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## CONSENSUS-MAKING SUPPORT SYSTEMS DEDICATED TO CREATIVE PROBLEM SOLVING

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There are many creative thinking manual methods in the world. They are brain-storming method, brain-writing method, mind mapping, NM method, Equivalent Transformation method, KJ method, etc. Human thinking process for creative problem solving consists of 4 sub-processes. They are divergent thinking sub-process, convergent thinking sub-process, idea crystallization sub-process, and idea verification sub-process. In accordance with this proposal, most Japanese research and development is centered on this four types of creative thinking manual methods and support systems.

In this paper, we describe three types of Group Decision Support Systems (DSSs) for creative problem solving, similar to KJ method. All design philosophy depends on bottom-up decision-making. They are knowledge acquisition support groupware GRAPE, consensus-making support systems Group Coordinator (I) and Group Coordinator (II).

The characteristic function of GRAPE is knowledge merging for GRAPE users, and that of Group-Coordinator (I) and Group-Coordinator (II) is tradeoff resolution by sensitivity analysis and adjusting of user requirements by the QDA method, respectively. The systems that we have developed are similar to the KJ method, which is the most popular methodology for creative problem solving in Japan. The essence of our developed methodology and tools is that it boosts intellectual productivity. GRAPE and its successors can speed-up the given group decision making problem by two to three times with respect to the idea crystallization (evaluation and judgment) sub-process.

*Keywords:* Creativity support system; decision making support system; bottom-up decision making; KJ method; AHP.

### 1. Introduction

In Japan, several manual creative-thinking methods such as, the KJ method<sup>1</sup>, NM method,<sup>2</sup> and equivalent transformation method<sup>3</sup> are employed. For example, Kawakita<sup>1</sup> says that every human creative problem solving process consists of nine sub-processes: (1) presenting the problem, (2) understanding the existing state of matters that are related to the problem, (3) hypothesis formation, evaluation, and decision-making, (4) forming a grand plan, (5) forming a detailed plan, (6) devising a procedure to solve the problem using PERT

(Program Evaluation and Review Technique) a methodology developed by the USN (U.S. Navy), (7) action, (8) verification, and (9) conclusion. However, there exist several other manual creative thinking methods: brainstorming method, brain-writing method, concept mapping, and mind mapping, etc. Based on this, we propose that the human thinking process for creative problem solving consists of four subprocesses-divergent thinking subprocess, convergent thinking subprocess, idea crystallization subprocess, and idea verification subprocess. In accordance with this proposal, most Japanese research and development is centered on these four types of creative thinking process.

Based on our proposed model, considerable research and development on creativity support systems has been carried out in Japan, especially in the Japan Advanced Institute of Science and Technology (JAIST). With regard to the divergent-thinking support systems, we developed the brainstorming support system, “Ba”;<sup>4</sup> brainwriting support system, “Hasso-tobi”;<sup>5</sup> keyword associator; know-who search engine, etc. For convergent-thinking support systems, we developed the e-KJ Method tool, Diagram Abductor, DMERGIN<sup>6</sup>, Comic Diary<sup>7</sup>, etc. It is difficult to implement the idea crystallization support systems; they are realized by awareness and/or tangibility support. With regard to the idea-verification support systems, we developed several decision-support groupware or consensus-making systems such as GRAPE<sup>8</sup>, Group Coordinator (I)<sup>9</sup>, Group Coordinator (II)<sup>10</sup>.

In this paper, we discuss knowledge acquisition support groupware, GRAPE and consensus-making systems Group Coordinator (I) and Group Coordinator (II) for creative problem solving.

## 2. The KJ method and creative problem solving systems

The small number of Nobel prizes received by the Japanese is considered to reflect the lack of creative talent. Therefore, the Japanese have developed several manual methods to support their intellectual activities for research and development management, requirement analysis, total quality control, and creative problem solving. They are based on the KJ method formulated by Kawakita Jiro, NM method by Nakayama Masakazu, equivalent transformation theory by Ichikawa Kikuya, and DTCN method by Esaki Michihiko<sup>11</sup>, etc.

