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# An Internet Based Intelligent Argumentation System for Collaborative Engineering Design

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# An Internet Based Intelligent Argumentation System for Collaborative Engineering Design

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## ABSTRACT

*Modern product design is a very complicated process which involves groups of designers, manufacturers, suppliers, and customer representatives. Conflicts are unavoidable in collaboration among multiple stakeholders, who have different objectives, requirements, and priorities. Unfortunately, current web-based collaborative engineering design systems do not support collaborative conflict resolution. In this paper, we will develop an intelligent computational argumentation model to enable management of a large scale argumentation network, and resolution of conflicts based on argumentation from many participants. A web-based intelligent argumentation tool is developed as a part of a web-based collaborative engineering design system based on the above model to resolve conflicts over the internet by enabling selection of the most favored design alternative in the design argumentation from multiple perspectives in collaborative engineering design.*

**KEYWORDS**: *argumentation, conflict resolution, fuzzy logic, collaborative engineering design, web-based system*

## 1. INTRODUCTION

With the need for reduced product development cost and time, products are increasingly designed via collaborations. Because of the involvement of various disciplinary groups on decision making in collaborative settings, numerous conflicts exist at every stage of a collaborative engineering design process [1]. Although different tools and software support systems have been developed to facilitate collaborative engineering design [11,12,13], the lack of effective intelligent conflict detection and resolution capabilities still hampers effective and efficient collaborative design. To deal with this problem, this research aims to investigate fundamental of conflict resolution through argumentation and to develop a software tool that facilitates web-based conflict resolution.

The paper is organized as follows. Next section outlines related works. Section 3 describes the architecture for a collaborative engineering design environment. Section 4 explains argumentation-based conflict resolution in collaborative engineering design environment. Section 5 describes design and implementation. In section 6, we present an example to illustrate our method and system.

## 2. RELATED WORK

Philosopher Stephen Toulmin developed a very influential model of argumentation [2] that has guided the development of software tools and systems intended to support the detection and resolution of conflicts in many knowledge domains. In the area of engineering design, several argumentation-based conflict resolution methods and systems have been derived from Toulmin's model. The first of them, gIBIS (graphical IBIS), represents the design dialog as a graph [3]. While representing issues, positions, and arguments, gIBIS fails to support representation of goals (requirements) and outcomes. IBE [4] extended gIBIS by integrating a document editor. REMAP [5] (REpresentation and MAintenance of Process knowledge) extended gIBIS and IBE by providing the representation of goals, decisions, and design artifacts. As opposed to these systems, Sillince proposed a more general argumentation model [6]. His model is a logic model where dialogs are represented as recursive graphs and the rules of both rhetoric and logic are used to manage the dialog and to determine when the dialog has reached closure. Alexander [7] has described the incorporation Toulmin's approach into a software product (Telelogic DOORS) that represents features of arguments in a visual hierarchy to aid the analysis of positions taken by proponents and opponents of particular design requirements. The biggest challenge with these systems is that the sizes of their argumentation networks are often too large to comprehend and therefore it is very difficult to use them to help make design decisions. In addition, they cannot deal with uncertainty associated with argumentation from multiple perspectives. In our preliminary study, we have developed a computational argumentation method for capturing and analyzing software design rationale[8]. S. Parsons and N.R. Jennings [14] proposed a framework, based upon a system of argumentation, which permits agents to negotiate to establish acceptable ways to solve problems. Besides, QuestMap[9] is a Computer Supported Collaborative Argumentation (CSCA) tool used to support legal argumentation by equipping the users with the language needed to construct and analyze arguments. The disadvantage of this tool is it lacks decision making capabilities. HERMES[10] system aids decision makers reach a decision, not only by efficiently structuring the discussion rationale, but also by providing reasoning mechanisms that constantly update the discourse status in order to recommend the most backed-up alternative. Its disadvantage is that the weighting factor becomes very ineffective as it is not related to the entered position.

