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A KNOWLEDGE-BASED SUPERPOSING SKETCH TOOL FOR DESIGN CONCEPT GENERATION THROUGH REFLECTION OF VERBAL AND DRAWING EXPRESSION

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ABSTRACT

Many researchers have focused on the role of sketching activity in design concept generation, and asserted that design is an iterative process of reflective interaction between thinking design concepts within designers' mind and externalizing them in verbal and drawing expression. Superposition of drawing is the typical operation in concept generation. Designers gradually shape an image by superposing, while concepts are gradually clarified. This paper proposes a knowledge-based sketch tool which manages a draw layer that is a unit of superposition and associates it with expressed design concepts. The sketch tool incorporates a concept network model, which integrates verbal and drawing expression. The tool automatically organizes alternatives of design concepts as well as alternatives of drawing so as to help a designer easily compare with each other and flexibly change an alternative. Those features facilitate designers to reflect the verbal and drawing expression. Its prototype is implemented by a knowledge-based design support framework named DRIFT which we have been developing. An example of coffee maker design is demonstrated in order to show the facility of the proposed tool.

Keywords: sketch, design concept generation, design support system, knowledge, reflection-in-action

1 INTRODUCTION

Sketching is a quick way of expressing designer's idea, and also takes an important role for generating design concepts. Many researchers have focused on the role of sketching activity in design concept generation. According with articles about design protocol analysis, design is an iterative process of reflective interaction between thinking design concepts within designers' mind and externalizing them in both verbal and drawing expression [1][2][3][4]. Designers progressively generate and develop design concepts through the interaction.

Superposition of drawing is the typical operation in sketching activity in design concept generation. While design concepts are gradually clarified, a designer gradually shapes an image by superposing lines, or often draws an outline box beforehand in order to roughly display shape and size of an object that a designer wants to express, and then the exact shape of the object is drawn superposing on the outline.

The aim of this research is to develop a computational tool supporting reflection of verbal and drawing expression for design concept generation. In this paper, a knowledge-based sketch tool is proposed, which manages a draw layer that is a unit of superposition and associates it with expressed design concepts. The sketch tool incorporates a concept network model, which integrates both verbal and drawing expression of design concepts. The system captures all operations on the expression, automatically organizes alternatives of design concepts as well as alternatives of drawing so as to help a designer easily compare with each other and flexibly change an alternative. Those features facilitate designers to reflect verbal and drawing expression. Its prototype is implemented by a knowledge-based design support framework named DRIFT, which we have been developing [5]. An example of coffee maker design is demonstrated in order to show the facility of the proposed tool.

2.1 Design Concept Generation

First, this subsection clarifies what *concept* means. Many researches have been taken for understanding and supporting concept generation in design research domain. However, there is no unified and common definition of concept. This research introduces two definitions. One is *an idea of design solution*, and the other is *designer's perception or knowledge about entity, function, attribute and so on* that is used to represent characteristics of design solution.

Researchers of creativity and design methodology tend to use the first definition. It is commonly asserted that the number of design concepts gradually decreases and converges as design process continues [6]. For instance, Cross [7] characterized the overall design process as being convergent, but maintained that it also contains deliberate divergence for the purpose of widening the search for new ideas. The size of the search space of design concepts after reaching its peak is gradually decreased as the design process continues. Pugh [8] mentioned that it is essential to carry out design concept