Since one of the authors is familiar with the KJ method and the method is effective for creative thinking, we would like to first explain the KJ method’s problem solving methodology. Kawakita<sup>1</sup> explained that any human problem solving process consists of the following steps ( Fig. 1 ).

“In a scientific inquiry, one encounters a problem at point A on the thought level. As the first step in solving this problem, he proceeds to explore the situation surrounding the problem between A and B, and next to collect all relevant and accurate data through field observation between B and C. By this data, he next formulates or develops a number of hypotheses between C and D. Having returned to the thought level, at point D, he next evaluates his hypotheses and decides which to adopt. Between D and E, he infers and revises the adopted hypothesis through deductive reasoning. Next, he plans an experiment for testing the adopted hypothesis between E and F, and observes the experiment between F and G. Given the results of the experiments, he can verify his hypothesis between points

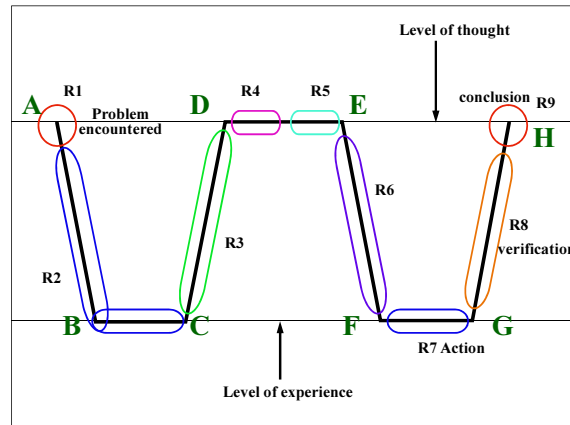


Fig. 1. Outline of basic steps in problem solving.

G and H, and can finally acquire a correct conclusion at point H.”<sup>1</sup>

Note that a similar idea had been proposed by C.S. Peirce. The steps from A to D, D to E, and E to H correspond to the abduction, deduction, and induction process, respectively. In other words, the human creative thinking consists of (1) a divergent thinking process from A to C, (2) a convergent-thinking process from C to D, (3) an idea-crystallization process at point D, and (4) an idea-verification process from D to H. Furthermore, C.M. Brugha proposed four phases which are similar to the above processes<sup>12,13</sup>, that is to say, the first four of Brugha’s eight phases match KJ’s four basic procedures - label making, label grouping, chart making, and verbal or written explanation.

Since the abduction step is the most difficult, Kawakita proposed the KJ method. The original KJ method comprises four basic procedures: (1) Label Making: Each label is generally obtained, using brainstorming as suggested by A.F. Osborn<sup>14</sup>. (2) Label Grouping: It consists of label collection, grouping and naming. The groups can be nested and each subgroup is also named. The label grouping is important in order to realize a new hypothesis. “The essence of the label grouping is to listen carefully to what the labels are trying to say.”<sup>1</sup> (3) Chart Making: This involves finding the relation among groups and/or labels. These relations can be “similar,” “opposite,” “cause-from,” etc. This is referred to as the A-type of KJ method. (4) Verbal or Written Explanation: The explanation is obtained by traversing through the entire chart beginning from any label along any relation edge. This is referred to as the B-type of KJ method. It is more important to prepare A-type chart as a creative-thinking support system than the B-type explanation.

Two types of abduction researches have been performed in Japan based on this method. One research includes abduction (or creativity) support systems for (1) divergent thinking such as the keyword associator<sup>15</sup>, etc, and (2) convergent thinking such as D-Abductor<sup>16</sup>, GRAPE, KJ Editor<sup>17</sup>, GUNGEN<sup>18</sup>. The other includes abduction systems by a machine itself such as: (1) hypothetical reasoning system like (HRS) and (2) knowledge acquisition

support system such as KAISER (Knowledge Acquisition-oriented Information SupplIER).

