The Argumentative Mediator

Carles Sierra[1], Ramon Lopez de Mantaras[1], Simeon Simoff[2]

[1] Artificial Intelligence Research Institute (IIIA-CSIC), Barcelona, Spain
[2] Western Sydney University, Sydney, Australia
{sierra,mantaras}@iiia.csic.es,s.simoff@westernsydney.edu.au

Abstract. In this paper we introduce a negotiation mediator in a multiagent context. When negotiation fails, a mediator can interact with the parties, find out about their goals, ontologies, and arguments for and against negotiation outcome, and suggest solutions based on previous experience. An algorithmic schema to be instantiated with particular argumentation, semantic alignment and case-base reasoning techniques is presented. The proposal is neutral with respect to which particular technique is selected. An example illustrates the approach that is framed in the existing body of literature on argumentation and mediation.

1 Introduction

Achieving an agreement in disputes and deals is a process by which two or more parties reach a mutually acceptable outcome. The focus of this work is in consensual dispute resolution, where the parties themselves make the decision about the process and the outcome. Among the consensual dispute resolution processes, this work addresses mediation – the confidential process where an independent and neutral third party assists the disputants to negotiate and reach a decision about their dispute. Unlike arbitration or expert appraisal, the mediator *cannot impose* a binding solution upon the parties.[3] However, if the parties do not reach a solution and a case goes to an arbitration, the documented intermediate solutions and parties positions through the mediation process can be provided in assistance to the arbitration process.

Through *problem interpretation and reframing capabilities* as well as through various facilitation strategies and procedures, mediators are able to assist negotiating parties to explore the negotiation issues in depth and reach acceptable joint decisions, in many cases, among the best feasible solutions that benefit all negotiating parties under the given circumstances. The long term goal of this work targets the integrative "value creating" mediation strategies [31], which, in addition to interest-based mediation, consider alternative approaches, where the mediator and the parties involved go beyond the "zero sum" view, arguing about the solutions, sometimes reconsidering the original problem in order to create more potential solutions and, if possible, to expand resources under negotiation. In line with the above, from the four categories of contemporary mediation approaches - evaluative, facilitative (also known as interest-based), transformative and narrative [23], we consider *transformative* (or *deliberative*) *mediation*,

[3] The Institute of Arbitrators and Mediators: http://www.iama.org.au/mediation.htm

where the mediator's function is to persuade disputants to transform their respective perceptions of and responses to the dispute or conflict [23]. The motivation for this work is the transformative view, first expressed in [9], that conflict is primarily related to human interaction rather than just conflict of interests of self-interested individuals, aiming only at maximising their individual gain. In some sense, we view mediation as a process of creating value in disputes in line with [28]. We are further motivated by the developments of the cognitive negotiation theory, which focused on what negotiators are likely to do rather than what they should do [44].

Through the process mediators have to remain neutral and to move parties through various impasse-points in the negotiation. How to get to the "win-win" solution or convince the parties to revisit their stance is the know-how that distinguishes a successful mediation *process* and a competent mediator. Designing such evolving process is essential for designing a skilful computerised mediator. In [40] we formulated the issues facing the development of an automated mediation agent. The paper formulated the necessary and sufficient conditions for a mediation to take place and demonstrated the validity of those conditions on examples from the area of international relations. The title of the paper — "Mediation = Information Revelation + Analogical Reasoning" summarised, respectively, the two intertwined sets of requirements towards computational automated mediator: a) capabilities to seek and utilise relevant information, and b) capabilities to "think out of the box", i.e. to approach the problem that has stalled negotiation from a fresh perspective, if necessary, reframe it and present to negotiating parties the new solution, possibly unseen by them when remaining within their "original boxes".

Subsequently, the authors have focused on the development of the computational ability to "think out of the box."[4] In Section 4 in [40] we have introduced a high level view of the MediaThor mediating agent, which utilises past experiences and information from negotiating parties to mediate disputes and change positions of negotiating parties. The realisation of MediaThor required the specification of the mental models $\mathcal{M}^t$ of the agents at time t, introduced in [40] and the mechanisms for aligning of/agreeing on the ontologies of the dispute they used. The architecture of the mediator, presented in [2], implemented MediaThor's case-based reasoning (CBR) approach to mediation integrating analogical and common sense reasoning, achieving both the ability to utilise experience with cases in different domains and the ability to structurally transform the set of issues of the dispute for a better solution. The above mentioned problem reframing has been implemented as a combination of case-based reasoning and common sense reasoning with structure mapping.

