their distribution.

5.1.2. Procedure

In this study, participants were asked to classify the five proposed behavior styles in four dimensions: (a) Concern for self; (b) Concern for others; (c) Resistance to change; (d) and Activity level in a questionnaire ranging from 0 to 10 (by means of a visual analogic scale). All respondents were asked to fill out the questionnaire in the researcher's presence to ensure engagement in the task and/or to provide assistance in the clarification of concepts or modes of signaling the answers.

To define "Concern for self", participants were asked "how worried about achieving his/her own objectives" is each style of functioning; to define "Concern for others" they were asked "how worried about achieving other's objectives" do they consider each behavioral style to be; to measure "Resistance to change" participants were asked "how likely to resist change" do you think each behavioral style is; and to measure "Activity level" participants were asked "how interventive" do they consider each behavioral style to be.

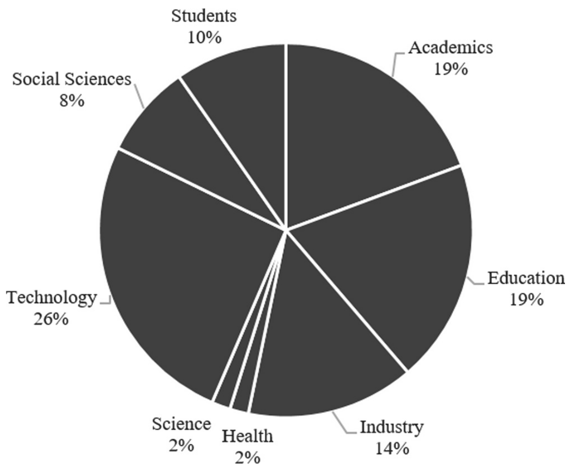

Fig. 3. Distribution of participants according to area of expertise.

To make it apprehensible, an example-situation was presented to the participants, concerning a hypothetical planning of a dinner (choosing a restaurant) in the context of a group.

Actual instructions read as follows:

The present study intends to contribute to the development of a tool that allows to assist several professionals in group decision-making processes. Each person will be represented by a virtual decision-maker – a "robot" – that acts according to a type of behavior he chose. You may think of him as if he was your "virtual assistant". This way you may choose your behavior style among multiple profiles and then delegate to him the function of making decisions on your behalf, in interaction with other agents either real or virtual.

For a better understanding, note the following example:

``Imagine that you worked in an organization and that your team would have to take part in choosing the restaurant where the Christmas dinner would be held. Certainly, there would be several possible options and also several criteria that would guide the discussion of the group, such as: the distance to the restaurant, the average price of the meal, the waiting time, the existence or not of a smoking area or even the desire to please the tastes of the team leader. Whatever the priorities might be, your assistant could represent you according to higher or a lower interest in forcing your position or let yourself be led by the opinions of others. Here are 5 types of functioning you could set for your assistant.''

After collecting the data from the 64 respondents, we could have values for mean and standard deviation for all four dimensions, which allowed us to compare each one according to all five behavior styles and also have numeric values for later use (in Study 2). Here, we present mean values and standard deviations for Concern for self (Fig. 4), Concern for others (Fig. 5), Resistance to change (Fig. 6) and Activity Level (Fig. 7).

5.2. Results

In this sub-section, we will report the values we obtained from our group of participants, that later will be used to

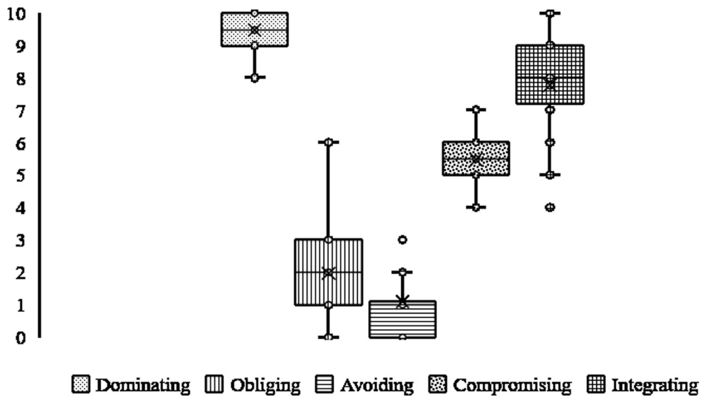

Fig. 4. Box plot of concern for self.

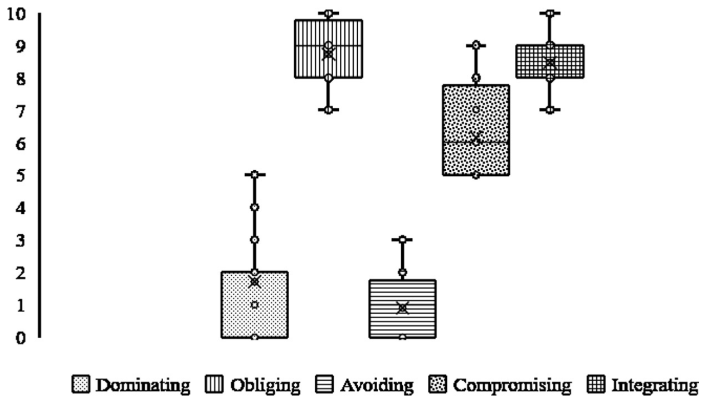

Fig. 5. Box plot of concern for others.

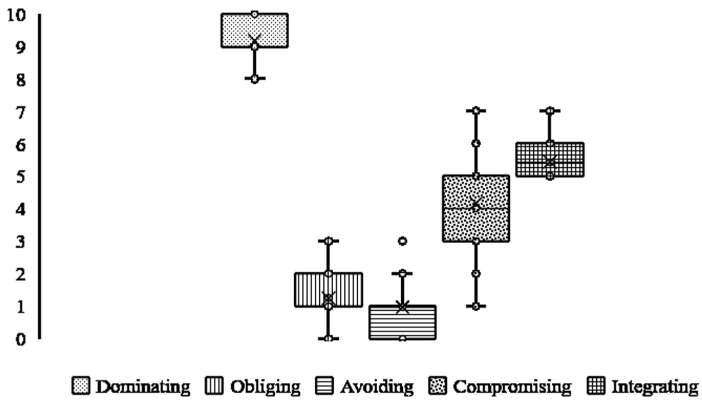

Fig. 6. Box plot of resistance to change.

model agents with the five behavior styles that we proposed. Values for each style will be grouped according to the four behavior dimensions that were evaluated.

Regarding the dimension Concern for self, the clearly highest scoring styles of behavior are Dominating ($M = 9.47$; $SD = 0.54$) and Integrating ($M = 7.77$; $SD = 1.43$), in this order. It is worth noting that when defining the values of Concern for self, participants showed more variability for the Integrating style. Then we have "medium" values for Compromising ($M = 5.48$;

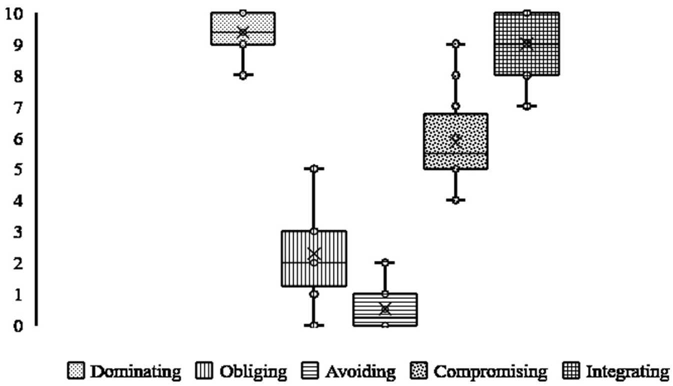

Fig. 7. Box plot of activity level.

$SD = 0.67$) and "low" and "very low" for Obliging ($M = 1.97$; $SD = 1.19$) and Avoiding ($M = 1.08$; $SD = 0.93$), respectively. We may be in the presence of a bottom effect regarding this dimension and style of behavior. In Fig. 4 we present the box plot of each style of behavior regarding the dimension Concern for self.

Regarding the Concern for others dimension, there are clearly three high scoring styles of behavior, in a decreasing order: Obliging ($M = 8.73$; $SD = 0.97$), Integrating ($M = 8.46$; $SD = 0.81$) and Compromising ($M = 6.16$; $SD = 1.33$) and two (very) low scoring styles: Dominating ($M = 1.71$; $SD = 1.44$) and Avoiding ($M = 0.90$; $SD = 0.91$). In Fig. 5 we present the box plot of each style of behavior regarding the Concern for others dimension.

In the Resistance to change dimension, the Dominating style clearly stands out as the highest scoring style ($M = 9.16$; $SD = 0.71$). Then, in a decreasing manner, Integrating ($M = 5.43$; $SD = 0.49$) and Compromising ($M = 4.16$; $SD = 1.23$) score "medium" values, and Obliging ($M = 1.24$; $SD = 0.82$) and Avoiding ($M = 0.96$; $SD = 0.88$) present "low" values. In Fig. 6 we present the box plot of each style of behavior regarding the Resistance to change dimension.

The highest values found for the dimension of Activity level are those of the Dominating ($M = 9.38$; $SD = 0.63$) and Integrating ($M = 9.00$; $SD = 0.87$) styles. Compromising ($M = 5.84$; $SD = 1.30$) has a "medium" value and both Obliging ($M = 2.28$; $SD = 1.28$) and Avoiding ($M = 0.52$; $SD = 0.59$) styles present a "low" activity level. In Fig. 7 we present the box plot of each style of behavior regarding the Activity level dimension.

With the purpose of assessing the consistency/reproducibility of the measurements made by our participants, next we present Intraclass Correlation Coefficient (ICC) for each of the behavior dimensions studied. For all dimensions results are above 0.900, more precisely between 0.915 and 0.941 so the agreement level can be considered excellent by any standards, for example Cicchetti (1994). We also can see that in all dimensions, results are highly significant ($p < 0.001$). In sum, these results show that our participants highly agree on how to define the dimensions of Concern for self, Concern for others, Resistance to change and Activity level both in magnitude in relative position across the five behavior styles. The same is to say that there is very high agreement on how to attribute different values according to the behavioral styles and also on how the 5 of them should be ordered within each of the 4 dimensions, which certainly may prove useful when presenting options for a problem/agent configuration. Table 5 presents ICC values for each dimension, with the responses of 64 participants for 5 behavior styles.

After what we presented for mean, standard deviation and ICC values, we are in position to state that we can safely rely on the attained values for their usage as operating values for the different styles of behavior. This way, we present in Table 6 average operating values for the 5 behavior styles so that they can be used in Study 2 as well as in future work that may rely on these variables.

6. Study 2

In this section, after having presented the attained operating values, we will assess whether computer agents can act according to the defined styles of behavior and if a group decision support system that uses agents modelled with behavior styles may benefit from their heterogeneity.

As we will see in Section 6.2, to run our experiments we implemented the argumentation-based negotiation model proposed in Joao Carneiro, Martinho et al. (2017), with a communication environment as proposed in Carneiro, Martinho, Marreiros, and Novais (2016b). However, for agents to have a social behavior equivalent to that performed by humans, it is necessary to define a correct communication flow. In a face-to-face meeting, decision-makers share the same space at the same time (DeSanctis & Gallupe, 1987). This means that when a decision-maker expresses himself/herself, whether it is verbal communication or otherwise, this communication is received by all other decision-makers at the same time. In a virtual environment, where agents communicate

Table 5
ICC values for each dimension.

Intraclass Correlation Coefficient – Concern for Self							
	Intraclass Correlation[b]	95% Confidence		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	927[a]	818	991	797.442	4	252	000
Average Measures	999[c]	997	1000	797.442	4	252	000
Intraclass Correlation Coefficient – Concern for Others							
	Intraclass Correlation[b]	95% Confidence		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	915[a]	791	989	744.848	4	252	000
Average Measures	999[c]	996	1000	744.848	4	252	000
Intraclass Correlation Coefficient – Resistance to change							
	Intraclass Correlation[b]	95% Confidence		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	938[a]	842	992	1017.069	4	252	000
Average Measures	999[c]	997	1000	1017.069	4	252	000
Intraclass Correlation Coefficient – Activity Level							
	Intraclass Correlation[b]	95% Confidence		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	941[a]	849	992	1026.275	4	252	000
Average Measures	999[c]	997	1000	1026.275	4	252	000

Two-way mixed effects model where people effects are random and measures effects are fixed.
[a] The estimator is the same, whether the interaction effect is present or not.
[b] Type A intraclass correlation coefficients using an absolute agreement definition.
[c] This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 6
Mean values of each behavior style in the four dimensions.

Behavior Style	Concern for self	Concern for others	Resistance to change	Activity level
Dominating	9.47	1.71	9.16	9.37
Obliging	1.97	8.73	1.24	2.28
Avoiding	1.08	0.9	0.96	0.52
Compromising	5.48	6.16	4.16	5.84
Integrating	7.77	8.46	5.43	9

simultaneously, this reception is not done at the same time due to technological limitations. This situation means that at certain moments of time there are agents who are in possession of knowledge that other agents still do not have, and can benefit from that prior knowledge unintentionally. Therefore, in this work we propose a communication flow that guarantees impartiality, promoting a type of interaction similar to that realized by real decision-makers, in face-to-face type meetings.

6.1. Communication flow

We assume that each decision-maker is represented in a GDSS by a participating agent (*AgP*). The participating agent seeks to represent the interests of the decision-maker. In addition, we also assume the existence of a facilitating agent (*AgF*). The *AgF* is responsible for managing the meeting, initiating/finalizing the process and managing/handling communications. In a simplistic way, the communication flow that we propose implements an acknowledgment mechanism that ensures the reception of the messages by the *AgP* before a new dialogue can be initiated.

In a first step the *AgF* notifies all *AgP* that the meeting started (Fig. 8 – Step 1). Then all *AgP* notify the *AgF* that they are ready to start the meeting (Fig. 8 – Step 2).

When the number of participating agents "Ready" equals the number of participants in the meeting process (see Fig. 12), *AgF* invites *AgP* to start a new dialogue topic (Fig. 9 – Step 3). *AgP* generate a participation time based on their style of behavior (if they have something to say, otherwise they return "No") and send it to the *AgF* (Fig. 9 – Step 4).

AgF (Fig. 9 – Step 4) selects the *AgP* that sent a higher participation time (of course, participating agents with a higher activity level are more likely to be selected). Then the *AgF* notifies all *AgP* about the *AgP* that was selected (Fig. 10 – Step 5). The selected *AgP* sends the message that

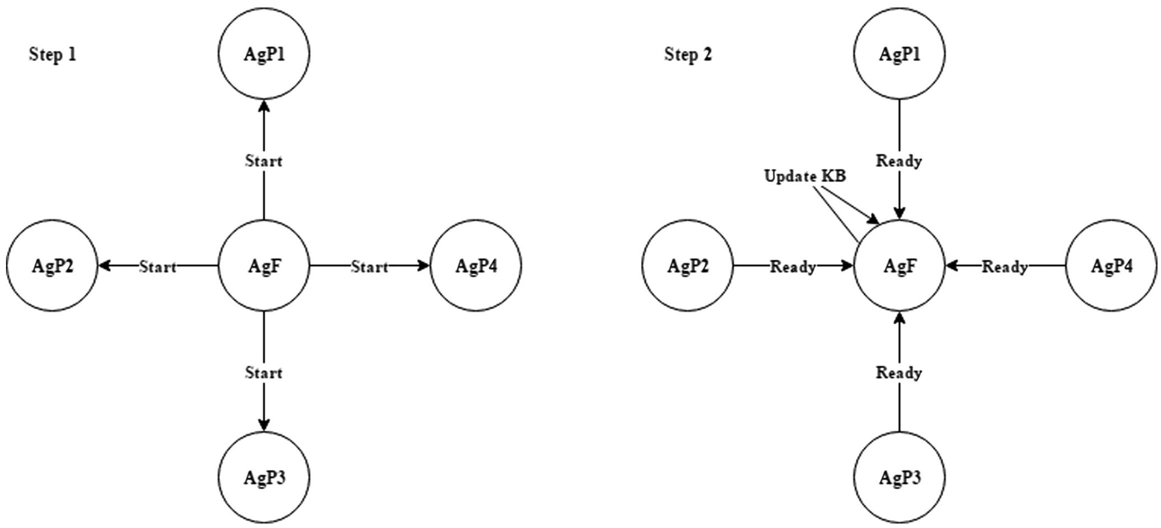

Fig. 8. Communication Flow's Step 1 and Step 2.

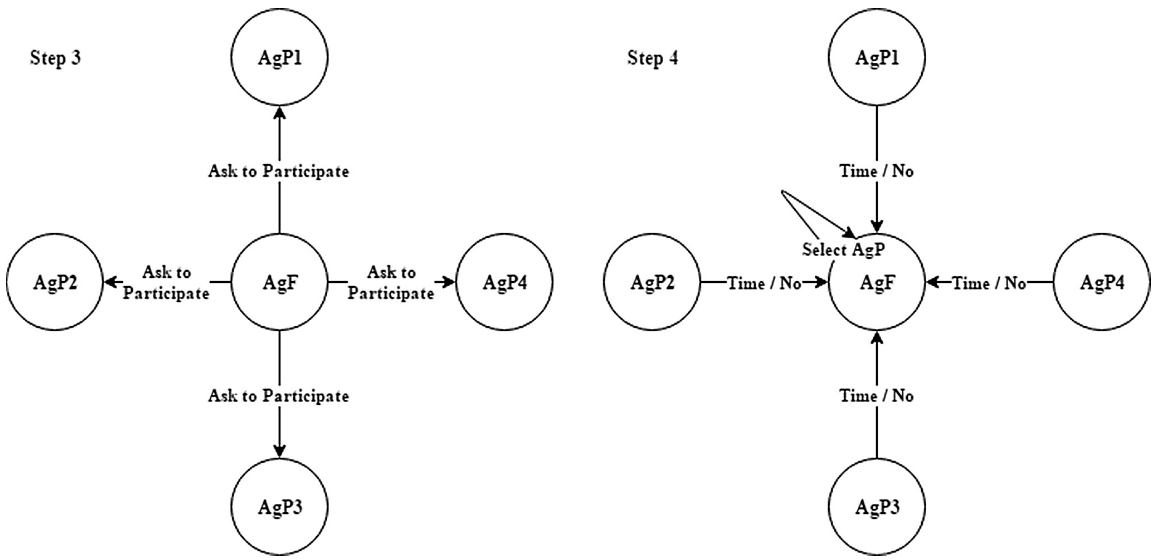

Fig. 9. Communication Flow's Step 3 and Step 4.

it wants to transmit to *AgF* and *AgF* spreads this message to all other *AgP* (Fig. 10 – Step 6).

All agents who have received the message may respond with a new Illocution or if they have nothing to respond they send an acknowledgment to notify the *AgF* that they have received $Illocution_x$ (Fig. 11 – Step 7). The first Illocution-type response that the *AgF* receives is sent to all *AgP* (repeating Step 6), causing all *AgP* that have responded to Step 7 with an Illocution to automatically know if the message being spread is theirs or not (Fig. 11 – Step 8). For each Illocution that *AgF* diffuses through *AgP* it expects to receive $n-1$ responses (Illocutions or acknowledgments), where n is the number of *AgP* involved in the decision process. In the case of Fig. 11 – Step 7, the *AgF* received 2 Illocution ($Illocution_y$ and $Illocution_z$) in response to $Illocution_x$. Therefore, *AgF* selects the Illocution it received first and sends this message to other *AgP* (Fig. 11 – Step 8). AgP_3 who had previously attempted to make a communication ($Illocution_z$) may try to send his message again if it still makes sense given the new knowledge it has received ($Illocution_y$). When for each Illocution sent, there are $n-1$ responses, the process returns to Step 3.

Now we will present the internal functioning of each of the agents involved in the process. As mentioned, the *AgF*

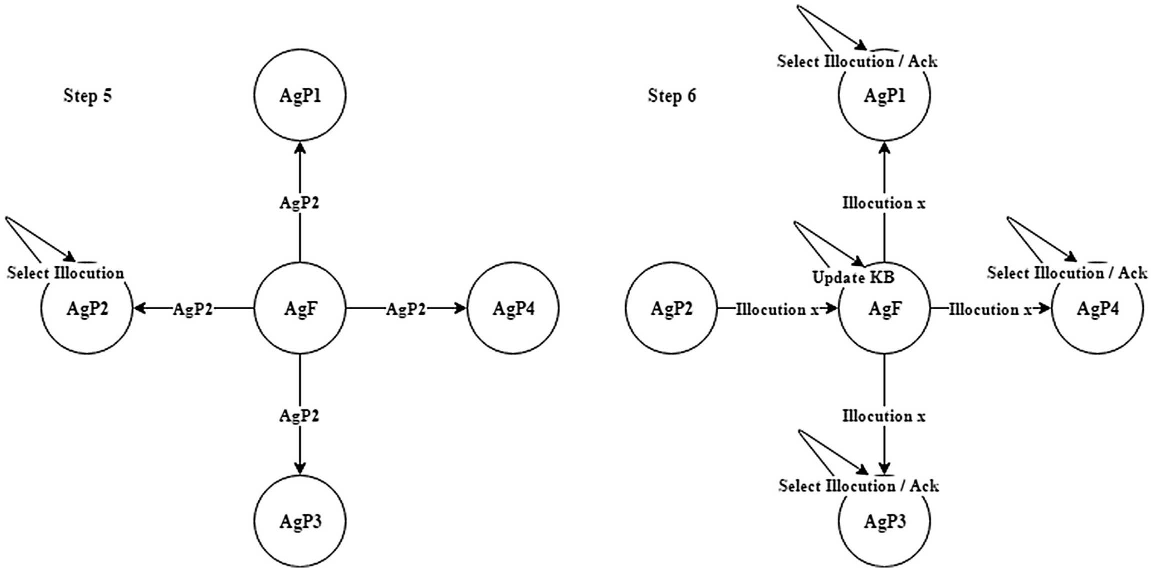

Fig. 10. Communication Flow's Step 5 and Step 6.

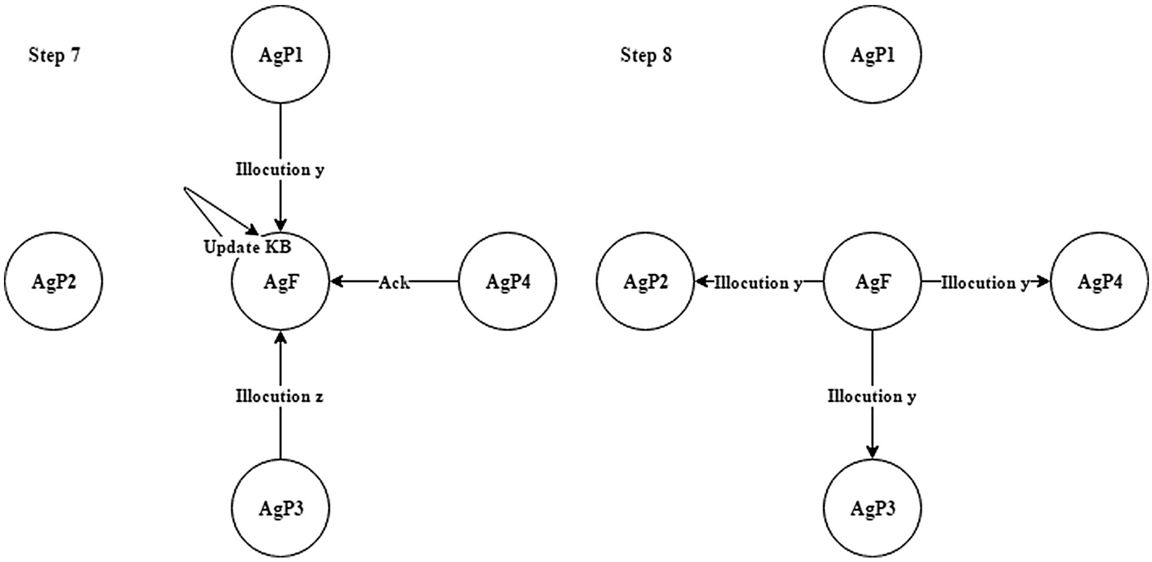

Fig. 11. Communication Flow's Step 7 and Step 8.

is responsible for "managing" the meeting. In this way, it is responsible for initiating/finalizing the process and managing the flow of communication. Fig. 12 shows the facilitator agent's flowchart. The *AgF* is responsible for initiating and terminating the decision process. Initially he starts by starting the meeting and expects all *AgP* to be ready. He then invites the *AgP* to initiate a dialogue and controls the flow of communication (as previously described). This process is repeated every time until one of two things happens: no participant agent wants to start a new dialogue or consensus has already been reached towards an alternative.

Participating agents represent decision-makers in this virtual environment. In the communication environment proposed in Carneiro et al. (2016b) and on the basis of which we rely, participating agents can conduct two types of conversations: public conversations (as previously described) and private conversations of type 1 to 1, which are used only for making requests. When a participating agent is notified by the *AgF* that the meeting will is about

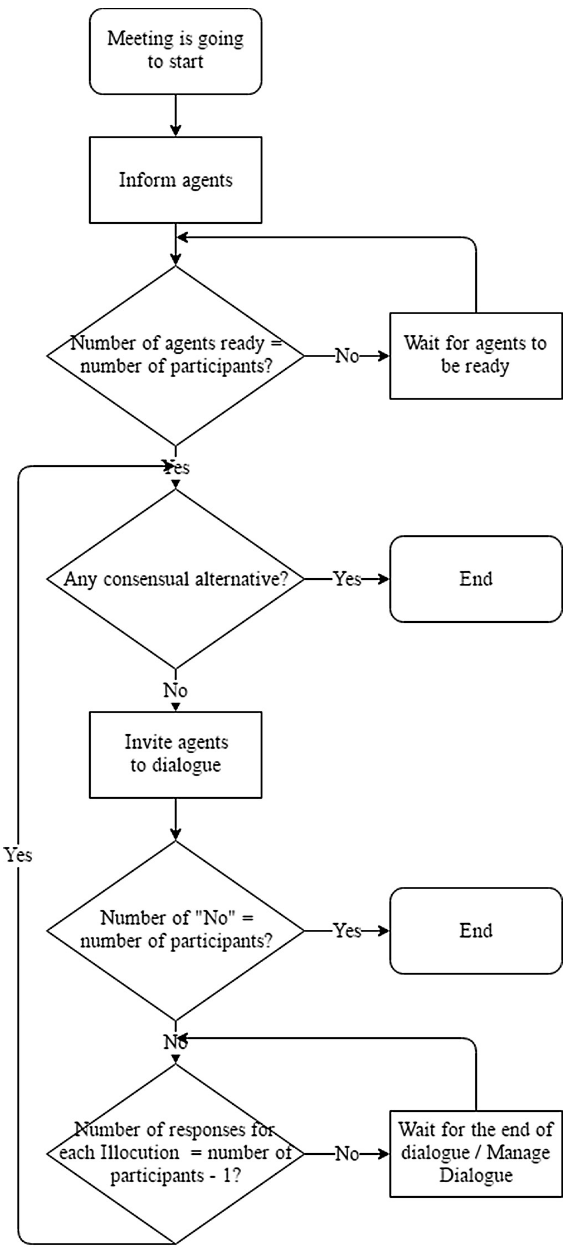

Fig. 12. Facilitator agent's flowchart.

to begin, the *AgP* will notify the *AgF* that it is Ready and sends back other information such as preferences and goals (Fig. 13). After the meeting has all the conditions to begin, *AgF* invites *AgP* to start a dialogue, each *AgP* checks if it has something to communicate, if it does, it generates a participation number based on its style of behavior (Fig. 13). If a certain *AgP* is selected to speak, it sends its message to the *AgF* otherwise it waits to receive a message (Fig. 13).

Finally (Fig. 14), when an *AgP* receives a new message it starts by checking which type of message, if it is a request (that is, it is a message from 1 to 1) it processes it and sends the response to *AgP* that had made the request. If it accepted the request, it will send a message to *AgF* to update it with his new preferences. If the message is not a request, it processes the message and checks if it has interest or conditions to respond to this message, if it does not send an "Ack" otherwise it sends a response. Each time an *AgP* receives a new message other than a request type message, it checks if this new information offers the conditions for it to make requests to other *AgP*, if this happens, it sends the requests (Fig. 14).

6.2. Experiment

Communication flow was created with the objective of studying two very concrete hypotheses. The first one (h2) is to understand if the agents can correctly represent the decision-makers taking into account the data obtained in experiment 1. This way, we intend to study if using a face-to-face decision scenario, agents can actually display behavior according to the modelled values (in each of the dimensions proposed in study 1). The second hypothesis (h3) is related to perceiving what kind of "impact" each of the proposed behavioral styles has. As mentioned earlier, given that this proposal has as its main objective to be applied in systems that are used in the real world by real decision-makers, it would not make sense to have a style of behavior that would always be benefited. It would not make sense for decision-makers to know that, in the end, whoever chooses a particular style of behavior always wins. That would not represent the heterogeneity of the world we live in. The point about representing the intentions of decision-makers through behavioral styles is that they may serve as an advantage for all decision-makers because they would be better represented in the system.

To perform our simulations, we used a prototype (previously developed) that uses a negotiation architecture based on social networks (Carneiro et al., 2016b) and implements the argumentation-based negotiation model proposed in Carneiro, Martinho et al. (2017).

To study (h2) we created 4 simulations environments, the first with 5 agents (1^{*}Dominating, 1^{*}Integrating, 1^{*}Obliging, 1^{*}Compromising, 1^{*}Avoiding) the second with 10 agents (2^{*}Integrating, 2^{*}Obliging, 2^{*} Compromising, 2^{*}Avoiding), the third with 20 agents (4^{*}Dominating, 4^{*}Integrating, 4^{*}Obliging, 4^{*} Compromising, 4^{*}Avoiding) and at last the forth with 40 agents (8^{*}Dominating, 8^{*}Integrating, 8^{*}Obliging, 8^{*} Compromising, 8^{*}Avoiding). We have created several simulation environments because we considered at the outset that because agents act using different behavioral styles, their behavior may vary according to the number of agents and the behavioral style of the other agents with which they are involved in the decision process. We used the multicriteria problem previously used in case studies as presented in Carneiro, Martinho,

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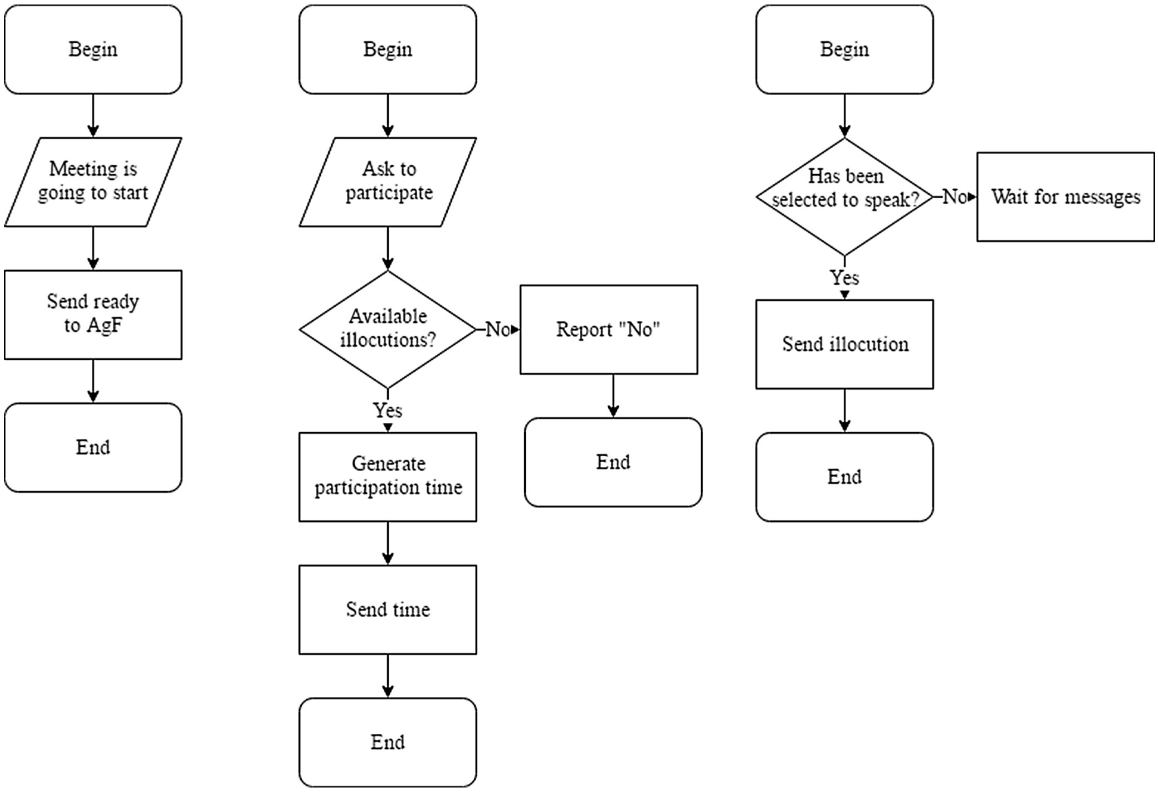

Fig. 13. Participant agent's flowchart.

Conceição, Marreiros, and Novais (2017), Carneiro, Martinho, Marreiros, and Novais (2016a) and each agent generated its preferences regarding the alternatives and criteria in a "random" way. Initially each agent randomly generated its preferences regarding the criteria and then, based on these preferences, it generated the preferences of the alternatives with a randomness that made would be plausible taking into account the values of the criteria of each alternative and preferences of previously generated criteria. For each simulation environment, we ran 100 simulations (100*4 in total).

Study of "Concern for self" dimension through the analysis of number of requests made by the agents.

To study the dimension of "Concern for self" we have analyzed the number of requests made by the agents of each behavior style. Table 7 presents data related to the analysis of Concern for self. The μ[0,1] represents the values obtained in experiment 1 relative to the dimension of "Concern for self" in each behavior style. G. represents the values μ[0,1] normalized on a scale of [0,1], where the sum of all values equals 1. The μ represents the average number of requests made by each style of behavior over the 100 simulations. The σ represents the standard deviation of the number of requests made by each style of behavior over the 100 simulations. The Min. is the minimum number of requests made and the Max. is the maximum number of requests made in the 100 simulations. P. represents the values of μ normalized on a scale of [0,1], where the sum of all values is equal to 1.

We can verify that in all simulation environments and as expected, agents with the "Dominating" behavior style are the ones that make the most requests. On the other hand, the agents that perform the least requests are the "Avoiding" style ones. We also found that the values of G. and P. are slightly different. However, this is because although agents with behavior styles such as "Dominating" and "Integrating" are more likely to make requests, this probability is also affected by the argumentation system used. In this case, using the one proposed in Carneiro, Martinho et al. (2017) they have a limited number of requests that can be made, which makes that in situations where agents do not quickly obtain consensus, these styles of behavior ("Dominating" and "Integrating") no longer have requests to make, causing agents with other styles to approach the number of requests made by them.

In order to study the dimension "Concern for others" we analyzed the number of appeal to prevailing practice accepted by the agents of each style of behavior. The appeal to prevailing practice was used to study the "Concern for others" dimension because the only situation in

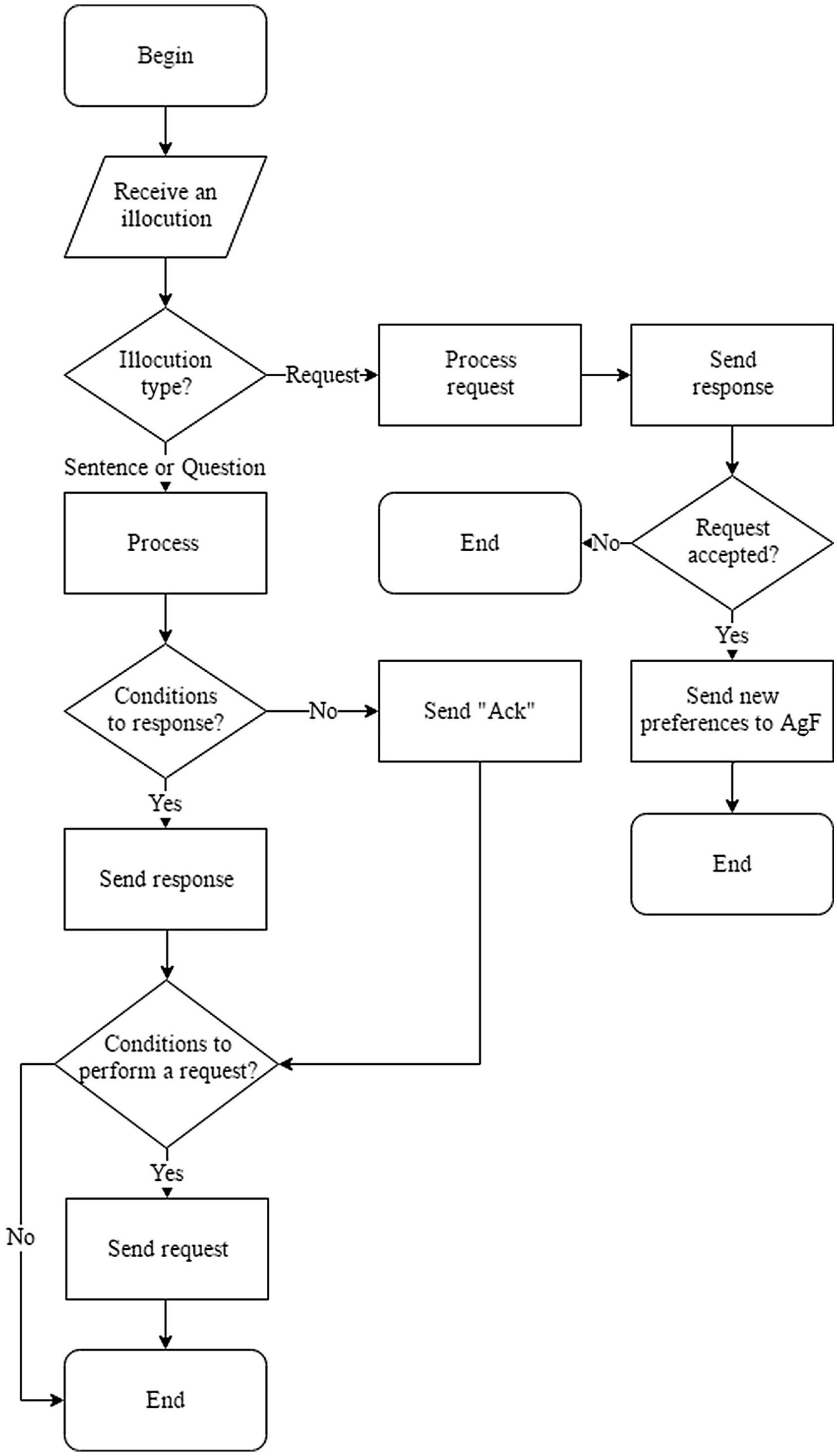

Fig. 14. Participant agent's flowchart.

Table 7
"Concern for self" dimension – number of requests made with n agents for the 5 behavior styles.

			Dominating	Integrating	Obliging	Compromising	Avoiding
		μ[0,1]	0.95	0.78	0.20	0.55	0.11
		G.	0.36	0.30	0.07	0.21	0.04
Concern for self	5 Agents	μ	12.65	11.91	7.96	10.72	7.2
		σ	4.89	4.67	2.66	3.81	2.79
		Min.	4	2	3	3	2
		Max.	27	24	15	23	15
		P.	0.25	0.23	0.15	0.21	0.14
	10 Agents	μ	43.99	40.03	27.06	35.85	23.54
		σ	11.64	9.97	5.05	8.03	4.41
		Min.	22	19	13	21	10
		Max.	74	74	43	59	38
		P.	0.25	0.23	0.15	0.21	0.13
	20 Agents	μ	118.69	110.74	75.19	103.06	64.89
		σ	28.93	24.61	12.07	21.08	10.15
		Min.	55	56	42	53	40
		Max.	214	183	118	186	99
		P.	0.25	0.23	0.15	0.21	0.13
	40 Agents	μ	305.75	282.32	186.30	256.97	160.98
		σ	62.86	55.65	22.93	42.64	19.47
		Min.	149	147	123	148	94
		Max.	499	540	268	381	227
		P.	0.25	0.23	0.15	0.21	0.13

which this dimension is used (according to the argumentation-based negotiation model implemented) is in the formula for evaluating this type of request. Table 8 presents data related to the analysis of "Concern for others".

The μ[0,1] represents the values obtained in study 1 relative to the dimension of "Concern for others" in each behavior style. G. represents the values μ[0,1], standardized on a scale of [0,1], where the sum of all values is equal to 1. μ represents the average number of common practices accepted by each behavior style over the course of the 100 simulations. The σ represents the standard deviation over the 100 simulations. The Min. is the minimum number of accepted requests and the Max. is the maximum number of requests accepted in the 100 simulations. P. represents the values μ of normalized on a scale of [0,1], where the sum of all values is equal to 1. In this case, we have verified that agents with the "Dominating" behavior style are the ones that accept fewer "common practices" requests. On the other hand, the agents who generally are more willing

Table 8
"Concern for others" dimension – number of appeals to prevailing practice accepted by n agents for the 5 behavior styles.

			Dominating	Integrating	Obliging	Compromising	Avoiding
		μ[0,1]	0.17	0.85	0.87	0.62	0.09
		G.	0.06	0.32	0.33	0.23	0.03
Concern for others	5 Agents	μ	0	0.09	0.16	0.11	0.19
		σ	0	0.28	0.36	0.31	0.39
		Min.	0	0	0	0	0
		Max.	0	1	1	1	1
		P.	0	0.16	0.29	0.20	0.34
	10 Agents	μ	0.015	0.11	0.17	0.09	0.11
		σ	0.12	0.31	0.41	0.30	0.31
		Min.	0	0	0	0	0
		Max.	1	1	2	2	1
		P.	0.03	0.22	0.34	0.18	0.22
	20 Agents	μ	0.01	0.08	0.18	0.09	0.07
		σ	0.11	0.28	0.42	0.30	0.26
		Min.	0	0	0	0	0
		Max.	1	2	2	2	1
		P.	0.02	0.18	0.40	0.21	0.17
	40 Agents	μ	0.008	0.09	0.17	0.06	0.06
		σ	0.09	0.30	0.39	0.25	0.27
		Min.	0	0	0	0	0
		Max.	1	2	2	2	2
		P.	0.02	0.23	0.41	0.16	0.16

to accept this type of request are the "Obliging". It is interesting to note that in the simulation environment with 5 agents, the "Avoiding" agents were the ones that most accepted this type of request, even though "Avoiding" had a low concern for others. However, this happens because the formula used to evaluate this type of requests, besides "Concern for others" also considers the agents' "Resistance to change", which in turn is known to be extremely low in the Avoiding. As shown in the 40 agent scenario, the values of G. and P. are quite similar, the existing difference is due to the fact that, in the acceptance formula for this type of requests, "Resistance to change" is considered as part of the agents' behavioral style.

To study the dimension of "Resistance to change" we analyzed the number of requests accepted by the agents of each style of behavior. Table 9 presents data related to the analysis of Resistance to change. The μ[0,1] represents the values obtained in study 1 regarding the dimension of "Resistance to change" in each of the behavior styles. A. represents the average percentage of accepted requests for each style of behavior. P. represents the values of A., standardized on a scale of [0,1], where the sum of all values is equals 1.

Irrespectively of the calculation the acceptance of any type of requests used in the argumentation-based negotiation model proposed in Carneiro, Martinho et al. (2017), and of having the agents expressing preferences for several alternatives and different criteria, it was verified that, in the long term, the values of G. and P. remain practically the same. The agents presented a resistance to change almost equal to that identified in study 1 for each of the behavior styles.

In order to study the dimension "Activity level" we analyzed the average number of statements and questions made by the agents of each style of behavior during the 100 simulations. Table 10 presents the data related to the analysis of "Activity level". The μ[0,1] represents the values obtained in study 1 regarding the dimension of "Activity level" in each behavior style. G. represents the values μ [0,1] normalized on a scale of [0,1], where the sum of all values equals 1. μ represents the mean number of statements and questions performed by each style of behavior over 100 simulations. The σ represents the standard deviation over 100 simulations. The Min. is the minimum number of interventions performed and the Max. is the maximum number of interventions in the 100 simulations. P. represents normalized values of μ on a scale of [0,1], where the sum of all values equals 1.

We have verified that in relation to the dimension of "Activity level" the values of G. and P. were very similar. It is interesting to note that as the number of agents was increased in the various simulation environments, the fact that there were several "Dominating" and "Integrating" agents in the same decision process led to the monopolization of the conversation by them.