Our aim is to combine a divergent thinking support system and convergent thinking support system. Hence, we have implemented the GRAPE system and we are now implementing its successors.

### 3. GRAPE

#### 3.1. *Decision supportgroupware GRAPE*

In order to solve the “barrier of complexity” problem in knowledge acquisition by expert systems, we focused on the groupware approach. This is because a human can easily make decisions based on hypotheses and the groupware facilitates the group work involved in decision making. The basic ideas were obtained from Colab<sup>19</sup> and the KJ method and a new type of groupware GRAPE was developed.

Colab by Xerox’s Parc, is a group-decision room with computer support functions for collaboration and problem solving. Its basic design concept is WYSIWIS (What You See Is What I See), that is, information sharing for everyone. The system has three tools: Board-noter, Cognoter, and Argnoter. The Cognoter contains three procedures namely, brainstorming, organizing (relating), and evaluating (clustering). These functions are similar to procedures of the KJ method. This is because the KJ method comprises brainstorming, clustering (label collecting, grouping and naming, nesting of groups and naming), relating (mapping and relating), and composition. The difference between Colab and the KJ method lies in the order of organizing and evaluating.

We changed the order of evaluating (clustering) and organizing (relating) of the KJ method and designed and implemented our system GRAPE on a Prolog machine PSI (personal sequential inference machine).

#### 3.2. *Design of GRAPE*

This section explains the outline of GRAPE along with the module composition. The GRAPE system consists of three modules and the second module comprises five sub-modules ( Table 1 ).

The execution progresses in the following sequence.

- 1 In the initialization module, the participants are decided and one of them is selected as a session coordinator. In the current implementation, the first user who starts the system becomes the coordinator. The role of the coordinator is same as the participants except for the authority to confirm the end of each step.
- 2 The knowledge acquisition module consists of five sub-modules: candidate acquisition, candidate structuring, attribute acquisition, attribute structuring, and class evaluation.
  - 2.1 In the candidate acquisition sub-module, the system prompts all the participants, including the coordinator, to input the names of the candidates that are a part of the solution to the problem.
  - 2.2 In the candidate structuring sub-module, the system prompts the participants to input information in order to structure the candidates. This results in a tree struc-

ture where each candidate is a leaf. In order to generate this tree, each participant inputs the degree of the similarity between the candidates which is a number from 0.0 to 1.0. A higher degree of similarity connects the candidates by a branch to the nearest leaf. A similarity degree of 1.0 implies that these candidates are equivalent while that of 0.0 implies that they are in equivalent. Then, the names of the cluster, which exist on the branch, are acquired from the participants.

- 2.3 In the attribute acquisition sub-module, the names of the attributes are acquired using the interview technique as in Kelly's PCP<sup>20</sup>, which is a similar technique proposed by Brugha<sup>13</sup> for the same stage. The names thus acquired are used as the criterion to evaluate the candidates and clusters containing the candidates in the latter class evaluation sub-module.
  - 2.4 In the attribute structuring sub-module, the system prompts the participants to enter information to structure the attributes and indicate the dependency between them. A tree structure is obtained by using Extended ISM (interpretive structural modeling)<sup>21</sup>. In this structure, the dependent attribute is placed near the root and the independent attribute is placed near the leaf. The mutually dependent attributes are considered to be equivalent and only one of them is used. The obtained tree structure is treated as an AHP (analytic hierarchy process)<sup>22</sup> tree structure.
  - 2.5 In the classes evaluation sub-module, the evaluation of each branch is performed by using AHP. In order to evaluate each branch, the system prompts the input of comparisons between pairs of candidates (or clusters of the candidates) for each attribute. The system also prompts the input of pairwise comparisons of the importance between the attributes. These comparisons are performed at each branch of the clustering tree of the candidates. It is appropriate to use AHP with choosing within several candidates which are not close because AHP tends to require excessive effort when dealing with many alternatives and have problems with choosing among very close candidates<sup>23</sup>.
- 3 In the calculation result module, the evaluations at each branch are integrated and the results of the evaluations of each candidate are displayed to the participants.

