

Group Thinking Support with Multiple Agents

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SUMMARY

Creative group activities, for example, the development of new products, have recently increased in importance. Hence, demands are growing for groupware that is able to help stimulate human creativity. In this article, aiming to achieve such a system of groupware, we first propose a group thinking model, based on the transitions of the mentality of a thinking entity, and divide group thinking into several basic tasks based on the model. We then describe a creative group thinking support system called "AIDE," which we have been researching and developing. From our experience in developing and testing the uses of AIDE, we have ascertained that multiagent architecture is very suitable for achieving a group thinking support system. © 1998 Scripta Technica, Syst Comp Jpn, 29(14): 21-31, 1998

Key words: Group creativity; group thinking model; groupware; AIDE (Augmented Informative Discussion Environment); multiple-agent architecture; creativity support software.

1. Introduction

Creative group activities have recently come to the fore due to growing complexities in society and business, as well as diversity in consumer needs. Accordingly, demands for methodologies and systems to effectively support and enhance group creative activities are rapidly increasing [6].

Supporting technologies and systems for cooperative works (mainly in business) have been studied in the context

of CSCW (computer-supported cooperative work) and groupware research. Teleconferencing systems, support systems for formalized routine office work, and management systems for large-scale software development are typical examples of traditional groupware.

However, most of these ordinary systems are not equipped with facilities to support and/or enhance the creativity of a group as one of its functions. This is mainly because there are generally no well-structured plans and no well-known procedures to achieve a goal in creative activities. In creative activities, members of a group shift among various thinking and processing modes. A system that deals with such activities can be categorized as a "conversation coordination system," a kind of groupware system. To date, however, efforts have been insufficient [14] at modeling this kind of conversation and there has not been enough discussion on the design of groupware systems in this category. Nonaka and Takeuchi analyzed the dynamics of innovation in Japanese companies, and proposed a theory and some models for creating knowledge in a company [12]. Though this research was full of ideas promoting the understanding of group creativity, it is as impractical to apply the theory as it is to implement a system that deals with group creativity.

In this article, we first propose a model of creative group thinking (which we will simply call "group thinking" hereafter), divide the whole group thinking process into several tasks based on the model, and discuss the contents of the tasks. We then explain a group thinking support environment called "AIDE" (augmented informative discussion environment), which we have been developing with a multiagent architecture based on the model. Based on our experience in developing and testing the uses of AIDE, we show several features of AIDE derived from the multiagent

architecture, and discuss the adaptivity of the multiagent architecture in an application, that is, group thinking support.

This paper is organized as follows: in section 2 we model the group thinking process and divide it into several basic tasks; in section 3 we explain the overall framework of AIDE and the functions and interactions of the agents that support each basic task; and in section 4, based on our experience in developing and testing the uses of AIDE, we discuss the advantages and the features of applying a multiagent architecture to group thinking support. Section 5 concludes this paper.

2. Group Thinking Model and Basic Tasks

2.1. Group thinking model based on transitions of members' mentality

In this section, we propose a universal model for group thinking. Group thinking varies according to the particular characteristics of a group, but a group activity consists of each member's actions and their interactions as the general basis.

Group thinking is founded on the thoughts and ideas of each member. However, group thinking cannot be achieved by merely collecting the individual thoughts of each member. It can be achieved through member interaction and collaboration. Noting the transitions of the members' mentality, we modeled the group thinking process in three modes:

- Individual thinking mode
- Cooperative thinking mode
- Collaborative thinking mode

Figure 1 illustrates the relationship between the above modes and the general idea of the group thinking model.

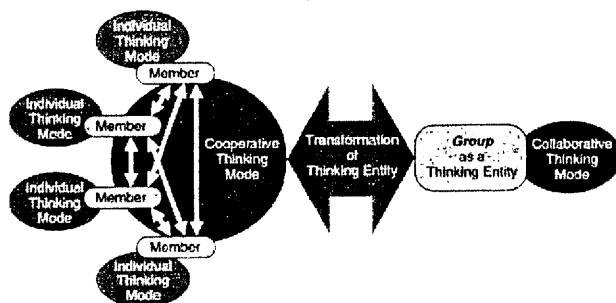


Fig. 1. Group thinking model.