To study (h3) we created 2 simulation environments where 5/12 agents sought to achieve consensus. We created groups of 5 simulations where in these 5 simulations each of the 5/12 agents always had the same preferences regarding the alternatives and criteria. In addition, 4/11 agents always maintained the same behavioral style and there was 1 agent (which was the target agent) that in each of the 5 simulations had each of the 5 possible behavior styles (without repetition). The idea was to compare each of the styles of behavior under the same context. Each group of 5 simulations was repeated 20 times, the difference from one group to another being that the agents generated new preferences for alternatives and criteria and the other 4/11 agents adopted a new behavioral styles (randomly). A total of 200 simulations were performed (2^*5^*20). To understand the impact of the decision on each of the agents, satisfaction was used as a metric, according to Carneiro, Santos, Marreiros, and Novais (2017). Satisfaction varies on a scale of [−1,1], where -1 means extremely dissatisfied and 1 means extremely satisfied.

Table 11 shows the average satisfaction and the standard deviation of the target agent using each behavior style in a simulation environment with 5 agents. We found that on average, satisfaction was higher using the "Dominating" behavior style, however, it was also with the "Dominating" behavior style that satisfaction showed the most variability. Through the use of the "Obliging" behavior style, the agent achieved on average the lowest satisfaction but also less variable.

Table 12 shows the number of times the target agent achieved more or less satisfaction in each of the groups

Table 9
"Resistance to change" dimension – number of requests accepted by n agents for the 5 behavior styles.

			Dominating	Integrating	Obliging	Compromising	Avoiding
		μ[0,1]	0.92	0.54	0.12	0.42	0.10
		G.	0.02	0.15	0.30	0.20	0.31
Resistance to change	5 Agents	A.	2.20%	9.81%	26.88%	14.66%	23.57%
		P.	0.02	0.12	0.34	0.19	0.30
	10 Agents	A.	0.71%	6.18%	11.45%	7.51%	10.19%
		P.	0.01	0.17	0.31	0.20	0.28
	20 Agents	A.	0.45%	2.71%	5.19%	3.39%	5.04%
		P.	0.02	0.16	0.30	0.20	0.30
	40 Agents	A.	0.21%	1.23%	2.45%	1.65%	2.40%
		P.	0.02	0.15	0.30	0.20	0.30

Table 10
"Activity level" dimension – number of statements and questions made by n agents for the 5 behavior styles.

			Dominating	Integrating	Obliging	Compromising	Avoiding
		μ[0,1]	0.94	0.90	0.23	0.58	0.05
		G.	0.34	0.33	0.08	0.22	0.02
Activity level	5 Agents	μ	3.6	3.28	1.31	2.19	0.65
		σ	1.48	1.82	1.06	1.30	0.71
		Min.	0	0	0	0	0
		Max.	8	9	4	6	2
		P.	0.32	0.29	0.11	0.19	0.05
	10 Agents	μ	3.28	3.41	0.8	1.65	0.59
		σ	1.41	1.50	0.79	1.13	0.69
		Min.	0	0	0	0	0
		Max.	8	9	4	5	3
		P.	0.33	0.35	0.08	0.16	0.06
	20 Agents	μ	2.56	2.56	0.38	0.87	0.18
		σ	1.41	1.52	0.63	0.89	0.41
		Min.	0	0	0	0	0
		Max.	8	9	3	5	2
		P.	0.39	0.39	0.05	0.13	0.02
	40 Agents	μ	1.82	1.54	0.11	0.33	0.05
		σ	1.27	1.21	0.34	0.61	0.24
		Min.	0	0	0	0	0
		Max.	8	7	2	5	2
		P.	0.47	0.4	0.02	0.08	0.01

Table 11
Mean and standard deviation of satisfaction with five agents.

	Dominating	Integrating	Obliging	Compromising	Avoiding
μ	0.33	0.21	0.19	0.21	0.25
σ	0.54	0.30	0.23	0.29	0.27

of 5 simulations with each behavior styles (5 agent). "1st means the highest satisfaction" and "5th" means the lowest satisfaction within each set of 5 simulations. For example, with the Dominating behavior style, the agent was able to achieve 14 times the best satisfaction result in relation to the other behavior styles (under the same conditions). However, the Dominating behavior style also caused the agent to get the worst satisfaction result 6 times. We found that by using the "Integrating" style of behavior in this simulation environment most of the times, the satisfaction obtained was intermediate.

Fig. 15 shows the satisfaction obtained by the target agent in the 5-agent simulation environment using the Dominating and Obliging behavior styles. As we can see, although most of the time the "Dominating" achieves greater satisfaction, when it cannot achieve its goals it is also much more dissatisfied. On the other hand, the "Obliging" shows that its satisfaction throughout the various simulations is more stable.

Table 13 shows the average satisfaction and standard deviation of the target agent using each of the behavior styles in a 12 agent environment simulation. It was again verified that the agent with the "Dominating" style continues to achieve the highest average satisfaction, showing also the most variability. With 12 agents, the average satisfaction of "Integrating" was quite close to that of "Dominating" with the advantage of showing much less variability.

Table 14 shows the number of times the target agent achieved more or less satisfaction in each of the 5-simulation groups with each of the behavior styles (12 agents) – "1st" means/refers to the highest satisfaction and "5th" means the lowest satisfaction within each set of 5 simulations.

Table 12
Number of times each style appears in the several ranks of satisfaction.

	Dominating	Integrating	Obliging	Compromising	Avoiding
1°	14	0	4	1	1
2°	0	2	3	4	11
3°	0	15	2	3	0
4°	0	2	2	10	6
5°	6	1	9	2	2

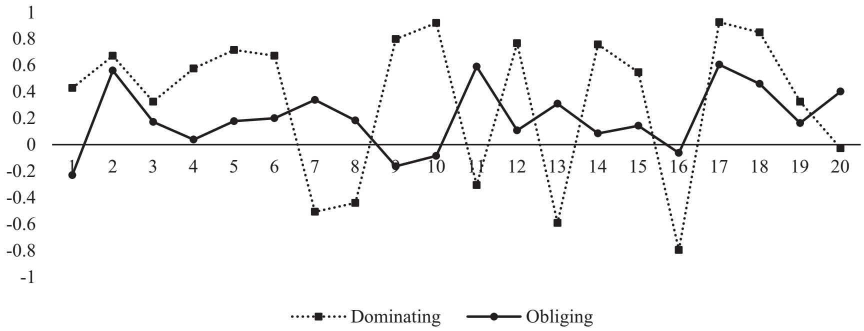

Fig. 15. Satisfaction with Dominating and Obliging in 100 simulations.

Table 13
Mean and standard deviation of satisfaction with 12 agents.

	Dominating	Integrating	Obliging	Compromising	Avoiding
μ	0.15	0.11	−0.03	0.09	−0.05
σ	0.47	0.32	0.38	0.36	0.36

Fig. 16 presents the satisfaction obtained by the target agent in the 12-agent simulation environment using the Dominating, Obliging and Compromising behavior styles.

7. Discussion

Using agents to represent decision-makers in group decision-making processes is a widely used strategy in our field. The representation of the decision-makers may have different levels of complexity and should be conceived according to the context and objectives of the system that will operate. We must be extremely mindful when designing the representation of decision-makers in group decision support systems that will be used by the decision-makers themselves during the decision process. Let us imagine a decision-maker, who has certain limitations, so that he/she is not able to dialogue with the other decision-makers in a face-to-face meeting. This decision-maker has no persuasive skills and the only influence he/she has in the decision is his/her own vote. If such a decision-maker was literally represented by an agent, he would generate a purely reactive agent, not having any influence in the decision (except for the fact that his/her own preferences would be taken into account). The question that arises is: would this decision-maker be interested in using a system that would represent him/her in this way, mimetizing his unwanted characteristics? This means that this decision-maker may have interest in the process and also knowledge that would add value to the decision-making process, but still could not show it in face-to-face meetings. Thus, the decision-making process would only benefit from representing the decision-maker in a way that he/she is not, or at least in a way he/she cannot be in face-to-face meetings. Moreover, as we have previously asserted, it would be impossible (with the current knowledge) to define a decision-maker in a way that allows him/her to be used in all future meetings. Regardless of the decision make's personality, due to his/her intentions/goals, the behavior will invariably shift according to his/her interests and context. Rather than a point in time, the decision-making process unfolds over a period of time. It requires several steps such as the exchange of ideas, reflection on the others' opinions, the maturing of ideas, etc. Therefore, the duration of the decision-making process depends on several factors, but what we would like to point out is that the important decisions made in large organizations do not happen over a short period of time. This means that a GDSS will be used throughout the process and it should allow the decision-makers to express different intentions during that same process. All of this led us to focus on defining behavioral styles rather than defining the decision-makers' personality.

The results we obtained with this work were way stronger than we anticipated. However, at this point we consider

Table 14
Number of times each style appears in the several ranks of satisfaction.

	Dominating	Integrating	Obliging	Compromising	Avoiding
1°	6	4	2	4	4
2°	4	5	3	5	3
3°	2	4	4	6	4
4°	3	4	6	0	7
5°	5	3	5	5	2

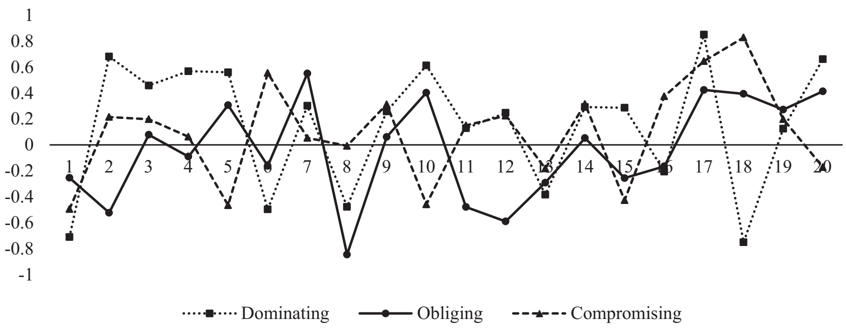

Fig. 16. Satisfaction with Dominating, Obliging and Compromising in 100 simulations.

that although we have verified the hypotheses h2 and h3, the results we achieved still aren't as beneficial as they could be in real scenarios. This happens because of the scarcely human way by which the variables are randomly generated. For example, in our simulations, agents with obliging behavior tend to reach/seek the goals of all other agents, which is a rather unrealistic scenario. In a real situation, an obliging agent will probably seek to achieve the goals of a subgroup of decision makers who, in turn, may even agree with each other. Also, in a real context, decision-makers are able to reconfigure their preferences throughout the process. This can happen (for example) because the decision maker may agree with arguments that support certain opinions and thereby change their preferences.

Another key feature in the development of this work was to verify that no style of behavior is the most or the least advantageous every single time, (which may occur in real situations), making it impossible for decision-makers to think that "it is worth trying to deceive the system" to their own benefit. The idea is that, for decision makers, best results may be achieved by selecting the behavior style that best represents their intentions. Besides demonstrating the interest of selecting a behavior that meets the intentions of decision makers, it helps decision-makers to feel motivated to make a rational choice of the behavioral style. In turn, GDSS may use this information (of what decision makers want) to, by means of algorithms or other strategies, promote consensus and the quality of the decision. In the experiments we ran, we showed that agents configured with the Dominating behavior style tend to reach their goals more often, while also being the ones who are the most harmed when they don't succeed.

8. Conclusions and future work

Ultimately, with the ever-increasing profusion of large organizations, group decision-making has become the rule in terms of decision format over the last decades. Organizational growth has posed new challenges, namely due to the difficulties experienced by top managers and executives when they need to meet in a same place at the same time. To support decision processes, Web-based Group Decision Support Systems have been widely proposed in literature as means to allow the decision-makers to participate in the decision process anytime and anywhere. The fact that they are web-based makes them multiplatform systems prone to be rendered accessible through almost any kind of device. However, several limitations make it hard for them to succeed, such as: endowing the representation, the interests and intentions of the decision-makers with accuracy.

In this work, we suggested a set of behavior styles that can be used to model agents that can represent decision-makers in the context of group decision-making. Our option renders the agents much more reality-based because, besides allowing the typical configurations related to the problem (alternatives and criteria), it makes them capable of representing the decision-makers' intentions. In this context, we conceive intentions as what the decision-makers wants to get from the decision-making process, i.e., not only what they intend to achieve (objectives) but also how they intend to face them. This means that in our approach, a decision-maker may consider (for instance) Alternative i: (a) the best solution for a certain problem and his main intention is to achieve that solution, (b) the best solution but his main intention may be to please and meet a subset of decision-makers' interests, or (c) in an earlier stage of the decision-making process but, because he considers his position to be less solid and by having little knowledge about the problem, he prefers to remain less interventive until he constructs a more solid and substantiated opinion.

This approach is intended to be used not only in simulators but also in real systems. This raised concerns that normally are not considered in the literature in this field, such as assessing how consensual is the understanding of the proposed behavioral styles and of how people classify them. Since we were able to validate our hypotheses, there are now exact operating values for each behavioral style that from now on, can be used elsewhere. Also, we developed a prototype that allowed us to perceive and interpret the results of using behavioral styles as the basis for modeling agents. We found that using behavioral styles allows the automatic negotiation mechanisms to enjoy the typical heterogeneity of real meetings.

In the future, the use of other models either derived from personality or attachment theory, or possibly both, may open new avenues for agent modeling, with further improvements in the quality of their representativeness. We foresee that these developments may meet the ever-changing needs of decision-makers, that may often be willing to shift from simulating their own traits to change functioning styles to optimize performance in different environments depending on the situation, present or absent he may be. If one can even configure his/her own pattern of changes, then intelligence systems will really keep pace with the complexities and subtleties of human behavior either for purposes of simulation/representation or intended enhancement. These changes may help a system to support group decision-making to perceive important information and to use that same knowledge to support the decision.

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3.3 EVALUATING THE PERCEPTION OF THE DECISION QUALITY IN WEB-BASED GROUP DECISION SUPPORT SYSTEMS: A THEORY OF SATISFACTIONN

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Evaluating the Perception of the Decision Quality in Web-Based Group Decision Support Systems: A Theory of Satisfaction

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Abstract. The future and success of organizations depend greatly on the quality of every decision made. It is known that most of the decisions in organizations are made in group. With the purpose to support the decision-makers anytime and anywhere, Web-based Group Decision Support Systems have been studied. The amount of Web-based Group Decision Support Systems incorporating automatic negotiation mechanisms such as argumentation is increasing nowadays. Usually, these systems/models are evaluated through mathematical proofs, number of rounds or seconds to propose (reach) a solution. However, those techniques do not say much in terms of decision quality. Here, we propose a model to predict the decision-makers' satisfaction (perception of the decision quality), specially designed to deal with multi-criteria problems. Our model considers aspects such as: alternatives comparison, style of behaviour, emotions, mood and expectations. The proposed formulation matches the assumptions previously defined in the literature.

Keywords: Group Decision Support Systems · Decision satisfaction · Decision quality · Outcomes · Affective computing

1 Introduction

It is known that many of the decisions in organizations are made in group [1]. Group Decision Support Systems (GDSS) have been widely studied throughout the last decades [2, 3] to support this type of decisions. However, in the last ten/twenty years, we have seen a remarkable change in the context where the decision-making process happens, especially in large organizations [4]. With the appearance of global markets, the growth of multinational organizations and a global vision of the planet, we easily find decision-makers (chief executive officers, managers and other members of global virtual teams) spread around the world, in countries with different time zones [5]. However, to support the group decision-making process in this context is especially

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complex, due to the decision-makers being geographically dispersed. To provide an answer and operate correctly in this type of scenarios, the traditional GDSS have evolved to what we identify today as Web-based GDSS [6, 7]. The idea behind the Web-based GDSS is to support the decision-making process "anytime" and "anywhere" [4]. The automatic negotiation mechanisms can be used (in Web-based GDSS) to help overcome the lack of interaction caused in the context described before [8]. Usually, these systems/models are evaluated through mathematical proofs, number of rounds or seconds to propose (reach) a solution [9]. However, those techniques do not say much in terms of decision quality.

In fact, the decision quality is impossible to measure in the end of a group decision-making process. What is possible to measure, or what can be valuable to know in the end of a group decision-making process is the perception of the decision-quality of each of the decision-makers (or their satisfaction) [10]. Satisfaction is therefore a strong indicator, not only of the results, but also of the whole decision process [11]. When someone is questioned about the quality of a decision, the answer does not reflect only the assessment of outcomes, but also, even unconsciously; it includes the evaluation process necessary to reach the decision [11]. Satisfaction as a metric has been applied in the literature to many different issues: life satisfaction [12], job satisfaction [13], etc. Satisfaction has also been applied in the GDSS topic. However, the existent proposals are not concerned with the perception of the decision quality but are concerned with decision-maker's satisfaction regarding the GDSS performance, usability, etc. [14–16].

In this work, we study satisfaction as a metric to understand the decision-maker's perception of the decision quality. Our proposal is defined based in the assumptions and premises previously published in [10], which contemplate different approaches from researchers of a wide range of areas in this thematic (computer sciences, psychology, economy, etc.). It intends to allow automatic assessment of the participants' satisfaction in a meeting supported by a Web-based GDSS. To evaluate decision-maker's satisfaction, we consider the alternatives comparison, style of behaviour, emotions, mood and expectations.

The rest of the paper is organized as follows: in the next (Sect. 2) section our satisfaction model is presented and in Sect. 3 some conclusions are taken, along with the work to be done hereafter.

2 Methods

As we have seen in [10], when a decision-maker is questioned about the quality of a decision, the answer does not reflect only the assessment of the outcomes, but also, even unconsciously; it includes the evaluation process necessary to reach the decision. To understand how suitable a decision is, it is necessary to understand and analyse the means to reach that decision [17]. Thus, one should give prominence to the process, when drawing conclusions about the results. Besides, the researchers agree that there is a great variety of factors responsible for affecting the satisfaction of a decision-making element with the decision made in a meeting: emotional variables (affective components) [18], the process [19], the outcomes [11], the factors that affect the situation [20] and expectations [21]. Our proposal (follows the assumptions and premises proposed in [10]) deals with these factors making use of the typical data configured by the decision-makers in the Web-GDSS (in disperse meetings [22]).

2.1 Outcomes

The alternative chosen by the group has impact in the decision-maker's satisfaction. This is an inescapable fact, since achieving the outcomes is the reason why the decision-making process happens. The satisfaction or the perception of the decision quality is related to the outcomes [10]. However, to understand the outcomes impact it is necessary to see the big picture. Higgins [11] says that "psychologically, then, a decision is perceived as good when its expected value or utility of outcomes is judged to be more beneficial than the alternatives". Thus, whereas the preferred alternative is the best in the decision-maker's perspective, the distance between the preferred alternative and the chosen one means a loss of the decision-maker's satisfaction. The loss of satisfaction comprises the difference in the assessment made by the decision-maker for each of the alternatives, as well as what the participant did not achieve with the final decision. In this work, we consider the participant's assessment of each alternative varying in a [0; 1] range, where 0 means "I do not like at all" and 1 means "I like very much" (see our proposal of a practical implementation based on this in [23]). To understand the satisfaction considering alternatives comparison, we suggest the following formulas:

$$D_{Lost} = Alt_F - Alt_P \tag{1}$$

$$A_{Conversion} = 2Alt_F - 1 \tag{2}$$

$$D_{Outcomes} = (1 - |A_{Conversion}|) * D_{Lost} + A_{Conversion} \tag{3}$$

Where:

- D_{Lost} is the loss of decision maker's satisfaction based in the difference between the assessments made for the alternative chosen by the group (Alt_F) and for his preferred alternative (Alt_P). The loss is zero when the chosen alternative is the same as his preferred alternative;
- Alt_F is the assessment made by the participant for the final alternative, alternative chosen by the group;
- Alt_P is the assessment made by the participant for his preferred alternative;
- $A_{Conversion}$ is the conversion of the assessment made by the participant into our scale of dissatisfaction/satisfaction;
- $D_{Outcomes}$ is the participant's satisfaction concerning the outcomes. Intends to evaluate the satisfaction based in the assessment made by the participant to the alternatives, including the loss of satisfaction in the case where his preferred alternative is not chosen by the group.

We assume the $D_{Outcomes}$ is the purely analytical evaluation of the decision-maker's satisfaction. All other points (presented below) have impact in $D_{Outcomes}$. The other points will depend on the context.

2.2 Expectations

Consciously or not, people create expectations on (almost) everything [21]. The relationship between expectations and the satisfaction is clear. Considering what we have stated before and our previous work [10], it is easy to understand the following rules:

$If\ Participant\ achieve\ goals = True$
$Then\ expectations\ impact = Positive\ or\ Neutral$

$If\ Participant\ achieve\ goals = False$
$Then\ expectations\ impact = Negative\ or\ Neutral$

In this work, we consider the Web-based Group Decision Support System as the only existent mechanism for the decision-makers communicate. Thus, we consider relevant to know the decision-makers' expectations regarding the chances in attaining their objectives.

- Probability of the participant's preferred alternative to be chosen: Understanding the expectations regarding the probability of the participant's preferred alternative to be chosen. "How likely you think your preferred alternative will be chosen?".

In a real scenario, decision-makers are creating expectations all the time: "Is he going to accept my request?", "Will he help me supporting my idea?", etc. However, when automated negotiation techniques are used, the decision-makers only create expectations about issues that they can expect something and which they interact. That is why we only consider the expectations regarding the achievement of results (at this step). The expectations can influence satisfaction in three different ways:

- Positive impact: When the results exceed the expectations;
- Negative impact: When the expectations are not achieved;
- Without impact: When the expectations are achieved.

The expectation value will be within the range [0; 1]. To evaluate expectation in this context, approaches as the ones proposed in [23] can be used. The calculus of satisfaction including expectations is divided in 2 different conditions. Firstly, we address the situation where expectations are matched. This means, the expectations have a positive impact in satisfaction.

Positive Impact. This type of impact occurs when the chosen alternative is the one preferred by the participant. In this case, the impact of the expectation will be positive or neutral (in case the expectation is 1). The following formula is used to calculate the positive impact:

$$P_{Impact} = (1 - E) * Alt_P \tag{4}$$

Where:

- E is the participant's expectation regarding the possibility of his preferred alternative being chosen by the group.
  For a better understanding of the proposed formula, let us consider the scenarios where the impact should have the maximum and minimum values (extreme cases):

- The positive impact should be 1 (maximum impact) when the participant's expectation regarding the preferred alternative being chosen by the group is 0 and the value of alternative assessment is 1;
- The positive impact should be 0 (no impact) when the participant's expectation regarding the preferred alternative being chosen by the group is 1. This means that the decision-maker is taking it for granted. The maximum expectation on a positive situation does not bring any increased satisfaction as a form as impact.

We can include now the expectations in the satisfaction calculation. $D_{Outcomes}$ can be recalculated using the following formula:

$$D_{Outcomes} = D_{Outcomes} + (1 - |D_{Outcomes}|) * P_{Impact} \tag{5}$$

The most important point of this formulation is the possibility to recalculate the $D_{Outcomes}$ satisfaction using the impact in a form of a variable.

In our proposal, we first understand which impact the expectation has (according to the different situations) and use the correct impact next (calculated according to the context). The use of $(1 - E)$ in our formula intends to reflect the difference between the maximum expectation (which would be 1) and the participant's expectation.

Negative Impact. This type of impact occurs when the chosen alternative is not the one preferred by the participant. In this case the impact of the expectation will be negative or neutral (in case the expectation is 0). The following formula is used to calculate the negative impact:

$$N_{Impact} = (Alt_P - Alt_F) * E \tag{6}$$

In the case of a negative impact, we propose a different formula because in this situation the impact represents an expectation that has not been met, symbolizing a loss. Moreover, in this situation, to truly understand the expectation impact, we need to analyse the relation between this loss and the difference between the assessments of his preferred alternative and the one chosen by the group. As we have done before, let us consider the scenarios where the impact should have the maximum and minimum values (extreme cases):

- The negative impact should be 1 (total impact) when the participant's expectation regarding the preferred alternative being chosen by the group is 1, the assessment of the alternative chosen by the group is 0 and the assessment of his preferred alternative is 1;
- The negative impact should be 0 (no impact) when the expectation is 0.

We can include now the expectations in the satisfaction calculation. $D_{Outcomes}$ can be recalculated using the following formula:

$$D_{Outcomes} = D_{Outcomes} + ((1 - D_{Outcomes}) * (-1)) * N_{Impact} \tag{7}$$

2.3 Style of Behaviour

The number of works including affective aspects in the field of computer science is growing exponentially. Previously [24], we proposed a model to define styles of behaviour in agents to represent the decision-makers' intentions. We adopted the conflict styles proposed by Rahim and Magner [25], and redefined them to be more adequate to our context. We called them styles of behaviour and defined them as follows:

- Dominating: A dominating individual believes that he owns the key to solve the problem. He plays a very active role during the decision-making process and tries to force his opinion on other participants;
- Integrating: An integrating individual favours a collaborative style. He aims to achieve consensual decisions and greatly values his and others' opinion. He prefers to manage assiduously the entire decision-making process;
- Compromising: A compromising individual favours a collaborative style. He aims to achieve consensual decisions and values his and others' opinion. He plays a moderately active role during the decision-making process;
- Obliging: An obliging individual tends to give up on his opinion in favour of the group interests. He prefers to follow others' opinions rather than sharing his own;
- Avoiding: An avoiding individual prefers to be freed from responsibility. Fundamentally, he prefers to not be involved in the decision-making process and devalues both the process and the opinion of other participants.

In this proposal, we consider the styles of behaviour described before to formulate the satisfaction model. However, this proposal can be easily adapted to situations where aspects such as personality and conflict styles are used. In this satisfaction model, we aim to assess the decision-maker's satisfaction, so we use behaviour to understand the impact of the process in the decision-maker. The process impact will vary according to the decision-maker's intentions. For instance, let us consider a situation where the participant defined his conflict style as "Dominating". If he notices that the most of other decision-makers do not like his preferred alternative, we can associate to him emotions as distress and disappointment. On the other hand, if the participant defined his conflict style as "Obliging", he may not feel the same emotions because his main intention his not to achieve is preferred alternative but to please some other/s decision-maker/s. This is a simple example to demonstrate that the impact will vary according to how the decision-maker experiences the process.

We define a set of situations that decision-makers experience using a GDSS and correlate them with conflict styles, using the OCC model [26]. Ortony et al. [26] proposed a global structure of emotion types where they defined "valenced reaction to": consequences of events, actions of agents and aspects of objects. For our purpose, we only use the consequences of events. Into the consequences of events they distinguish between the consequences for other and consequences for self, what means a remarkable correlation with the classification of conflict styles proposed by Rahim and Magner [25] where they defined the conflict styles according to the concern for self and the concern for others (see Table 1).

We have considered that the integrating and compromising styles will be affected emotionally by the "consequences for other" and "consequences for self", the obliging

Table 1. Styles of behaviour

Style of behaviour	Concern for self	Concern for others
Dominating	High	Low
Integrating	High	High
Compromising	Moderate	Moderate
Obliging	Low	High
Avoiding	Low	Low

style will be affected emotionally by the "consequences for other", the dominating style will be affected by "consequences for self" and the avoiding will not be emotionally affected. The compromising style of behaviour will be affected with a half of the emotions intensities when compared with the integrating. The set of events that may occur are expressed in the Table 2. (CO is consequences for other and CS is consequences for self).

We have defined some rules to deal with hope and fear emotions (according to [26]).

Table 2. Considered events and respective definition

Event	CO	CS	Emotions
Participant's preferred alternative was chosen by the group	×	✓	Joy and (check rules below)
Participant's preferred alternative was not chosen by the group	×	✓	Distress and (check rules below)
Participant changed his preference to another alternative	×	✓	Hope
The majority prefers the participant's preferred alternative	×	✓	Joy and hope
A few or none decision-maker prefers the participant's preferred alternative	×	✓	Distress and fear
The preferred alternative of the decision-maker/s that the participant considers credible/important was chosen by the group	✓	×	Happy-for, joy and (check rules below)
The preferred alternative of the decision-maker/s that the participant considers credible/important was not chosen by the group	✓	×	Pity, distress and (check rules below)
The majority prefers the same alternative as some other decision-maker/s that the participant considers credible/important	✓	×	Happy-for, joy and hope
The majority do not prefer the same alternative as some other decision-maker/s that the participant considers credible/important	✓	×	Pity, distress and fear

$$\begin{aligned}&If\ Participant\ experience\ hope\ and\ it\ is\ confirmed\\&Then\ Participant\ will\ experience\ satisfaction\end{aligned}$$

$$\begin{aligned}&If\ Participant\ experience\ hope\ and\ it\ is\ not\ confirmed\\&Then\ Participant\ will\ experience\ disappointment\end{aligned}$$

$$\begin{aligned}&If\ Participant\ experience\ fear\ and\ it\ is\ confirmed\\&Then\ Participant\ will\ experience\ fears-confirmed\end{aligned}$$

$$\begin{aligned}&If\ Participant\ experience\ fear\ and\ it\ is\ not\ confirmed\\&Then\ Participant\ will\ experience\ relief\end{aligned}$$

2.4 Emotional Changes and Mood Variation

It is clear in the literature how important is to include in the analysis of satisfaction the affective and emotional components [18, 20, 21].

Due to the brilliant work proposed by Gebhard [27] where he correlates the PAD [28] and the OCC model, many works appeared using the triggered emotions in order to update the mood state (including ourselves). For this model, we propose a correlation between the events defined in Subsect. 2.3 with a set of triggered emotions for each of the situations (Table 2). We used the work proposed in [26] to define a set of emotions for each of situations and analyse the emotions triggered during the process to understand the emotional cost.

In Table 2, we presented the set of considered situations and the emotions associated to each situation. As we can see, all the situations are in some way related to the alternatives. These situations describe the scenarios the decision-makers face every time they interact with the system (GDSS). However, it is also important to define the impact of each situation. The impact of "Participant's preferred alternative was not chosen by the group", should be different if previously the participant face a situation of "A few or none decision-maker prefers the participant's preferred alternative" or a situation of "The majority prefers the participant's preferred alternative". Thus, we consider the process expectations:

$$P_{Expectations} = N_p / N_t \tag{8}$$

Where:

- N_p is the number of decision-makers supporting the participant's preferred alternative or some other decision-maker/s that the participant considers credible/important;
- N_a is the total number of decision-makers.

The $P_{Expectations}$ calculated in each situation will have impact in the emotions calculated in the next interaction because every time a decision-maker faces a new situation, he will be affected by the new information plus the expectations that he created based in previous information. Next, we will describe how to process the emotions created in each situation:

Let Emo_S be a set of emotions of one situation:

$$Emo_S = \{(P_1, A_1, D_1), \ldots, (P_n, A_n, D_n)\} \tag{9}$$

Where:

- n is the number of created emotions;
- P_i, A_i, D_i are the values of Pleasure, Arousal and Dominance for emotion i (based in [27]).

Let Emo_T be the sum of emotions in Emo_S:

$$Emo_T = \sum_{i=1}^{n} (P_i, A_i, D_i) \tag{10}$$

Where:

- n is the number of created emotions;
- $P_i, A_i, D_i \in Emo_S$.

Let Int_{Emo_T} be the intensity of Emo_T:

$$Int_{Emo_T} = \frac{\sqrt{(P)^2 + (A)^2 + (D)^2}}{\sqrt{3}} \tag{11}$$

Let $Exp_{Int_{Emo_T}}$ be the Int_{Emo_T} considering $P_{Expectations}$:

$$Exp_{Int_{Emo_T}} = Int_{Emo_T} * P_{Expectations} \tag{12}$$

Let $Pos_{Emotions}$ be the sum of intensities of all positive emotions (joy, hope, happy-for, satisfaction and relief) created in each situation along the process:

$$Pos_{Emotions} = \sum_{i=1}^{n} \left(Exp_{Int_{Emo_{T_i}}} \right), Emo_S \text{ is a set of positive emotions} \tag{13}$$

Let $Cons_{Emotions}$ be the sum of intensities of all negative emotions (distress, fear, pity, disappointment and fears-confirmed) created in each situation along the process:

$$Cons_{Emotions} = \sum_{i=1}^{n} \left(Exp_{Int_{Emo_{T_i}}} \right), Emo_S \text{ is a set of negative emotions} \tag{14}$$

After calculating $Pos_{Emotions}$ and $Cons_{Emotions}$, we compare the two intensities to understand the emotional cost. According to that, we propose the following simple rules:

$If\ Pos_{Emotions} = Cons_{Emotions}$
$Then\ Cost = Neutral$

$If\ Pos_{Emotions} > Cons_{Emotions}$
$Then\ Cost = Positive$

$If\ Pos_{Emotions} < Cons_{Emotions}$
$Then\ Cost = Negative$

Now, we normalize the $Pos_{Emotions}$ and $Cons_{Emotions}$, such that $Pos_{Emotions} + Cons_{Emotions} = 1$:

$$Norm_{PosEmotions} = Pos_{Emotions}/(Pos_{Emotions} + Cons_{Emotions}) \quad (15)$$

$$Norm_{ConsEmotions} = Cons_{Emotions}/(Pos_{Emotions} + Cons_{Emotions}) \quad (16)$$

The difference of intensities will then be considered as a gain or a loss (or neutral in case of no emotional cost). Let us assume this value as Dif_{Emo}:

$$Cost = Norm_{PosEmotions} - Norm_{ConsEmotions} \quad (17)$$

2.5 Final Satisfaction Calculation

Considering the value of participant's satisfaction concerning the alternative chosen by the group and the value of his mood (both contemplating the expectations), now we are going to join them to do our final calculation of satisfaction:

$$Satisfaction = D_{Outcomes} + (1 - |D_{Outcomes}|) * Cost \quad (18)$$

The interval for the result of satisfaction will be [−1; 1]. We propose an adaptation of a scale based in the work of Babin and Griffin [29] and represented in the Table 3.

Table 3. Scale of satisfaction

Designation	Interval
Extremely satisfied	[0,75; 1]
Much satisfaction	[0,5; 0,75[
Satisfaction	[0,25; 0,5[
Some satisfaction	[0; 0,25[
Some dissatisfaction	] −0,25; 0[
Dissatisfied	] −0,5; −0,25]
Very dissatisfied	] −0,75; −0,5]
Extremely dissatisfied	[−1; −0,75]

3 Conclusions and Future Work

In this article, we proposed a whole new model which allows the automatic assessment of the participants' satisfaction in a meeting supported by a Web-based Group Decision Support System. We believe that the proposed model allows the attainment of a large amount of useful and valuable information. The satisfaction can be used as a metric to compare different Web-based GDSS or automatic negotiation mechanisms. In addition, satisfaction can be used as a utility function to maximize the decision-makers' satisfaction or can be used by agents to predict the decision-maker's satisfaction. To evaluate satisfaction, we considered the alternatives comparison and evaluation, the expectations, emotions, mood and the process. The values obtained in the calculus of satisfaction respect the premises that were defined in a previous work.

As future work, we intend to conduct a case study with real people, in partnership with psychologists. With that work, we also intend to make the model more assertive by the possible improvements that might result after analysing and studying the collected data.

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3.4 INCLUDING COGNITIVE ASPECTS IN MULTIPLE CRITERIA DECISION ANALYSIS

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Including cognitive aspects in multiple criteria decision analysis

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Abstract Many multiple criteria decision analysis (MCDA) methods have been proposed over the last decades. Some of the most known methods share some similarities in the way they are used and configured. However, we live in a time of change and nowadays the decision-making process (especially when done in group) is even more demanding and dynamic. In this work, we propose a MCDA method that includes cognitive aspects (cognitive analytic process, CAP). By taking advantage of aspects such as expertise level, credibility and behaviour style of the decision-makers, we propose a method that relates these aspects with problem configurations (alternatives and criteria preferences) done by each decision-maker. In this work, we evaluated the CAP in terms of configuration costs and the capability to enhance the quality of the decision. We have used the satisfaction level as a metric to compare our method with other known MCDA methods in literature (utility function, AHP and TOPSIS). Our method proved to be capable to achieve higher satisfaction levels compared to other MCDA methods, especially when the decision suggested by CAP is different from the one proposed by those methods.

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1 Introduction

Making decisions is intrinsic to the human being. Each action, more or less significant, conscious or unconsciously, results in a decision. Therefore, we could say we are all natural decision-makers (Saaty 2008). The decision-making process can be seen as selecting one or more alternatives to be the solution for a certain problem/task (Chen 2000).

Nowadays most of the decision-making processes happening in organizations are done in group (Luthans 2011; Simon 1965). There are many advantages related to group decision-making: to improve the quality of the decision, to share workloads, to gain support among stakeholders, to train less experienced group members and due to the majority of organograms existing nowadays (Dennis 1996; Huber 1984). However, due to market globalization and the firms' internationalization it is very hard to match each top managers' agenda, making it difficult for them to meet in the same space or time (Carneiro et al. 2015). Therefore, it is no surprise that more techniques, models, methods and tools that support groups and individuals in the decision-making process are being developed.

Multiple criteria decision analysis (MCDA) methods are one of the techniques used to support the decision-making process. MCDA is considered appropriate to deal with conflicting opinions and also qualitative and quantitative objectives (Ram et al. 2011; Golmohammadi and Mellat-Parast 2012). MCDA provides a framework which deals with complex decision problems. In order to reach a consensus, a MCDA framework allows decision-makers to share information through problem configurations (Dehe and Bamford 2015). Throughout the last decades, a wide variety of analytical models have been proposed in literature (Tavana et al. 2010). Some of the most acknowledged MCDA methods in literature are: ER, ELECTRE, PROMETHEE, AHP, ANP, TOPSIS, MACBETH (Figueira et al 2005). Even though there is a very decent amount of work proposed under the topic of MCDA, the issues associated to MCDA are easy to identify. Tavana et al. (2010) have identified certain issues such as: deficiencies when considering objective and subjective criteria, imprecise information due to the lack of the decision-makers' expertise, unavailability of data and time constraint, etc. Besides these issues, we can still include the lack of information about each decision-maker (Levy 2007), the difficulty or impossibility for each decision-maker to express how he intends to face the decision-making process (Rahim and Magner 1995) and the difficulty (the cost) associated to problems configuration (Dehe and Bamford 2015).

The area of decision-making has always been very studied in literature. Since the early days of psychology and economy there has been a clear interest to study the topic of decision-making (Edwards 1954; Simon 1959, 1986). If economists have always looked at decision-making in a completely rational perspective, psychologists look at decision-making in a perspective which allows them to understand the individual judgement and the decision-making concerning both irrational and rational aspects of behaviour (Simon 1986). It is evident that most of the existent MCDA methods have been based in an economic perspective which we could call as the rational choice. Simon (1979) pointed the interest of economists to explore domains that belonged, traditionally, to political sciences, sociology, and psychology. This interest is very similar to what happens nowadays between computer science researchers and those same domains (Castelfranchi 1994; Smith and Conrey 2007; Falcone and Castelfranchi 2001; Bates 1994; Ogiela and Ogiela 2014a, b). It is known that cognitive aspects are present and affect the individual during the decision-making process (Schwarz 2000). Therefore it is assumed to be necessary to consider cognitive aspects in order to make a correct representation of the interests of decision-makers. With that being said, it can then claim that including cognitive aspects allow obtaining better decisions which are fundamentally more adjusted to the real interests of decision-makers.

In this work, we present a new MCDA method named as cognitive analytical process (CAP). CAP allowed decision-makers to represent their preferences about a problem (criteria and alternatives) and also represent what we referred as their intentions, being directed towards supporting group decision-making. Decision-makers could: express their intentions by selecting a behaviour style that better represents how they intend to face the decision-making process, select an expertise level about the topic being discussed and select which decision-makers involved in the same process they consider to be more credible. CAP is an analytic method that aims to provide a decision based on the values mentioned in the previous configurations and that maximizes the satisfaction level of the group and of each one of the decision-makers.

The rest of the paper is organized as follows: in the next section is presented the Sect. 2, where we enumerated the essential methods to define our proposal, in the Sect. 3 we presented our approach, where the cognitive analytic process is described and the model is formulated. In Sect. 4 it is shown the evaluation and results of this work and in Sect. 5 the discussion is presented. Finally, some conclusions were taken in Sect. 6, along with the work to be done hereafter.

2 Background

It is easy to find in literature several authors which refer to the importance of psychological and cognitive aspects in the decision-making context (Schwenk 1988; Frith and Singer 2008; Schwarz 2000). Moreover, there are authors which defend that the quality of the decision decreases when theses aspects are not considered (Simon 1987). Some authors consider that including cognitive and psychological aspects help to achieve decisions with higher quality (Simon 1987; Fenton-O'Creevy et al. 2011). Having all these evidences into account it becomes clear how a decision made using automatic mechanisms can be affected. There are many factors and knowledge which may be lost when the human interaction stops existing, even if there can be other advantages associated (Kiesler et al. 1984). By using a typical multi-criteria problem configuration, how will the system manager knowledge and expertise levels of each decision-maker? Will it be fair to weight all configurations as the same? How to deal with different intentions which the decision-maker may have in each decision-making scenario? In this work we intend to answer these questions as well as verify if our method manages to achieve higher results (compared to other methods) by considering some of these points.

In this section, the models used by CAP are presented and allow us to better understand how it works. Besides this, it is explained the reasons why behaviour styles, credibility and expertise are considered by CAP as well as how they relate with the topic of group decision-making. All these points have been discussed in some of our most recent works (Carneiro et al. 2015a, b, c; Martinho et al. 2015), and they have been used because according to the work published in (Carneiro et al. 2015c) they are part of a multi-criteria configuration template that proved to be very easy and fast to configure. This fact was important due to big concerns related to the usability and the resources needed to use CAP. The description next presented for each point is based in the analysis done previously in (Carneiro et al. 2015c).

2.1 Behaviour style

The behaviour style can be seen as the expected behavior or the desirable behaviour. In some of our previous works, we studied the difference between using the decision-maker's personality or to create the possibility for the decision-maker to select the conflict style or the behaviour that he intended to use (to read more about this see Martinho et al. 2015). During our life, we are constantly presented with the need to make decisions. Some decisions are less relevant, others are not. Fundamentally, when we are taking decisions in group, and independently of our personality, we express and behave differently according to different situations such as: the topic of the problem to be solved, to consider the others decision-makers as more expert than us, to intend to be pleasant and try to pursue other decision-makers' goals, the level of the interest on the topic, the mood, etc. This means that in a hypothetical scenario where a decision-maker and his family are deciding from a group of alternatives to choose a restaurant to celebrate his son's birthday, maybe his main concern is to satisfy his son's preferred alternative. However, he still has his own preferences regardless of the kind of behaviour he shows during the negotiation process. In Martinho et al. (2015), five behaviour styles were considered: Dominating, Integrating, Compromising, Obliging and Avoiding. These styles differentiate from each other by what was thought to be four essential dimensions for this context:

1. Concern for self—This dimension was related to the individual's concern for his own opinion above the others since he was likely to adapt a more one-sided attitude during the decision-making process by making statements, questions and requests that detailed that opinion;
2. Concern for others—This dimension was related to the individual's concern for other individuals' opinion. He adapted a more altruist attitude during the decision-making process, tried to understand other opinions and made an effort to reach a decision that benefited or pleased most of the participants;
3. Activity—This dimension was related to the effort put into the decision-making process by the individual, meaning that the more active an individual was, the more questions and statements and requests he was likely to make;
4. Resistance to change—This dimension was related to how hard or easy it was for an individual to accept other opinions.

In Table 1, we describe each behaviour style by providing a value for every dimension (concern for self, concern for others, activity and resistance to change) mentioned before.

Table 1 Behaviour styles and corresponding dimensions, adapted from Martinho et al. (2015)

Behaviour style	Concern for self	Concern for others	Activity	Resistance to change
Dominating	3	1	3	3
Integrating	3	3	3	3
Compromising	2	2	2	2
Obliging	1	3	1	1
Avoiding	1	1	1	1

Table 2 Expertise levels

Expertise level	Inverse of expertise level	Definition
5	1	Expert
4	2	High
3	3	Medium
2	4	Low
1	5	Null

The numeric values (1, 2 or 3 for low, mid and high respectively) given to each dimension are correlated with the definitions established by Rahim and Magner (1995) (to learn more about this correlation see Rahim and Magner 1995; Martinho et al. 2015).

2.2 Credibility

There is not a universally accepted definition for credibility. Besides that, the study of credibility is highly multi-disciplinary and some of the suggested definitions are related to their area of operation (Flanagin and Metzger 2008). In our work, it was considered the definition proposed by Flanagin and Metzger (2008) when they said that "the overarching view is that credibility is the believability of a source or message, which is made up of two primary dimensions: trustworthiness and expertise". Trustworthiness was related with subjective components while expertise was related with more objective components. The notion of credibility was related with many other concepts including trust, reliability, accuracy, quality, authority, reputation, competence, etc (Flanagin and Metzger 2008). In our work, the main idea was to let a decision-maker choose which other decision-maker he considered to be credible towards a certain topic. This credibility evaluation was related with the concepts mentioned above and would be the reason why a decision-maker might consider another decision-maker to be credible for a topic and not for a different topic (for example, with the related expertise level recognized for that decision-maker), and also why a decision-maker might consider another decision-maker always credible despite of the topic's difference (for example, due to reasons such as authority, reputation, etc.).

