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Apply Linkogragh to Sketch Ideas in Design Modeling

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Abstract: The purpose of research on design thinking and the design process is to analyze the source of designers' innovation ability and find out the rules of design behavior and the key factors affecting design practice. Sketching is one of the most important activities in design practice, and the process of sketching is inseparable from creativity. In design modeling, the sketch thinking of designers, that is, "drawing graphics to help thinking", is the description of sketch behavior from the perspective of cognition. Based on the sketch ideas obtained by designers in modeling design, we analyzed the design process to find commonalities and differences in the sketch ideas of novice designers. Two subjects were selected to sketch for 30 min each, and the whole design process was recorded. We used linkography to identify the behaviors of the designers in sketching as design moves and links. At last, we built linkographs to present the process of designers identifying shapes from fuzzy sketches to new ideas. Based on the similarities and differences in the sketch ideas between designers, we provided suggestions and considerations to improve design methods and support creative design for novice designers.

1. Introduction

Design is a specialized creative behavior. Generally, the purpose of design is to achieve an expected state or ideal result that does not exist for the time being, and such an expected target often cannot be easily satisfied by existing design solutions. The problems confronting designers are often ambiguous and complicated, requiring them to rely on their insights, instead of fixed standards and decompose the problems and envision possible outcomes of their approaches. Many design solutions appear to be developed in rather accidental and random processes instead of via specific steps or operations. Therefore, terms like the "stroke of genius" and "eureka moment" are often used to describe the process of design thinking and reasoning, which is widely considered a "black box". Recently, we have witnessed numerous studies and approaches attempting to decipher the "black box" of the design thinking and reasoning process, to find the source of designers' innovation and replicable patterns in specialized design behaviors. The research questions relevant to such a quest include "How to think like a designer?", "In which stage does a designer make breakthrough progress?", or "What is the difference in thinking patterns between expert and novice designers?"

The sketching process has been a topic of much interest in relevant studies. As one of the most important activities in design, sketching plays an irreplaceable role in the positioning, development, extrapolation, and formation of modeling concepts (Sun, Wang, Chai, Feng, and Xiang, 2013). The sketching process is inseparable from the designer's reasoning approach and creativity. In this research, we applied linkograghy as a technique to record and visualize the sketching design process. We attempted to reveal the similarities and differences between designers in creative exploration and design expression in the design thinking dimension.

2. Literature Review

2.1. Design Thinking and Reasoning

Presently, many researchers see the design process as a reasoning process based on designers' knowledge. Examining designers' thinking patterns and reasoning methods helps researchers understand the process of how design problems are tackled. Drawing on achievements of existing studies, we divided the frameworks describing the design thinking and reasoning process into two categories.

- Cycle of Thinking-Expression-Reflection (Sun and Xiang, 2021). This descriptive framework focuses on the process of cognitive processing and summarizes designers' behaviors into a cycle of drawing, checking, and thinking (Cross, 2006). The framework highlights the three types of key behaviors in the design process: (1) producing inspirations for specific problems, (2) expressing design solutions using sketches or prototypes, and (3) reflecting on the solutions to advance the thinking and

discovering new inspirations (Cross, 2006). In this process, design expression represents an important constituent of design thinking. Designers rely on the expression of sketches or prototypes to stimulate inspiration and address design problems.

- Co-evolution of Problem-Solution (Dorst and Cross, 2001; Sun and Xiang, 2021): Focusing on changes in problems and solutions in design, this framework emphasizes that design problems and solutions are mutually aroused in their co-evolution (Dorst and Cross, 2001). In the design process, designers raise new design problems (definition) or propose new design solutions (generation) based on their understanding of the design problem; designers' evaluation of design solutions gives rise to new design problems (analysis) or inspires new design solutions (evolution) (Sun and Xiang, 2021).

The Co-evolution of the Problem-Solution model describes the diverging and converging characteristics of design thinking in the design process, as well as the continuously changing attribute of design solutions. Such a perspective of understanding echoes descriptions of mainstream design thinking models, that is, a designer defines and refines problems and generates solutions based on these problems. For example, the Stanford d.school asserts that design thinking deconstructs design practices into modules of Empathizing, Defining, Ideating, Prototyping, and Testing and a model encompasses all processes from problem definition to solution generation (d.school, 2022). In actual design activities, a designer's design thinking exhibits a pattern of alternating divergence and convergence, with the former generally appearing first and the latter later (Leifer and Steinert, 2011).

