THEME II. INTUITION
ONE MAP MANY IDEAS: HOW NOVICE DESIGNERS GENERATE CONCEPTUAL DESIGNS FROM AN IDEA MAP
IH-CHENG LAI AND TENG-WEN CHANG 341

INTUITIVE AUGMENTED REALITY NAVIGATION SYSTEM DESIGN –IMPLEMENTATION BY NEXT-GENE20 PROJECT
YEN-LING CHEN AND PEI-CHIEN HUNG 351

SIMPPLICITY
ZI-RU CHEN 361

METHODOLOGY FOR IDEATION OF INTERACTION DESIGN
HSUTUNG WANG, YU-PIN MA, HSUAN-CHENG LIN, TAYSHENG JENG AND SHYHNAN LIOU 371

REDESIGNING THE BRICK
MICHAEL A. FOX 381
Abstract. Brainstorming is a method for creative problem solving in the design studio learning. In brainstorming, linking ideas is regarded as searching design in design space which is constructed by a graph-like knowledge structure between participants’ knowledge. Idea Map provides the potential knowledge representation for representing such design space. This research conducts an experiment to understand how novice designers generate conceptual designs through an idea map. Finally, a preliminary computational mechanism for controlling an effective map size to develop conceptual designs is proposed.

Keywords. Linking ideas: idea map; design space; conceptual design; brainstorming.

1. Searching Design as Linking Ideas in Brainstorming

Brainstorming is a well-known method for supporting the divergent thinking process in obtaining diverse information, especially novice designers. A group of people with the similar knowledge domain participate in interactive communication for exchanging ideas. In brainstorming, idea association plays an important role in linking and generating diverse design ideas (Osborn, 1963). Idea association is a method by which one idea leads to another idea by a connection made in long-term memory through the three principles (similarity, contrast and contiguity).
A similar approach, linkography, proposed by Goldschmidt (1995) records design moves and the links among them. The system helps them assess the effectiveness in the problem solving process through finding the ratio of links between design moves. Van der Lugt (2000) applies linkography to understand effectiveness in different kinds of communication in brainstorming. Thus, searching design in brainstorming can be considered as linking ideas between different participants’ knowledge, which construct a group design space. Idea Map proposed by Lai (2005) is a potential knowledge representation schema to represent such design spaces for novice designers.

1.1. LINKING IDEAS

The three principles of idea association (similarity, contrast and contiguity) provide effective strategies to link the designer’s long-term memory internally and participant’s knowledge externally (Lai, 2005). Similarity principle links ideas with similar attributes; conversely, contrast principle links different ideas based on their dissimilarity. The reasoning relationship between different ideas can be linked using the contiguity principle. These three principles, which embody the different relationships among the ideas, provide the mechanism of linking ideas in brainstorming.

Linking ideas involved dynamic action and reaction of the participants’ internal and external knowledge through communication (Lai and Chang, 2006). Through playing different roles, there are two kinds of interactions between participants: internal interaction and external interaction. In the internal interaction, each participant plays different roles and uses different principles to link ideas to the long-term memory. To generate ideas in conjunction with those of other participants, each designer interacts with the other participants as well as the external design situation in the external interaction.

1.2. IDEA MAP

Through the linking ideas process, generated ideas and their links construct a graph-like knowledge structure called an idea map (Lai, 2005). An idea map can be interpreted as representing important aspects of organization of ideas of participants’ minds. An idea and a link between ideas can be regarded as a node and an arc respectively in a graph-like knowledge structure (Figure 1).

In an idea map, there is only one link \((\overrightarrow{st}, \overrightarrow{CR} \text{ or } \overrightarrow{CI})\) between two ideas (ie). Each idea can have more than one link connecting other ideas. The link has no weight and direction. The path is defined as the length from one idea to another idea. The length is measured by the number of links between the two assigned ideas. For example, the length between the idea “ie1” and the
idea “ie<sub>7</sub>” in the path <i>ie<sub>1</sub><sup>st</sup>→ie<sub>2</sub><sup>st</sup>→ie<sub>4</sub><sup>CR</sup>→ie<sub>7</sub></i> is three links. The definitions of the idea and the link are described following.