This paper continues the development of an automated mediation agent within the 'curious negotiator' framework [39]. The automated mediator `MediaThor` presented in [40] and [2] generates the solution and presents it to the negotiating parties. Both works [40,2] are focused on solution construction aspects of mediation, based on the information revealed by the negotiating agents, including their goals and reservations. An acceptable solution was constructed in a single CBR cycle. What if one of the negotiating agents does not accept the solution proposed by the mediator and *argues* against it? What if both agents argue against parts of the solution and the mediator has to support

[4] Not to be confused with the term "computational thinking" as introduced and discussed in [48]

the proposed solution with arguments relevant to the stance of each negotiator? These questions, related to the dynamics of the mediation process, were beyond the scope of both works [40,2]. They are the focus of the developments presented in this paper.

The contribution of this paper includes the integral analysis of the interplay of mediation and argumentation and the development of a high-level computational model of the transformative mediation process. Specifically, section 3 presents five aspects of mediation, where structured argumentation offers means for realising automated mediation process. These are the overarching five principles for building an automated mediator, which uses argumentation through the mediation process for extracting additional information about the position of the negotiating agents, finding solutions and justifying them. The section then presents the high level modifications of the formal models of negotiating agents and the cases in the case base of the mediating agent, and the suitability of bipolar argumentation frameworks. Sections 4 and 5 present a high level view of the way a computational mediator can use argumentation and a case study which demonstrates how that works.

2 Computational mediators

Early work on computational mediation has recognised the role of the mediator as a problem solver. The `MEDIATOR` [26,25] focused on case-based reasoning as a single-step for finding a solution to a dispute resolution problem. The case-based cycle of the `MEDIATOR` operated within a single domain. In the example with the Israel-Egypt dispute, the similarity was sought within political disputes that involved land and military force (see details in [26], p. 512). The selection of the closest case was biased towards the similarity of the arguments thrown in the dispute rather than the object of the dispute. The mediation process was reduced to a one-step case-based inference, aimed at selecting an abstract "mediation plan". The work did not consider the value of the actual dialog with the mediated parties.

Computational capabilities for problem restructuring in negotiation and mediation has been investigated in [41] as means for manipulating mediated parties in order to change their perceptions of the issues. The `PERSUADER` operated within the game theory paradigm, applied to labor management disputes. It deployed mechanisms for problem restructuring that operated over the goals and the relationships between the goals. It used means to manipulate the utility values of negotiating parties. To some extent this work is a precursor of another game-theoretic approach to mediation, presented in [47] and the interest-based negotiation approach in [32].

Manipulative mediation of human parties involved in dispute resolution has been attempted in the area of decision support systems. The `Family_Winner` [3] treats the dispute resolution process as a series of "mutual trade-offs" aiming at modifying the initial preferences of the parties in order to converge eventually to a feasible and mutually acceptable solution. Further, this line of works considered the incorporation of the notion of fairness in the mediation strategies [1].

MArCo is a theoretical framework, presented in [42], which stands aside of the mainstream works on computational mediation. It recognises that the computational system has to analyse the ongoing interaction and have the capability to identify a conflict and to mediate it. It does not necessarily aim at achieving conflict resolution per se. MArCo mediation framework is geared towards conflict control strategy, which attempts to reduce the negative consequences of conflict, rather than solely looking for a negotiation outcome that resolves the conflict. The mediator is oriented towards facilitating group development, hence the goal of the mediation is to suggest courses of action that provoke articulation and reflection [42].

Notable is the recent series of publications about the computational mediators `AutoMed` [13,14] and `AniMed` [29,30] for multi-issue bilateral negotiation under time constraints. Common to this family of game-theoretic creatures is that the solution space is known and that the mediator can offer either specific complete instances out of this space (`AutoMed`) or incremental partial solutions which are subsets of the solution set (`AniMed`). The later offers a better interaction interface. Similar to the mediator proposed in the 'curious negotiator' [39], both mediators monitor negotiations and intervene when there is a conflict between negotiators.

One of the reasons why negotiation may end up in a need for mediation is that in real settings information only about negotiation issues is not sufficient to derive the outcome preferences [46]. An exploratory study [36] of a multiple (three) issue negotiation setting suggest the need for developing integrative (rather than position-based) negotiation processes which take into account information about motivational orientation of negotiating parties. Incorporation of information beyond negotiation issues has been the focus of a series of works related to information-based agency [17,18,38] and the LOGIC framework [37]. These works are part of our broader series of works which consider the incorporation of information extracted from the illocutions of the negotiation dialogue as well as information provided by external information mining agents in response to a query from a negotiating agent. The research in value-focused thinking [24], value-based argumentation frameworks [5], interest-based negotiation [33] and interest-based reasoning [46] considers the treatment of information related to the preferences of parties involved in negotiation and decision making, in addition to the concrete negotiable matter (aspect, issue). These are the fundamental objectives, values, concerns, goals and desires, labeled as *interests* - any kind of motivational information that leads to a preference [46].

