

# A Sketch Support System Based on Behavior of Designers

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**Abstract**—We have developed a design-support system which enhances design ideas by activating divergent thinking and convergent thinking of a designer, and offers a natural user interface that does not interrupt the thinking of a designer using the faculty of a computer. The system is composed of three user interfaces (UI)—a historical-view UI which analyzes partitions and branches of a design process automatically and displays them in the form of a tree structure, a spatial-view UI with which a designer can freely arrange past sketches in two-dimensional space, and a time-line and partial undo/redo UI which provides free undoing/redoin in units finer than a stroke—based on the results of analysis of a typical design process (i.e., designing a car), behavior analysis on several designers participating in a drawing experiment, and previous research. The effectiveness of this system was confirmed by the results of evaluation experiments with professional designers.

**Keywords**—component; sketching; pen; divergent thinking; convergent thinking; creativeness; idea generation

## I. INTRODUCTION

As a result of the rapid development of information technology in recent years, the personal computer (PC) has become a general tool, and anyone can easily create complicated and beautiful sketches of designs by using an advanced design-support system based on PCs. However, certain issues that inhibit human creativity and sensitivity have been reported; that is, a designer will persist only in changing the details of a certain design and not attempt a comprehensive change because of the completed successful design display [1].

In the present study, first, to determine how designers develop an idea, a video analysis of a scene in which they are designing on paper was carried out. Based on the results of this analysis and previous studies, three user interfaces were developed, and a design support system that inspires designers' ideas without inhibiting their creativity and sensitivity was implemented. Finally, two evaluation experiments for verifying the validity of this system were conducted.

## II. ANALYSIS AND ISSUE OF DESIGN PROCESS

The flow of a general design process was analyzed, and the key issues concerning this process were identified. As shown in Fig. 1, first, designers generally sketch out their ideas with paper and pencil, and after an idea sufficiently expands, they use a PC for clarifying and finishing the sketch [2]. This design

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process is divided into three steps, and the issues concerning each step are described as follows.

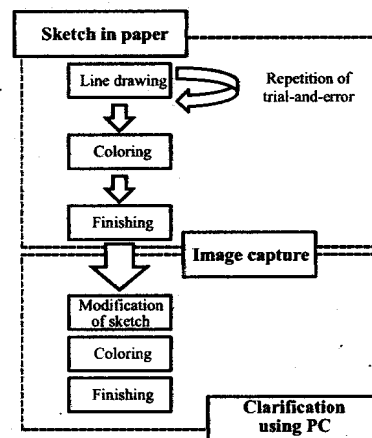


Figure 1. General design process.

### A. Issues Concerning Design-creation Process

In the early design-creation process, in which the designer yields an idea by free-hand sketch, two different thinking processes take place, namely, a process in which the idea which occurred is sketched out, and a process in which one sketch is gradually developed and modified to acquire a new design [3][4][5][6]. To design more creatively, it is desirable to activate both these thinking processes, but no system for supporting both thinking processes exists presently.

### B. Issues Concerning Coloring Process

A color plays the role of backing up the shape of a design, and there is a close relation between color and shape [7]. Properly speaking, design work that applies a trial-and-error method using color and shape simultaneously is desirable. However, since it is difficult to repaint a sketch on paper, design work including coloring is difficult, and designers generally start coloring after completion of a line drawing.

Since coloring can these days be easily done by computer, the design work to which a trial-and-error method is repeatedly applied using a color and the shape is achieved. However, only poor coloring methods such as painting a specified color on the completed sketch and changing overall color tone are available.

Consequently, although trial-and-error methods of color combination after the shape is fixed and coloring of the final design are available, it is not possible to do design work using a trial-and-error method repeatedly in the early design stage using color and shape simultaneously.

### C. Issues Concerning Design Process Using a PC

In the design process shown in Fig. 1, when design work shifts from paper to a PC, it is an issue that design thinking, namely, a designer's thought process when designing a product, is interrupted. Moreover, present design systems are complicated and not intuitive, designers must make compromises when using computer systems that are difficult to use, and intellectually creative activities are inhibited. If a "natural" computer system, namely, one that does not interrupt a designer's thinking were available, a complete design—from a sketch to the final form—could be performed using a PC.

## III. RELATED SYSTEMS AND RESEARCHES

### A. Research on Idea-generation Support

As for the design-creation process, several researches on creation of new ideas—in fields other than design—have been reported.