2.2. Linkograghy

Proposed by Goldschmidt, linkograghy is a technique for unfolding the design process (Goldschmidt, 2014) (Fig. 1). It has many advantages: researchers may use it to identify a designer's thinking nodes, the design process is not limited by the number of designers, and the linkograghy can completely present the design thinking process at specific times in the form of linkographs (Kan and Gero, 2008). Linkograghy helps researchers concentrate on designers' behaviors like observation, information, and solution searching. Essentially, linkograghy is to describe the design process as a set of links between design behaviors, which can be visualized as connecting lines between a series of dots (Goldschmidt, 2014). In terms of representation forms, a linkogragh is comprised of elements such as design moves, links, designer codes, and critical moves (Goldschmidt, 2014). Researchers not only observe how the links between design moves exist in graphs of different stages, but use quantitative analytical methods such as calculating the number of critical moves and link index, to measure a designer's productivity (Kan and Gero, 2008). The following are key elements used in this research (Goldschmidt, 2014; Hatcher et al., 2018; Kan and Gero, 2008). Design moves such as a step, an act, or an operation transform the design situation.

- Link- the relationships among the move form links: Goldschmidt identified two types of links. Backlinks are links of moves that connect to previous moves and forelinks are links of moves that connect to subsequent moves.
- Critical moves (CM) are design moves that are rich in links. CM^n is a critical move with more than N links.
- Link index is the ratio between the number of links and the number of moves.
- Link patterns: (1) Chunk is a group of moves that are almost exclusively linked among themselves, (2) Web is a large number of links among a relatively small number of moves, and (3) Sawtooths is a special sequence of moves link each to proceeding move.
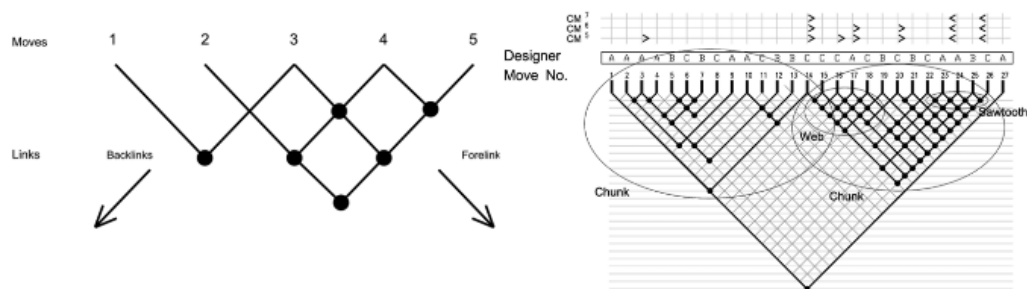

Fig 1. Key elements of linkograph (Goldschmidt, 2014).

2.3. Sketch Ideas

We focused on the sketching process in this research. Sketching is a vital procedure for a designer to attain the final design solution (Cross, 2006). In the sketching process, a designer needs to carry out intensive design thinking, sketch expression, and visual stimuli-feedback work to constantly generate the new shape. The sketch ideas arising from this stage, that is, the "drawing graphics to help thinking", represent a description of sketching behavior from a cognitive perspective. In the sketching process of a designer, the stages of creative exploration and expression alternate repeatedly, with sketch ideas showing a pattern from divergence to convergence. In the creative exploration stage, a designer constantly stimulates his/her thinking to explore the effect of design knowledge and generate new cognition by affirming the parts of observation, thinking, discrimination, and judgment while negating others. In the creative expression stage, a designer records the shapes on paper and then evolves and associates procedures with original shapes, followed by the interpretation of newly generated creative ideas (Sun, Xiang, Chai, Wang, and Huang, 2014). The key factor of sketch ideas is how a designer recognizes shapes from vague sketches and then converts them into different distinct shapes, that is, repeated observation and generation of new ideas based on finished ones. Exploring designers' sketch ideas helps researchers better understand the evolution of the sketching process, thereby providing a basis for design education.