There is no interaction between the group members in the individual thinking mode. Each member develops thoughts in isolation, and this helps all of them establish personal opinions and facilitates the creation of individual ideas. Deep thinking is easier in this mode than in any of the other modes.

The cooperative thinking mode is also referred to as the communication mode. In this mode, members work together to understand each other through their interactions. They learn to understand the way other members think; they also exchange opinions, argue their positions, and communicate ideas. As a result, pieces of knowledge, viewpoints, and ways of thinking of all of the members are shared by all of them. The cooperative thinking mode is preparatory to the collaborative thinking mode.

Through the cooperative thinking mode, the group is transformed from a simple set of individual members to a system with connected members. Finally, the group comes to behave like "a thinking entity." This mode's objective is to establish and unify the opinions and obtain the position of the group. As a result, the individual thinking systematically merges to a unified "intention of the group."

In appearance, the cooperative thinking mode and the collaborative thinking mode are the same, that is, the members interact and think in both modes. However, in the cooperative thinking mode, the members convey and understand information without creating anything. In the collaborative thinking mode, the members (the group as a thinking entity) create something new altogether. This is the significant and essential difference between the two thinking modes.

Furthermore, the group cannot initially shift directly from the individual thinking mode to the collaborative thinking mode. Once some common ground in the cooperative thinking mode is obtained, the transition proceeds smoothly. Group thinking can proceed while switching back and forth between the modes. It is not necessary for the whole group to join in the activity in each mode; instead, members of subgroups can be engaged in only one mode.

2.2. Basic tasks of each thinking mode

2.2.1. Tasks of the individual thinking mode and collaborative thinking mode

As described in section 2.1, in this model, the ideas of each member are pieces that make up the foundation. The members exchange and understand each other's ideas, and then fuse, refine, and improve them. Following this, the ideas of the group are finally created. The thinking for the individual thinking mode can therefore be regarded as a creative problem-solving process. Because of the similarity between the individual thinking mode and the collaborative thinking mode, the thinking for the collaborative thinking

mode can also be regarded as a creative problem-solving process.

Kunifuji's model [5] is employed as the model for the creative problem thinking process. Based on this model, the two modes consist of the following four tasks:

Divergent thinking task: From various viewpoints, relative pieces of information are retrieved (as many as possible).

Convergent thinking task: By structuring the pieces of information collected, and by extracting the essential information from the structure, several hypotheses are generated.

Idea crystallization task: By evaluating the various hypotheses, the one regarded as the most effective is selected.

Proof and evaluation task: By applying the selected hypothesis to the real world, its effectiveness is proved or disproved. Test and evaluation planning are also included in this task.

It has been pointed out that the tasks of divergent and convergent thinking cannot clearly be distinguished, and that the actual thinking frequently comes and goes between these two tasks [15]. In other words, creative thinking does not monotonically progress from divergent thinking to the proof and evaluation task.

2.2.2. Tasks of the cooperative thinking mode

In this mode, it is essential that members work out points of agreement and disagreement among themselves in ways to grasp certain facts, opinions, and ideas. Furthermore, repeating simulations of how individual thoughts are considered by other members is important for promoting mutual understanding among the members.

Therefore, we assume that ideas and opinions, or the general *intentions* of members, can be represented in terms of viewpoints and knowledge, and divide the thinking in this mode into the following three tasks:

Overlaying viewpoints: By overlaying different viewpoints, an entity does not only overlay its viewpoint with that of another viewpoint (or other viewpoints), but also has the potential to generate a new viewpoint.

Applying viewpoints to knowledge: By applying a viewpoint to certain pieces of knowledge, the knowledge is restructured. This allows a user, for example, to see his or her own knowledge through the viewpoint of another user.

Overlaying types of knowledge: By overlaying various types of knowledge, differences surface and new knowledge is synthesized.

Here, viewpoints are either a framework to structure information, or the structure itself. Knowledge is a set of organized fragments of information. Namely, the basis for organizing the fragments is the viewpoint.

A structure of information described with links in hyper-text format is a typical example of a viewpoint. This structure represents the way of grasping, on fragments of information, of the one who constructed the hyper-text under a certain context or situation. Any hyper-text like this is a typical example of knowledge. As described in section 3.3, in this study, fragments of information are statistically structured based on sharing and co-occurrence relations of key words among the fragments. As a result, an entity's viewpoint and knowledge are temporarily structured.