One is research on displaying the design process visually, not only in language, so that designers can communicate the intention of a design with one another [8]. The intention of a design can be understood more clearly by observing the modification process, and a new design is produced by the intellectual stimulus between designers and the fusion of various viewpoints. However, the forms that the system can generate are limited, because the design work generates form variations first and then selects and modifies them.

Another research focused on "idea collection" for reuse of ideas by using a PDA [9]. An idea input by hand writing can be used with a KJ-method (one of the famous idea generation method in Japan) and an intellectual stimulus is provided by reusing the result of the KJ-method as one of the next ideas. Although the intellectual stimulus provided by this space arrangement is useful, the research uses a KJ-method for language arrangement and is not design support. Research [10] treats KJ-method as a collaborative tool used by designers.

### B. Research on Coloring

As for the design-coloring process, research on whether a color is an important element and research that give designers an intellectual trigger by a color are described in the following.

Research on the image projected by the shape and color of a newspaper advertisement found that color, shape, and image content are mutually related to each impression [11].

Another research found that a new color is made from the synergistic effect of the color painted on canvas and the color of a brush being used for coloring [12]. Although this effect can make many color variations from few operations and the intellectual trigger by a color is given, it is an issue that the color that a designer intends is hard to realize.

### C. Researches on Design Support Using PC

Researches on design support using a computer examined how to support a designer's design work without inhibiting his or her thinking. They were performed from various viewpoints as explained below.

One research looked at artwork rotation; that is, a user interface (UI) is kept upright even if the drawing canvas is tilted by rotating a tablet display [13]. Other researches focused on showing the history of a discussion or collaborative work by offering a time-line that can move time backward and forward and which enables semi-infinite undoing [14][15]. ART019 [16] provides a timeline-based representation of free-hand drawing. Calico [17] offers a grid view which provides an overview of all the canvases.

## IV. PURPOSE OF THIS RESEARCH

The purpose of the present research was to construct a sketch-support system that does not inhibit designers' creativity and sensitivity; instead it enhances them and provides the following functions.

- Enhances design ideas by activating divergent thinking and convergent thinking of a designer.
- Offers a natural user interface that does not interrupt the thinking of a designer using the faculty of a computer.

Note that although coloring is considered to be an important element in improving a designer's creativity and sensitivity, it is not treated in this research.

## V. ANALYSIS OF DESIGNERS' SKETCH BEHAVIORS

Although observation and analysis of the design-creation process were carried out qualitatively in the same manner as previous researches, in this study, the specific actions performed during design activities were analyzed quantitatively in the experiment described below.

### A. Experiment Setup

To analyze in detail how a designer does design work and to analyze clues that give a design idea to a designer, the task of designing a car—namely, six exterior designers expressed a specified design concept by pencil and paper during a 60-minute experiment—[17] was analyzed. The design work was recorded on videotape. Examples of one of the designers drawing and a finished sketch are shown in Fig. 2.



Figure 2. Drawing experiment and example design sketch.

## B. Quantitative Video Analysis by Time Sampling

To make quantitative analysis of the specific actions of the designer performing the design task more objective, analysis was carried out by the "time-sampling method"—a kind of observational method used in psychology. Time sampling is a kind of quantitative analysis in which an "occurrence frequency" is defined by stopping the action at certain time intervals (called "observational units") and recording the action that is occurring at that time [19].

Using time sampling, an observer classifies the actions for observation into categories and creates a check-list of action categories beforehand. The observer then checks the column of the action observed at a certain observational unit.

The check-list main and sub-categories observed in this experiment are listed in Table I. Moreover, in the observed design work, since a change of action was observed on the time scale of seconds, the observational unit was set to five seconds.

TABLE I. CATEGORIES OF TIME-SAMPLING CHECK LIST

Main category	Sub-category	
new paper		
drawing of an object	target	new object, past object
	action	drawing, copying
arrangement of paper	target	present paper, past paper
	action	arrangement, rotation/displacement, stacking
	place (left, right, top and bottom)	
eye gaze	target sketch	present sketch, past sketch
	target paper	present paper, past paper
	other	
thinking		

## C. Analysis Results

### 1) Eye gaze

It was assumed that the designers would receive a certain trigger, produce a new design idea, and develop their current design by referring to past sketches that they drew themselves. To determine how many of their past sketches are referred to during the design task, the number of checks on the target sketch sub-categories "present sketch" and "past sketch" in the "eye gaze" category of the check list were counted (Table II).