![Figure 1. The graph-like knowledge structure in an idea map.](image)

An idea contains two parts: a design problem and its solution. Each solution includes an abstract concept and a concrete example represented by the conceptual vocabularies along with multimedia. ICF (Issue, Concept and Form) schemata proposed by Oxman (1994) provide a potential method to represent such knowledge of an idea.

Three types of links create various relationships among the ideas in an idea map. They are similarity (SI), contrast (CR) and contiguity (CI). Based on ICF schemata, the three linking types help designers to link ideas dynamically. From any node of issue, concept or form in the graph-like knowledge structure, any related ideas could be linked together.

1.3 NOVICE DESIGNERS USE BRAINSTORMING TO GENERATE IDEAS

Novice designers are not familiar with transformation of linked ideas into different ideas. Idea maps are the structure of knowledge that can be taught by the instructors, but the generation of ideas from a well-planned structure will take longer learning process for a novice designer to get used to it. This is the learning pattern occurs in design tutoring session. However with the researches done by the authors show there is a systematic outcome that might be able to support the aids for effective learning process of novice designers. Therefore, following the concept of idea maps describe above, the approach of DIM to initiate and generate possible/relevant ideas from existing design knowledge–idea maps is adapted and experimented against several novice designers. The result is documented and analyzed in the following sessions.

2. DIM as a Tool for Generating an Idea Map

With case based reasoning (Kolodner, 1993) and software agent (agents) technologies (Russell and Norvig, 1995), DIM (proposed by Lai and Chang, 2006) is a computer system for supporting the distributed linking in the idea associa-
tion process. Through linking distributed and related ideas automatically, a graph-like knowledge structure (an idea map) with nodes (ideas) and arcs (links) is generated (an example is shown in Figure 2).

![Figure 2. A generated idea map.](image)

Inspired by the mechanism of generative interplay (Chang, 2006), DIM includes two kinds of components: agent entities and design knowledge. Agent entities are assigned to different sub-tasks that are decomposed from a specific design task. According to different design situations, these agent entities collaborate to generate design ideas and links. The *script* is the main structure for describing sequential events including the list of RAs, the acting of RAs, performing time duration and so on. Through the sequential events, the agent entities interact dynamically each other in different design situations.

2.1. AGENT ENTITIES

Five types of agent entities are role agent (RA), user agent (UA), director agent (DA), stage agent (StA) and scene agent (ScA). Each RA has the reasoning skill and memory to link and generate ideas. The ScA controls the list of RAs and time duration in each scene. StA is in charge of storing the design outcomes. UA and DA are regarded as the user interfaces that provide human designers to interact each other in the DIM environment. Through the DA or the UA, participants (human designers) can individually load different RAs to play (linking and generating ideas) in sequential scenes which are controlled by ScAs. The design outcome (an idea map) in each scene is automatically stored in the StA's repository.

2.2. DESIGN KNOWLEDGE WITH DIM

Three kinds of design knowledge support the behaviors within agent entities mentioned above. They are *knowledge*, *principles* and *linking process*. Knowledge represents design ideas and memory organization within agent
entities based on ICF schemata. Principles provide the capability to allow agent entities to link diverse ideas through three kinds of reasoning (similarity, contrast and contiguity). Through linking process in the internal and external interplay, these agent entities can communicate dynamically through the speech acts proposed by Searle (1969).

As mentioned before, using and understanding one idea map to generate diverse conceptual designs is an approach towards examining what is the result of brainstorming and how the idea map relates to design. Due to the limitation of human working memory, it is difficult for novice designers to remember all the generated ideas and their relationships (or links) in brainstorming. Also, their novice experiences means that it is not easy for them to understand how their conceptual designs relate to the correlated ideas they generated. These situations reduce the design outcomes in their leaning process. Furthermore, the characteristics of idea association (such as immediateness, reflection and correlation) are hard for humans to record and understand the relationships among ideas and links in brainstorming (Lai, 2005). Therefore, this research needs the computational tool to generate an idea map first, and then use the idea map to understand how novice designers generate conceptual designs.

3. An Experiment

For understanding how novice designers use an idea map to generate diverse conceptual designs in brainstorming, an experiment including two stages is conducted: generating an idea map and using the idea map.

- **Design Task:** In order to encourage participants to concentrate on generating diverse ideas and links during the experiment, the design task and addressed design problem should be simple and recognizable. Thus, the design task is to develop conceptual designs for the spatial organization of a single-family row house in the conceptual design stage. The addressed design problem was daylight.