3. AIDE: A Creative Group Thinking Support Environment

In this section, we explain a group thinking support environment called "AIDE" that we have been developing based on the model described in section 2. In order to implement AIDE, we have applied a multiagent architecture. AIDE consists of several agents, each of which is in charge of supporting one of the basic tasks of the group thinking model. In AIDE, group thinking progresses through the cooperative activities of the members of a group and the agents. The remaining part of this section describes the functions of each of the agents and how the agents interact with one other.

3.1. Overview of AIDE

AIDE consists of five functional blocks: the basic communication block, the basic information extraction block, the individual thinking support block, the cooperative thinking support block, and the collaborative thinking support block. Figure 2 shows the relationship between the five blocks and the agents included in the blocks. The arrows illustrate the flow of data.

Conversations input through a keyboard are treated as the most fundamental data. Outwardly, AIDE seems to be a server-client system. A user can join a conversation with AIDE by invoking the client system on his or her own desktop workstation, and connecting to the server. Figure 3 shows the user interface of AIDE on a client system.

3.2. Basic communication block

This block provides primitive communication functions among the users of AIDE. Each utterance from conversations by members of a group is extracted as text data, with the utterance time as additional data.

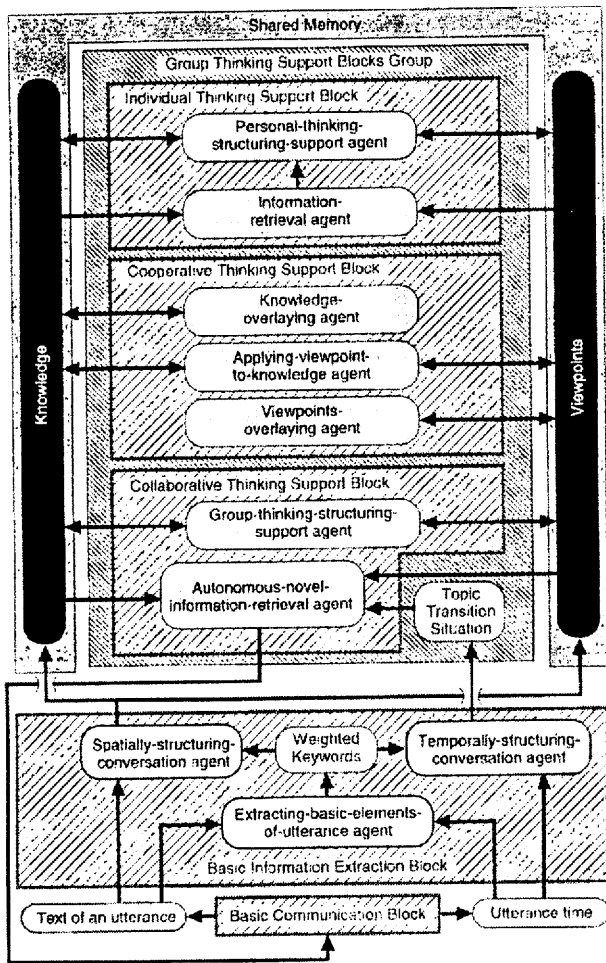


Fig. 2. The five functional blocks of AIDE and the agents belonging to the blocks.

The upper part of Fig. 3 lists a record of utterances in a conversation thread, and the lower part is a window for inputting and editing utterances. After the input of an utterance, it is submitted to the server by clicking the "submit" button at the bottom-right of the window. The server processes each received utterance (described later) and then dispatches the utterance to all of the clients. A client adds the received utterance at the bottom of his or her record of utterances.

3.3. Basic information extraction block

Based on the information extracted by the basic communication block, this block extracts and provides data or pieces of information that are to become material for thinking by the users, and for thinking support by the agents belonging to the remaining three blocks. This block consists of the following three agents:

Extracting-basic-elements-of-utterance agent: This agent is equipped with a morphological analysis module. By morphologically analyzing each utterance, the agent extracts key words and weighs them by considering their frequency in the conversation and the interval between their appearances [10].

Spatially structuring-conversation agent: By using the weighted key words provided by the extracting-basic-elements-of-utterance agent, this agent represents the mutual relationships between utterances in a conversation spatially, as far or near relations, by applying the dual-scaling method [11], which is a statistic analysis method. Simply speaking, if a certain pair of utterances share many of the same key words, they should be located close together. On the other hand, if a certain key word is shared by a pair of utterances, the key word should be located between the utterances. We call any space constructed in this way a "conversation space" [18].