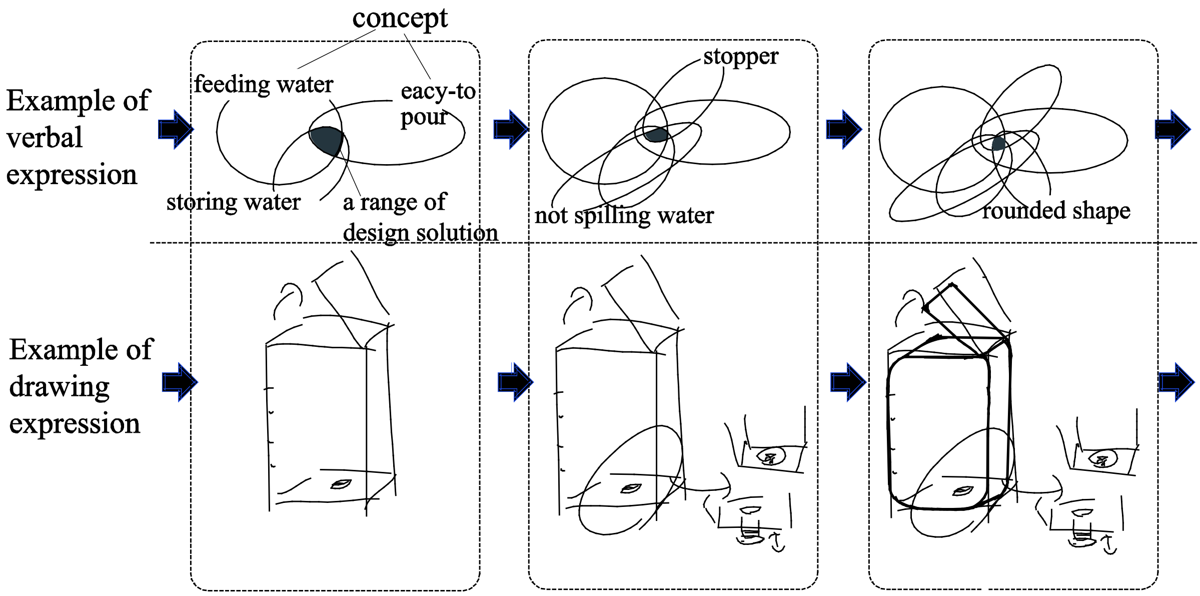

Figure 1. Progress of Design Concept Generation and Progress of Sketch

generation and evaluation in a progressive and disciplined manner so as to generate better designs. This progressive and disciplined manner is illustrated as an iterative, repeated divergent and convergent process with the number of concepts gradually decreasing.

By contrast, researchers of design theory, knowledge modeling and artificial intelligence who are mainly interested in intelligent computational tools supporting design activity tend to use the second definition. Yoshikawa's general design theory (GDT) [9][10] is one of the pioneers. In GDT, two kinds of concepts are defined, i.e. concept of entity, which is a concept which a designer has formed according to the actual experience and the imagination of an entity, and abstract concept, which is derived by the classification of concepts of an entity according to the meaning or the value of it. Function and physical attribute is an example of abstract concept. Design solution is represented as an intersection of abstract concepts. Therefore, the number of concepts gradually increases as design process continues in contrast to the case of the first definition of concept. The upper part of Figure 1 illustrates progress of design process of a water tank of a coffee maker. At the beginning, design solution of a water tank is represented by a few concepts such as "storing water" and "easy-to pour water." As design process continues, designers acquire knowledge, and the number of concepts characterizing design solution increases. Note that it is not contradictory to the case of first meaning, because a range of design solution, which corresponds to *concept* in the first definition, decreases.

In the rest of this paper, we use design concept in the second definition, because we are interested in a knowledge model of design concept generation and a computational tool based on it.

2.2 Interaction between Verbal and Drawing Expression

When reflecting on the nature of thinking, most people associate it primary with words or with language [2]. Design concept can be theoretically represented by verbal expression as shown in the upper part of Figure 1. In actual design process, however, many of design concepts cannot be perceived with words but with just images at the beginning. Drawing expression is used instead of verbal expression in order to represent such image of concepts as shown in the lower part of Figure 1. Many researchers have focused on the role of sketching activity in design concept generation, and asserted that design is an iterative process of reflective interaction between thinking design concepts within designers' mind and externalizing them in verbal and drawing expression [1][2][3][4] as shown in Figure 2. Designers express design concepts (Figure 2 (1)), see the expressed design concepts, notice something unreasonable of the expression (Figure 2 (2)), which Schön calls back-talk [1], revise design concepts or make them explicit (Figure 2 (3)), and then express revised design concepts.

The design concept generation basically proceeds in progressive and disciplined manner [7][8]. Therefore, superposition of drawing is the typical operation in design concept generation. Designers gradually shape an image by superposing, while design concepts are gradually clarified.