## 3. AN ARCHITECTURE FOR A WEB-BASED INTELLIGENT COLLABORATIVE ENGINEERING DESIGN ENVIRONMENT AND ITS APPLICATION SCENARIOUS

A prototype of a web-based intelligent collaborative system for engineering design is being developed. It is based on client-server architecture, as shown in Figure. 1. On the client side, the system provides user interfaces for solid modeling, annotation, and whiteboards for design alternatives, argumentation-based conflict resolution, and chat rooms for real-time information exchange. On the server side, it manages client communication, concurrent access to design objects, and argumentation network. In this paper, we will focus on its intelligent argumentation subsystem for conflict resolution.

In the collaborative design process, when a conflict is detected, an argumentation-based conflict resolution session will be initiated. A design issue concerning the conflict is raised first in the session. After multiple design alternatives are generated from participants, arguments can then be proposed to either support or oppose the design alternatives or arguments themselves. Our system will help to identify the alternative most favored by all participants considering all arguments to resolve the conflicts.

## 4. ARGUMENTATION-BASED CONFLICT RESOLUTION IN THE COLLABORATIVE ENGINEERING DESIGN ENVIRONMENT

The argumentation framework of this conflict resolution system is an extension of the informal IBIS model of argumentation. We have developed a computational argumentation method for collaborative engineering design based on our preliminary work on software design rationale capturing. It will help to achieve a consensus among stakeholders and identify the most favorable design alternative through argumentation by computing favorability of individual design alternatives from all arguments in the argumentation network in an uncertain environment based on fuzzy logic.

The components of the proposed design argumentation model for collaborative engineering design includes stakeholders, requirements, conflicts, design issues, parts, alternatives, arguments, and decisions, as shown in Figure 2. We view collaborative design as the process of negotiating the resolution of design issues through dialog between the stakeholders. The dialog for a given design issue is represented by the alternatives that are related to a design issue, and the arguments for or against each alternative. Resolution of a design issue is represented by a decision that selects an alternative which is the most favored.

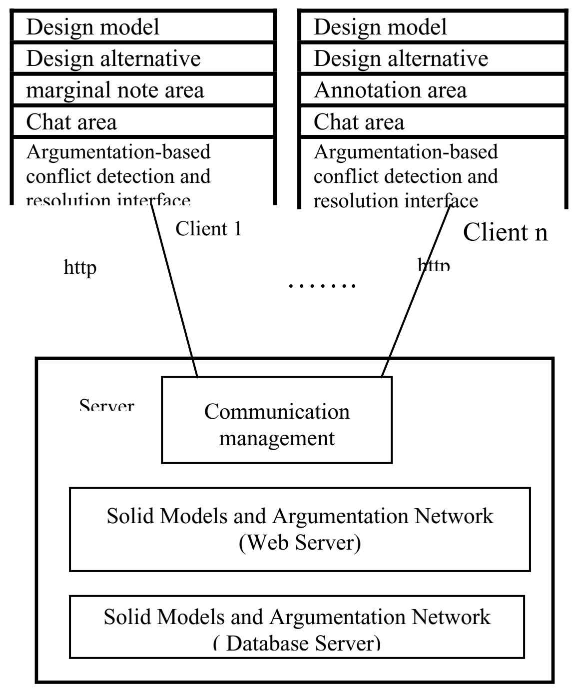



**Figure 1. Architecture for a Web-Based Intelligent Collaborative Engineering Design Environment**

### 4.1. Structured Argumentation Through Dialog Graph

The design dialog for a design issue is captured as a weighted directed graph called a dialog graph [8]. The nodes denoted by a circle are *Positions* i.e. the alternatives and the nodes denoted by rectangles are *Arguments*. Arcs represent a relationship (attack or support) from the originating argument node to the terminating argument or position node. Position node contains the name of the stakeholder posting the position and the text of the position. Each Argument node contains the name of the stakeholder posting the argument, the text of the argument and a weight value. The weight attached to an argument is known as the Argument strength. It is the measure of an arguments degree of attack or support of either a position or another argument in the position dialog graph [8]. The weight value is a real number between -1 and 1. A positive number denotes support and a negative number denotes attack while zero denotes Indecision. The strength of the argument is viewed as a fuzzy set and linguistic labels are used to represent the strength. It is easy to use linguistic labels to denote the strength of an argument over another argument or a position instead of a real number value. By doing so fuzzy inference can be used to evaluate a position. A position node contains a label associated with it which gives the measure of the position's strength relative to the strengths of the arguments under it. This measure is known as the favorability factor of the position.