### **3.3. Implementation and Evaluation of GRAPE**

The display images of the example to demonstrate the sequence of the execution are shown. Determining the best computer for groupware, in this example, poses a problem.

Each participant inputs the similarity values between the candidates to structure them. While executing this sub-module, the similarity matrix is displayed at the left of the window system. The participant can see the current tree structure, the tree structures of other participants, and if necessary, the average tree structure in the output window and can see the tree structures of the other participants and the average tree structures if necessary ( Fig. 2 ). These optional tree windows are shown at the bottom of the window system. After the system merges the trees by using the Fuzzy Clustering method<sup>25</sup>, each participant inputs the names of the clusters at the branches of the tree.







### 3.4. GRAPE Reconsidered

GRAPE is a knowledge acquisition support groupware and it acquires knowledge for the classification-choice type knowledge-based system. GRAPE is similar to ETS<sup>26</sup> and YUAI<sup>27</sup> from the viewpoint of the knowledge acquisition system, but it incorporates many features as groupware.

GRAPE is similar to GDSS (Group Decision Support System)<sup>28</sup> in the view that it uses decision support methods. Unlike the GDSS, the contents of the agreement are not important. GRAPE does not have a negotiation feature because it is a knowledge acquisition tool. The knowledge is common to all the participants; therefore, it is merged into a shared knowledge repository without negotiation.

Although GRAPE was developed with the intention of avoiding backtracking, the participants often tended to backtrack and add knowledge. We observed that typically, there are two types of backtracking: One is the backtracking to add candidates in Fuzzy Clustering and the other is the backtracking to add attributes in Extended ISM. Both types of backtracking are invoked by the structuring of the knowledge. It may be because the tree structure makes clear view about the candidates. It is expected that the integrated methods will acquire both items and its structures from multiple users incrementally.

GRAPE is designed to reduce the number of inputs, but the number of inputs increases because the participants confer with each other and tend to input knowledge that the other participants had already entered. In other words, the groupware tends to facilitate high quality knowledge; thus indicating that “two heads are better than one.”

Table 2. GRAPE and the KJ method.

Procedure	GRAPE	KJ method
Input	Input of Hypothesis similar to Brainstorming	Making Cards By Brainstorming
Structuring hypothesis	Fuzzy Clustering based on Similarity × (input to Similar Properties) △	Collecting Cards based on Similarity Naming each Group of Cards (indexing) Nesting of Groups and Naming
Structuring Properties (Criteria)	×	Mapping the Nested Structure to the 2 Dimensional Space Verifying Relationships among Groups
	Extended Interpretive Structuring Modeling based on Dependency Analysis	(Cause-and-Effect Property, Implication Property, etc.)
Determining Evaluation Structure	Analytic Hierarchy Process (Subjective Bottom-up Judgement by Pairwise Comparisons)	Subjective Top-Down Judgement by All Participants
Plan Generation	Parallel Constraint Solving	Pert Deployment by KJ Method B-type

Finally, Table 2 compares GRAPE and the KJ method. The main differences between them are the “Nesting of Groups and Naming,” “Mapping of the Nested Structure to the 2 Dimensional Space,” and “Top-down (or Bottom-up) Judgment.”

GRAPE can solve many problems such as group decision making and mutual agree-

ment support, evaluation of multimedia software, decision of the status, evaluation of training/education effect, conflict analysis, and so on.

#### 4. Consensus-making Support System Group Coordinator

Achieving the consensus making process is generally complicated because participants have individual viewpoints and preferences based on their own sense of values. In order to achieve the consensus making among all participants effectively, it is necessary to externalize the individual viewpoints of each participant and share them among the others. Thus, it is important that all participants grasp the situation where each viewpoint of the participants is applicable and further how important it is.