Before getting into the technical aspects, it is worth mentioning that the award of the 2002 Nobel Peace Prize to Jimmy Carter recognises the role of successful mediation in contemporary world.[5] Distinct element of Jimmy Carter's mediation strategies is

[5] Though Jimmy Carter as a President launched a number of controversial weapons programs, see "The Nobel Peace Prize 2002 - Presentation Speech." [http://www.nobelprize.org/nobel_prizes/peace/laureates/2002/presentation-speech.html] for the supportive argument about his contribution as a mediator. Whilst Jimmy Carter's mediation between Israel and Egypt (the Camp David Accords) is a well-known classics, less known are his other numerous successes. For example, in 1994 his mediation resulted in a four-month cease-fire agreement in Bosnia at the the height of the ethnic violence in the

the intertwining of the settlement-centred strategies, in which the mediator is highly manipulative in order to bring the parties to a resolution, proposed by the mediator, and relationship-centred (transformative) where the mediator assists parties in building mutual trust and understanding, and developing mutually-acceptable solutions on their own. Both types of mediation strategies involve elements of argumentation [35].

3 Unfolding argumentation in the mediation process

Below we consider the aspects of mediation, where computational argumentation offers means for realising computational mediation.

I. *Mediation is a fluid and evolving process* [23]. Argumentation offers the machinery, which will enable the evolution of the process. It is very unlikely that the mediator is an "oracle", who knows the overall solution set at the beginning of the process. The mediator constructs the alternative solution sets with the help of the information extracted from the interaction with the negotiating parties. In real world a solution may emerge as a result of a change of the problem space. This is in fact what a skilful mediator does. This implies that the mediator will need to convince negotiators that the problem space needs to be and can be changed.

II. *The mediator should be capable to justify (explain) its suggestions*. Argumentation offers such justification mechanism. The approach in mediation can be analogous to the approach developed in argumentation-based machine learning [7], where an inductive learning algorithm is extended to use part of the data to form explanatory arguments for the outputs.

III. *The mediator should be capable to develop, adjust or extend an agreed ontology*. The agreed ontology, established at the beginning of the mediation session, may evolve as a result of the mediation process. Argumentation offers means to justify changes in the agreed ontology. The ontology is both means in the mediation and argumentation process (it is essential in the implementation of analogy in [40]) or can be the object of the argumentation when mediator develops the ontology on which both parties agreed, or attempt to change it.

IV. *The mediator should be capable to extract information (intelligence) and use it in the mediation process*. Such information comes from the mediation process and from external sources. Argumentation can provide information about the process, encoded in the arguments, and can trigger external information queries.

V. *The mediator should be capable to combine different argumentation systems*. Each of the negotiators, involved in the mediation process most likely will have, loosely speaking, a collection of arguments in support of their position. If mediation allows argumentation, then the mediator will need to combine these argumentation systems in an argument that supports its proposed solution.

Balkans, and a pledge from all sides to resume peace talks, which eventually led to a peace agreement between Croatia, Bosnia, and Serbia in 1995. In 2008, his mediation led to the re-establishment in 2009 of relations at the level of charge d'affaires between Colombia and Ecuador.

We develop further the mediation approach, introduced in [40] and developed further in [2]. In layman terms, the approach views the problem solving process in mediation as a combination of analogous reasoning and *information revelation*,[6] and part of the mediator's strategy is guiding the process of information revelation. The framework assumes that negotiating agents α and β are willing or are required to achieve a mutually beneficial agreement; that α and β are seeking or will accept mediation; and a mediating agent μ is available, hence, the set of agents involved is $A = \{\alpha, \beta, \mu\}$.

