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Computer-Aided Communications by Visualizing Thought Space Structure

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SUMMARY

There has been an increase in collaborative work among specialists from multiple disciplines in recent years. Accordingly, building methods and tools to facilitate communications in those collaborative projects has become an essential issue. This paper describes a method that helps people working cooperatively to form new concepts in areas such as science and engineering. The proposed method supports personal or group concept formation by visualizing the relationships between concepts and their microcontents, given by users, in a metric space. Showing individual spaces presented by communication support system (a tool implemented using this method) to individual users and merging them are useful in clarifying personal backgrounds and viewpoints.

Key words: Creativity; concept formation; CSCW; human communication; visualization; though space.

1. Introduction

In recent years, there has been an increase in the number of large-scale problems that cannot be solved using the expert knowledge from only one discipline. This has necessitated cooperation among specialists from multiple disciplines. In this paper, we present the notion of computer-aided communications through verbal media.

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There are two major purposes in communicating during daily collaboration:

1. accurately conveying perceptions, feelings, and thoughts to others; and

2. clearly recognizing one's own ideas and identifying new ideas through communications with others.

The purpose of our research is to develop tools facilitating the second aspect of human communications through computing power.

The authors have proposed a model of concept formation for humans, and have developed tools supporting creative concept formation [4, 5, 12, 13]. Our view of concept formation upholds Koestler's idea [7]. He proposed that scientists arrive at a new idea by the collision of two different planes of association, which we can describe using different words, i.e., *context*. We will use the term "context" to refer to a situation in which we reflect individual ideas or deal with knowledge situated in some special field. The essential role of communications with others in creative activities such as scientific research and the development of new products is acquisition of a new context from outside the individual's mental word.

It is generally difficult to convey individual *mental content* (e.g., ideas, tacit knowledge, subjective preference) to others. This difficulty may be due to the following two problems:

difficulty caused by receivers: Receivers may be unfamiliar with terms used by providers. Even when the receivers are familiar with the terms, the correspondence of the receivers' terms with concepts in their minds may differ from those of the providers'.

difficulty caused by providers: The mental constructs used by the providers may be so nebulous that they cannot either understand the whole structure or verbalize it.

It would be untrue to say that communications cannot occur until these difficulties are overcome. On the contrary, we often communicate in order to conquer these difficulties in actual social activities. To lessen these difficulties, we are developing a computer tool to support the following work:

- to recognize one's own thought space;
- to understand others' thoughts through communications; and
- to obtain new ideas through collaboration.

We define a *thought space* as an externalized mental space consisting of fragments of ideas or the knowledge and relationships among them during the activity of thinking.

We propose a method of visualizing thought spaces and show an implemented tool based on the method, CSS (Communication Support System), in section 2. In sections 3 to 6, we describe ways to utilize thought spaces visualized by CSS for creative concept formation and human communications, e.g., individual reflection, clarifying the difference in the subjective viewpoints of members during collaborative work, eliminating unconscious communication gaps by merging the thought spaces of multiple users and structuring a common space for a group discussion. Section 7 has the conclusions.

2. Communication Support System

2.1. Visualization of thought space for creative concept formation

The authors have proposed several computer tools to aid in creative concept formation by visualizing snapshots of the topological structure of a user's thought space using statistical methods [4, 13]. These tools have been successfully applied to idea generation, knowledge acquisition, software requirement acquisition, information retrieval, etc. They have also been distributed outside the author's group. For example, one of these, CAT1 [13], has had over ten copies distributed, which have been used in various domains, e.g., research, development, management, design.

CAT1 visualizes a user's thought space structure by automatically mapping electronic memos, called *text-objects*, into a two-dimensional metric space according to the number of common *keywords* declared in the text-objects. CAT1 works successfully on visualizing the global structure of the users' thought space. These visualizations enable users to reconsider their own ideas from *another person's perspective*, encouraging them to think further, such as finding the axes in a presented space explaining the semantic structure, or finding new ideas in empty regions in the presented space. CAT1 can also store results for other users in databases, which users can use for new thinking activities. These precedent thought spaces can be used as tentative spaces at the beginning of new thinking activities. Alternately, these can be stimuli for new concepts or views from outside the current users' thinking, which has the potential *to rescue them from a morass of conventional thinking*.