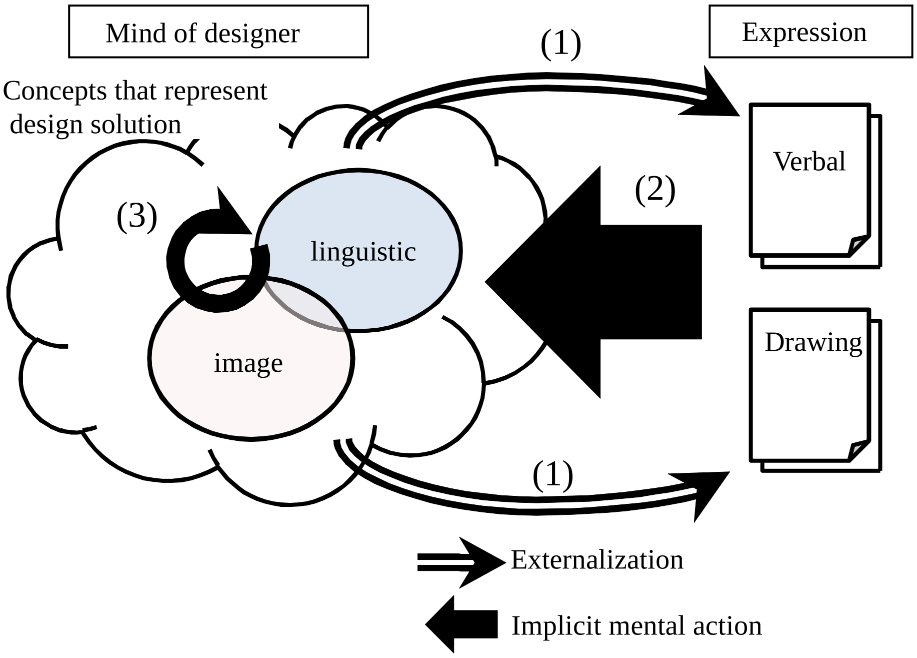

Figure 2. Interaction between Verbal/Drawing Expression and Explicit/Tacit Concept

2.3 Visual Thinking

Visual thinking [3][11][12][13] is a familiar viewpoint of sketching activity focusing on concept generation through the interaction of designer's thought and expression. It is asserted that reflection-in-action [1] is a key paradigm to understand cognitive behaviors of designers [14][15][16]. Woolsey formalized process of visual thinking as iterative cycle of three steps, i.e. act, reflect and change, as shown in Figure 3 [17]. Act is a step in which designers externalize design concepts by verbal and drawing expression. Reflect is a step in which designers see, analyse and evaluate the expressed concepts such that designers not only can communicate each other, but also can notice from the expression by backtalk. Comparison is effective for the reflection. Reflection is often carried out by comparing multiple alternatives of design solution, or by comparing with the past design cases. Change is a step in which designers refine the design solution based on the results of refection in his/her mind by generating design concepts. As a consequent of change step, designers externalize concepts again. It would backtrack to a former design solution that was formerly rejected.

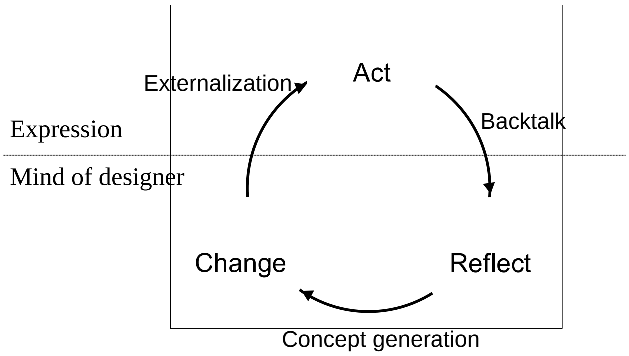

Figure 3. ARC Cycle in Visual Thinking

2.4 Research Issues and Our Approach

Based on the above discussion, this research addresses three issues for a computational tool supporting design concept generation.

1. In order to support act step, a system should have an interface by which designers can easily represent both verbal expression and drawing expression.
2. In order to support reflect step, a system should have a mechanism to facilitate comparison of multiple alternatives of design solution.
3. In order to support change step, a system should have a mechanism to flexibly change the design solution.

Many sketching tools have even been developed in various domains for supporting design concept generation, and they have tackled those research issues. For instance, there are tools that have user-friendly interface of drawing and annotating text [18][19][20][21], tools that can manage alternatives and argumentation of sketches [22][23], and tools that record history of drawing and facilitating backtrack [24], and so on. However, few tools have comprehensively solved those three research issues.

This research solves those issues as follows. As for the first issue, this research develops a sketch tool which is integrated with some conceptual design tools, such as a value graph and a function-structure mapping tool. This sketch tool has a layer management mechanism. A layer works as a unit of superposition and is associated with expressed design concepts. For the second and the third issue, this research employs DRIFT [5], a knowledge-based framework of an integrated design support system which we have been developing.

Next section discusses the first issue, especially about what functions a draw tool should have. The details of the second and third issues are briefly explained in Section 4.

3 TOWARD A SKETCH TOOL SUPPORTING DESIGN CONCEPT GENERATION

3.1 Scenario of Sketch Process with Layer Mechanism

This subsection illustrates a scenario of sketching process using an example design of a water tank of a coffee maker as shown in Figure 4, and clarifies operations required for a support system. It is assumed that designers can use a drawing layer in sketching.