3. Research Methods and Procedure

We carried out a design modeling experiment with a specific theme to examine sketch ideas. As a central analytical tool for this research, linkograghy was used to graphically visualize the sketching process of different designers. We first identified the critical moves and link patterns in the linkogragh and then commonalities and differences of designers' thinking in the generation process of sketch ideas using qualitative and quantitative analytical methods.

3.1. Experimental Design

In this experiment, two sophomore undergraduate students majoring in digital media were recruited. With an average age of 20 and a design learning experience of 2.5 years, they were both novice designers. The test was conducted in the exclusive computer lab of the School of Design based on the course Modeling Design of Animation Characters. The theme of the experiment was "Animation Character Design based on Traditional Cultural Elements related to the Guangdong-Hong Kong-Macao Greater Bay Area". The two designers were required to carry out 30-min sketching according to the theme. They were asked to sketch the standing front view of characters using a uniform drawing tablet provided by the computer lab. We used the screen recording software to record the entire sketching process. To ensure the quality of the experiment, the two designers experimented independently with consistent operating procedures, and neither interfered with the other during the sketching process. The sketches of character modeling completed by the two designers are as follows (Fig. 2).
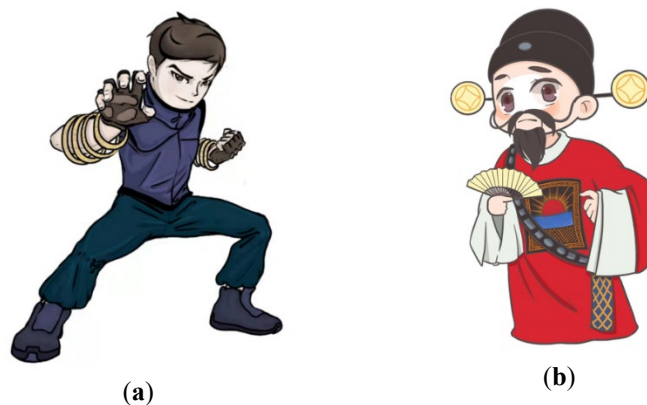

(a)   (b)

Fig 2. Sketches by two designers (**a**) Sketch by Designer 1; (**b**) Sketch by Designer 2.

3.2. Data Encoding

Two coders participated in the encoding of experimental data. Using the manual encoding method, they extracted key information from three stages of operation and collaboratively completed data encoding for the two videos recorded on the screen. The main steps are as follows.

- Encoding sketching steps and behaviors: The coders divided the sketching process into steps of creative exploration (A) and creative expressions (B). After that, the steps were aligned and coded separately. In the two steps, drawing (O) behaviors such as drawing a shape and overstriking a character's contour and texting were identified as creative expressions of the designers,

while the remaining non-drawing (X) behaviors such as moving, pausing, or erasing were identified as a creative exploration of subjects.

- Building linkography of the sketching process: The coders first found out key sketching behaviors and then recorded them as design moves. Subsequently, the experimenters constructed the links between design moves by comparing them with the sketching progress and design logic in the original videos, then recorded the attributes of the links, such as forelinks, backlinks, or both.
- Identifying critical moves and link index: The coders identified design moves with more than 5, 6, and 7 links critical moves and labeled them with corresponding steps of sketching. The link index of the two graphs was determined by the ratio of the number of links to the number of moves. On that basis, the experimenters identified specific link patterns from the two linkograghs based on Goldschmidt's approach and then analyzed the commonalities and differences of the two designs in sketch ideas and creative productivity.