According to Table II, subjects were clearly referring to their past sketches during the design task, and the ratio of the reference time to the total time spent on the design task was 10 to 30%. It should be noted that subjects D, E, and F had low ratios of reference to past sketches. Since subjects D and E were drawing many objects on one sheet of paper, it was hard to detect the direction of their eye gaze on the same sheet of paper in the video; in practice, they might have referred to even more past sketches than we noticed.

TABLE II. TARGET OF EYE GAZE

Target sketch	Subject					
	A	B	C	D	E	F
present sketch	97%	81%	82%	99%	90%	97%
past sketch	17%	23%	34%	4%	11%	3%

### 2) Arrangement of paper

During the design task, the subjects cut a piece of paper drawn from a sketchbook, placed it next to another piece and moved to somewhere else repeatedly.

An "arrangement" action stated here is not an action that rotates or displaces a piece of paper slightly in order to make it easy to draw a design sketch; it is the action of putting pieces of paper drawn in present and past somewhere else in order to arrange them into a design. Therefore, to determine the occurrence frequency of the paper-arrangement action during the design task, the number of checks on the action "arrangement" in the "arrangement of paper" category of the check list was counted (Table III).

Table III indicates that all subjects perform more than one arrangement action during the 60 minutes of the design task. One subject even performed the arrangement action 30 times.

TABLE III. NUMBER OF TIMES OF ARRANGEMENT

Action	Subject					
	A	B	C	D	E	F
arrangement of paper	11	9	11	4	30	3

### 3) Additional drawing and the copy to the past object

During design task, designers add drawings to an object drawn in the past and thereby generate a new idea. Therefore, to examine the occurrence frequency of such additional drawing to a past object, the number of checks in the target "past object" in the "drawing of an object" category was counted. Designers copy a past sketch in order to reuse it or to develop a new design. Therefore, to examine the occurrence frequency of such copying, the number of checks on the action "copying" in the "drawing of an object" category was counted. Table IV lists those occurrence frequencies.

Table IV indicates that the subjects did additional drawing to a past object about five times during the design task, and they performed the copying action several times. One subject even copied past sketches 10 times.

TABLE IV. NUMBER OF TIMES OF ADDITIONAL DRAWING AND COPYING

Action	Subject					
	A	B	C	D	E	F
additional drawing to past object	4	5	6	1	16	0
copying	1	2	10	0	0	1

## VI. USER INTERFACE DESIGN

Effective user interfaces were examined by referencing the results of analysis of the design drawing work from previous studies and from the results stated in the preceding paragraph.

As described in the previous paragraph, designers recalled the feeling, the situation, and the design flow concerning a past sketch by referring to it, and they used these factors for

generating new ideas. However, it is very hard to understand the design flow only by referring to a final sketch drawn in the past. Since a form of expression by which the designer can perceive a design flow immediately and more clearly was considered to help his or her self-reflection, we devised a "historical-view" user interface.

It is thought that the paper-arrangement action itself is stimulating. However, the arrangement action with paper cannot be freely performed because of spatial constraint. Even if a large configuration space could be prepared, it would be difficult to arrange or to refer to several arranged sketches at once. To help a designer perform the arrangement action of old sketches more freely and browse through them more easily in order to give the designer an "intellectual trigger," a "spatial-view" user interface was devised. Furthermore, it was thought that the designer receives an intellectual trigger by accessing the sketch drawn in the past by the actions such as additional drawing and copying. In the case of the design on paper, it is possible to modify a present sketch by additional drawing, but it is difficult to modify it by deleting and modifying the past drawing. Especially in an area in which drawings overlap, it is difficult to delete only the lower drawing.

Offering a means by which the idea that the designer wants to express can be expressed more easily by a direct and natural method using a computer can lead the designer to think creatively. Accordingly, a "time-line and partial undoing/redoing" user interface was devised. The three user interfaces are described in detail below.

#### A. Historical-view Interface

It is known that a designer refers to past sketches that he or she drew in previous design work. In previous research [15], the chronological flow of the entire history of a collaborative work was clarified by providing a parallel time line (namely, a directed acyclic graph) of the history of a parallel collaborative work. It is thought that understanding one's own design process leads to an intellectual trigger also in the case of design work done alone. It seems that seeing the sketches drawn up until the present and understanding the design process gives a stimulus for design creation.

