A COGNITIVE STUDY OF SHAPES AND FUNCTIONS IN DESIGN SKETCHES

Simulating an Industrial Design Case by Neural Networks

YING-HSIU HUANG
Institute of Applied Arts, National Chiao Tung University, Hsinchu Taiwan 30050, China

Abstract. The present research focuses on transforming shapes that had been drawn by designers on the sketches and on evaluating the shapes from design requirements. In this research, neural networks simulate the result from collecting shapes that designers transformed from original shapes and evaluations from all ones. There are four steps in this research: First, a cognitive experiment. I collected real shapes that designers drew and evaluations from the experiment in order to training the neural networks. Second, a transforming neural network is simulating the behavior in which designers transformed one shape into another without evaluating the design requirements. Third, a evaluating neural network that trained by the evaluations that collected from the experiment is simulating how designers criticized the shapes in terms of design requirements. Fourth, modifying program is trying to modify the evaluations that had been criticized by designers from all shapes and generating a new shape from modified evaluations. This research proposed a synthetic system that simulating the behavior during design sketching, therefore, computers could also generate some ideas like human designer.

1. Introduction

Designing is one kind of mental activity. During design processes, there are many ambiguous and intuitive behavior (Akin, 1984). Designing behavior is so complex that many researchers have attempted to reveal the behavior of design.
The processes of design thinking had described by many researches. Designing is a process of the "analysis and synthesis"(Alexander, 1964). Subsequently, Schön and Wiggins (1992) proposed that solving design problem is a process of the "seeing-moving-seeing". They emphasized the importance of seeing in design processes.

Before investigating the visual cognition in design processes, many scholars discovered the phenomena of visual cognition from general visual theories (Kosslyn et al., 1983; Kosslyn, 1990; Reed, 1974). During the processes of seeing, not all of the objects that presented on the retinal were saw simultaneously. Nevertheless, a small area or one of these objects could been attended (Palmer, Ames and Lindsey, 1993).

Moreover, the design cognition has been discussed from the view of visual cognition. Liu (1995) studied the phenomena of seeing shapes between the

experienced and non-experienced designers. He discovered that experienced designers could see more implicit shapes from the original shapes than non-experienced designers did. Some other researchers directly investigated the seeing behavior from design sketching by protocol analysis in order to survey the design behavior (Goldschmidt, 1991, 1992, 1994). Subsequently, many researches discovered that the behavior of idea sketching is the most important and creative section in design behavior. Then they discussed the structure of sketching behavior (Verstijnen et al., 1998; Kavakli et al., 1998; McGown et al., 1998; Purcell and Gero, 1998).

Connectionist models explore how to connect neurons together to manipulate for high-level cognition, such as classification, pattern recognition and memory retrieval. Many different connectionist models which simulate how a brain works had been developed, such as perceptron (Minsky and Papert 1969), pattern association (PA) model (MeClelland and Rumelhart, 1989), back propagation (BackProp) model (Rumelhart et al., 1986a).

The neural networks could been trained sequentially by training patterns. Therefore, they can recognize shapes and transform them into other ones. The well-trained neural networks can recognize incomplete shapes, and transform them into attributes stored in the memory, as human visual behavior.

2. Problem Statement

During human designing behavior, Schön and Wiggins (1992) proposed that designing behavior is a sort of the "Seeing-Moving-Seeing" process. They emphasized the importance of seeing in design behavior. Liu (1996) proposed that the visual cognition behavior separated in to two levels: recognition and transformation. In the recognizing process, people focused their visual searchlight and then selectively recognized the shapes that they saw. After recognizing, they encoded the object that they attended, and put it into working memory. In the transforming process, designers who had recognized shapes retrieved transforming rules from the long-term memory, and transformed the original shape into another one.