Consequently, we can say that a conversation space corresponds to the "knowledge of the group," which is constructed by structuring the pieces of information provided by the members of the group. The bases of the conversation space correspond to the "viewpoints of the

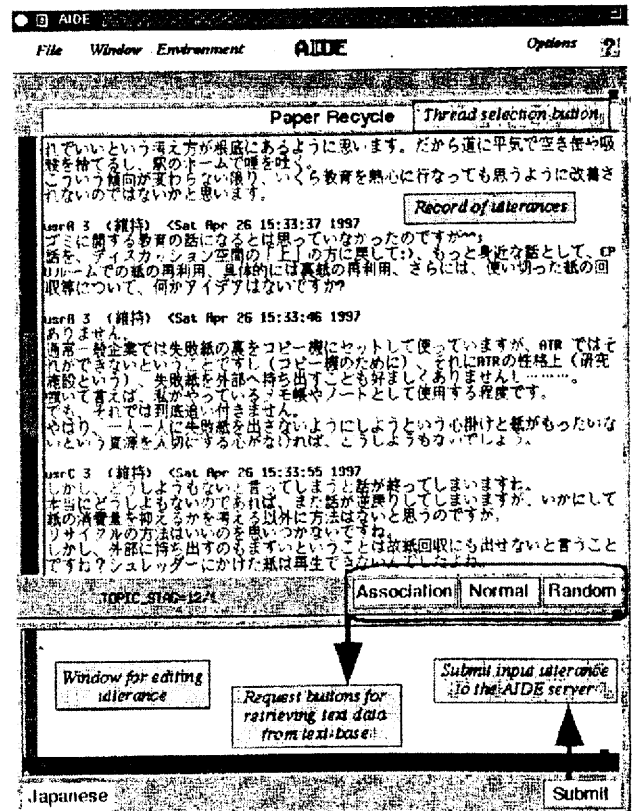


Fig. 3. User interface of AIDE on a client system.

group.” Moreover, the relationships among the contents of the utterances represent a kind of conversation situation at a specific time point in the conversation.

Figure 4 is an example of a conversation space. This figure represents the conversation situation shown in Fig. 3 as a two-dimensional (2D) spatial structure. For example, when a new member joins an existing conversation thread halfway, he or she is immediately able to easily grasp what the topic is. Furthermore, by observing the space, by thinking of what the branch from the center of the space to the upper-right means, and by discussing what kinds of topics or concepts can be placed in the empty area where no utterances are arranged, the member can obtain his or her own fixed ideas.

The knowledge and viewpoints presented by this agent are not yet sufficiently refined. Frankly speaking, they are usually still quite premature. Therefore, the knowledge and viewpoints of the group are provided to the agents belonging to the remaining three blocks through the shared memory, as well as to the members of the group. The members

cooperate with the agents to establish well-refined knowledge and viewpoints.

Temporally structuring-conversation agent: This agent detects topic transitions in real time by temporally segmenting a conversation based on the transitions of its contents. Based on the weighted key words provided by the extracting-basic-elements-of-utterance agent and the time data provided by the basic communication block, segment boundaries are determined by the balance of power among several factors. For example, the interval time and frequency of each key word, the sharing relations of key words between consecutive utterances, and cue phrases that indicate a topic transition. In addition, this agent can decide that a conversation is stagnant if a topic transition is not detected over a specific number of utterances [10]. In this way, this agent temporally structures each conversation in a different way than the spatially-structuring-conversation agent. This is another conversation situation. This information is provided to the conversationalist agent, which will be described later.

3.4. Group thinking support block group

This group consists of three blocks, that is, the individual thinking support block, the cooperative thinking support block, and the collaborative thinking support block. Each block corresponds to each of the thinking modes described in section 2.1, and each agent that is included in one of the blocks supports one of the tasks of the thinking mode corresponding to the block. By exchanging intention information (namely, viewpoints and knowledge) through the shared memory, the agents can act asynchronously and cooperatively. Each agent extracts some of the viewpoints and/or the knowledge required by a user from the shared memory, processes them in its own particular way (autonomously or by obeying a user's directions), and then returns refined viewpoints and/or knowledge to the shared memory. The presentation of extracted knowledge from the shared memory to a user is shown as a 2D space structure in Fig. 4, as it is currently configured.

