On a Persuasion Mechanism Among Agents for Group Choice Design Support Systems

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Abstract

In this paper, we propose a group decision support system based on persuasion among agents. In the system, each user manages a system for an Analytic Hierarchy Process (AHP) and an agent. Each user subjectively constructs a decision hierarchy and determines the various weights of alternatives by using AHP. Based on the hierarchy and weights, agents negotiate with each other on behalf of their users. In general, existing systems use a voting method for negotiating method among agents. But the result of voting are often inconsistent, largely due to the inconsistency of voting rules. Therefore, we propose a persuasion mechanism rather than voting methods for negotiation among agents. Adopting some of the features of AHP, we implement a new persuasion mechanism. The agents have an explanation mechanism. They can explain to their users why they have been persuaded, when they are persuaded, who persuaded them and how they are persuaded. Finally, we show the results of our current experiments. The results demonstrate that the persuasion mechanism is an effective method for a group decision support system based on multi-agent negotiation.

Keywords:Multi-agent system, persuasion, group decision support system, and AHP.

1 Introduction

The field of operations research have given much attention to Group decision Support Systems(GDSSs)[15][16]. The GDSS aims to improve the process of decision-making [5] by removing common communication barriers in a group. The GDSS provides techniques for structuring decision analysis, and systematically directing the pattern, timing or content of discussions. The GDSSs can be classified into three types according to their functionality for supporting a group. Type 1 GDSSs facilitate the exchange of information among users. Type 2 GDSSs reduce the uncertainty and noise that occur in the group's decision process by providing decision-modeling and group-decision techniques Type 3 GDSSs are characterized by machine-induced group communication support. Type 3 GDSSs need to provide expert advice in the selection and arrangement of rules to be applied during a meeting[2][14]. We can expect to further enhance the intelligence of the Type 3 GDSS' support by introducing Artificial Intelligence(AI) methods into the Type 3 GDSSs. For this reason, and in keeping with the current high expectations for effective GDSSs, we here implement a Type 3 GDSS using intelligent agents.

Agents has recently commanded much attention in the field of AI[6]. the term *agent* is used in a variety of ways. For purpose of this paper, we define the term *agent* as follows: Agents can act autonomously and cooperatively in network environment on behalf of their users. Agents have many crucial functors, one of the important being the attainment of consensus[11][12]. Reaching a consensus also is a group decision process that should be supported by the Type 3 GDSS.

The general method for reaching a consensus among humans are voting. But the result of voting are often inconsistent, largely due to the inconsistency of voting rules: Majority Rule, Single Voting Rule, etc. Arrow's impossibility theorem has shown that no voting method exists which satisfies all of the following four conditions: positive association of social and individual values, independence of irrelevant alternatives, citizen's sovereignty and no-dictatorship[20]. In this paper we propose a persuasion mechanism[7, 8] rather than voting methods for negotiation among agents.

In order to realize the persuasion among agents, we need to analyze the humans' persuasion.

[18] defines the persuasion as follows: "Persuasion is a task in which the persuading person leads the persuaded person to act pro-actively by using language mainly." One of the important factor of persuasion between agents is agent's pro-active action. In this paper, we define the persuasion mechanism among agents as follows When agent P persuades agent C, agent P sends a persuasion message to agent C. Then, according to the message, agent C tries to change its belief. If agent P is able to change its belief, the persuasion is a success. However, if agent C cannot change its belief, the persuasion is a failure[9]. A concrete method for implementing the persuasion mechanism is given in section 3.2.

The agents, who carry out tasks on behalf of their users, make suggestions to their users, are known as *interface agents*[17]. Reliability and the ability to depute are important qualities of the interface agents. It can be said that our agents have a high ability to depute users, since our agents negotiate with each other by use of the persuasion mechanism on behalf of users. In addition, our agents have an explanation mechanism. They can explain to their users why they have been persuaded, when they are persuaded, who persuaded them and how they are persuaded by use of graphical user interface. Because of their explanation mechanism, our agents are more reliable.

In this paper, we implement the group choice design support system (GCDSS) as a group decision support system based on persuasion among agents. In order to measure subjective judgements of users, we employ AHP (Analytic Hierarchy Process)[13] in the GCDSS.