In this chapter, we describe two types of consensus-making support systems Group Coordinator (I) and Group Coordinator (II) that share individual viewpoints and have a tradeoff analysis function for measuring the coordination among the participants.

##### 4.1. Group Coordinator I

A consensus-making support process in the system is composed of the following three parts:

- (1) **Construction support of an evaluation structure** In this process, all participants must have a common recognition of consensus making. Moreover, the evaluation structure of the problem that they consent to must be effectively constructed. At this point, we use a thinking support method in the group, called the KJ method, which is widely used in Japan. This method is used to analyze the primary factors of a decision problem and construct a hierarchical evaluation structure of the problem. ISM can also be used for the same purpose.
- (2) **Alternative evaluation support based on the evaluation structure** Generally, the evaluation elements that compose an evaluation structure have some subjective characteristics and often differ from each other in their measures. The viewpoints of the participants are directly reflected in the order of preference by comparisons among the evaluation elements. Therefore, we try to show differences between the viewpoints of each participant by quantizing the preference order.  
At this point, we try to quantize the subjective judgment of each participant based on the evaluation structure derived by using AHP.
- (3) **Consensus-making support among the participants** We have designed a tradeoff analysis support function that uses a sensitivity analysis method<sup>29</sup> to form consensus effectively. Unlike conventional methods that use AHP, our method is more analytical and focuses on the importance of supporting the consensus making process. In this case, we define the weight distribution of the evaluation elements obtained by AHP as the viewpoints of each participant. We can apply a strategy that attempts to form consensus by choosing the evaluation elements in order, extracting conflict elements, and adjusting the weights by repetitive tradeoff analysis. In some cases, during this process, some priorities have to be sacrificed in order to realize another priority. There-

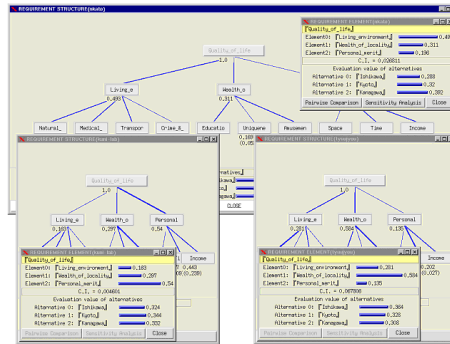


Fig. 6. An example of operation windows.

fore, in such cases, an appropriate judgment of the value of the priority is necessary. This procedure is referred to as tradeoff. Since sensitivity analysis is effective for actual consensus making, we used it as the tradeoff analysis method. In our system, tradeoff analysis mechanisms are implemented to obtain the requirements of all participants and to support consensus making. We define the tradeoff analysis as finding requirement element sets that have a tradeoff relation and analyzing the sensitivity for tradeoff cancellation. By repeating the above procedure, we attempt to support the consensus making process. An adjustment result is displayed in all windows on the terminals of each participant at once. Each participant can adjust his own evaluation if necessary by referring to the adjustments made by the other participants. Thus, the consensus making process can proceed in this manner.

#### 4.1.1. Implementation example

We emphasize the importance of the implementation of WYSIWIS groupware functions, including the GUI. Both Group Coordinator (I) and Group Coordinator (II) have been implemented on a SUN workstation with X window system environment. These systems incorporate a thinking support system- D-ABDUCTOR- for the construction support of the evaluation structure. By using these systems, we can expect to improve the common consciousness required for problem solving in a better manner than the conventional method; thus, construction of the evaluation structure will become more accurate.

An example of the operation windows of Group Coordinator (I) in the consensus making process is shown in Fig. 6. This system can be executed as an interactive multi-window system and the same screen can be made visible on the terminal display of every user. In Fig. 6, the window in the background at the screen center shows the evaluation structure of a participant, the windows on the lower-left and lower-right show the evaluation structure of the two opponents. Each user can thus observe that all participants have rather different individual viewpoints. The result of the adjustment is reflected in all the windows on the terminals of each participant.