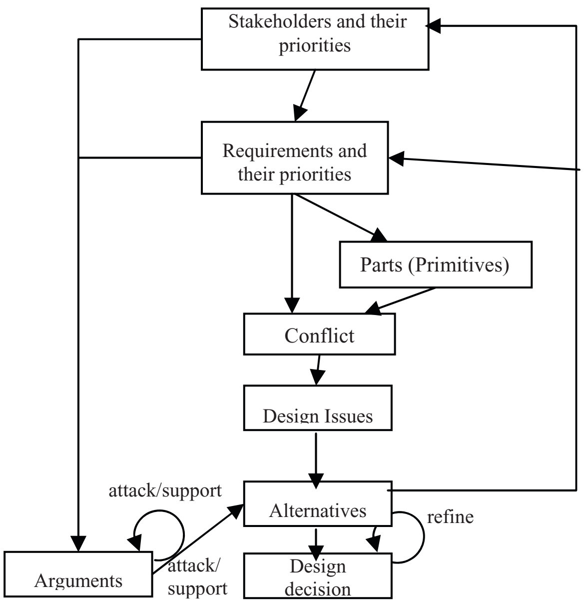



**Figure 2. Framework for Design Argumentation**

## 4.2. Argument Reduction Through Fuzzy Inference

In figure 3, we can see some arguments attached to some other arguments, by a label to denote the degree of support or attack on the arc going between arguments, other than directly attached to the position. For example, A3 medium attack(MA) A1 and A5 strong support A3.Argument reduction means reducing the arguments which are not directly connected to the position in order to have them directly connected to the position i.e. Argument A3 which is posted as an argument that attacks argument A1, actually attacks the position P after reduction.

There are four possible General Argumentation Heuristic Rules that can be formulated as follows [8],

- General Argumentation Heuristic Rule 1: If argument B supports argument A and argument A supports position P, then argument B supports position P.
- General Argumentation Heuristic Rule 2: If argument B attacks argument A and argument A supports position P, then argument B attacks position P.
- General Argumentation Heuristic Rule 3: If argument B supports argument A and argument A attacks position P, then argument B attacks position P.
- General Argumentation Heuristic Rule 4: If argument B attacks argument A and argument A attacks position P, then argument B supports position P.

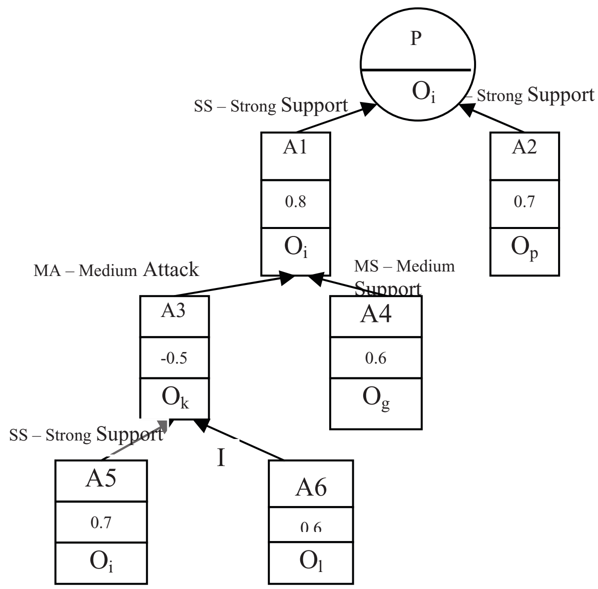



**Figure 3. Position Dialog Graph**

As the linguistic labels used are Strong Support (SS), Medium Support (MS), Indecisive (I), Medium Attack (MA) and Strong Attack (SA), the above four General Argumentation Heuristic Rules can be extended to obtain twenty-five Argumentation Heuristic Rules shown in Figure 4.