A mediator analyses the way negotiation parties have built their views on the disputed issues [22], i.e. the *sets of arguments* or *argumentation systems* that underpin their respective positions when negotiation stalled. This is in accordance with the view that negotiation can be conceptualised as a problem-solving enterprise in which *mental models* guide the behaviour of negotiating parties [45]. The mental model[7] $\mathcal{M}^t$ at time t, introduced in [40], denotes the internal model (representation) of the agent of the problem about which it negotiates. It represents the knowledge of an agent about a dispute, including the *arguments that support her stance* Γ^t; about the views of the other parties on that dispute that the agent is aware and the expected outcomes. This knowledge is internal to the agent and is being updated as the process progresses, so t will go from t_1 when the mediation starts to t_n when the mediation ends. At each time instant the ontology, goals and arguments may get modified due to the interaction.[8] We thus modify the mental model $\mathcal{M}^t$ presented in [2], and include the agent's set of arguments as $\mathcal{M}^t = \{o^t, G^t, \Gamma^t\}$, where o^t, G^t, Γ^t denote the agent's ontology, goals, and set of arguments at time t, respectively. We also extend the case-base format in [2], so that each case c_i in the case base is described by $c_i = \{o_i, A_i, G_i, \Gamma_i^{t_1}, \Gamma_i^{t_n}, S_i\}$, denoting respectively the finally agreed ontology of the dispute, the participating agents, the (consistent) union of their goals at time t_n, their joint argumentation system at the beginning and at the end of the mediation, and the final solution itself.

In this work we reuse Dung's theory of argumentation[9] [20], as it reduces argumentation to a completely abstract system consisting of a set of "atomic" arguments and (a set of) binary relation(s) over these. For example, such an atomic argument can be represented in a rule-based fashion as a pair $\{Antecedent, Consequent\}$, where $Antecedent$ is a set of premises. Dung's original work [20] follows the majority of argumentation frameworks, which consider only conflicts between arguments, represented by a single type of binary relation — "attack", "defeat". In order to use argumentation, the mediator, will have to create an acceptable (by both parties) sets of arguments for each proposed solution that it offers. The concept of acceptability is well explored and developed in

[6] The utilisation of information in negotiation is central to the 'curious negotiator' framework [39].

[7] The term was introduced by Kenneth Craik in [16] to label the models of reality that the mind forms and uses to anticipate events; we follow the terminology introduced and used in [40,2].

[8] In a previous work [40] we introduced *reservations* as those constraints that an agent requires the solution to satisfy. Here we will consider reservations as properties of the solution that the agent is never giving up and thus simply consider them a special kind of goal.

[9] For a broader and detailed overview of the state-of-the-art in argumentation the reader is referred to the editorial [4] to the special issue on argumentation of the Artificial Intelligence journal and to the recent collection of chapters [34].

[20] in a setting abstracted from the nature of the arguments, and interaction between the arguments limited to the "attack" relation. However, this limitation on the relations is counter-intuitive to the way we operate. Indeed, a seres of recent works from Cayrol and Lagasquie-Schiex [10,11,12] strongly argue in favour of modeling *bipolarity* in argumentation, when the argumentation system supports both *defeat* and *support* relations. This distinction has been supported by studies in cognitive psychology which have shown that the two kinds of preferences are completely *independent* and are processed separately in the mind [10]. For instance, it is not clear how an "attack"-based argumentation system will help our mediator μ to handle a situation when negotiating agent α advances an argument that confirms premises used by an argument provided earlier to μ by negotiating agent β. We adapt and extend bipolar argumentation frameworks, developed by Cayrol and Lagasquie-Schiex [10,11,12] as they reuse the principles, properties and algorithms of Dung's framework. We also consider mechanisms for building a "common" argumentation system acceptable to both α and β and mechanisms for merging argumentation frameworks as discussed in [15].

Every argument coming from α and β is a piece of information available to the mediator μ. Dubois and Prade's analysis of bipolarity of information for the needs of knowledge representation [19] supports the need for separate treatment of support relation, so that μ can assess such piece of information as a positive or negative with respect to another argument.

Definition 1. *An Argumentation System $AS = \langle \mathcal{A}, \mathcal{R} \rangle$ is defined by a set of arguments $\mathcal{A} = \{a_i | i \in \mathbf{N}^+\}$ and a set of binary relations between arguments $\mathcal{R} = \{r_k\}_{k \in K}$ where $r_k = \{(a_i, a_j) | a_i \in \mathcal{A}, a_j \in \mathcal{A}, i, j \in \mathbf{N}^+\}$.*

For Dung's framework $\mathcal{R} = \{attack\}$; for bipolar argumentation frameworks $\mathcal{R} = \{attack; support\}$. We recall the three postulates for the automated mediator, formulated in [40]:

Postulate 1 *An automated mediator μ should start interaction with extracting information about the position of the parties on the negotiation;*

This information is formulated as a collection of arguments $\mathcal{A} \subset \Gamma^t$.