3.4.1. Individual thinking support block

This block consists of agents that support each task of the individual thinking mode. Currently, AIDE is equipped with the two agents described below.

Personal-thinking-structuring-support agent: This agent mainly supports the task of “convergent thinking.” First, the agent extracts the knowledge required by a user from the shared memory. The user refines this knowledge by deleting utterances and/or key words that are out of focus in the user's thoughts, changing the weights of key words, and adding several new pieces of information (e.g.,

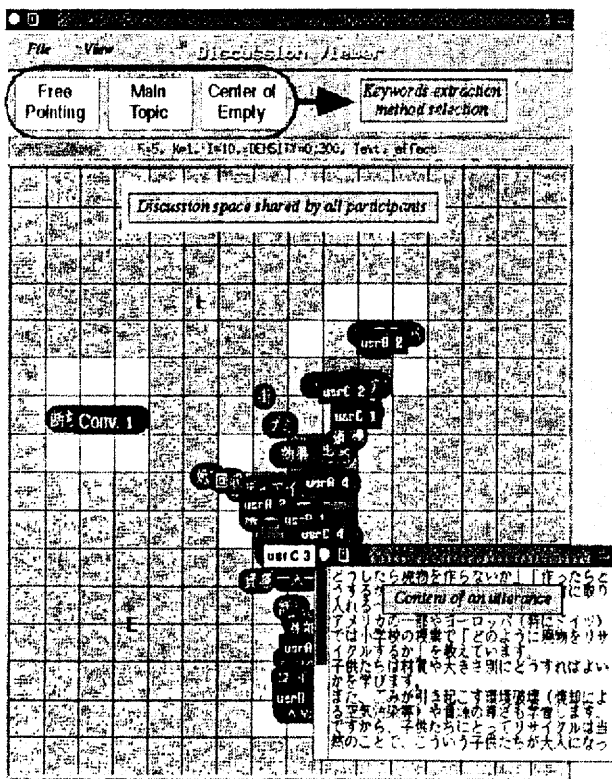


Fig. 4. Example of a conversation space.

the user's private information or pieces of information provided by the information-retrieval agent, described later). Then, following the refinement, the agent structures the refined data in the same way as the spatial structuring-conversation agent and presents the newly obtained spatial structure to the user. After analyzing the result, the user refines the knowledge again, if needed, and then the agent structures the space again. By repeating this, the user works to sharpen his or her own thought structure by cooperating with the agent. We call the final spatial structure a "personal thought space" [19].

A personal thought space represents a user's knowledge, and the framework of the space, (e.g., the bases of the space), implies the user's viewpoints. The user can direct the agent to return the refined knowledge to the shared memory, if he or she thinks that this would be meaningful. Consequently, the user's personal intention can be indicated to the other members and the agents.

In ordinary systems, (e.g., Refs. 7, 13, 17), in order to structure human thoughts based on the KJ method [3], users must manually determine all of the structures of the space alone. Therefore, it is very difficult to obtain the mathematical data of the bases of the space and, hence, it is almost impossible to reuse the structure (i.e., the viewpoints). With AIDE, in contrast, the users and agents can structure the space cooperatively and mathematically. Therefore, it is easy to reuse the bases of the space. This is a great advantage.

Information-retrieval agent: This agent mainly supports the task of "divergent thinking." In order to support divergent thinking, it is necessary to challenge one's fixed ideas. Hence, we employ an approach that allows a user to notice his or her fixed ideas and to expand his or her limited scope by providing pieces of information that have various (unexpected) relevance to the matter at hand from external databases. These pieces are possibly out of the framework of his or her fixed ideas.

The information-retrieval agent extracts knowledge that is required by the user from the shared memory and shows it to the user. The user specifies a certain point in a 2D space, and then the agent collects a constant number of key words in the order of their distance from the specified point. Then, using the key words, the agent retrieves a database and extracts pieces of information including different relations [9, 10]. If the obtained pieces seem meaningful, the users can let the personal-thinking-structuring-support agent restructure the knowledge at hand, including the pieces of information obtained.