2.2. Implementation of CSS

Supporting communications among groups of people with various backgrounds requires a method that allows for recognition and analysis of the mental contents of a user's colleagues as well as of himself/herself. CAT1 is capable of showing the global structure of a user's thought space. However, it is not sufficient for analyzing concepts or ideas appearing nebulously in a user's mind because the text-objects are too coarse as externalized media. To solve this problem, we propose another method that visualizes the relationships among concepts and their microconcepts in the user's mental world by mapping not only text-objects but also their keywords into the same metric space. We developed the other tool, CSS, using a statistical method called the dual scaling method [10], which automatically reconstructs a space.

CSS inherits a feature from CAT1 that deals with text-objects and their keywords as the externalized information of the user's thinking. While CAT1 visualizes relationships among only text-objects according to the number of common keywords based on the idea that keywords are mere components of text-objects, CSS visualizes relationships among keywords as well as text-objects in the same space by exploiting the duality of reactions between text-objects and keywords. This enables a user not only to recognize a global structure of his/her thought space, but also to analyze the hierarchical structures of their ideas in the local parts of the space.

The dual-scaling method is used to find eigenvectors of multivariate data from sets of data objects with multiple quantified attributes. The eigenvectors are measures to quantify the relationship between data objects and their attributes. This method is derived from a conventional statistical method, called principal component analysis, possessing a peculiar feature that allows the vector of data objects and attributes on the same measure to be evaluated together. We applied this method to quantify the relationships between text-objects and their keywords in one metric space by taking the keywords declared by users to be attributes, and their defined weight values to be attribute values.

Figure 1 shows an example in which CSS is used to arrange the research memos written by one of the authors. CSS is implemented under the X Window System on a UNIX workstation, and offers a user interface with multiple windows. CSS manages a data table that contains the text-objects, keywords, and weight values given by users to text-object and keyword pairs. The users reflect their thoughts when changing the data set. Whenever the users instruct CSS to reconfigure the space, it calculates and then shows the new configuration according to the current data. The rectangular and oval icons in the main window represent text-objects and keywords, respectively. A user can enter new text-objects and keywords by putting icons into the space at any time. The declaring and changing of keywords and their weight values can be invoked with commands on the icons. Users can freely designate keywords and their weight values in their own way and, hence, results depend on differences among individual users. CSS currently accepts users' input as they give it, and does not have any control.

Spaces provided by CSS give the user opportunities for further thinking. Users can gradually bring up their thought spaces, externalized using CSS, along with their mental world by inputting and modifying text-objects, keywords and their weight values. The repetition of these might be a burden to some users. However, making this work completely automatic would be counterproductive since this process is essential in making users think. CSS is a tool that enables users to concentrate their attention on the essential aspects of thinking by offering them an environment for manipulating information externalized from their thoughts.

3. Visualization of Relationships among Concepts and Microconcepts

In this section, we describe using CSS for individual thought before discussing effects when CSS is used by multiple users.

3.1. Dynamics of concept formation

We assume that concept formation is the repetition of clustering and segregating microconcepts. Moreover, we believe that the combination of microconcepts changes dynamically through interaction between the mental and external world [5]. To date, this idea has been accepted by cognitive scientists and philosophers [3, 11]. Assuming that text-objects correspond to the tentative concepts appearing in the user's mind and that keywords are microconcepts used to construct the text-objects, we can say that CSS is a tool that visualizes the relationships among the concepts and microconcepts during the dynamics when the user is formulating concepts.

The hierarchical relationships between concepts and microconcepts do not always correspond to that between text-objects and keywords. That is, that correspondence changes dynamically while thinking. Consequently, it is very difficult for users to build up their thought spaces while consciously being concerned with the hierarchical relationships between concepts and microconcepts from the early stages of thinking. A CSS user can begin his/her