At the beginning, “water tank of coffee maker” is set as a theme of drawing. A designer draws an outline box that sketchily indicates a size of a water tank considering a ratio of width, height and depth (S1 in Figure 4). Then, he/she draws a base of a water tank superposing it on the outline box (S2 in Figure 4). A brief of a main body of a water tank is drawn superposing on S2 (S3 in Figure 4). S4 and S5 derive from S3, each of which represents an alternative appearance of a water tank.

In this process, five draw layers are used as shown in Layer 1 to 5 in Figure 4, each of which draws an outline box, a base, a main body of a water tank and its alternatives, respectively. A sketch is composed by superposing multiple layers. A different layer is drawn in different line width and different blackness. For example, an outline box is drawn in thinner line, because it becomes unnecessary after a main body is drawn. Some sketches are derived from the other sketch expressing the same theme in the detailed viewpoint or from the other direction.

3.2 Required Function

Based on the scenario stated in Subsection 3.1, this research asserts that the following operation is required for a drawing tool.

1. Setting a theme of drawing
2. Making a draw layer
3. Changing line width and blackness of a drawing layer
4. Superposing draw layers
5. Recording a sketch alternative
6. Making a branch sketch

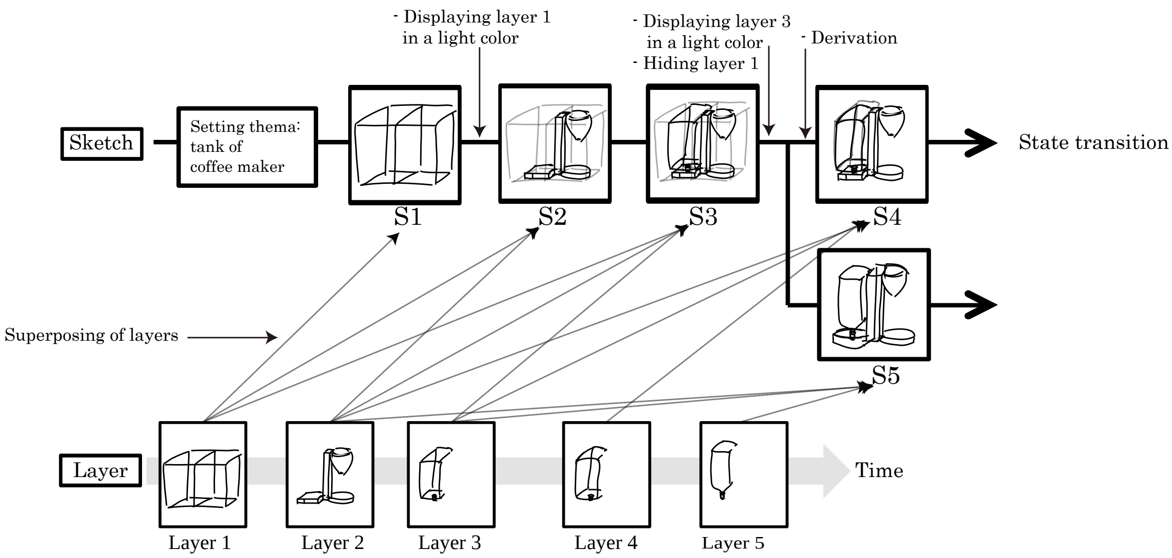

Figure 4. Scenario of Sketching Process with Layer Mechanism

4 IMPLEMENTATION METHODOLOGY

4.1 Management of Design Concept Generation Process

This research adopts a framework of DRIFT in order to implement a sketch tool so as to integrate drawing tools and conceptual design tools, and to flexibly manage alternatives. Figure 5 shows the overview of the framework. The framework employs a concept network model (Figure 5-(3)) which is often used as a generic form of design representation in the design engineering community, e.g., [25]. Some conceptual design tools such as a value graph and a function-structure mapping, which represents design concepts in a verbal expression, are incorporated as a front end of a concept network model (Figure 5-(2)). A drawing tool which has functions stated in Subsection 3.2 is also incorporated as the front end of the concept network model so as to handle both drawing expression and verbal expression in a single framework. The concept network model can associate a drawing expression with each design concept represented in verbal expression.