3.4.2. Cooperative thinking support block

This block consists of agents that support each task of the cooperative thinking mode. Currently, AIDE is equipped with the following three agents:

Viewpoint-overlying agent: This agent supports the task of "overlying between viewpoints." Viewpoint data dealt with by the agent are represented in an associative dictionary format. The associative dictionary used in this research describes co-occurrent relationships among key words in a specific domain knowledge. Therefore, the associative dictionary represents viewpoint information obtained from the domain knowledge [9].

This agent takes out the associative dictionaries required by a user from the shared memory, merges the dictionaries, and returns the result to the shared memory. The authors have confirmed that novel relationships can be obtained by the merging. Such novel relations cannot be obtained by using the dictionaries individually. This suggests that a new viewpoint is generated by the merging [9]. The newly generated dictionary is utilized by the information-retrieval agent and the conversationalist (described later) to retrieve relevant pieces of information based on the fused viewpoints.

Applying-viewpoint-to-knowledge agent: This agent supports the task of "applying a viewpoint to a piece of knowledge." First, this agent takes out a piece of knowledge required by a user from the shared memory and shows it to him or her. The user selects several interesting utterances in the space. Then, the agent discards key words that are included in none of the selected utterances, as well as utterances that include no key words that are included in the selected utterances. Finally, the agent performs structuring by using only the remaining key words and utterances based on the dual-scaling method. As a result, the obtained space is knowledge that is obtained by applying a viewpoint to a piece of knowledge [2]. The restructured knowledge is returned to the shared memory at the user's direction if he or she thinks that this would be meaningful.

Knowledge-overlying agent: This agent supports the task of "overlying between some pieces of knowledge." First, the agent takes out pieces of knowledge required by a user from the shared memory. Then, the agent structures a 2D space by applying the dual-scaling method to the sum of the sets of the utterances and key words included in all of the pieces of knowledge. The newly obtained knowledge with a new structure can be said to have been obtained by the fusion of the selected knowledge [19]. The new knowledge is returned to the shared memory at the user's direction if he or she thinks that this would be meaningful.

3.4.3. Collaborative thinking support block

This block consists of agents that support each task of the collaborative thinking mode. Currently, AIDE is equipped with the following agents:

Conversationalist: Autonomous-novel-information-retrieval agent: This agent supports the task of "di-

vergent thinking.” Under the necessity of supporting divergent thinking *by a group*, this agent is able to behave autonomously according to the circumstances of the conversation, without any direction from the user.*

This agent’s purpose is to let a conversation develop over wide and interesting topics. In order to achieve this aim, the agent has the belief that it is effective to provide pieces of information that are relevant and are also slightly different from the topic at hand when the conversation appears stagnant.

Hence, this agent is always checking the temporal structure of the conversation relayed by the temporally-structuring-conversation agent. If stagnation is detected, the agent automatically retrieves the conversation space of the group from the shared memory and analyzes it by applying an image-processing method. The agent detects all empty regions where no utterances are arranged and/or all topic centers where utterances crowd. Then, a constant number of key words surrounding one of the empty regions or topic centers (depending on the situation) are selected, and the agent retrieves pieces of information in the same way as the information-retrieval agent.

The pieces of information extracted in this way are input into the basic communication block, like the user’s utterances, and are listed in the record of the utterance window in the user interface of AIDE, while being processed by the agents of the basic information extraction block. Therefore, this agent behaves as if it is equal to the user. Hence, we call this agent the “conversationalist,” a personified agent [10].

Group-thinking-structuring-support agent: This agent will mainly support the task of “convergent thinking”; we have not yet implemented an agent specialized for this task. Therefore, at present, users can only execute this task on AIDE by analyzing the conversation space and also by discussing the axes, clusters of utterances, and empty regions in the space.

The necessary functions of this agent are similar to those of the personal-thinking-structuring-support agent. However, in order to operate an identical space shared by all members of the group, some social protocols, for example, exclusive control of the rearrangement of utterances and key words, should be considered [16]. Munemori et al. have already minutely studied the effects of the distributed environment to their KJ-method-based convergent thinking support tool “Gungen” [8]. It may be effective to apply their information in order to achieve the construction of this agent.

3.5. Interaction among agents and problem solving

As described above, the agents of AIDE mutually exchange information and work cooperatively. In particular, the agents belonging to the group thinking support block group are loosely coupled with each other through the shared memory, and mutually exchange “intention” information. Each agent processes the information, complying with the tasks of which it is in charge. Therefore, the agents asynchronously refine the intention of a person, a subgroup, or the whole group. Hence, there are multiple instances of intentions of various thinking entities at various steps of a job, with a variety of processing.