- **Participants:** For keeping the group process simple, observable and controlled, the participants include a design tutor (Tutor_1) and three novice designers (Student_1, Student_2, and Student_3) who are second year architectural students. They work at the tutor’s design studio and are accustomed to working together. All participants are familiar with the DIM environment.

- **Process:** Before the experiment, a warm-up activity is conducted to keep the experiment fluent and comprehensible. The duration times in the two stages are 20 minutes and 40 minutes. The whole process is recorded by a digital video to complement insufficient information.
3.1. STAGE 1: GENERATING AN IDEA MAP

For generating an idea map, the four participants work in a computer laboratory where the DIM environments have been installed in the four assigned computers. In DIM, a design task of linking ideas is called play. Only DA can edit the script of the design knowledge of ScAs and StA. In the play, Tutor 1 is the DA who directs the play through editing the script. Three students are UAs. The order of generating ideas is Student 1, Student 2, and Student 3. For playing different roles, the three participants are asked to insert three RAs. A play includes the following three steps.

1. Initializing play: All participants should load agents in their DIM platforms and connect these platforms together through HTTP.
2. Editing script: Tutor 1 starts to edit script through inputting the information of StA and ScA. The information includes design task (row_house), the design problem (daylight), the duration time (20), the number of RAs and RAs’ skills (similarity, contrast or contiguity).
3. Linking ideas: Three students then input the ICF (Issue, Concept and Form) information to link and generate ideas according to the order of generating ideas.

Each step has its individual window for participants to input related information. When the time (20 minutes) is up, DIM automatically terminates the play.

3.2. STAGE 2: USING THE IDEA MAP

The partial idea map is shown in Figure 3, where each box as an idea includes four kinds of information. They are the AID (Agent Identifier) of RA that generates this idea and the ICF value within this idea. Each arc (or link) between the two boxes represents a kind of relationships including similarity (SI), contrast (CR) or contiguity (CI).

Figure 3. The enlarged dotted-line area that one student frames
For example, in Figure 3, the idea (on the right corner) is the third idea \((i3)\) generated by RA_7. The ICF value is daylight, shade, and tree respectively. Also, the URL of the form “tree” can be hyperlinked to a specific design case with photo images. The idea \(i3\) has four similarity links (SI) connecting to other ideas including \(i1, i12, i13\) and \(i20\), which are generated by RA_1, RA_9, RA_2 and RA_3 respectively. The idea \(i3\) has no contrast links and contiguity links which connect to other ideas. Thus, its total number of links is four.

Based on the idea map, the three students are asked to develop conceptual designs for solving the problem “daylight” by drawing idea sketches (seen in Figure 4) in a design studio classroom. According to each developed conceptual designs, each student individually frames the range of the selected ideas and their links (Figure 3) in this idea map, which is printed on the A3 size papers. In each A3 size paper, the framed ideas and three types of links are labeled and numbered for our further analysis. The duration time is 40 minutes.

4. Analysis and Observation

In this experiment, the generated idea map includes 21 ideas and 35 links. In the 21 ideas, three new design problems (issues) and 18 new design solutions (concept and form) are generated. The three new design problems are circulation, view and in-between. In the 35 links, there are 20 similarity links, 8 contrast links and 7 contiguity links. In the idea map, each box as an idea includes four kinds of information. They are the AID of RA that generates this idea and the ICF values within this idea. Each link between two boxes represents one kind of relationships including similarity (SI), contrast (CR) or contiguity (CI).

4.1. ANALYSIS

The three students develop eight conceptual designs (cases) through the idea map. Student_1, Student_2, and Student_3 develop three, two and three cases respectively. According to the 8 sheets of A3 size papers that they frame before, the number of ideas and links (including different principles of links) within the framed range of conceptual designs are shown in Table 1. In the Table 1, the Case 1 developed by Student_1 composes of 5 ideas and 4 links. The 5 ideas are \(i18, i12, i13, i5, i1\). The 4 links include 1 similarity links, 4 contrast links. All cases compose of the idea \((i18)\) with the most links.
TABLE 1. Ideas and their links in the different conceptual designs