The core of this framework is the three-layered design process model of action, model operation, and argumentation, which is shown in Figure 5–(1). In the three-layered process model, a design operation is defined as a unit design activity that generates concepts. Because the design process is a sequence of generating alternative of design concepts, the design process can be represented by a sequence of design operations. The three-layered process model adopts the representation format of gIBIS (graphical Issue Based Information System) [26], a well-known argumentation model, for the logical representation of the design process. In addition, the three-layered model records the design state transition by capturing a snapshot of the design state before and after performing the design operation. The level of performing design operations is called the *action level*, the level of recording the design state transition is called the *model operation level*, and the level of recording multiple alternatives is the called the *argumentation level*. By integrating all three levels, the framework realizes a recording of the design process as a byproduct of the natural design activities that is performed on the conceptual design tools and a drawing tool.

The framework manages multiple design states over the single concept network model using a truth maintenance system (TMS) [27] as shown in Figure 5–(5). Its algorithm maintains a concept is active or inactive, and updates the active/inactive status at every moment when a new concept is added. Thanks to this mechanism, a designer can change alternative design concepts and backtrack to earlier design states by one-click operation.

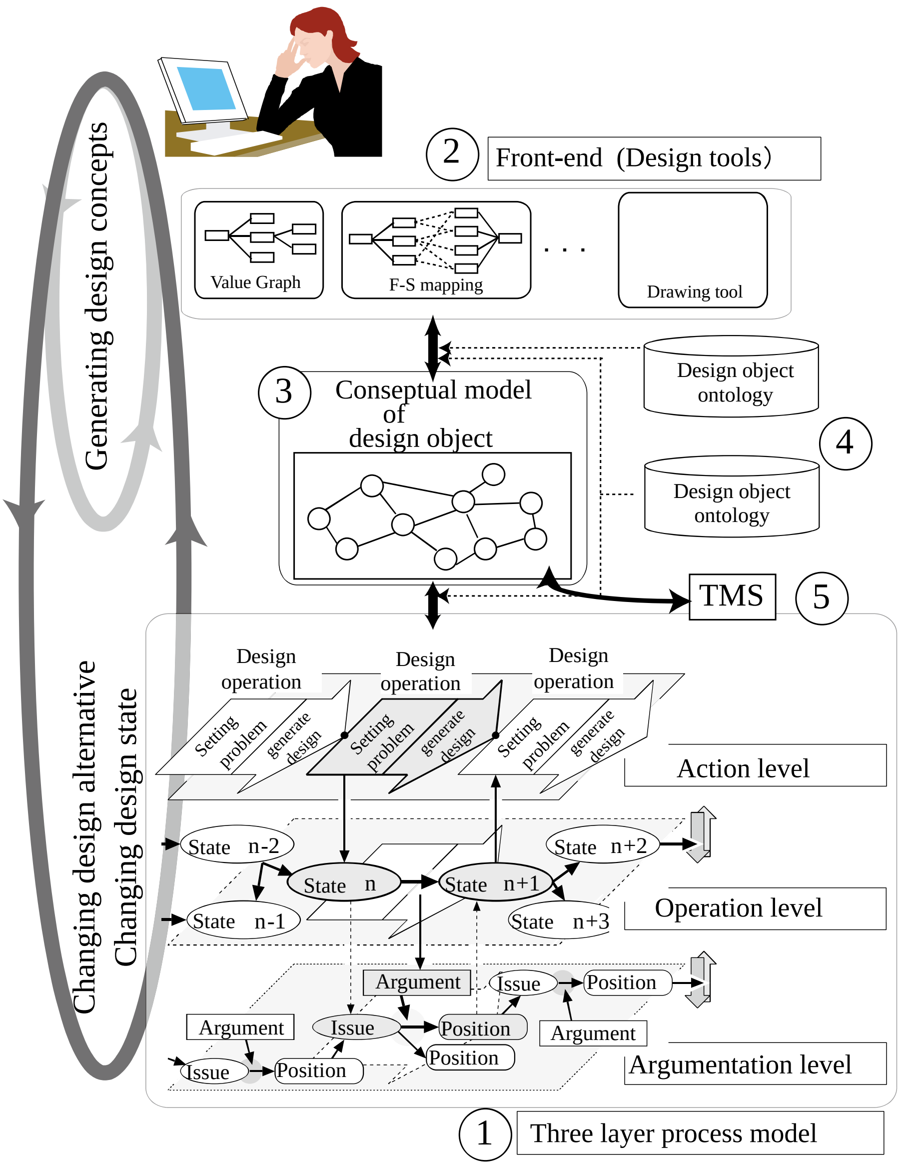

Figure 5. The Overview of Sketching Tool based-on DRIFT

4.2 Information Model of Integrating Verbal and Drawing Expression

Figure 6 shows classes of node that is used in the concept network and relations among the nodes in UML format. The node class that represents verbal expression, such as *function*, *entity* and *function-entity relation*, are already defined in our past research [5] that is formalized as an ontology (Figure 5–(4)). This research defines node classes of drawing expression, i.e. *sketch*, *draw layer*, *draw line* and *sketch derivation relation*. A draw line is a primitive element of drawing expression. Its node has information of coordinates of points composing the line, and information of line appearance such as line color, line type and line width. A draw line belongs to only one draw layer (Figure 6-(1)). A sketch is composed of multiple draw layers (Figure 6-(2)). A draw layer can be included in different sketches. A sketch is associated with an entity or a function that means a theme of the sketch (Figure