2.3 Expertise

Expertise is considered as one of the credibility dimensions (affected by objective components) (Flanagin and Metzger 2008). In our work, it was intended to allow the decision-maker to make a self-evaluation about his expertise level for the topic at hand. It was considered the existence of five different expertise levels: Expert, High, Medium, Low and Null (the definition of the expertise levels definitions and values can be consulted in Table 2). Why is this information relevant and how can it be used? This kind of information could have many applications. One could be to use it to compare the self-evaluation made by the decision-maker for its expertise level with its credibility which is recognized by other decision-makers, allowing further conclusions to be made. This information could also be used to compare the self-evaluation with the chosen conflict style.

3 Cognitive analytic process

In this section, we present all the steps necessary to formalize the Cognitive Analytic Process. This formalization is based in the general concept of multi-criteria decision-making and was

Table 3 Notation correspondence

Terminology	Notation
Decision matrix	D
Set of criteria	C
Set of alternatives	A
Criterion	C_i
Alternative	A_i
Decision-maker	Dm_i
Weight	W
Criterion importance	$Impc_i$
Set of decision-makers	DM
Preferences of a set of decision-makers	WDM
Criteria preference matrix	CP
Set of sums of the best criteria weighting	HSc

first inspired in the works of other authors (Bozóki et al. 2013; Wang 2012; Ahn and Choi 2012; Kou and Wu 2014). For each step, we present definitions related with multi-criteria decision-making and our model. In Table 3 it is presented all notations necessary to better understand our formalization.

Step 1 Multi-criteria problem definition

The first step of CAP was to define the multi-criteria problem. Therefore:

Definition 1 Let D be a decision matrix, where $D = A \times C = \begin{bmatrix} c1_{a_1} & c2_{a_1} & \cdots & cn_{a_1} \\ c1_{a_2} & c2_{a_2} & \cdots & cn_{a_2} \\ \vdots & \vdots & \cdots & \vdots \\ c1_{a_m} & c2_{a_m} & \cdots & cn_{a_m} \end{bmatrix}$ and consists of:

- a set of criteria $C = \{c_1, c_2, \ldots, c_n\}, n > 0$;
- a set of alternatives $A = \{a_1, a_2, \ldots, a_m\}, m > 0$;

Rule 1 $\forall a_i \in A, \forall c_j \in C, c_{j_{a_i}} \in D$
Each alternative $a_j \in A$ is related with each criteria $c_i \in C$. There cannot be an existing alternative with values for criteria that are not considered in the problem.

Definition 2 A criterion $c_i = \{id_{c_i}, v_{c_i}, m_{c_i}\}$ consists of:

- $\forall c_i \in C, i \in \{1, 2, \ldots, n\}$;
- id_{c_i} is the identification of a particular criterion;
- v_{c_i} is the value of a particular criterion (Numeric, Boolean or Classificatory);
- m_{c_i} is the greatness associated with the criterion (Maximization, Minimization, Positivity, Negativity and without value).

Example 1 Let us consider criteria Price, Size and Quantity. This criteria can be defined as follows:

- $c_1 = \{Price, Numeric, Minimization\}$;
- $c_2 = \{Size, Numeric, Maximization\}$;
- $c_3 = \{Quantity, Numeric, Maximization\}$.

Definition 3 An alternative $a_i = \{id_{a_i}, [c1_{a_i}, c2_{a_i}, \ldots, c_{n_{a_i}}]\}$ consists of:

- $\forall a_i \in A, i \in \{1, 2, \ldots, m\}$;
- id_{a_i} is the identification of a particular alternative;
- $[c1_{a_i}, c2_{a_i}, \ldots, c_{n_{a_i}}]$ is the instantiation of each criterion.

Example 2 For the same example, let us consider three alternatives. Each alternative is defined as follows:

- $a_1 = \{alternative1, [10{,}000\$, 100\,\text{cm}, 90]\}$;
- $a_2 = \{alternative2, [12{,}500\$, 150\,\text{cm}, 50]\}$;
- $a_3 = \{alternative3, [15{,}000\$, 170\,\text{cm}, 70]\}$.

Step 2 Criteria weighting

The second step of CAP was to define the weights given by each decision-maker towards each criterion and alternative.

Definition 4 Let $w_{dm_{i_{c_j}}}$ be the weight or preference given to the criterion c_j by a decision-maker dm_i and $c_n \in C$.

Example 3 For the same example a possible weight given to each criterion by a decision-maker dm_i could be $W_{dm1_{c_1}} = 0.4$, $W_{dm1_{c_2}} = 0.6$, $W_{dm1_{c_3}} = 0.8$.

Rule 2 A decision-maker dm_i may define a set of W_{dm_i} weights where:

- $W_{dm_i} = \{w_{dm_{i_{c_1}}}, w_{dm_{i_{c_2}}}, \ldots, w_{dm_{i_{c_n}}}\}, n > 0, \forall j \in \{1, 2, \ldots, n\}, 0 \leq w_{dm_{i_{cn_j}}} \leq 1$;
- $\langle W_{dm_i} \rangle = \langle C \rangle$.

We defined a function which returned the difference between the maximum and minimum weights that belonged to a set of W_{dm_i} weights.

$$F_{Dif} : W_{dm_i} \begin{cases} max(W_{dm_i}) - min(W_{dm_i}), & \text{if } max(W_{dm_i}) \neq min(W_{dm_i}) \\ max(W_{dm_i}) \end{cases}$$

This difference was classified in five different levels in the following order according to Table 4. The values presented in the table for each level are related with the fact that we are dealing with five criteria classifications (VIC, IC, MD, NIC and INC). Since each criteria weighting is done in a scale of [0, 1] the minimum difference between two criteria is less than 0.2 and the maximum difference is greater than 0.8. Measuring the difference (using function F_{Dif}) between the criterion with more weight and the criterion with less weight we can obtain (according to Table 4) the "l" value. This value is then used in the algorithm to measure the classification done for each criterion (*imp*).

Table 4 F_{Dif} levels

Level (l)	F_{Dif}
5	≥0.80
4	≥0.60
3	≥0.40
2	≥0.20
1	<0.20

Table 5 Criterion importance

$imp_{c_{j_{dm_i}}}$	Definition
VIC	Very important criterion
IC	Important criterion
MC	Medium criterion
NIC	Not important criterion
INC	Insignificant criterion

Example 4 For the same example we know that $W_{dm_1} = \{0.4; 0.6; 0.8\}$.

We classified the importance $imp_{c_{j_{dm_i}}}$ for each criterion $c_j \in C$ to the decision-maker dm_i by using the following Algorithm 1.

foreach $c_j \in C$ **do**
  if $\left(w_{dm_{i_{c_j}}} > max(W_{dm_i} - \frac{max(w_{dm_i})-min(w_{dm_i})}{l}\right)$ **then**
    $imp_{c_{j_{dm_i}}} \leftarrow VIC$
  else if $\left(w_{dm_{i_{c_j}}} > max(W_{dm_i} - 2 \times \frac{max(w_{dm_i})-min(w_{dm_i})}{l}\right)$ **then**
    $imp_{c_{j_{dm_i}}} \leftarrow IC$
  else if $\left(w_{dm_{i_{c_j}}} > max(W_{dm_i} - 3 \times \frac{max(w_{dm_i})-min(w_{dm_i})}{l}\right)$ **then**
    $imp_{c_{j_{dm_i}}} \leftarrow MC$
  else if $\left(w_{dm_{i_{c_j}}} > max(W_{dm_i} - 4 \times \frac{max(w_{dm_i})-min(w_{dm_i})}{l}\right)$ **then**
    $imp_{c_{j_{dm_i}}} \leftarrow NIC$
  else
    $imp_{c_{j_{dm_i}}} \leftarrow INC$
  end
end

Algorithm 1: Importance classification algorithm

The importance given to a criterion depended on l and varied in the following order, represented in Table 5.

Example 5 For the same example, let us consider the decision-maker dm_1, the set of criteria $C = \{c_1, c_2, c_3\}$, and the set of weights $W_{dm_1} = \{0.4; 0.6; 0.8\}$. $F_{Dif} = 0.80 - 0.40 = 0.40$.

Looking at Table 5 we now know that $l = 3$. We can use algorithm 1 to classify each criterion as:

$$w_{dm1_{c_1}} > 0.8 - 4 \times \frac{0.8 - 0.4}{3} \equiv 0.4 > 0.266 \rightarrow imp_{c1_{dm_1}} = NIC;$$
$$w_{dm1_{c_2}} > 0.8 - 2 \times \frac{0.8 - 0.4}{3} \equiv 0.6 > 0.533 \rightarrow imp_{c2_{dm_1}} = VIC;$$
$$w_{dm1_{c_3}} > 0.8 - \frac{0.8 - 0.4}{3} \equiv 0.8 > 0.666 \rightarrow imp_{c3_{dm_1}} = VIC.$$

Definition 5 Let W_{DM} be the preferences of a set of decision-makers DM where:

$$W_{DM} = \{W_{dm_1}, W_{dm_2}, \ldots, W_{dm_z}\}, \quad z > 0;$$

Definition 6 Let DM be a set of decision-makers where $DM = \{dm_1, dm_2, \ldots, dm_k\}, k > 0$.

Definition 7 Let CP be a criteria preference matrix, where:

$$CP = C \times W_{DM} = \begin{bmatrix} w1_{c_1} & w2_{c_1} & \ldots & wz_{c_1} \\ w1_{c_2} & w2_{c_2} & \ldots & wz_{c_1} \\ \vdots & \vdots & \ldots & \vdots \\ w1_{c_m} & w2_{c_m} & \ldots & wz_{c_m} \end{bmatrix}$$

Example 6 For the same example let us now consider two more decision-makers dm_2 and dm_3, $DM = \{dm_1, dm_2, dm_3\}$, two more sets of weights $W_{dm_2} = \{0.2; 0.8; 0.45\}$, $W_{dm_3} = \{0.7; 0.55; 0.6\}$.

We combined all three sets of weights into $W_{DM} = \{W_{dm_1}, W_{dm_2}, W_{dm_3}\}$ and obtained the following preference matrix:

$$CP_{DM} = C \times W_{DM} = \begin{bmatrix} W_{dm1_{c_1}} & W_{dm2_{c_1}} & W_{dm3_{c_1}} \\ W_{dm1_{c_2}} & W_{dm2_{c_2}} & W_{dm3_{c_2}} \\ W_{dm1_{c_3}} & W_{dm2_{c_3}} & W_{dm3_{c_3}} \end{bmatrix} = \begin{bmatrix} 0.40 & 0.20 & 0.70 \\ 0.60 & 0.80 & 0.55 \\ 0.80 & 0.45 & 0.60 \end{bmatrix}$$

We applied Algorithm 1 to measure the importance given to each criterion by each decision-maker and obtained:

$$CP_{DM} = \begin{bmatrix} 0.40 & 0.20 & 0.70 \\ 0.60 & 0.80 & 0.55 \\ 0.80 & 0.45 & 0.60 \end{bmatrix} = \begin{bmatrix} MC & INC & VIC \\ VIC & VIC & IC \\ VIC & MC & VIC \end{bmatrix}$$

We defined a function which returns 0 or 1 depending if a $w_{z_{cm}}$ was either VIC, IC, or not.

$$F_{highimp} : W_{z_{cm}} \begin{cases} 1, & \text{if } w_{z_{cm}} = VIC \vee w_{z_{cm}} = IC \\ 0 \end{cases}$$

Definition 8 Let HS_c be a set of sums of the best criteria weighting $HS_c = \{hs_{c_1}, hs_{c_2}, hs_{c_3}, \ldots, hs_{c_m}\}$, where:

$$\forall i \in \{1, 2, \ldots, m\}, hs_{c_i} = \sum_{w_{z_{c_i}} \in CP} F_{highimp}(w_{z_{c_i}})$$

is the sum of all elements in a criteria preference matrix CP which are either VIC or IC for each criterion c_m.

Example 7 For the same example using the criteria preference matrix CP_{DM} we would obtain the following sums:

$$\begin{aligned} hs_{c_1} &= \sum_{w_{z_{c_1}} \in CP} F_{highimp}(w_{z_{c_1}}) = 0 + 0 + 1 = 1 \\ hs_{c_2} &= \sum_{w_{z_{c_2}} \in CP} F_{highimp}(w_{z_{c_2}}) = 1 + 1 + 1 = 3 \\ hs_{c_3} &= \sum_{w_{z_{c_3}} \in CP} F_{highimp}(w_{z_{c_3}}) = 1 + 0 + 1 = 2 \\ HS_c &= \{1, 3, 2\} \end{aligned}$$

Step 3 Credibility and expertise readjustment

The third and final step of CAP was to measure the added value to criteria preferences depending on the credibility and expertise of the decision-makers. For this, we used a criteria preference matrix $CP_{DMCredble}$ which contained criteria weights given by each credible decision-maker. Depending on the conflict style (see Table 1) of the decision-maker dm_i the following formula was used to readjust the preference for criterion c_j:

$$\forall dm_i \in DM, \forall c_j \in C, crw_{dm_{i_{c_j}}} = \frac{F_{highimp}\left(W_{dm_{i_{c_j}}}\right) \times CS_{dm_i} + \left(\frac{TP}{ND}\right) \times CO_{dm_i}}{CS_{dm_i} + CO_{dm_i}} \quad (1)$$

where:

- $F_{highimp}\left(W_{dm_{i_{c_j}}}\right)$ returns 1 or 0 depending on the importance given to criterion c_j by decision-maker dm_i;
- CS_{dm_i} is the value of concern for self [1, 2, 3] of the decision-maker dm_i;
- TP is the total sum of the weights given to criterion c_j by each credible decision-maker;
- ND is the total number of credible decision-makers;
- CO_{dm_i} is the value of concern for others [1, 2, 3] of the decision-maker dm_i.

Example 8 For the same example let us consider that decision-maker dm_1 thinks dm_2 and dm_3 are credible, $DMCredible_{dm_1} = \{dm_2, dm_3\}$. Let us also consider that dm_1 has the conflict style 'Obliging'. $CP_{DMCedible_{dm_1}}$ is:

$$CP_{DMCredible_{dm_1}} = \begin{bmatrix} 0.20 & 0.70 \\ 0.80 & 0.55 \\ 0.45 & 0.60 \end{bmatrix} = \begin{bmatrix} INC & VIC \\ VIC & IC \\ MC & VIC \end{bmatrix}$$

We used formula 1 to readjust the weight given to each criterion by decision-maker dm_1 as:

$$\begin{aligned} crw_{dm_{1_{c_1}}} &= \frac{0 \times 1 + \left(\frac{0.20+0.70}{2}\right) \times 3}{1 + 3} = \frac{1.35}{4} = 0.3375 \\ crw_{dm_{1_{c_2}}} &= \frac{1 \times 1 + \left(\frac{0.80+0.55}{2}\right) \times 3}{1 + 3} = \frac{3.025}{4} = 0.75625 \\ crw_{dm_{1_{c_3}}} &= \frac{1 \times 1 + \left(\frac{0.45+0.60}{2}\right) \times 3}{1 + 3} = \frac{2.575}{4} = 0.64375 \end{aligned}$$

Next, we readjusted the value of $crw_{dm_{i_{c_j}}}$ with the level of expertise of the decision-maker dm_i and the inverse of the expertise level (see Table 2) using the following formula:

$$\forall dm_i \in DM, \forall c_j \in C, neww_{dm_{i_{c_j}}} = \frac{crw_{dm_{i_{c_j}}} \times e_{dm_i} + \left(\frac{TP}{ND}\right) \times e'_{dm_i}}{e_{dm_i} + e'_{dm_i}} \quad (2)$$

where:

- $crw_{dm_{i_{c_j}}}$ is the readjusted weight given to criterion c_j by decision-maker dm_i using formula 1;
- e_{dm_i} is the expertise level of decision-maker dm_i;
- TP is the total sum of the weights given to criterion c_n by each credible decision-maker;
- ND is the total number of credible decision-makers;
- e'_{dm_i} is the inverse of the expertise level of decision-maker dm_i.

Example 9 For the same example, let us consider that decision-maker dm_1 has an expertise level $e_{dm_1} = 4$. Using formula 2 we will obtain:

$$neww_{dm_{1_{c_1}}} = \frac{0.3375 \times 4 + \left(\frac{0.20+0.70}{2}\right) \times 2}{4+2} = \frac{2.25}{6} = 0.375$$

$$neww_{dm_{1_{c_2}}} = \frac{0.75625 \times 4 + \left(\frac{0.80+0.55}{2}\right) \times 2}{4+2} = \frac{4.375}{6} = 0.7292$$

$$neww_{dm_{1_{c_3}}} = \frac{0.64375 \times 4 + \left(\frac{0.45+0.60}{2}\right) \times 2}{4+2} = \frac{3.625}{6} = 0.6041$$

We measured the final classification given by a decision-maker dm_i with a criteria preference matrix $CP_{DMCredible_{dm_i}}$ for each criterion c_j using the following formula:

$$\forall dm_i \in DM, \forall c_j \in C, finalw_{dm_{i_{c_j}}} = \left(\frac{hs_{c_j}}{ND}\right) \times \left(\frac{TP}{ND}\right) + \left(1 - \frac{hs_{c_j}}{ND}\right) \times neww_{dm_{i_{c_j}}} \quad (3)$$

Where:

- $neww_{dm_{i,c_j}}$ is the readjusted weight given to criterion c_j by decision-maker dm_i using formula 2;
- hs_{c_j} is the sum of all elements the criteria preference matrix $CP_{DMCredible_{dm_i}}$ which are either VIC or IC for each criterion c_j;
- TP is total sum of the weights given to criterion c_j by each credible decision-maker;
- ND is the total number of credible decision-makers.

Example 10 For the same example decision-maker dm_1 reclassifies each criterion as:

$$finalw_{dm_{1_{c_1}}} = \left(\frac{1}{2}\right) \times \left(\frac{0.20+0.70}{2}\right) + \left(1 - \frac{1}{2}\right) \times 0.375 = \frac{0.90}{4} + \frac{0.375}{2} = 0.4125$$

$$finalw_{dm_{1_{c_2}}} = \left(\frac{2}{2}\right) \times \left(\frac{0.80+0.55}{2}\right) + \left(1 - \frac{2}{2}\right) \times 0.7292 = \frac{1.35}{2} = 0.675$$

$$finalw_{dm_{1_{c_3}}} = \left(\frac{1}{2}\right) \times \left(\frac{0.45+0.60}{2}\right) + \left(1 - \frac{1}{2}\right) \times 0.6041 = \frac{1.05}{4} + \frac{0.6041}{2} = 0.56455$$

Looking only at W_{dm_1} initial setup we have $W_{dm_1} = \{0.4; 0.6; 0.8\}$, and therefore $w_{dm_{1_{c_3}}} > w_{dm_{1_{c_2}}} > w_{dm_{1_{c_1}}}$. Using CAP method which takes into account the preferences, the conflict

Table 6 Multi-criteria problem

	Efficacy	Safety	Convenience	Low cost
Antihistamines	0.98	0.26	0.72	0.47
Corticosteroids	0.60	0.85	0.05	0.60
β-adrenoceptor agonists	0.38	0.51	0.64	0.42
Methylxanthines	0.91	0.07	0.15	0.82
Anticholinergic	0.21	0.89	0.76	0.26

style and the expertise level of the decision-maker as well as the credibility of other decision-makers, the predicted classification will be $finalw_{dm1_{c_2}} > finalw_{dm1_{c_3}} > finalw_{dm1_{c_1}}$.

4 Experiments

To test the CAP, we developed a prototype which could load a multi-criteria problem, and analyzed and compared each solution found with all chosen and implemented methods including the analytic hierarchy process (AHP) (Saaty 1988), TOPSIS (Tzeng and Huang 2011) and a typical utility function method (UF).

We opted to compare CAP with these three methods since our approach followed a very different perspective from what is currently observed under the topic of MCDA. Therefore we thought it was relevant to compare CAP with some of the more recognized methods that gave origin to many existing proposals we know today. Since our main focus was to support group decision-making, the developed prototype was also a multi-agent system where each agent represented a real decision-maker.

The adopted multi-criteria problem was to choose a medication. All considered criteria and alternatives were selected based on the work of De (1993). Each agent represented one member of the medical team. All alternatives were classified according to four criteria: efficacy, safety, convenience and low cost. These criteria were numeric and of maximization. In Table 6, all specifications are presented for each considered alternative (this information did not represent real data and was only used as an example for each performed simulation).

The satisfaction was used as a metric to evaluate the overall performance of the different methods. The satisfaction metric was used to understand the perception (by the decision-maker) of the quality of the chosen alternative or the alternative supported by most agents at a certain time. For that, the notion of satisfaction that was used was the one proposed in (Carneiro et al. 2015a). It was the only satisfaction metric existing in literature adapted to this type of context. According to this model, the satisfaction of each decision-maker corresponded to the perception of the quality of the decision and was created based on assumptions which reflected what a decision-maker psychologically considered as a good decision. The satisfaction was measured in two parts (only CAP includes the second part). It was first measured objectively through the formulas (4), (5) and (6).

$$D_{Lost} = Alt_F - Alt_P \tag{4}$$

$$A_{Conversion} = 2 \times Alt_F - 1 \tag{5}$$

$$D_{Satisfaction} = 1 - |A_{Conversion}| \times D_{Lost} + A_{Conversion} \tag{6}$$

Table 7 Head table with the results obtained for each method throughout 10,000 simulations

	CAP	TOPSIS	AHP	UF
Average	0.3309	0.3193	0.2966	0.3238
Minimum	−0.0858	−0.0886	−0.1776	−0.1410
Maximum	0.8119	0.7838	0.7838	0.7838
Median	0.3285	0.3183	0.2960	0.3203

where:

- D_{Lost} is the loss of decision maker's satisfaction in the difference between the assessments made for the alternative chosen by the group and for his preferred alternative. The loss is zero when the chosen alternative is the same as his preferred alternative;
- Alt_F is the assessment made by the participant for the final alternative, alternative chosen by the group;
- Alt_P is the assessment made by the participant for his preferred alternative;
- $A_{Conversion}$ is the conversion of the assessment made by the participant in the range $[-1, 1]$.

The second part related the $D_{Satisfaction}$ and the behaviour defined by the decision-maker. In this second part, the satisfaction was measured according to the values of the agent's defined behaviour [agent's with defined behaviour follow the work proposed in Martinho et al. (2015)] for concern for self and concern for others dimensions. So, the $D_{Satisfaction}$ was remeasured using formula 7.

$$D_{Satisfaction} = \frac{D_{Satisfaction} \times CS + OAAD_{Satisfaction} \times CO}{CS + CO} \tag{7}$$

where:

- CS is the value of concern for self $[1, 2, 3]$;
- $OAAD_{Satisfaction}$ is the average satisfaction of all remaining agents;
- CO is the value of concern for others $[1, 2, 3]$.

In order to evaluate CAP, we created several simulation environments referring to the multi-criteria problem presented above. The first simulation environment tested 12 agents. For this environment 10,000 simulations were run and in each simulation the four methods (CAP, TOPSIS, AHP and UF) were used to study and compare the results obtained using the same configuration parameters. Table 7 represents the main data retrieved in all those simulations. It was easy to observe that the data obtained using each method was very similar. We verified, however, agents' satisfaction throughout each simulation was higher when CAP was used. Besides this, CAP also included best results towards minimum, maximum and median values.

In order to know if the average satisfaction level obtained in CAP was indeed higher throughout each simulation, the added satisfaction levels are presented in Fig. 1 (X-axis represents the simulation number and Y-axis represents the sum of the satisfaction level) for each method from a sample of 100 simulations. We verified that the values obtained in Table 7 corresponded to the growth presented by each method. As mentioned before the general data presented in each method was very similar. However, we intended to study the results for each method in situations where the chosen alternative or decision was different. More specific results were then presented which resulted from a direct comparison between CAP and all other considered methods.

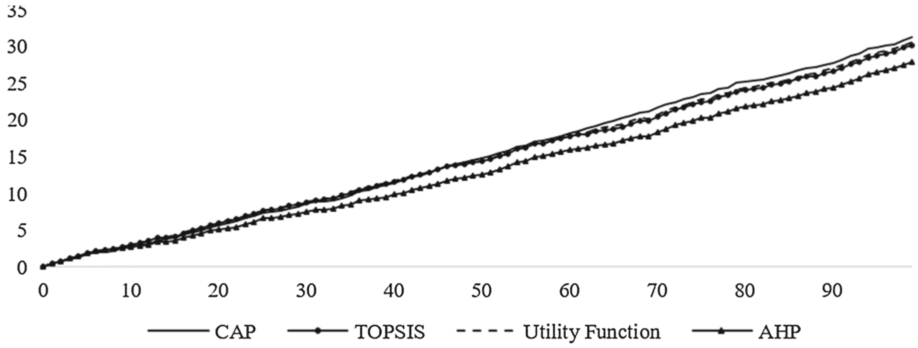

Fig. 1 Graphic with main comparisons taken with a sample of 100 simulations from 10,000 total simulations

Table 8 Comparison between CAP and AHP in 10,000 simulations

	CAP	AHP
Count	6241	3759
Average	0.0830	0.0464
Standard deviation	0.0726	0.0375
Maximum	0.4408	0.2706
Minimum	2.3872×10^{-6}	4.5927×10^{-6}
Median	0.0614	0.0381

As mentioned before the general data presented in each method was very similar. However, what we intended to study was the results for each method in situations where the chosen alternative or decision was different. The more specific results were then presented which resulted from a direct comparison between CAP and all other considered methods.

Table 8 shows the results collected for CAP and AHP. In 10,000 simulations CAP obtained a higher satisfaction in 6241 occasions. The average, standard deviation, maximum, minimum and median values concern CAP when the satisfaction obtained was higher and corresponded to the difference of satisfaction between CAP and AHP (CAP–AHP). Likewise, when AHP obtained a higher satisfaction those values corresponded to the difference of satisfaction between AHP and CAP (AHP–CAP). It was verified that the average obtained in CAP was almost the double compared to the average obtained by AHP. The standard deviation value indicated that the average in AHP was less variable. The minimum, maximum and median values obtained by CAP were all higher compared to the values obtained by AHP.

CAP selected a different alternative from AHP in 3233 occasions. Figure 2a (X-axis represents the simulation number and Y-axis represents the satisfaction level) shows the results from a sample of 50 simulations. It was verified that the satisfaction obtained was almost always higher when CAP was used. The average satisfaction level obtained by agents in those 3233 simulations was of 0.2944, while AHP was only of 0.1995. Besides this, in 2609 of those 3233 simulations CAP obtained a higher satisfaction.

Figure 2b (X-axis represents the simulation number and Y-axis represents the satisfaction level) shows the results obtained in a sample of 50 simulations of 6767 where the alternative selected by CAP was the same as AHP. These results confirmed that the satisfaction obtained by agents using CAP and AHP was always very similar. Besides this it was verified that the average satisfaction level obtained by CAP in these 6767 simulations was of 0.3484 and AHP

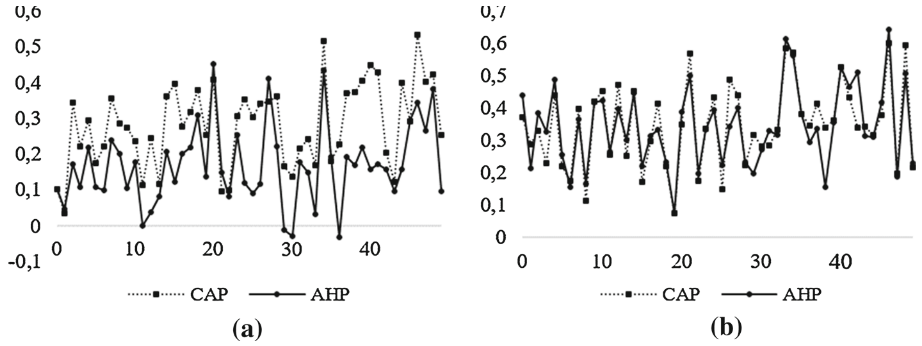

Fig. 2 Comparison between CAP and AHP towards the satisfaction obtained in simulations. **a** Where the chosen alternative (output) is different, **b** where the chosen alternative (output) is the same

Table 9 Comparison between CAP and UF in 10,000 simulations

	CAP	UF
Count	5448	4552
Average	0.0526	0.0451
Standard deviation	0.0438	0.0358
Maximum	0.3826	0.2656
Minimum	2.3876×10^{-6}	4.5927×10^{-6}
Median	0.0423	0.0377

was of 0.3429. CAP obtained a higher satisfaction in 3632 simulations while AHP obtained a higher satisfaction in 3135 simulations.

Table 9 shows the results collected for CAP and UF. In 10,000 simulations CAP obtained a higher satisfaction in 5448 occasions. The average, standard deviation, maximum, minimum and median values concerned CAP when the satisfaction obtained was higher and corresponded to the difference of satisfaction between CAP and UF (CAP–UF). Likewise, when UF obtained a higher satisfaction those values corresponded to the difference of satisfaction between UF and CAP (UF–CAP). It was verified that the average obtained in CAP was almost the same as the average obtained by UF. The standard deviation, minimum, maximum and median values obtained by both methods were also very similar.

CAP selected a different alternative from UF in 1072 occasions. Figure 3a (X-axis represents the simulation number and Y-axis represents the satisfaction level) shows the results from a sample of 50 simulations. Identical to CAP/AHP comparison, in this situation CAP also obtained a higher satisfaction in most of the times compared to UF. The average satisfaction level obtained by agents in those 1072 simulations was of 0.2840 and UF was only of 0.2365. It was verified that the average difference was inferior in this situation compared to CAP/AHP comparison. Besides this, CAP obtained a higher satisfaction in 770 out of the 1072 simulations.

Figure 3b (X-axis represents the simulation number and Y-axis represents the satisfaction level) shows the results obtained in a sample of 50 simulations of 8928 where the alternative selected by CAP was the same as UF. These results were identical to the results obtained in CAP/AHP comparison with the satisfaction obtained by CAP and UF also being very similar. Besides this it was verified that the average satisfaction level obtained by CAP in these 8928

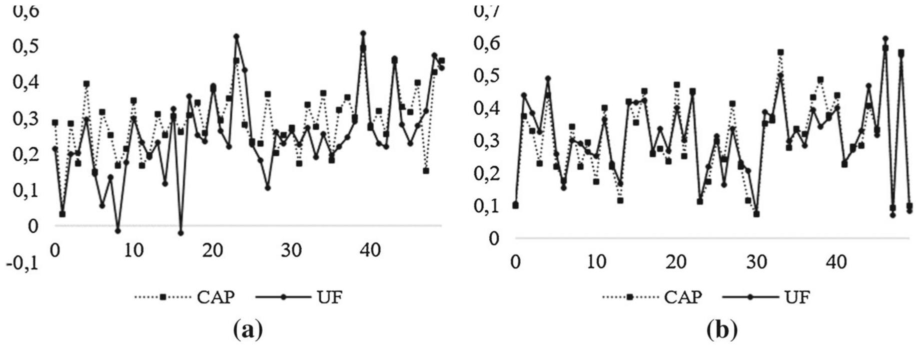

Fig. 3 Comparison between CAP and UF towards the satisfaction obtained in simulations. **a** Where the chosen alternative (output) is different, **b** where the chosen alternative (output) is the same

Table 10 Comparison between CAP and TOPSIS in 10,000 simulations

	CAP	TOPSIS
Count	5536	4464
Average	0.0580	0.0460
Standard deviation	0.0506	0.0366
Maximum	0.3826	0.2589
Minimum	2.3872×10^{-6}	4.5927×10^{-6}
Median	0.0423	0.0377

simulations was of 0.3366 and UF was of 0.3332. CAP obtained a higher satisfaction in 4678 simulations while UF obtained a higher satisfaction in 4250 simulations.

Table 10 shows the results collected for CAP and TOPSIS. In 10,000 simulations CAP obtained a higher satisfaction in 5536 occasions. The average, standard deviation, maximum, minimum and median values concerned CAP when the satisfaction obtained was higher and corresponded to the difference of satisfaction between CAP and TOPSIS (CAP–TOPSIS). Likewise, when TOPSIS obtained a higher satisfaction those values corresponded to the difference of satisfaction between TOPSIS and CAP (TOPSIS–CAP). It was verified that the average obtained in CAP was almost the same as the average obtained by TOPSIS. The standard deviation, minimum, maximum and median values obtained by both methods were also very similar.

CAP selected a different alternative from TOPSIS in 1506 occasions. Figure 4a (X-axis represents the simulation number and Y-axis represents the satisfaction level) shows the results from a sample of 50 simulations. Identical to CAP/AHP and CAP/UF comparisons, in this situation CAP also obtained a higher satisfaction in most of the times compared to TOPSIS. The average satisfaction level obtained by agents in those 1506 simulations was of 0.2681 and TOPSIS was only of 0.21. It was verified that the average difference was inferior in this situation compared to CAP/AHP comparison and was very similar to the CAP/UF comparison. Besides this, CAP obtained a higher satisfaction in 1063 out of the 1506 simulations.

Figure 4b (X-axis represents the simulation number and Y-axis represents the satisfaction level) shows the results obtained in a sample of 50 simulations of 8494 where the alternative selected by CAP was the same as TOPSIS. These results were identical to the results

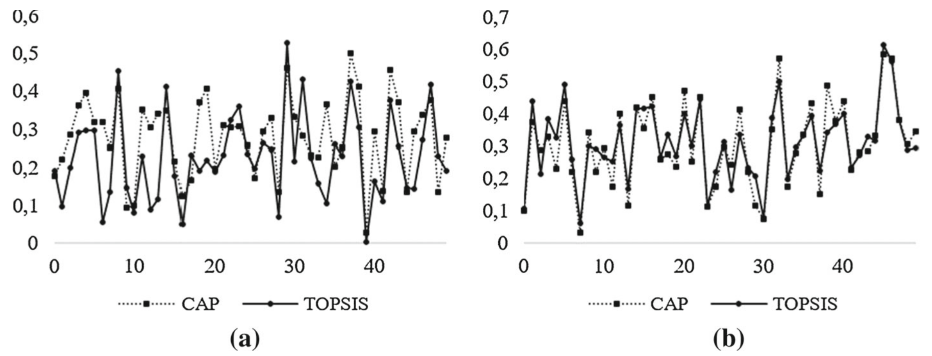

Fig. 4 Comparison between CAP and TOPSIS towards the satisfaction obtained in simulations. **a** Where the chosen alternative (output) is different, **b** where the chosen alternative (output) is the same

Table 11 Satisfaction comparison between all methods

	AHP	CAP	UF	TOPSIS
Best	191	5195	308	48
Best or equal	3516	5195	4317	4272

obtained in CAP/UF comparison with the satisfaction obtained by CAP and TOPSIS also being very similar. Besides this it was verified that the average satisfaction level obtained by CAP in these 8494 simulations was of 0.3421 and TOPSIS was of 0.3380. CAP obtained a higher satisfaction in 4473 simulations while TOPSIS obtained a higher satisfaction in 4021 simulations.

To close the study on this simulation environment (10,000 simulations) we compared the number of times when each method obtained the best satisfaction compared with the other methods. Table 11 shows the data collected. It was verified that the satisfaction level obtained was higher by CAP in 5195 simulations, by AHP in 191 simulations, UF in 308 simulations and TOPSIS in only 48 simulations. In situations when more than one method obtained the same highest satisfaction level it was possible to observe that CAP obtained the same result and the remaining methods increased significantly. It was possible to conclude that in 4258 simulations more than one method achieved the same highest satisfaction level. Because of that it was important to figure if CAP obtained much worse results. Average satisfaction values obtained in the 4805 simulations when CAP did not achieve the best results were of 0.2975, 0.2833, 0.3238 and 0.3204 for AHP, CAP UF and TOPSIS respectively.

Another point that was studied was related with the differences between criteria weighting and rankings comparison done by each method. In Table 12, it is presented the values obtained by each method for criteria weighting and rankings comparison in four simulations. In each simulation a random agent was selected and used as reference. For this problem (not too complex, with just four criteria) it was verified that AHP and TOPSIS obtained the same criteria ranking (in all simulations) even with different criteria weighting. In case of CAP, the criteria ranking was similar to AHP and TOPSIS but with some differences. For example, in the second simulation, CAP classified "Safety" and "Convenience"? as VIC while AHP and TOPSIS classified those same criteria differently even though their weighting was very similar. Another interesting fact that was verified was related with how AHP and TOPSIS criteria ranking was always done based on the weighting value which resulted in a sequential order $(1, 2, 3, \ldots, n)$. In case of CAP criteria ranking this order was not necessarily sequential

Table 12 Example of criteria ranking according to each method

Simulations	Criteria	CAP		AHP		TOPSIS	
		Weight (%)	Rank	Weight (%)	Rank	Weight (%)	Rank
1	Efficacy	–	MC	14.35	3	23.15	3
	Safety	–	VIC	58.49	1	45.37	1
	Convenience	–	INC	4.55	4	1.85	4
	Low cost	–	IC	22.61	2	29.63	2
2	Efficacy	–	INC	5.10	3	0.50	3
	Safety	–	VIC	45.86	1	49.74	1
	Convenience	–	VIC	43.93	2	49.24	2
	Low cost	–	INC	5.10	3	0.50	3
3	Efficacy	–	VIC	44.49	1	43.47	1
	Safety	–	INC	5.16	4	3.86	4
	Convenience	–	NIC	7.76	3	9.66	3
	Low cost	–	VIC	42.56	2	42.99	2
4	Efficacy	–	MC	16.38	3	25.47	3
	Safety	–	VIC	55.66	1	43.39	1
	Convenience	–	INC	4.58	4	0.94	4
	Low cost	–	IC	23.36	2	30.18	2

and there were situations where two or more criteria were given the same rank. For example in the second simulation, CAP ranking classified two criteria as VIC and two criteria as INC in a scale with the following decreasing order: VIC, IC, MC, NIC and INC.

For the last study, a simulation environment was created to understand how the results obtained by each method varied depending on the number of agents (decision-makers) involved in the decision-making process. 1000 simulations were run for each group of decision-makers (2, 4, 8, 10, 20, 30, 40, 50, 100, 200, 300, 400 and 500 agents) totaling 13,000 simulations. Similarly to previous procedure, CAP was compared directly with each other method. The main goals were to measure the variation of the average satisfaction level obtained by each method with the variation of the number of decision-makers involved in the process and also measure how that variation brought each method closer according to the number of equivalent decisions.

Figure 5a (X-axis represents the number of agents and Y-axis represents the satisfaction level) shows the average satisfaction level obtained by CAP and AHP (when the achieved decisions were different) for each set of 1000 simulations done with each group of decision-makers (2, 4, 8, 10, …, 500). It was verified that the satisfaction obtained by AHP was relatively the same throughout each scenario. In case of CAP the average satisfaction level obtained was higher when there were a small number of decision-makers involved in the process and decreased and stayed relatively constant as the number of decision-makers involved in the process increased. However, the average satisfaction level obtained by CAP was always higher compared to AHP in all scenarios, more particularly when the number of decision-makers was less than 20.

Figure 5b (X-axis represents the number of agents and Y-axis represents the number of simulations) shows the number of times in each scenario when CAP and AHP reached same or different decisions. It was possible to notice that there were more different decisions when

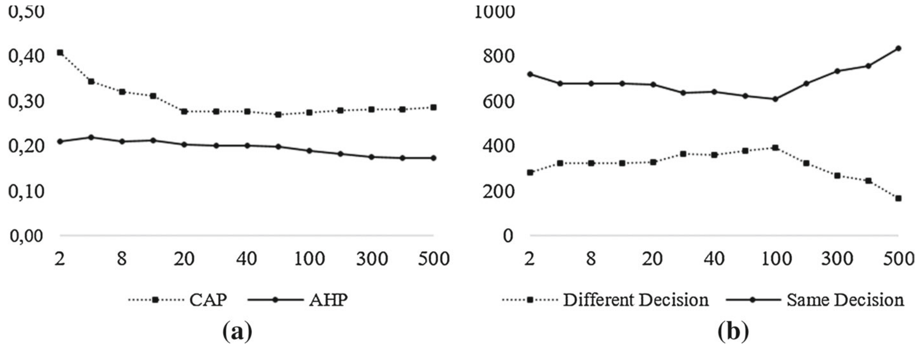

Fig. 5 Comparison between CAP and AHP. **a** Satisfaction obtained, **b** average number of different and same decision

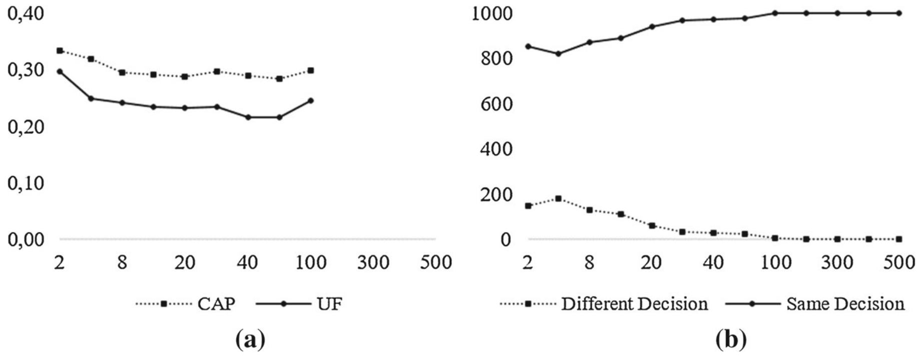

Fig. 6 Comparison between CAP and UF. **a** Satisfaction obtained, **b** average number of different and same decisions

the number of decision-makers involved in the process ranged from 30 to 100. Decisions were least different when 500 decision-makers participated in the process (83.3%).

Figure 6a (X-axis represents the number of agents and Y-axis represents the satisfaction level) shows the average satisfaction level obtained by CAP and UF (when the achieved decisions were different) for each set of 1000 simulations done with each group of decision-makers (2, 4, 8, 10, …, 500). It was verified that the average satisfaction level obtained in both methods was very similar. However, CAP still obtained better results compared with UF in each scenario. In scenarios where more than 100 decision-makers were considered (200, 300, 400 and 500) there was no average satisfaction level obtained as both methods always reached the same decision.

As can be seen in Fig. 6b (X-axis represents the number of agents and Y-axis represents the number of simulations) when the number of decision-makers involved in the process is higher than 100 both methods always reached the same decision. It was also verified that the most significant difference in the decisions reached by both methods occurred between 2 and 20 participant agents.

Figure 7a (X-axis represents the number of agents and Y-axis represents the satisfaction level) shows the average satisfaction level obtained by CAP and UF (when the achieved decisions were different) for each set of 1000 simulations done with each group of decision-makers (2, 4, 8, 10, …, 500). Unlike previous methods comparisons, in this situation CAP

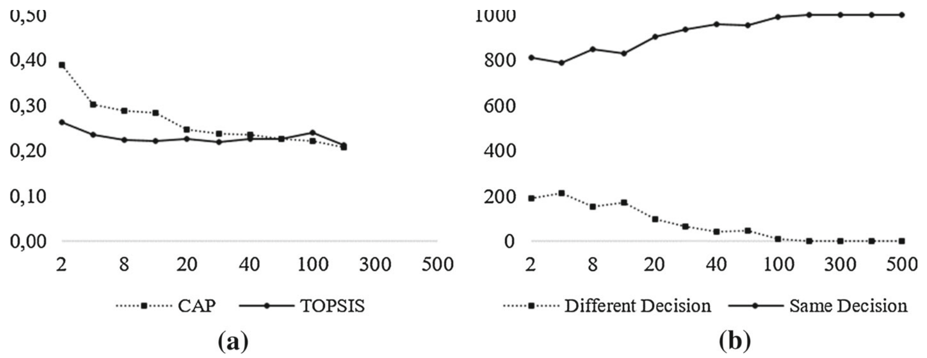

Fig. 7 Comparison between CAP and TOPSIS. **a** Satisfaction obtained, **b** average number of different and same decisions

obtained a lower average satisfaction level than TOPSIS in two scenarios (100 and 200 decision-makers), but still not too relevant. When we considered between 2 and 10 decision-makers participating in the process, CAP obtained an average satisfaction level considerably higher than TOPSIS. When the number of decision-makers was greater than 10, both methods obtained very similar satisfaction levels. In this comparison it was also verified that when there were more than 200 decision-makers participating in the process, both methods reached the same decision.