In consideration of the above-described researches, a "historical view" (Fig. 3)—which analyzes partitions and branches of a design process automatically and displays them in the form of a tree structure—was devised. By tracing the tree from past to present, the designer can understand and reconfirm the design flow and, in doing so, activate convergent thinking that modifies an idea. Moreover, by looking through the branching and spreading tree, the designer can get intellectual triggers from a wide range of viewpoints and, in doing so, activate divergent thinking that creates new ideas.

#### B. Spatial-view Interface

The designers rearranged the pieces of papers, in addition to rotating or moving them, to make a sketch easy to draw. This action was arranged in two-dimensional space and has two characteristics, and it makes a designer do two kinds of self-reflection thinking [20]. One, called "reflection on action," is the static characteristic of performing self-reflection, that is,

following the "position" of the pieces of paper as a result of the arranging them. The other, called "reflection in action," is the dynamic characteristic of performing self-reflection within the "action" of arranging.

The "spatial-view" interface, with which a designer can freely arrange past sketches in two-dimensional space, is shown in Fig. 3. The designer can use a wider range of visual-space information by expanding or reducing the size of each sketch and annotating it in addition to moving its position.

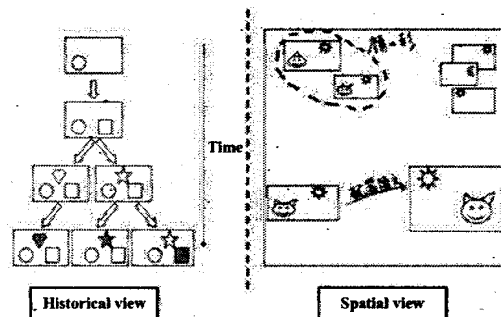


Figure 3. Historical view and spatial view.

#### C. Time-line and Partial-undo/redo Interface

The actions of making additional drawings on past sketches or copying past sketches were observed during design task. This infers that a function by which it is possible to return to a specific time in the past easily is required. Moreover, the present undoing function is effective only in the regard to behavior performed immediately before the present action, and modifying a past drawing is difficult. What's more, that function can only undo per stroke; it cannot return to the halfway point between certain strokes.

Consequently, the "time-line and partial-undoing/redoing" interface shown in Fig. 4 was devised. Free undoing/redoing in units finer than a stroke can be performed by moving a slider forward and backward. Moreover, if a certain drawing area is selected, the time range corresponding to the area is specified, as shown in Fig. 4, and only the inside of the selection of drawing area can be undone backward in time. It is thought that by using the partial undoing/redoing interface, a designer can revise a sketch at any time in the past by drawing freely and concentrate on his or her design work without interrupting his or her thinking.

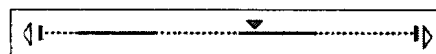


Figure 4. Time line.

### VII. IMPLEMENTATION OF A SKETCH-SUPPORT SYSTEM

Based on the user interfaces described at the previous paragraph, a sketch-support system for prompting a designer's ideas without interrupting his or her thinking was developed. All the operations of this system are done by electronic pen. It consists of a "canvas" on which sketches are actually drawn, a "historical view" by which the designer is intellectually stimulated by visualization of the design process, a "spatial

view" with which he or she is intellectually stimulated by arranging designs in space, and a "time line" allowing undoing and redoing of sketched freely in any area at any time. An overview of this system is shown in Fig. 5.

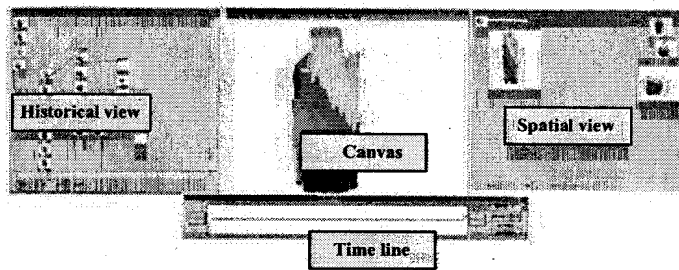


Figure 5. System overview.

#### A. Historical View

This system observes all the operations of a user, sets the partitions and branches of the design process, and forms a tree in the historical view. The preliminary experiment examined what kind of situation in a design process can regard as a partition or branch. In this experiment, according to the questionnaire results of the preliminary experiment, the following situations were considered as a partition or branch.