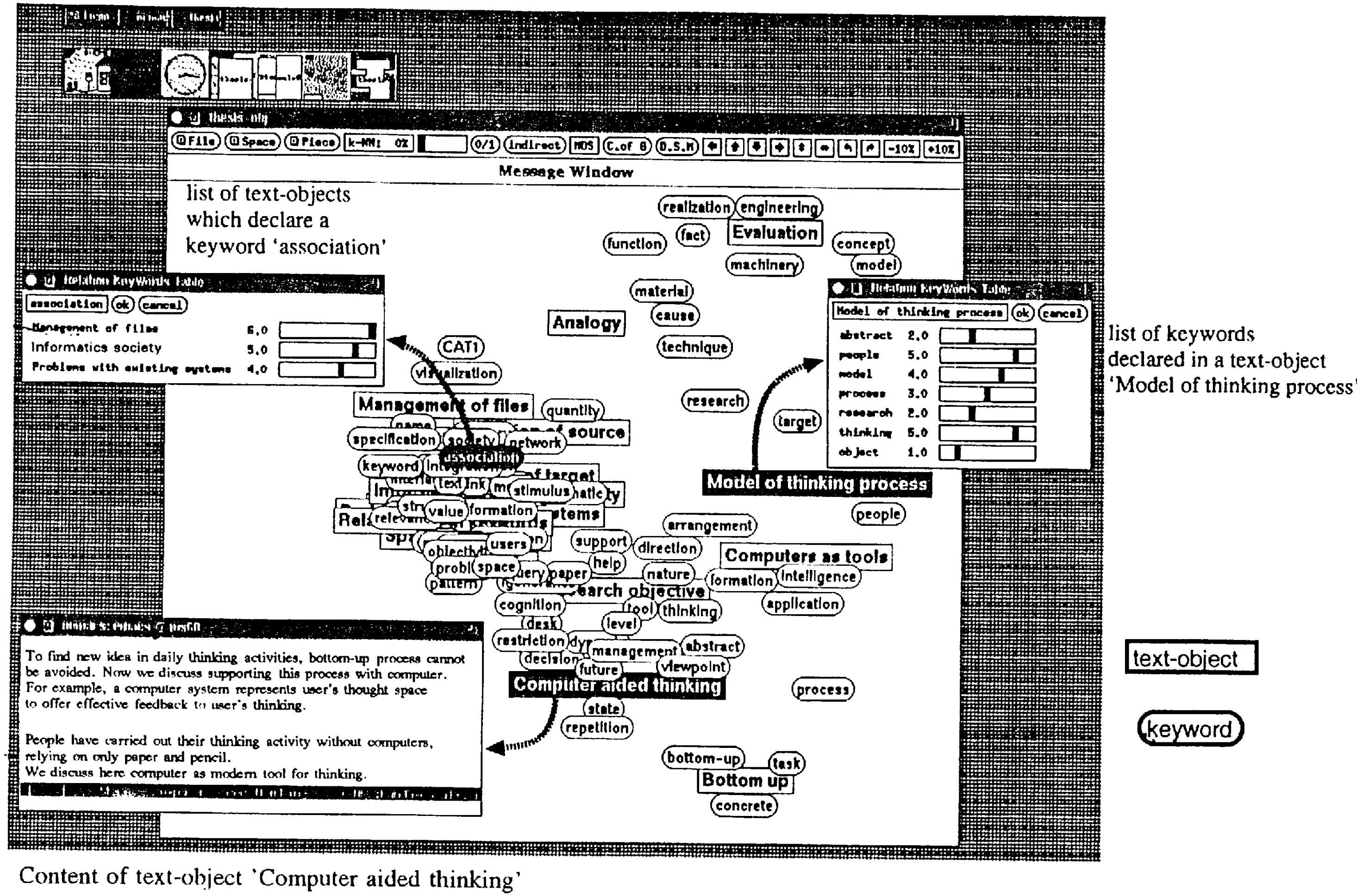

Fig. 1. Usage of CSS.