| | SS | MS | I | MA | SA |
|---|---|---|---|---|---|
| SS | SS | MS | I | MA | SA |
| MS | MS | MS | I | MA | SA |
| I | I | I | I | I | I |
| MA | MA | MA | I | MS | MS |
| SA | SA | MA | I | MS | SS |

SS: Strong Support | MS: Medium Support
I: Indecisive | MA: Medium Attack
SA: Strong Attack

**Figure 4. Argumentation Heuristic Rules**

Consider an instance where the strength of the level-1 argument is Strong Attack and that of the level 2 argument is Medium Support then the reduced strength of the level-2 argument will be Medium Attack as shown by the entry in column 3 and row 5.

A fuzzy inference engine has been built to infer the reduced strengths of the arguments as discussed later in this section. Using this fuzzy inference engine we can reduce a given Position dialog graph into one in which all the argument nodes are directly attached to the position node. Consider the example in figure 3, where we have arguments occurring at level 3.

First, the argument nodes at level 3 are reduced, i.e. their reduced strengths are computed using the fuzzy inference engine and are attached to the argument node at level 1, which is on the path from the argument node to the position node. Hence from level 3 the arguments come to level 2. It is shown in figure 5.

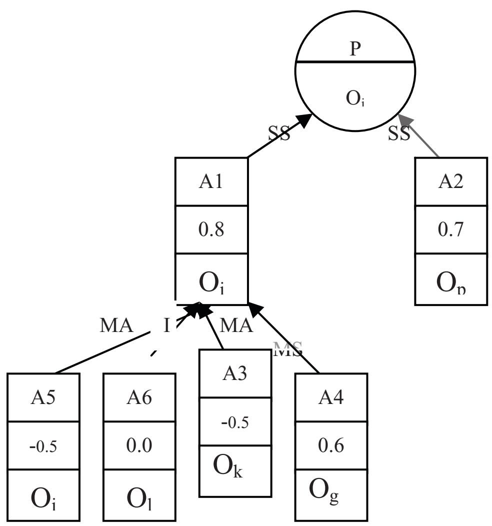



**Figure 5. Position Dialog Graph after One Level Reduction**

Now there is one level of arguments which are not directly attached to the position and hence argument reduction has to be performed once again to have the reduced position dialog graph which will have all the arguments directly attached to it. The arguments at level 2 are reduced using the fuzzy inference engine and attached directly to the position node as shown in figure 6.

So far the procedure of argument reduction has been discussed. The fuzzy inference engine takes in two inputs and gives one output. The inputs are the weights or the strengths of the argument to be reduced and the argument right above it. The output of the fuzzy inference engine is the reduced strength of the argument that had to be reduced.

### 4.2.1. Characterization of Linguistic Variable Through Fuzzy Membership Functions

Fuzzy membership functions are used to characterize quantitatively linguistic systems represented as fuzzy set, such as strong attack, The fuzzy membership function chosen for this system is the piecewise linear trapezoidal function. Several membership functions are defined by using a,b,c,d to denote the four vertexes of the trapezoids. Five membership functions have been defined for the five fuzzy sets. The five fuzzy sets are Strong Attack (SA: a = -1, b = -1, c = -0.8, d = -0.5), Medium Attack (MA: a = -0.8, b = -0.6, c = -0.4, d = -0.2), Indecisive (I: a = -0.3, b = 0, c = 0, d = 0.3), Medium Support (MS: a = 0.2, b = 0.4, c = 0.6, d = 0.8) and Strong Support (SS: a = 0.5, b = 0.8, c = 1, d = 1). Figure 7 shows the five membership functions for the above five linguistic terms.