In the idea sketches, there are many ambiguous and implicit shapes. Designers will recognize the shapes from sketches and associating other ones (Liu, 1993). Simultaneously, designers are also considering the functional needs of shapes (Schön and Wiggins, 1992). Liu (1996) proposed that designing is a combination of two search models: restructuring search and transforming search. However, his conclusion is a theoretical model. In his research, Liu emphasized the visual behavior of recognizing and transforming shapes. He simulated the behavior by neural network, and pointed out the content-addressable memory simulations of design shapes have proposed a new idea for shapes transformation, which retrieved knowledge from the long-term memory to the

working memory. On the other side of two-search model, transforming search, he didn't simulated by computer systems.

On the other hand, Stiny (1980) proposed a shape grammar system that solved the problems of design shapes and building functions by techniques of symbolic approach. However, this system only generated more shapes by applying some shape grammars, but it wasn't able to evaluate the shapes in terms of design requirements. In addition, Akiner (1986) proposed a knowledge-based system that reasoned the relationships between object and space. He emphasized the rule applications in the space. However, the system couldn't recognize the shapes in the space.

During idea sketching, the development of design thinking in designers' mind is serial (Suwa et al., 1998). Designers will laterally generate some idea from one part of entire design that decomposed by designers (Goel, 1995). Furthermore, they will evaluate the new-generated shapes in terms of functions and design requirements (Schön and Wiggins, 1992). Then they will modify the shapes in order to matching the design requirements. In this research, I illustrated the visual behavior of idea sketches during the design processes (Figure 1.).

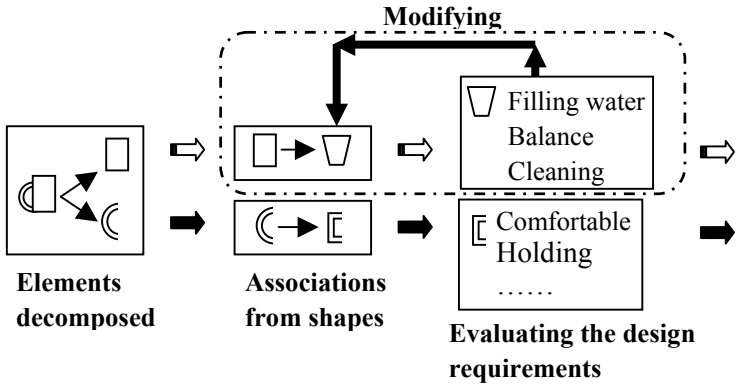

Figure 1. The visual behavior of idea sketches during the design processes

Therefore, the objective of this research is exploring the phenomena of shape transformations and evaluations that discovered from designers' behavior in the idea sketches, and simulating the phenomena by neural networks. Then, the computers could make some ideas like human designing behavior. This system is combating with two neural networks and one modifying program (Figure 2.). All of them are devoting to simulate some parts of the design thinking behavior in the design sketching section.

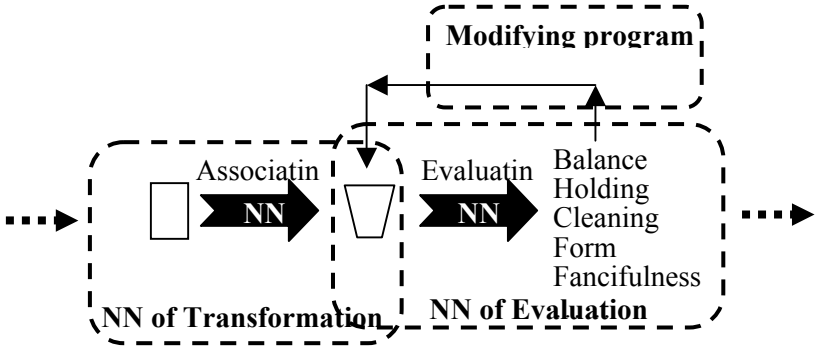

Figure 2. The structure of the combination system

3. Objective

Recently, many researches explored the design behavior of the idea sketching section from cognitive experiments. After realizing some theories of the visual cognition, they initially simulated some cognitive behavior, such as recognition, transformation and association, by neural networks (Coyne and Newton, 1989; Liu, 1993,1995, 1996a, 1996b; Rueckl et al., 1989). On the other hand, some researches aimed the design knowledge applications that found from design processes, and then simulated the rule applications by computer systems (Stiny, 1980; Akiner, 1986; Liu, 1991).