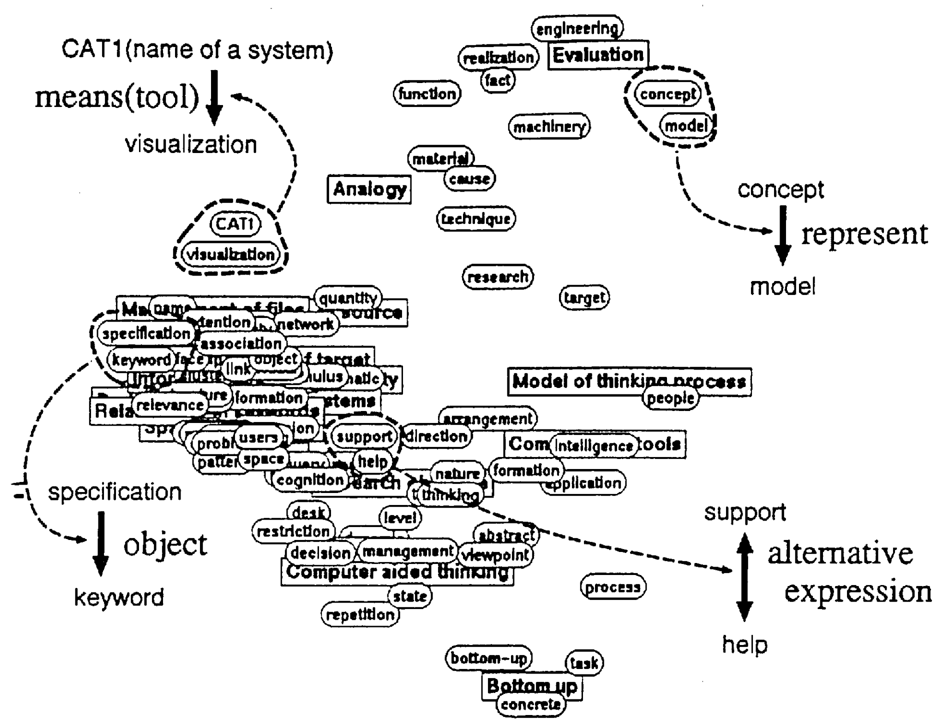

Fig. 2. An example of CSS use in individual reflection. Annotations were provided by the user to permit relationships of some pairs of microconcepts on the space presented by CSS to be interpreted.

thinking from the ideas entering his/her mind as text-objects. These text-objects might not correspond to modules of ideas in the user's mind, i.e., different text-objects often share the same concept, or only one text-object holds several concepts. CSS helps users restructure multiple concepts lying scattered in text-objects by clustering and segregating their microconcepts, i.e., keywords, and it visualizes the topological structure of these. Spaces reconfigured by CSS provide new clusters of keywords which are independent of text-objects as clusters of keywords. These new clusters of keywords in the space provided by CSS can be candidates for new concepts coming into the user's mind. Moreover, the spaces also give the user topological relationships among concepts, and thereby the user can grasp not only the hierarchical relationships between concepts and their microconcepts but also the nonhierarchical relationships between the concepts.

3.2. Analysis of relationship between microconcepts in a space presented by CSS

Spaces provided by CSS generally have several clusters of concepts. Figure 2 is an example of a thought space that gives several notes by the user from the example of CSS usage shown in Fig. 1. We describe the effect of spaces provided by CSS by detecting the relationships between microconcepts pairs in the spaces and analyzing these.*

- Cooccurrence of the pair of two keywords, "support" and "help," shows that these words occur in the same context. Moreover, these keywords can be interpreted to have a synonymous relationship. Such information tells us much about the user's preference in using words.
- We can detect the relationship between *action* and its *object* in the pair of "specification" and "keyword."
- "CAT1" can be interpreted as the means of "visualization" when "CAT1" and "visualization" cooccur.

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*We discuss the relationships of only pairs of keywords here. However, we do not mean to restrict the manner of thinking, i.e., analyzed relationships must be pairs, or analyzed pairs must consist of keywords. A combination of more than two text-objects and keywords might be an effective stimulus for new ideas.

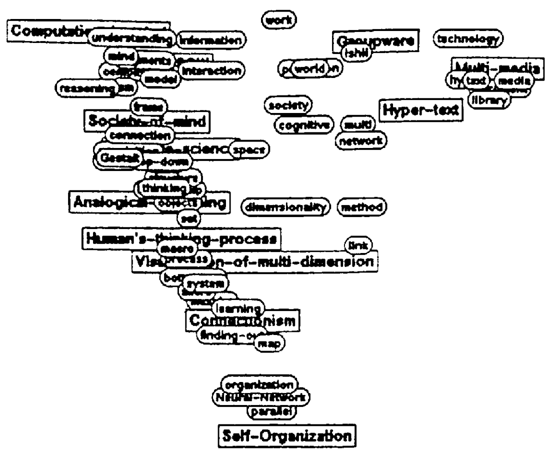
- The pair of "concept" and "model" seems to be nonhomogeneous microconcepts to others except the user who was building the space. However, the user instantly found the relation that the "model" was to *represent* "concepts." This interpretation strongly depends on the context when the user built the thought space. In another context, "concept" and "model" possibly have other relationships with other microconcepts. Consequently, we can say that CSS is useful in visualizing the user's viewpoints and context, and storing their snapshots.