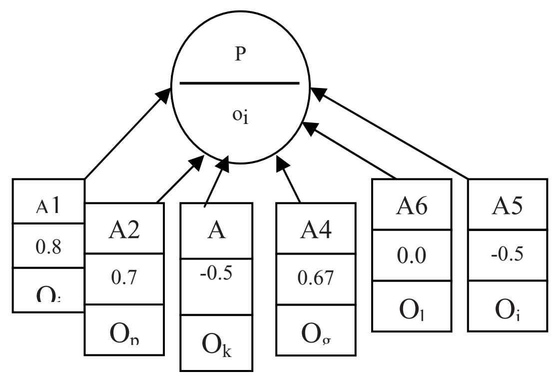



**Figure 6. Position Dialog Graph after Complete Reduction**

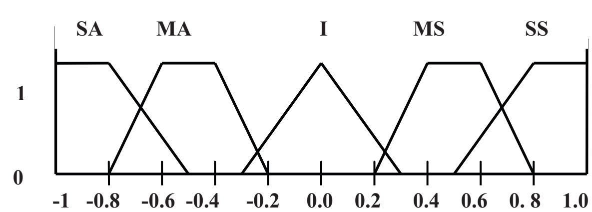



**Figure 7. Five Membership Functions**

### 4.2.2. Fuzzy Inference Rules

Fuzzy inference rules combine two or more input fuzzy sets and associate with them an output set. The input sets are combined by means of operators that are analogous to the usual logical conjunctives "and", "or", etc. The fuzzy rules, also termed later as argumentation rules, are presented in Figure 4. The fuzzy or argumentation rules are stored and represented through the use of fuzzy association memory (FAM) matrix shown in Figure 8. There are two inputs X and Y for each rule. Each input variable is one of five input sets, such as "SS", "MS", "I", "MA", and "SA". The output variable Z is one of five output sets which are same as the five input sets. Each FAM matrix entry is an output fuzzy set that is the output fuzzy set of the fuzzy rule. For example, the shaded part in the figure 8 represents the rule: "If X is Strong Attack (SA) and Y is Strong Support (SS), then Z is Strong Attack (SA)."

### 4.2.3. Fuzzy System and Defuzzification

The system associated with the FAM matrix is shown in figure8. In this case we have two input variables, *X* and *Y*, with associated fuzzy sets SS, MS, I, MA and SA. Figure 7 shows how the membership functions may look for these sets.

| | SS | MS | I | MA | SA |
|---|---|---|---|---|---|
| SS | SS | MS | I | MA | SA |
| MS | MS | MS | I | MA | SA |
| I | I | I | I | I | I |
| MA | MA | MA | I | MS | MS |
| SA | SA | MA | I | MS | SS |

**Figure 8. The Fuzzy Association Memory(FAM) Matrix I**

The membership functions for the fuzzy sets SS, MS, I, MA and SA is denoted by $F_{SS}$, $F_{MS}$, $F_I$, $F_{MA}$ and $F_{SA}$ respectively. A value x of the input variable *X* then has membership degrees $F_{SS}(x)$, $F_{MS}(x)$, $F_I(x)$, $F_{MA}(x)$ and $F_{SA}(x)$ *in respective fuzzy sets*. For example, with the trapezoidal membership functions shown in figure 7 and a value x = -0.7, we would have:

$F_{SS}(-0.7) = 0.0$
$F_{MS}(-0.7) = 0.0$
$F_I(-0.7) = 0.0$
$F_{MA}(-0.7) = 0.5$
$F_{SA}(-0.7) = 0.67$

Similarly, a value y of the input variable *Y* has membership degree values $F_{SS}(y)$, $F_{MS}(y)$, $F_I(y)$, $F_{MA}(y)$ and $F_{SA}(y)$. For example, the value y = 0.6 as shown in figure 9 would result in

$F_{SS}(0.6) = 0.33$
$F_{MS}(0.6) = 1.0$
$F_I(0.6) = 0.0$
$F_{MA}(0.6) = 0.0$
$F_{SA}(0.6) = 0.0$

Consider x = -0.7 and y = 0.6 as values of the input variables X and Y. A weight value is assigned to each entry in the FAM matrix by taking the minimum of the membership function values associated with that entry. Now consider the FAM matrix entry corresponding to X a member of the fuzzy set MA, and Y a member of the fuzzy set SS. The weight w1 associated with the entry would be computed as:

$$\begin{aligned} w_1 &= \min [F_{MA}(-0.7), F_{SS}(0.6)] \\ &= \min [0.5, 0.33] \\ &= 0.33 \end{aligned}$$

