Computer-Supported Argumentation for Cooperative Design on the World-Wide Web

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Abstract: This paper describes an argumentation system for cooperative design applications on the Web. The system provides experts involved in such procedures means of expressing and weighing their individual arguments and preferences, in order to argue for or against the selection of a certain choice. It supports defeasible and qualitative reasoning in the presence of ill-structured information. Argumentation is performed through a set of discourse acts which call a variety of procedures for the propagation of information in the corresponding discussion graph. The paper also reports on the integration of Case Based Reasoning techniques, used to resolve current design issues by considering previous similar situations, and the specification of similarity measures between the various argumentation items, the aim being to estimate the variations among opinions of the designers involved in cooperative design.

I. Introduction

In cooperative design processes, experts usually face the problem of identification and selection among alternative solutions. This is usually solved through debates, negotiations and argumentation among designers [6,19], the aim being to reach understanding and resolve conflicts (for an axiomatic approach supporting negotiated resolution of design conflicts in concurrent engineering, see [2]). In such environments, experts need appropriate systems that facilitate the communication process and support effective decision making even in the presence of ill-structured information [9,12]. Moreover, such systems should account for defeasible reasoning (further information may cause another alternative to be more preferable than what seems optimal at the moment).

Argumentation has been the focus of research in various well-established areas. Most approaches follow two main methodologies, namely, formal and informal logic (for an extensive survey see [4]). According to the formal perspective, arguments are de-contextualized sets of sentences or symbols viewed in terms of their syntactic or semantic relationships. On the other hand, informal logic views arguments as pragmatic, i.e., their meaning is a function of their purposive context. AI researchers have mainly focused on formal models of argumentation based on various logics. Instead of proposing another argumentation theory, or presenting a new formal model, this paper illustrates an argumentation-based system for cooperative design tasks. According to it, designers may argue about a variety of existing alternatives with supporting or counter-arguments. Similarly, they may argue about these arguments with positions that speak in favour or against them. Moreover, participants may weigh certain argumentation items, putting forward preference relations that hold among them. In general, the system can be used by a group of experts to express their claims and judgements, aiming at informing or convincing, depending on the kind of the design task. Unlike most other systems which merely provide threaded, hierarchical discussion forums, the proposed one includes reasoning mechanisms that monitor the discussion, *checking for inconsistencies* and constantly *updating* the status of argumentation. The system focuses on distributed, asynchronous collaboration, allowing designers to surpass the requirements of being in the same place and working at the same time.

In a variety of design applications, domain theories are usually weak, i.e., rules and concepts may have not been expressed and, if they exist, they are often subjective and suffer from definitional flaws [3,8]. In such domains, Case Based Reasoning (CBR) and learning techniques have been particularly useful [18], due to their resemblance to the way people evaluate a potential future action by using past experience [1,20,21]. Integration of CBR techniques in the argumentation system is also discussed here. The involvement of a variety of experts from different disciplines in a design task implies the presence of various selection criteria, preferences, goals, or, in other words, various *viewpoints*. Integration of CBR techniques aims at supporting designers to retrieve, adapt and re-use old cases. We view cases not only as representations of past data, but as flexible entities that can be filtered according to the viewpoint of an agent and the episode of the corresponding discussion (i.e., previous instances of the related argumentation graph). Similar ideas have been described in [14], where a perspective-based critiquing system allows designers to explicitly represent their intentions and solution forms according to the specified perspectives.

Finally, in cooperative design processes, existence of diverging positions among experts is rather unavoidable, and *consensus seeking* is, in most cases, a desirable procedure. Definition of appropriate measures of the "distance" between one's and the group's opinions might be useful for the estimation of the conflict's sources. To address this issue, the paper also reports on the specification of *similarity measures* between the various argumentation items, the aim being to estimate variations among the opinions of an individual designer and the whole group.

II. The argumentation-based platform

The argumentation framework described in this section is a part of a Group Decision Support System for Argumentation Based Reasoning on the Web [11]. The platform system, called HERMES (http://aid.inria.fr/), is implemented in Java and can be run using any standard Web browser. It maps a multi-agent design task to a discussion graph with a tree-like structure. Throughout this paper, we refer to a real example about the design of cyclepaths in the city of Bonn (Figure 1). The experts involved represent various parties such as the Cyclists Union, City Hall Planning department etc.