During the development of ideas in the design sketches, two kinds of the phenomena that mentioned above are rapidly and repeatedly operating in the brain of designers. Therefore, combining two sort of the researches will let people realize the design behavior more than before. The objective of this research is exploring the transformations and evaluations from shapes that designers saw in the sketches in the design processes, and simulating the visual cognitive behavior in the design sketches by neural networks. Furthermore, the computer has some design cognitive behavior like a designer, and makes some suggestions from current shapes.

4. Methodology and Steps

The simulation of idea sketching is a serial process. First, recognizing the shapes from idea sketches is the most important step of the design behavior. In this step, the transformation of the shapes that had been recognized in the sketches is simulating the “seeing” activity of design behavior and then generating other shapes from the shapes they saw. Moreover, the next step is

evaluating the new generated shapes in terms of design requirements. After before section, it will modify shape from the lack of the evaluations and generate the another shape. The structure is illustrated from computer operation (Figure 3.).

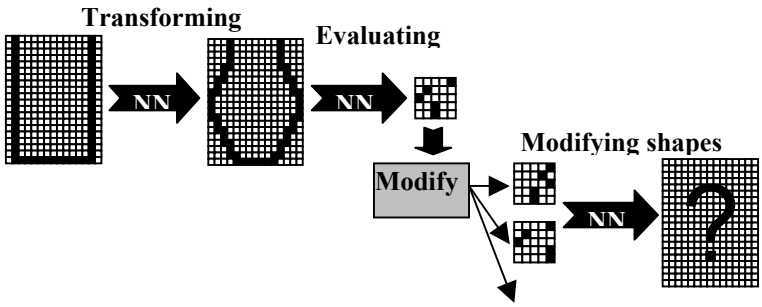

Figure 3. The serial process of computer simulation

In terms of computer generation, the serial process that illustrated above is the most efficient system. But in terms of visual cognition of designers, the knowledge-based systems of evaluations and modifications of shapes belong to the same knowledge. Therefore, the knowledge of evaluations and modifications will be simulating by only one neural network (Figure 4.).

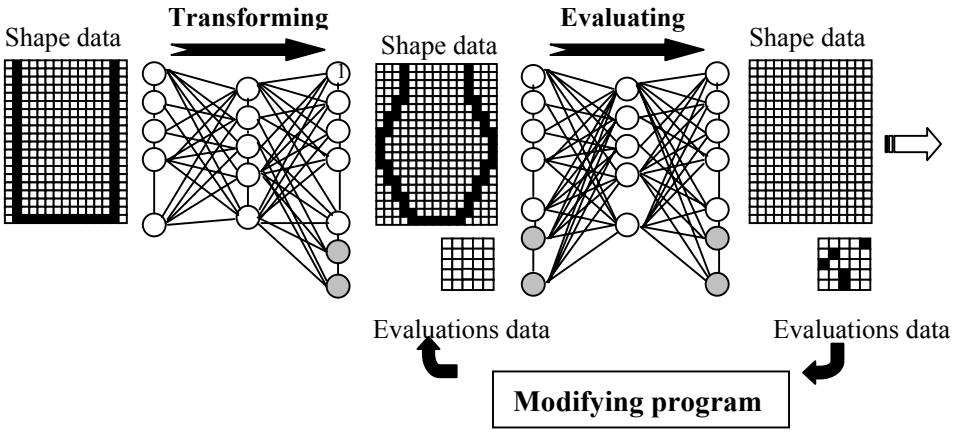

Figure 4. The serial process of computer simulation

The system includes two neural networks that simulated transformations and evaluations by different one. This research contains four steps. First. The cognitive experiment. We collected real shapes that designers drew and evaluations from the experiment in order to training the neural networks. Second,

the transforming neural network is simulating the behavior in which designers transformed one shape into another without evaluating the design requirements. Third, the evaluating neural network that trained by the evaluations that collected from the experiment is simulating how designers criticized the shapes in terms of design requirements. Fourth, modifying program is trying to modify the evaluations that had been criticized by designers from all shapes and generating a new shape from modified evaluations.