6-(3)). If there is a derivation sketch expressing the same theme in the detailed viewpoint or from the other direction, a derivation relation node is added to the related sketches (Figure 6-(5)).

4.3 Defining Design Operations

Defining design operations is especially important in the framework, because each design operation is the basis of recording design process and managing design alternatives. Some design operations performed on conceptual design tools, such as *developing function*, *developing entity* and *setting relation from a function to entities*, were defined in our past research [5]. This research defines design operations of drawing activities as follows.

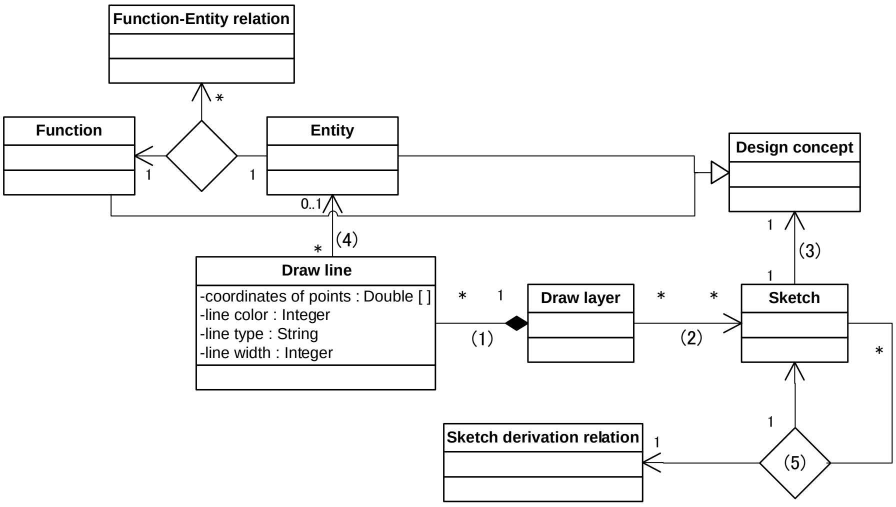

Figure 6. Node Classes and their Relation

1. Drawing a sketch about a theme of a function
2. Drawing a sketch about a theme of an entity
3. Setting layers of a sketch
4. Setting entities relating to a sketch
5. Drawing a detailed sketch
6. Drawing a sketch from the other direction

By associating each of those design operations to an operation of a drawing tool, the system automatically captures a history of operation and organizes design alternatives of each design operation. For example, an alternative of a sketch is organized to each theme of a function or an entity by the first and second design operation, respectively.

5 PROTOTYPE TOOL

5.1 Implementation

The prototype tool is implemented by object-oriented programing language Java (SDK 6.0) on Windows XP. WACOM LCD tablet DTU-710 is used in order to input drawing expression by pen gestures. Figure 7 shows a snapshot of coffee maker design process performed on the prototype tool. The left side of the prototype is a design process manager. Designers can change a current design state or change a current design alternative by one-click operation on a design process manager. The right side of the prototype is a drawing tool incorporated with a value graph tool and a function-structure mapping tool. A drawing tool consists of two sub panels. In a thumbnail panel, thumbnails of draw layers and sketches that are already drawn are displayed. Designers can change a draw layer and superposing a draw layer to a sketch. In a drawing panel, a designer can choose line color and line width, make a new draw layer by clicking corresponding button, and draw lines by pen gestures.

5.2 Design Example

An example design of a coffee maker shown in Figure 4 is performed on the prototype system. Figure 7 depicts its snapshot. A designer designates a theme of sketches as “coffee maker” that is represented by verbal expression in function-structure mapping tool. As design process continues, a designer draws many sketches and updates concepts using conceptual design tools. All draw layers associated with this theme are displayed in the thumbnail panel. A design process manager automatically organizes those sketches as alternative drawing expression of a coffee maker, and displays them in gIBIS format. Figure 8 shows the detail of the gIBIS representation. This shows that four alternatives of drawing expression are drawn. The right one displayed by a red node is currently accepted, and the other three alternatives displayed by a gray node are currently rejected. A design can reflect those alternatives by the gIBIS representation, and can write the contents of the reflection using an argument node. In Figure 8, a green node displays argument for the alternatives. This argument node shows that the current alternative is accepted because it has enough volume of water tank and cool appearance.