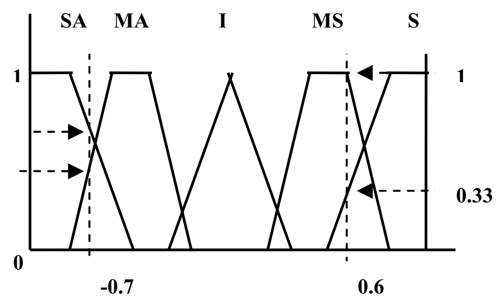



**Figure 9. Membership Degrees**

Only those FAM matrix entries which have nonzero membership-function values for both *X* and *Y* will have nonzero weights associated with them. The shaded entries in the figure 10 show the four activated rules for the values in the example. In addition to $w_1$, there are three more non-zero weights.

$$\begin{aligned} w_2 &= \min [F_{MA}(-0.7), F_{MS}(0.6)] \\ &= \min [0.5, 1.0] \\ &= 0.5 \\ w_3 &= \min [F_{SA}(-0.7), F_{SS}(0.6)] \\ &= \min [0.67, 0.33] \\ &= 0.33 \\ w_4 &= \min [F_{SA}(-0.7), F_{MS}(0.6)] \\ &= \min [0.67, 1.0] \\ &= 0.67 \end{aligned}$$

| | SS | MS | I | MA | SA |
|---|---|---|---|---|---|
| SS | SS | MS | I | MA | SA |
| MS | MS | MS | I | MA | SA |
| I | I | I | I | I | I |
| MA | MA | MA | I | MS | MS |
| SA | SA | MA | I | MS | SS |

**Figure10. The Fuzzy Association Memory(FAM) Matrix II**

The output variable *Z* also has five fuzzy sets associated with it i.e. SS, MS, I, MA and SA. Specific values are assigned to these fuzzy sets, i.e. SS = 1, MS = 0.5, I = 0, MA = -0.5 and SA = -1. The system output is computed as follows:

$$\text{Output} = \frac{(w1 . MA + w2 . MA + w3 . SA + w4 . MA)}{(w1 + w2 + w3 + w4)}$$

$$= -0.59$$

### 4.3. Conflict Resolution By Computing Favorability of Positions (Design Alternatives)

The favorability factor of a position is a value which gives the strength of the position. It is calculated by taking the sum of the strengths of arguments obtained by performing reduction on the ones which were not directly connected to the position. Such a measure allows the participants in a design deliberation to compare positions based upon the argument strength.

In order to resolve conflicts and identify a good design concept, multiple design alternatives are usually developed and explored, and the one which satisfies all stakeholders' requirements to the highest degree is selected. These alternatives are known as positions. The designers would argue over each position giving their arguments and respective weights. In order to resolve the conflict, i.e. to decide which position is the best design alternative, we need to calculate the favorability factor for each position. The position with the maximum favorability factor is the best design option for the conflicting design issue.

At every point in the argumentation, the designers can view which position has the maximum favorability factor and can post their arguments accordingly. For example, a designer may observe that the favorability factor of a given position to which he is supporting is low. He may then decide to post a Strong Support on that position or a strong Attack on the argument having a Strong Attack on the position.

## 5. DESIGN AND IMPLEMENTATION OF THE INTERNET BASED INTELLIGENT ARGUMENTATION SYSTEM FOR CONFLICT RESOLUTION

The tool is a part of a web-based intelligent collaborative engineering design system. It is implemented using JAVA based on a client-server structure

### 5.1. Design and Implementation

The elements used for argumentation include Project, Issues, Positions and Arguments. Information has to be entered in text format which can be viewed by every design member participating in the argumentation. If a conflicting issue has occurred in a new project, the designer has to first create a new project, entering details of the project. Then he can add an issue under that project. If in future another conflicting issue occurs on the same project, the designer has to retrieve the old project from the list of projects and then add an issue under the same. Once an issue is created, the designers can enter their options i.e. the positions to solve the issue. The designers can then enter their opinions in the form of arguments to the positions.