Postulate 2 *An automated mediator μ should develop an independent "grand view" of the problem, which is more comprehensive than the individual views of α and β;*

Postulate 3 *An automated mediator μ should operate from the initial stance that α and β are willing to achieve a mutually beneficial agreement and will accept mediation by μ.*

In this paper we have committed to deliberative mediation, hence, we add the following postulate for the automated mediator:

Postulate 4 *An automated mediator μ should be capable of developing an argumentation system AS^t_μ supporting the proposed solution, which is acceptable under agreed semantics by α and β.*

For instance, this may be achieved by the incorporation of the argumentation systems AS^t_α and AS^t_β in line with the ways proposed in [15], or with the *ArgMed* algorithm, presented in next section.

4 The Argumentative Mediator - integrating CBR and Argumentation

In this section we present in layman terms how the mediator can use argumentation. At t_1 the mediator μ requests α and β for their respective ontologies of the dispute $o^{t_1}_\alpha$ and $o^{t_1}_\beta$. If $o^{t_1}_\alpha$ and $o^{t_1}_\beta$ are not the same, μ aligns these ontologies through *argumentation*[10] with α and β into the agreed ontology $o^{t_1}_\mu$. This step can adapt the methodology of the DILIGENT argumentation process in ontology engineering [43] and elements of the argumentation based approaches for ontology alignments presented in [27,6]. Further, μ provides to α and β the agreed $o^{t_1}_\mu$. The mediator μ requests the goals $G^{t_1}_\alpha$ and $G^{t_1}_\beta$ from α and β in terms of the working ontology $o^{t_1}_\mu$. If $G^{t_1}_\alpha$ and $G^{t_1}_\beta$ do not conflict, then $S^{t_1} = G^{t_1}_\alpha \cup G^{t_1}_\beta$. If there is a conflict then μ requests the argumentation systems that agents want to make public at time t_1, $AS^{t_1}_\alpha = \langle \mathcal{A}_\alpha, \mathcal{R}_\alpha \rangle$, such that $\mathcal{A}_\alpha \subseteq \mathcal{A}^{t_1}_\alpha$, $\mathcal{R}_\alpha \subseteq \mathcal{R}^{t_1}_\alpha$ and $AS^{t_1}_\beta = \langle \mathcal{A}_\beta, \mathcal{R}_\beta \rangle$, such that $\mathcal{A}_\beta \subseteq \mathcal{A}^{t_1}_\beta$, $\mathcal{R}_\beta \subseteq \mathcal{R}^{t_1}_\beta$, and merges them into $AS^{t_1}_\mu$. Next the mediator queries the CBR system. The query includes structural and semantic compositions of $o^{t_1}_\mu$, $G^{t_1}_\alpha$, $G^{t_1}_\beta$, and $AS^{t_1}_\mu$, with capability to retrieve cases analogous to the current conflict/dispute and not necessarily in the same problem domain. If the solution is not accepted by the parties the process iterates until a solution is accepted or no progress can be made. During the process agents α and β update their mental models.

The solution sets in the case base can include two types of solutions - those that are directly applicable and those that require reframing of the problem. For example, in the case of resource disputes, the equal division of the resource between the disputing parties is a directly applicable solution. Reconsideration of the resource, as a collection of different structural parts, can lead to splitting the resource in different sets of its parts. This is restructuring of the problem; the solution in this case is offering different sets to the disputing parties.

5 Case study: The Orange Dispute Revisited

We show the interplay of argumentation and case-based reasoning in the mediation process following an extended version of the Orange Dispute, introduced in [25] and considered in [40]. Two sisters need an orange each and there is one orange left, hence, they negotiate. The sisters are the negotiation agents α and β. Negotiation stalled at t_1 and the mediating agent μ intervenes, following the $ArgMed$ procedure of previous section. In order to show the approach we extend the formulation of the orange dispute

[10] See [21] for a compact overview of the area.