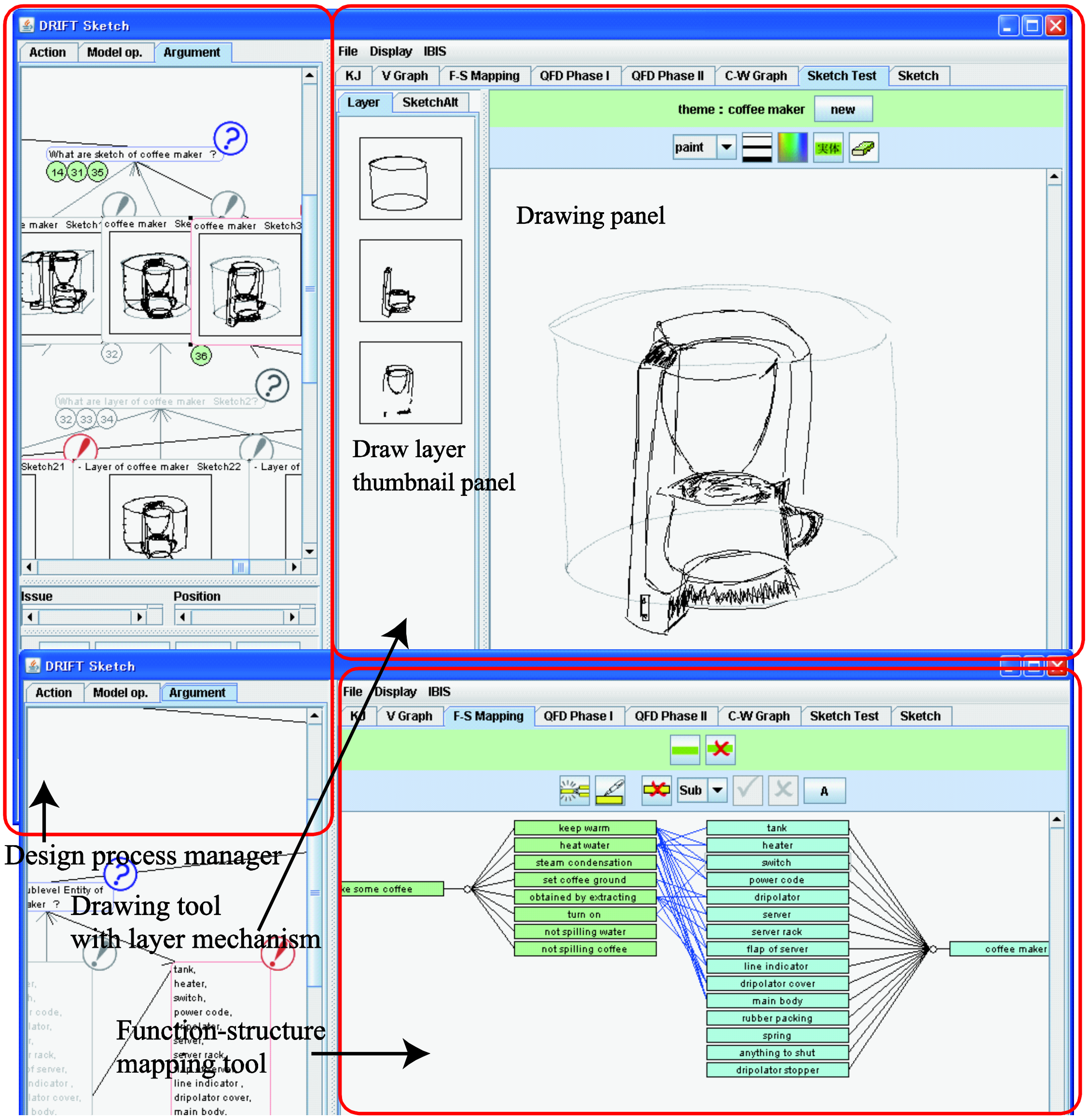

Figure 7. Snapshot of Coffee Maker Design Performed on Prototype Tool

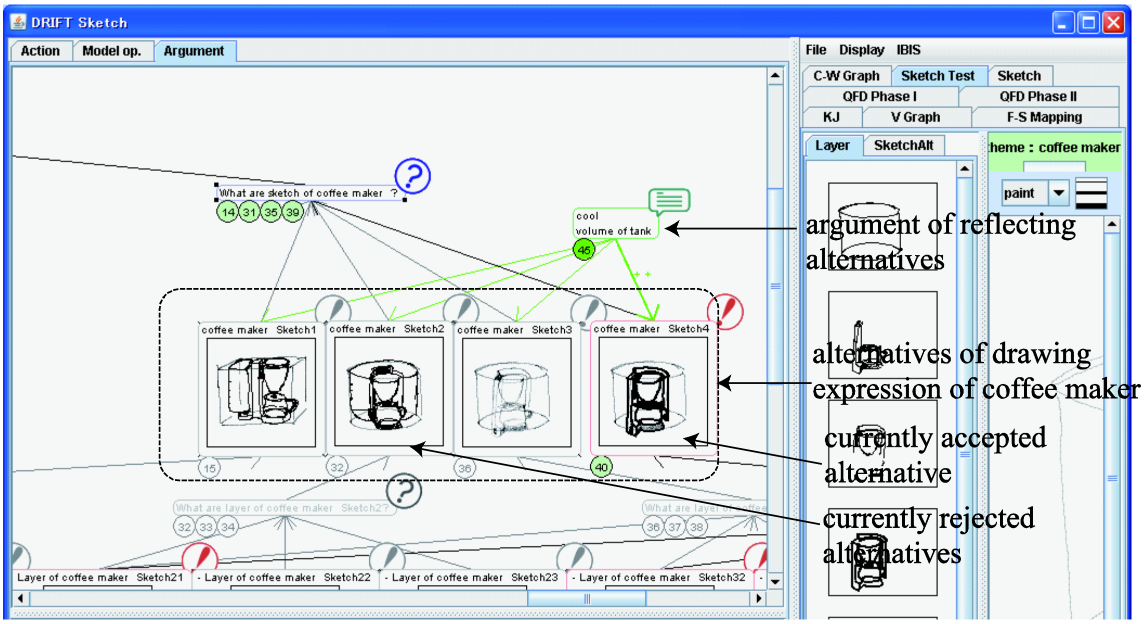

Figure 8. Automatically Generated gIBIS Representation of Alternatives of Drawing Expression

6 DISCUSSION

An iterative trial-and-error loop is an indispensable activity in conceptual design phase. Many researches of design protocol analysis show that iteration has not only negative but also positive impact, which makes designers reflect and flexibly change their own idea without falling into a single ordinary idea [28][29]. It enhances design performance and creativity. An advanced knowledge-based design support system should focus on the positive impact of iteration. A knowledge-based sketch tool introduced in Section 5 aims at such a design support system by promoting reflection and changing of thought. The sketch tool facilitates designers to represent verbal expression of design concepts using various conceptual design tools incorporated in DRIFT, as well as drawing expression of design concepts using a sketch tool with layer mechanism. The represented expression can be flexibly compared and changed by gIBIS and TMS mechanism. Those features are new and not yet focused by any sketch tools which have been developed by past researches [18][19][20][21][22][23][24].

By the design example shown in Subsection 5.2, it is verified that the prototype system can support a designer to represent both verbal and drawing expression, to reflect it by comparing alternatives, and to change it by an easy operation. These features facilitate design concept generation. We need more practical case studies in order to validate its effectiveness objectively. That is included in our future works.

7 CONCLUSION

This paper proposed a knowledge-based sketch tool that promotes reflective interaction of verbal expression and drawing expression for design concept generation. The tool manages a sketch layer which is a unit of superposition and associates it with expressed design concepts. The tool is integrated with some conceptual design tools such as a value graph and a function-structure mapping, which represent design concept in verbal expression, in order to represent both verbal and drawing expression. It captures all operations on the expression, automatically organizes alternatives of design concepts as well as alternatives of drawing so as to help a designer easily compare with each other and flexibly change an alternative. The prototype system was implemented based on a framework of DRIFT. The example process of coffee maker design showed the facility of the proposed system. The prototype system can support a designer to represent both verbal and drawing expression, to reflect it by comparing alternatives and to change it by an easy operation. These features facilitate reflectively interact with verbal expression and drawing expression, and then facilitate design concept generation.

Our future works include the further validation of the proposed system by more practical case studies. Collaboration among designers promotes design concept generation, because designers can share knowledge, stimulate each other and notice more from externalized expression. Incorporating a networked environment for collaboration is also included in our future works.

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