The paper is organized as follows: In section 2, we show the architecture of our system and the process of group decision support. In section 3, we present an agent mechanism for our system. Our agent has a management mechanism for the user's hierarchy of AHP, a persuasion mechanism for negotiating with other agents, and an explanation mechanism for their reliability. In section 4, we show an implementation of the GCDSS using the persuasion mechanism and discuss the results of our current experiments. Some concluding remarks are presented in section 5.

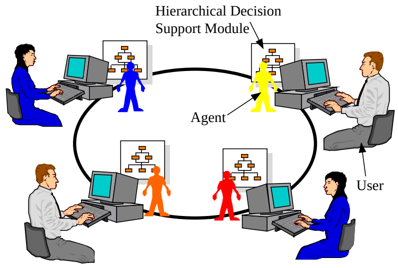

Figure 1: System Architecture

2 Group Choice Design Support System

2.1 System Architecture

The system architecture of the GCDSS is shown in Figure 1. Each user's decision-making is supported by their own hierarchical decision support module in our system. Agents manage their particular user's hierarchical decision support module, and negotiate based on the information it supplies. The agent's tasks are described in section 3. In our system, users' computers are connected by a network. The hierarchical decision support module has functions to help generate alternatives, to make judgements for pairwise comparisons, and to construct a hierarchy. In order to lighten users' work load, we realize these functions using graphical user interfaces.

The GCDSS supports group decision-making according the process described as follows: (1)A host user proposes a topic to be decided. (2)Users make and choose alternatives from alternative database they share. In order to get alternatives, users can employ a variety of methods, e.g., brainstorming. These methods are provided by the hierarchical decision support module. (3)Each user constructs a decision hierarchy for AHP using the hierarchical decision support module. The hierarchy clarifies elements which should be considered in the decision making process. The module is used to quantify subjective judgements of users by using AHP based pairwise comparisons. (4)Agents negotiate with each other based on their users' subjective weights and decision hierarchy. Negotiation among agents is based on the persuasion mechanism described in section 3.2. (5)The result of the negotiation is reported to all users.

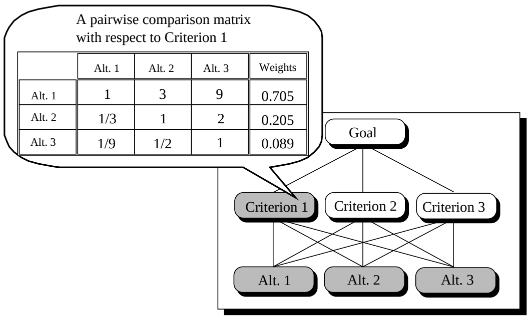

Figure 2: A decision hierarchy using the AHP

2.2 Using the AHP

The AHP(Analytic Hierarchy Process)[13] is a method for making decisions that are hard to analyze quantitatively. It combines both systems approach and subjective judgements, and its primary purpose is to maximize the user's intuition and experience. In the AHP, a user decomposes the problem into a hierarchy that consists of a goal, criteria and alternatives. The judgement of the pairwise comparison between factors (in Figure 2, alternatives $Alt.1$,$Alt.2$ and $Alt.3$) on a certain level is made with respect to the criterion that is a factor (in Figure 2, criterion $Criterion1$) on the upper level. By interpreting a set of values of judgements as a matrix (top left of Figure 2), the weights (i.e., measurement of criteria) of factors are calculated analytically. To put it more concretely, we can achieve the weights of each factor as the eigen-vector for the max eigen-value of the pairwise comparison matrix. As a whole hierarchy, the weights of the alternatives can be calculated by composing the weights of the criteria.

The feature of a pairwise comparisons matrix is described as follows: (1)diagonal values are 1, and (2) the values of elements in a matrix are $a_{ij} = 1/a_{ji}$. For judgements of pairwise comparisons in the AHP, we can use a 9 point scale(Figure 3).

The AHP provides a measure the inconsistency in each set of judgements. This measure is called the inconsistency ratio (I.R.) Ideally, a set of judgements in a pairwise comparisons matrix will be consistent, and the inconsistency ratio will be 0. If the inconsistency ratio is no more than 0.1, this means that the pairwise comparison matrix is consistent.