As can be seen in Fig. 7b (X-axis represents the number of agents and Y-axis represents the number of simulations) when the number of decision-makers participating in the process is greater than 200, both methods always reached the same decision. In the scenario with 200 decision-makers both methods achieved different decisions in just two simulations (out of 1000). It was also verified that the most significant difference in the decisions reached by both methods occurred between 2 and 10 participant agents.

5 Discussion

Including cognitive aspects in MCDA methods is something still inexistent in literature (to the best of our knowledge). Some "not rational"? questions are known to affect the decision-making process (Simon 1987). The reason why MCDA methods do not consider cognitive aspects might be related to something more important than just not agreeing or accepting their advantage. Which cognitive aspects should be considered? How should they be included in the decision-making process? etc.

Let us imagine a simple scenario where a family is trying to decide a restaurant to celebrate the anniversary of one of its family members. In this scenario, it is easy to understand the advantage of configuring/modelling not only the preferences towards criteria and alternatives but also the intentions of each family member. It is very likely that the main goal (or main intention) of each member is to please the one whose birthday is being celebrated. Therefore, if the decision reached was choosing a restaurant which is the favourite of some of the family members but on the other hand makes the person whose birthday is being celebrated very unsatisfied, that dissatisfaction will affect all family members and make them think it was a bad decision. Any existing MCDA method is yet not capable to deal with this kind of problem, unlike CAP which is proposed for the first time in this work.

It was verified that CAP, on average, managed to be almost always superior to any other tested method. CAP had an even more considerable advantage compared with other methods when the decision reached was different from the others presented by those methods. It is important (and somehow interesting) to refer that in situations where the decision reached by all methods was the same, even if CAP considered cognitive aspects, the average satisfaction values obtained were be very similar.

Including the “irrational”? component to the typical MCDA rationality provided better results in almost all scenarios that were considered. It was verified that CAP lost many of its benefits when considering a group with more than 20/30 decision-makers. In those situations CAP revealed a very similar performance compared to TOPSIS method or an UF. However, this situation was a good example to consider cognitive aspects in CAP correctly. The intentions of each decision-maker in a very large group would be diluted. It is unthinkable to consider using cognitive aspects, for example, for each voter in presidential elections of a country. CAP was advantageous especially when the group decision-makers varied between 2 and 20 elements. This allowed us to conclude that including cognitive aspects could be very irrelevant if we were dealing with very large groups of decision-makers.

It must also not be forgotten that CAP was very easy to configure and did not require more data than what was presented in (Carneiro et al. 2015c). On the other hand, using AHP which is considered to have a very high configuration cost (Dehe and Bamford 2015) might result in decision-makers refusing or rejecting to use software with such kind of approach.

With this work a new hypothesis of research is raised: The advantages identified in this work by using CAP method will be even more evident in real scenarios. This happens because it is mathematically impossible to define agents that can create and imagine typical intentions of a human being in very specific real contexts.

6 Conclusion and future work

Nowadays the decisions made by managers and executives are mostly performed in groups. Thereby, group decision-making is a process in which a group of people, called participants, act collectively analyzing a set of variables, considering and evaluating the available alternatives in order to select one or more solutions. The number of participants involved in the process is variable and all of them may be at the same space/place at the same time or either geographically dispersed at different times.

Usually, MCDA methods are techniques used to support the decision-making process. MCDA methods allow decision-makers to make a certain multi-criteria problem configuration and based on that configuration a solution will be suggested (supposedly the best). MCDA methods, however, have certain problems (according to literature) due to the completely analytical and rational way in which the multi-criteria problems are considered.

In this work, we presented CAP which is MCDA method that included cognitive aspects in its analysis and that let decision-makers configure not only their preferences (criteria and alternatives) but also their intentions. CAP allowed decision-makers to configure a multi-criteria problem (criteria and alternatives) as well as their behaviour style (which could be seen as their position before the problem and the decision-making group), their expertise level and select which other decision-maker was credible or not. It also had the advantage of only requiring information that allowed fast configurations (resulting in a very high level of usability) with the particularity that CAP worked even if the decision-maker did not configure any of the points mentioned before. This way, CAP could process all the information and suggested a solution combining the rational component with the irrational dimension (which is sometimes difficult to explain by decision-makers themselves).

The results achieved in this work confirmed the advantage of what was being expressed in literature for many decades. Considering cognitive aspects brought advantages to the group decision-making process and allowed reaching higher quality decisions and with more satisfaction. Moreover, we made this idea computationally feasible. CAP demonstrated that it could almost always be superior than some of the most acknowledged MCDA methods existing in literature. Besides this, CAP demonstrated that it was especially useful in process that included a maximum number of 20 decision-makers.

As future work, there are still some points to be studied. In first place, we intend to compare CAP with most recent MCDA methods. After that, we intend to compare CAP with those methods in a case of study with real decision-makers, since we believe that in a real environment CAP is capable to be even better than other MCDA methods. Finally, we want to learn with all these processes and work in shaping CAP to make it an even stronger and more complete MCDA method.

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3.5 DYNAMIC ARGUMENTATION IN UBIGDSS

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REGULAR PAPER

Dynamic argumentation in UbiGDSS

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Abstract Supporting and representing the group decision-making process is a complex task that requires very specific aspects. The current existing argumentation models cannot make good use of all the advantages inherent to group decision-making. There is no monitoring of the process or the possibility to provide dynamism to it. These issues can compromise the success of group decision support systems if those systems are not able to provide freedom and all necessary mechanisms to the decision-maker. We investigate the use of argumentation in a completely new perspective that will allow for a mutual understanding between agents and decision-makers. Besides this, our proposal allows to define an agent not only according to the preferences of the decision-maker but also according to his interests towards the decision-making process. We show that our definition respects the requirements that are essential for groups to interact without limitations and that can take advantage of those interactions to create valuable knowledge to support more and better.

Keywords Argumentation · Automatic negotiation · Multi-agent systems · Group decision support systems · Ubiquitous computing

1 Introduction

There are several reasons which lead decisions to be made in group: to improve the quality of the decision, to share workloads, to gain support among stakeholders, to train less experienced group members, and due to the majority of organograms existing nowadays [1,25]. It has been proven that groups obtain performances that are qualitatively and quantitatively superior

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Published online: 17 August 2017 Springer to the individual performance [24,43]. However, in order to take advantage of the benefits behind group decision-making, it is necessary to create conditions in which groups can perform certain tasks, such as generating ideas and solutions through group interaction [21, 47]. It is considered that with the group decision-making process, members will enhance the ability to learn and stimulate the cognition level [31,38]. Moreover, studies [24] show that cognitive stimulation helps people to think of new ideas, "unique combination or sub-ideas, or a complex solution whose total value is greater than the sum of its parts".

Group decision support systems (GDSS) appeared with the goal to support groups in the decision-making process [13]. They have been studied over the past 30 years and have become one of the most important investigation topics in the area of artificial intelligence [12,13,25, 35]. With the appearance of global markets, the growth of multinational enterprises and a more global vision of the planet, we easily find chief executive officers and top managers (decision-makers) spread around the world, in countries with different time zones [20]. Nowadays, the study of GDSS has been oriented to support groups with members that cannot gather at the same place and at the same time [30]. In order to provide an answer and operate correctly in this type of scenarios the traditional GDSS have evolved to what we identify today as Ubiquitous group decision support systems (UbiGDSS). The UbiGDSS support the decision-making process by using the main characteristics of ubiquity ("anytime and "anywhere") [11,30]. For UbiGDSS to be advantageous, they must share a number of features that put them above all the traditional GDSS. In order to support the decision-making process in an ubiquitous context, it makes sense that UbiGDSS should: allow automatic negotiation, represent interests of decision-makers, allow the existence of a process, generate ideas, discuss points of view, etc [5,8]. However, something is wrong with GDSS that we know today. Everyone has acknowledged the benefits of this type of systems; however, we do not actually see these systems being used in reality, and it is not because the concept is still fresh. In fact, it is impossible to identify the reasons that lead to their absence and why they are not accepted in the industry sector nowadays. On the other hand, what we know is that most of artificial intelligence techniques proposed in the literature that could be used in UbiGDSS go against what are considered to be the benefits of group decision-making.

In this work, we propose a refreshing look into the concept of what and how should be the artificial intelligence mechanisms that compose an UbiGDSS. For that, we introduce a dynamic argumentation framework, which provides the system with the features that are necessary for decision-makers to take advantage of the benefits of group decision-making. Our proposal intends to follow decision-makers throughout the entire process. Our approach allows a group of decision-makers, where each agent represents a decision-maker, to seek a possible solution to a problem (choosing between several alternatives) while taking into account all the preferences of the decision-makers. Besides this, and considering that the decision-makers can understand the conversation performed between agents, those agents will also be able understand the new arguments created and exchanged between decision-makers. These new arguments can be processed and used by agents not only to advice decision-makers, but also to find solutions throughout the decision-making process.

With this work, we intend to change the current perspective on UbiGDSS. The idea is that decision-makers see the system as something that is easy to use and that guides them throughout the decision-making process, helps them to achieve better decisions, is clear, does not inhibit the generation of new ideas, allows decision-makers to create new arguments, etc. Our approach intends, above everything else, to promote group interaction and help achieving the typical high-quality decisions that are common in face-to-face meetings. We believe that our proposal will allow to overcome many issues while supporting ubiquitous group decision-making, but mainly (1) make it possible for both agents and decision-makers to use a dialogue which is clear to everyone involved in the decision-making process (2) let both agents and decision-makers to take advantage of the knowledge which is generated and (3) not force decision-makers with information formulation patterns which may compromise the usability of the entire system as well as the process.

The rest of the paper is organized in the following order: Sect. 2 exposes the literature review of most recent works related to argumentation-based negotiation. In Sect. 3, our approach is presented and the definition of the argumentation model is described. In Sect. 4, we can find the evaluation and results of this work, and in Sect. 5 the discussion is presented. Finally, some conclusions are taken in Sect. 6, along with the work to be done hereafter.

2 Related work

In the literature, there are various negotiation models adapted to decision-making [19,26, 27,29,35]. To study argumentation (in the perspective of automated negotiation), it is crucial to read Dung [14] "On the acceptability of arguments and its fundamental role in non monotonic reasoning, logic programming and n-person games," Kraus et al. [28] "Reaching agreements through argumentation: a logical model and implementation," Sierra et al. [44] "A framework for argumentation-based negotiation," and other works in this area. However, in this document, only the most recent literature will be reviewed.

Heras et al. [22] analysed how argumentation schemes theory can be used to formalize and structure online discussions and user opinions. They considered a social network to be an abstraction of social structures that connect individuals or organizations. They distinguished implicit and explicit social networks and presented several features that could be used to define those networks (purpose, nodes, roles, etc.). They also identified three main advantages of applying argumentation schemes to social network business (to provide a formal structure to opinions and recommendations, to provide a way of evaluating user opinions and recommendations, and to provide a formal structure to the dialogue). As a final remark, they believe that argumentation can enhance business driven social networking.

Sánchez-Anguix et al. [42] proposed and studied the performance of several intra-team strategies that could be used by negotiation teams. These strategies define how the communication is carried out between team members and how decisions can be made (which requests are sent to the opponent and what mechanisms are used for the opponent to accept or refuse the request). They concluded that the negotiation environment (diversity, negotiation on time, concession strategy) affects greatly the performance of the intra-strategy that is chosen. They also referred to the fact of their approach being new in the literature and that they could further improve its performance by considering more environmental conditions (opponent strategies, non-static team memberships, etc.)

Van der Weide et al. [46] published a scientific work where they proposed a formalism to argue on a meta-level about which argument an agent should select in a given persuasion dialogue. They claimed their approach is easier to design compared to a purely quantitative approach, it allows the use of criteria that are partial and/or incommensurable, and it is possible for the agent to explain why a certain argument is selected.

El-Sisi and Mousa [15] presented a paper where they analysed the benefits of argumentation-based negotiation (ABN) against proposal-based approaches (PBA). They considered the possibility to exchange additional information as the biggest advantage of ABN. They concluded that the argumentation increased the quality of the agreements. Another very important fact was that all the failed examples in PBA become accepted in

ABN. They stated the ABN is much better than PBA in terms of the quality of the agreements and the quantity of unsuccessful negotiations.

Booth et al. [4] addressed a work where they proposed a way to measure and quantify the disagreement in argument-based reasoning. They highlighted the need for an approach to measure the distance between different positions. To achieve this objective, they presented several different distance functions. As future work, they pretend to continue studying this issue and apply it to the problems of revision and judgement aggregation in argumentation.

Müller and Hunter [37] published a work proposing the use of argumentation to satisfy the needs to support the decision-maker and to document the reasons behind decisions. Their framework consists in two different steps: the first step is related to the creation of arguments, and the second step is to consider arguments created and choose the best alternative. Although their work has a strong relation with industry, they did not present any validation.

Bonzon et al. [3] presented an extended abstract where they proposed a reasoning mechanism "that allows negotiating agents to take into account information about their counterparts". To validate their approach, they ran a wide set of experiments, where they compared the negotiation strategy with and without their approach. They concluded that the new approach improves the performance of the system (namely the length of the negotiation and the quality of the agreement).

Wyner et al. [48] presented a notable work about abstract argumentation and argumentation schemes. Their idea was to integrate the argumentation schemes with abstract argumentation through a functional language. They did not run any tests until then; however, they intend to "implement argumentation schemes in a database for Web-based applications and functional or logic programs that instantiate the argumentation schemes, as well as to generate arguments, calculate attacks and determine extensions".

Heras et al. [23] proposed an argumentation framework for multi-agent systems using case-based reasoning. In their framework, the agents use arguments to reach an agreement. During the dialogue, the arguments can be classified as acceptable, unacceptable, or undecided. They evaluated their system in terms of knowledge which agents have about the social context of their partners, performance, percentage of agreement and influence on the amount of argumentation knowledge of each agent. They concluded that arguments used by experts are usually preferred; agents using their argumentation framework usually provide more accurate solutions and achieve higher percentages of agreement compared to agents who do not use it; the more knowledge an agent possess about the context of the argumentation process, the number of agreements as well as the number of agreeing agents will also increase. However, they also pointed to the fact that achieving a consensus could be difficult in case all agents had the same amount of knowledge and, therefore, had the same persuasive power.

Fan et al. [16] published a scientific work about assumption-based argumentation for decision-making including preferences over goals. One of the most interesting points of this work is the possibility to define preferences over combined goals. They applied their approach to a case study in medical research area, and they obtained satisfactory results. They claimed that their approach is easy to apply to other domains.

Parsons et al. [39] produced a research where they included the concept of trust in their argumentation-based approach. The focus of their work is to support the decision-making in scenarios where trust is variable. In their work, they used an example of military decision-making where they applied their argumentation-based approach. However, no results were presented, nor any kind of evaluation.

Fan and Toni [17] presented a relevant work about assumption-based argumentation. In this work, they presented two different frameworks to represent decision-making. They introduced very interesting notions of dominant decisions: strongly dominant, dominant and weakly dominant. In one of their frameworks, they included the possibility to define preferences over goals. The main advantage of their work is the possibility to explain the selected decisions through argumentation-based justification. However, they considered important to continue the studies for decision-making with preference.

Fan et al. [18] addressed a work about assumption-based argumentation. They considered that most works found in the literature related to argumentation-based decision-making did not pay attention to decision-making among multiple agents. The main contribute of this paper is how it covers the entire decision-making process: decision frameworks, argumentation-based computation, dialogues and a real-world application with implementation. They concluded that successful dialogues generate good decisions.

Marey et al. [32] published a paper where they included uncertainty in argumentation-based negotiation. This work came in the sequence of the one presented in Marey et al. [33]. They conducted a case study (buyer/seller scenario) based on their proposed approach and concluded that with their techniques negotiating agents achieve better results than non-negotiating agents.

Marey et al. [34] addressed the problematic of negotiation in ambiguous conditions. They proposed a framework capable of tackling the agents' uncertainty. Their framework allows to measure agents' uncertainty and helps them to select better choices among the available possibilities. They ran a case study (Buyer/Seller), and they considered their results were better than others that use pure argumentation without considering uncertainty.

Sklar et al. [45] conducted a study in order to evaluate the effectiveness of "ArgTrust". The "ArgTrust" is an interactive application developed to help human users in the decision-making process [39]. In this work, they tested the "ArgTrust" in an ambiguous and complex scenario, where participants completed pre-, mid- and post-surveys based in their understanding about a certain scenario, before and after use "ArgTrust". The major conclusion is that "ArgTrust" has contributed to help users "consider their decisions more carefully".

3 The argumentation model

In this paper, we consider the following structure of a decision problem: there are a set of possible alternatives A, a set of criteria C and a set of agents Ag, such that an alternative $a \in A$ has a value for all the defined criteria C. The decision problem has a defined communication language $\mathcal{L}_c$ which allows agents A_g to communicate. In order to operate with the defined $\mathcal{L}_c$, there is a set of algorithms $\mathcal{L}_a$, which specify for each locution $\varphi \in \mathcal{L}_c$ its effect. The relations between alternatives, criteria, agents, communication language and algorithms jointly form a decision system, represented as follows:

Definition 1 A decision system $(C, A, A_g, \mathcal{L}_c, \mathcal{L}_a)$ consists of:

- a set of criteria $C = \{c_1, c_2, ..., c_n\}, n > 0$;
- a set of alternatives $A = \{a_1, a_2, ..., a_m\}, m > 0$;
- a set of agents $A_g = \{ag_1, ag_2, ..., ag_k\}, k > 0$;
- a communication language $\mathcal{L}_c$, consisting of a set of all locutions;
- a set of algorithms working as regulation $\mathcal{L}_a$ for $\mathcal{L}_c$, specifying for each locution $\varphi \in \mathcal{L}_c$ its effect.

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

Definition 2 A criterion $c_i = \{id_{c_i}, v_{c_i}, m_{c_i}\}$ consists of:

- $\forall c_i \in C, i \in \{1, 2, ..., n\}$;
- id_{c_i} is the identification of a particular criterion;
- v_{c_i} is the value of a particular criterion (Numeric, Boolean or Classificatory);
- m_{c_i} is the greatness associated with the criterion (Maximization, Minimization, Positivity, Negativity and Without Value).

Example 1 For the previous example, let us consider three criteria: Price, Transmission, Air Conditioning. Each criterion is defined as follows:

- $c_1 = \{Price, Numeric, Minimization\}$;
- $c_2 = \{Transmission, Classificatory, WithoutValue\}$;
- $c_3 = \{AirConditioning, Boolean, Positivity\}$.

Definition 3 An alternative $a_i = \{id_{a_i}, [c1_{a_i}, c2_{a_i}, cn_{a_i}]\}$ consists of:

- $\forall a_i \in A, i \in \{1, 2, ..., n\}$;
- id_{a_i} is the identification of a particular alternative;
- $[c1_{a_i}, c2_{a_i}, ..., cn_{a_i}]$ is the instantiation of each criterion.

Example 2 For the previous example, let us consider three alternatives. Each alternative is defined as follows:

- $a_1 = \{car1, [10000, automatic, no]\}$;
- $a_2 = \{car2, [15000, manual, yes]\}$;
- $a_3 = \{car3, [12500, manual, no]\}$.

The way each criterion is defined allows an agent to know (in the previous example) that $c1_{a_1} > c1_{a_2} \wedge c1_{a_1} > c1_{a_3} \wedge c1_{a_2} > c1_{a_3}$, and $c2_{a_1} \neq c2_{a_2} \wedge c2_{a_1} \neq c2_{a_3} \wedge c2_{a_2} = c1_{a_3}$ and $c3_{a_2} > c3_{a_1} \wedge c3_{a_2} > c3_{a_3} \wedge c3_{a_1} = c3_{a_3}$.

An agent has a special structure that allows him to act according to the interests of the decision-maker he represents. Besides the agent's identification code, the decision-maker can also define the agent's style of behaviour for a certain time interval. The decision-maker may change that style of behaviour whenever he thinks to be appropriate. The proposed styles of behaviour (previously defined in [6,36]) allow the agent to act according to four dimensions: activity, resistance to change, concern for other and concern for self. Agents also include a protocol where it is defined a set of available locutions available to ag_i in a time instant of t. An agent also holds the information about the evaluation done by the decision-maker about the preference of each alternative and the importance given to each considered criterion. In order to perform these configurations, the decision-maker can use a template that was proposed in [7,9]. This template is very easy and fast to configure and can be used to obtain all this information with mechanisms that make it easier for the decision-maker to express his opinion and evaluations. The agent also includes a list of objectives to pursue after. This list is ordered ($preference\,relation \geq on\,the\,set\ O_{ag_i}$) and may contain alternatives and criteria. An agent can have as the main objective to achieve alternative a_1 as the final decision or to achieve an alternative with the best c_1 as possible, which in our example would correspond to the "the less expensive car". Agents may keep adding new objectives to their list of objectives throughout the process as well as reordering existing ones.

Example 3 An agent ag_i with the defined behaviour 'Obliging' can start a discussion with the main objective to achieve the alternative, which the decision-maker (that he represents) chose as the most preferred (in the problem configuration). However, if more and more agents support another alternative, and since that agent has a high level of "concern for others", he may reorder his objectives and choose other alternatives as his main objective.

Definition 4 An agent $ag_i = \{id_{ag_i}, uid_{ag_i}, \beta_{ag_i}, Pr_{ag_i}, C_{ag_i}, A_{ag_i}, O_{ag_i}, K_{ag_i}\}$ consists of:

- $\forall ag_i \in Ag, i \in \{1, 2..., n\}$;
- id_{ag_i} is the identification of a particular agent;
- uid_{ag_i} is the identification of the decision-maker represented by the agent ag_i;
- β_{ag_i} is the agent's behaviour (Dominating, Compromising, Obliging, Integrating, Avoiding and No Style);
- Pr_{ag_i} is the agent's protocol for $\mathcal{L}_c$, specifying the 'legal' moves at each instant. A protocol on $\mathcal{L}_c$ is a set of locution available to ag_i, where $Pr_{ag_i} \subseteq \mathcal{L}_c$;
- C_{ag_i} is the agent's evaluation of each criterion, $C_{ag_i} = \{E_{c_1}, E_{c_2}, \ldots, E_{c_n}\}$, $Ev_{c_i} \in \{[0, 1], \perp\}$;
- A_{ag_i} is the agent's evaluation of each alternative, $A_{ag_i} = \{E_{a_1}, E_{a_2}, \ldots, E_{a_n}\}$, $Ev_{a_i} \in \{[0, 1], \perp\}$;
- O_{ag_i} is the set of agent's objectives, $O_{ag_i} \subseteq A \cup C, preference\ relation \geq on\ the\ set\ O_{ag_i}$;
- K_{ag_i} is the agent's knowledge, where he can access the list of all sent and received messages, as well as the preferences of other agents, according to the knowledge he possess in a certain time instant of t.

O_{ag_i} can be reordered using the following formula:

$$A_{Result_{o_i}} = \frac{o_i * CS + \left(\frac{NS}{ND}\right) \times CO}{CS + CO} \quad (1)$$

where:

- o_i is the assessment done to the objective i for which the result is being measured;
- CS is the value of Concern for Self [1, 2, 3];
- NS is the current number of agents supporting Alt_x;
- ND is the total number of participating agents;
- CO is the value of Concern for Others [1, 2, 3].

Formula 1 reflects the importance of the objective to an agent with a certain style of behaviour, while he takes into account the probability to achieve that same objective. Our proposal intends to (besides helping to achieve a consensus) help the group to take advantage of the benefits related to group decision-making and be able to achieve decisions with more quality. Therefore, an important metric is to relate the level of consensus with the final level of satisfaction that is achieved by each decision-maker.

Definition 5 A behaviour $\beta_i = \{Rc_{\beta_i}, Al_{\beta_i}, Cs_{\beta_i}, Co_{\beta_i}$ consists of (according to [36]):

- Rc_{β_i} is the agent's resistance to change dimension value;
- Al_{β_i} is agent's activity level dimension value;
- Cs_{β_i} is the agent's Concern for Self dimension value;
- Co_{β_i} is the agent's Concern for Others dimension value.

Definition 6 A locution $\varphi_i = \{id_{\varphi_i}, Tp_{\varphi_i}, Tx_{\varphi_i}, Ct_{\varphi_i}, Vr_{\varphi_i}, Dr_{\varphi_i}, Dm_{\varphi_i}, Av_{\varphi_i}\}$ consists of:

- $i \in \{1, 2, \ldots, n\}$;
- id_{φ_i} is the locution's id (unique);
- Tp_{φ_i} is the locution's type (Question, Statement and Request);
- Tx_{φ_i} is the text associated with the locution;

Table 1 Considered Locutions (some examples)

Locution	Type	Text	Context	Variables	Domain
Criteria general preference	Statement	"For me the most important criterion/a is/are 1, 2, ..., n"	Criterion	Criterion 1, 2, ..., n	General
End of participation	Statement	"I have nothing more to say"	Without context	–	General
Alternatives individual preference	Question	"Who prefers the alternative/s n?"	Alternative	Alternative 1, 2, ..., n	Specific
...	...	...	...	...	...

- Ct_{φ_i} is the locution's context (Alternative, Criterion or Without Context);
- Vr_{φ_i} is the set of variables associated with the locution (Alternative or Criterion);
- Dr_{φ_i} is the direction associated with the locution (infavor, against, null);
- Dm_{φ_i} is the locution's domain (General or Specific);
- Av_{φ_i} is the locution's state (Available or Not Available).

Rule 2 Whenever a locution is added to Pr_{ag_i} in the time instant t, its state will be $Av^t_{\varphi_i}, Av = Available$.

Rule 3 Whenever a locution is used at a time instant t, its state will change to $Av^t_{\varphi_i}, Av = Not\ Available$.

Rule 4 Whenever a locution $Dm_{\varphi_i}, Dm = Specific$ is added to Pr_{agk} at the time instant t, then $\forall Dm_{\varphi_i} \in \mathcal{L}_{Dm} \subset Pr_{agk}, Dm = General$ and its state will be $Av^t_{\varphi_i}, Av = Available$.

Rule 5 For any locution $\varphi_j \in \mathcal{L}_{sp_{c_i}} \wedge c_i \subset Vr_{\varphi_j}$, there cannot be another locution φ_k where $c_i \subset Vr_{\varphi_k} \wedge \varphi_k \notin \mathcal{L}_{sp_{c_i}}$.

Rule 6 For any locution $\varphi_j \in \mathcal{L}_{sp_{a_i}} \wedge a_i \subset Vr_{\varphi_j}$, there cannot be another locution φ_k where $a_i \subset Vr_{\varphi_k} \wedge \varphi_k \notin \mathcal{L}_{sp_{a_i}}$.

Some examples of possible locutions are specified in Table 1 (in our experiments we are dealing with 18 different locutions).

Definition 7 A message $\psi_i = \{id_{\psi_i}, \varphi_{\psi_i}, tr_{\psi_i}, \alpha_{\psi_i}, en_{s_{\psi_i}}, En_{r_{\psi_i}}\}$ consists of:

- $i \in \{1, 2, \ldots, n\}$;
- id_{ψ_i} is the conversation code;
- φ_{ψ_i} is the locution sent in the message;
- tr_{ψ_i} is the target associated with the message (can be null or be another message);
- α_{ψ_i} is the justification associated with the locution (can be an argument or can be null);
- $en_{s_{\psi_i}}$ is the agent/user who sent the message;
- $En_{r_{\psi_i}}$ is the set of agents/users who will receive the message (can be 1 or *).

Rule 7 For any message ψ created by a decision-maker $Dr_{\varphi_\psi}, Dr \neq null$. This means that the message's locution can only be either infavor or against Vr_{φ_ψ}.

Definition 8 An argument $\alpha_i = \{id_{\alpha_i}, tx_{\alpha_i}, Vr_{\alpha_i}\}$ consists of:

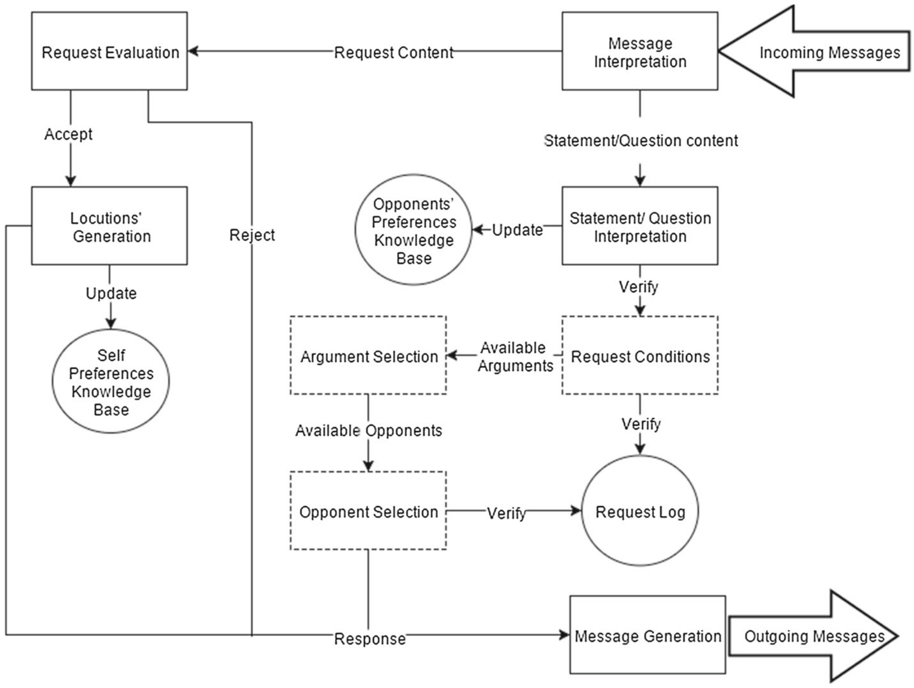

Fig. 1 Agent's communications workflow

- $i \in \{1, 2, \ldots, n\}$;
- id_{α_i} is the identification of a particular argument;
- tx_{α_i} is the text associated with a particular argument;
- Vr_{α_i} is the set of variables associated with a particular argument (can contain alternatives and criteria).

Figure 1 represents the workflow proposed to use the argumentation model definition that is presented in this work. This workflow represents the communications and the interactions which can be performed by agents. The process is very clear and allows the decision-makers to understand the interactions and communications that happen between agents.

Proposition 1 *The system is finite.*

Proof The size of the list of objectives of an agent ag_i, which includes criteria and alternatives will be $|O_{ag_i}| \leq |A| \cup |C|$, which corresponds at best to the entire set of all criteria and alternatives. This means that at a certain time instant t agent ag_i may use legally $\mathcal{L}^t_{Ct}$, $Ct = Alternative \vee Criterion$ locutions. Whenever a new objective is added (for example, a new alternative), the $\mathcal{L}_{sp_{a_j}}$ is added to Pr_{ag_i}. If in a time instant $t+x$ all the criteria and alternatives were added to Pr_{ag_i}, then $Pr^{t+x}_{ag_i} = \mathcal{L}_c$. Since $\forall Dm_{\varphi_j} \in \mathcal{L}_{Dm} \subset Pr^{t+x}_{ag_i}$, $Dm = Specific$ can only be used once, even if Pr_{ag_i} size may increase throughout the process, the system will be always finite. □

Up until now, we have presented the definition for the proposed argumentation model only considering the agents' point of view. From this point forward, all the definitions presented will be directed towards to the interactions between decision-makers. However, these definitions are an extent of what has been proposed so far which will allow both agents and humans to use the same model definition.

Decision-makers, compared to agents, can also create messages that will hold the new knowledge as well as a new set of dynamic arguments. We can imagine an UbiGDSS as something that can be used in all sort of electronic devices and that allows quick interactions. An example of a quick interaction would be the easiness in which we can leave a "Like" in a Facebook photograph. Our approach allows decision-makers to create messages that include arguments that are infavor or against. Each created message may lead to $n - 1$ messages, where n is the number of decision-makers evolved in the process. Decision-makers can argue against a message through the use of an attack or argue in favour of a message through the use of a reinforcement. The way the model is defined allows the message content to be of any sort of format like text or voice, since that information is irrelevant to the agent. A decision-maker may evaluate messages sent by other decision-makers, and this will allow agents to understand human interactions and the impact of every conversation. Figure 2 represents the workflow proposed for all the interactions and communications that happen between decision-makers.

Example 4 (Message pro) $Dr_{\varphi_\psi}, Dr = infavour$. That means something positive related to Vr_{φ_ψ}. Such message is said pro the Vr_{φ_ψ}. For our previous example, a message ψ pro could have $Vr_{\varphi_\psi}, Vr = a_1 \wedge Tx_{\alpha_\psi}, Tx =$ "$1st\ maintenance\ service\ is\ free$".

Example 5 (Message cons) $Dr_{\varphi_\psi}, Dr = against$. That means something negative related to Vr_{φ_ψ}. Such message is said cons the Vr_{φ_ψ}. For our previous example, a message ψ cons could have $Vr_{\varphi_\psi}, Vr = c_3, c_{3_a} = no \wedge Tx_{\alpha_\psi}, Tx =$ "$The\ high\ temperatures\ in\ our\ area\ will\ damage\ the\ product\ in\ a\ car\ without\ air\ conditioning$".

Definition 9 Let $\Psi = \{\psi_1, \psi_2, \ldots, \psi_n\}, n > 0$ denote a finite set of n messages that are exchanged during a human discussion.

Let us now define two functions that relate the messages in favour or against an $a_i \in A, c_j \in C, A_k \subseteq AorC_l \subseteq C$ (Let us consider $X \asymp a_i \cup c_j \cup A_k \cup C_l$):

- $F_{infavour} : X \to \forall\psi \in \Psi, Dr_{\varphi_\psi} = infavour$, is a function that returns the messages in favour of X. Such messages are said pro the X;
- $F_{against} : X \to \forall\psi \in \Psi, Dr_{\varphi_\psi} = against$, is a function that returns the messages against X. Such messages are said cons the X.

Rule 8 A message is either in favour or against X. It cannot be both, so: $\forall\psi \in \Psi s.t.\neg(\psi \in F_{infavour}(X) \wedge \psi \in F_{against}(X))$.

It is obvious that we are dealing with a context where we can easily find many conflicts of interests. This means that even if decision-makers have the collective goal to achieve the best possible solution for the group, they will still try to persuade each other to accept their preferred alternatives that they consider to be the best solution for the problem. This leads to different views on how to solve the problem (which is an advantage of group decision-making). In order to represent this situation, our proposal allows decision-makers to evaluate messages created by other decision-makers.

Our messages may have strengths of various weights. But those strengths depend on each decision-maker evaluation. This means that in our proposal a decision-maker can consider an argument to be very strong (or important), while another decision-maker may consider that same argument to be completely irrelevant. That strength allows arguments to rank-order each alternative according to the decision-maker point of view. We believe that this evaluation

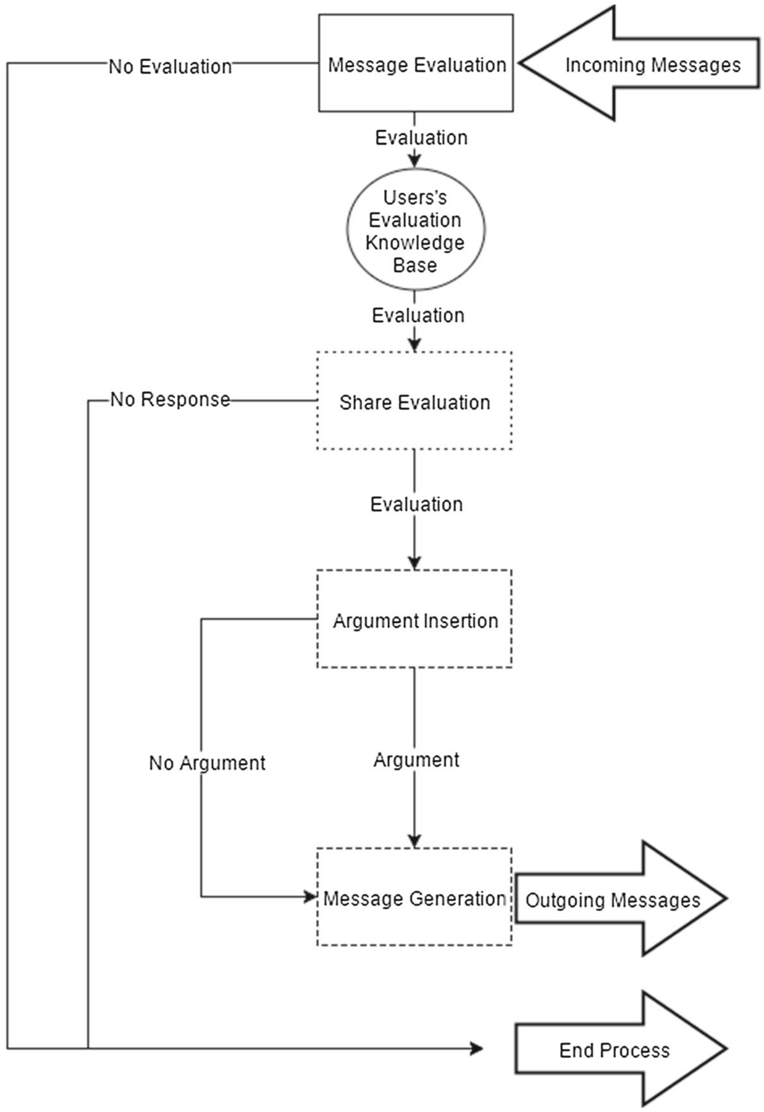

Fig. 2 Decision-makers' communications workflow

should be made in a very simple way, similarly to how a person leaves a "Like" in a social network. With the definition here proposed, it is possible to filter all the information towards decision-makers' evaluations and the messages interdependency.

Definition 10 A message evaluation $\xi = \{en_{\xi_i}, \psi_{\xi_i}, ev_{\xi_i}\}$ consists of:

- $i \in \{1, 2, \ldots, n\}$;
- en_{ξ_i} is the user who performed the evaluation;
- ψ_{ξ_i} is the message being evaluated;
- ev_{ξ_i} is the evaluation mode $[-1, 1]$.

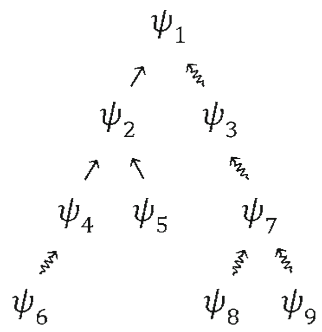

Fig. 3 Representation of $(n-1)$ary tree messages

Definition 11 Let $\Xi = \{\xi_1, \xi_2, \ldots, \xi_n\}$ denote a finite set of n evaluations that are made during a human discussion.

Let us now define two functions that return all messages approving or disapproving a message ψ_i:

- $F_{approval} : \psi_i \rightarrow \forall \xi \in \Xi, \psi_\xi = \psi_i \wedge ev_{\xi_i} > 0$, is a function that returns all messages approving ψ_i;
- $F_{disapproval} : \psi_i \rightarrow \forall \xi \in \Xi, \psi_\xi = \psi_i \wedge ev_{\xi_i} > 0$, is a function that returns all messages disapproving ψ_i.

In our proposal, the notion of attack is intrinsically directional: if ψ_1 attacks ψ_2, this corresponds to the fact that ψ_1 has the power to affect ψ_2, and not vice versa. Likewise, if ψ_1 reinforce ψ_2, this corresponds to the fact that ψ_1 has the power to support ψ_2. Notice that, we consider the attacks and reinforcements between messages and not between arguments. However, when a decision-maker decides to perform an attack or a reinforcement, it is mandatory to insert the justification, so a message has mandatorily an argument included. We represent an attack through $\psi_1 \rightarrow \psi_2$ and a reinforcement through $\psi_1 \rightsquigarrow \psi_2$. Each message can result in $n-1$ messages, where n is the number of decision-makers evolved in the process. A group of messages with the same id_{ψ_i} can be represented through a $(n-1)arytree$ (Fig. 3).

A message ψ_i can only affect a message ψ_j only if there is a directed path from ψ_i to ψ_j. That means (considering Fig. 3) if a decision-maker evaluates positively the ψ_9, his evaluation is also affecting ψ_9, ψ_7, ψ_3 and ψ_1. On the other hand (and again considering Fig. 3), if the decision-maker evaluates positively ψ_4, although ψ_4 has the same sign as ψ_3, we cannot correlate the messages.

Let us now define two functions that relate a message ψ_1 to the messages reinforcing it and to the messages attacking it:

- $F_{reinforcement} : \psi_1 \rightarrow \forall \psi \in \Psi, tr_\psi = \psi_1 \cap F_{approval}(\psi_1)$, is a function that returns the messages reinforcing ψ_1. Such messages are said pro the message ψ_1;
- $F_{attack} : \psi_1 \rightarrow \forall \psi \in \Psi, tr\psi = \psi \cap F_{disapproval}(\psi_1)$, is a function that returns the messages attacking ψ_1. Such messages are said cons the message ψ_1.

Let us define a function which returns the messages sent by user en_1:

- $F_{sentby} : en_1 \rightarrow \forall \psi \in \Psi, en_\psi = en_1$, is a function that returns all the messages sent by user en_1.

Let us define a function which returns all evaluations done by user en_1:

- $F_{evaluatedby} : en_1 \rightarrow \forall \xi \in \Xi, en_\xi = en_1$, is a function that returns all evaluations done by user en_1.

Let us define a function which returns all messages evaluated by user en_1:

– $F_{msgevaluatedby} : en_1 \rightarrow \forall \psi \in \Psi, \forall \xi \in F_{evaluatedby}(en_1), \psi_\xi = \psi$, is a function that returns all messages evaluated by user en_1.

Let us define a function which returns the evaluation given to a message ψ_1 by user en_1:

– $F_{usermessageevaluation} : en_1, \psi_1 \rightarrow \forall \xi \in F_{evaluatedby}(en_1), \psi_\xi = \psi_1$, is a function which returns the evaluation given to a message ψ_1 by user en_1.

Let us now define a function to identify leaf messages sent during a human discussion:

– $F_{last} : \Psi \rightarrow \forall \psi \in \Psi, F_{reinforcement}(\psi) \cup F_{attack}(\psi) = \emptyset$, is a function that returns the messages that are not attacked or reinforced thus being leaf messages exchanged in a human discussion.

Let us now define a function that returns all the messages done until message ψ_1 which can be more than one reinforcement or just only one attack:

– $F_{reinforcementrow} : \psi_1 \rightarrow \forall \psi \in \Psi, \begin{cases} F_{reinforcementrow}(\psi), \psi \in F_{reinforcement}(\psi_1) \\ \psi_1, \psi \in F_{attack}(\psi_1) \\ \psi_1, \psi \notin F_{attack}(\psi_1) \vee F_{reinforcement}(\psi_1) \end{cases}$, is a function that returns all the reinforcement or the attack done until ψ_1.

Let us now define a function that returns all the messages prior to each last message in a human discussion that are either reinforcements (in the limit it could be all reinforcements until the initial message) or an attack:

– $F_{lastdiscussions} : \Psi \rightarrow \forall \psi \in F_{last}, F_{reinforcementrow}(\psi)$, is a which returns all the messages prior to each last message that are either reinforcements or an attack.

Let us define a function that returns all the last evaluations done by user en_1:

– $F_{lastevaluatedby} : en_1 \rightarrow \forall \xi \in F_{evaluatedby}(en_1), \psi_\xi \in F_{lastdiscussions}$, is a function that returns all the last evaluations done by user en_1.

In order to identify all the last evaluations done by en_1 in a certain dialogue, the id_ψ can be used to filter those evaluations, and therefore the function which returns all the leaf evaluations done by user en_1 in a dialogue with id_{ψ_1} would be:

– $F_{lastevaluationsin} : id_{\psi_1} \rightarrow \forall \xi \in F_{lastevaluatedby}(en_1), id_{\psi_\xi} = id_{\psi_1}$, is a function that returns all the last evaluations done by user en_1 for the human dialogue with the id id_{ψ_1}.

In [41] the researchers state that argumentation-based decision process can be decomposed into the following steps: (1) Constructing arguments infavor/against statements (beliefs or decisions), (2) Evaluating the strength of each argument, (3) Determining the different conflicts among arguments, (4) Evaluating the acceptability of arguments and (5) Comparing decisions on the basis of relevant "accepted" arguments. We consider that in our work, we are able to deal with all of this topics as we will prove in our experiments. In addition, our model has the advantage of integrating those points in a perspective that deals with both agents and humans using the same definition.

It will be next described each step for agents to take advantage of the information exchanged during human dialogues.

When an agent is starting a new discussion, it will first select the highest evaluation whose representing decision-maker evaluated from all topics that were created. For that, it is next shown a function that returns all root messages from Ψ set:

– $F_{root} : X \rightarrow \forall\psi \in \Psi, tr_{\psi} = null$, is a function that returns all root messages.