As a result, we can consider that spaces by CSS provide users with opportunities for detecting many relationships between microconcepts without any classification. These detected relationships should be interpolated into a description with primitives for knowledge representation, e.g., relationships of *generic-specific*, *whole-part*, *subject-object*, *function-data*, and *equality*. Users of CSS do not need to be concerned with the kinds of relationships among concepts and microconcepts in the early stages and, hence, they can start by analyzing each local relationship between microconcepts by browsing their own thought spaces provided by CSS.

Several systems that support the assembly and organization of knowledge by arranging and structuring concepts and their components have been proposed. Many of these request their users to give meanings predefined by the developers of the tools' to the relationships between the components (e.g., [2, 8]). However, forcing users to specify combinations and the meanings of microconcepts from the beginning restricts users significantly, since the relationships among concepts and micro-concepts gradually become fixed during the repetition of changing these in concept formation. On the other hand, CSS users can begin thinking even without recognizing the existence of any relationships between microconcepts, which are indicated by CSS. They can then consider their significance. Support in describing the existence and meaning of relationships among microconcepts is a consequent issue.

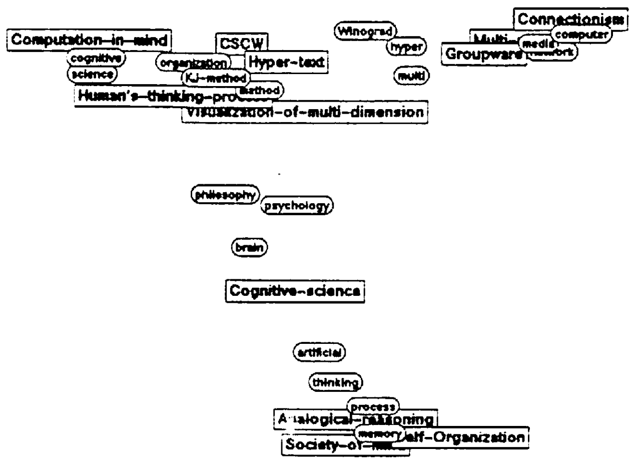
4. Revealing Differences between Subjective Views of Multiple Users

From the viewpoint of concept formation, one main process of human creative activities is *divergent thinking*, in which many alternatives are sought. Another process is *convergent thinking*, in which a unique solution is sought [6]. Divergent thinking is especially indispensable in the early stages of creative activities, while these two processes must be repeated in concept formation. That is



(1) User A's thought space

(2) User B's thought space



(3) User C's thought space

Fig. 3. An example of clarifying differences in thought space structures built by different users.

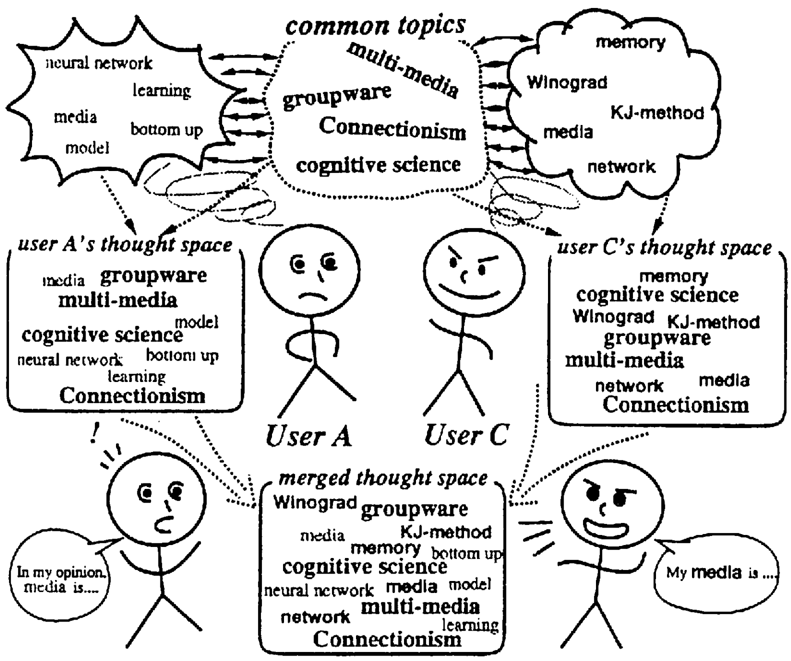


Fig. 4. Merging multiple users' thought spaces.

the reason people involved in closed personal thought will communicate with others to search for alternatives to their ideas. This is an important aspect of collaborative work for human creativity.