4.1. COGNITIVE EXPERIMENT

The cognitive experiment separate into two steps, one is transforming shapes of cups from original ones; the other one is evaluating all of the cups in terms of design requirements. The first step is associating by a professional designer who had 10-year experience of cup design. He generates one shape from each cup shape on the card laterally. Then he evaluates all cup shapes including original and new-generated shapes in terms of design requirements. Further more, the shapes and data of the two steps will train the next two neural networks.

Original shapes – There are 20 original shapes that tested by the professional designer (Figure 5.). Each shape was printed on the card which fold in the first step experiment. The designer is generating shapes on each card without evaluating the design requirements. Then he opened the hold card and evaluated all shapes in the scales on the back of card.

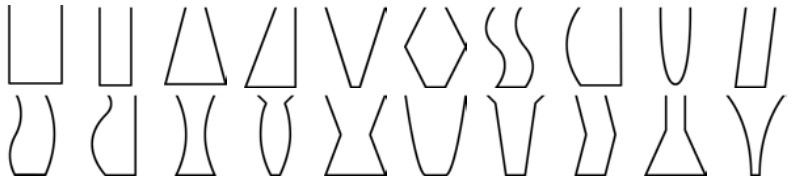

Figure 5. The original cup shapes

Subject – a professional designer who had 10-year experience of cups design.

Process – first, he generated one shape on each card without evaluating. Second, he evaluated all of the shapes on cards.

Design requirements – there are 5 design requirements including balance, holding, cleaning, form and fancifulness. Each requirement has 5 scales.

4.2. THE TRANSFORMING NEURAL NETWORK

In this section, the network is simulating the behavior of seeing ambiguous or clear shapes in the sketches, and then transforming the original shape into another one that retrieved from the long-term memory. It is a multi-layer

backpropagation neural network, and its knowledge representation of this network is the bitmap model that proposed by Hinton (1989).

Structure – The structure of this network is a 300-250-325 network. The input layer has a matrix of 15x20 grids. But the other end of this network, the output layer has two matrices. One is demonstrating the shape data (15x20), and another is demonstrating the evaluating data (5x5). The hidden layer has 250 units.

Training patterns – the training patterns of this network are collected from the prior experiment. The original shape on each card is the input pattern, and the new-generated shape is the output pattern.

Simulating conditions – the learning rate is 0.1, and total error is 0.05.

4.3. THE EVALUATING NEURAL NETWORK

In this section, the network is simulating the behavior of evaluating shapes that transformed from the sketches. The knowledge of evaluating shapes in design behavior is not only the evaluations of the design requirements, but also the interactions of shape and its evaluations. Therefore, this network will been trained by the interactions of shape and evaluations. These interactions had been collected from the prior experiment. This network is also a back-propagation neural network, but its knowledge representation of this network is the object-oriented model that proposed by Hinton (1989).

Structure – The structure of this network is a 325-250-325 network. The input layer or out layer has two matrices. One is demonstrating the shape data (15x20), and another is demonstrating the evaluating data (5x5). The hidden layer has 300 units.

Training patterns – the training patterns of this network are collected from the prior experiment. The training patterns are combined by shapes and evaluations. Each shape has its own evaluations and these evaluations have one shape themselves (Figure 6).

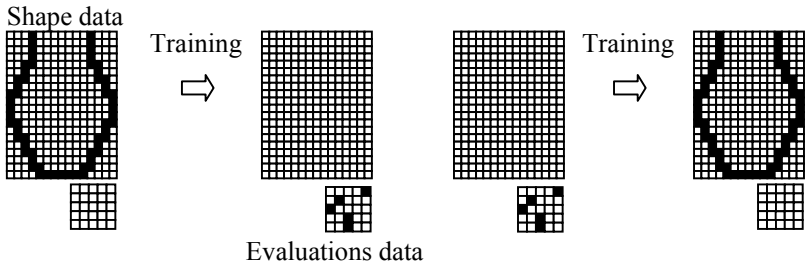

Figure 6. The train patterns of evaluating neural network

Simulating conditions – this neural network of evaluations is a 325-300-325 network. The learning rate of the network is 0.1, and total error is 0.05.