4. Results and Discussion

4.1. Linkograraghy of Sketching Process

In the sketching process of Designer 1 (Fig. 3), 89 design moves and 173 links were identified. From the perspective of sketching steps, among the 89 design moves, three were used for creative exploration, and 66 were used for creative expressions. In combination with the images of original video files, we observed the priorities of the subject's thinking over sketching from the linkograghs. Designer 1 showed few moves in the color and shadow expression stage coupled with sparse links, but more design moves in the regional structure refinement stage coupled with dense links. From a perspective of sketching behaviors, 7 design moves fell in non-painting behaviors in Linkograghy 1, while the remaining 82 moves are painting behaviors, representing a ratio of 7:82. These two behaviors appeared alternately across different character design stages in a rather regular manner, exhibiting insignificant span of leaps between links. This showed that Designer 1 was accustomed to stopping drawing and shifting to explore information when he met a problem before continuing with the creative expression.
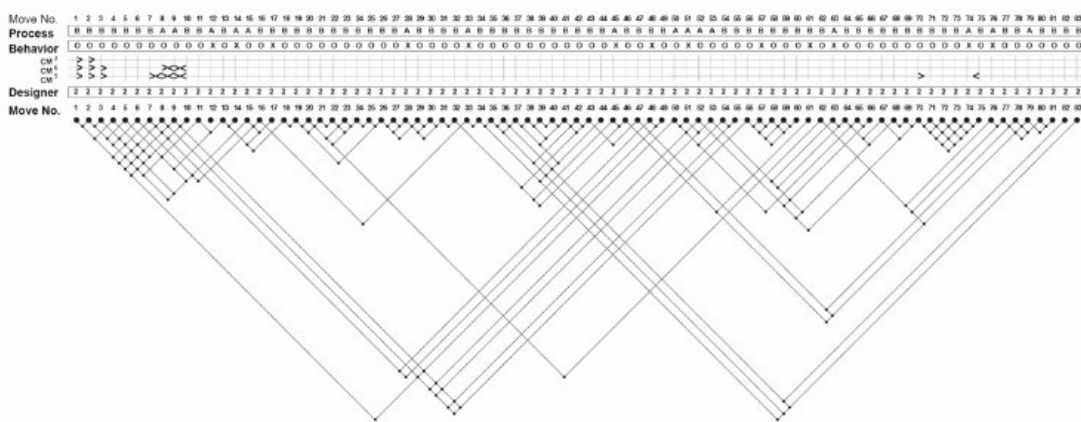

Fig. 3. Linkography 1.

In the Linkography of Designer 2 (Fig. 4), 83 design moves and 163 links were identified. 16 were used for creative exploration and 67 were used for creative expressions. Compared with linkograghy 1, linkograghy 2 showed fewer and rather sparse design moves. This graph showed particularly dense links during the regional structural refinement, as compared with relatively sparse links during the skeleton construction and scale adjustment. From a perspective of sketching behavioral analysis, the ratio of non-painting to drawing behaviors in Linkograghy 2 was 13:70, showing a higher percentage of non-painting behaviors, and longer duration in the video, compared with those in Linkograghy 1. This indicated that Designer 2 was accustomed to concentrating on thinking first and then completing the sketching expression phase in a one-off manner.
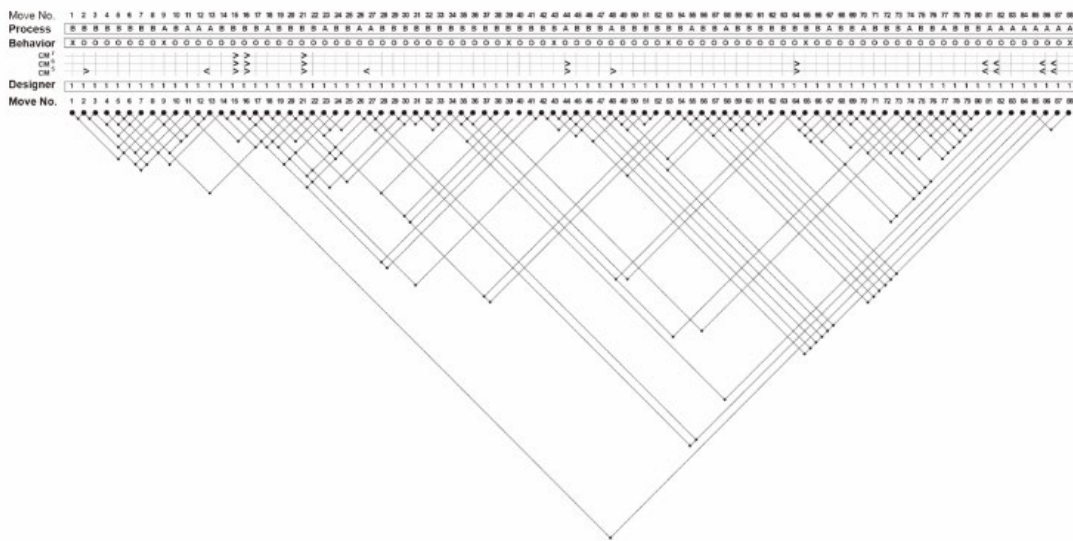
Fig. 4. Linkography 2.