<table>
<thead>
<tr>
<th>Participants</th>
<th>Student₁</th>
<th>Student₂</th>
<th>Student₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual designs</td>
<td>Case1</td>
<td>Case2</td>
<td>Case3</td>
</tr>
<tr>
<td>Ideas</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>i₁₂, i₁₃, i₅, i₁</td>
<td>i₁₈, i₉, i₁₂, i₁₁</td>
<td>i₁₈, i₁₂, i₁₇, i₁₃, i₁</td>
<td>i₁₈, i₁₂, i₁₈, i₁₂, i₁₃, i₁</td>
</tr>
<tr>
<td>Links</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Similarity</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Contrast</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Contiguity</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

While the contiguity link is applied to find different design problems with same solutions, the analysis also quantifies the links within the ideas that has the contiguity link. The purpose is to understand how the students decide the priority of the design problems. The number of the different types of links within the different design problems is shown in Table 2. In Table 2, the ideas i₁₀ with “circulation” issue, i₇ with “view” issue and i₈ with “in-between issue” have 2 contiguity links, 4 contiguity links and 2 contiguity links respectively. All participants select the “view” issue within i₇ as the first priority for the next problem solving.

TABLE 2. Three design issues and their numbers of links

<table>
<thead>
<tr>
<th>Issue</th>
<th>circulation</th>
<th>view</th>
<th>in-between</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideas</td>
<td>i₁₀</td>
<td>i₇</td>
<td>i₈</td>
</tr>
<tr>
<td>Links</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Similarity</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Contrast</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Contiguity</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Participants</td>
<td>No</td>
<td>Student₁, Student₂, Student₃</td>
<td>No</td>
</tr>
</tbody>
</table>

4.2. OBSERVATIONS

According to our analysis, an idea map can help the novice designers to generate diverse conceptual designs through combining the correlated ideas and their links in the idea map. The quantity of the ideas and the links and the functions
of different types of links are the key factors for them to develop conceptual designs. Some observations are described as follows:

- An idea with most links is selected as the first candidate for combining ideas. The idea is regarded as the key idea which provides an important start point for participants to search other ideas in the idea map. We call such phenomenon as design consonance.

- The ideas, which are combined with the key idea, mostly compose of more links than other ideas that are not combined. While ideas are as good as more links (Goldschmidt and Tatsa, 2005), the selected ideas can be regarded as good ideas for developing conceptual designs.

- Based on the design consonance, the combined ideas in these conceptual designs are not over 7. While the length between an idea and the key idea is over 3 links, the idea can not be searched for combining. The phenomena show that they have quantitative limitation in their working memory.

- The three types of principles provide different functions for them to search good ideas. The similarity link and the contrast link offer an important guideline for combining ideas. The contiguity link provides the indication to decide the priority of design problem (or issues) based on the quantity of links to an idea with new issue.

5. Toward a Computational Mechanism for Generating Conceptual Designs by Using An Idea Map

To generate diverse conceptual designs by using an idea map, a computational mechanism for controlling the size of the idea map with the deliberate reduces should be made. Besides, the three types of principles have different functions for novice designers to search the related ideas for two purposes: combining ideas and searching a new design problem. Based on design consonance, there are two levels of controlling strategies: quantity control and link control. The quantity control includes idea control and length control. Their computational mechanisms are described below.

1. Idea control: an idea-map can be reduced by identifying the range of number of ideas with more links by comparing to other ideas. For the novice designers, the range of number of ideas is between 2 and 7.

2. Length control: the range of idea-map can be reduced through decreasing the length of the paths from the key idea to other linked ideas. For the novice designers, the range of length in a path is between 1 and 3.

3. Link control: the ideas can be linked together to a sub-map through the similarity links or the contrast links according to designers’ preferences. The contiguity links provides them to find a new design problem.
Based on the DIM framework, the three controlling strategies are embedded with the design knowledge of ScA. Through ScA, UAs and DA can use the controlling strategies to automatically construct effective sub-maps to develop diverse conceptual designs in brainstorming. These sub-maps are all stored in the StA repository. Thus, the design tutor and students can share these sub-maps together in the DIM environment. The research will provide an essential prerequisite of preparation for supporting distributed design collaboration in any creative problem solving meetings without the barriers of geographic limitations and different time zones.

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References