4.4. MODIFYING PROGRAM

This program attempts to simulate the modifications of human when they evaluated the shape and tried modifying the shape in terms of the lack of design requirements. Generally, the shape matched all of the design requirements is the better design. However, the simulations of neural networks are not as well as real design situations. As a result, the modifying program attempts to modify some evaluations that evaluated from the prior network. Then putting each modified evaluation into the evaluating network will get some possible suggestions that the network learned from cognitive experiment.

Combining the transforming and evaluating neural network and modifying program will become a system that can preliminary simulate the visual transforming and evaluating behavior of design sketching section. The system could have more real behavior than other system before.

5. Results

The result of this research is tested by four ambiguous shapes that modified form the original shapes. Getting the four ambiguous shapes from the original shape is as similar as the ambiguous shapes that designers saw on the sketches. Then the transforming neural network will generate another one retrieved from the network. After transformation, next network will evaluate the shape in terms of design requirements. The evaluative data display the characteristic of the shape. Using the modifying program improves one or two design requirements of the shape. Then putting the modified evaluations into the evaluating program will get a suggestion from the network that trained the evaluations. Therefore, the computers do what designers can do (Figure 7.).

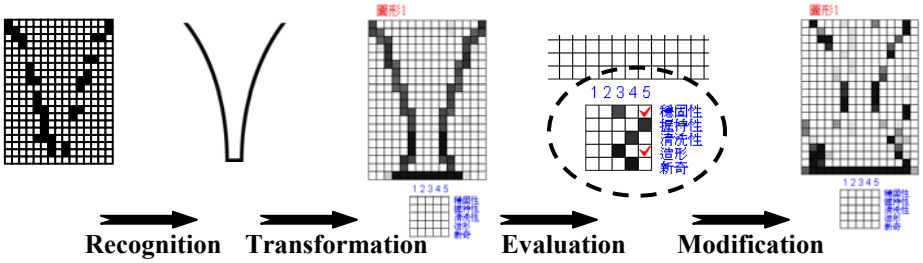

Figure 7. The test of example one

In the example one (Figure 7.), the modifying program improves the balance and form. In terms of balance (marked), we can find the bottom of modified shape is wider then transformed one. This suggestion matches our design requirement. Therefore, the system may have ability make modification in terms of design requirements.

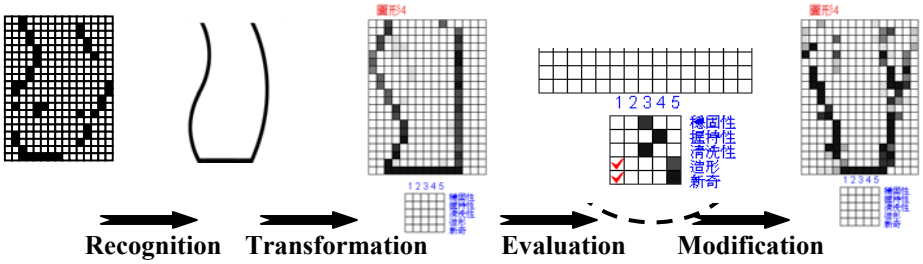

Figure 8. The test of example two

In the example two (Figure 8.), the modifying program reduces the level of form and fancifulness (marked). We can see the modified shape as similar as we saw on the market. Therefore, the system will have some behavior that designers had.

6. Conclusions

This research will collect the training data from the cognitive experiment, and explore the relationships between the shapes and evaluations. Furthermore, simulating some visual cognitive behavior by neural network can make the computers modify the shapes in terms of design requirements. As a result, the computer will be a designer like a human designer in the future.