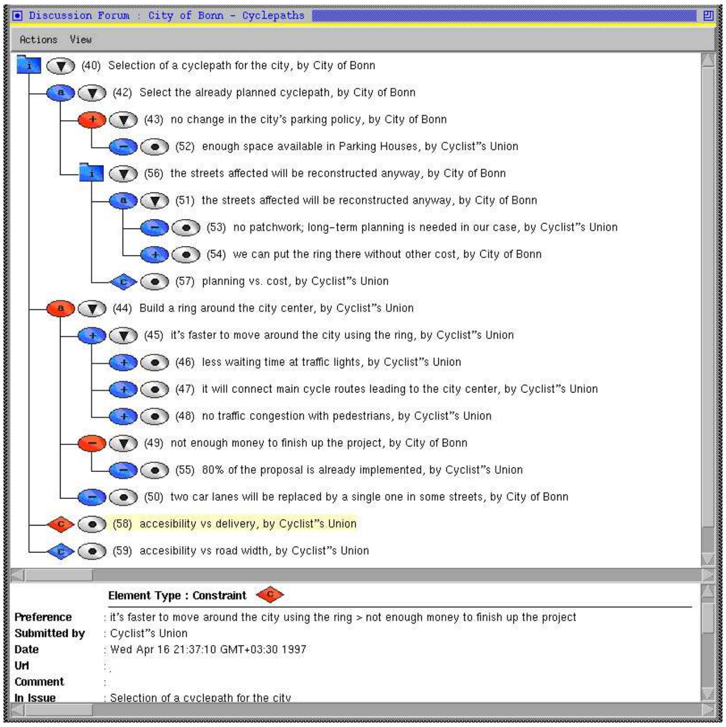

Figure 1: The system's basic user interface.

The argumentation elements of our framework are issues, alternatives, positions, and preferences (for a more comprehensive description, see [11]). *Issues* correspond to decisions to be made, or goals to be achieved (e.g., issue i_{40} :"Selection of a cyclepath for the city of Bonn", see Figure 1). They consist of a set of alternatives that correspond to potential choices (e.g., alternatives a_{42} : "Select the already planned cyclepath", a_{44} : Build a ring around the city center". *Positions* are asserted in order to advocate the selection of an alternative, or avert the agents' interest from it. For instance, position p_{45}: "it's faster to move around the city using the ring" is asserted to support a_{44}, while position p_{50}: "two car lanes will be replaced by a single one in some streets" to express one's objection to a_{44}. Positions may also refer to some other position in order to provide additional information about it. For instance, positions p_{48}: "no traffic congestion with pedestrians (when using the ring)", and p_{52}: "(there is) enough space already available in Parking Houses" provide details about p_{45} and p_{43}, respectively.

Arguments in our framework are tuples of either the form $(position, link, position)$ or $(position, link, alternative)$, where a link marked by $+$ denotes a *supporting argument* and a link marked by $-$ a *counterargument*. In other words, arguments link together a position with an alternative (e.g., $(p_{43}, +, a_{42})$ is a supporting argument for a_{42}) or another position (e.g., $(p_{55}, \text{-}, p_{49})$ is a counterargument for p_{49}). As in real life instances, two or more conflicting arguments can be simultaneously applied.

Preference relations are formulas that relate two argumentation items. They provide a qualitative way to weigh reasons for and against the selection of a certain course of action. In our system, a preference relation is a tuple of the type $(Position, Relation, Position)$. Preference relations may attach various levels of importance to positions or alternatives. They may *refer to* another preference relation, a position, or an issue. Like the other argumentation elements, they are subject to discussion; therefore, they may be "linked" with positions supporting or challenging it, as well as other preference relations that refer to it.

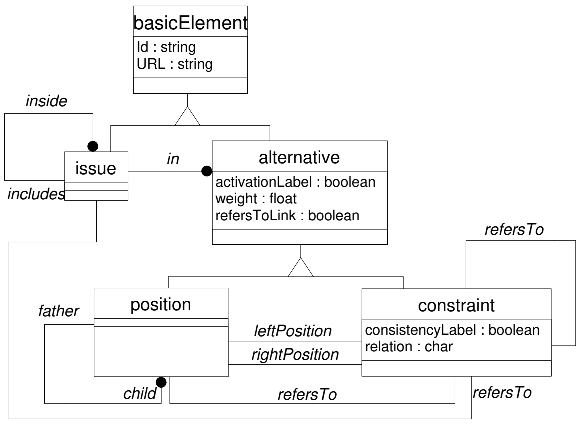

Figure 2: OMT diagram of the argumentation elements.