Absolute judgements are harder for users to make than relative judgements. In order to lighten their work load, users can make comparisons between criteria using verbal and fuzzy expressions (equally, slightly, strongly, very-strongly and extremely) in the AHP. Thus, the value of a pairwise comparison in the AHP is not a strict expression of a user's subjective judgement, but rather a rough approximation of that judgement. In the GCDSS, it may safely be assumed that a user's subjective judgement expresses 2 intervals with a certain value as the center point of the intervals on the 9 point scale (Figure 3). An interval is an unit of the 9 point scale. For example, while in the AHP the verbal expression "Very Strongly Important" means the value of 7 internally, in our system it means the values 6, 7, or 8 (Figure 3).

In addition, we propose the expressions *fixed* and *assumed* to describe a user's belief in a judgement of pairwise comparison. For example, if the judgement is labeled *fixed* by the user, this means that the judgement value itself is fixed (i.e., the value is reliable). On the other hand, if the judgement is labeled *assumed* by the user, this means that the judgement value is also assumed (i.e., the value is unreliable). If an agent is persuaded in negotiation, the agent tries to adjust assumed judgements within 2 intervals in order to change the weights of the alternatives. These adjustments are made under the constraint of I.R. less than 0.1. We describe the persuasion mechanism more concretely in the section 3.2.

2.3 Partial Sharing of Decision Hierarchy

The AHP is generally employed in the common objective context where all users have the same objectives[3]. In this context, users decide one decision hierarchy among them first, then each user judges pairwise comparisons individually based on the decision hierarchy. In this case, because all

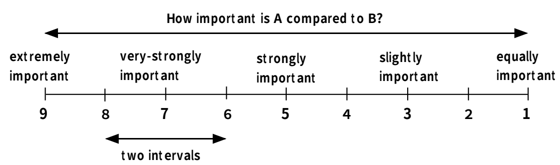

Figure 3: Scale of measurement for AHP

users have the same objectives , i.e., criteria, the existing systems support users to construct only one decision hierarchy and to judge pairwise comparisons. On the other hand, our system supports group decision-making in the non-common objective context where each user has non-shared and sometimes hidden objectives. In the non-common objective context, it is difficult to construct a decision hierarchy among users, because the users have non-shared and hidden objectives and criteria. In our system, each user may construct a decision hierarchy individually. However, when there are same criteria among users, if the users can notice this fact, each can construct a decision hierarchy more effectively.

In the non-common objective context, users who have different decision hierarchies can not reach a consensus effectively. Therefore, the aim of our system is to attain the consensus in term of weights of alternatives. Consensus is more attractive than voting for two reasons as follows: Firstly, the negotiation is beneficial because relevant information possessed by any of the members is made available to the entire group. Secondly, the group members can be satisfied because they feel that they are owners of the decision.

In the GCDSS, a decision hierarchy has public parts and private parts in order to make an effective group decision. The public parts can be referred by all users. The users can get more information from the other users' public parts for group decision-making and, cooperatively construct a decision hierarchy by referring the other user's public parts positively. The private parts are hidden from other users. The users can have partial hierarchies which has non-shared or hidden objectives in the private part. In the concrete system, the whole decision hierarchy is basically public. Individual users can designate as public or private each new criterion they create. The goal and alternatives must be public.

3 Agent

3.1 Management of Decision Hierarchy

User's decision hierarchy and pairwise comparisons matrixes are managed by its agent. The AHP requires too many judgements of its user. If there are n factors for a criterion, the user has to make $n(n-1)/2$ judgements. If the number of levels of the decision hierarchy or the number of factors of the level increases, more and more judgements are required. Acting on the user's behalf, the agent effectively reduces the number of judgements, which leads the user to make consistent judgements dynamically.

In our system, the initial value of the elements of all pairwise comparison matrixes is 1 (i.e.,"Equally Important") as an assumed value. If the user has confidence in a judgement of a pairwise comparison, the user changes the label of the judgement of pairwise comparison into *fixed*. If the user does not have confidence in a judgement of a pairwise comparison, the user changes the label of the judgement into *assumed*. Since there are initial values, the user changes only the value that the user wants to judge.