This research is a preliminary idea that combines two kinds of design knowledge representations. Practically, the knowledge that used by designers in the design processes is not only the design requirements that I defined for the experiment, but also other general and professional knowledge. In this research, I only explore the relationships between shapes and some of the design requirements. In addition, some models of human design thinking are not distinct in contemporary researches. It is impossible that computer can simulate all behavior that surveyed from human activities. For example, the modifying program is a limitation of AI. How designers modify the shapes that they saw from the sketches are not able to predict. They considerate either the lack of design requirements or self-intuition. Therefore, the modifying program in this research only demonstrated the possibilities that suggested by computers which were trained with some shape transformations and evaluations from the cognitive experiment.

During the design processes, the ideas that generated in preliminary stage

had very important effect in the next stages. Researchers are trying to realize the phenomena of shape associations and simulating by the computer systems. Consequently, computer systems may also generate more different associations that matched the design requirements. This research attempts to realize the relationships between the shapes and design knowledge, and lets computers that absorbed the knowledge from human behavior are able to design possibly.

References

Akiner, V. T.: 1986, Topology-1: a knowledge-based system for reasoning about objects and spaces, *Design Studies 7*(2), 94-105.

Alexander, C.: 1964, *Notes on the synthesis of form,* Cambridge, MA: Harvard University Press.

Coyne, R. D. and Newton, S.: 1989, Design reasoning by association, In *Environment and Planning B,* Vol.17, 39-56.

Gero, J. S.: 1985, Logic programming as a means of representing semantic in design languages, *Environment and Planning B,* Vol.12, 351-369

Goldschmidt, G.: 1991, The dialectics of sketching, *Design Studies 4,* 123-143.

Goldschmidt, G.: 1992, Serial sketching: visual problem solving in designing, *Cybernetics and System: An International Journal,* Vol. 23, 191-219.

Goldschmidt, G.: 1994, On visual design thinking: the vis kids of architecture, *Design Studies 15,* 158-174.

Kosslyn, S. M., Reiser, B. J., Farah, M. J. and Fliegel, S. L.: 1983, Generating Visual Images: Units and Relations, *Journal of Experimental Psychology: General,* Vol. 112, No. 2, 278-303.

Kosslyn, S. M.: 1973, Scanning visual images: Some structural implications, *Perception and Psychophysics 14*, 90-94.

Kosslyn, S. M.: 1990, Mental Imagery, *Visual Cognition and Action,* Vol.2, 73-97.

Liu, Y. T.: 1993, A connectionist approach to shape recognition and transformation. In *Flemming U and Van Wyk s (Eds.) CAAD Future '93* Elservier, Amsterdam.

Liu, Y. T.: 1995, Some phenomena if seeing shapes in design, *Design Studies 16*, 367-407.

Liu, Y. T.: 1996a, Restructuring shapes in terms of emergent subshapes: a computational and cognitive model, In *Environment and planning B*, Vol.23, 313-328

Liu, Y. T.: 1996b, Is designing one search or two? a model of design thinking involving symbolism and connectionism, *Design Studies 17*, 435-449

Newell, A. and Simon, H. A.: 1992, Human problem solving prentice-hall, *Englewood Cliffs NJ*.

Palmer, J., Ames, C. T. and Lindsey, D. T.: 1993, Measuring the effect of attention on simple visual search, *Journal of Experimental Psychology: Human Perception and Performance*, Vol. 19, No. 1, 108-130.

Reed, S. K.: 1974, Structural descriptions and the limitations of visual images, *Memory & Cognition*, Vol. 2, No. 2, 329-336.

Rueckl, J. G., Cave, K. R., and Kosslyn, S. M.: 1989, Why are “What” and ”Where” Processed by Separate Cortical Visual Systems? A Computational Investigation, *Journal of Cognitive Neuroscience.*

Schön, D. A. and Wiggins, G.: 1992, Kinds of seeing and their functions in designing. *Design Studies 13*, No.2: 135-156.

Stiny, G.: 1980, Introduction to shape and shape grammars, *Environment and Planning B 7*, 343-351.