Figure 2 illustrates the OMT diagram for the argumentation elements of our framework[1]. The *Basic Element* consists of two attributes: an *Id* (primary key) and a *Url* that contains relevant information (sender of the argumentation element, submission date, comments, etc.). It is an abstract class that acts as a superclass for all the others. An *issue* is a basic element that contains other issues and alternatives. Each alternative has a *weight*, which is determined by its supporting and counter-arguments, an *activation label* indicating its status (it can be *active* or *inactive*), and a *proof standard* (discussed in the next section). In addition, each position has a boolean *link* that denotes whether it participates in a supporting (+), or a counter-argument (-).

[1]Object Modeling Technique (OMT) is one of the most well-tried analysis and design methods, able to illustrate object-oriented systems from three perspectives: *object diagrams* showing data structures and their relationships, *functional diagrams* showing data flow between processes, and *dynamic models* describing events, states and causal dependencies.

The argumentation framework suggested in this paper combines concepts from various well-established areas such as Decision Theory, Non-Monotonic Reasoning, Constraint Satisfaction and Cognitive Modeling. As a stand-alone module, it can act as an assistant and advisor, by recommending solutions and leaving the final enforcement of decisions and actions to the designers. The system platform used facilitates access to the current knowledge by making available all relevant data and documents (with URL links), and maintaining them in a well-structured way.

According to our framework, alternatives and positions may be *active* or *inactive*, depending on the related argumentation. Active alternatives correspond to "recommended" choices, i.e., choices that are the strongest among the alternatives in their issue. Active positions are considered "accepted" due to the discussion underneath (e.g., strong supporting arguments, no counter-arguments), while inactive positions are considered "rejected". The mechanisms for the calculation of activation labels are described in detail in [11].

The system involves numerous procedures for the propagation of the argumentation up in the discussion tree, such as *labelling* of the argumentation elements according to the different *proof standards* (they correspond to the type of evidence needed to decide if an element is active or not), aggregation of preferences, *consistency checking*, *scoring mechanisms* (in order to decide which is the best alternative), etc. Different elements of the argumentation, even in the same debate, do not necessarily need the same type of evidence. Quoting the well-used legal domain example, the arguments required to indict someone need not be as convincing as those needed to convict him [5]. Therefore, a generic argumentation system requires different *proof standards* (work on AI and Law uses the term *burdens of proof*). The proof standards integrated in our system are:

Scintilla of Evidence (SoE): according to this proof standard, a position is active, if at least one active position is supporting it (linked with "+"):
$active(P_i) \Leftrightarrow \exists P_j \ (active(P_j) \wedge link(P_j) \wedge Refers\_To(P_j, P_i))$.

Beyond Reasonable Doubt (BRD): according to *BRD*, a position is active if there are not any active positions that speak against it (linked with "-"):
$active(P_i) \Leftrightarrow \neg\exists P_j \ (active(P_j) \wedge \neg link(P_j) \wedge Refers\_To(P_j, P_i))$.

Activation in our system is a recursive procedure; a change of the activation label of an element is propagated upwards. When an alternative is affected during the discussion, the issue it belongs to should be updated because a new choice may be made. This brings us to the last proof standard, *Preponderance of Evidence (PoE)*, used for the selection of the best alternative (however, it can also be used for activation/inactivation of positions).

In the case of *PoE*, each position has a $weight = (max\_weight + min\_weight)/2$ while an alternative has $weight = min\_weight$. Max_weight and min_weight are initialized to some pre-defined values (for the following discussion we assume that initially $min\_weight = 0$ and $max\_weight = 10$; this may be changed by preference constraints). The *score* of an element E_i (position or alternative) is used to compute its *activation label* (score is calculated on-the-fly and is not stored in the database; therefore, it does not appear in the OMT diagram of Figure 2). If an element does not have any arguments, its score is equal to its weight; otherwise, the score is calculated from the weights of the active positions that refer to the element:

$$score(E_i) = \sum_{\substack{Refers\_To(P_j,P_i)\wedge \\ link(P_j)\wedge active(P_j)}} weight(P_j) - \sum_{\substack{Refers\_To(P_k,P_i)\wedge \\ \neg link(P_k)\wedge active(P_k)}} weight(P_k) \qquad (1)$$

Preponderance of Evidence: according to this standard, a position is *active* when the active positions that support it outweigh those that speak against it:
$active(P_i) \Leftrightarrow score(P_i) \geq 0$.
In case of alternatives, *PoE* will produce positive activation label (meaning that the alternative is a "recommended" choice) when there are no alternatives with larger score:
$active(A_i) \Leftrightarrow \forall A_j \ inissue(A_i), \ (score(A_j) \leq score(A_i))$.