We require personal background knowledge and subjective views to be conveyed to others during the early stages of collaborative work since this information depends on each participant even if common topics are being discussed [12, 13]. We experimented using CSS to support this. The subjects using CSS were three researchers who had common interests. The three users are given several topics* relevant to their common interests, and they independently built their thought spaces containing these topics as text-objects with CSS. Content and keywords of the text-objects were freely given by each user. In order to simplify the user's work, we let them designate 1 as the weight values for all keywords.

Figure 3 shows that CSS can visualize the relationships among the concepts and their microconcepts making up each user's thought space and can reveal the difference in the structure of individual thought spaces. These spaces facilitate the conveying individual user's mental content to others and the creation of common understandings. This can eliminate the unconscious communication gap occurring among members working in collaboration, and can lead to the *cooperative creation of new ideas*, i.e., the invention of new ideas through communication in collaboration, which had not been noticed by individual participants beforehand.

*The given titles of the text-objects correspond to 12 topics, i.e., "CSCW," "Connectionism," "Hypertext," "Multimedia," "Society of mind," "Analogical reasoning," "Groupware," "Visualizing multidimensional spaces," "Cognitive science," "Computation in mind," "Human thinking process," and "Self-organization."

5. Merging Multiple Users' Thought Spaces

In the previous section, we showed that building the thought space of each participant in collaboration using CSS and showing the space to others was effective in allowing the difference in the participants' viewpoint and mental content to be recognized. In this section, we propose another powerful method that not only clarifies the difference in the participants' mental content and its structure, but also visualizes the topological relevance in the thought spaces by merging the multiple users' thought spaces built using CSS.

We had a trial in which the two thought spaces of user A and user C are merged as shown in Fig. 3. We employed a method to restructure the merged space through the mediation of text-objects contained in both the

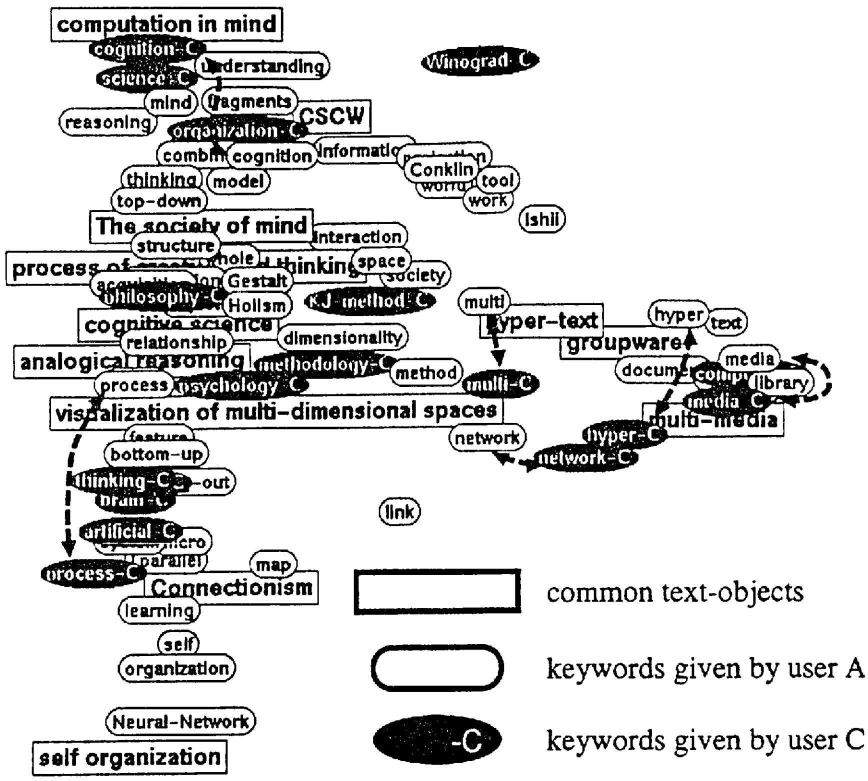


Fig. 5. An example of merging thought spaces built by two users.

users' thought spaces.* This method simply mixed keywords, which have been declared in both users' thought spaces, respectively, into a merged space while retaining information about the designation of the keywords (see Fig. 4). A result of this experiment is shown in Fig. 5, where the white oval icons indicate keywords declared by user A and the oval icons with suffix "-C" indicate the keywords declared by user C.