Let us now define a function which returns the root message from the same topic of a message ψ_1:

– $F_{topicofmessage} : \psi_1 \rightarrow \forall\psi \in \Psi, \begin{cases} F_{topicofmessage}(\psi), tr_{\psi_1} = \psi \wedge \psi \notin F_{root} \\ \psi, tr_{\psi_1} = \psi \wedge \psi \in F_{root} \end{cases}$, is a function which returns the root message from the same topic of a message ψ_1.

Let us now define a function which returns all messages from a topic whose root message is ψ_1:

– $F_{messagesintopic} : \psi_1 \rightarrow \forall\psi \in \Psi, F_{topicofmessage}(\psi) = \psi_1$, is a function which returns all messages from a topic whose root message is ψ_1.

Let us now define a function which returns all evaluations by a user en_1 for a topic whose root message is ψ_1:

– $F_{evaluationsintopic} : \psi_1, en_1 \rightarrow \forall\xi \in F_{evaluatedby}(en_1), \psi_{\xi} \in F_{messagesintopic}(\psi_1)$, is a function which returns all evaluations by a user en_1 for a topic whose root message is ψ_1.

In order to select the highest evaluation $\xi_{highest}$ given by an agent en_1, we can perform algorithm (1).

After identifying the highest evaluation, the agent should express whether he agrees or disagrees with the corresponding evaluated topic.

Let us define a function which returns a sorted list of messages exchanged prior to a message ψ_1 until the root message:

Let en_1 *be the agent*;
Let $maxeval$ *be the highest evaluation value*;
Let m *be a float*;
Let $\xi_{highest}, \xi_1$ *be two evaluations*;
begin
    $maxeval \leftarrow 0$;
    $\xi_{highest} \leftarrow Null$;
    foreach $\psi \in F_{root}$ **do**
        $\xi_1 \leftarrow Null$
        $m \leftarrow 0$
        foreach $\xi \in F_{evaluationsintopic}(\psi, en_1)$ **do**
            if $ev_{\xi} \geq m$ **then**
                $m \leftarrow ev_{\xi i}$;
                $\xi_1 \leftarrow \xi$;
            end if
        end foreach
        if $m \geq maxeval$ **then**
            $maxeval \leftarrow m$;
            $\xi_{highest} \leftarrow \xi_1$;
        end if
    end foreach
end

Algorithm 1: Select the highest evaluation of all messages

– $F_{messagesbefore} : \psi_1 \rightarrow \begin{cases} F_{messagesbefore}(tr_{\psi_1}), tr_{\psi} \neq null \\ \psi_1, tr_{\psi} = null \end{cases}$, is a function which returns a sorted list of messages exchanged prior to a message ψ_1 until the root message.

Let us now define a function which returns the direction value of a given message ψ_1. It returns 1 in case $Dr_{\varphi_{\psi_1}} = infavour$ and -1 in case $Dr_{\varphi_{\psi_1}} = against$:

- $F_{direction} : \psi_1 \rightarrow \begin{cases} 1, Dr_{\varphi_{\psi_1}} = infavour \\ -1, Dr_{\varphi_{\psi_1}} = against \end{cases}$, is a function which returns the direction value of a given message ψ_1.

To know whether an agent agrees or disagrees with a certain topic, with a root message ψ_{root}, depending on the highest evaluation given to that topic, we can perform algorithm (2).

The remaining agents can respond to the message created in the previous algorithm and may extend the discussion on the same branch whether there is more relevant information that can be exchanged or not depending if the message is a leaf in that branch.

Let us define a function which returns the evaluation done by an agent en_1 for a message ψ_1. It returns 1 in case the agent agrees with the message and -1 if the agent disagrees with the message:

```
Let ξ_highest be the highest evaluation value;
Let ψ_root be the root message;
Let ψ_received be the received message;
Let value be a Boolean;
begin
  value ← F_direction(ψξ_highest);
  ψ_root ← F_topicofmessage(ψξ_highest);
  foreach ψ ∈ F_messagesbefore(ψξ_highest) do
    value ← value × F_direction(ψ);
  end foreach
  if value = −1 then
    Tx_φψ_created = "I disagree with ψ_root because ψξ_highest";
  else
    if value = 1 then
      Tx_φψ_created = "I agree with ψ_root because ψξ_highest";
    end if
  end if
end
```

Algorithm 2: Message creation

- $F_{messageevaluation} : \psi_1, en_1 \rightarrow \forall \xi \in F_{evaluatedby}(en_1), \begin{cases} 1, \psi_\xi \wedge \xi \in F_{approval}(\psi_1) \\ -1, \psi_\xi \wedge \xi \in F_{disapproval}(\psi_1) \end{cases}$, is a function which returns the evaluation done by an agent en_1 for a message ψ_1.

The algorithm (3) shows how an agent can respond to a message $\psi_{received}$ in a branch in case that message is one of the leaf messages exchanged.

```
Let en_1 be the agent;
Let ψ_created, ψ_received be the two messages;
Let value be a Boolean;
begin
    if ψ_received ∈ F_last then
        if ψ_received ∈ F_msgevaluatedby(en_1) then
            value ← F_messageevaluation(ψ_received);
            if value = −1 then
                Tx_φψ_created = "I disagree";
            else
                if value = 1 then
                    Tx_φψ_created = "I agree";
                end if
            end if
        else
            if ψ_received ∉ F_msgevaluatedby(en_1) then
                Tx_φψ_created = "I do not have information";
            end if
        end if
    end if
end
```

Algorithm 3: Response to leaves' messages

In the case the agent has to respond to a message $\psi_{received}$ and that message is not one of the leaf messages exchanged, then ψ_{root} became $\psi_{received}$ and the highest evaluation $\xi_{highest}$ after that message is measured using the algorithm (4).

```
Let en_1 be the agent;
Let ψ_root be the root message;
Let maxeval be the highest evaluation value;
Let m be a float;
Let ξ_highest, ξ_1 be two evaluations;
begin
    maxeval ← 0;
    ξ_highest ← Null;
    ξ_1 ← Null;
    m ← 0;
    foreach ξ ∈ F_evaluationsintopic(ψ_root, en_1) do
        if ev_ξ ≥ m then
            m ← ev_ξ;
            ξ_1 ← ξ;
        end if
    end foreach
    if m ≥ maxeval then
        maxeval ← m;
        ξ_highest ← ξ_1;
    end if
end
```

Algorithm 4: Message's children evaluations analysis

After identifying the $\xi_{highest}$ value, agent en_1 responds using the algorithm (5).

```
Let en_1 be the agent;
Let ξ_highest, ξ_1 be the new highest evaluation;
Let ψ_root be the new root message;
Let ξ_root be the new root evaluation;
Let value_root, value_highest be the two Booleans;
begin
    value_highest ← F_direction(ψ_ξhighest);
    value_root ← F_direction(ψ_root);
    if value_highest = value_root then
        ξ_root ← F_usermsgevaluation(en_1, ψ_root);
        if ev_ξhighest > ev_ξroot then
            tx_φψcreated = "I agree with ψ_root because ψ_ξhighest";
        else
            if ev_ξhighest ≤ ev_ξroot then
                tx_φψcreated = "I agree";
            end if
        end if
    else
        if value_highest ≠ value_root then
            tx_φψcreated = "I disagree with ψ_root because ψ_ξhighest"
        end if
    end if
end
```

Algorithm 5: Response to non-leaves' messages

The response process repeats until there are only last messages to be discussed, and agents must obligatorily respond with either "Agree" or "Disagree" or "With no Information" thus not being able to extend the conversation in that branch. The discussion on the same topic ends if no agent intends to discuss more information existing in different branches of the same topic. Otherwise, the agent must repeat algorithm (4) to identify $\xi_{highest}$ value and then repeat algorithm (2) only if $\psi_{\xi_{highest}}$ has not been discussed before.

4 Experiments

To validate our approach, we have implemented the proposed argumentation model and a multi-agent decision-making dialogue system using JADE [2]. In addition, we developed a graphical user interface (GUI), to the decision-makers interaction with the system. The main goal of the performed experiments was to validate each hypothesis defined in this work: (1) make it possible for both agents and decision-makers to use a dialogue which is clear to everyone involved in the decision-making process (2) let both agents and decision-makers to take advantage of the knowledge which is generated and (3) not force decision-makers with information formulation patterns which may compromise the usability of the entire system as well as the process.

We have used a very simple scenario where decision-makers would feel comfortable with the chosen topic. The idea was to put four persons together (which represented each decision-maker) with the goal to choose a certain car model that would be purchased by an organization (each decision-maker was told that it would be purchased 300 units of the chosen model). For

Table 2 Multi-criteria problem

Alternative	Price	Con	CO2	CC	HP	TS	Fuel
Brand_A1p	19,100	3.3	87	1248	95	182	Diesel
Brand_B2er	19,065	3.2	82	1461	90	180	Diesel
Brand_C3fr	17,158	4.2	112	1248	75	165	Diesel
Brand_D4t	15,400	4.3	106	988	90	180	Petrol

Table 3 Criteria specification

Criterion	Greatness	Value	Scale
Price (Prc)	Numeric	Minimization	Euros
Consumption (Con)	Numeric	Minimization	l/100km
CO2	Numeric	Minimization	g/km
Displacement (CC)	Numeric	Maximization	cm^3
Horse power (HP)	Numeric	Maximization	Horses
Top speed (TS)	Numeric	Maximization	Km/h
Fuel	Classificatory	Without value	Petrol/diesel

this work, it is not relevant to perform demographic analysis as it is not intended to evaluate the quality of the decision, and these experiments will be only focused on each hypothesis that was introduced.

However, all participants were graduated and aged between 23 and 45 years. Each agent intended to represent one member of the organization administration board. This means that agents are cooperative because they all have to choose the best decision for that organization and they are also competitive because they aim to persuade other agents to accept what they believe that is the best decision (according to their configuration).

Table 2 represents the multi-criteria problem in question. There have been identified four possible alternatives.

These alternatives have been classified according to seven criteria (see Table 3 for all the information regarding the criteria). Considering that we do not evaluate criteria while trying to solve a multi-criteria problem [6,7,9], a decision-maker may prefer a certain alternative for subjective or unknown reasons that are not specified in the problem configuration.

In order to let decision-makers interact with the system, four basic functions were created: problem configuration (evaluation of alternatives, criteria and style of behaviour), message creation, message evaluation (and response to that message) and the possibility to view results (from the decision-making process as well as other information). Figures 4, 5, 6 and 7 represent the GUI developed to support these functions.

Decision-makers classify both alternatives and criteria using slide bars with values ranging from 0 to 100 (Fig. 4). These slide bars are based on the visual analogue scale (VAS) as many studies have proven that VAS allows obtaining information more quickly and assertively [40]. It is very easy to configure and can be used in many different electronic devices. Besides this, it also enhances the interaction between the user, and the system allowing him to compare directly different alternatives and criteria and make more accurate evaluations.

To create a new message, decision-makers can select the variable that will be discussed and insert an argument in favour or against that variable (Fig. 5). Once again, this step is

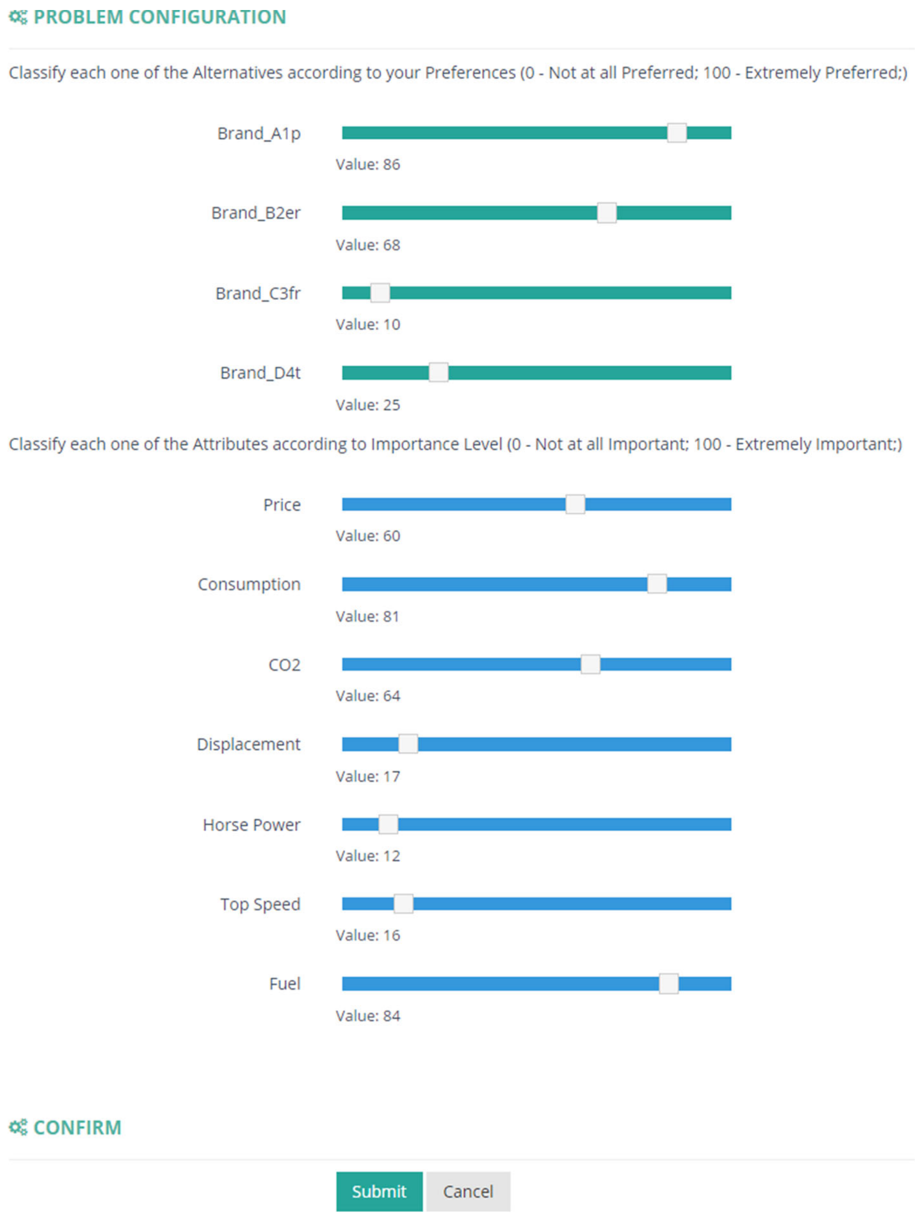

Fig. 4 Multi-criteria problem configuration's GUI

very easy and fast to configure and the components are accessible on all kind of electronic devices.

When evaluating received messages, decision-makers can once again use a slide bar and the system will automatically suggest the user respond that message with an attack or reinforcement depending on the given evaluation (Fig. 6). If the user approved the message, he will be suggested to reinforce that message. If the user disapproved the message, he will be

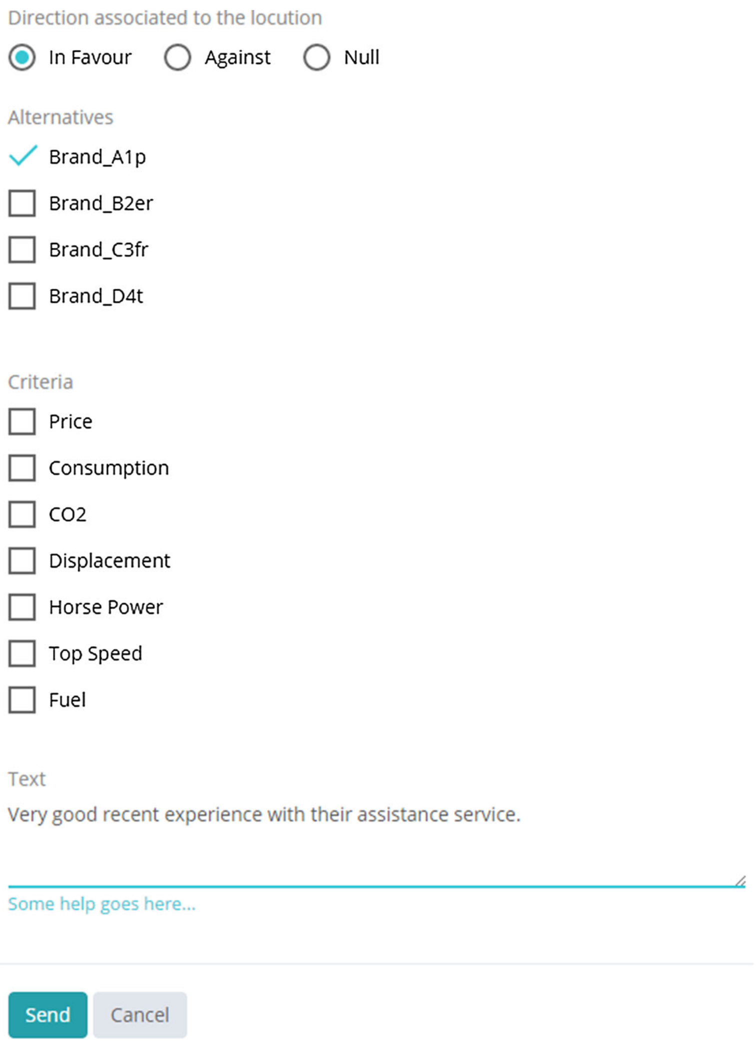

Fig. 5 Message creation GUI

suggested to attack that message. It must be noted that both evaluations and responses are not mandatory and can be done only if the user intends to do so.

As can be seen in these figures, each step requires very simple and intuitive configuration. To perform all experiments, it was requested to each participant (decision-maker) to imagine and reflect on which alternative he would personally consider as the best and only after that reflection that interaction process could be started. It was requested for all participants to configure the problem according to that initial reflection. The results are shown in Tables 4, 5, 6 and 7.

4.1 Experiment #1

The first experiment studied the way in which agents use the configurations done by decision-makers and the type of information that they can collect and provide to each decision-maker

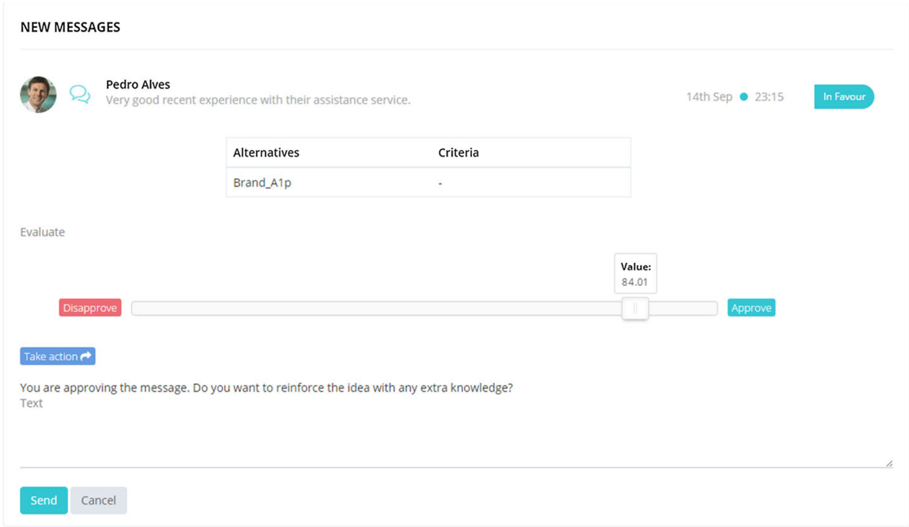

Fig. 6 Received message's evaluation and message's response creation

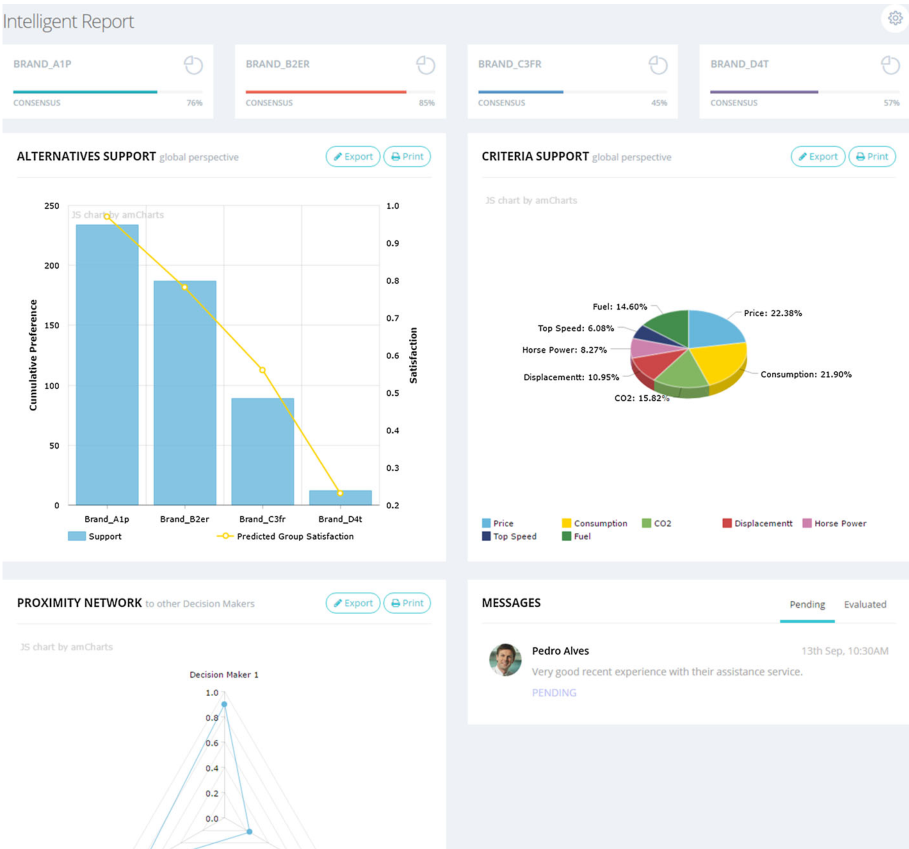

Fig. 7 Results' report

Table 4 Participant 1 problem configuration

Topic	Value
Brand_A1p	0.86
Brand_B2er	0.80
Brand_C3fr	0.70
Brand_D4t	0.40
Price	0.95
Consumption	0.99
CO2	0.85
Displacement	0.60
Horse power	0.60
Top speed	0.40
Fuel	Diesel
Agent's behaviour	Integrating
Credible agents	Participant 2, participant 3

Table 5 Participant 2 problem configuration

Topic	Value
Brand_A1p	0.75
Brand_B2er	0.80
Brand_C3fr	0.90
Brand_D4t	0.30
Price	1.00
Consumption	0.80
CO2	0.50
Displacement	0.65
Horse power	0.65
Top speed	0.30
Fuel	Diesel
Agent's behaviour	Integrating
Credible Agents	–

they represent. The dialogue performed between agents is shown next, where it is possible to understand the course of the conversation (note: the several types of arguments used in requests as well as the algorithms used to evaluate and accept/decline requests are not the main focus of this work and therefore will not be explored in more detail).

```
Facilitator: The Meeting is going to start...
(Public Conversation)
Agent4: I prefer the Alternative Brand_B2er.
Agent1: I disagree.
Agent3: I disagree.
Agent2: I disagree.

(Private Conversation)
Agent3 -> Agent4: Will you accept Alternative Brand_A1p?
```

Table 6 Participant 3 problem configuration

Topic	Value
Brand_A1p	0.57
Brand_B2er	0.55
Brand_C3fr	0.20
Brand_D4t	0.00
Price	0.90
Consumption	0.90
CO2	0.60
Displacement	0.80
Horse power	0.60
Top speed	0.30
Fuel	Diesel
Agent's behaviour	Obliging
Credible Agents	Participant 2

Table 7 Participant 4 problem configuration

Topic	Value
Brand_A1p	0.60
Brand_B2er	0.68
Brand_C3fr	0.30
Brand_D4t	0.20
Price	0,95
Consumption	1.00
CO2	0.56
Displacement	0.70
Horse power	0.45
Top speed	0.10
Fuel	Diesel
Agent's behaviour	Compromising
Credible agents	–

```
Agent4 -> Agent3: I refuse.

(Public Conversation)
Agent3: Which criteria do you consider as most important?
Agent2: For me the most important criterion is: Price
Agent1: For me the most important criterion is: Consumption.
Agent4: For me the most important criterion is: Consumption.
Agent3: For me the most important criteria are: Price and Consumption.

(Private Conversation)
Agent4 -> Agent1: Will you accept Alternative Brand_B2er?
Agent1 -> Agent4: I accept.

(Private Conversation)
Agent2 -> Agent1: Will you accept Alternative Brand_C3fr?
Agent1 -> Agent2: I refuse.

(Public Conversation)
```

```
Agent1: I prefer the Alternative Brand_B2er.
Agent2: I disagree.
Agent3: I disagree.
Agent4: I agree.

(Private Conversation)
Agent2 -> Agent4: Will you accept Alternative Brand_C3fr?
Agent4 -> Agent2: I refuse.

(Public Conversation)
Agent2: Do you prefer the Alternative Brand_C3fr?
Agent1: No.
Agent3: No.
Agent4: No.

(Private Conversation)
Agent1 -> Agent2: Will you accept Alternative Brand_B2er?
Agent2 -> Agent1: I accept.

(Private Conversation)
Agent2 -> Agent3: Will you accept Alternative Brand_B2er? (It has
         been accepted by more than half of the total number of
         participants)
Agent3 -> Agent2: I accept.

The agents reached consensus.
Chosen alternative: Brand_B2er.
Facilitator: The Meeting is over.
```

Agents actions were different according to the style of behaviour that was chosen by each representing decision-maker. Agents achieved a consensus towards alternative Brand_B2er. The dialogue is relatively short due to the quickness in which agents were able to achieve the consensus. However, it was still possible for agents to know during each phase of the dialogue the numbers of supporters for each alternative as well as the most preferred criteria. It was also still possible to identify alternatives which were not initially preferred but were still within the acceptation range of participants (always considering the style of behaviour and the goals for the meeting).

4.2 Experiment #2

The second experiment consisted in decision-makers proceeding with the decision-making process and using the system to insert new knowledge (creating new messages with arguments) about the problem. In this experiment, it was requested for each decision-maker to evaluate all existing messages in order to understand how agents would use the new information shared between decision-makers (Figs. 8, 9). The result was the following:

```
#1 Topic
ψ1 - Participant1 (In Favour - Brand_A1p): Very good recent
    experience with their assistance service.
ψ3 - Participant2 (Attack): I think that argument can be applied to
    every brand.
ψ4 - Participant1 (Attack): That is not true.
ψ5 - Participant2 (Attack): If you check car magazines you will see
    that the other brands also have good marks in terms of
    assistance service.
ψ6 - Participant1 (Attack): Yes. However, this particular brand has
    always the highest scores and more importantly we have a
    positive past experience with this brand.
ψ7 - Participant4 (Attack): That was verified on previous models.
    However, if you check the tests regarding the newest models, you
     will see that the difference is considerable.
```

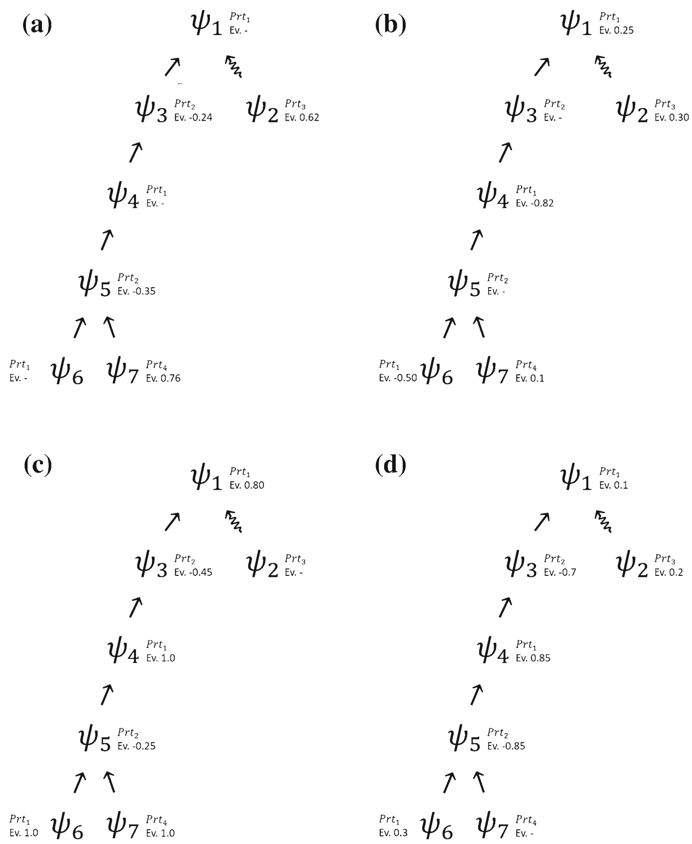

Fig. 8 Participants' messages evaluation regarding #1 Topic. **a** Participant1 messages' evaluation. **b** Participant2 messages' evaluation. **c** Participant3 messages' evaluation. **d** Participant4 messages' evaluation

ψ_2 - Participant3 (Reinforcement): Furthermore, I read a study in a car magazine where they considered this brand as the best in terms of assistance service in 2016.

#2 Topic
ψ_1 - Participant4 (In Favour - Consumption): Considering each vehicle does 3000km (in average) per month, we all should consider the ''consumption'' as the most important criterion.
ψ_2 - Participant2 (Attack): I disagree because we are going to purchase 300 vehicles, so for me the price should be the most important criterion.
ψ_3 - Participant3 (Attack): I also think the price is a very important criterion however, since there is not a big difference between the prices for each alternative, we should focus our attention in the consumption.
ψ_4 - Participant4 (Reinforcement): Besides this we will set up a payment plan with instalments (in 5 years) turning the price difference even less significant.
ψ_5 - Participant1 (Reinforcement): That is true but only in alternatives with diesel fuel.

After participants (decision-makers) have performed a few conversations (2 topics), the goal was to understand how agents would use the new knowledge in their dialogue. For that,

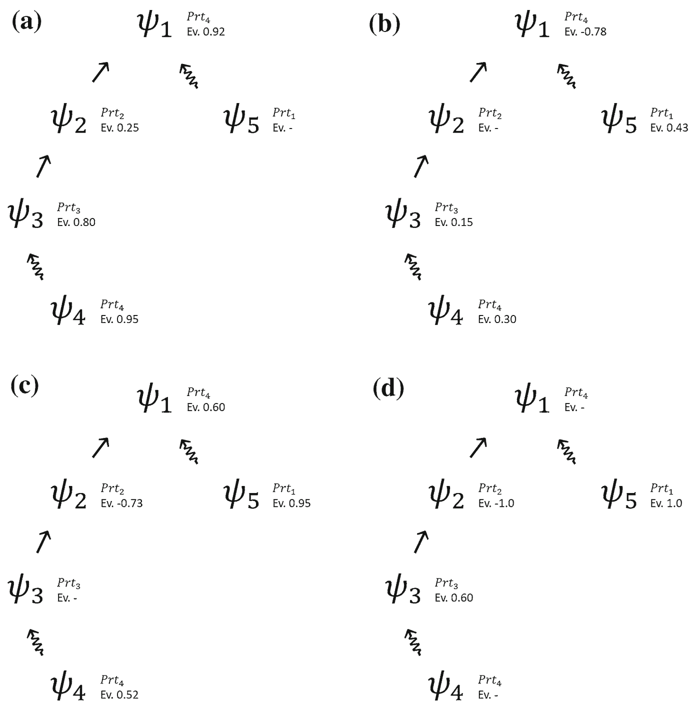

Fig. 9 Participants' messages evaluation regarding #2 Topic. **a** Participant1 messages' evaluation. **b** Participant2 messages' evaluation. **c** Participant3 messages' evaluation. **d** Participant4 messages' evaluation

a new negotiation round was generated. It is next presented the dialogue performed between agents. It is only shown the part of dialogue which differs from the first experiment.

```
(Public Conversation)
Agent1: I agree with ψ1 because ψ7.
Agent4: I agree.
Agent3: I agree.
Agent2: I agree.
Agent2: Furthermore ψ2.
Agent4: I agree.
Agent1: I agree.
Agent3: I agree.
Agent4: Furthermore ψ6.
Agent2: I disagree.
Agent1: I agree.
Agent3: I agree.

(Private Conversation)
Agent1 -> Agent4: Will you accept Alternative Brand_A1p?
Agent4 -> Agent1: I accept.

(Public Conversation)
Agent1: I agree with ψ1 because ψ4.
Agent4: I agree.
Agent3: I agree.
Agent2: I agree.
Agent3: Furthermore ψ5.
Agent2: I agree.
Agent4: I agree.
Agent1: I agree.

(Private Conversation)
```

```
Agent3 -> Agent2: Will you accept Alternative Brand_A1p?
Agent2 -> Agent3: I accept.

The agents reached consensus.
Chosen alternative: Brand_A1p.
Facilitator: The Meeting is over.
```

4.3 Experiment #3

In the third experiment, it was intended to study how agents would behave in case decision-makers did not evaluate all existing messages. For that it was requested for each decision-maker to only evaluate some existing messages in order to simulate more realistic situations in which decision-makers may not have enough time to completely follow the decision-making process (Fig. 10). It should be once again mentioned the main purpose of a group decision support system which is to support the decision process and not replace decision-makers, which means that it is very important that the system is able to provide sustained solutions as the process proceeds further. It should be possible for a decision-maker who may not have enough time to follow the process closely to still be able to collect and access information at a later time which will allow him to understand how the process evolved and still be able to insert new information as well as reconfigure the problem if it is necessary.

The results obtained in the new evaluations are the following:

Using this more complex scenario with much less available information, it was then intended to study how agents would use the new existing knowledge in their dialogue, similarly to the previous experiment. For that, a new negotiation round was generated. It is next show the dialogue performed between agents. It is only shown the part of the dialogue which differs from the first experiment.

```
(Public Conversation)
Agent3: I agree with ψ1 because ψ1.
Agent4: I agree.
Agent1: I agree.
Agent2: I disagree with ψ1 because ψ3.
Agent3: I disagree.
Agent1: I disagree with ψ3 because ψ4.
Agent3: I do not have that information.
Agent2: I disagree with ψ4 because ψ5.
Agent4: I agree.
Agent4: I disagree with ψ3 because ψ7.
Agent3: I do not have that information.
Agent2: I do not have that information.
Agent1: I do not have that information.
Agent1: Furthermore ψ6.
Agent3: I do not have that information.
Agent2: I do not have that information.
Agent4: I do not have that information.

(Private Conversation)
Agent1 -> Agent4: Will you accept Alternative Brand_A1p?
Agent4 -> Agent1: I accept.

(Private Conversation)
Agent3 -> Agent2: Will you accept Alternative Brand_A1p?
Agent2 -> Agent3: I refuse.

(Public Conversation)
Agent1: I agree with ψ1 because ψ1.
Agent4: I agree.
Agent3: I agree with ψ1 because ψ5.
Agent1: I agree.
Agent4: I do not have that information.
Agent2: I do not have that information.
```

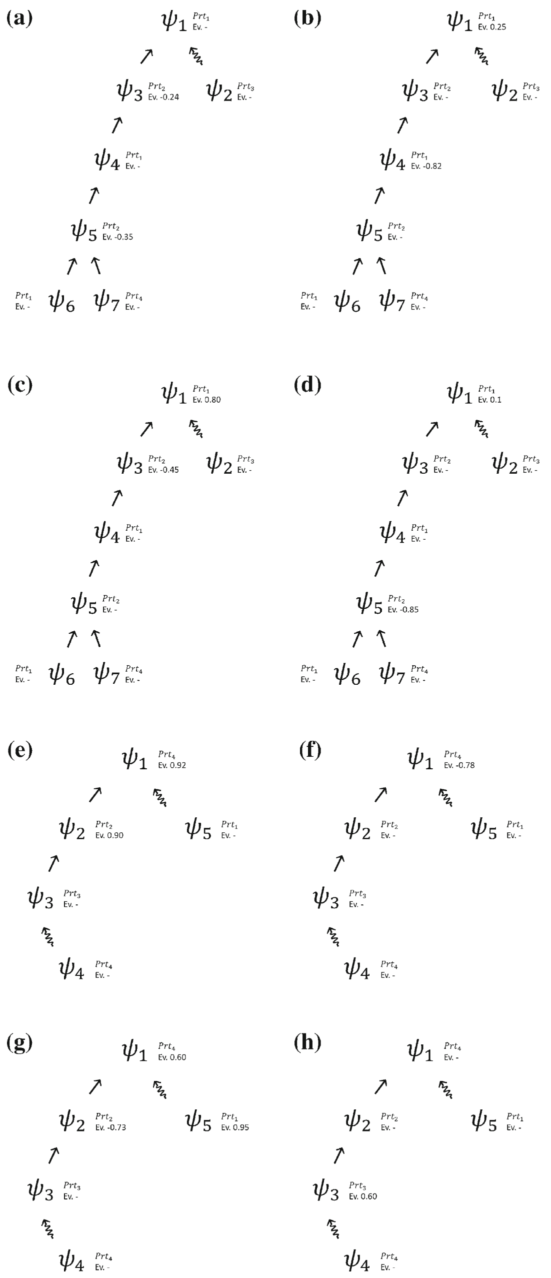

Fig. 10 Participants' messages evaluation regarding #1 Topic and #2 Topic. **a** Participant1 messages' evaluation regarding #1 Topic. **b** Participant2 messages' evaluation regarding #1 Topic. **c** Participant3 messages' evaluation regarding #1 Topic. **d** Participant4 messages' evaluation regarding #1 Topic. **e** Participant1 messages' evaluation regarding #2 Topic. **f** Participant2 messages' evaluation regarding #2 Topic. **g** Participant3 messages' evaluation regarding #2 Topic. **h** Participant4 messages' evaluation regarding #2 Topic

Agent2: I disagree with ψ_1 because ψ_2.
Agent4: I disagree.
Agent1: I do not have that information.
Agent3: I disagree with ψ_2 because ψ_3.
Agent1: I do not have that information.
Agent2: I do not have that information.
Agent4: I agree with ψ_3 because ψ_4.
Agent1: I do not have that information.

```
Agent3: I do not have that information.
Agent2: I do not have that information.

The agents reached consensus.
Chosen alternative: Brand_B2er.
Facilitator: The Meeting is over.
```

4.4 Experiment #4

In this last experiment, random arguments were created in order to build a more complex tree. The idea was to study how agents would use the information existing in a tree with higher complexity compared with the trees that were created in simulations with real participants. The resulting tree as well as its information usage between agents is in Figs. 11 and 12.

Tree 1 is the initial tree. Tree 2 corresponds to the selection of most important argument (ψ_6) of the agent ag_1. When ag_1 uses ψ_6 (Tree 3), the entire path from the root message (ψ_1) until ψ_6 is locked and cannot be used again by other agents. In Tree 4 it is possible to identify an agent (ag_2) which considers the argument in message ψ_{11} as the most important which belongs to a branch that was not discussed before. He will then use that argument (Tree 5). Since no other agent considers to be relevant to answerψ_{11} with an attack or reinforcement, despite ψ_{11} not being the leaf message in that branch, the discussion about it will then end. In Tree 6 we can see that for agent ag_4 the most important argument in this topic was in message ψ_8, and therefore, he then uses this argument (Tree 7) to express his opinion on the topic. However, agent ag_1 disagrees with this argument and performs an attack to message ψ_8 using message ψ_9 (Tree 8 and 9).

5 Discussion

In this section, all the hypotheses are discussed. Besides this, some important points are also considered. As mentioned before, the goal of this work is to answer each hypothesis that was previously identified.

5.1 Experiments overview

The first experiment reflects most aspects which are observed in existing argumentation models. It allows creating statistic data and at the same time aim to identify a possible agreement for all agents. We can already consider that our approach differs from this more conventional paradigm since agents are defined with a style of behaviour which allows to better represent the interests of decision-makers. Therefore, we think agents behave in a more dynamic and intelligent way. Nevertheless, this behaviour is not the focus of how work (to learn more please consult [36]).

In the second experiment, agents used all information obtained from the first experiment plus the dialogues performed between decision-makers. It was possible to verify that agents used the dialogues performed between decision-makers successfully. They are able to justify the reasons to support certain preferences as well as identify which agents supported (or not) each argument used by decision-makers. However, since the dialogues used in these experiments were very short, agents used most of the arguments that were not attacked or reinforced. Besides this, since agents could use this dynamic argumentation, they were able to reach a consensus on a different alternative compared to the first experiment.

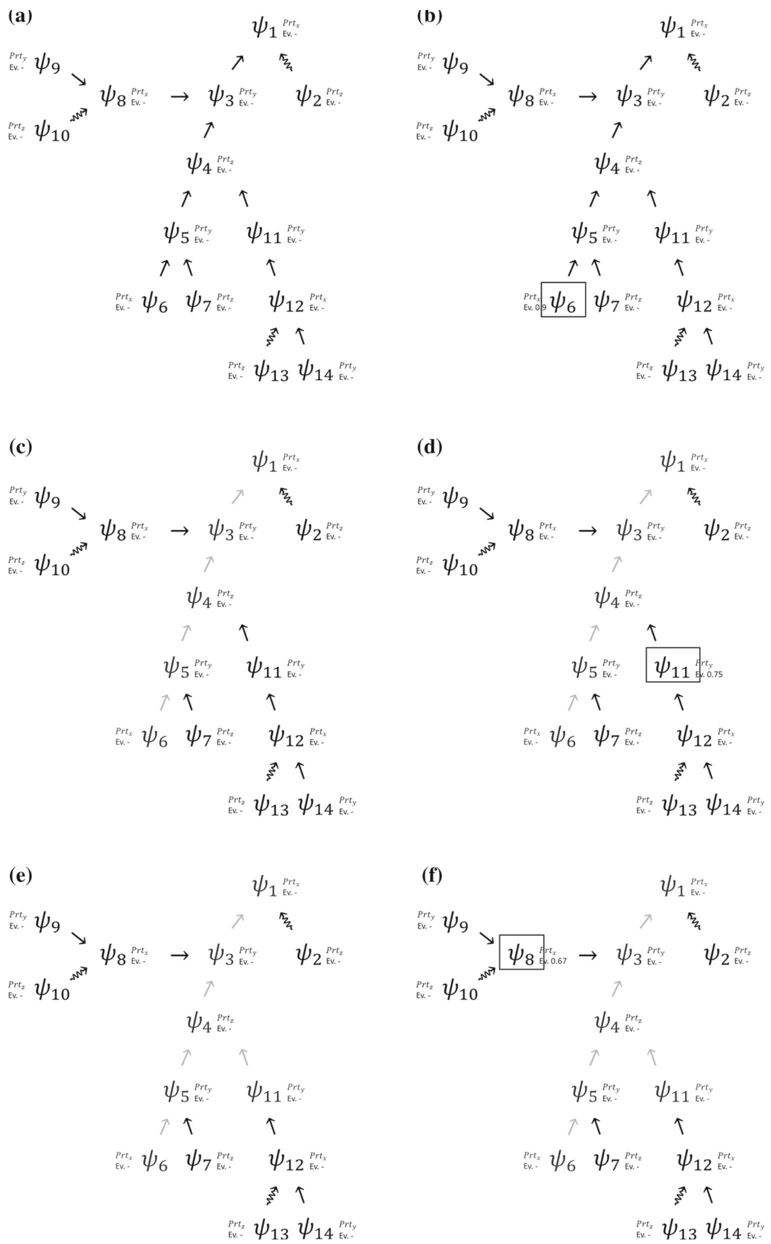

Fig. 11 Discussion flow—Part 1. **a** Initial state of the messages' tree. **b** Selection of a message. **c** Branch lock. **d** Selection of a message. **e** Branch lock. **f** Selection of a message

In the third experiment, it was verified that using dynamic argumentation was not very useful as decision-makers evaluated very few messages. The decision achieved was the same of the first experiment. It was still considered as an advantage the fact that new information can be created such as decision-makers knowing why ag_1 agrees with message ψ_5 but at

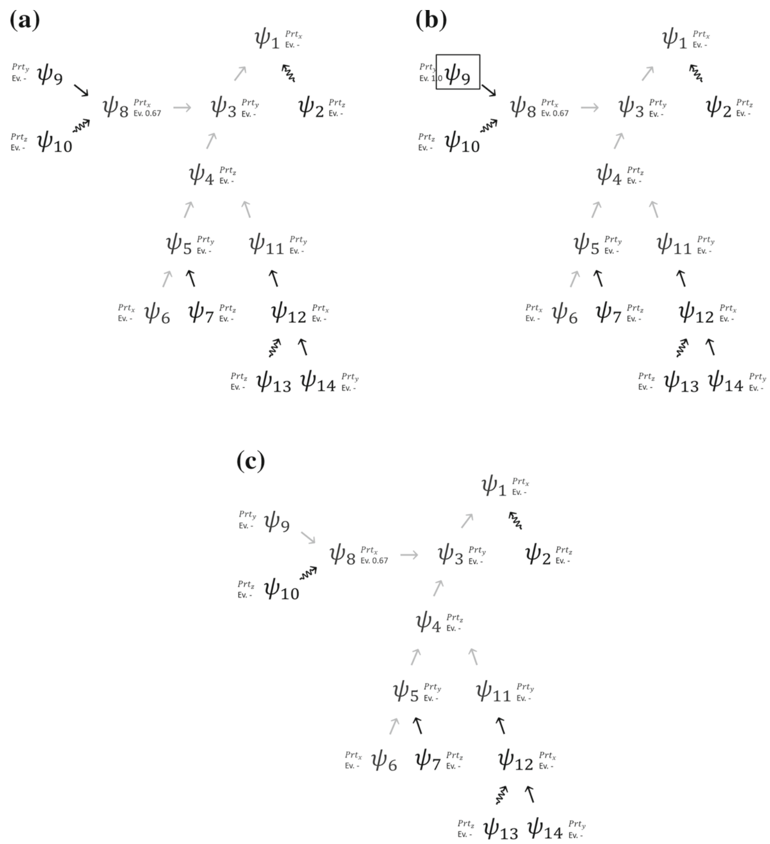

Fig. 12 Discussion flow—Part 2. **a** Branch lock. **b** Selection of a message. **c** Branch lock

the same time did not evaluate any message attacking it, or which decision-maker does not have an opinion on each message, etc. Finally, in the last experiment, it was necessary to create artificial dialogues with a higher level of complexity in order to learn if agents are able to deal with such kind of context. It was verified that agents are able to "ignore" less relevant messages and create interesting dialogues about only the most relevant messages. The dialogue presented a natural flow which allows agents to take further advantage of this process when making requests in the future.