Based on these standards, activation of the various argumentation items is performed according to the following procedure:

```
boolean compute_activation(position P) {
boolean ¬ status_changed, old_activation=activation(P);
switch Proof_Standard(P) {
        case Scintilla of Evidence {
                ¬activation(P);
                for all positions P_j that refer to P
                        if (active(P_j) ∧ link(P_j))
                        {       activation(P);
                                break; }}
        case Beyond Reasonable Doubt {
                activation(P);
                for all positions P_j that refer to P
                        if (active(P_j) ∧ ¬link(P_j))
                        {       ¬activation(P);
                                break; }}
        case Preponderance of Evidence {
                score(P)=0;
                calculate_weights(P);
                for all positions P_j that refer to P
                        if (active(P_j) ∧ link(P_j))
                                score(P) += weight(P_j);
                        else if (active(P_j)∧ ¬link(P_j))
                                score(P) -= weight(P_j);
                if (score(P) ≥ 0) activation(P);
                        else ¬activation(P) }}
if (¬ old_activation==activation(P)) status_changed;
return status_changed; }
```

III. Integrating CBR techniques

The representation of a case should clearly reflect the purpose for which it will be used. In order to provide the ability of extracting multiple views of cases representing the same data, we follow a hybrid approach based on the classical case representation [13] and the structure of the argumentation graph. A case consists of a set of argumentation elements that directly depend on the current status of the discourse and the designers' viewpoints [7,10]. Except of an *Id*, cases consist of the following parts:

- *situation:* the relevant part of the discussion at the time the case has been stored; it is composed by:
  - *target:* represents the argumentation element to be argued by a designer. It can be an issue, alternative or position.
  - *Discussion:* the discussion which the case has been extracted from; it is related to *time* and includes: (i) *initialIssue:* the issue at the top of the discussion tree; (ii) *discussion-Context:* information about the *domain* and the *problem type* the discussion refers to (e.g. cooperative design); (iii) *basicElements* (ordered list): refer to the corresponding discussion graph and describe the status of the dispute at the time the case has been involved. Cases have a link to the relevant part of the discussion tree they *refer to* (case situation). That is, whenever we store a case, we keep track of the related discussion graph (i.e., the issue it refers to, alternatives and constraints of the issue, agents in the discussion, discussion domain, etc.).
- *solution:* it is the solution the system derives in order to argue about the target; the solution returned can be of the class *alternative* or *position*, depending on whether the case target above was an *issue* or *alternative*, respectively.

- *evaluation:* an indication of how well the case fits to the designers' agenda. It is calculated (using various formulas depending on the discussion domain and type) from the number of the current's case *brotherCases* (cases with the same target element) and *childrenCases* (cases that have as target the solution element of the current case).

Argumentation with CBR includes four phases: *CBR agenda construction*, *case retrieval and selection*, *case adaptation*, and *argument assertion*. Designers may first submit their intensions, by declaring the arguments they want to bring up in the discussion. This phase is considered to be a mapping of each expert's viewpoint to the current design task. The explicit declaration of designers' intensions "drives" the argumentation process by motivating search for similar instances in the case base (search should be oriented towards similar argument structures). Designers' intensions implicitly specify the *CBR agenda*, i.e., actions to be performed through the case base (at the next phase).

Case retrieval is performed with the use of topical fields from designers' dictionaries. The case base is initially checked for precedent instances with the same field(s) at the *target* case element, taking into account the *situation* of the desired case (for the domains we address, when *target* is an alternative, the topical field used is *"selection of alternative"*). During the case retrieval phase, designers may also alter their viewpoints, while observing similar precedent instances under the presence of certain participants in the corresponding discussions.

Case selection and *case adaptation* are based on designers' viewpoints and the current status of argumentation. While case selection is automatic, case adaptation is semi-automatic, in that the system proposes potential matches and the user selects the cases he thinks appropriate to adapt (according to the context of the current discussion) and use. Shortly, *ranking* of best cases is performed according to the number of *brother* and *children cases* of the ones retrieved, the justification being that the more cases are related to them, the more robust they are (due to their potential challenge in previous disputes). Using the retrieved (and possibly adapted) cases, designers provide warrants for their assertions. The *argument assertion* phase involves firing of the appropriate discourse acts for the propagation of the information in the discussion graph, and storage of the new case used.

IV. Similarity measures

This section reports on some appropriate measures in order for designers to effectively consider the multitude of the existing solutions in the type of problems described above. As pointed out in [16], approximation is inherent in applications of fuzzy set theory, and it is automatically implied in such cases. Many measures of similarity of fuzzy values, together with interesting properties, have been recently proposed in the literature (e.g., see [15–17]).

