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CREATIVE DESIGN THINKING BY WALKING THROUGH VIRTUAL CONCEPT SPACE

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Abstract: In order to confirm how the visual understanding of the structure of concepts by walking through a virtual concept space can support design thinking, a virtual concept space is constructed based on a concept dictionary and is then visualized in a 3D virtual space. Then, two experiments are conducted to find the centre of three certain concepts in, first, virtual concept space and second, in ordinary space. The results show that new centred-concepts are formed by associating three certain concepts by the subjects as they are walking through the virtual concept space. In addition, the results indicate that the subjects experience no sensory discomfort as they perform the task. Hence, it is suggested that walking through a virtual concept space might support creative design thinking.

Keywords: *Virtual concept space, Walkthrough, Concept structure*

1. Introduction

Humans think of objects, such as a dog or a star, as concepts. Concepts are structured in the mind in accordance with personal experiences and/or social pursuits. Some concepts are organized into knowledge while some are dispersed in the individual mind. Furthermore, it is stated that sequentially tracing the structured concepts, while relating concepts to each other, leads to the generation of concepts (design ideas) with high originality (Taura, 2016).

Based on the above considerations, the following questions are raised. First, how are concepts structured in peoples' minds? Second, if we could visually immerse into and trace the structure, could that experience then support creative design thinking? By answering these questions, creative design thinking could be understood more deeply.

Recently, many rigorous concept dictionaries have been constructed. Concept dictionaries contain not only a list of concepts and their meanings but also speech classification, usage, and semantic relationships between those concepts. In the field of virtual reality research, intricate (i.e., complicated and complex) data are visualized in 3D virtual reality spaces. To understand the data more deeply, walking through the space serves an effective method to support the ability of spatial cognition intuitively.

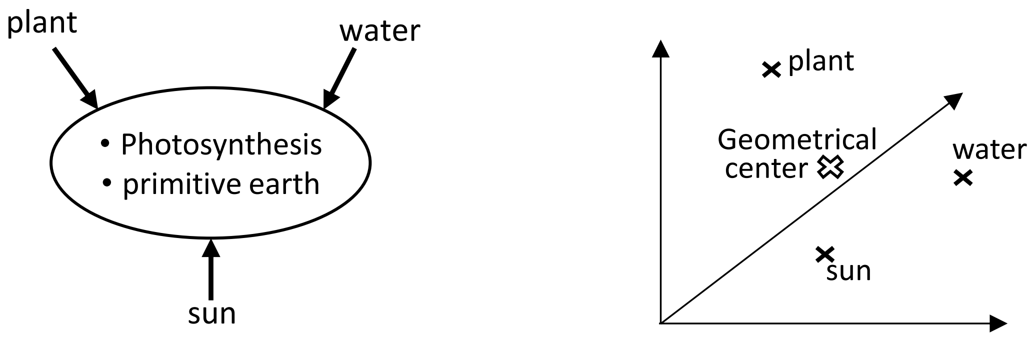
Based on the above discussion and the questions raised, it is suggested that the 3D visualization of concept dictionaries in VR space allows for visual understanding via a walkthrough of concept space and that this method might support creative design thinking. Concept dictionaries contain a significant number of words. For an example, WordNet (Fellbaum, 1998) is a large electric lexical database comprising of over 150,000 words that contains information on the manner in which human beings process language and concepts. It is very difficult to capture the entire view of such large numbers of concepts. However, if structured in 3D, the 150,000 concepts can be placed on a cube having 60 concepts on each side. Using this approach, it might be easy to visually understand the entire structure of the concepts.

2. Aims and method

This research attempts to visualize a concept dictionary in 3D virtual reality space to understand the structure of concepts by walking through the space. Furthermore, this research aims to determine how this visualization can support creative thinking. In this research, the visualized 3D space of the concepts is referred to as a "virtual concept space".

For this purpose, an experiment was set up to find the centred-concepts of three certain concepts. Centred-concepts are concepts that are associated from three certain concepts. For examples, 'photosynthesis' and 'primitive earth' can be conceived from the centred-concepts of 'plant', 'water', and 'sun' (Fig. 1 (a)). Finding the centred-concepts of several concepts is related to a design method that creates a new concept by blending existent concepts (Taura, 2016). This is assumed to be one of the basic creative thinking processes.