5.2 Hypotheses

The main goal of this work was to validate each hypothesis that was defined: (1) make it possible for both agents and decision-makers to use a dialogue which is clear to everyone involved in the decision-making process (2) let both agents and decision-makers to take advantage of the knowledge which is generated and (3) not force decision-makers with information formulation patterns which may compromise the usability of the entire system as well as the process.

This work allowed to validate each hypothesis by observing the results. This means that it was not possible to mathematically validate each hypothesis; however, it seems their validation can still be supported looking at the obtained results for each experiment. It was possible to verify that agents were able (with great success) to use the dialogue performed between decision-makers to create new dialogues, and these dialogues offered several advantages to decision-makers as can be seen in the next section of this work. In terms of configuration costs and looking at the figures presented in previous sections of this work (as well as with the feedback received from the participants in the experiments), they were almost null. When a decision-maker intends to respond to a message, he only needs to evaluate that message using a one-click slide bar.

5.3 Advantages of the proposed approach

The approach here introduced should be used in a ubiquitous group decision support system. Therefore, in this context, decision-makers do not have much availability or means to gather at the same place and at the same time just to make a decision. It is necessary to use an approach which can suggest intelligent solutions but also report those solutions in a very clear and organized way to each decision-maker saving time and also supporting solutions with explanations that actually let decision-makers learn the reasons behind such suggestions. This allows decision-makers to trust the system and eventually accept the proposed solution or make them look for different options.

Looking at all the reviewed works, it seems that there is not a single proposal that can represent the decision-making process as it happens in face-to-face meetings. This is a very important issue that may compromise the success of the system. Furthermore, looking at the negation process itself, some authors refer the need to define a flexible argumentation framework; however, the current proposals cannot suggest a dynamic approach that allows decision-makers to participate in the decision-making process like it happens in face-to-face meetings. The existing approaches only allow to define initial configurations and generate final outputs (undervaluing the process). Besides this, looking at existing proposals, it seems that there is some difficulty to generate information which both decision-makers and agents can understand and use.

The approach presented in this work aims to answer all these necessities. It is the first existing approach in literature completely directed to ubiquitous scenarios which combines both agent and human dialogues. Agents are able to report decision-makers typical questions such as: percentage of agents in favour of each alternative, which agent supports each alternative/ criterion, which criterion is considered as the most important and many other statistical data that can be retrieved from initial configurations. Besides this, with the approach here presented, agents are able to use the arguments created by decision-makers in their dialogue, and learn (within their necessities) its meaning and importance. It is also possible for agents to report decision-makers the most disagreed points of the discussion which are impeding an eventual consensus. It is possible to know exactly who is in favour of certain alternatives/criteria and also measure, or at least guess, with which level of intensity. This approach allows (due to the type of argumentation that is considered) documenting decisions so that in the future it can be known the reasons that made certain decisions. It is obvious that agents can report the main aspects in favour/against each criterion/alternative and measure the strength-/trust for arguments sustaining certain messages, allowing to "ignore" less relevant arguments and building more intelligent reports based on the interests of the decision-makers.

Finally, looking at the definition of the approach, it will be possible to obtain many future advantages which will depend on the work that can be done using the same approach. For example, the intelligence complexity hat can be included in agents. There is enough information that allows agents to perform and accept requests in a much more complex yet interesting way compared to other existing models.

5.4 Complex or problematic situations

Some problems may occur under certain situations. One of those is when the decision-maker approves (positively evaluates) an attack done to a message created by him. This situation may seem strange but may still happen; for example, if the message which is attacking contains new knowledge which the decision-maker did not know in first place and he agrees with it. Another problematic situation happens when a decision-maker evaluates (approves or disapproves) two branches with different signs (one branch is attacking the initial message and the other is reinforcing it) with the same value. However, we think that these situations are not too problematic in our approach as the algorithm always considers the message which the decision-maker considered as most important. That message with the highest evaluation is used as reference to know the opinion of the decision-maker towards the root message. We still think that it is fundamental, for this specific situation, that the system should warn the decision-maker in the moment of the evaluation (through the user interface). Furthermore, we even consider that if a decision-maker evaluates a message with a value higher than another message which he had evaluated previously, the system should also warn him asking if he really intends to consider the new message more important than the previous evaluated message.

6 Conclusions and future work

Supporting and representing the group decision-making process is a complex work, especially when we consider decision-makers that cannot gather at the same place and time. One of the mechanisms suggested in the literature that supports this type of problem is the automatic negotiation. This mechanism aims to find possible solutions to solve a problem while considering every preference of each decision-maker for that problem.

In this work, we introduced the possibility to create dynamic arguments through a definition of an argumentation model. With our proposal, it is possible (and motivates) for an interaction between decision-makers, which allows to create new arguments (in favour or against) and also reinforce or attack other arguments created by other decision-makers. The way decision-makers can evaluate each argument will allow the agents to understand the impact of the interactions for the decision-maker they represent and not the content of the conversation (which could be text, sound, etc.). Besides this, since agents share the same problem definition, it allows decision-makers to understand all the interactions between those agents and the reason why they suggest a certain solution for the problem. This approach may also be advantageous to register the reasons that led decision-makers to choose a certain decision. In this work, we also proposed an algorithm that allows agents to navigate and manipulate message trees.

It is always very difficult to validate a proposal of this nature, mainly because we are talking about something that will be used by human beings, and therefore there is not a mathematical proof that grants the acceptance of a model/system. However, our proposal was defined so that it takes advantage of the typical benefits related to group decision-making (unlike the approaches on existent argumentation models that deal with this type of context). We verified that agents were able to use dialogues performed by decision-makers and create/organize new knowledge which in turn is completely perceptible to decision-makers. We verified that our approach takes advantage of the benefits inherent to group decision-making and deals with the decision-making process in a continuous way through several interactions. Besides this, we verified that our approach can be implemented without compromising the system in terms of usability.

As future work, we intend to develop a framework where the information will be analysed using multidimensional matrices. This way agents will be able to use this new knowledge and improve their ability to make requests and consequently evaluate them. Besides this, the agent should also take his defined behaviour into account when doing any analysis in order to properly support and defend the perspective of the decision-maker he represents. Finally, we intend to work on the branch of how and what type of information should be presented to the decision-maker, through what we will call as intelligent reports.

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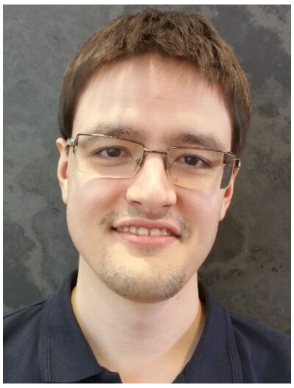

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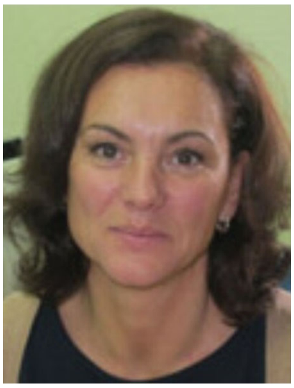

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3.6 ARGUING WITH BEHAVIOR INFLUENCE: A MODEL FOR WEB-BASED GROUP DECISION SUPPORT SYSTEMS

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ARGUING WITH BEHAVIOR INFLUENCE: A MODEL FOR WEB-BASED GROUP DECISION SUPPORT SYSTEMS

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In this work, we propose an argumentation-based dialogue model designed for Web-based Group Decision Support Systems, that considers the decision-makers' intentions. The intentions are modelled as behavior styles which allow interactions between agents in a very similar way to those as humans would have in face-to-face meetings. In addition, we propose a set of arguments that can be used by the agents to perform and evaluate requests, while considering the agents' behavior style. The inclusion of decision-makers' intentions intends to create a more reliable and realistic process. Our model proved, in several different perspectives, that in a virtual context, higher levels of consensus and satisfaction are achieved when using agents modelled with behavior styles compared to agents without any features to represent the decision-makers' intentions.

Keywords: Web-based Group Decision Support Systems; Argumentation; Multi-Agent Systems; Decision-Making; Multi-Criteria Problems; Cognitive aspects.

1991 Mathematics Subject Classification: 22E46, 53C35, 57S20

1. Introduction

It is known that many of the decisions that take place in organizations are made in group (Lunenburg, 2011). Group decision-making is a process in which a group of people, called participants, act collectively to analyze a set of variables, considering and evaluating the available alternatives in order to select one or more solutions. The number of participants involved in the process is variable and all of them may be either at the same place at the same time or geographically dispersed at different times (Luthans, Luthans, & Luthans, 2015). There are 2 main reasons for which decisions are made in group: on the one hand, most of the current organizations organigrams involve several decision-makers (Luthans

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et al., 2015), both at the strategic (Eisenhardt & Zbaracki, 1992) and at the technical level (Montoya-Weiss, Massey, & Song, 2001), on the other hand, to decide in group can potentiate the decision quality (Dennis, 1996; Hill, 1982; Huber, 1984). Group Decision Support Systems (GDSS) have been widely studied throughout the last decades to support this type of decisions (DeSanctis & Gallupe, 1984; Desanctis & Gallupe, 1987; Gray, 1987; Marakas, 2003). However, in the last ten/twenty years, we have seen a remarkable change in the context where the decision-making process happens, especially in large organizations (Chen, Liou, Wang, Fan, & Chi, 2007; Grudin, 2002). With the emergence of global markets, the growth of multinational organizations and a globalist view of the planet, we can easily find decision-makers (chief executive officers, managers and other members of global virtual teams) spreading around the world, in countries with different time zones (Shum, Cannavacciuolo, De Liddo, Iandoli, & Quinto, 2013). Moreover, to support the group decision-making process in this context is especially complex, due to the decision-makers being geographically dispersed. This can lead to additional problems: failure to communicate and retain contextual information, unevenly distributed information, difficulty to communicate and to understand the salience of information, differences in the speed of access to information, and difficulty to interpret the meaning of silence (Bjørn, Esbensen, Jensen, & Matthiesen, 2014); and to deal with temporal issues, which can originate: ambiguity, conflicting temporal interests and constraints, and scarcity of temporal resources (McGrath, 1991). To provide an answer and operate correctly in this type of scenarios, the traditional GDSS have evolved to what is known today as Ubiquitous/Web-based Group Decision Support Systems (Web-based GDSS) (Alonso, Herrera-Viedma, Chiclana, & Herrera, 2010; Kwon, Yoo, & Suh, 2005; Marreiros, Santos, Ramos, & Neves, 2010) . The idea behind the Web-based GDSS is to support the decision-making process “anytime” and “anywhere”, and to help dealing with some of the referred problems (Santos, Marreiros, Ramos, Neves, & Bulas-Cruz, 2006; Shim et al., 2002).

In a group decision-making process there is a conflict of interests and each of the parties involved may (or may not) have different objectives and needs that intends to satisfy (Lewicki & Litterer, 1985). Some strategies that can be used in Web-based GDSS have been proposed, such as Multiple-Criteria Decision Analysis (MCDA) methods and automatic negotiation models (game theory, heuristics and argumentation) (Carneiro, Conceição, Martinho, Marreiros, & Novais, 2016; Rahwan et al., 2003). They intend to help decision-makers in achieving an agreement through frameworks and other specific strategies (Fedrizzi & Kacprzyk, 1988; Iván Palomares & Martínez, 2014). During the process of a real face-to-face decision-making scenario, dialogues can assume different types like: persuasion, information-seeking, inquiry, among others (D. Walton & Krabbe, 1995). The argumentation-based dialogue models can be a suitable strategy to help overcome the lack of interaction inherent to the decision-making processes in which decision-makers are geographically dispersed (Kakas & Moraitis, 2003; Karacapilidis & Papadias, 2001; Rahwan et al., 2003). They allow agents (that can represent decision-makers) to exchange proposals including justifications and explanations which are essential for an agent to properly negotiate with other agents (Marey, Bentahar, Asl, Mbarki, & Dssouli, 2014). Furthermore, the arguments can be used to explain to decision-makers the reasons why agents propose a certain solution (Amgoud & Prade, 2006). The most striking approaches were proposed about 2 decades ago (Dung, 1995; Kraus, Sycara, & Evenchik, 1998; Sierra, Jennings, Noriega, & Parsons, 1997). Since then, we have seen different (extensions) approaches to formulate argumentation frameworks, such as: abstract argumentation (Bondarenko, Dung, Kowalski, & Toni, 1997; Prakken, 2010), logic-based argumentation (Amgoud, 2014; Besnard & Hunter, 2001), value-based argumentation (T. Bench-Capon, 2002; D'Avila Garcez, Gabbay, & Lamb, 2005), assumption-based argumentation (Dung, Kowalski, & Toni, 2009; Fan, Craven, Singer, Toni, & Williams, 2013), among others (Amgoud & Vesic, 2011). However, these approaches deal with argumentation as a somewhat one-sided-process "in which a single party merely presents a reasoned justification" (T. J. Bench-Capon & Dunne, 2007). In the context of group decision-support the paradigm is different, the argumentation is "an informed exchange of ideas and positions involving several contributors: in other words, argumentation concerning an issue", which typically, arises as a dialogical process (T. J. Bench-Capon & Dunne, 2007). Some strategies have been proposed to deal with dialogical processes (Johnson, McBurney, & Parsons, 2005; McBurney & Parsons, 2001; Parsons, McBurney, Sklar, & Wooldridge, 2007), most of which are oriented to be used in multi-agent systems and to formalize some typical aspects, such as: locutions, utterances, rules for dialogue continuation and termination. However, when we search for argumentation-based dialogue models specifically adapted to GDSS, the results are practically inexistent. The few existing results are outdated (Karacapilidis & Papadias, 1996, 2001) and even if some seemed promising in the way they could be adapted to this area (Kraus et al., 1998; Sierra et al., 1997), the works that came next followed (most of the times) another path (despite some of them remain within decision support).

When developing a Web-based GDSS it is necessary to be aware of the benefits inherent to group decision-making. A typical face-to-face meeting allows the decision-makers' interaction, exchange of ideas, work on new knowledge and intelligence generation (Dennis, 1996; Hill, 1982; Huber, 1984). As we had seen, (in an ideal scenario) we can achieve some of these benefits using automatic negotiation models (for instance: argumentation-based dialogue models). However, there is so much more besides the "messages" exchanged by decision-makers, it is necessary to work in the representation of those decision-makers. The representation can range from criteria's evaluation (for instance in a multi-criteria problem (Carneiro, Martinho, Marreiros, & Novais, 2015)) to a complete representation of the individual (for instance: personality, emotions and mood (Gmytrasiewicz & Lisetti, 2002; Raja & Srivatsa, 2006; Santos, Marreiros, Ramos, Neves, & Bulas-Cruz, 2009). The face-to-face meetings benefit from the decision-makers' heterogeneity (Hambrick, Cho, & Chen, 1996). This heterogeneity is related to the decision-makers' temperament but also with the decision-makers' intentions. Let us consider a scenario where a group of friends intends to choose a restaurant to celebrate the anniversary of one of them. Obviously, as in any other multi-criteria problem, each person would have his own preferences concerning each of the possible alternatives. However, how important would be the consideration of each element's intentions? Is it possible that some just want to please the birthday person? If so, should not they be more willing to accept that person preferences? What would happen if they used a Web-based GDSS which only considered the preferences of participants (towards alternatives and criteria) and ignored their intentions? Would the group satisfaction resulting from the decision made be the expected? In order to answer these questions, it is necessary to allow decision-makers to configure not only their preferences (on alternatives and criteria), but also their intentions and other aspects that may be relevant, so that their position can be expressed with the best possible representation.

To model agents with human-like aspects is not new. At the start of the new millennium, some projects dealing with agents' humanization began to appear (André, Klesen, Gebhard, Allen, & Rist, 2000). Nowadays, there are many proposals that intend to model human characteristics in agents, such as: personality (Dimuro, da Rocha Costa, Gonçalves, & Hübner, 2007; Padgham & Taylor, 1997), emotions (Ball & Breese, 2000; Gmytrasiewicz & Lisetti, 2002), cognitive styles (Frank, Bittner, & Raubal, 2001), among others (Ghavami & Taleai, 2017; Ghavami, Taleai, & Arentze, 2016, 2017). There are also some proposals under the topic of GDSS (Ivan Palomares, Martinez, & Herrera, 2014; Iván Palomares, Rodríguez, & Martínez, 2013; Recio-García, Quijano, & Díaz-Agudo, 2013; Santos et al., 2009). All of them share the idea that including cognitive/affective aspects will benefit in some way the decision-making process. However, to the best of our knowledge, most of them are envisaged for use in simulated environments. The usage of such techniques in real systems can bring some disadvantages. "A real me" can be a bad approach if my persona is less persuasive/intelligent/capable than others. No one will be interested in using an application that depreciates you. Moreover, the inclusion of aspects such as personality, does not permit to reflect other aspects such as intentions and objectives. For each decision-maker the objectives and intentions can vary even for the same problem. Returning to the previous example (to select a restaurant to celebrate the birthday of one of the group members), we could use the decision-makers' personality to define the interactions between agents and how each agent could behave, however this approach is not enough to identify the intentions of each one of the decision-makers.

In this article, we propose an argumentation-based dialogue model to support decision-makers in the group decision-making process. In our proposal, each agent can assume a style of behavior to represent the intentions of the decision-maker. The behavior is responsible for defining how agents use the argumentation model and how they evaluate the received requests. Due to the specific needs inherent to the group decision-making process, our proposal allows agents to be: competitive between them, i.e., allow agents to be capable of pursuing the decision-makers' preferences; and collaborative, i.e., allow agents to work together in order to achieve the best outcomes for the group. We intend to prove that including styles of behavior is a major asset in this type of context. In addition, we study if by including styles of behavior, the amount of intelligence generated does not decrease (in fact, our goal is to generate more and better intelligence). We also do not want to achieve a fake increase of the consensus level by including styles of behavior. It is important to know if agents do not neglect their preferences while trying to defend the intentions of the decision-maker. We believe that a correct representation of the decision-makers' intentions improves the ability to achieve consensus and at the same time improves the decision quality. However, in our proposal, the achievement of consensus is not forced, the process flows naturally and there is an understanding that sometimes there are no conditions for consensus. We are in front of a process with almost no interaction between decision-makers, which means they need an iterative process to reason about the problem, to understand other points of view and to reconfigure their preferences. These points are respected in our proposal. Finally, our proposal allows to work with multiple agents and benefits from some of the main advantages of group decision-making process through the agents' capacity to represent the decision-makers' preferences and intentions.

The rest of the paper is organized in the following order: in the next section, we contextualize the reader through the presentation of our previous approach to deal with styles of behavior in decision-making. Our proposal is presented in Section 3. In Section 4, we deal with the evaluation and results and in Section 5 the discussion is presented. In Section 6, we present the related work and finally, some conclusions are taken in Section 7, along with the work to be done hereafter.

2. Styles of Behavior for Decision-Making

There are a considerable number of proposals in the literature of computer science related to the agents' humanization. For that, most of them have been using models such as: Five Factor Model (Howard & Howard, 1995), OCC (Ortony, Clore, & Collins, 1990) and PAD (Mehrabian, 1996). To develop more intelligent applications, we have seen an increasing of multi-disciplinary works. There are some models in the literature of psychology that define roles/behaviors/designations to individuals. These approaches can be used, adapted or included in simulators or real systems.

In this section, we describe a model previously proposed by us ([SELF-CITATION]) that intends to allow agents to represent the decision-makers' intentions. The theoretically understanding of this model is essential to a better comprehension of the work proposed in this paper. We consider the decision-makers' intentions as what they: intend (a purpose), plan, desire and/or aspire. Previously, we demonstrated (in the introduction section) that intentions can vary for a same problem in different situations/contexts. To reach the decision-maker's intentions the agent should behave accordingly. We adopted the conflict styles proposed by Rahim and Magner (1995), and redefined them to be more adequate to the context of group decision-making. We called them styles of behavior and defined them as follows:

- **Dominating**: A dominating individual believes that he owns the key to solve the problem. He plays a very active role during the decision-making process and tries to force his opinions on other participants;
- **Integrating**: An integrating individual favors a collaborative style. He aims to achieve consensual decisions and greatly values his and others' opinions. He prefers to manage assiduously the entire decision-making process;

- **Compromising**: A compromising individual favors a collaborative style. He aims to achieve consensual decisions and values his and others' opinions. He plays a moderately active role during the decision-making process;
- **Obliging**: An obliging individual tends to give up on his opinions in favor of the group interests. He prefers to follow others' opinions rather than sharing his owns;
- **Avoiding**: An avoiding individual prefers to be freed from responsibility. Fundamentally, he prefers to not be involved in the decision-making process and devalues both the process and the opinions of other participants.

Using a correlation between the work proposed by Rahim and Magner (1995) and the facets identified by Costa and MacCrae (1992) we proposed 4 dimensions suitable to the context of group decision-making: activity level, resistance to change, concern for self and concern for others. These dimensions represent:

- **Activity level**: High activity levels reflect leadership and vigorousness. Low activity levels reflect leisurely and low need for thrills;
- **Resistance to change**: High resistance to change reflect humble, eager to help and easily moved. Low resistance to change reflect aggressive, superior and skeptical;
- **Concern for self**: High or low interests to satisfy his or her concerns;
- **Concern for others**: High or low interests to satisfy the concerns of others.

The information available in the literature only allows to define each style of behavior in these dimensions using classifications as low, mid and high. However, to computerize this model and to make agents represent the intentions as well as possible, we needed to transform this classifications into numerical values. Moreover, let us suppose that an existent model considers a Dominating behavior as having a low concern for others. How can we know if whenever a decision-maker selects the dominating behavior style to model his agent, he is expecting this "low concern for others"? To deal with these issues, we ran a survey to understand if it was possible to find homogeneous answers to define each style of behavior in each dimension (numerically). The objective was to verify if the behavior styles are perceived in the same way and if that can be expressed numerically. The study involved 64 participants, 39 men and 25 women, aged between 19 and 68 years old (M=33,56; SD=10,84) all of which either had higher education degrees or were undergraduate students (10%). In respect to their fields of expertise, respondents were professionals from a wide variety of backgrounds, ranging from technology to social sciences. Basically, we asked them to classify the five proposed behavior styles in four dimensions: Concern for self; Concern for others; Resistance to change; and Activity level in a questionnaire ranging from 0-10 (by means of a visual analogic scale). All respondents were asked to fill out the questionnaire in the researcher's presence to ensure engagement in the task and/or to provide assistance in the clarification of concepts or modes of signaling the answers. We used the Intraclass Correlation Coefficient to study the agreement level.

For all dimensions results were above ,900, more precisely between ,915 and ,941, with highly significant results (p<,001).
The values obtained in this study helped us to define the actuation levels for each style of behavior in each dimension as can be consulted in Table 1 (the values were normalized to the [0,1] range). This behavior style model plays an important role in the work proposed in this paper.

Table 1. Behaviour style measures for each dimension

Behavior Style	Activity Level ($\bar{x}$)	Resistance to Change ($\bar{x}$)	Concern for Self ($\bar{x}$)	Concern for Others ($\bar{x}$)
Dominating	0,94	0,92	0,95	0,17
Integrating	0,90	0,54	0,78	0,85
Compromising	0,58	0,42	0,55	0,62
Obliging	0,23	0,12	0,20	0,87
Avoiding	0,05	0,10	0,11	0,09

An interest finding of this work was that none of the proposed styles of behavior is always more advantageous over others regardless of context. This is an incentive for decision-makers to choose the style of behavior that better fits to their intentions.

3. Methods

In this paper, we consider the following structure of a decision problem: there are a set of possible alternatives A, a set of criteria C, and a set of agents Ag, such that each alternative $a \in A$ has a value for all the defined criteria C. The decision problem has a defined communication language $\mathcal{L}_c$ which allows agents Ag to communicate. To operate with the defined $\mathcal{L}_c$, there is a set of algorithms $\mathcal{L}_a$, which specify for each illocution $\varphi \in \mathcal{L}_c$ its effect. The relations between alternatives, criteria, agents, communication language and algorithms jointly form a decision system, represented as follows:

Definition 1: A decision system $(C, A, Ag, \mathcal{L}_c, \mathcal{L}_a)$, is a 5-tuple where:

- a set of criteria $C = \{c_1, c_2, \dots, c_n\}, n > 0$;
- a set of alternatives $A = \{a_1, a_2, \dots, a_m\}, m > 0$;
- a set of agents $Ag = \{ag_1, ag_2, \dots, ag_k\}, k > 0$;
- a communication language $\mathcal{L}_c$, consisting of a set of all illocutions;
- a set of algorithms working as regulation $\mathcal{L}_a$ for $\mathcal{L}_c$, specifying for each locution $\varphi \in \mathcal{L}_c$ its effects.

An agent is a virtual representation of a decision-maker and is defined as follows:

Definition 2: An agent $ag_i = \{id_{ag_i}, \beta_{ag_i}, Pr_{ag_i}, C_{ag_i}, A_{ag_i}, O_{ag_i}, K_{ag_i}\}$ is a 7-tuple where:

- $\forall\ ag_i \in Ag, i \in \{1, 2, \dots, n\}$;
- id_{ag_i} is agent's identification;
- β_{ag_i} is the agent's behavior style (Dominating, Compromising, Obliging, Integrating, Avoiding and No Style);

- Pr_{ag_i} is the agent's protocol for $\mathcal{L}_c$, specifying the 'legal' moves at each instant t. A protocol on $\mathcal{L}_c$ is a set of illocutions available to ag_i, where $Pr_{ag_i} \subseteq \mathcal{L}_c$;
- C_{ag_i} is the agent's evaluation of each criterion, $C_{ag_i} = \{Ev_{c_1}, Ev_{c_2}, \dots, Ev_{c_n}\}, Ev_{c_j} \in \{[0,1], \perp\}$;
- A_{ag_i} is the agent's evaluation of each alternative, $A_{ag_i} = \{Ev_{a_1}, Ev_{a_2}, \dots, Ev_{a_n}\}, Ev_{a_n} \in \{[0,1], \perp\}$;
- O_{ag_i} is the set of agent's objectives, $O_{ag_i} \subseteq A \cup C,\ preference\ relation \geq on\ the\ set\ O_{ag_i}$;
- K_{ag_i} is the agent's knowledge, where he can access the list of all sent and received messages, as well as the preferences of other agents, according to the knowledge he possess in a certain time instant of t.

The agent's objectives (O_{ag_i}) are sorted in a list using the following formula:

$$A_{Result_{o_i}} = \frac{o_i * CS + \left(\frac{NS}{ND}\right) * CO}{CS + CO} \quad (1)$$

Where:

- o_i is the assessment done to the objective i for which the result is being measured;
- CS is the value of Concern for Self;
- NS is the current number of agents supporting o_i;
- ND is the total number of participating agents;
- CO is the value of Concern for Others.

Agent's objectives change throughout the decision-making process. This formula relates the concern for self of the behavior style defined by the decision-maker with the evaluation done for each alternative ($o_i * CS$). This way, the agent can measure the "analytical" interests of the decision-maker. Besides this, the formula relates the number of supporters for each alternative with the concern for others of the defined behavior style which will allow the agent to measure the social interests of the decision-maker ($\left(\frac{NS}{ND}\right) * CO$).

Definition 3: A behavior $\beta_i = \{Rc_{\beta_i}, Al_{\beta_i}, Cs_{\beta_i}, Co_{\beta_i}\}$ is a 4-tuple where:

- Rc_{β_i} is the agent's resistance to change dimension value;
- Al_{β_i} is agent's activity level dimension value;
- Cs_{β_i} is the agent's concern for self dimension value;
- Co_{β_i} is the agent's concern for others dimension value.

A behavior style is represented by the values on each dimension, e.g., Dominating (0.92, 0.94, 0.95, 0.17). In this work, we used the value of each dimension to define the probability for an agent performs an action:

- **Activity level**: probability for an agent to start a dialogue;
- **Resistance to change**: is used to define the acceptance range when an agent receives a request;

- **Concern for self**: is used to order objectives and when the agent decides to perform a "prefer" or a "question" illocution;
- **Concern for others**: is used in the evaluation of requests with the argument appealing to common practices, to order objectives and when the agent decides to perform a "prefer" or a "question" illocution.

Agents communicate by exchanging messages. Figure 1 represents the internal message flow of an agent. Messages exchanged by agents are defined as illocutions. Among other things, an illocution is composed by an utterance and may include (or not) an argument. The agent begins by checking the type of illocution that it receives in the message. In the case of a request, it is evaluated and, based on the evaluation, a response is generated indicating whether the request was accepted or rejected. Based on these request-reception and response-formulation events, the agent updates its "Self Preferences Knowledge Base" and finally, sends the response in the format of a message. In case the type of illocution the agent received in the message is of the type Statement or Question, the agent begins by updating its "Opponents' Preferences Knowledge Base" according to that new received knowledge. The agent then performs two actions. The first one, that always and necessarily happens, is to generate a message to respond to the received message, the second one is to verify if, according to that new received knowledge, the conditions are fulfilled to make a request. To do this, the agent checks for available arguments as well as opponents to receive those arguments. If so, the illocution is generated and the message is sent.

An illocution is represented as follows:

Definition 4: An illocution $\psi_i = \left\{tr_{\psi_i}, \varphi_{\psi_i}, \alpha_{\psi_i}, Vr_{\psi_i}, en_{s_{\psi_i}}, En_{r_{\psi_i}}\right\}$ is a 6-tuple where:

- $i \in \{1, 2, \dots, n\}$;
- tr_{ψ_i} is the target associated with the illocution (can be null or be another illocution);
- φ_{ψ_i} is the utterance sent in the message;
- α_{ψ_i} is the justification associated to the illocution (can be an argument or can be null);
- Vr_{ψ_i} is the set of variables associated to the illocution (Alternative or Criterion);
- $en_{s_{\psi_i}}$ is the agent/user who sent the message;
- $En_{r_{\psi_i}}$ is the set of agents/users who will receive the message (can be 1 or several).

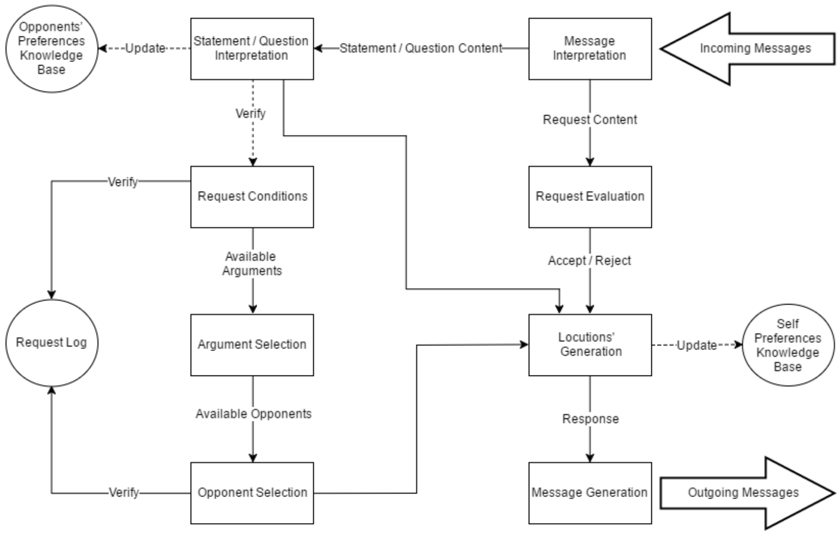

Figure 1. Agents' Communication Workflow

We defined a set of possible illocutions (presented in Table 2). These illocutions represent what agents can dialogue about using a typical multi-criteria problem configuration (for instance, using the template proposed in (Carneiro, Martinho, et al., 2015)). We considered 8 different illocutions (prefer, question, agree, disagree, no-knowledge, request, accept and reject). The "prefer" type of illocutions is more used by agents with a higher value of concern for self than the value of concern for others. We assume that agents with a higher concern for self, try to "impose" their preferences to other agents. The "questions" type of illocutions is more used by agents with a higher value of concern for others than the value of concern for self. We assume that agents with a higher concern for others are more concerned about other agents' opinions.

There is an impact associated to start a dialogue with either a "question" or a "prefer" illocution. For example, when an agent says: "My preferred alternative is a_i", other agents can answer using 4 possible illocutions: agree, disagree, question and no-knowledge. This means that at a certain moment in the process those agents will know who is supporting a_i and will not have any knowledge regarding other alternatives. This information has impact in the order of objectives of each agent, in the selection of arguments to use in requests and in the evaluation of requests.

Table 2. Considered Illocutions

Illocution	Interpersonal Conflict	Utterance	Variables
prefer	CS	"For me the most important criterion/a is/are 1, 2, …, n"	Criterion 1/2/…/n
prefer	CS	"For me the less important criterion/a is/are 1, 2, …, n"	Criterion 1/2/…/n
prefer	CS	"My preferred alternative/s is/are 1, 2, …, n"	Alternative 1/2/…/n

prefer	CS	"My least preferred alternative/s is/are 1, 2, …, n"	Alternative 1/2/…/n
question	CO	"Which criterion/a do you consider most important?"	-
question	CO	"Which criterion/a do you consider less important?"	-
question	CO	"Which alternative/s do you prefer?"	-
question	CO	"Which alternative/s do you prefer to discard?"	-
agree	-	"I agree."	-
disagree	-	"I disagree."	-
no-knowledge	-	"I do not have that information."	-
request	-	"Do you accept the alternative x as the solution?"	Alternative x
request	-	"Can you discard alternative x?"	Alternative x
accept	-	"I accept."	Alternative 1/2/…/n
reject	-	"I do not accept."	Alternative 1/2/…/n

The Figure 2 is the sequence diagram that represents the proposed negotiation protocol. This diagram is a representation of our technical implementation and was used in the prototype that was developed to run the simulations presented in Section 2. We created a Facilitator Agent (AgF) to manage the meeting. We have defined 2 termination rules: when the agents have no more illocutions to exchange and when consensus is reached. When an agent wants to start a dialogue (using a "prefer" or a "question") he generates a participation time based in his style of behavior. Obviously, the dominating and integrating agents have a higher probability to start a dialogue because they have a higher value for the activity level. The AgF will select the agent with the higher participation time and allows him to speak. All other agents are informed by AgF that they do not have the right to speak. The messages exchanged between AgP(i) and AgP(x) represent just an example of a dialogue between participating agents. The purpose of this representation is to demonstrate what is happening when an agent adds a new preference. Every time an agent adds a new preference he sends a message to AgF informing. The flow represented between AgF and AgP(i) is the same that occurs between AgF and all other participating agents.

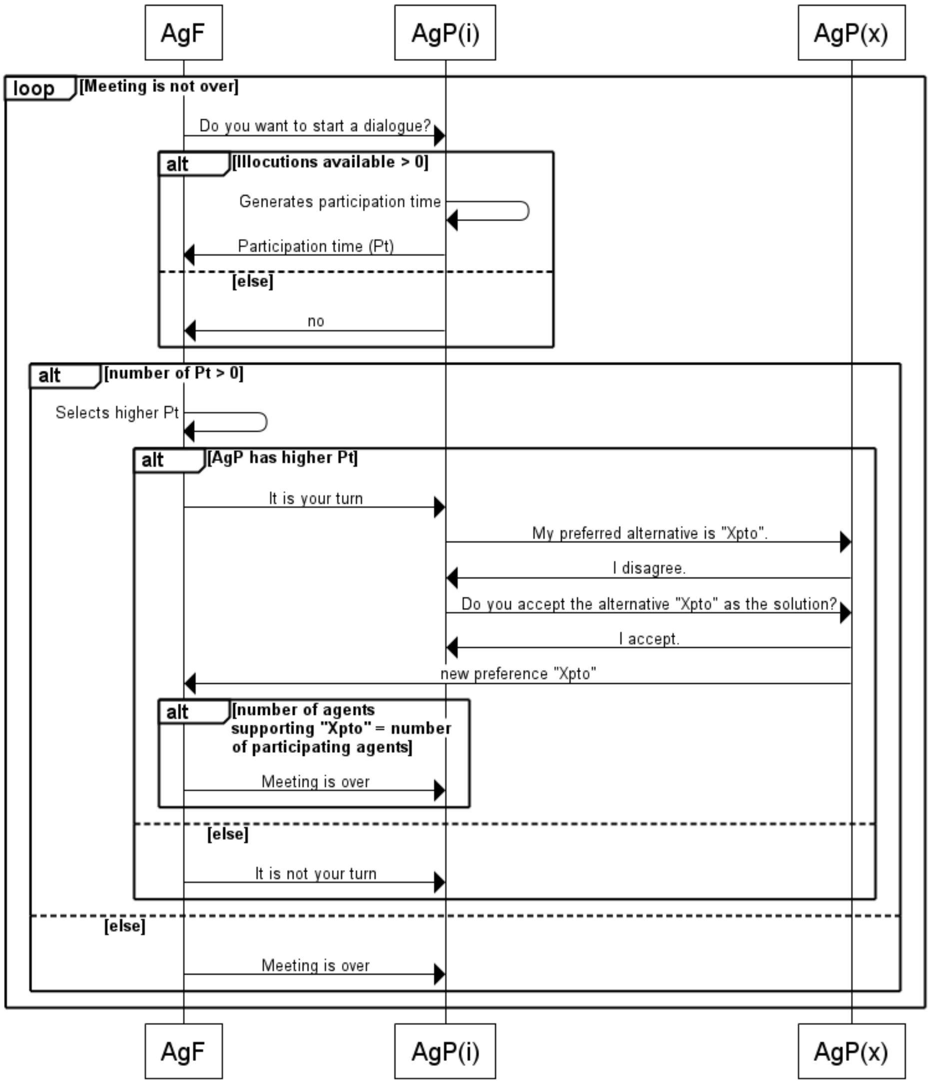

Figure 2. Agents' Interaction Workflow

The dialogue moves

With this background, we can present the set of dialogue moves that we use. For each move, we define what we call rationality rules, dialogue rules, and action rules. These are based on the rules suggested by Maudet and Evrard (1998). The rationality rules specify the preconditions for playing the move. The action rules specify the move's implications. The dialogue rules specify the moves other agents can make next, and so specify the protocol under which the dialogue takes place.
We start with the dialogical move "prefer":

$prefer(\psi_x \vee null, \varphi_{\psi_i}, \alpha_{\psi_i}, Vr_{\psi_i}, ag_{\psi_i}, En_{r_{\psi_i}})$ is an illocution ψ_i in $\mathcal{L}_c$.

rationality the agent ag_{ψ_i} intends to declare his opinions about an alternative/s or a criterion/a. He also intends to know if other agents agree/disagree with him and to create a group supporting his preferences.

dialogue $\forall ag_j \in En_{r_{\psi_i}}$ can:
agree($\psi_i, \varphi_{\psi_k}, \alpha_{\psi_k}, Vr_{\psi_k}, ag_j, En_{r_{\psi_k}}$),
disagree($\psi_i, \varphi_{\psi_k}, \alpha_{\psi_k}, Vr_{\psi_k}, ag_j, En_{r_{\psi_k}}$),
request($null, \varphi_{\psi_k}, \alpha_{\psi_k}, a_k, ag_j, En_{r_{\psi_k}}$),
no-knowledge($\psi_i, \varphi_{\psi_k}, \alpha_{\psi_k}, Vr_{\psi_k}, ag_j, En_{r_{\psi_k}}$).

action $retract(\psi_i \in Pr_{ag_{\psi_i}})$, $retract(\psi_i \in Pr_{ag_j})$. All the agents that have ψ_i in their Pr will retract the illocution because we are dealing with a dialogue between multiple agents. An agent that shares the same preferences will answer with an "agree" so it does not make sense if that agent can use the same illocution again.

$question(null, \varphi_{\psi_i}, \alpha_{\psi_i}, Vr_{\psi_i}, ag_{\psi_i}, En_{r_{\psi_i}})$ is an illocution ψ_i in $\mathcal{L}_c$.

rationality the agent ag_{ψ_i} intends to perform a question when he wants to know about other agents' preferences.

dialogue $\forall ag_j \in En_{r_{\psi_i}}$ can:
prefer($\psi_i, \varphi_{\psi_k}, \alpha_{\psi_k}, Vr_{\psi_k}, ag_j, En_{r_{\psi_k}}$),
no-knowledge($\psi_i, \varphi_{\psi_k}, \alpha_{\psi_k}, Vr_{\psi_k}, ag_j, En_{r_{\psi_k}}$).

action $retract(\psi_i \in Pr_{ag_{\psi_i}})$, $retract(\psi_i \in Pr_{ag_j})$. As we described in the "prefer" illocution, also here the agents will perform the same actions for the same reasons. Agents select whether to send a prefer or question illocutions based on their concern for self and concern for others. An agent has a higher probability to send a prefer illocution if his concern for self is higher than his concern for others. On the other hand, an agent has a higher probability to send a question illocution if his concern for others is higher than his concern for self. In case of agents without a defined behavior style, the illocution is selected randomly (50/50).

$request(null, \varphi_{\psi_i}, \alpha_{\psi_i}, a_j, ag_{\psi_i}, En_{r_{\psi_i}})$ where a_j is an alternative being requested in ψ_i which is an illocution in $\mathcal{L}_c$.

rationality the agent ag_{ψ_i} performs a request when he believes there is a reason for the other agent to accept it.

dialogue $\forall ag_j \in En_{r_{\psi_i}}$ can:
accept($\psi_i, \varphi_{\psi_k}, \alpha_{\psi_k}, Vr_{\psi_k}, ag_j, ag_{\psi_i}$),
reject($\psi_i, \varphi_{\psi_k}, \alpha_{\psi_k}, Vr_{\psi_k}, ag_j, ag_{\psi_i}$).

action $retract\left(\psi_i \in Pr_{ag_{\psi_i}}\right)$

agree($\psi_i, \varphi_{\psi_k}, \alpha_{\psi_k}, Vr_{\psi_k}, ag_j, En_{r_{\psi_k}}$)

rationality the agent ag_j informs about his agreement.

dialogue There is no dialogical sequence.

action $\forall ag_l \in En_{r_{\psi_k}}\ asserts\ Vr_{\psi_k}\ in\ O_{ag_{j_{K_{ag_l}}}}$. When an agent ag_j states his agreement about a ψ_i, other agents assert this information.

accept($\psi_i, \varphi_{\psi_k}, \alpha_{\psi_k}, a_i, ag_j, ag_l$)

rationality the agent ag_j informs about his acceptance.
dialogue There is no dialogical sequence.
action
$ag_l\ asserts\ a_i\ in\ O_{ag_{j_{K_{ag_l}}}}\ and\ ag_j\ asserts\ a_i\ in\ O_{ag_j}\ and\ ag_j\ asserts\ \psi_m\ in\ Pr_{ag_j}$ where ψ_l is an illocution indicating the preference regarding alternative a_i. The disagree, reject and no-knowledge illocution are not specified because they do not have any kind of consequences.