Locally, the progress of the whole group thinking may fall into stagnation, looping, or regression. Globally, however, through the asynchronous cooperative work, the intention of the whole group gradually continues to be refined from a primitive and non-differentiated state to a final well-refined state on the shared memory. Due to the character of creative thinking, the final state itself will not always indicate concrete solutions. However, the final state should represent the knowledge and the viewpoint of the group, elaborated by their cooperative, as well as their collaborative, efforts. Therefore, this final state will certainly become information that very strongly and effectively suggests a solution to the problem. Accordingly, creative group thinking proceeds in AIDE through the cooperative and collaborative work of the agents and users.

AIDE is not equipped with any mechanisms to control the interactions and cooperation among agents and users in a top-down manner. All of the viewpoints and pieces of knowledge can be referred to by all of the agents and users at any time. Moreover, the refined viewpoints and pieces of knowledge can be returned to the shared memory at any time too. When they are returned, however, the original viewpoints and pieces of knowledge are never overwritten, and are returned as new viewpoints and pieces of knowledge. Accordingly, in AIDE, obstruction by a user of another user never occurs. Therefore, AIDE is not equipped with any agents in charge of exclusive control.

However, a lot of conflicts will occur due to the characteristics of the works of the creative problem solving. It may even be the case that two users refine an identical piece of knowledge into completely different (in some cases, conflicting) forms. In practice, it is impossible to control and to resolve such semantic conflicts automatically. To begin with, the thinking process to resolve such conflicts in a dialectical way, or by finding new relations among pieces of information that are seemingly unrelated, is the creative thinking itself. Hence, the occurrence of such conflicts is natural. In AIDE, we can say that each agent actively lets conflicts become evident and concrete to facilitate the resolution of the conflicts, say, creative thinking.

* However, a user can invoke this agent with an explicit direction.

4. Discussion: Group Thinking Support and Multiagent Architecture

There has been a lot of research on group thinking support systems and some good individual results have been obtained. These systems have been developed based on various kinds of architectures, and hence it is hard to determine which architecture is the best to use in constructing a group thinking system. However, as described in section 3, based on our research and development, we believe that a multiagent architecture has several desirable features for a group thinking support system. In this section, we discuss this point and show the advantages and features of applying a multiagent architecture to a group thinking support system.

Several trials that model group thinking as a multiagent system have already begun. For example, Yanagisawa et al. modeled the framework of groupware as a multiagent system consisting of agents and humans, and proposed a mechanism to have agents form agreements [20]. However, this study focused only on the process of forming agreements, and hence did not deal with the total group thinking process.

Generally, it is said that agent technology is suitable for applications that have the following features [4]:

1. When the target or environment with which the system deals changes dynamically.
2. When resources are distributed and a mechanism to share them is required.
3. When a faculty that can substitute for users is required.

We can say that our target application, that is, group thinking (support) work, is endowed with the features above, because:

1. The environment with which group thinking deals, that is, "thinking" itself, is always changing and progressing (the first feature).
2. Knowledge, viewpoints, and ideas are the resources for group thinking and they are distributed to the members of a group (the second feature).
3. Because of the following reasons, a faculty that substitutes for the users is required in group thinking (the third feature):
 - (a) It is essential to break people's fixed ideas in creative thinking. Therefore, talking with a partner who thinks differently is desirable.
 - (b) By having agents substitute for specific users, any group thinking job is freed from the limitations of location and time.

Consequently, agent technology is suitable for group thinking (support) systems.

In AIDE, these three features are covered by applying agent technology as follows:

1. The agents of the basic information extraction block autonomously structure continuously progressing discussions in a spatial, as well as a temporal, manner without bothering the users.* This enables them to deal with dynamically changing situations of "thinking."
2. Each member's knowledge, viewpoints, and ideas are effectively shared by all of the members and agents through the shared memory.
3. The agents of the group thinking support block group in AIDE can be regarded as "partners who think in different ways" because they structure knowledge in an objective way based on statistical analysis.
4. In cases where the agents of the group thinking support block group work by applying the knowledge and/or viewpoints of a specific person or group, the agents can literally be seen as a collective "agent" of the person or the group.