If a pairwise comparisons matrix is consistent (i.e., $I.R. = 0$), a certain element can be inferred from the other two elements in the AHP. The value of an element a_{ij} in the matrix equals W_i/W_j. Here, the W_i expresses the weight of the factor i. For example, in a matrix, because the value of an element a_{12} is W_1/W_2 and the value of an element a_{23} is W_2/W_3, we can infer that the value of an element a_{13} is $a_{12} \times a_{23} = W_1/W_2 \times W_2/W_3 = W_1/W_3$. In the GCDSS, in order to reduce the number of judgements, agents infer the value of an element in a matrix using this feature of the AHP. When the agent infers the value of an element, if the element was judged by the user, the agent asks the user to change the judgement. If the element has never been judged, the agent changes the value of the element to the new value inferred. In this case, the new value is labeled as *assumed*. In general, in order to reduce the number of judgements, the Harker method [4] is now widely employed. However, to use the Harker method, the covering condition must be satisfied on a matrix. In order to satisfy the covering condition, many judgements, from which all elements in

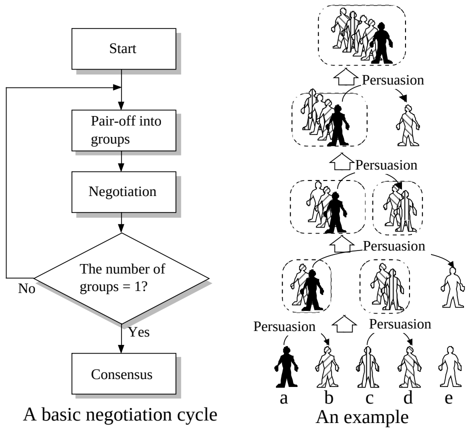

Figure 4: Negotiation among agents

the matrix must be inferred, are required[19]. In a real system, it is also hard for the user to make judgements with the covering condition. If the user has a chance to satisfy the covering condition, the system exploits the Harker method instead of the simple method mentioned above to omit some redundant pairwise comparisons and check the consistency of each comparison dynamically.

In a pairwise comparisons matrix, when the value of $I.R.$ is more than 0.1, this means that the matrix is inconsistent and the user must remake all the judgements. Naturally, this remaking creates additional work load for the user. In our system, while the user is making judgements in a matrix, the agent is watching the $I.R.$ dynamically. When the $I.R.$ is more than 0.1, the agent requests that the user remake the present judgement.

3.2 Persuasion Mechanism

A negotiation among agents consists of persuasions between two agents. In this section, we show the process of a negotiation among agents, then we show the process of a persuasion between two agents.

Figure 4 shows a basic negotiation cycle and an example of a negotiation among agents. A basic negotiation cycle is shown in the left of Figure 4. First, a host user start a negotiation among agents. Secondly, two groups are paired off. Each initial group consists of one agent. Here, two agents are randomly selected and paired off. Thirdly, within each group one agent who selected

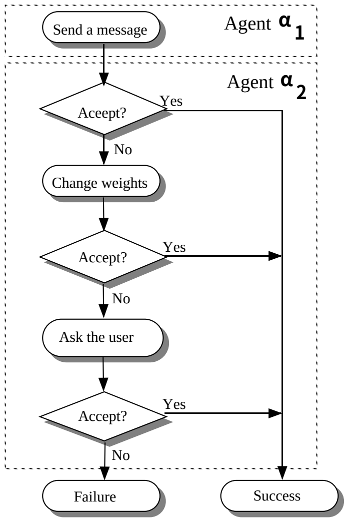

Figure 5: The process of persuasion between 2 agents

randomly persuades the other. In the real persuasion, the more loudly a person speaks or the more rapidly a person speaks, the more the person's opinions are accepted. Namely, opportunity for speaking is not equal between the persons. Therefore, in order to give agents equal opportunity for speaking (i.e. reflecting the user's preference), we randomly pair off two agents and select a agent who persuades the other. If the persuasion succeeds, the pair makes a group. If not, the agents would change their positions and an agent, who is persuaded previously, persuades the other again. If the agents can not persuade each other, the pair does not make a group and they proceed the next cycle. Fourthly, if the number of group is 1, the agents reach a consensus. If not, restart from creating pairs.

In the GCDSS, agents do not need to reach a consensus since the case that agents can not reach a consensus means that the opinions among users are divided. In the GCDSS, the number of negotiation cycles is decided by a host user. If agents can not reach a consensus, the host user can stop the negotiation and can analyze how the agents make groups(i.e. how the users have opinions).

Figure 4 shows an example of negotiation among agents a, b, c, d, and e in the system. First, agents pair-off into groups: agents a and b make a group and agents c and d make a group.