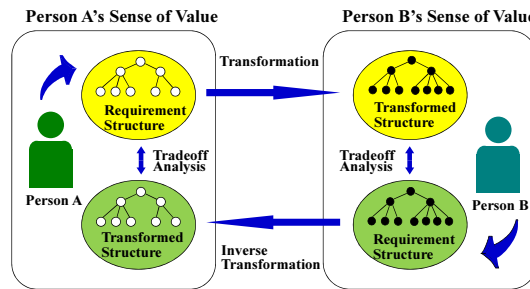


Fig. 7. Basic concept of Group Coordinator II.

#### 4.1.2. Evaluation experiment

We implemented the evaluation test “quality of life” which is an administrative problem in each of the administrative divisions in Japan, as an experimental example. The fourteen test subjects were divided into five sets. The comparative experiment of the consensus making among the test subjects who used the tradeoff analysis support function reveals the following results. When using a tradeoff support function within the sensitivity analysis, the number of negotiation times decreased by half as compared with the case in which it was not used. From this result, we observe that it is easy to determine the part of the coordination that should be discussed in order to harmonize with the opponent’s requirements and the adjustment of requirements among the test subjects could be easily judged based on the level of each requirement element throughout the consensus-making process.

#### 4.2. Group Coordinator II

The basic concept of Group Coordinator (II) is depicted in Fig. 7. A requirement of a participant depends on his sense of value and his standpoint at the time of consensus making.

Firstly, we introduce a point of view that is called a priority, as the basic measure to reveal the difference in the sense of value or the degrees of compromise. According to this, we suppose that a participant’s requirement is composed of some requirement elements associated with weight values that denote the priority. Such a requirement is represented by a hierarchical tree structure. Hereafter, we will deal with the requirement as mentioned above.

Next, we transform the dimension of requirement based on one’s sense of value to that based on the other’s sense of value and vice versa. Thus, the requirement of the other person can be understood in terms of one’s sense of value and vice versa. We believe that it is possible to support consensus making by sharing a mutual requirement with each person and by analyzing the difference in the mutual sense of value. A relationship matrix is used for the transformation and inverse transformation process. We contrived this relationship matrix based on QDA (quality deployment approach)<sup>30</sup> which is known as the methodology for product quality control management to reflect customer’s requirement.

#### 4.2.1. Transformation of user requirements

We suppose that the sense of value of a user is subjective and qualitative, while that of an opponent is objective and quantitative. For example, some of the user requirements are as follows: ease in viewing display, ease in operation, high responsibility, and so on. However, the requirements of the opponent are functions such as menu operation, learning, high-speed calculation, and so on.

Therefore, we suppose a relationship table that indicates the strength of the relationship between the requirements of the user the opponent. The users requirements are given in the row of the table, and the opponent's requirement elements are given in the column of the table. We represent the strength of the relationships in the table by the symbols  $\odot$ , (strong);  $\circ$ , (medium); and  $\triangle$ , (weak). Lastly, a relationship matrix is constructed by assigning five points to  $\odot$ , three points to  $\circ$ , one point to  $\triangle$ , and zero points to the others. In this manner, a relationship matrix of two types of requirements is represented by the two dimensional matrix based on the QDA method.

This relationship matrix transforms a weight vector of the user's requirement into a weight vector in the dimension of an opponent's requirement. With this procedure, the opponent can thus understand the wants and the priorities from the user requirements due to the transformation. We have to assign the relationship strengths carefully because they influence the result directly.

Next, an inverse transformation procedure that provides an opponent's requirement to a user is described. The transpose relationship matrix is generally a rectangular matrix. According to the theory of the generalized inverse matrix<sup>31</sup>, it is known that an inverse matrix exists uniquely when the condition of Moore-Penrose generalized inverse matrix is met. In other words, the opponent's requirement weight vector should be transformed into that of the user's by the above inverse matrix operation.