As made clear in the previous sections, each designer may express his individual opinion about the relevance or importance of an argumentation item, which opinion is to be eventually aggregated with those of the others, in order to produce a *collective assertion* or *decision*. The idea here is to use fuzzy sets for a representation of the designers' assessments, and apply similarity measures in order to evaluate the "difference" between two experts' assessments, the "difference" between an individual and the collective assessment, etc.

We first outline some basic notations and definitions: A fuzzy set A of the universe of discourse $U = \{u_i \mid i = 1, \cdots, m\}$ is a set of ordered pairs $\{(u_i, \mu_A(u_i)) \mid i = 1, \cdots, m\}$, where μ_A is the membership function of A, $\mu_A : U \rightarrow [0, 1]$, and $\mu_A(u_i)$ indicates the grade of membership of u_i in A. When U is a finite set, then A can also be represented by $\sum_{i=1}^{m} \mu_A(u_i)/u_i$, and the vector of scalars $\vec{a} = (a_1, a_2, \cdots, a_m)$ corresponds to A iff $a_i = \mu_A(u_i), \forall i = 1, \cdots, m$. Let also the following notations hold between two scalars a and b:

$$a \wedge b : min(a, b), \text{ and } a \vee b : max(a, b).$$

The similarity measures defined in [15,16] are based on the operations of union and intersection, on the maximum difference, and on the differences and the sum of grades of membership. More analytically, the following grades of similarity between two fuzzy sets A and B have been defined:

$$M_{A,B} = \frac{\sum_i (a_i \wedge b_i)}{\sum_i (a_i \vee b_i)},$$

$$L_{A,B} = 1 - max_i(\mid a_i - b_i \mid),$$

$$S_{A,B} = 1 - \frac{\sum_i (\mid a_i - b_i \mid)}{\sum_i (a_i + b_i)} = 1 - \frac{\sum_i (a_i \vee b_i - a_i \wedge b_i)}{\sum_i (a_i + b_i)}.$$

A and B are said to be *approximately equal* (denoted by $A \sim B$) iff $GS_{A,B} \leq \epsilon$, where $GS_{A,B}$ is any of the $M_{A,B}, L_{A,B}, S_{A,B}$, and ϵ, the *proximity measure* of A and B, is a given small non-negative number.

Assume now that after the appropriate aggregation and defuzzification processes, alternatives a_1 and a_2 take the "performance values" shown in the table below (first two rows). The "performance values" of the third row correspond to the "ideal" solution.

	p_{43}	p_{45}	p_{49}	p_{50}
a_1	0.5	0.8	0.2	0.5
a_2	0.9	0.4	0.6	0.7
ideal	0.7	0.4	0.6	0.5

Performance values are in the interval [0,1], where 0 and 1 denote minimum and maximum performance, respectively. For instance, as shown in the table above, a_1 has received a very good performance value for position (criterion) p_{45} (0.8) and an average one for position p_{50} (0.5). According to the first similarity measure, it is:

$$\begin{aligned} M_{a_1,ideal} &= (0.5 + 0.4 + 0.2 + 0.5)/(0.7 + 0.8 + 0.6 + 0.5) = 0.615, \\ M_{a_2,ideal} &= (0.7 + 0.4 + 0.6 + 0.5)/(0.9 + 0.4 + 0.6 + 0.7) = 0.846, \\ M_{a_1,a_2} &= (0.5 + 0.4 + 0.2 + 0.5)/(0.9 + 0.8 + 0.6 + 0.7) = 0.533. \end{aligned}$$

It is clear that alternative a_2 is "closer" to the ideal solution, while there is a significant difference among the two existing alternatives. The ideas described in this section can be applied to the evaluation of the existing cases (see previous section). However, more work may be done on the specification of a framework, based on fuzzy sets concepts, for the definition of cooperative design concepts such as *consensus, conflict, indeterminateness*, etc.

V. Conclusion

Use of information technology may assist multi-agent cooperative design in various ways. An important goal is to provide, at any time, easy access to the current knowledge. This would be greatly facilitated if all relevant data and documents are made available and maintained in electronic form, in a well-structured and organized way. Our system's primary task is to provide direct computer support for the argumentation, negotiation and mediation process in these environments. A computer network can be used as a medium for such a process, in which documents are indexed according to their role and function, using the presented model of argumentation. We view the system presented in this paper to act as an assistant and advisor, by recommending solutions and leaving the final enforcement of decisions and actions to designers.

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