As can be seen by comparing the merged space shown in Fig. 5 and the separated spaces shown in (1) and (3) of Fig. 3, the merged space is not a simple pile of spaces of the two users, but a *novel emergent* one. This merged space visualizes the relationships between micro-concepts, i.e., the keywords, given by user A and user C.

The pairs of keywords annotated with arrows indicate keywords having the same expression accidentally given by the two users. As shown in the result, pairs of technical terms, e.g., "hyper," "media," "multi," "network," are closely mapped. This result indicates that the two users used these terms in a very relevant context. On the other hand, pairs of abstract and general terms, e.g., "cognition," "process," are mapped at a distance, and other relevant keywords cluster around the pair. This visible information reveals the divergence in the two users' views concerning "cognition." Other keywords gathering around the keywords, e.g., "model," "organization," "reasoning," were used as footholds in their further conversation to cover the divergence in their views. Moreover, the cluster of keywords around "method" located at the center of the space gave them an opportunity to exchange personal knowledge and ideas about certain technical matters.

As previously described, the use of CSS, and occasionally the merging of multiple users' spaces, facilitates the recognition and analysis of relationships between the mental structures of participants in collaboration. Supporting communications in this way can be applied to various collaborative projects such as discussions by groups of researchers, conversations between users and developers in artifact design, and the education of students undertaken experts, etc.

*The two users' thought spaces commonly have only titles of text-objects and, hence, the users' mental content corresponding to these text-objects and the relationship between the mental content vary. It is the purpose of this experiment to visualize this situation.

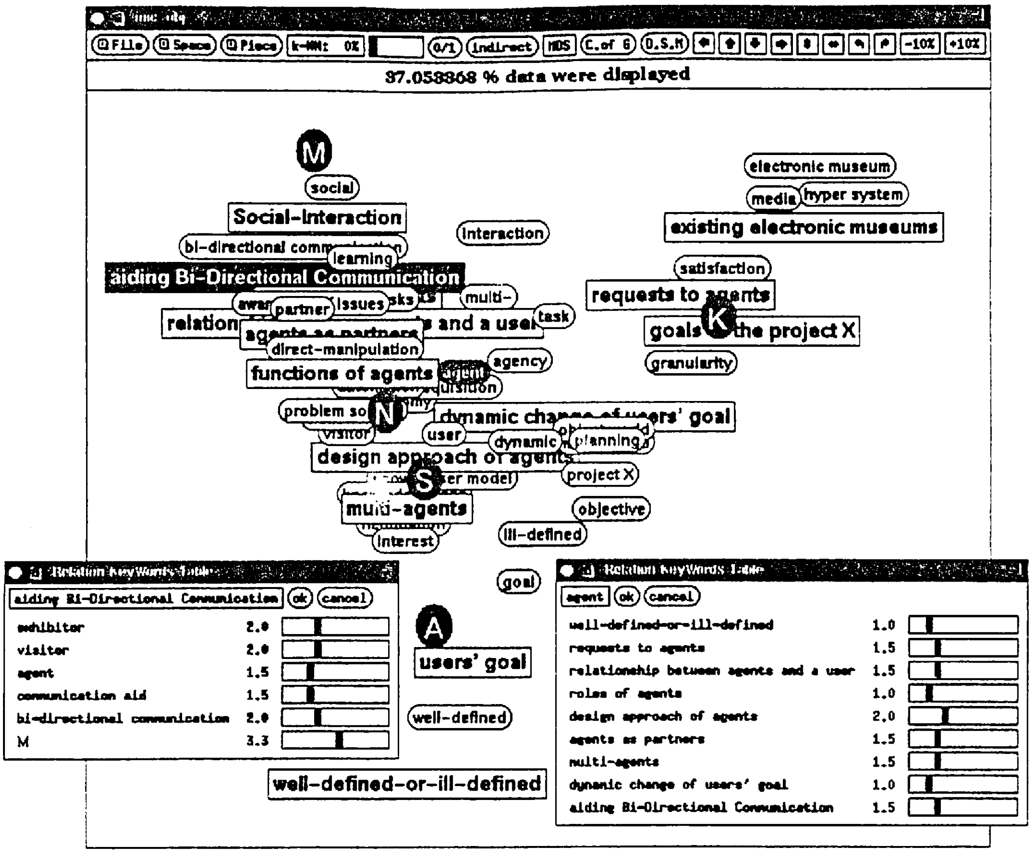


Fig. 6. An example of using CSS in a group discussion.