Next, we discuss applying the *multi-agent* architecture to group thinking (support).

A multi-agent system is what achieves new and higher functions through interactions, for example, cooperation and negotiations, among the multiple agents. Group thinking as a whole is a complicated and complex field. Therefore, it is quite difficult to construct a system capable of directly supporting such work. However, as described in section 2, a group thinking process can be divided into relatively simple (multiple) tasks, and by cooperative execution of the tasks, the total complicated thinking process can be achieved. Therefore, we can say that a multiagent architecture is very suitable for achieving a system to deal with group thinking.

We have constructed AIDE by equipping it with agents, each of which supports a specific task in the group thinking process. In AIDE, the agents and the users, as heterogeneous resources of knowledge, cooperatively and asynchronously refine the intentions on the shared memory step-by-step from parts that can be processed, share the interim results, and refine them still more. As a result, a potential clue for problem solving by the group can be established. It can be seen that this is a realization of opportunistic problem solving. In this sense, the shared memory of AIDE can be regarded as a "single-layer black-board" [1].

*This also frees the users from informing detailed circumstances of a job to the agents of the group thinking support block group. This leads to a reduction in the users' workload.

The advantages to AIDE of the multiagent architecture are as follows: First, the extensibility of AIDE is very pronounced. It took less than one year from the beginning of the development of AIDE, as described in section 3, for AIDE to be equipped with nine agents. Furthermore, four more agents are scheduled to be implemented. This is a very important characteristic for a group thinking support system because there can be various methods to support a certain task, and each of such methods has its own peculiar characteristics. It is desirable that an appropriate method always be available, depending on the needs and progress of a job. Therefore, good extensibility has become a significant design prerequisite because of the assumption of the frequent addition or expansion of necessary functions.

Second, because the system was constructed as a set of loosely coupled agents, users are led to freely use the transitions among the tasks and/or thinking modes according to their needs. This also improves the extensibility of AIDE. Furthermore, with the autonomous abilities of the agents to grasp the circumstances of the group thinking process in progress, and the unified format of data exchanged among the agents, the psychological and physical barriers for transitions between tasks and/or thinking modes have become low. Hence, users are now able to seamlessly move from any task/mode to another.

On the other hand, the second advantage causes a problem: The system becomes seemingly a mere set of independent tools; besides, it is not equipped with any control mechanisms for the work flow due to the characteristic of creative thinking. Therefore, it is perhaps quite difficult for novices to understand how the whole system works and to efficiently use AIDE. To tackle this problem, equipping a mechanism with each agent of the group thinking support block group to autonomously decide the timing to intervene, to negotiate with other agents, and to offer support to users, like the conversationalist, might be a good solution. However, it must be considered that excessive offers by the agents may obstruct the users' thinking and actions.

5. Conclusions

Aiming at achieving a groupware system that supports creative activities by a group, we first proposed a group thinking model, focusing on the transitions of the mentality of a thinking entity, and divided the whole group thinking process into several basic tasks. Then, based on the model and tasks, we described AIDE, which is a group thinking support environment and that is currently being implemented. We applied a multiagent architecture to construct AIDE. That is to say that, AIDE is equipped with several agents, each of which supports a specific task of group thinking. Each agent mainly exchanges the intention

of a member or group through a shared memory and refines the intention by cooperating with the other members of the group. From our experience in developing and testing the uses of AIDE, it has been ascertained that a multiagent architecture is very suitable for achieving a group thinking support system. By applying a multiagent architecture, AIDE has many advantages, for example, good extensibility and seamless operability.

In this paper, the target application was group thinking support. However, there are many more applications for which a multiagent architecture is suitable. From our experience in developing and testing the uses of AIDE described above, we believe that one of the most important points in applying a multiagent architecture to a new application is to determine the contents and the format of the information exchanged between agents. In AIDE, we think that the information that must be exchanged between agents in order to support group thinking involves viewpoints and knowledge, and therefore, we have represented them in formalized and reusable formats, such as the conversation space and associative dictionaries. Due to this decision, we think that AIDE has many excellent features that are derived from the multiagent architecture.

In the near future, we would like to improve the total performance for group thinking support by adding a variety of functions and agents. Furthermore, we hope to create agents that not only aid in simple support, but also participate more actively in generating consensus or ideas.

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