Algorithm 1 $ArgMed$

Require: $A = \{\alpha, \beta\}$ the set of agents
Ensure: S a solution to the conflict

$t = t_0$
$S^t = \emptyset$
repeat
    $t = t + 1$
    get $o_\alpha^{t'}$ $\{o_\alpha^{t'} \sqsubseteq o_\alpha^t$ if $t' \leq t\}$
    get $o_\beta^{t'}$ $\{o_\beta^{t'} \sqsubseteq o_\beta^t$ if $t' \leq t\}$
    $o_\mu^t = agree(o_\alpha^t, o_\beta^t)$ {via [43,27,6]}
    send o_μ^t to α and β
    $G_\alpha^t = get(\alpha, G_\alpha^t|_{o_\mu^t})$ {goals aligned to o_μ^t}
    $G_\beta^t = get(\beta, G_\beta^t|_{o_\mu^t})$ {goals aligned to o_μ^t}
    if $conflict(G_\alpha^t, G_\beta^t)$ **then**
        get AS_α^t
        get AS_β^t
        $AS_\mu^t = merge(AS_\alpha^t, AS_\beta^t)$
        $S^t = Adapt(CBR(o_\mu^t, G_\alpha^t, G_\beta^t, AS_\mu^t))$
    else
        $S^t = G_\alpha^t \cup G_\beta^t$
    end if
until $accept(\{\alpha, \beta\}, S^t)$ or $S^t = S^{t-1}$ {repeat until the agents agree or there is no progress}
if $accept(\{\alpha, \beta\}, S^t)$ **then**
    $memorise(o_\mu^t, \{\alpha, \beta\}, G_\alpha^t \cup G_\beta^t, AS_\mu^{t_1}, AS_\mu^t, S^t)$
    return S^t
else
    return $\emptyset$
end if

scenario with additional facts, that contribute to the rationale about why each sister wanted the orange — the set of arguments which each sister has, some of which or all can be used in support of having the orange, namely:

- α is expecting a business visitor to come for an afternoon tea. α plans to prepare an *orange chiffon cake*, as its interesting history[11] can be a good conversation starter. The recipe requires both *orange zest* and *orange juice*. She plans to serve it with a Calvados cocktail, which also requires orange juice. As the orange is a large one, α believes the juice of the orange will be sufficient for both.
- β has a flu. She wants to immediately start treatment as her timely recovery is critical due to forthcoming performance on stage over the weekend. She follows treatment with natural remedies, so she plans to take *orange juice* for the high concentration of vitamin C.

We represent the narrative in terms of propositions that constitute the argumentation knowledge bases $\Gamma_{\alpha}^{t_x}$ and $\Gamma_{\beta}^{t_x}$ which are part of the mental models $\mathcal{M}_{\alpha}^{t_x}$ and $\mathcal{M}_{\beta}^{t_x}$ of α and β, respectively, for $t_1 \leq t_x \leq t_n$. We denote by a_i, b_i and m_i the propositional symbols representing the facts in $\Gamma_{\alpha}^{t_x}$, $\Gamma_{\alpha}^{t_x}$ and $\Gamma_{\mu}^{t_x}$. The sets of arguments $\Gamma_{\alpha}^{t_1}$ and $\Gamma_{\beta}^{t_1}$ are shown in tables 1 and 2.

Table 1. The set of arguments $\Gamma_{\alpha}^{t_1}$ that α has at t_1

$a_1 =$ α plans to impress the business visitor
$a_2 =$ α's selection of a cake with interesting history is part of the plan
$a_3 =$ α's selection of the accompanying drink with interesting history is part of the plan
$a_4 =$ the orange chiffon cake has an interesting history, dating back to 1927
$a_5 =$ Calvados has an interesting history, dating back to Napoleonic times
$a_6 =$ accompanying drink matches selected cake
$a_7 =$ the recipe of the orange chiffon cake requires orange *zest* and *juice*
$a_8 =$ the recipe of the Calvados cocktail requires orange *juice*
$a_9 =$ one large orange is sufficient for both the cake and the cocktail
$a_{10} =$ α knows the visitor likes citruses and citrus flavour
$a_{11} =$ α respects her sister β commitment to performances
$a_{12} =$ α needs an orange

Step t_1: When negotiation between α and β stalled at t_1, the mediator μ, following the $ArgMed$ procedure, requests from α and β their respective ontologies of the dispute $o_{\alpha}^{t_1}$ and $o_{\beta}^{t_1}$. In this case $o_{\mu}^{t_1}$ is a replica of either of $o_{\alpha}^{t_1}$ and $o_{\beta}^{t_1}$, as they are aligned, representing orange as a dividable resource with peel, pulp and juice, as shown in [40]. The mediator μ received from α and β their goals $G_{\alpha}^{t_1} = \{a_{12}-$*need a full orange*$; a_1-$

[11] Harry Baker (1883 – 1974), a Los Angeles insurance agent turned caterer, is said to have invented the original chiffon cake in 1927. Baker kept the recipe secret for 20 years, baking the popular creation for the Hollywood elite. Finally, in 1947, he sold the recipe to Betty Crocker's parent company, General Mills, which released it to the public in 1948, naming it "the first really new cake in 100 years".