6. Supporting Group Meetings

In this section, we will apply CSS to free discussion among groups of people. Although CSS can also be used in actual discussions, this time, we will describe CSS use by a participant at group meetings by looking back at the meeting and discovering new ideas in discussion content.

The two approaches below should be considered in structuring the information acquired from the meeting such as statements by participants and the topics at the meeting.

1. Recording and arranging facts and their superficial relationships, i.e., *who* uttered *what*, causality between statements, temporal relationships among statements.

2. Supporting recognition and analysis of semantic relationships between topics at the meeting without being bound by information about speakers and temporal flow.

Most former computer-supported cooperative work (CSCW) systems organizing statements by participants at meetings focused on the first approach above. For example, [14] and [1] employed a method that required users to explicitly specify the placement or causality of each statement (e.g., argument, counter, acceptance, support, response) whenever users made a statement. On the other hand, the second approach requires topics of a discussion to be organized at the semantic level. In other words, we could say that the second approach is aimed at external media as a projection of the users' thoughts that can be manipulated by them at any time, while the first approach is aimed at external storage of information inputted by users. CSS targets the second approach.

We conducted an experiment on CSS use to visualize the relationships among topics and participants at a meeting. There were five participants at the meeting, and the number of topics extracted by a user, who himself was one of the participants, was 13. The meeting was to discuss "project X," whose objective and approach had not yet been decided, in a brainstorming style. At the meeting, many topics on each participant's interests and technical issues were discovered.

Figure 6 shows the space that one of the participants at the meeting built using CSS. The rectangular icons in the space indicate text-objects corresponding to the topics extracted by the user, and the oval icons indicate their keywords. The elliptical icons indicate the names of the participants. In this experiment, we also defined the name of each participant as a kind of keyword, and the user declared each participant's name as the keyword for text-objects corresponding to topics keenly participated in by him/her. This method visualized the relationships among not only topics and their keywords but also the participants.

The result space was shown to the other four participants. They had a tendency first to pay attention to the clusters of icons in the space, then to turn their attention to the empty regions in the space. Although the comments on these empty regions varied according to individuals, they generally found the potential for new directions for "project X" in the empty regions, or became aware of the necessity for further discussions. Moreover, they found the space useful for recognizing the transition and semantic relationships between topics, and they could thereby recognize the central topic of the discussion and seize the opportunity for further effective discussion.

We acquired other comments such as:

- "Clusters located toward the peripheries of the space seem to have contrary directions to our research interests";
- "I detect axes in the space that outline the whole structure of the discussion";
- "I noticed that we spent too much time in discussing topics different from the original subject";
- "The space indicates each member's position in the group."

7. Conclusions

A tool for aiding creative concept formation, called CSS, was introduced. CSS visualizes the users' mental worlds by mapping text-objects and their keywords, which externalize the users' ideas, into a metric space. We showed three typical examples of using CSS: 1) individual reflection, 2) merging two users' thought spaces to fill a communication gap which depends on the personalized connection between verbalized keywords and concepts in individual mental worlds, and 3) visualizing the semantic structure of a group meeting.

A flood of electronic documents exists today based on the many intellectual activities being done with computers. Furthermore, with the spread of electronic mail, bulletin board systems (BBS) and the World Wide Web, a novel form of communications is emerging in today's computer network society. Consequently, electronic information is strongly expected to be able to be effectively utilized to stimulate further creative activities, by adaption to problems being faced and user interests. CSS is one solution to this issue. Currently, however, CSS requires users to provide whole text-objects and keywords to represent their thinking. This is a heavy burden. We are examining the integration of our approach with other methods to extract topics or keywords representative of users' thoughts automatically from huge databases or computers on networks (e.g., see [9]).

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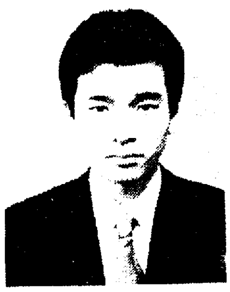

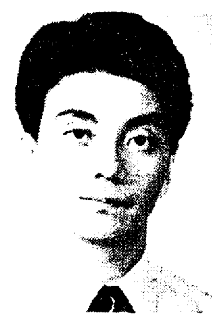

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