Partition situations:

- At the time of changing a color, thickness, or a pen and an eraser
- At the time of total deletion
- After the elapse of a certain period of time from the last partition or branch
- When a user returns to the past sketch using partial undoing and adds some drawing to it
- When a sketch is taken into a spatial view

Branch situations:

- When a user returns to the past sketch using methods other than partial undoing and does additional drawing

Although a tree is formed as mentioned above, a different tree from the flow that the designer intends may be formed. To handle such a case, a function to displace or delete one or more nodes was implemented so that the designer could edit the tree structure freely. Moreover, a function that returns to the past sketch on the tree was also implemented so that the designer could do additional drawing on it or could see it on a large screen of canvas. If the designer does additional drawing on the past sketch, a new branch is derived from the past node on the tree in the historical view.

#### B. Spatial View

A spatial view is a user interface that allows a designer to place and arrange an old design onto a space in the same manner as the KJ-method. By pushing the "capture" button of the spatial view, the sketch currently drawn on canvas at present is taken into a spatial view as a small thumbnail. The

user can displace, expand, and reduce the thumbnail in the spatial view freely, and can annotate the spatial view. Furthermore, in the manner of a historical view, it can also return to the past sketch corresponding to the thumbnail.

#### C. Time Line and Partial Undo/redo

The time line is a user interface in a slider style that enables access to any past sketch and offers the following four kinds of undo/redoing in respect to the drawing.

- undoing every stroke by the "undo" button
- undoing finer than one stroke by slider operation
- undoing only drawings in a certain selected area (partial undoing by area selection)
- undoing only drawings in a certain selected time range (partial undoing by time-range selection)

### VIII. EVALUATION EXPERIMENTS

To evaluate this sketch-support system, two kinds of experiments were conducted: a "scenario experiment" (for measuring whether the system can be used naturally) and a "design experiment" (for verifying the validity of the system). The participants in the experiments included eight men and three women, three of whom were professional designers. The subjects responded to a questionnaire at the beginning of the experiments. After that, they were taught how to operate the system while looking at an operation manual. They then used the system freely in order to get used to it, looking at the manual for about 10 minutes. Two experiments were conducted after the subjects become familiar enough with the operation. The behaviors of the subjects during the experiment were recorded by video, and all operations (such as pushing buttons or drawing) were recorded in log files. Moreover, an eye-gaze tracking system was used to record each subject's point of eye gaze during the design experiment. At the end of the two experiments, the subjects answered a questionnaire followed by an easy oral inquiry lasting about 15 minutes.

#### A. Experiment 1: Scenario Experiment

##### 1) Setup

Subjects operate the system according to 22 scenarios set up beforehand so as to use each user interface. Each operation was investigated to determine whether "it was possible without a manual", "it was possible after reading a manual", or "it was impossible despite reading a manual."

##### 2) Results

The bar graph of Fig. 6 shows the operation results for each scenario. According to these results, there were almost no scenarios in which the system could not be operated. The line graph in Fig. 6 shows the ratio of operations performed while looking at the manual. It is clear that many operations were carried out without referring to the manual.

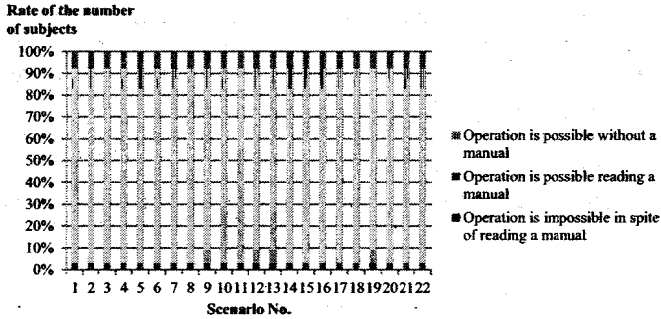


Figure 6. Operation classification in each scenario.

**B. Experiment 2: Design Experiment**

**1) Setup**

In the design experiment, the validity of the system and the difference in designs due to three pen-input environments (i.e., a “direct pen-based input device,” that is, stylus input and display are coincident, the “indirect pen-based input device”, that is, stylus input and display are separated, and traditional “paper and pencil”)

were verified together. The subjects drew the design of three specified themes for 30 minutes each in the three input environments. In addition, the three subjects who were professional’s designers performed one theme for 90 minutes only in the direct pen-based-input device environment in order to verify long-time design work. Scenes from the experiment in the three input environments are shown in Fig. 7.



(a) Direct-pen-based input device (b) Indirect-pen-based input device



(c) Paper and pencil

Figure 7. Three input environments.