At every stage in the argumentation process, the designers can view the result of the process so far i.e. they can view the position which is most backed-up and then proceed accordingly. This states that, if the position with the maximum favorability factor is the one the designer is attacking, he can then post an attack on that position or post a support on the position he is supporting (Thus increasing the favorability factor of the position he is supporting).

The graphical user interface for web-based intelligent argumentation is shown in figure 11. *Control Panel*: The Control Panel has five menus viz. *Project, Issue, Position, Argument* and *Calculation/Clear*. Each menu had submenus which perform unique actions on the respective argumentation elements viz. Project, Issue, Position and Argument.

### 5.2. Hierarchical Structure of Argumentation

As we studied earlier, one of the drawbacks of the current systems in this field of research is that the sizes of their argumentation networks are often too large to comprehend and therefore it is very difficult to use them to help make design decisions. Hence in this system, we have represented the argumentation network in the form of a tree.

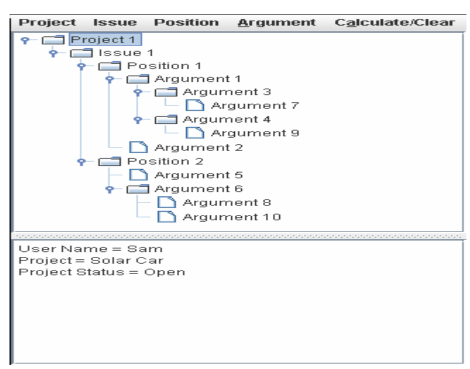



**Figure 11. Conflict Resolution Window**

The basic argumentation elements are *project, issues, positions* and *arguments*. Project forms the root node, followed by issues i.e. the conflicting design issues that are generated under a particular project. Under issues are positions i.e. the design alternatives which can solve the issue. Under positions are arguments and every argument can have any number of arguments under it. The tree structure is so designed that a designer at a time can work on any sub-tree of the complete argumentation tree. This helps the designer to concentrate on a specific part of the argumentation. The argumentation tree is not too large and as the fuzzy inference engine is used to solve the conflict, design decisions can be made without any difficulty.

## 6. AN APPLICATION EXAMPLE

UMR's Solar Car Team, a student design team, which won the competitions in 2001 and 2003 American Solar Challenge, is confronted with many challenging issues including resolving various design conflicts. One of the design tasks is to design a reliable latch mechanism that holds the base frame with the body for the solar car (Figure. 12). After the design team came up with two latch mechanism designs as shown in Figures. 13 and 14, the team needs to select the best design. Some obvious pros and cons of both designs have been identified. While design 1 is easier to be analyzed at the detail design stage and is also easier to be manufactured than design 2, it is harder to be assembled and needs extra work for a locking system. A simplified argumentation network is developed to show resolution of the conflicts based on argumentation, as shown in Figure 15. The argumentation network displayed by the system is shown in Figure 16.

The design dialog reduction is done by an inference engine developed using Java. The reduced argumentation tree is shown in Figure 17 and the result is shown in Fig. 18, which indicates that design 2 is favored most by participants based on the argumentation since its favorability index is greater than that of design 1. The above result of argumentation is concurred by the UMR solar car design team.