4.2. Critical Moves and Link Patterns

Table 1 shows percentages of the number of critical moves to the total number of moves in the two linkograghs. Linkograghy 1 contains 13 critical moves, including 4 CM^5 (30.8%), 6 CM^6 (46.2%), and 3 CM^7 (23.0%). We compared the result with video images, finding that these 8 critical moves were respectively used to design the character's gesture, hairstyle, and style of the collar that matches the top clothing. Linkograghy 2 contains 11 critical moves, including 4 CM^5 (36.4%), 5 CM^6 (45.4%), and 2 CM^7 (18.2%). The highest number of critical moves, 9, occurs in the creative expression stage. The critical moves were mostly used in depicting facial expressions and designing clothing accessories.

Table 1. Critical moves analysis.

Designer 1	Linkography 1		
	$CM^5(\%CM^5)$	$CM^6(\%CM^6)$	$CM^7(\%CM^7)$
Forelinks	2 (50%)	2 (33.3%)	3 (100%)
Backlinks	2 (50%)	4 (66.7%)	0 (0%)
Total	4 (30.8%)	6 (46.2%)	3 (23.0%)
Designer 2	**Linkography 2**		
	$CM^5(\%CM^5)$	$CM^6(\%CM^6)$	$CM^7(\%CM^7)$
Forelinks	2 (50%)	3 (60%)	2 (100%)
Backlinks	2 (50%)	2 (40%)	0 (0%)
Total	4 (36.4%)	5 (45.4%)	2 (18.2%)

The link indexes of Linkograghy 1 and Linkograghy 2 were 1.94 and 1.96, respectively. Link index indicated that both designers rather put their efforts to achieve a synthesis. However, the link index cannot be used as the only criterion to directly determine the difference between the designers in creative design. Therefore, we used the three patterns proposed by Goldschmidt in an in-depth analysis of the structures of their reasoning process (Goldschmidt, 2014).

The links in Linkograghy 1 (Fig. 5) exhibited 4 chunks and 4 sawtooth tracks alternately, and links existing in the forms of groups and special series appeared between design moves concentrated in small-scale ranges. By comparing with video images, we found that design moves under the chunk pattern were mutually associated but not completely connected. Designer 1 obtained new ideas from non-adjacent moves as shown by the distinct progression of the sketch. Under the sawtooth tracks, design moves were only connected with adjacent moves, indicating that Designer 1 was trying new ideas by linear reasoning as the sketch progressed step by step. As such, we speculated that Designer 1 had stable opportunities to generate creative design ideas in the sketching process and he habitually checked relevant design problems and attributes to steadily explore the design solution.
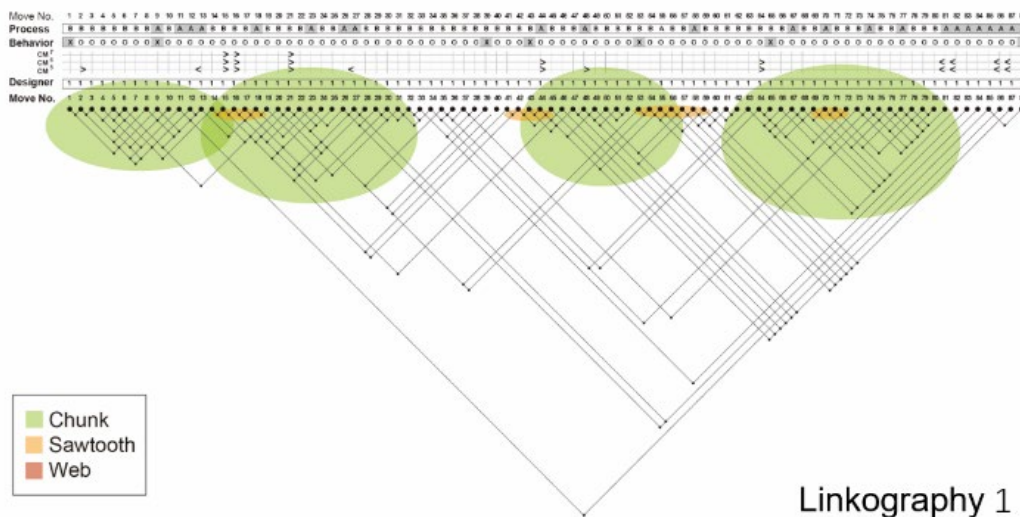
Fig. 5. Link patterns of Linkography 1.