Requests

Throughout the dialogue agents exchange requests that can be followed by an argument (or not). To send a request an agent must decide what kind of request should be made. This depends on the knowledge acquired during the dialogue and that is associated with the preferences of other agents. The arguments that can be used in each request are of three types: appeal to self-interest, appeal to prevailing practice and appeal to common sense. The first two types were chosen based on literature and have been first proposed by Kraus et al. (1998) and have been adapted to later works in the area of argumentation. The third type is introduced in this paper and in the literature for the first time and is essential to make the negotiation process closer to what can be observed in real scenarios. It is common to find in the literature argumentation models that use argument types such as rewards or threats, however in our proposal we did not consider these types mainly because they cannot be used to discuss the problem's specific information. In fact, the information exchanged using these types of arguments may not be related to the problem at all. For example, an agent ag_1 threatening another agent ag_2 who does not want to go to restaurant a_1 by saying he will not be invited to future meetings does not bring more intelligence to the decision-making process, despite being useful to unlock conflict situations. Our approach focuses entirely on a logic to achieve the best possible level of consensus while always maintaining the same level of concern towards the amount of intelligence that can be generated. The idea is to support decision-makers using valuable knowledge instead of supporting fake consensual decisions every time this knowledge could be concealed. Below we move on to a more detailed description of each one of the argument types that have been considered.

Appeal to self-interest. This argument is used whenever an agent intends to convince another agent to accept a request claiming to be of his interest to accept it. This happens whenever an agent prefers a certain criterion and prefers an alternative which does not have the best values for the preferred criterion.

Example 1.1: Let us consider a car purchase example with two criteria $c_1 = Price, c_2 = Durability$, two alternatives $a_1 = (10000€, 8\ years), a_2 = (15000€, 10\ years)$ and two agents ag_1 with $O_{ag_1} = \{a_2, c_1\}$ and ag_1 with $O_{ag_1} = \{a_1, c_1\}$.

Looking at ag_1 we know that his current objective is to choose the second alternative as the solution to the problem. However, since ag_1 prefers criterion c_1 then agent ag_2 is in condition to send a request message ψ_1 appealing to self-interest of ag_1, where α_{ψ_1} = "Accept a_1 because a_1 is cheaper than a_2.".

Appeal to prevailing practice. This argument is used whenever an agent intends to convince another agent to accept a request by referring to most participants which have already accepted the requested alternative.

Example 1.2: Let us consider the same car purchase example and this time there are 5 agents with the following objectives in time instant t: ag_1 and $O_{ag_1} = \{a_2\}$; ag_2 and $O_{ag_2} = \{a_2\}$; ag_3 and $O_{ag_3} = \{a_2\}$; ag_4 and $O_{ag_4} = \{a_1\}$; and ag_5 and $O_{ag_5} = \{a_1\}$. Both ag_1, ag_2, ag_3 prefer alternative a_1 and which means the total number of agents in favour of a_1 in time instant t corresponds to more than half of the total number of participants. Therefore, either ag_1, ag_2 or ag_3 could send a request message ψ_1 to ag_4 or ag_5 appealing to prevailing practice, where α_{ψ_1} = "Accept a_2 because it has been accepted by more than half of the total number of participants.".

Appeal to common sense. This argument can be used to convince an agent if he is the only one preferring a certain alternative while not accepting any other available alternatives. This can be seen in real situations whenever a participant is stuck with only one choice and refuses to accept different opinions thus becoming an obstacle to improve the flow of the discussion. At first glance, this argument might seem to be a type of appeal to prevailing practice, however if we look closer, we will see that both kind of arguments are completely different. An appeal to prevailing practice is an argument that involves an action performed by other agents. On the other hand, the appeal to common sense, involves an individual action which the agent who receives it did not perform yet.

Example 1.3: Let us consider the same car purchase example and this time there are 5 agents with the following objectives in time instant t: ag_1 and $O_{ag_1} = \{a_2\}$; ag_2 and $O_{ag_2} = \{a_2\}$; ag_3 and $O_{ag_3} = \{a_2\}$; ag_4 and $O_{ag_4} = \{a_2\}$; and ag_5 and $O_{ag_5} = \{a_1\}$. Only agent ag_5 still has not accepted a_2 so all other agents ag_1, ag_2, ag_3, ag_4 could send a request message ψ_1 to ag_5 appealing to common sense, where α_{ψ_1} = "You are the only one who has still not accepted a_2.".

Selection

Each request may include one of each type of arguments presented above and an agent may also send requests without arguments. Every time an agent exchanges new information, each other agent will process that information and verify if he can send a request or not. This request is not always targeted at the agent who shared the information. In fact, there may be situations where an agent may be able to send a request to someone else depending on the newly received information.

Example 1.4: Let us consider the same car purchase (considering 5 agents involved in the process) example and this time there is an agent ag_1 with $O_{ag_1} = \{a_2\}$, and he receives the following messages ψ_1 and ψ_2, where $en_{s_{\psi_1}}$ = ag_2, φ_{ψ_1} = "I prefer a_2.", $en_{s_{\psi_2}}$ = ag_3, φ_{ψ_2}= "I prefer a_2.". This means ag_1 now knows 3 agents prefer a_2 and he could send a request message appealing to prevailing practice to ag_4, even though ag_4 did not share any information.

Many proposed systems in the literature have been developed considering that an agent will always start by selecting another agent to send the request and only then will verify what type of argument is more adequate. In our proposal, we have chosen a different strategy where the agent will start by selecting the argument which we consider having the most persuasion power (according to strength level of the type of that argument) and only then select the agent that will receive the request. The order of the arguments persuasion power is: appeal to common sense, appeal to self-interest, appeal to prevailing practice and finally simple request (request without an argument). This order is based in the definitions proposed by Kraus et al. (1998) and the agent will always try to send requests starting with the argument which we consider to be stronger until no arguments can be selected and he is only allowed to make requests without an argument.

Restrictions

Let us define a function that returns the number of agents which agent ag_i knows that prefer alternative a_j in a time instant of t_k.

$$F_{agentspreferalt}: ag_i, a_j, t_k \rightarrow \forall ag \in K_{ag_i}, O_{ag} \supset a_j \wedge t_{K_{ag_i}} = t_k$$

Now, let us assume that agent ag_1 sent a request message ψ_1 to another agent ag_2 to accept alternative a_1 in the time instant t_1. Agent ag_1 cannot send another request message ψ_2 in the time instant t_2 if:

$$\begin{aligned} En_{r_{\psi_1}} = En_{r_{\psi_2}} &= ag_2 \wedge Vr_{\psi_1} = Vr_{\psi_2} = a_1 \wedge \alpha_{\psi_1} \\ &= \alpha_{\psi_2} \wedge \left|F_{agentspreferalt}(ag_1, a_1, t_1)\right| \\ &= \left|F_{agentspreferalt}(ag_1, a_1, t_2)\right| \end{aligned}$$

In other words, an agent must not send more than one request to accept the same alternative, to the same agent, with the same argument if the number of agents in favour of that alternative is also the same for each request. This will stop agents from always sending the same request to the same agent which in turn will always refuse that request. On the other hand, this strategy allows agents reusing requests sent to the same agents under different conditions.

Now, let us define a function that returns the number of agents which agent ag_i still does not know their preferences in a time instant of t_k:

$F_{agentsnopref}: ag_i, t_k \rightarrow \forall ag \in K_{ag_i}, \ |O_{ag}| = 0 \wedge t_{K_{ag_i}} = t_k$

An agent ag_1 cannot send a request message to ag_2 appealing to common sense at the time instant t_1 if $|F_{agentsnopref}(ag_1, t_1)| > 0$. This means that agent ag_1 still does not know the preferences for each participant in that time instant. This is done to avoid situations where an agent would use this type of requests right at the beginning of the discussion without even knowing if more agents could also share the same preferences of the agent that would receive the request.

Evaluation

Our agents evaluate the requests with argument using subjective considerations (Rahwan et al., 2003). This means that our agents use "its own preferences and motivations in making that judgement".
An agent may accept or refuse a request depending on its resistance to change level. As mentioned before, resistance to change is one of the dimensions used to model agent's style of behavior. With this, agents will make requests depending not only on their preferences but also on their style of behavior. In a very simple way we can say that the agent will:

Accept the request if:

$$RAP \geq PAP - AI \quad (2)$$

Where:

- RAP is the Requested Alternative Preference;
- PAP is the Preferred Alternative Preference;
- AI is the Acceptance Interval.

Refuse the request if:

$$RAP < PAP - AI \quad (3)$$

The acceptance interval will vary depending on the resistance to change of the agent, the argument type and any variable related to the argument.

Request – Without an argument

When evaluating a request without an argument this interval will be affected by the percentage of agents in favour of the requested alternative at the time it is received. The formula used to calculate the acceptance interval for requests without arguments (4) is:

$$\mathrm{AI}_{rwa} = (1 - \mathrm{resistance}) * \frac{\mathrm{NAFRA}}{\mathrm{TNA}-1} \quad (4)$$

Where:

- $resistance$ is value of the resistance to change (of a specific behavior style);
- $NAFRA$ is the Number of Agents in Favour of Requested Alternative;

- TNA is the Total Number of Agents.

That means requests will always be evaluated according to the context. The AI_{rwa} value for an alternative a_i increases as that alternative is gaining more supporters. The agent can accept the request (formula 2) if the preference for the requested alternative is higher than the difference between his most preferred alternative and the AI_{rwa} that is measured. For agents without a defined behavior we defined the value of resistance to change as 0.75.

Request – Appealing to self-interest

When evaluating requests with the argument appealing to self-interest the acceptance interval is affected by the preference (normalized) of the agent towards the criterion associated to the argument plus the value of AI_{rwa}. The formula used to calculate the acceptance interval for requests with the argument appealing to self-interest (5) is:

$$\mathrm{AI}_{rsi} = \left((1 - \mathrm{resistance}) - \mathrm{AI}_{rwa}\right) * \mathrm{CPN} + \mathrm{AI}_{rwa} \quad (5)$$

Where:

- CPN is the Normalization of the Preferred Criterion.

This allows the agent to widen its acceptance range according to the importance given to the criterion associated to the argument appealing to self-interest.
In case the agent does not have a defined behavior, the evaluation of the request with an argument appealing to self-interest will be done using the following formula:

$$\mathrm{AIWB}_{rsi} = \left(\frac{\mathrm{NAFRA}}{\mathrm{TNA}} * \mathrm{CPN}\right) * (1 - \mathrm{RAP}) + RAP \quad (6)$$

Where:

- $NAFRA$ is the Number of Agents in Favour of Requested Alternative;
- TNA is the Total Number of Agents;
- CPN is the Normalization of the Preferred Criterion;
- RAP is the Requested Alternative Preference.

Request – Common practices

When evaluating requests with the argument appealing to common practices the acceptance interval is affected by the level of concern for others which the agent has towards the alternative plus AI_{rwa}. The formula used to calculate the acceptance interval for requests with the argument appealing to common practices (6) is:

$$\mathrm{AI}_{rcp} = \left((1 - \mathrm{resistance}) - \mathrm{AI}_{rwa}\right) * \mathrm{CO} + \mathrm{AI}_{rwa} \quad (7)$$

Where:

- CO is the value of Concern for Others (of a specific behavior style).

In case the agent does not have a defined behavior, the evaluation of the request with an argument appealing to common practices will be done using the following formula:

$$\mathrm{AIWB}_{rsi} = \left(\frac{\mathrm{NAFRA}}{\mathrm{TNA}}\right) * (1 - \mathrm{RAP}) + RAP \quad (8)$$

Where:

- $NAFRA$ is the Number of Agents in Favour of Requested Alternative;
- TNA is the Total Number of Agents;
- RAP is the Requested Alternative Preference.

Request – Common Sense

When evaluating requests with the argument appealing to common sense the acceptance interval will be the opposite of the resistance's level of the agent. The formula used to calculate the acceptance interval for requests with the argument appealing to common sense (7) is:

$$\mathrm{AI}_{cs} = (1 - \mathrm{resistance}) \quad (9)$$

The appeal to common sense is used in very specific situations. The agent that receives this request is the only agent which is still against a consensual decision. Therefore, the maximum acceptance interval will be used for the agent to verify if the requested alternative can be accepted.
In case the agent does not have a defined behavior, the evaluation of the request with an argument appealing to common sense will be done based on the difference between the number of agents in favour of requested alternative (NAFRA) and the the number of agents in favour of the preferred alternative (NAFPA). The agent will accept the alternative if:

$$NAFRA > NAFPA \quad (10)$$

4. Evaluation and Results

In this section, we are going to describe all experiments that were conducted to evaluate the proposed work. We used a group of 12 agents with different styles of behavior for each experiment. We conducted an exhaustive number of simulations to achieve solid results. We first detail the experimental settings and describe the types of agents we benchmark our framework against as well as the metrics used in our tests. Considering this, we provide the results of our experiments and go on to analyze the results under different agents' configurations.

Experimental Settings

In the considered scenario agents negotiate to choose a desktop monitor for an organization. That organization intends to buy 200 new desktop monitors to one of its subsidiaries. Each agent represents one member of the organization administration board. This means agents must be cooperative because they all intend to choose the best decision

for that organization and they also must be competitive because they aim to persuade other agents to accept what they believe that is the best decision (according to their configuration).
Table 3 represents the multi-criteria problem. 5 possible alternatives have been identified. These alternatives have been classified according to 5 criteria: Size, Resolution, Hz, Ms and Price. Considering that we do not only evaluate criteria while trying to solve a multi-criteria problem, a decision-maker may prefer a certain alternative for subjective or unknown reasons that are not specified in the problem configuration.

Table 3. Multi-criteria problem

Alternatives	Size	Resolution	Hz	Ms	Price
Asus 27" ROG SWIFT PG278Q	27	2560*1440	144	1	699,99€
BenQ 27" XL2720Z	27	1920*1080	144	1	489,00€
AOC 24" E2476VWM6	24	1920*1080	60	1	154,90€
BenQ 24" XL2430T	24	1920*1080	144	1	399,00€
LG 27" 27MP37VQ-B	27	1920*1080	60	5	210,80€

We used the satisfaction and consensus levels as metrics to evaluate the overall performance in different scenarios. Satisfaction metric is used to measure the perception of the quality (of the decision-maker represented by the agent) towards the chosen alternative or the alternative supported by most agents during a certain moment. For this, we used the definitions proposed in (Carneiro, Marreiros, & Novais, 2015) and the formulation used in (Carneiro, Santos, Marreiros, & Novais, 2017). The level of consensus is measured according to the alternative that is supported by most agents in the time instant t, iteration i or round r. It is neither mandatory or negative that agents cannot achieve a consensual decision by the end of the round. In fact, agents act according to an objective configuration logic and through a "social interaction" that portrays the interests of decision-makers. This means that if an agent does not accept a certain alternative then the decision-maker may still not be ready to accept it as well (although he may accept it in the future). That decision-maker should first assimilate and think about the new information and eventually understand the situation and agree with it. Our approach does not intend to force a solution at all costs. Because of this, we use these 2 metrics (satisfaction and consensus) simultaneously. Our goal is to increase the levels of consensus without diminishing the levels of satisfaction in any possible way. Finding consensus while compromising the quality of the decision is not the solution.
The agents' preferences regarding alternatives and criteria, as well as their style of behavior, were randomly generated. However, in order for the evaluation of alternatives and criteria to make sense, the following approach was used, where each agent:

1. Randomly generated his preferences for each of the existing alternatives. Those preferences varied on the [0,1] interval, where 0 means "Not at all preferred" and 1 means "Extremely preferred";
2. Selected the top preferred alternatives, i.e., those with the highest values;

3. Checked for those (top preferred) alternatives which criteria stand out, i.e., which criteria (comparatively) make sense to be valued in order to prefer those alternatives;
4. And finally, generated a random preference in a [0.5,1] interval for those stood out criteria, and a random preference in a [0,0.5] interval for the remaining criteria.

Experiments

In the first experiment, 35*101 simulations were performed. In each set of 101 simulations (let us call it a scenario) the preferences of each agent towards the problem (alternatives and criteria) were the same. Each simulation included 12 agents. In the first simulation, all 12 agents were configured without a defined behavior and in the following 100 simulations different styles of behavior were generated for each agent in each simulation. The average results that were obtained by agents with a defined behavior in 100 simulations were compared with the results of the simulation where these agents were configured without a defined behavior.
Figure 3 shows the satisfaction values obtained by agents without a defined behavior (AgWDB) and the average satisfaction values obtained by agents with a defined behavior (AgDB).

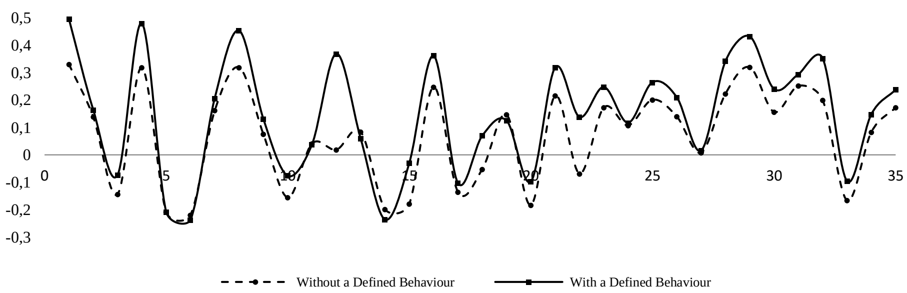

Figure 3. Satisfaction values obtained in each scenario

Since both AgWDB and AgDB average satisfaction values are being compared it is important to know what this average means. For that, Figure 4 shows the number of times in which AgDB obtained a higher or lower satisfaction in each scenario. It is possible to identify that in most scenarios AgDB obtained a higher satisfaction. Counting all simulations performed in this experiment, the satisfaction was higher in 70,2% of the times and lower in 29,8% of the times. Another important point is related with the obtained average satisfaction value. AgDB obtained in all simulations an average of 0,147 while AgWDB obtained just 0,069.

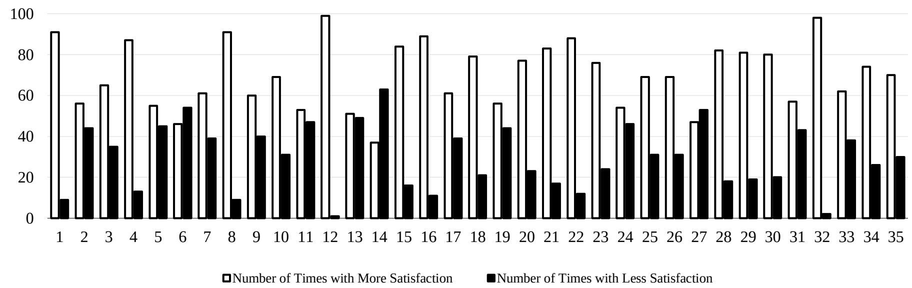

Figure 4. Number of times when AgDB obtain more/less satisfaction than AgWDB in each scenario

The impact of situations where AgDB obtained a higher or lower satisfaction compared to AgWDB was also studied. It was important to know if there was a big difference when AgDB obtain a lower satisfaction compared to AgWDB. Figure 5 shows the results between the average gain and loss of satisfaction of AgDB and AgWDB. In 70,2% of the times where AgDB obtained a higher satisfaction, the average gain was of 0,158, however in 29,8% of the times where AgDB obtained a lower satisfaction, the average loss was of 0,117.

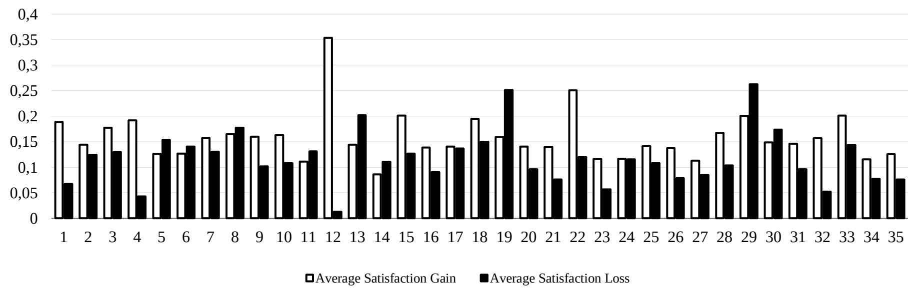

Figure 5. Gain/Loss of satisfaction every time AgDB obtain more/less satisfaction than AgWDB

Figure 6 shows the consensus values obtained by AgWDB and the average consensus values obtained by AgDB in each scenario. It is possible to see that AgDB also a higher consensus compared to AgWDB in most of the times.

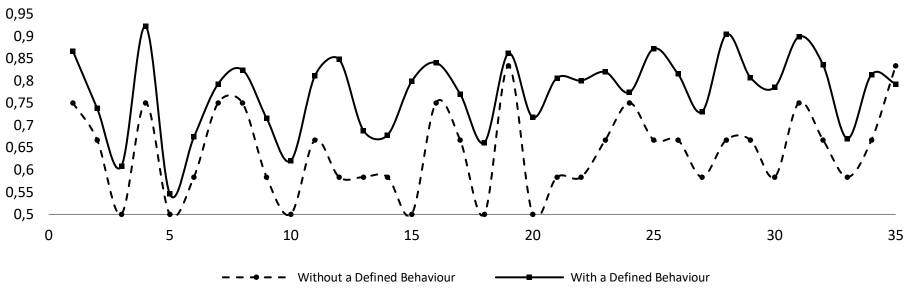

Figure 6. Consensus values obtained in each scenario

Figure 7 shows the number of times in which AgDB obtained more/less/same consensus than AgWDB. AgDB obtained a higher average consensus in 74,3% of the times, equal in 14,5% of the times and lower in 11,1% of the times.

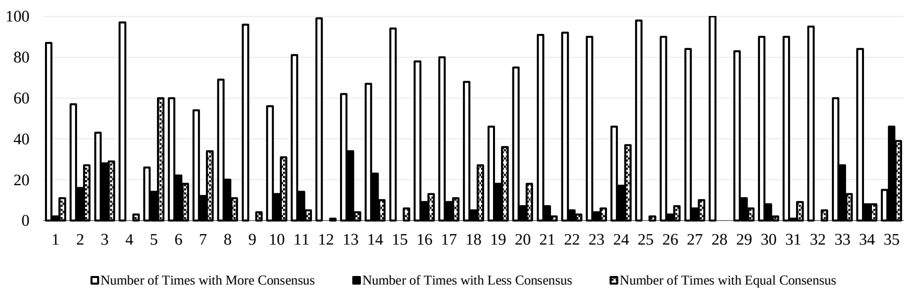

Figure 7. Number of times when AgDB obtain more/less consensus than AgWDB in each scenario

As we did in the satisfaction analysis, the impact of gain and loss of consensus was also analysed in situations where the consensus is higher or lower respectively. Figure 8 shows the results that were obtained. As can be seen, the gain of consensus is higher (0,192 average) when the consensus obtained is also higher and the loss is lower (0,091 average) when the consensus obtained is also lower.

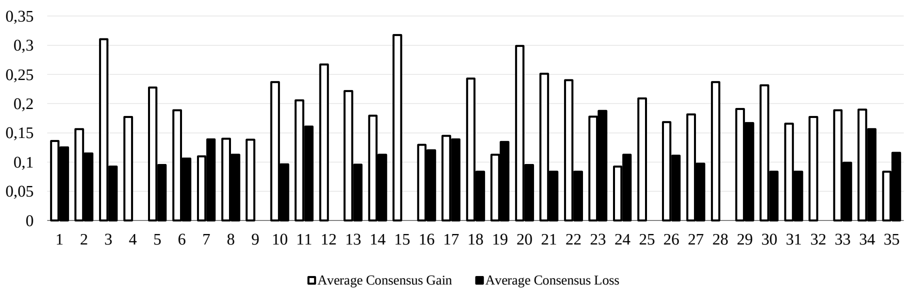

Figure 8. Gain/Loss of consensus every time AgDB obtain more/less consensus than AgWDB

In the second experiment, 35*6 simulations were performed. In each scenario agents had different problem configurations (regarding alternatives and criteria). For all 6 simulations in the same scenario agents' configurations were the same. In each simulation 12 agents were used and were all defined with the same style of behavior (1st Simulation – 12 AgWDB, 2nd Simulation – 12 agents Integrating, 3rd Simulation – 12 agents Obliging, 4th Simulation – 12 agents Dominating, 5th Simulation – 12 agents Compromising and 6th Simulation – 12 agents Avoiding).

Figure 9 shows the satisfaction results obtained by agents with the same style of behavior throughout all 35 scenarios. Integrating agents achieved higher satisfaction levels compared to other agents while it seems that Dominating agents, on the opposite turn, obtained the lower satisfaction levels. The average satisfaction values obtained for each style of behavior were the following: Integrating – 0,122; Compromising – 0,097; Avoiding – 0,05; Without a Defined Behavior – 0,036; Dominating – 0,036 and Obliging – 0,031.

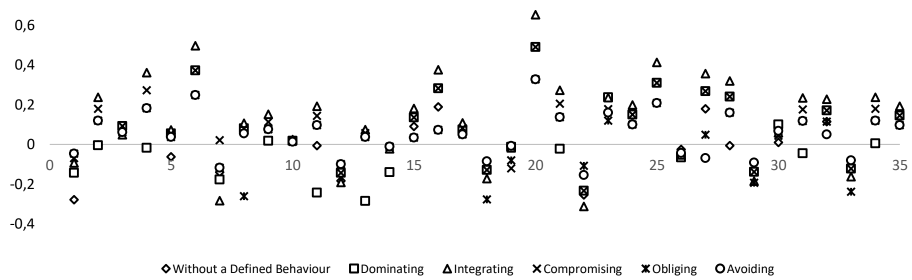

Figure 9. Satisfaction obtained in each scenario

Figure 10 shows consensus values obtained by agents in each simulation. It is possible to see that in many times both Obliging and Avoiding agents obtain the same consensus (value 1 which means they achieved a consensual decision) and therefore appear overlaid. In this experiment, it was possible to identify that Obliging and Avoiding agents always obtained the highest consensus, Dominating agents obtained the lowest consensus and the remaining styles of conflict obtained intermediate values. Besides this, and looking at the graph the consensus values obtained by each group of agents with the same style of behavior are very constant throughout all 35 scenarios, even if agents' configurations were different in all of them. The average consensus for each style of behavior for each scenario was the following: Obliging – 0,959; Avoiding – 0,945; Integrating – 0,73; Compromising – 0,728; Without a Defined Behavior – 0,609 and Dominating – 0,39.

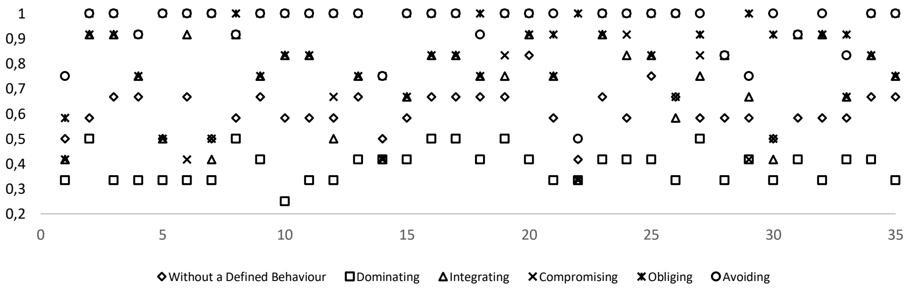

Figure 10. Consensus obtained in each scenario

5. Discussion

In this Section, all the hypotheses are discussed. The first hypothesis is the most important and is the reason for all the experiments performed in this work. The other hypotheses were identified as the study progressed. Given this, we postulate several hypotheses regarding the performance and behavior of the agents.

Hypothesis 1: Agents that represent/support decision-makers in the ubiquitous group decision-making process and that use styles of behavior can obtain higher consensus and quality decisions more easily.

AgDB obtained higher satisfaction levels compared to AgWDB in 70,2% of the simulations and obtained higher consensus levels in 74,3% of the times. Besides this, it was also verified that in the 70,2% of the times when the satisfaction obtained is higher, there was a gain of satisfaction that was superior (0,158) to the loss of satisfaction (0,117) in the remaining 29,8% of the times when the satisfaction obtained is lower. These results were very positive. In the case when the consensus obtained was higher, the gains were even more significant. Not only do agents obtained higher consensus in more simulations (89,9%), the gain was also higher (0,192). On the other hand, the consensus obtained was lower in the remaining 11,1% of the times with a loss of 0,091. With these results confirmed we have all the necessary conditions to accept the formulated hypothesis.

Hypothesis 2: Agents with a higher level of concern for others obtain higher satisfaction levels.

This hypothesis was rejected. Integrating and Obliging are the styles of behavior with the highest level of concern for others, followed by Compromising style, and lastly Avoiding and Dominating styles. The hypothesis was rejected since Obliging agents achieved low average satisfaction levels when agents with the same style of behavior were being studied. By rejecting this hypothesis, we did formulate a new one (Hypothesis 2.1).

Hypothesis 2.1: Agents that are naturally more competitive and collaborative obtain higher satisfaction levels.

If we make a purely comparative analysis (as done in the second experiment) we can accept this hypothesis. We verified that Integrating and Compromising styles, which have very similar concern for self and concern for others values, achieved the highest levels of satisfaction. This may lead us to think that other styles only harm the process. However, (as can be seen) in the first experiment (when we used agents with all sorts of styles) agents achieved an average satisfaction level of 0,147 which is superior to the value obtained by Integrating agents (0,122). This let us conclude that the diversity of styles of behavior allows obtaining higher satisfaction levels compared to the situation where all agents share the same style. Considering that we live in a diversified reality, this hypothesis would be rejected. This conclusion allows formulating a new hypothesis that was not studied in this work: Obliging agents, due to their high level of concern for others and low level of concern for self, are especially useful in scenarios where other agents with different styles of behavior also participate. The study of Obliging agents is a paradox.

Hypothesis 3: Agents with a low concern for self obtain consensus more easily.

Obliging and Avoiding agents have the lowest level of concern for self, followed by Compromising agents while Integrating and Dominating agents have the highest level of concern for self. If we just look at the concern for self we are forced to reject the hypothesis, because Integrating agents have a higher concern for self compared to Compromising agents but still obtain slightly higher average consensus levels. However, we have identified a pattern that let us explain this situation. Obliging agents obtained higher average consensus levels compared to Avoiding agents even though both styles share almost the same level of concern for self. However, since Obliging agents have higher level of concern for others this let us believe that in situations where agents with the same concern for self will obtain higher consensus levels if they have a higher concern for others. This explains why Integrating agents obtain slightly higher consensus levels compared to Compromising agents.

Hypothesis 4: Using agents defined with a style of behavior is always advantageous.

This hypothesis has been rejected because we can see in the second experiment Dominating agents obtained worse satisfaction and consensus values compared with AgWDB. This means that in a hypothetical situation in which all decision-makers choose the Dominating style of behavior they would obtain worse results in case we did not use any kind of behavioral modelling. However, we consider that a situation in which all agents are defined with the Dominating style can still generate valuable knowledge that can be used in the future to support group decision-making in that kind of scenario. On the other hand, when we only deal with AgWDB we cannot generate and use such kind of knowledge.

It is also important to relate this work with current literature. As referred before, our argumentation-based dialogue model aims to support the group decision making process. Our approach is very different to what can be found in literature. This is because our model was defined in order to take advantage of what the benefits associated with the group decision-making process are. Thus, contrary to what happens in most of the existing proposals (Black & Hunter, 2009; Prakken, 2005), our model deals with several types of dialogue, since, despite the objective of achieving consensus, there is also the objective of enhancing the quality of the decision. In this way, our model focuses not only on dialogue types such as negotiation or persuasion, but also on strategies that allow agents to discover new information and perceive the reasons for the preferences of other decision-makers.

The difference of the proposal presented in this work is also distinguished by the way it is validated. A lot of works are validated using the Seller/Buyer example (El-Sisi & Mousa, 2012; Marey et al., 2014; Marey, Bentahar, Khosrowshahi-Asl, Sultan, & Dssouli, 2015) which is a context completely different from the one presented in this work. As we said, we do not want to make a deal, nor want agents to reach a consensus at any costs. Our model aims to support the decision-making process by using and creating new knowledge. Our work takes advantage of the typical benefits inherent to group decision-making and proved that it is possible to obtain results that follow that perspective. Por isso, neste trabalho a validação ocorre estudando simultaneamente o nível de consenso e a qualidade de decisão.

Other authors with a relevant work in this area considered in very recent papers that most the work found in the literature related to argumentation-based decision-making did not pay attention to decision-making amongst multiple agents. In fact, Fan and Toni (2014) refer to the necessity of studying "decision-making in the context of multiple agents, in which agents may share potentially conflicting knowledge and preferences". In our work, besides proposing a model that supports multiple agents interacting in a very similar way as humans do in face-to-face meetings, the created prototype had an exceptional performance without presenting any sort of issues.

One of the main points of this work is the capacity the agents start to have to represent the intentions of the decision-makers. Although there are some works in the field of decision-making in which the authors try to make this type of representation (Marreiros et al., 2010; Iván Palomares & Martínez, 2014; Iván Palomares et al., 2013; Santos et al., 2009), it is done in a very ambiguous way, where the values of performance of those styles are not scientifically validated, being merely indicative and approximations of what is thought to make sense. In addition, they do not validate in a real system if the decision-makers would be able to configure and understand the objectives of each of those styles. Although it is obvious that it would be advantageous to include affective components in this type of context, it had never been proved as it happens in this work.

Finally, it is not less important to mention the potentiality that the proposal here presented has to document and explain the reasons that lead to a certain decision. Muller and Hunter (2012) consider that it is very important that argumentation models can generate documentation and also explain why certain decisions are made. Our approach is also clear to the decision-maker and allows him to understand the process and properly explains the reason why a certain solution is decided. Knowing how agents communicate with each other, the text composing each locution could be used to make that documentation.

6. Related Work

Dialogue theory was first addressed in modern philosophy by Grice, Cole, and Morgan (1975). For them, an argument is a contribution that is given in a collaborative conversation. In their perspective, an argument must be evaluated from the point of view of its collaborative value considering the time it is spoken (Grice et al., 1975). There are several types of dialogues. Each of them is characterized by having different objectives, and different sets of rules that make it easier to achieve those objectives (D. N. Walton, 1989). One of the most recognized dialogue taxonomy was proposed by D. Walton and Krabbe (1995). They divided dialogues into six types (Table 4):

- Persuasion: In this type of dialogue, the proposer tries to persuade the other party that a certain fact is true and vice versa. Basically, both parties try, by using arguments, to convince the other party to change its opinion;
- Negotiation: The goal of negotiation is to reach an agreement. In this type of dialogue, both parties seek to maximize their benefits while achieving a consensus that is, at the same time, acceptable to both;
- Inquiry: This type of dialogue arises from the need to establish or prove propositions. It aims to achieve general agreement on the subject that is on the table. Here, the objective is not to satisfy interests as it happens in negotiation, since there is no conflict of opinions but an open problem;
- Deliberation: As in the inquiry, this type of dialogue is about an open problem. However, the goal here is to decide how to act. In this way, it is also intended to achieve an agreement, but the agreement does not have to be obligatorily general;
- Information-seeking: This type of dialogue concerns to the search for information by the participants. This search for information happens through requests to an expert, where the goal is to spread knowledge. Here it is not intended to prove anything but to retrieve a piece of knowledge;
- Eristic: This kind of dialogue is a bit different in that its purpose is to seek conflict instead of seeking to resolve the conflict. The idea is to go against the opponent regardless of what he says.

Table 4. Dialogue types (adapted from D. Walton and Krabbe (1995))

Type	Initial Situation	Main Goal	Participants' Aim
Persuasion	Conflicting point of view	Resolution of such conflicts by verbal means	Persuade the other(s)
Negotiation	Conflict of interests and need	Making a deal	Get the best out of it for oneself
Inquiry	General Ignorance	Growth of knowledge and agreement	Find a "proof" or destroy one
Deliberation	Need for action	Reach a decision	Influence outcome
Information-seeking	Personal ignorance	Spreading Knowledge and revealing positions	Gain, pass on, show or hide personal knowledge
Eristics	Conflict and antagonism	Reaching (provisional) a accommodation in a relationship	Strike the others party and win in the onlookers

Dialogue systems have also been studied by computer science scientists (McBurney & Parsons, 2002; Prakken, 2000, 2006). In these systems, agents exchange messages with a certain objective, e.g., negotiation, persuasion and seeking information. The use of arguments allows agents to justify their positions, actions or preferences when carrying out any of those dialogues (Rahwan et al., 2003).
According to Prakken (2006), a dialogue system should include the following elements:

- Topic language: The language that designates the meaning of each utterance;
- Communication language: The language that enables the discussion;
- Dialogue purpose: Purpose of the dialogue;
- Participants: The participants involved in the process (at least 2), who may have several roles, objectives and beliefs;
- Context: The type of dialogue;
- Logic: The logic used in the dialogue, which may or may not be monotonic and which may or may not be argument-based;
- Effect rules: Defines the effect of utterances;
- Protocol: Specifies which movements are possible to be performed during the dialog;
- Outcome rules: The set of rules that define the outcome of the dialogue.

Black and Hunter (2009) presented a framework for representing dialogues of the type inquiry. Their argumentative system is based in Defeasible Logic Programming (DeLP). In their work, they consider two types of inquiry dialogues: argument inquiry and warrant inquiry. The former intends that agents can jointly construct arguments to support a particular claim that would not be possible if done separately (alone). The latter intends that agents can share arguments in order to construct a dialectical tree that they could not do alone with their own beliefs. In these two types of inquiry dialogues, agents jointly seek to inquire about topics. However, the argument inquiry dialogue does not allow to determine the acceptability of the constructed arguments, and in warranty inquiry dialogue the agents work together to determine the acceptability of the arguments (they do this by jointly constructing a dialectical tree). The authors named the communicative acts as "moves". They considered the existence of three different moves: open, assert and close. A move is represented as $\langle Agent, Act, Content\rangle$, where $Agent$ is the agent generating the move, Act is the type of the move and $Content$ contains information about the details of the move. The dialogue is always performed by exactly two agents and always starts by an "open" move. They represent the first move as $\langle x, open, dialogue(\theta, \gamma)\rangle$, where θ is the type of the dialogue and γ is the topic of the dialogue. So, the type and the topic of the dialogue are defined in the content of the first move. The dialogue ends when both agents make the "close" move.

Prakken (2005) proposed a formal framework of argumentation dialogues for persuasion. In his work, he presents an example of a persuasion dialogue, which we present below:

1. ag_1: My car is very safe. *(making a claim)*
2. ag_2: Why is your car safe? *(asking grounds for a claim)*
3. ag_1: Since it has an airbag. *(offering alternative grounds for a claim)*
4. ag_2: That is true, *(persuasion: conceding a claim)* but I disagree that this makes your car safe: the newspapers recently reported on airbags expanding without cause. *(stating a counterargument)*
5. ag_1: Yes, that is what newspapers say *(conceding a claim)* but that does not prove anything, since newspaper reports are very unreliable sources of technological information. *(undercutting a counterargument)*
6. ag_2: Still your car is still not safe, since its maximum speed is very high. *(alternative counterargument)*

This example demonstrates the complexity of the persuasion dialogues. As we can see, during a dialogue of this type, an individual/agent can refer back to previous choices in the same dialogue, as well as justify a certain point of view in different ways.
In his work, Prakken (2005) introduced the "liberal" and "relevant" dialogue systems. Table 5 presents the moves for liberal dialogues.

Table 5. Speech acts for liberal dialogues (adapted from Prakken (2005))

Acts	Attacks	Surrenders
claim φ	why φ	concede φ
why φ	argue $\mathrm{A}(\mathrm{conc}(\mathrm{A}) = \varphi)$	retract φ
argue A	why $\varphi(\varphi \in \mathrm{prem}(\mathrm{A}))$ argue $\mathrm{B}(\mathrm{B}$ defeats $\mathrm{A})$	concede φ $(\varphi \in \mathrm{prem}(\mathrm{A})$ or $\varphi = \mathrm{conc}(\mathrm{A}))$
concede φ		
$retract\ \varphi$		

As in the work of Black and Hunter (2009), Prakken's liberal dialogues are represented as trees and the arguments of a tree are always relative to only one topic. An argument is a deduction with a conclusion (conc) and premises (prem), and "An argument B extends an argument A if $\mathrm{conc}(\mathrm{B}) = \varphi$ and $\varphi \in \mathrm{prem}(\mathrm{A})$". The author also defined a turn-taking function that specifies which agent does the next move, which basically guarantees the existence of a "ping-pong" dialogue, where the first move is responsible for specifying the dialogue's topic. One of the most relevant parts of this work is the way Prakken determines the outcome of a dialogue by defining an in/out labelling. Theoretically, what happens is that a node is in if it withstands its attacks, otherwise it is out. So, considering that the root of a dialogue is responsible for defining the topic, the proponent wins the dialogue if the root node is in.

Parsons, Wooldridge, and Amgoud (2003) presented a study about argumentation-based dialogues between agents. They have defined locutions from which agents can exchange arguments. In addition, agents may adopt different attitudes which will condition the arguments that they can build and what locutions they can make. They also defined a set of protocols which determine the entire functioning of the dialogue (termination, dialogue outcomes and complexity). In this work, they deal with three types of dialogues: information seeking, inquiry and persuasion. They assume the dialogues are always

performed by only two agents, which can use several utterances, such as: assert, accept, challenge and question. One of the most fascinating points of this work is the relation defined between the agents' attitudes and their way of acting. For instance, an agent can have three different assertion attitudes: confident, careful and thoughtful, and three acceptance attitudes: credulous, cautious and skeptical.
Next, an example of a possible information seeking dialogue is presented, using the protocol proposed by the authors:

1. ag_1 asks $question(p)$;
2. ag_2 replies either $assert(p)$ or $assert(\neg p)$ if it can, and $assert(\mathcal{U})$ if it cannot. Which response is given will depend upon the contents of its knowledge base and its assertion attitude. $\mathcal{U}$ indicates that, for whatever reason, $\mathcal{B}$ cannot give an answer;
3. ag_1 either accepts $\mathcal{B}$'s response, if its acceptance attitude allows, or $challenges$. $\mathcal{U}$ cannot be $challenged$ and as soon as it is asserted, the dialogue terminates without the question being resolved;
4. ag_2 replies to a $challenge$ with an $assert(\mathcal{S})$, where $\mathcal{S}$ is the support of an argument for the last proposition challenged by ag_1;
5. Go to 3 for each proposition in $\mathcal{S}$ in turn;
6. ag_1 accepts p if its acceptance attitude allows.

There is a large number of applications of dialogue systems in literature (Mackenzie, 1990; D. Walton & Krabbe, 1995; Woods & Walton, 1978) covering various topics, such as: resource-bounded reasoning (Brewka, 2001; Loui, 1998), legal reasoning (T. J. Bench-Capon, 1998; Hage, Leenes, & Lodder, 1993), to support agent interaction (Amgoud, Maudet, & Parsons, 2000; Parsons et al., 2003),among others. However, argumentation-based dialogue models specifically targeted at the context of group decision-making and that benefit from group decision-making are practically non-existent.

Many approaches have been put forward in literature, where agents are defined with characteristics that set them apart from each other (Allbeck & Badler, 2002; Badler, Allbeck, Zhao, & Byun, 2002; Velsquez, 1997; Zamfirescu, 2003). Also under the topic of group decision-making several works with agents have been proposed (Aronson, Liang, & Turban, 2005; Olfati-Saber, Fax, & Murray, 2007), some of which used agents as a way to represent decision-makers/experts (Carneiro, Martinho, Marreiros, Jimenez, & Novais, 2017; Iván Palomares & Martínez, 2014; Santos et al., 2009). This representation of decision-makers allows the systems to become more intelligent and dynamic, given they are capable of dealing with aspects of great relevance in face-to-face type meetings. Next, we will see some works in the context of the decision-making that present strategies to represent the decision-makers.

Santos et al. (2009) presented a scientific work where they proposed a multi-agent architecture model designed to support groups in the decision-making process. The novelty of their work is the possibility to model the agent's personality. The idea is to humanize agents and with that, facilitate the negotiation process. They used four personality types

(Negotiator, Aggressor, Submissive and Avoider) based on the Five Factor Model (McCrae & John, 1992) to define the agents' personalities. To select the agent's personality, each decision-maker needs to answer a questionnaire named Big Five Inventory (John, Donahue, & Kentle, 1991). They also proposed a simple negotiation model where the agents use the personalities to choose which kind of requests they should send and to process the received requests. The publication does not include any case study; however, the content is very interesting because the proposed model is based in strong assumptions existent in the literature.