In order to verify that after walking through the virtual concept space, the subjects could associate centred-concepts in the virtual concept space, which are different from those in ordinary space, the results from an experiment conducted in virtual concept space were compared to those conducted in ordinary space. Moreover, to confirm that subjects could explore the virtual concept space without sensory discomfort, the subjects were asked to respond to a questionnaire. In addition, in the case of the virtual concept space, a geometrical centre point of the three concepts (Fig. 1 (b)) was shown to the subject.



(a) Associated centre of three concepts (b) Geometrical centre of three concepts

Figure 1. Notion of Centred-concepts

3. Virtual fields

The VR device π-Cave[1], which is a variant of CAVE (Cruz-Neira *et al*., 1992), was used in this research. π-Cave is composed of four upright screens (two in the front and one at each side) and two screens on the floor (Fig. 2), onto which a visual image can be projected. π-Cave has a rectangular parallelepiped configuration with dimensions 3 *m* × 3 *m* × 7.8 *m*. Users are able to see the stereoscopic visual image by using three-dimensional glasses equipped with a tracking device. This provides users with the experience of walking through virtual space as they walk on the floor.

[1] http://www.eccse.kobe-u.ac.jp/pi-cave/

Figure 2. π-Cave

4. Construction of the virtual concept space

4.1. WordNet

In this research, WordNet, as a concept dictionary, is used to construct the virtual concept space. In WordNet, each concept is bundled into groups of synonyms, idiomatic words or compound words. The semantic relationships between the synsets are structured using the hierarchical relationship shown in Fig. 3. From top to bottom, the order is as follows: entity, physical entity, whole, and artefact.

WordNet contains a large number of concepts and it was created taking into account the knowledge behind human language processing. It is said that understanding this structure will assist in determining the patterns of thinking (Taura *et al.*, 2012). Based on the above arguments, the WordNet dictionary was selected for the virtual concept space.

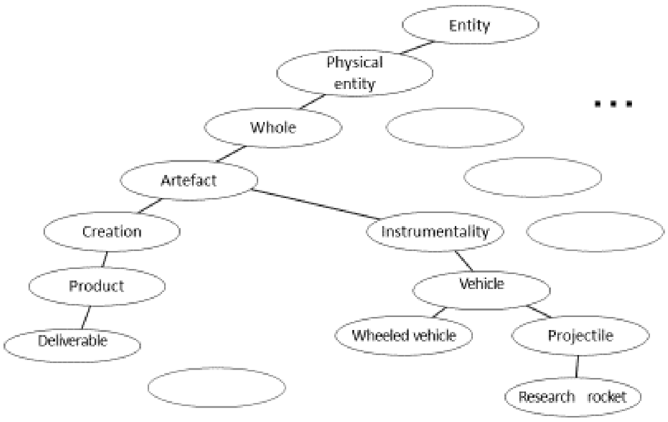


Figure 3. Hierarchical structure of WordNet

4.2. Networking and algorithm of the visualization.

The Fruchterman–Reingold algorithm (Fruchterman and Reingold, 1991) is used to create a network of the dictionary concepts. This algorithm has two principles for graph drawing: first, the vertices connected by an edge should be drawn near each other; however, they should not be drawn too close to each other. Specifically, this algorithm adds the total displacement limited by the temperature parameter to each iteration for the networking algorithm based on the force-directed graph drawing (Di Battista, 1999), and determines the maximum value displacement of the node. In networks based on force-directed graph drawings, spring-like attractive forces based on Hooke’s law are used to attract pairs of endpoints of the graph’s edges towards each other. Simultaneously, repulsive forces like those of electrically charged particles based on Coulomb's law are used to separate all node pairs. When the system of forces reaches an equilibrium state, the edges tend to have a uniform length (because of the spring forces) and the nodes that are not connected by an edge tend to be drawn further apart (because of the electrical repulsion). In the Fruchterman–Reingold algorithm, each node of the network is created so that the link lengths are equal and are arranged so that none of the nodes intercepts another in the 3D space. In addition, the Pajek[2] was used to visualize the network.