In Linkograghy 2 (Fig. 6), 5 chunks and 6 sawtooth tracks also appear alternately, representing that Designer 2 achieved multiple breakthroughs. In the color and shadow expression stage, Linkograghy 2 also showed a distinct web pattern where the design moves were mutually connected to form a large-scale network. This indicated that design expression in this stage might arise from matured ideas of Design 2, and there were few opportunities for innovation. In Linkograghy 2, links during the creative expression stage showed large spans, indicating that the creative thinking of Design 2 was leaping and intrigued temporarily by abrupt inspirations that forced her to modify earlier shapes.
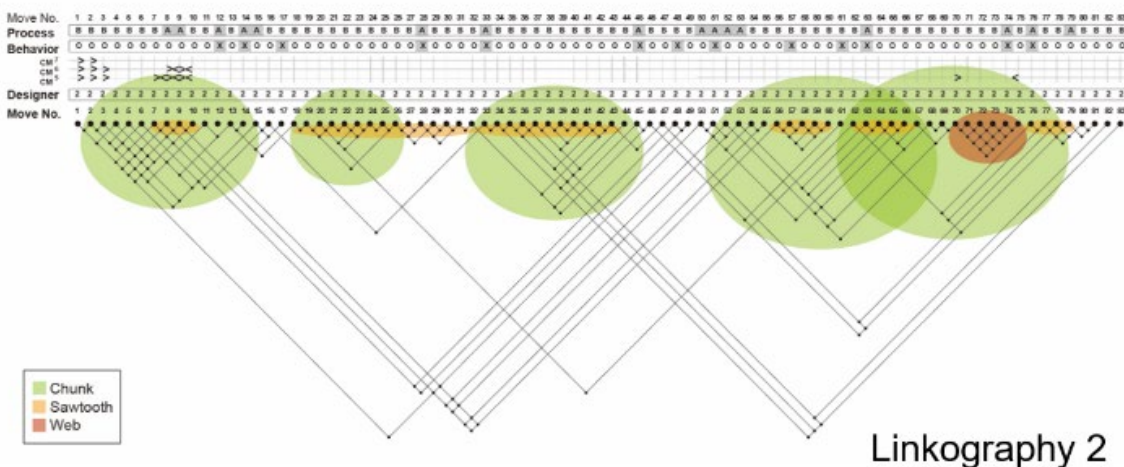

Fig. 6. Link patterns of Linkography 2.

Additionally, we further analyzed the link patterns, finding that the two linkographs showed fewer design moves related to the characters' skeleton construction. Even though progress was made, the two designers' sketch ideas were not professional enough. This result indicated that novice designers involuntarily paid less attention to the overall modeling and more to detailed expression when sketching.

5. Conclusions

We conducted a 30-min design experiment of animation character modeling and traced the designers' sketching processes by video in this research. We used linkograghy as an analytical technique to identify design moves and links during the sketching process and created two linkograghs on that basis. Linkograghy allowed us to quantitatively and descriptively analyze the numbers of critical moves and link patterns. In combination with the images of original video files, we inferred the commonalities and

differences in subjects' sketch idea reasoning, creative exploration, and expression by analyzing the characteristics of the number of critical moves and specific manifestation forms of link patterns in the linkographs.

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