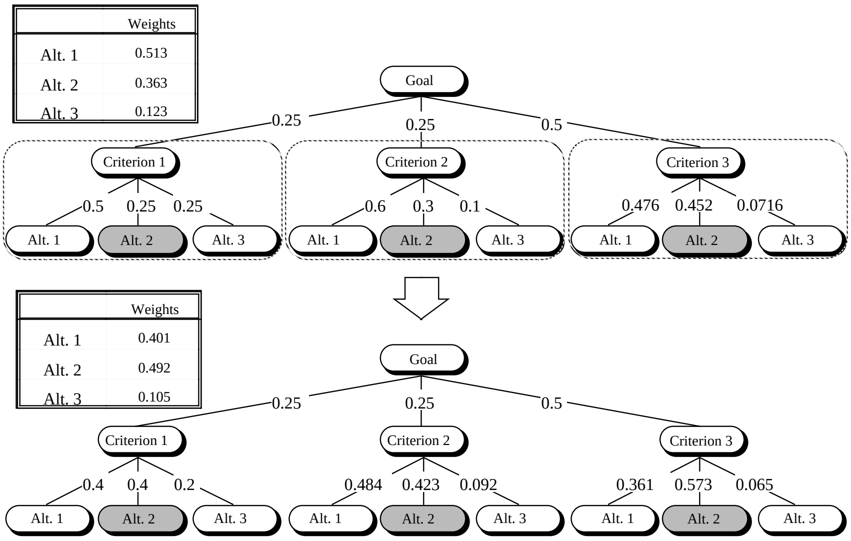

Figure 6: An example of adjusting weights

Next, within each group one agent who selected randomly persuades the other. In Figure 4, agent a persuades agent b and agent c persuades agent d. If these individual persuasions succeed, the persuading agents assume the representation of their respective groups. In Figure 4, each persuasion succeeds, and agent a and agent c are representative of their groups. The groups are now a, b and c, d, and the representatives advance to negotiate with each other singly. During negotiation between agents a, c, and e, agent a persuades agent e. So that the groups become a, b, e and c, d. Finally, agent c persuades agent a, and the agents reach a consensus.

In the persuasion between groups, the representatives of the groups negotiate with each other singly. For example, suppose that there are two groups, group A and group B. If the representative of group A succeeded to persuade the representative of group B, the representative of group B participates into group A and group B is divided into groups which consist of one agent. For example, in the right of Figure 4, the groups are a, b, e and c, d. The representative of the group a, b, e is a and the representative of the group c, d is c. If agent a persuades agent c, agent c participates in the group a, b, e and agent d make a group by herself. Namely, the groups are a, b, c, e and d.

The process of persuasion between two agents, agent α_1 and agent α_2, is shown in Figure

5. First, agent α_1 sends a persuasion message to agent α_2. The persuasion message is the most preferable alternative that has the highest weight and is decided by agent α_1's user with the AHP. Secondly, agent α_2 accepts or rejects this message according to the following process.

First, agent α_2 checks whether its own most preferable alternative is the same as that in the persuasion message. If this alternative is mutual, the agent α_2 accepts the persuasion message. If not, agent α_2 does not accept the message and the persuasion process advances to the next step. If the persuasion message is accepted, this persuasion is a success.

Secondly, agent α_2 tries to change the preference order of alternatives by adjusting the judgements of matrixes in the decision hierarchy. We show an example in Figure 6. The top and bottom halves of Figure 6 show, respectively, the hierarchy before and after adjustment. In the top half of the figure, alternative *Alt*.1 is more preferable than alternative *Alt*.2 or *Alt*.3. Now, suppose that agent α_1 proposes alternative *Alt*.3 as the persuasion message. Agent a_2 tries to adjust the judgements in order to change the preference order so that alternative *Alt*.2 is more preferable than alternative *Alt*.1. In the GCDSS, as a heuristic for changing the preference order, the agent tries to adjust the judgements of pairwise comparisons matrix in the assumed criterion which connects to alternatives directly. The reason is that each level of the hierarchy must be independent in the AHP. For example, in Figure 6, the pairwise comparisons matrixes in the assumed criteria encycled by dotted line are adjusted by the agent. By employing the following method, the agents adjust the judgements in a matrix which factors are alternatives. From the feature of the AHP, in order to increase the weight of the alternative *Alt*.i, we increase the value of elements at ith row except a diagonal element. In the system, the agents increase the value of assumed elements of ith row of the matrix except a diagonal element within 2 intervals of the 9 point scale, in order to increase the weight of alternative *Alt*.i and change the preference order of the alternatives. Figure 7 shows an example of such an adjustment. Suppose that all elements of the matrix are labeled *assumed*, and agent α_2 wants to increase the weight of alternative *Alt*.2. In this case, agent α_2 increases 1 interval of the value of elements (i.e., judgements) on alternative *Alt*.2 against the alternative *Alt*.1 and *Alt*.3. By this adjustment, alternative *Alt*.2 becomes most