**2) Results**

The number of times each user interface was operated (i.e., acquiring system log files) is shown in Fig. 8. Canvas, spatial view, and the historical view were used equally (and effectively) in the design-work experiment. However, the time line was used much less than the other functions.

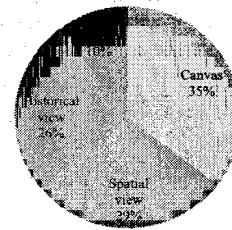


Figure 8. Ratio of usage amount of operations with each UI.

Fig. 9 shows the ratio of the amount of references by each user interface calculated from the data obtained by the eye-gaze tracking system. It is clear that the system urges reference to at least “past paper”. It also shows that the indirect pen-based input device promoted more action referring to past sketches in comparison with the direct pen-based input device. Furthermore, it is clear that the historical view and the spatial view are referred to equally.

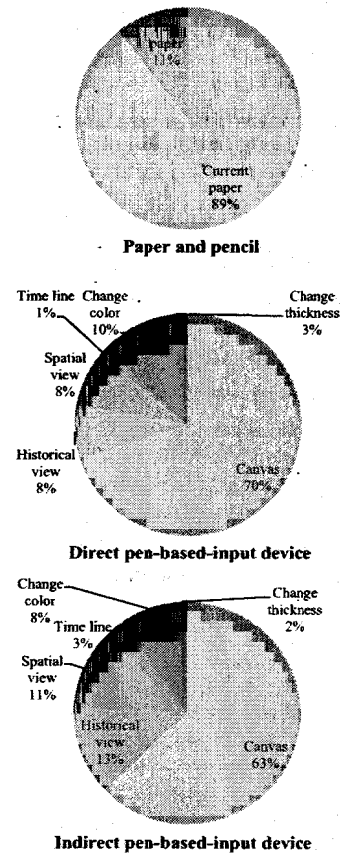


Figure 9. Ratio of amount of references.

Fig. 10 shows the results of the post-experiment questionnaire, which was evaluated on a five-point scale by the subjects. The figure shows that the spatial view received high evaluation in regard to all the items. Although the historical evaluation did not receive high evaluation, comments such as “the historical view would be useful in longer design work” were

acquired. As a matter of fact, the average evaluation of the design-support and idea-generation user interface by the three subjects who worked on one design theme for 90 minutes is high, namely, 4.5. The example comments obtained from subjects are shown below.

- “The next new idea came to me on seeing casual scribble and old unsuccessful designs”.
- “This system is especially useful in regard to trial-and-error with ideas in the early stage of design”.
- “The time line is good for showing old drawings continuously and discovering my own habits in design work”.
- “Partial undoing is convenient for making fine modifications”.
- “I would like to also perform color-hue selection in addition to spatial selection and time selection”.

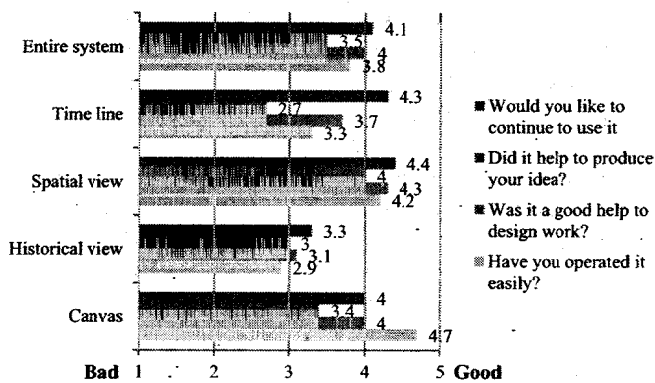


Figure 10. Evaluation score of each UI.

## IX. CONCLUSION

A sketch-support system for enhancing designers' creativity and ideas while not inhibiting their creativity or sensitivity was developed. The system provides three user interfaces, a historical view, a spatial view, and a time line, implemented according to the results of an analysis on a typical design process, a drawing experiment with professional designers, and previous studies. To verify the validity of the system, two kinds of experiments were conducted. The experimental results show that each user interface is equally effective. They also show that the system stimulates actions by referring to past sketches, prompts new design ideas by arrangement actions with a spatial-view interface, and gives a historical view of the design process that is effective for long design.

As for future works, it is necessary to further examine the timing of at which partitions and branches automatically created by the historical-view interface and to devise a display method for understanding all the design processes more intuitively. Moreover, it is necessary to devise a coloring method for prompting design ideas that was not treated in this study.

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