Therefore, the opponent and the user are able to comprehend each other's viewpoint at the level of their own viewpoint.

#### 4.2.2. Evaluation experiment

Group coordinator (II) provides a distributed environment to show both the user and the opponent their requirements by transforming them into a dimension by which they can interpret each other's requirement. The subjective evaluation of the user and the objective evaluation of the opponent can be connected mutually and their creative thinking can be inspired by the bi-directional repetitive transformation procedure.

With regard to the qualitative evaluation, we confirmed the effectiveness of our system with regard to the following aspects:

- (1) **Ease in constructing the requirement structure** We confirmed that our system makes it easier to embody and refine the requirement structure gradually and creatively by interactive consensus-making support functions.
- (2) **Equality between the participants in the consensus making process** In the conventional method, a user is often dissatisfied with the result of requirement analysis be-

cause his/her requirement is not well identified by the opponent. In the case of the evaluation experiment, consensus making progressed in a situation where the user is the same as the opponent. In the future, the objective and quantitative evaluation experiments on the system are necessary.

#### **4.3. Group Coordinator reconsidered**

In this chapter, we proposed two kinds of consensus-making support systems. The main difference between them is the use of a common evaluation structure or two different evaluation structures.

A characteristic of these systems is that they integrate divergent thinking support functions and convergent thinking support functions using the KJ method, decision-making method, and QDA method. The systems effectively facilitate cooperation among the participants who among themselves have a different sense of value. Through experimental examples for consensus making by using these systems, an improvement in the consensus making support effect was found by using the tradeoff analysis support function.

#### **4.4. Conclusion**

We developed several types of group decision support systems, such as GRAPE, Group-Coordinator (I), and Group Coordinator (II). They are all bottom-up decision making support groupware similar to the KJ method. All consensus making mechanisms are based on the Japanese decision-making style.

The characteristic function of GRAPE is knowledge merging for GRAPE users, and that of Group-Coordinator (I) and Group-Coordinator (II) is tradeoff resolution by sensitivity analysis and adjusting of user requirements by the QDA method, respectively. The systems that we have developed are similar to the KJ method, which is the most popular methodology for creative problem solving in Japan.

The essence of our developed methodology and tools is that it boosts intellectual productivity. The brainstorming and/or brain-writing method and tools can quantitatively boost idea generation two to three times in the divergent thinking sub-process. The KJ method and tools qualitatively boost idea generation, in the convergent thinking sub-process. GRAPE and its successors can speed-up the given group decision making problem by two to three times with respect to the idea crystallization (evaluation and judgment) sub-process.

#### **References**

1. J. Kawakita, *The KJ Method: A scientific approach to problem solving*. Kawakita Research Institute, 1975.
2. M. Nakayama, *A logic of abduction*. Chukoushinsho, 1970. (in Japanese).
3. K. Ichikawa, *A methodology for original research*. Sanwashobo, 1960. (in Japanese).
4. K. Fujita, K. Nishimoto, Y. Sumi, S. Kunifuji, and K. Mase, "Meeting support by visualizing discussion structure and semantics," in *Proc. of KES'98*, vol. 1, pp. 417–422, 1998.
5. T. Kawaji and S. Kunifuji, "A prototyping and an evaluation of an idea generation support groupware "hasso-tobi"," *Journal of Japan Creativity Society*, vol. 4, pp. 18–36, 2000. (in Japanese).