4.3. The creation of the virtual concept space.

In this research, the top five classes of the hierarchical structure of WordNet is extracted. This results in approximately 5000 words. Figure 4 shows a 2D visualization of the network concept created using this method. Figure 5 shows a 3D visualization. Figure 6 shows the image that was projected onto π-Cave. The visualization shown in Figure 4 is difficult to understand in regards to the depth. However, by using VR as shown in Figure 6, the depth of the network is clearly recognizable and it is easier to see the structure of the network.

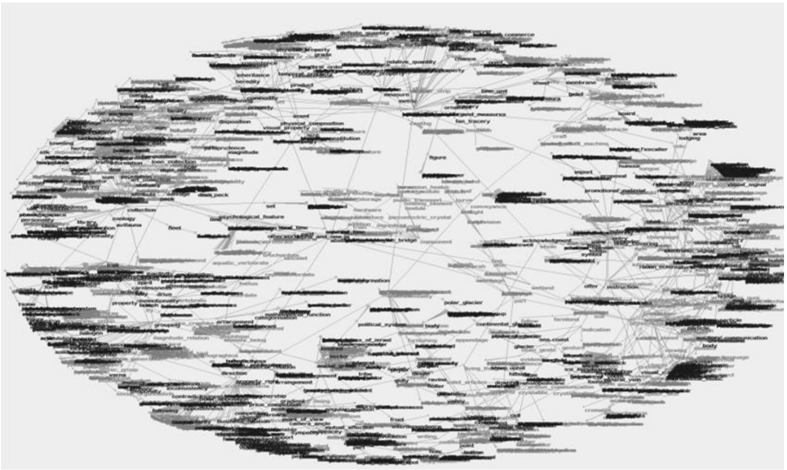


Figure 4. Example of a network visualized in two dimensions

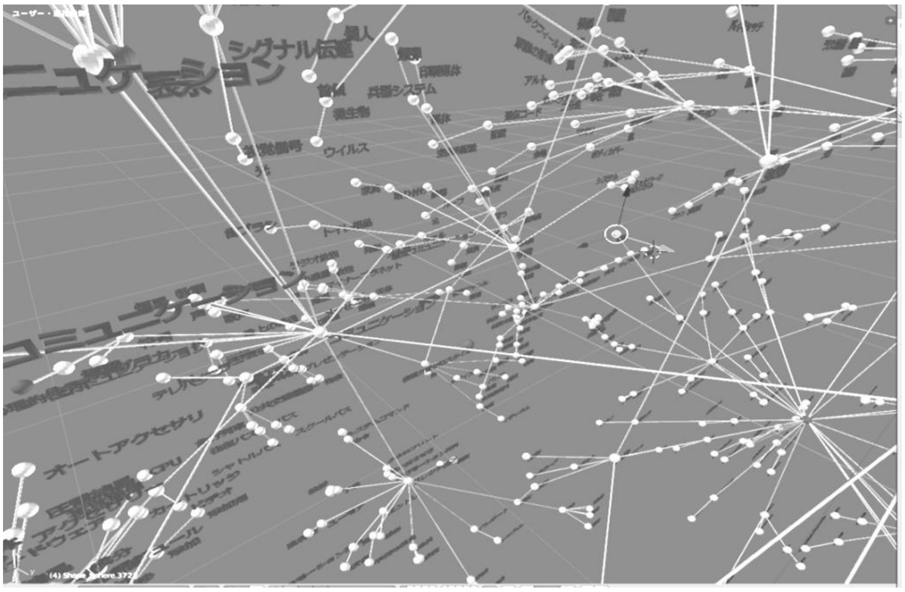


Figure 5. Example of a network visualized in three dimensions

[2] http://mrvar.fdv.uni-lj.si/pajek/

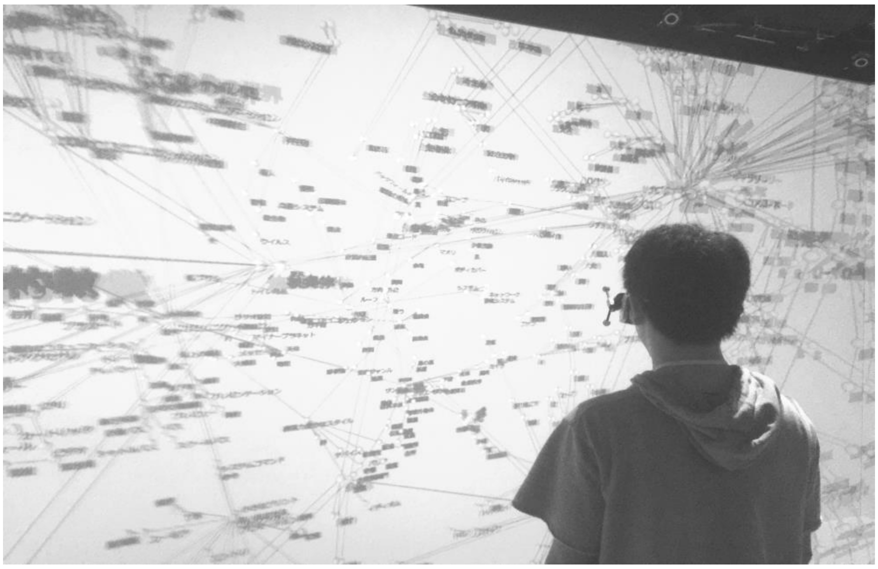


Figure 6. Image of a network projected on π-Cave

5. Experiment

5.1. Overview

Two experiments were conducted to find the centred-concept out of three concepts, of which the first was held in the virtual concept space while the second was held in ordinary space. Six university students participated in the experiments.

5.2. Task

For Task-1, the three concepts of 'frog', 'train', and 'polka-dot' were given. Subsequently, for Task-2, the three concepts of 'planet', 'music', and 'sea creatures' were given. These concepts were selected because they were thought to be familiar to the subjects and to attract their interests. These are concepts that are relatively easier to find associations. In addition, in the virtual concept space, it was confirmed that some concepts exist at the geometric centre or around the three concepts.

5.3. Procedure

- Step 1: The procedure was explained in the virtual concept space. The idea of the WordNet was also explained.
- Step 2: The notion of centred-concept was explained using examples. For example, to associate 'pet' and 'quadruped' from 'dog' and 'cat', the examples were first shown, and then repeated until the centred-concept concepts became easier to imagine.
- Step 3: The experiment was conducted in a situation where the virtual concept space was not projected. A centred-concept was asked to be imagined within 5 min. The subject was also asked to describe the centred-concepts and the reasons as to why they imagined it as such, in as many ways as possible. The answers of this Step are labelled as A.