Table 2. The set of arguments $\Gamma_{\beta}^{t_1}$ that β has at t_1

$b_1 = \beta$ plans immediately to take measures against the flu to restore her health	
$b_2 = \beta$ needs timely recovery	
$b_3 = \beta$ aims to be ready for the performance over the weekend	
$b_4 =$ orange *juice* is an excellent natural source of vitamin C	
$b_5 = \beta$ prefers treatment with natural remedies	
$b_6 = \beta$ likes cakes with orange flavour	
$b_7 = \beta$ needs the juice of an orange	

impress a business visitor$\}$ and $G_{\beta}^{t_1} = \{b_7 -$ *need the juice of a full orange*; $b_2 -$ *need timely recovery*$\}$. The working ontology $o_{\mu}^{t_1}$ recognises the divisibility of the orange, hence the conflict in the two goals is in the requirement for the orange juice. As $conflict(G_{\alpha}^{t_1}, G_{\beta}^{t_1}) = True$, μ requests the argumentation systems $AS_{\alpha}^{t_1}$ and $AS_{\beta}^{t_1}$.

The argumentation systems are described in terms of *support* and *attack* relations: $\mathcal{R} = \{r_k\}_{k\in\{supp,att\}}$.

$AS_{\alpha}^{t_1} = \langle \mathcal{A}_{\alpha}^{t_1}, \mathcal{R}_{\alpha}^{t_1} \rangle = \langle \{a_1, a_3, a_5, ..., a_{10}, a_{12}\}, r_{supp} = \{(a_6, a_9), (a_5, a_3), (a_3, a_1), (a_{10}, a_{12}), (a_8, a_9), (a_9, a_{12}), (a_{12}, a_1)\}\rangle$

$AS_{\beta}^{t_1} = \langle \mathcal{A}_{\beta}^{t_1}, \mathcal{R}_{\beta}^{t_1} \rangle = \langle \{b_1, ...b_5, b_7\}, r_{supp} = \{(b_1, b_3), (b_2, b_3), (b_3, b_7), (b_4, b_7), (b_5, b_7), (b_7, b_2)\}\rangle$

The operator $merge(AS_{\alpha}^{t_1}, AS_{\beta}^{t_1})$ returns the merged argumentation system $AS_{\mu}^{t_1}$, in which μ finds out that argument b_7 attacks both a_7 and a_8. Arguments b_7 and a_{12} mutually attack each other as shown in Figure 1a. This means $S^t = \emptyset$, which result triggers the case base retrieval and case adaptation operator $Adapt(CBR(o_{\mu}^{t_1}, G_{\alpha}^{t_1}, G_{\beta}^{t_1}, AS_{\mu}^{t_1}))$ of μ. As a result of this operation, μ adds to $AS_{\mu}^{t_1}$ two new arguments: m_1 = *the recipe of the almond pound cake with orange glaze requires only orange zest* and m_2 = *the recipe of limoncello does not require orange juice*, which both support a_1, and attack a_{12} as shown in Figure 1b. μ returns to α and β the following solution $S^{t_1} = \{m_1, m_2, b_7, b_2, a_1\}$.

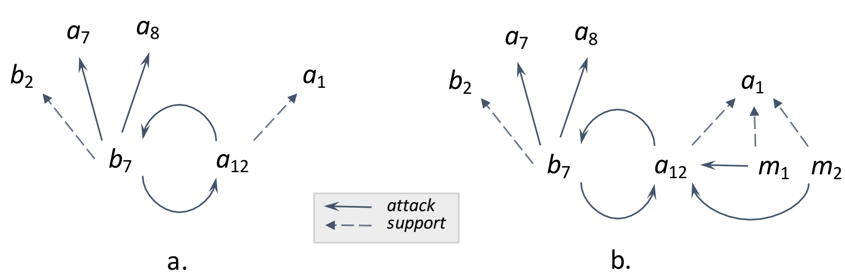

Fig. 1. The merged argumentation system $AS_{\mu}^{t_1}$ before (a) and after (b) the application of the case adaptation operator $Adapt(CBR(\cdot))$ in t_1.