6. T. Onabuta, "A study of group thinking support system based on extracting a difference and an intersection among kj method's diagrams," Master's thesis, Japan Advanced Institute of Science and Technology, March 1996. (in Japanese).
7. R. Sakamoto, K. Nakano, Y. Sumi, and K. Mase, "Comiciary: Representing individual experiences in comic style," *SIGGRAPH2001: Sketches and Applications*, 2001.
8. H. Ueda and S. Kunifuji, "Grape: Knowledge acquisition support groupware for the classification-choice problem - the design principles, groupware functions, and a suggestion to extend for the planning problem -," in *Modern Tools for Manufacturing Systems* (R. Zurawski and T. S. Dillon, eds.), pp. 119–135, Elsevier Science, 1993.
9. N. Kato, M. Chujyo, and S. Kunifuji, "A group decision support system by externalizing sharing and reflecting individual viewpoints," in *Proc. of 6th IFIP Conference on Human-Computer Interaction*, pp. 600–601, 1997.
10. N. Kato and S. Kunifuji, "Consensus-making support system for creative problem solving," *knowledge-based systems*, vol. 10, no. 1, pp. 59–66, 1997.
11. M. Esaki, *Advanced Project Management Methodology with Method for Changing Knowledge to Wisdom in Wisdom Management Era*. ASI Press, 2001.
12. C. M. Brugha, "Priority pointing within the systems development life cycle," *International Journal of Knowledge and Systems Sciences*, vol. 2, no. 2, pp. 25–32, 2005.
13. C. M. Brugha, "Structure of multiple criteria decision-making," *Journal of the Operational Research Society*, vol. 55, pp. 1156–1168, 2004.
14. K. Fujita and S. Kunifuji, "A realization of a reflection of personal information on distributed brainstorming environment," vol. 1274 of *Lecture Notes in Computer Science*, pp. 166–181, Springer, 1997.
15. I. Watanabe, "Ideaeeditor overview." Research Report IIAS-RR-90-2E, 1990.
16. K. Sugiyama and K. Misue, "Visualization of structural information; automatic drawing of compound digraphs," *IEEE Trans. of SMC*, vol. 21, no. 4, pp. 876–892, 1991.
17. H. Ohiwa, K. Kawai, and M. Koyama, "Idea processor and kj method," *Journal of Information Processing*, vol. 13, pp. 44–48, 1990.
18. J. Munemori, "Kj method support groupware: Gungen," in *The second symposium on creative thinking support tools*, Fujitsu Makuhari System Laboratory, December 1993. (in Japanese).
19. M. Stefik, et al., "Beyond the chalkboard," *CACM*, vol. 30, no. 1, pp. 32–47, 1987.
20. G. A. Kelly, *The Psychology of Personal Constructs*. Norton Press, 1955.
21. S. Kunifuji and T. Takeshima, "Reachability: analysis on a directed graph with compound vertices - an extension of ism," *IEICE CAS79-110*, pp. 61–66, 1979. (in Japanese).
22. T. L. Saaty, *The analytic hierarchy process*. McGraw-Hill, 1980.
23. C. M. Brugha, "Phased multicriteria preference finding," *European Journal of Operational Research*, vol. 158, no. 308-316, 2004.
24. J. N. Warfield, "Developing interconnection matrices in structural modeling," *IEEE Trans of SMC*, vol. 4, no. 1, 1974.
25. L. A. Zadeh, "Similarity relations and fuzzy ordering," *Infor. Sciences*, vol. 3, no. 177-200, 1971.
26. J. H. Boose, *Expertise Transfer for Expert System Design*. Elsevier, 1986.
27. S. Sawai and T. Terano, "Yuai: A knowledge acquisition support system for classification-type problem," in *Proc. of TIMS89*, 1989.
28. P. Gray, "Group decision support system," *Decision support systems*, vol. 3, no. 233-242, 1987.
29. T. Masuda, "Sensitivity coefficients of consistency index and priorities used in the analytic hierarchy process," *The Transactions of IEICE*, vol. J70-A, no. 11, pp. 1562–1567, 1987. (in Japanese).
30. A. Ohmori, "Software quality deployment approach: framework design, methodology and example," *Software Quality Journal*, vol. 3, no. 11, pp. 209–240, 1994.
31. Y. Okamoto, *Inverse problem and its solving method*. Ohmsha, 1992. (in Japanese).