- Step 4: The subject was asked to conduct the same task as in Step-3 but with the concept space projected. A centred-concept was asked to be imagined within 10 min. The subject was asked to describe the centred-concepts and their reasons as to why they imagined it as such, in as many ways as possible. The answers of this Step is labelled as B. This step is shown in Figure 6.
- Step 5: The same procedure was conducted as per Step-3 for the remaining task.
- Step 6: The same procedure was conducted as per Step-4 for the same task in Step-5.
- Step 7: The subject was asked to evaluate the questionnaire given below based on a five-point scale. (1. Totally disagree, 2. Disagree, 3. Neither disagree nor agree, 4. Agree, 5. Totally agree).

Questionnaire

- Q1. In the virtual concept space, were you able to find the centred-concept through viewing and moving around without feeling any sensory discomfort?
- Q2. Was moving around in the virtual concept space freely helpful for thinking the words associated from the given three words?
- Q3. Was the geometric centre helpful for thinking the words associated from the given three words?
- Q4. Did you have any discomfort in regard to the data structure presented in the virtual concept space?

Furthermore, for the experiment, the word 'concept' was thought to be difficult to understand, so 'word' was used instead.

5.4 Results

Figure 7 shows the results of the questionnaire. The average result of Q1 was 4.33, with all the responses from the three subjects being over 4.0. This shows that the subjects were exploring the virtual concept space without any sensory discomfort. In fact, behaviors of the subjects such as leaning, moving around, crouching down, and peeking were observed, which confirm these results. The average result of Q2 was 3.83, suggesting that walking through the virtual concept space helped the subjects to think of the centred-concept from the three concepts. The average value of Q3 was 3.00. From observations, the subjects appeared to first check the geometric central position but later appeared to focus their attention on the concepts around them. The average of Q4 was 2.16. For the subjects, even though it was the first time experiencing such a conceptual structure, they did not feel any discomfort from it. This is because WordNet itself is structured based on typical exposure to the human senses.