Iván Palomares et al. (2013) presented a Web-based consensus support system that permits the integration of the decision-makers' attitude regarding consensus. They study the importance that decision-makers place in reaching consensus regarding the possibility of modifying their own preferences. Decision-makers can/adopt three attitudes: pessimistic, indifferent and optimistic. For example, a decision-maker who adopts an optimistic attitude, means that for him to reach the agreement is more important than his own preferences. In this way, the group's options will be given more importance. They argue that (as might be expected) optimistic attitudes help to reach consensus while pessimistic attitudes hamper the achievement of consensus.

Recio-García et al. (2013) presented a group decision support system where each decision-maker is represented by an agent who argues with the other agents in order to achieve the best alternative for the group. The presented negotiation model includes the users' social factors, personality and trust in the argumentative process. The personality of decision-makers is represented by a number ranging from [0,1] where 0 means a very cooperative person and the reflection of a very selfish one. To study the trust, they use the interaction of decision-makers in social networks through a set of 10 factors. For the argumentation model, they used D^2ISCO, which is a platform for the design and implementation of deliberative and collaborative CBR applications. They concluded that the proposed model allows to achieve better satisfaction rates when compared to the standard "fully connected" group recommender.

Iván Palomares and Martínez (2014) presented a semisupervised consensus support system (CSS) based on the multiagent system paradigm. The main purposes are to overcome the difficulties associated with managing large groups of experts and the need for constant human supervision. In order to minimize the need for experts' interactions with the system, they defined a strategy that allows the experts to express their individual concerns. To do so, they defined three different profiles: sure profile, unsure profile and neutral profile. The first, intends to represent experts that are very confident about their preferences. Therefore, they do not intend to change them. The second, represents experts that want to achieve a consensus but are unsure about their opinions. The third, represent the experts that want to achieve a consensus and are moderately sure about their opinions. They conducted a case study made up by a set of experiments with the intent of understanding the different evolution of the degree of consensus between the proposed semisupervised CSS and a full-supervised CSS. They concluded that through the proposed system it was possible to minimize the need for expert human supervision and more importantly, they concluded that their proposal helps to achieve high levels of consensus faster than the full-supervised CSS.

7. Conclusions and Future Work

The future and success of organizations depend greatly on the quality of every decision made. It is known that most of the decisions in organizations are made in group. To support this type of decision, the Group Decision Support Systems (GDSS) have been widely studied throughout the last decades. However, in the last ten/twenty years, we have seen a remarkable change in the context where the decision-making process happens, especially in large organizations. With the appearance of global markets, the growth of multinational enterprises and a global vision of the planet, we easily find chief executive officers and top managers (decision-makers) spread around the world, in countries with different time zones. To provide an answer and operate correctly in this type of scenarios the traditional GDSS have evolved to what we identify today as Web-based Group Decision Support Systems (Web-based GDSS). The idea behind the Web-based GDSS is to support the decision-making process "anytime" and "anywhere". However, supporting groups in this context is a very complex task. It is necessary to create conditions in which the decision-maker can acknowledge the advantages of using the system and feels motivated to do so. The system must allow the decision-maker to express himself and this includes problem and communication configurations. We must keep in mind that the best algorithm will fail if the final user does not want to use it. Besides this, a Web-based GDSS must support decision-makers throughout the decision-making process until the best solution can be found. This support includes not only obtaining consensus but also the best possible solution. Therefore, strategies that "hide" information just to achieve a faster solution must not be used.

In this work, we propose an argumentation-based dialogue model for Web-based GDSS. This model provides a set of features that allows taking advantage of the known benefits inherent to group decision-making. Our proposal allows interactions between agents in a very similar way as humans do in face-to-face meetings. Each agent represents a real decision-maker and will attempt to defend his interests and persuade other agents according to the knowledge he possesses. However, agents do not persuade "foolishly" as they will be guided by the style of behavior defined by their decision-maker. Decision-makers may select 5 different styles of behavior which define the way their agent will behave and act, for a better representation of their interests and objectives. Each style of behavior proposed in this work has been defined according to 4 dimensions. To figure how agents will act in each dimension, real results were used and analyzed how people expect an agent to behave depending on his style of behavior. This means that when a decision-maker selects a certain style of behavior for his representing agent he is unconsciously sharing information with the system.

We proposed a model that works well when multiple agents communicate and interact with each other. Second, our work takes advantage of the benefits inherent to group decision-making. Our proposal let decision-makers recognize the importance of the process. Third, and most importantly, with this work we have proved the prevalence of using styles of behavior in this type of context. Our approach allows decision-makers not only to configure their preferences but also their intentions (for instance: strategies and interest in the process). With this, we could conclude many details explained previously, as for example, why agents with a high concern for others tend to obtain higher satisfaction levels as well as agents with low concern for self tend to obtain higher consensus levels. However, although we could identify these tendencies, we also saw the system can reflect the positive and typical diversity of human interactions. If we do not forget that the real world is diversified and that diversity is a benefit, then our approach does not lead to a very inflexible system but rather to a system that can take advantage of it.

As future work, we intend to study ways to deal with complex situations. We consider a complex situation, for example, a scenario where all agents have the Dominating style of behavior. The idea is to take advantage of the previous knowledge that tells us how difficult it is to achieve a consensual decision in that context and find specific mechanisms for that kind of scenarios. These mechanisms should follow the logic applied to this work meaning the goal should always be to seek consensus through the free exchange of knowledge and motivate the decision-makers to understand arguments exchanged by other decision-makers. Another question we intend to study is how the entire decision-making process (and not only a simple iteration as studied in this work) using our framework model allows us to achieve even higher levels of consensus and satisfaction.

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4 CONCLUSIONS

A good decision is based on knowledge
and not on numbers.

— Plato

The work carried out in this doctorate was mainly to give answers to some existing problems in the field of group decision-making in which the elements are geographically dispersed. It was found that the current approaches do not take advantage of the benefits associated to the group decision-making process. Furthermore, the existing methods to represent decision-makers have limitations. In order to address these problems, a number of solutions have been presented in this work.

This chapter begins by exploring the contributions of this doctoral thesis in the light of the objectives initially outlined. Then, it discusses the hypotheses that were formulated at the beginning of this document to perceive if they were verified or rejected. A summary of the activities carried out during the period of this PhD is also presented. Finally, some considerations are made and the possibilities of future work are addressed.

4.1 CONTRIBUTIONS

The work presented in this thesis has resulted in a significant number of contributions. The path undertaken to study the hypotheses enumerated in Section 1.2 and discussed in Section 4.2 lead us to develop a set of models/methods that became important contributions to the scientific and organizational world, including publications in several conferences and journals. Table 11 presents the objectives attained with the performed work and the document's section in which they are described.

Table 11: List of the defined objectives and respective sections where they were addressed.

Objective	Section
Objective 1: To ascertain the state of the art in the following areas: group decision-making, group decision support systems, argumentation, argumentation-based negotiation, argumentation-based dialogue models, affective computing and decision satisfaction.	Section 2.1, Section 2.3 and Section 2.2
Objective 2: To develop an automatic negotiation model under the logic of a real decision-making process, involving the decision-makers in the process, allowing them to contribute with new knowledge and to perceive the process and the reason for which a given solution is presented.	Section 3.1, Section 3.5 and Section 3.6
Objective 3: To develop a model that is capable of representing decision-makers according to their intentions in respect to a particular decision process.	Section 3.2
Objective 4: To develop a model capable of predicting the satisfaction or the perception of the decision quality of each decision-maker and of the group regarding the proposed solution.	Section 3.3
Objective 5: To formalize/propose an argumentation-based dialogue model that considers agents (with behavioral styles) to represent decision-makers, and that contemplates affective issues and satisfaction prediction algorithms regarding how agents dialogue and evaluate requests.	Section 3.5 and Section 3.6
Objective 6: The developed models should not require a large set of configurations, enhancing the usability of a future system to meet/match the lifestyle and agenda of executives and top managers.	Section 3.4 and Section 3.5

Next, all the contributions that sprout from this work are enumerated and described.

1. Identification of relevant issues and possible solutions in GDSS development.

   The first contribution of this work was the idea that leveraged everything that was accomplished. When we started reading about GDSS, we found inconsistencies in the way the core problem was addressed. The GDSS have, as the name implies, the objective of supporting the group decision-making process. However, there are many ways to support it, but neither of them allow the decision-makers to benefit from the group decision. One must be aware that when it comes to supporting humans, it is only possible if the humans accept to be supported in that way. They need to feel comfortable with the way they are supported and to see advantages in the support they are having. For this, it was necessary to read work on group decision-making in order to answer three questions:

   - Why are decisions made in group?
   - What are the benefits of group decision-making?
   - Can these benefits be achieved through the use of GDSS?

   The identification in several publications of inconsistencies, as well as the presentation of solutions to take advantage of the benefits associated to the group decision-making, constitutes what is the first contribution of this work. The case studies and experiments, conducted to validate the proposed models and algorithms, allowed us to understand that the identified problems were well founded. This contribution allowed to accomplish **Objective 1**.

2. A model for satisfaction analysis capable of predicting the perceived decision quality by the decision-makers and the group.

   This contribution is described in Section 3.3 and addresses a model for analyzing the satisfaction of decision-makers and the group. This satisfaction model allows us to predict the perception of decision quality from the standpoint of decision makers and of the group, working as a metric that can be used for different purposes. In the first instance, this model allows to humanize the system, since it includes aspects such as preferences (alternatives and criteria), intentions, expectations, emotions and mood. It can also be used (as demonstrated in Carneiro et al. (2017a)) in algorithms that aim to improve the satisfaction of decision-makers (and the group), and can also serve as a metric to evaluate the ability of different negotiation models or GDSS to enhance decision quality. This model was formulated based on a set of previously defined assumptions and premises. This contribution allowed to accomplish **Objective 4**. It was possible to verify the advantages and usefulness of this satisfaction model in several studies Carneiro et al. (2016a, 2017e).

3. A model to represent the intentions of decision-makers through the use of behavioral styles.

   A strong contribution of this work was the proposal of a model to configure agents with behavior styles, to reflect the intentions of the decision-makers they represent. In this model, five different behavioral styles that vary according to four dimensions were proposed. To find the operating values of the dimensions, a case study with real participants (64) was conducted. The study allowed not only to find the operating values, but also to verify that the evaluations performed by the participants were homogeneous, thus demonstrating the participants had the same perception of each of the behavioral styles. This contribution allowed to achieve **Objective 3** and is described in Section 3.2.

4. A dynamic dialogue-based argumentation model adapted to be used in Web-based/Ubiquitous GDSS considering affective aspects.

   One of the major contribution of this work was the formulation of a dialogue-based argumentation model adapted to support group decision-making, in which group elements are geographically dispersed. This model allows the agents to practice different types of dialogues and considers the preferences and intentions of the decision-makers regarding the decision problem. The specification of the model is used both to represent the messages exchanged by the agents and the messages exchanged by the decision-makers, allowing a mutual advantage of the knowledge generated by both parties. The evaluation of the requests made by the agents considers cognitive and affective aspects. This model takes advantage of the benefits associated with face-to-face group decision-making in that it encourages and enables decision-makers to participate in the process and allows agents to use the messages created by decision-makers to engage in new dialogues. In addition, the dialogues made by the agents are perceptible to the decision-makers, allowing them to understand the reasons why a particular solution is proposed, and the whole process is taking into account not only the preferences of the decision-makers but also their intentions. Several studies were conducted using this model, which allowed us to perceive the advantages associated with the use of agents modeled with behavioral styles, as well as how the evaluation that the decision-makers make of the messages they receive affects the dialogue carried out by the agents. This contribution allowed to achieve **Objectives 2** and **5**, and is described in Section 3.5.

5. A general template to configure multi-criteria problems in Web-based/Ubiquitous GDSS.

   One of the factors that can affect the acceptance of a GDSS is the complexity associated with the configuration of the problem. Due to the type of schedule of executives and top managers, matters such as time and ease of configuration are key factors for the system acceptance. Therefore, a general template to configure multi-criteria problems in Web-based GDSS has been proposed. Specifying a multi-criteria decision problem using this template has proven to be easy and fast. This template is organized in 3 sections: Problem Data, Personal Configuration and Problem Configuration. The Problem Data section is where all the information related to the problem is presented; Personal Configuration section allows the decision-maker to configure "personal" issues such as expertise level, credibility of other decision-makers, his agent's behavior style, etc.; and the Problem Configuration section serves to configure the problem's alternatives and evaluation criteria, to select the preferred alternatives, whether the configured data is public or not, etc. The configuration of the alternatives and criteria is performed using sliding bars, which due to the way they are arranged allows the decision maker (even if unconsciously) to make a comparison between the various alternatives/criteria at the time of configuration. A case study involving real decision-makers was conducted, where 73.33% of the users considered the template as an easy way to configure the problem, 23.33% were undecided and only 3,33% did not consider the template easy to use. Relatively to how fast it was to configure the multi-criteria problem using this template, the big majority (86.66%) felt satisfied with the configuration speed and only 13,3% were undecided. 100% of the users considered they were prepared to use this template if they had to repeat the experience. The configuration times of each point were quite good. The average configuration time was 188.53 seconds (a bit more than 3 minutes). The slowest user took almost 6 minutes to configure the problem, the second slowest took 310 seconds and the third took 298 seconds (almost 5 minutes). Only 2 users required more than 5 minutes (6.66%). This contribution allowed to achieve **Objective 6**.

6. A model and an algorithm to analyze tendencies regarding the number of supporters for each alternative along the process.

   This contribution was published in Carneiro et al. (2017a) and consists of a tendency analysis model with the goal to improve the agents' intelligence (improving the quality of the decision-making as well as the group's capacity to achieve a consensus). For that, agents representing decision-makers analyze the alternatives' tendency and continuously use an algorithm to identify situations where they should reformulate their objectives. With this algorithm, when the agents verify they will not be able to reach the preferred solutions (since if they continued trying to reach the preferred solutions they would run the risk of obtaining a less preferred), they try conquering solutions of intermediate interest (from the perspective of the decision-maker they represent). When an agent identifies a tendency, it means that there is a "flock" effect on a given alternative. In order to "evaluate" the alternatives based on this algorithm, agents use a formula that verifies for a given alternative, according to their behavior style, i.e., their interest in achieving their own goals and the goals of others, which one gives them the most guarantees. It was verified that the agents that used this algorithm (in the most complex scenario), on average reached a superior consensus in 65% of the situations, compared to those who did not use it, which only reached a superior consensus in 12% of the situations. Regarding satisfaction, the agents that used the algorithm reached a superior satisfaction in 93% of the times. This contribution allowed to achieve **Objective 2**.

7. An algorithm that allows agents to reason about self-expertise and the other decision-makers' credibility.

   Another contribution was the development of an algorithm that allows agents to consider the evaluator's assessment of his expertise level and of the credibility of other decision-makers regarding the problem in question. With this algorithm, agents are able to check if conditions are met so that new alternatives can be added to their list of possible solutions. In addition, a formula that allows agents to reorder their objectives and start (if fitting) making requests for another alternative has been proposed. Agents consider the satisfaction prediction the decision-maker they represent will get with the solution, taking into account the self-expertise and the evaluation of the other decision-makers' credibility. In the paper in which this work was published Carneiro et al. (2017e), a study was also presented, having verified that, fundamentally in the most complex scenarios, the agents that used this algorithm reached higher levels of consensus in 87.5% of the times, whereas those who did not use it only reached it in 8.5% of the times. It was also verified that the agents who used this algorithm reached higher satisfaction levels in 66% of the times compared to those did not use it. This publication (Carneiro et al., 2017e) was invited to be extended in the journal "Expert Systems" and has already been accepted for publication (Carneiro et al., 2017d). This contribution allowed to achieve **Objectives 2** and **3**.

8. Introducing new ideas regarding intelligent reports.

   Another contribution of the work developed during this PhD was the introduction of what we called "intelligent reports", i.e., mechanisms/algorithms to (intelligently) report information to the decision-makers throughout the decision process. Literature on reporting and group decision-making was related, having proposed three factors that should influence the format of the report presented to a decision-maker: expertise level, available time (Time) and level of interest in the process. Different approaches have been presented taking into account the relationship between the decision-maker's expertise level and the time he had available to allocate to the decision-making process. In addition, a set of topics and sub-topics that should affect the structure and content of an intelligent report were discussed: Data, Affective Issues, Relationships, Interpersonal Conflicts and Usability. This work is already being followed by another researcher who took up our initial proposal and presented a set of algorithms to select the topics that should be included in the report of a given decision-maker (Conceição et al., 2016).

9. A MCDA method that includes cognitive aspects.

   A work not initially in our plans was the development of a method for multicriteria decision analysis. Assuming that it is possible to reach better quality decisions considering cognitive aspects, a MCDA method denominated Cognitive Analytic Process (CAP) that considers aspects such as: expertise level, credibility and behavior style of the decision-makers, has been proposed. In the CAP, the criteria are classified through an algorithm like: Very important criterion, Important Criterion, Medium Criterion, Not important criterion and Insignificant criterion. The criteria are then balanced taking into account the level of expertise that the decision-maker considers to have in the problem in question, and the assessment each decision-maker makes of the other decision-makers credibility. In comparison to the MCDA methods that are a reference in literature, such as AHP and TOPSIS, the CAP demonstrated to allow more satisfactory decisions. This contribution is presented in Section 3.4 of this document.

10. Other (minor) contributions.

    In addition to the contributions previously presented, other minor contributions were accomplished during this doctorate. In Carneiro et al. (2017g) a model of agent communication that allows to have a type of communication similar to what happens in face-to-face meetings between real decision-makers was proposed. Due to technological issues, it was noticed that even in a group setting, there were agents who sometimes acted according to knowledge that other agents did not yet have, when this knowledge should have been available to all agents at the same time (copying the actual operation in which when one decision-maker speaks, all the others receive the message at the same time). This situation created disadvantages, which should not happen. In order to overcome this problem, a communication model for agents has been proposed which guarantees that, as in reality, agents always act in possession of the same knowledge when this knowledge is stated "publicly". Architectures for Web-based/Ubiquitous GDSS were proposed in Conceição et al. (2017) and Martinho et al. (2017). The proposed architectures were designed according to the assumptions of "anytime" and "anywhere" ubiquity. In Conceição et al. (2017), a Service Oriented Architecture approach was used, focusing on the possibility of including in a GDSS (that can be used through almost any type of technological device) the various functionalities that have been presented in this document (creation of solutions, intelligent reports, configuration of problems, etc.). In Martinho et al. (2017), a programmers' approach was presented, i.e. for people wishing to develop their own GDSS including affective aspects and meeting ubiquity assumptions.

4.2 VALIDATION OF THE RESEARCH HYPOTHESES

This work was carefully elaborated following the scientific method. The presented methods and the conducted experiments Chapter 3 aimed to study the hypotheses that were enumerated in Section 1.2 of this document. Those hypotheses are furtherly discussed and validated in this section. We can consider that the formulated hypotheses fit into the 4 topics discussed subsequently.

Satisfaction or Perception of the Decision Quality

It was verified in literature that there were no strategies to predict satisfaction, or the perception of the decision quality, of decision-makers in which the elements of the group are dispersed and the process is supported by a GDSS. As we have seen previously, the ability to predict satisfaction with reasonable accuracy has many uses. First, it allows each agent to "work" in a way that seeks to maximize the satisfaction of the decision-maker it represents, which means that the agent, besides orienting himself according to the preferences of the decision-maker, can also use a metric to compare the impacts of different solutions. Second, agents can cooperatively use this metric to maximize group satisfaction, or the satisfaction of other agents they wish to "please". Third, it can be used as a metric to evaluate the capability to enhance satisfaction of different automatic negotiation models, methods of Multi Criteria Decision Analysis, and even decision support systems.

No studies (in the computer science field) that could serve as a basis for developing this model were found, so it was necessary to perform work to identify the factors that are taken into consideration by humans (even unconsciously) in their formulation of the perception of the decision quality. The works of E. Tory Higgins were of great inspiration, namely the "Making a good decision: value from fit" (Higgins, 2000). From the literature, it was possible to create assumptions and premises of ideas that are relatively consensual, originating the paper Carneiro et al. (2015a). From this knowledge, it was possible to formulate a satisfaction model, which went through different stages until approaching the one proposed in the paper Carneiro et al. (2017f). Considering how the formulation of the satisfaction model obeys the assumptions and premises previously defined, we can say the hypothesis "It is possible to predict the decision-makers' perception of the decision quality" has been verified. This means that the satisfaction model correctly expresses (mathematically) the assumptions identified in Carneiro et al. (2015a), for example: "When expectations are exceeded the final satisfaction will be positively affected" and "A positive emotional cost positively affects the final satisfaction". However, according to the preliminary results of a paper that is being written (that extends the proposal in Carneiro et al. (2017f)), we can anticipate that the satisfaction model can predict the decision-makers' perception of the decision quality with a fairly high degree of accuracy. With respect to the hypothesis "If we predict the decision-makers' perception of the decision quality, we can use this prediction in a negotiation model in order to maximize the decision quality", we can also affirm it has been verified. In addition to the obvious advantages that the model demonstrated in the papers published in Carneiro et al. (2016a, 2017e), it was specifically possible to verify this hypothesis in the works published in Carneiro et al. (2016b, 2017a). In addition, in the work published in Carneiro et al. (2017a), it was also possible to verify that the agents with the capacity to predict satisfaction were able to obtain higher levels of satisfaction in 93% of the times and higher levels of consensus in 65% of the times. Moreover, the agents with the ability to predict satisfaction proved to be more capable as the more complex the problem was.

Argumentation-based Dialogue Model

To study the topic of automatic negotiation, more specifically of argumentation-based negotiation models, is quite interesting and "different". First, the groups of researchers who are dedicated to the study of argumentation-based negotiation models are well identified. Secondly, the existing works are very well defined, which allows a very direct comparison between the proposal of a new work and others that already exist. Finally, there is a very well defined verification of the problem formulation and of the validity of the models presented. This verification seems reminiscent of the theoretical physicists' modus operandi, which causes some confusion, since they all should have the objective of being able to be implemented in real systems. An argumentation-based negotiation model, or in the case of this work (and more specifically) an argumentation-based dialogue model, adapted to the context of supporting dispersed groups in decision-making presents very particular characteristics. This is due to the need of having agents able to present a great level of versatility, since several types of dialog are used: negotiation, persuasion, inquiry, information seeking, etc. Moreover, there is no concrete definition as to whether these agents should be collaborative or competitive. If we think from the point of view of the company they represent, they should be collaborative. However, purely collaborative agents would lose their ability to analyze and achieve their own goals, which would lead to poorly reflected and low quality solutions. Therefore, agents must be sufficiently competitive in order to achieve what they believe to be the best solution for them and for the group. As we have seen in Section 2.3.2, the most relevant works present specific formulations for a type of dialogue (negotiation, persuasion, etc.) and are mostly thought of (tested) for one-to-one dialogues. In fact, several recent papers and prestigious researchers in the area of argumentation mention that, as future work, they intend to adapt their formulations to multiple agents. In addition, the recent proposals of argumentation-based dialogue models that are adapted to the context of group decision-making support do not take advantage of the benefits associated to the face-to-face group decision-making processes. In order to meet the benefits associated with group decision-making, the work proposed in this thesis followed a set of essential characteristics:

- Potentiate the decision quality: This means that there should be no obligation to present a solution at the end of the first simulation run. Sometimes decision-makers are not yet in a position to make a conscious and thoughtful decision, the GDSS must be able to demonstrate that state. Decision-makers need time to reflect on other points of view that are being presented. It is necessary to create conditions under which ideas can mature;

- Be able to present the reasons why an alternative is proposed as a solution: If decision-makers do not understand the reasons why a decision is proposed, this will generate mistrust. Justifying the reasons for the proposal of a solution helps decision-makers to reflect and understand those reasons. Only in this way the system can become a credible element;

- Allow to add new and dynamic knowledge, in the sense that what is now true, may not be so tomorrow: The argumentation-based dialogue model cannot follow a set of steps known beforehand. Decision-makers should be free to enter new knowledge and the system must be able to deal with this new knowledge. Otherwise, decision-makers will feel limited, without the ability to express what they think and share the knowledge they want to convey.

As one can perceive, to reach these characteristics a model/system that allows a series of functionalities that are considered current challenges in the literature was needed. The type of dialogue practiced by the agents must be highly dynamic and the dialogues shall be performed by N agents simultaneously. In addition, there was a need for a formulation that allows decision-makers to insert new knowledge, which in turn can be used by the agents and that the justification of the solutions proposed by them is perceptible to the decision-makers. The models here presented were successfully implemented in the developed prototypes that supported the conducted case studies. This means the models have proven to work perfectly over tens of thousands of simulations.

The hypotheses "An argumentation-based negotiation model is capable of improving the intelligence (of the agents or entities) and not only to reason about a solution", "it is possible for both agents and decision-makers to use a dialogue which is clear to everyone involved in the decision-making process" and "it is possible for both agents and decision-makers to take advantage of the knowledge which is generated" were verified in the papers published with the titles" Carneiro et al. (2017b) and Carneiro et al. (2017c). As we could verify, the agents were able to use the dialogue between the decision-makers by using the evaluations that the decision-maker they represent made of the received messages. It was also possible to verify that, besides the agents being capable of using the messages created by the decision-makers, the decision-makers are also capable of perfectly perceiving the dialogue between the agents. As verified in Carneiro et al. (2017b), agents are also able to report other important information by grouping preferences and producing other statistical data. It is therefore obvious that both agents and decision-makers take advantage of the generated knowledge.

A point also relevant in the development of this work was the creation of a model adapted to the needs of highly demanding decision-makers, that is, people with a very busy schedule. For this, a template was proposed in ref Carneiro et al. (2015b), where it was found that a multi-criteria decision problem using this template has an average configuration time of 188.53 seconds, which allowed us to verify the hypothesis "it is possible to configure the preferences and intentions of a complex multi-criteria problem without compromising usability and within an acceptable time frame".

Modelling Agents with Behavior Styles

There are many works in literature that address the problem of modeling behavioral styles (or other typical human attributes, such as personality, emotions, conflict styles, etc.) in agents. However, many of those proposals follow very dubious scientific methods, more precisely in terms of validation. In this work, we intended to study some topics that already are morally accepted but were never really verified.

Specifically, and in order to meet the needs of this work, 3 topics were studied: the possibility of the agents being able to act according to the behavioral style with which they are defined, if the decision-makers perceive a behavioral style in the same way, and what consequences do behavior styles have in the ability to reach consensus and enhance satisfaction.

With respect to the hypothesis "It is possible for decision-makers to select behavioral styles to model computer agents in the context of group decision-making so that the behavior of the agents is as expected by the decision-makers" proposed for this part of the work, there are some notes worth mentioning. In this context, we deal with a type of system (GDSS) that has constant interactions with users (decision-makers). Users visualize information about the problem, configure their intentions, preferences, and perform as many reconfigurations as desired throughout the decision process. This means that, even when assuming that there is a set of behavioral styles so the decision-makers can select the type of behavior they want their agent to have, and that these behavioral styles are defined without any kind of failure, one need to know if there is an homogeneous understanding on the part of the decision-makers regarding the meaning of each behavioral style. Let us assume that an agent modeled with the "Avoiding" behavior style can act exactly like a real "Avoiding" person would act in a decision context. Theoretically, this would be fantastic and the goal would be achieved; still, let's now imagine that a decision-maker, when configuring his agent with the "Avoiding" behavior, actually expects it to have "Obliging" behavior or to have a resistance to change that is very different from that associated with an "Avoiding". In this case, the existence of behavioral styles would be of no use, since what decision-makers hope to achieve is different from what is actually going to happen. As such, and in order to verify this hypothesis, it was necessary to understand if there is an homogeneous understanding regarding the operating values of each behavior style in each of the proposed dimensions. In the work proposed in the paper entitled "Representing decision-makers using styles of behavior: an approach designed for group decision support systems" (Carneiro et al., 2017g), it was possible to verify high levels of agreement in the meaning of each behavior style by the inquired persons, which leads us to affirm that this hypothesis was verified.

The hypothesis "Computer agents can act according to the style of behavior with which they are defined" was also studied in the paper with the title "Representing decision-makers using styles of behavior: an approach designed for group decision support systems" (Carneiro et al., 2017g). In the hundreds of simulations that were ran, it was possible to verify that the operating values of the agents lean towards those with which they are modeled in each one of the dimensions.

The hypothesis "Agents that represent/support decision-makers in the Ubiquitous/Web-based group decision-making process and that use styles of behavior can obtain higher consensus and quality decisions more easily" was also verified. In the paper entitled "Arguing with Behavior Influence: A Model for Web-based Group Decision Support Systems" (Carneiro et al., 2017c) was demonstrated that agents modeled with behavioral styles achieved higher satisfaction levels 70.2% of the times and higher consensus levels 74.3% of the times, when compared to agents without a defined behavioral style.

The hypothesis "Agents with a higher level of concern for others obtain higher satisfaction levels" was rejected. Although we initially considered that comparatively, agents with higher levels of concern for others tended to obtain higher levels of satisfaction, this did not occur. When scenarios composed of agents where everyone had the same style of behavior were tested, we noticed that the Obliging agents (which have the highest level of concern for others) had lower levels of satisfaction than groups composed only by agents of the type "Integrating", "Compromising" and "Avoiding". This ended up making sense because it was a dysfunctional group where every agent wanted to please the others, but where no agent "wanted to please itself". With this we ended up formulating a new hypothesis "Agents with a higher level of concern for others and a higher level of concern for self obtain higher satisfaction levels", which in turn was confirmed. Groups composed of agents in which every agent is "Integrating" or "Compromising" can achieve higher levels of satisfaction. However, as will be seen later, this does not imply that other styles of behavior are "useless".

The hypothesis "Agents with a low concern for self obtain consensus more easily" was rejected. Concern for self on its own does not allow us to verify that the lower the concern for self the easier it is to obtain the consensus. However, we have found that a low level of concern for self combined with a high level of concern for others substantially helps reaching consensus. Finally, the hypothesis "Using agents defined with a style of behavior is always advantageous" was also rejected. It was verified that there are situations in which behavior styles hinder the achievement of high levels of satisfaction, as well as the attainment of consensus, especially when all agents are modeled with the "Dominating" style of behavior. However, we could not verify this hypothesis with the already existing knowledge and models, but in the future, it may be verified using new strategies.

Group Decision Support System

Some studies related to the developed prototypes were carried out during this PhD, where some hypotheses of "lesser" relevance were studied. However, the most important study was related to the hypothesis "A cooperative decision system that uses agents modeled with behavioral styles should be able to benefit from this heterogeneity and not present a biased functioning". Here the goal was to see if, in practice, the whole approach actually proved to be useful and reliable, i.e., to what extent the modelling of behavioral styles is interesting for real decision-makers and, if in a real context, decision-makers would not use strategies in the behavioral style selection with the intent to control the outputs of the system instead of actually representing their intentions. This hypothesis was verified. On the one hand, in the study published in the paper entitled "Arguing with Behavior Influence: A Model for Web-based Group Decision Support Systems" (Carneiro et al., 2017c), we had already verified that the levels of satisfaction obtained by heterogeneous groups are higher than those presented by groups composed of agents with the same behavioral style (irrespective of the style); on the other hand, in the work published in the paper with the title "Representing decision-makers using styles of behavior: an approach designed for group decision support systems" (Carneiro et al., 2017g), it was possible to verify that there is no style of behavior that is always advantageous with respect to others, which may avert those who wish to deceive the system.

4.3 DISSEMINATION OF RESULTS AND RELEVANT WORK

To disseminate the results, a series of activities were carried out during the PhD, which allowed to learn more, exchange ideas and evolve both as a researcher and as a person. These activities are presented in this section.

4.3.1 *Other publications*

During the curricular part (1st year) of this PhD it was taught the meaning of the expression "Publish or Perish". The impact of this teaching was great and it turned into the desire of always publishing more and better. As such, besides those presented in Chapter 3 of this document, many papers have been published. Below is the full list of the publications made during this PhD.

International Journals

- Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2017). How cognitive and affective aspects can influence the outcome of the group decision-making process. Expert Systems;

- Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2017). Arguing with behavior influence: A model for web-based group decision support systems. International Journal of Information Technology & Decision Making;

- Carneiro, J., Martinho, D., Marreiros, G., Jimenez, A., and Novais, P. (2017). Dynamic argumentation in ubigdss. Knowledge and Information Systems, pages 1–37;

- Carneiro, J., Martinho, D., Conceição, L., Marreiros, G., and Novais, P. (2017). How the ability to analyse tendencies influences decision satisfaction. Inteligencia Artificial, 20(59):8–20;

- Carneiro, J., Saraiva, P., Martinho, D., Marreiros, G., and Novais, P. (2017). Representing decision-makers using styles of behavior: An approach designed for group decision support systems. Cognitive Systems Research;

- Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2016). Intelligent negotiation model for ubiquitous group decision scenarios. Frontiers of Information Technology & Electronic Engineering, 17(4):296–308;

- Carneiro, J., Conceição, L., Martinho, D., Marreiros, G., and Novais, P. (2016). Including cognitive aspects in multiple criteria decision analysis. Annals of Operations Research, pages 1–23;

- Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2015). A general template to configure multi-criteria problems in ubiquitous gdss. International Journal of Software Engineering and Its Applications, 9(11):193–206;

- Carneiro, J., Santos, R., Marreiros, G., and Novais, P. (2015). Ubigdss: A theoretical model to predict decision-makers' satisfaction. International Journal of Multimedia and Ubiquitous Engineering, 10(7):191–200;

- Carneiro, J., Marreiros, G., and Novais, P. (2015). Using satisfaction analysis to predict decision quality. International Journal of Artificial IntelligenceTM, 13(1):45–57;

- Carneiro, J., Laranjeira, J., Marreiros, G., Freitas, C. F., and Santos, R. (2012). A context-aware model to support ubiquitous group decision making. J. Internet Serv. Inf. Secur., 2(1/2):105–118.

Conference Proceedings and Book Chapters

- Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2017). Including credibility and expertise in group decision-making process: An approach designed for ubigdss. In World Conference on Information Systems and Technologies, pages 416–425. Springer;
- Carneiro, J., Santos, R., Marreiros, G., and Novais, P. (2017). Evaluating the perception of the decision quality in web-based group decision support systems: A theory of satisfaction. In International Conference on Practical Applications of Agents and Multi-Agent Systems, pages 287–298. Springer;
- Martinho, D., Carneiro, J., Marreiros, G., and Novais, P. (2017). Defining an architecture for a ubiquitous group decision support system. In International Symposium on Ambient Intelligence, pages 246–253. Springer;
- Conceição, L., Carneiro, J., Marreiros, G., and Novais, P. (2017). A soa web-based group decision support system considering affective aspects. In Portuguese Conference on Artificial Intelligence, pages 65–74. Springer;
- Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2016). The effect of decision satisfaction prediction in argumentation-based negotiation. In International Conference on Practical Applications of Agents and Multi-Agent Systems, pages 262–273. Springer;
- Conceição, L., Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2016). Generation of intelligent reports for ubiquitous group decision support systems. In Global Information Infrastructure and Networking Symposium (GIIS), 2016, pages 1–6. IEEE;
- Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2016). Introducing dynamic argumentation to ubigdss. In Distributed Computing and Artificial Intelligence, 13th International Conference, pages 471–479. Springer;
- Carneiro, J., Conceição, L., Martinho, D., Marreiros, G., and Novais, P. (2016). Intelligent reports for group decision support systems. In Intelligent Environments 2016: Workshop Proceedings of the 12th International Conference on Intelligent Environments, volume 21, page 4. IOS Press;

- Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2015). Individual definition of multi-criteria problems in ubiquitous gdss. Adv. Sci. Technol. Lett, 97:99–106;
- Martinho, D., Carneiro, J., Marreiros, G., and Novais, P. (2015). Dealing with agents' behaviour in the decision-making process. In Intelligent Environments (Workshops), pages 4–14;
- Carneiro, J., Marreiros, G., and Novais, P. (2015). An approach for a negotiation model inspired on social networks. In International Conference on Practical Applications of Agents and Multi-Agent Systems, pages 409–420. Springer;
- Carneiro, J., Martinho, D., Marreiros, G., and Novais, P. (2015). Defining agents' behaviour for negotiation contexts. In Portuguese Conference on Artificial Intelligence, pages 3–14. Springer;
- Carneiro, J., Santos, R., Marreiros, G., and Novais, P. (2014). Overcoming the lack of human-interaction in ubiquitous group decision support systems. Advanced Science and Technology Letters, 49:116–124;
- Carneiro, J., Santos, R., Marreiros, G., and Novais, P. (2014). Understanding decision quality through satisfaction. In International Conference on Practical Applications of Agents and Multi-Agent Systems, pages 368–377. Springer;
- Laranjeira, J., Marreiros, G., Carneiro, J., and Novais, P. (2013). An emotional aware architecture to support facilitator in group idea generation process, pages 299–306. Springer;
- Carneiro, J., Laranjeira, J., Marreiros, G., and Novais, P. (2012). Analysing participants' performance in idea generation meeting considering emotional context-aware. In ISAmI, pages 101–108. Springer;
- Laranjeira, J., Freitas, C., Marreiros, G., Ramos, C., and Carneiro, J. (2011). A digital secretary for smart offices setup up. Ambient Intelligence-Software and Applications, pages 69–76;
- Laranjeira, J., Marreiros, G., Freitas, C., Santos, R., Carneiro, J., and Ramos, C. (2011). A proposed model to include social and emotional context in a group idea generation support system. In Privacy, Security, Risk and Trust (PASSAT) and 2011 IEEE Third Inernational Conference on Social Computing (SocialCom), 2011 IEEE Third International Conference on, pages 609–612. IEEE;

- Carneiro, J., Santos, R., Marreiros, G., and Laranjeira, J. (2011). A theory to measure participant satisfaction in a meeting supported by a gdss. EPIA, Lisboa, Portugal.

4.3.2 *Participation and Organization of Events*

During this PhD there was the opportunity to participate and contribute to the organization of national and international scientific events. These opportunities allowed to live new experiences as well as to learn from other researchers from different backgrounds and cultures.

Organization of Events

- International Conference on Ambient Intelligence (ISAmI 2017): ISAmI is the International Symposium on Ambient Intelligence, aiming to bring together researchers from various disciplines that constitute the scientific field of Ambient Intelligence to present and discuss the latest results, new ideas, projects and lessons learned. Participated as a member of the organizing committee;

- International Conference on Distributed Computing and Artificial Intelligence (DCAI 2016): The DCAI is an annual forum that will bring together ideas, projects, lessons, etc. associated with distributed computing and artificial intelligence, and their application in different areas. Participated as a member of the program committee;

- International Symposium on Intelligent Distributed Computing (IDC 2015): IDC is a symposium focused on the emergent field of Intelligent Distributed Computing and the development of a new generation of intelligent distributed systems. Participated as a member of the organizing committee;

- Doctoral Symposium on Informatics Engineering (DSIE 2012): The DSIE is a focal point for academic efforts in all areas of research and innovation, involving all areas of informatics and informatics engineering. The main goal of the conference is to leverage new advancements on these areas, including new approaches and methodologies contrasting and expanding on the current state of the art. Participated as a member of the organizing and scientific committee.

Participation in Events

- Encontro Português de Inteligência Artificial (EPIA) 2017, Porto, Portugal;
- International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS) 2017, Porto, Portugal;
- International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS) 2016, Seville, Spain;
- Global Information Infrastructure and Networking Symposium (GIIS) 2016, Porto, Portugal;
- Distributed Computing and Artificial Intelligence (DCAI) 2016, Seville, Spain;
- International Conference Ubiquitous Computing and Multimedia Applications (UCMA) 2015, Porto, Portugal;
- International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS) 2015, Salamanca, Spain;
- Encontro Português de Inteligência Artificial (EPIA) 2015, Coimbra, Portugal;
- International Conference on Software Technology (SofTech) 2014, Yeosu, Korea;
- International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS) 2014, Salamanca, Spain;
- Distributed Computing and Artificial Intelligence (DCAI) 2013, Salamanca, Spain;
- International Symposium on Ambient Intelligence (ISAmI) 2012, Salamanca, Spain;
- Doctoral Symposium on Informatics Engineering (DSIE) 2012, Porto, Portugal;
- Encontro Português de Inteligência Artificial (EPIA) 2011, Lisbon, Portugal;
- European Conference on Artificial Intelligence (ECAI) 2010, Lisbon, Portugal.

4.3.3 *Invited Presentations*

Besides the presentation of the published scientific articles, the research work was also addressed in invited talks and tutorial demonstrations. The list of oral presentations made in this context was the following:

- New trends in Group Decision Support Systems: presentation to the students of the Masters in Computer Engineering of the School of Technology and Management of Polytechnic of Porto (2015);
- UbiGDSS Communication Issues in Emergency Contexts: Guest speaker in the 8th International Conference on Crisis and Emergency Management (2014);
- Developing Multi-Agent Systems with the Open Agent Architecture (OAA): presentation to the students of the Masters in Medical Computing and Instrumentation Engineering of the Institute of Engineering of Polytechnic of Porto (2012).

4.3.4 *Lecturing*

During the doctoral programme, the doctoral candidate was invited to be a guest professor at the School of Technology and Management (Polytechnic of Porto). The list of lectured courses was the following:

- Software Development Laboratory (2017-2018), Recitations;
- Structured Processing of Information (2016-2017), Laboratory Practice;
- Software Development Laboratory (2016-2017), Recitations and Laboratory Practice;
- Structured Processing of Information (2015-2016), Laboratory Practice;
- Software Development Laboratory (2015-2016), Recitations and Laboratory Practice;
- Data Structures (2014-2015), Laboratory Practice;
- Intelligent Systems (2012-2013), Laboratory Practice.

4.3.5 *Supervision of Students*

During the doctoral programme, the doctoral candidate co-supervised, along with Professor Maria Goreti Carvalho Marreiros, master students and undergraduate students that developed work in the context of this thesis at the Institute Polytechnic of Porto. The list of students and their respective dissertation titles was the following:

- Luís Manuel Conceição (2017), Masters in Computer Engineering, Dissertation: "Sistema de Apoio à Tomada de Decisão em Grupo baseado em web que considera aspetos cognitivos";

- Branca Sofia Silva (2016), Graduation in Computer Engineering, Dissertation: "Sistema Multi-Agente para Suportar Diálogos num Contexto de Tomada de Decisão em Grupo";
- Leonardo Machado (2016), Graduation in Computer Engineering, Dissertation: "Agent Development Framework for Group Decision Making";
- Diogo Emanuel Martinho (2015), Masters in Computer Engineering, Dissertation: "Desenvolvimento de uma Framework de Argumentação para Apoio à Tomada de Decisão Ubíqua".

4.4 FINAL REMARKS AND FUTURE WORK CONSIDERATIONS

The Web-based/Ubiquitous Decision Support Systems present (theoretically) a set of benefits and potentialities that are recognized in the community. Yet, the problems of acceptance posed by this type of systems are overly evident. During the implementation of the work described in this document, new strategies were developed to overcome certain previously identified problems. In addition, some hypotheses that were already morally accepted in the literature, were studied and verified.

In spite of the various proposed models, algorithms and formulations comprising what is really relevant in terms of scientific work (in its contribution to the state of the art) and consequently as evaluation material, during this work there was a great interest in reflecting and dialoguing on this topic in order to hear other points of view, and also in taking advantage of the scientific meetings to see how other researchers would react to our ideas.

In this work, the decision-maker and the group of decision-makers are taken as the central element, rendering everything else to be created to meet the needs of this element. As such, it was critical to understand the benefits associated to group decision-making. What are the benefits of making group decisions? What are the necessary conditions to take advantage of group decision-making and achieve those benefits? It was with the answers to these questions in mind that this work was developed, which led to the ideas shared in the scientific meetings over the last years.

With this work, we believe that we seed a new perspective on how to approach this problem. The obtained results permitted to verify that this approach allows to reach/achieve positive results that must be explored. It has also been found that there is much work that can and should be done after the one presented here. As for future work there is a special interest in:

- Working on strategies that allow agents to intelligently use the assessments that the decision-makers make of the messages, in particular for building smarter dialogues;

- Developing intelligent reporting mechanisms that allow the information that an agent reports to the decision-maker it represents, to be structured, organized and oriented according to the interests and intentions of that decision-maker;
- Adapting the developed prototype to a specific context to be able to study other needs of the decision-makers and to refine the proposed models;
- Creating smarter models to deal with situations identified/deemed as "complex". That is, specific models to deal with situations in which there are, for example, several agents with a "Dominating" behavior style, or when all agents are "Avoiders";
- Developing a framework where the information will be analysed using multidimensional matrices. This way, agents will be able to use the knowledge generated by that analysis and improve their ability to make requests and consequently evaluate them;
- Studying the possibility of using two types of "Avoider" agents, to be able to represent those who are "Avoiders" because they do not want to participate and those who are "Avoiders" because they lack the ability to participate.

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