Step t_2: The operator $accept(\{\alpha, \beta\}, S^{t_1}) = false$, meaning that S^{t_1} has not been accepted, triggers the beginning of the next step. During this step α uses argumentation to inform μ that m_1 does not have an interesting history. There are no changes in the agreed ontology: $o_\mu^{t_2}$=$o_\mu^{t_1}$. The mediator μ receives from α and β their revised goals $G_\alpha^{t_2} = G_\alpha^{t_1} \cup \{a_2\}$ and $G_\beta^{t_2} = G_\beta^{t_1}$, and the updated argumentation systems $AS_\alpha^{t_2}$=$\langle \mathcal{A}_\alpha^{t_1} \cup \{a_2, m_1, m_2\}, \mathcal{R}_\alpha^{t_1} \cup \{\{r_{supp} = (a_2, a_1)\}, \{r_{att} = (a_2, m_1), (a_2, m_1)\}\}\rangle$ and $AS_\beta^{t_2}$=$AS_\beta^{t_1}$. The operator $merge(AS_\alpha^{t_2}, AS_\beta^{t_2})$ returns the merged argumentation system $AS_\mu^{t_2}$, shown in Figure 2a, in which μ finds out that its suggestion m_1 and m_2 is attacked by a_2, which in turn supports a_1. This results in S_1^t= $\emptyset$, which triggers the case base retrieval and case adaptation operator $Adapt(CBR(o_\mu^{t_2}, G_\alpha^{t_2}, G_\beta^{t_2}, AS_\mu^{t_2}))$ of μ. As a result of this operation, μ replaces m_1 and m_2 in $AS_\mu^{t_2}$ with two new arguments: m_3 = *the recipe of the orange Santiago tart requires only zest and has an interesting history* and m_4 = *crema de limoncello does not require orange juice*, which both support a_1 and a_2, and attack a_{12} as shown in Figure 2b. μ returns to α and β the following solution S^{t_2}=$\{m_3, m_4, b_7, b_2, a_1, a_2\}$.

The proposed solution S^{t_2} satisfies the goals $G_\alpha^{t_2}$ and $G_\beta^{t_2}$ of α and β, and $accept(\{\alpha, \beta\}, S^{t_2}) = True$. Consequently, the operator $memorise(o_\mu^{t_2}, \{\alpha, \beta\}, G_\alpha^{t_2} \cup G_\beta^{t_2}, AS_\mu^{t_1}, AS_\mu^{t_2}, S^{t_2})$ updates the case base of μ and this concludes the execution of $ArgMed$.

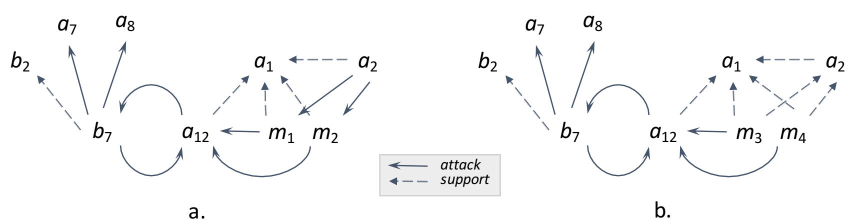

Fig. 2. The merged argumentation system $AS_\mu^{t_1}$ before (a) and after (b) the application of the case adaptation operator $Adapt(CBR(\cdot))$ in t_2.

6 Conclusions

In this paper we have proposed a negotiation mediator, which builds on and develops further the work presented in [40,2]. The mediator μ in [40] demonstrated the problem reframing capabilities and the case-based reasoning approach to implementing such capabilities [2]. These works assumed that α and β provided all the information, requested by μ, and accepted the solutions provided by μ. Whilst both assumptions served the purpose of the work developed in [40,2], it is unlikely that these assumptions will hold in a majority of real world problems, which require mediation. The work presented in this paper demonstrates the next step towards the development of mediation agents, which can utilise argumentation in the mediation process. The proposed mediator follows an algorithmic schema to be instantiated with particular argumentation semantic alignment and CBR techniques. Similar to [40], the case study uses the popular Orange Dispute problem, extending the information about the reasons for the position of each party involved. This information is then utilised by the mediator in the subsequent cycles. The proposal is neutral with respect to which particular technique is selected.

The interplay between argumentation and the mediation process, presented in section 3, has not discussed the time dependency of arguments. Arguments, for instance those related to specific legislation, may be valid until a new legislation is put in place and then become invalid. Capturing the time dependency of arguments and argumentation systems will require extensions of argumentation frameworks, like the ones proposed in [8], and modification of the description of each case c_i in the case base, the case-based reasoning cycle $CBR(\cdot)$ and the $Adapt(CBR(\cdot))$ operator.

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