Table 1 shows the example of the centred-concept that the subjects associated from the three concepts. In the left column are shown the concepts and their associations while in the right column are their reasons for imagining those concepts. From this table, it is seen that all the subjects associated completely different centred-concepts after walking through the virtual concept space (B) as compared to before walking through (A). This shows that walking through the virtual concept space may be able to support creative design thinking.

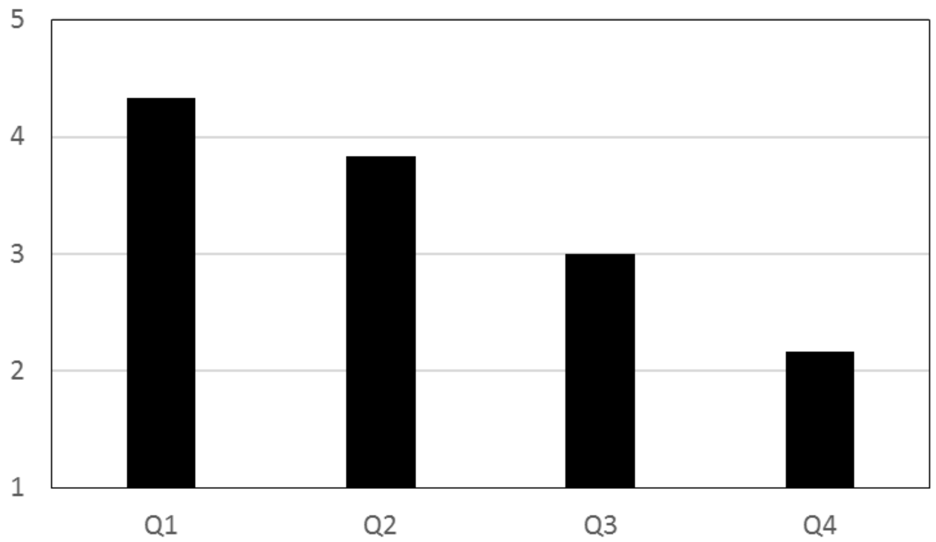


Figure 7. Averages of questionnaire results

Table 1. Centred-concept associated from the three concepts.

Task 1-A

Rain	Take the train when it rains. Frogs like rain. Polka dots look like rain.
Amazon	The train goes somewhere far away. Frogs seem to live there. The polka dots represent moisture.

Task 1-B

Crowd	The trains are connected. Polka dots are crowds of white circles. The frogs are also a crowd in the paddy field
Night	Night train. A frog that cries in the quiet night. Polka dots are stars.
Large amount	Large amount of people. Crowd of frogs. Image of polka dots

Task 2-A

Primitive	Planets have existed long before the earth. Music has also existed for a long time. Sea creatures have existed for a long time.
Mysterious	There are many things not known about planets. There is some mysterious music. There are many creatures that are still unknown in the sea.
Mermaid	Image of them singing while living. Mysteries of the stars.

Task 2-B

Dynamic	Dynamism of the planets moving actively. Dynamism to move to the feeling of music. The dynamism of creatures.
Darkness	Deep under the sea where the sound becomes more important than the light.

6. Conclusion

This research constructed a virtual concept space and had subjects walk through the space to visually understand the structure of concepts. In order to confirm how it could support creative design thinking, a task was created to find the centred-concept from three certain concepts. Two experiments were conducted to compare the results from tasks performed in virtual concept space to those in ordinary space. The results show that the subjects explored the virtual concept space without any sensory discomfort. In addition, after walking through the virtual concept space, the subjects associated centred-concepts that are differed from those before the walkthrough. These results indicate that visually tracing the networks of concepts in virtual concept spaces could support creative design thinking. Although, it is difficult to answer the first question in the introduction "how are concepts structured in peoples' minds?", the result of this research indicates that the structure of the concept dictionary is not so different from that in peoples' minds. Regarding the second question "if we could visually immerse into and trace the structure, could that experience then support creative design thinking?", a task which is more directly related to "design thinking" will be conducted.

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