	Alt.1	Alt.2	Alt.3	Weights
Alt.1	1	2	2	0.5
Alt.2	1/2	1	1	0.25
Alt.3	1/2	1	1	0.25

	Alt.1	Alt.2	Alt.3	Weights
Alt.1	1	2	2	0.4
Alt.2	1	1	2	0.4
Alt.3	1/2	1/2	1	0.2

Figure 7: An example of adjusting weights in a matrix

preferable. Agent α_2 asks the user for permission to change the weights in practice. If the user permits, agent α_2 changes the judgements. If not, agent α_2 tries to adjust again.

Thirdly, agent α_2 checks whether the persuasion message can be accepted using his new preference order. If the persuasion message can be accepted, this persuasion is a success. If not, this persuasion is a failure.

Fourthly, agent α_2 asks the user to change his or her judgements by default. If the user agrees, agent α_2 indicates which judgement the user should change.

Finally, agent α_2 again checks whether or not the persuasion message can be accepted.

We implement agent's function for the fourth step shown above as an optional function. Namely, agent α_2 asks the user to change his or her judgments by default. This function allows the user to manage agent's action. In the optional setting, this function is not used and the agents negotiate each other autonomously. The reason which we make an agent autonomously is that our research aims to realize agents who act autonomously on network and support user's daily activity. Maes[10] implemented agents which learn appropriate behavior from user's feedback. In future works, it is possible to implement agents which learn appropriate behavior from user's feedback by using the function described in the forth step mentioned above.

3.3 Explanation Mechanism

The agent briefs its user on the details of negotiation via graphical user interface during negotiation. The agent explains which agents persuaded, which element in a matrix should be changed, which group the agents participated in at the time, and so on. To put it more concretely, the agent has

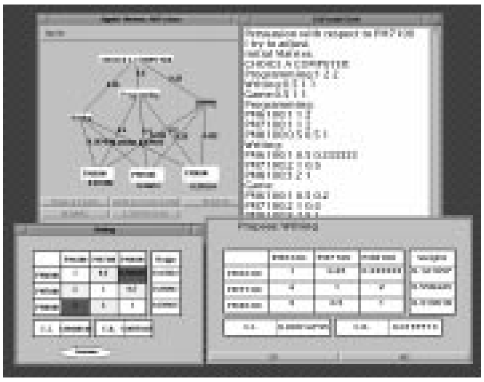

Figure 8: An example

an explanation mechanism for the process of (I)inference and (II)negotiation. For explanation for (I)inference, the agent shows the new pairwise comparison matrix changed by her, the original pairwise comparison matrix, and the process of inference. As an explanation for (II)negotiation, the agent presents agents' groups, the representatives of groups, and a history of persuasion and negotiation at the time. In our system, as the explanation mechanism for (I)inference, agents shows the original and new matrixes as figures in the respective windows. The process of inference is shown in the window simply. Presenting inference processes by natural languages is our future work. As the explanation for (II)negotiation, our system visualizes relations among agents in the window. These explanation mechanisms render the agents more reliable. The reliability is an important factor to implement a software agent.

4 Discussion

4.1 Evaluating the System

Figure 8 shows an example of the agent's explanation mechanism described in section 3.3. In this example, the agent received an alternative "PM7100" as a persuasion message. Then, the agent adjusted judgements and proposed the new judgements by showing the window at the bottom right of Figure 8. The top right window in Figure 8 gives a detailed explanation. This shows the agent's explanation in the process of a persuasion. The agent asks the user's permission to change particular judgements. The user agrees by pushing the *OK* button, or disagrees by pushing the *NO* button. In the optional setting, these buttons are not shown to users and agents dynamically adjust judgements.