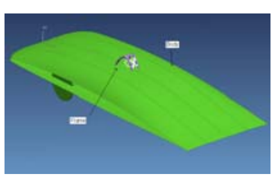


**Figure 12. Solar Car**

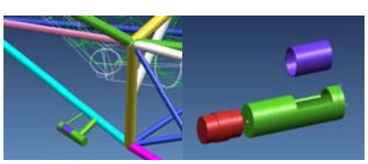


**Figure 13. Design 1**

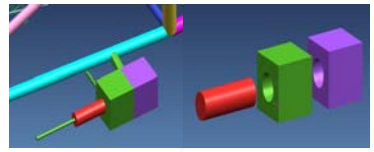
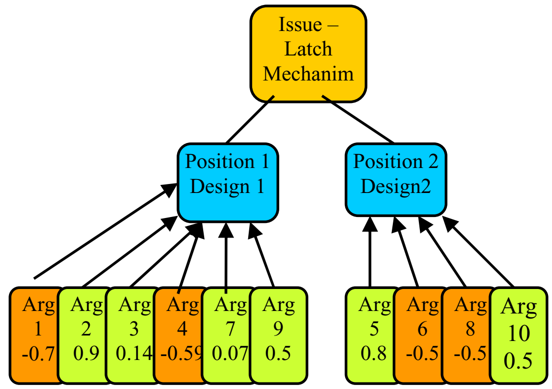


**Figure 14. Design 2**




Argument 1 – The pin aligning will be a problem.
Argument 2 – Design 1 is simpler and cost effective
Argument 3 – It is feasible to design a pin aligning and locking can be designed easily
Argument 4 – The pin aligning is sensitive and will cause a lot of vibration
Argument 5 – A chamfer at both ends of the mating cylinder will allow smooth insertion
Argument 6 – Strength of the cylinders will depend on the material and thickness and that is sensitive
Argument 7 – Manufacturing will be cost effective
Argument 8 – The pin retraction will be a problem when removing the body from the frame
Argument 9 – If the two blocks are mated via a design, then aligning will not be a problem

**Figure 15. Argumentation Tree**

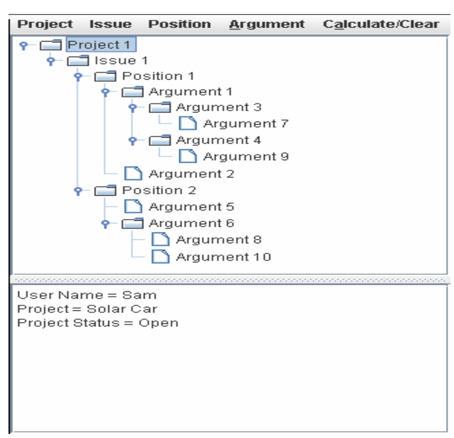



**Figure 16. Argumentation Network**

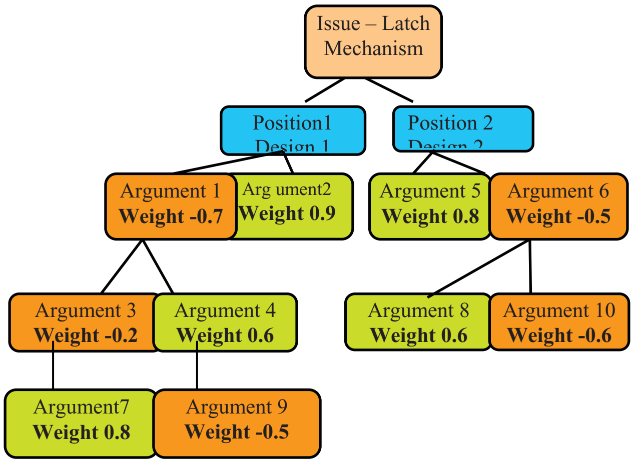



**Figure 17. Reduced Argumentation Tree**

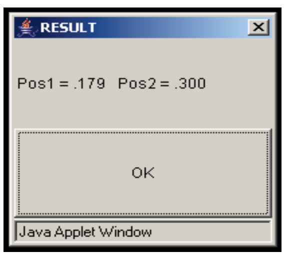



**Figure 18. Argumentation Result – Solar Car**

## 7. CONCLUSION

A web-based intelligent tool is developed to support decision making and conflict resolution for collaborative engineering design based on intelligent argumentation. The reduction of an argumentation hierarchy is based on fuzzy logic. The web-based intelligent argumentation tool enhances conflict resolution capability in web-based collaborative engineering design systems by capturing design rationale using argumentation hierarchies and providing intelligent aids to identify the most supported positions (design alternatives). It is developed using Java. There are several future works. One of them is about improving the mechanism for priority assessment of positions (design alternatives) and arguments in the intelligent argumentation system.

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