Our current experiments have yielded some interesting results that merit discussion. A consensus is sometimes disturbed by the user who makes arbitrary judgements. To deal with such cases, we must consider the following. (1) In the AHP, we generally make decisions constructively. For this reason, arbitrary judgements should be prohibited. This idea can be applied to many cases of group decision making, but it also restricts the user's judgements. (2) An arbitrary judgement can be regarded as an opinion of the user. In this case, it will be worth reaching a consensus among a sub group that excludes this user. In addition, this idea can be applied to cases in which a group does not need consensus among all members. For example, in deciding the destination for a trip, we do not require consensus among all members. We can assume that the member who makes arbitrary judgements does not want to go on the trip, and can thus be disincluded.

The necessity of the explanation mechanism, particularly with regard to the persuasion mechanism, should be discussed. The successful persuasion of an agent requires the compliance of that agent's user. At first, we implemented a system in which the users were removed from the negotiation of their agents. In this case, we found that even if the users knew the system architecture and the process of agent negotiation in advance, the users who were persuaded were not satisfied. In other words, the reliability of agents is an important factor in realizing a multi-agent system. For this reason, in our system, as we have proposed in section 3.3, each agent explains to the user the details of the negotiation, in order to gain the user's consent and make agents more reliable.

4.2 Evaluating the Persuasion Mechanism

Figure 9 shows several types of negotiation among agents in our system. The horizontal axis indicates the number of groups. The vertical axis shows the number of negotiations. The lines (a), (b) and (c) show negotiations among 10 agents. Agents do not ask the users to change his or her judgements. Namely, agents change user's judgements automatically. Here, if agents

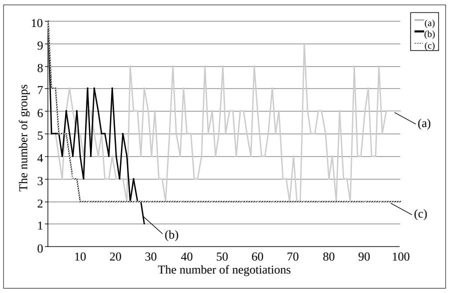

Figure 9: An experiment on the persuasion mechanism

reach a consensus, the number of groups is one. A negotiation consists of five steps shown in the Section 3.2. Figure 9 shows three types of negotiations, (a), (b), and (c). In the negotiation (a), the number of groups fluctuated and agents could not reach a consensus. Here, we can see that there are several opinions among users. In the negotiation (b), agents reached a consensus in 28 negotiations. In the negotiation (c), two groups remained stable after 10 negotiations and could not reach a consensus. We can see that there are two opinions among users.

We can summarize the availability of our system from Figure 9. As the example (b) shows, in the GCDSS agents can reach a consensus on behalf of users. As you can see the example (a) or (c), users can identify how many groups exist and which agents are included in each group. Existing GDSSs aim to support the process of group decision-making. For example, gIBIS[1] supports discussion for designing softwares in a group. The gIBIS allows for recording the group decision making process. The GCDSS carries the issues a step further by allowing agents to actually carry out the process by representing and negotiating via the decision hierarchy of AHP in order to reduce users' work load for negotiation. Even if agents can not reach a consensus, the GCDSS allows users to analyze the opinions among them. The main features of our approach can be shown as follows: First, the GCDSS can reduce users' work load for negotiation in group decision-making by agents' acting on behalf of the users. Next, users can analyze their opinions by following the agents' negotiation.

5 Conclusion

In this paper, we implemented the group choice design support system as a group decision support system based on persuasion among agents. We proposed the persuasion mechanism as a negotiation method among agent rather than voting methods which include variety paradox. In order to see how effectively the persuasion mechanism can be used, we implemented the group choice design support system. In the persuasion mechanism, agents persuade each other. When an agent is persuaded, the agent explains the reason why the agent is persuaded to its user. In the GCDSS, in order to make the system more reliable, agents have the explanation mechanism. The results of our current experiments demonstrated that the GCDSS can reduce users' work load for negotiation in group decision-making and allow users to analyze their opinions by following the agents' negotiation. Namely, the persuasion mechanism can be used effectively for group decision support systems based on multi-agent negotiation.

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