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WINNING FORMULAS FOR METAPHOR DESIGN: A CASE STUDY OF DESIGN COMPETITIONS

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1. Introduction

Design competitions are a powerful marketing tool not only for design professionals, but also for business. Since most design competitions encourage innovation, the award winners are often characterized by analogy for generating novel, valuable designs. The method of design by analogy is to creatively relate some analogous source to the problem to define and solve. A typical analogous product design is that some of its features in one domain are implemented or represented by some common features of something in another domain. The features are either aesthetics, emotional aspects or functional, technical aspects.

In the design process, analogical thinking plays a key role to draw a comparison of two different things in order to show their similarity in some respect. This type of thinking, sometimes called analogical reasoning, has importance in scientific discovery (e.g., [Rumelhart and Norman 1981], [Gentner 1982], [Gentner and Jeziorski 1989]), problem-solving (e.g., [Polya 1954], [Schon 1979]), and engineering design (e.g., [Cross 1994], [Ball et al. 2004]). Its principles for generating metaphorical design are explored in [Warren 2000], [Casakin 2007], [Nagai et al. 2009]), while its applications to creative design are illustrated in ([Imaz and Benyon 2007], [Hey et al. 2008], [Wang and Chan 2009]).

However, few studies focused on the design-by-analogy methods that can be derived from available information about award winners. It would be very valuable if we can summarize the implicit rules for winning design competitions. Therefore, this paper is to specify the design-by-analogy formulas from a set of award winners, and to test the formulas with a set of other winners, as well as to practise these formulas in an entry to a metaphor-oriented design competition.

2. Design by analogy for metaphor

As metaphor helps us understand the unfamiliar things from familiar things [Ortony 1991], it plays key roles in term of functionality and expressionism. The metaphor is useful not only for function-oriented problem solving but also for expression-oriented sense making. For example, the desktop metaphor in user interface increases the functionality of computer operation systems, for it is easy to understand and use.

In contrast, some metaphor designs are of emotion rather than function. Take Anna G. corkscrew, one of the best sellers of Alessi Company, for example. The corkscrew is 'a tongue-in-cheek homage to a real woman' [Alessi 2015], in which a woman figure is mapping onto the wing corkscrew (also called angel corkscrew because of its two handles) in terms of structure and movement. As a result, this expressive product becomes popular as a gift, delivering good quality of beauty and humour. No matter which orientation the metaphor is, design-by-analogy works in its design process.

Still, metaphor is vital for designers and users. Designers often try various metaphors to obtain insight on the problem they encounter (i.e., to reframe problem with metaphors), and to generate surprisingly creative solutions for the problem. On the other hand, good metaphor helps users understand how to use products, and interpret the meanings they expect. In the above example of Anna G., the user can identify the similarity between the corkscrew and the woman figure without difficulty. Such similarity is not only an essential property for human perceiving and interpreting external things, but also the basis to construct metaphor by comparing the attributes of two different things [Goldstone 1999]. Thus, design-by-analogy for metaphor is a winning weapon to meet the user needs.

2.1 Analogy as structure mapping

To investigate the analogy-by-design methods used in award winners of design competitions, we need adequate theories to describe, explain, and even predict analogous designs. Structure mapping theory (SMT), proposed by D. Gentner [1983, 1986, 1988] is applicable to product design, because it is generally corresponding with the structure of systematic design methods, such as AEIOU (Activities, Environments, Interactions, Objects, Users) observation, morphology analysis, and product architecture. The core concept of SMT is structural alignment based on a mapping from source domain onto target domain. The alignment is based on element similarity and relation similarity, and thus can be divided into several types, such as 'literal similarity', 'analogy', 'mere-appearance', and 'anomaly' by various degrees of the similarity. Notice that this paper replaces the term 'attribute' with 'element' to avoid confusion with attributes used in rough sets theory in the following section.

In SMT, the metaphor comes up with the three conditions: (1) low element similarity and high relation similarity, (2) medium element and relation similarity, and (3) high element similarity and low relation similarity. SMT suggests analogical comparison is the most important mechanism for discovering relational patterns in human creativity. As our inert knowledge problem may result in failure to retrieve prior relational matches, missing many opportunities for insight, SMT is helpful to make the relational structure more explicit, more likely to transfer to new contexts.

2.2 Decision rules in incomplete data

Every entry of design competition is the product of its designer's thinking process. The information in the process and product is usually very vague, for the designer's knowledge is imperfect, decision making is uncertain, and concepts are imprecise. For example, the concept of a beautiful chair is vague, because some chairs cannot be decided whether they are beautiful or not, and, therefore, they remain in the doubtful area. So, it is not surprising that the information about the winning factors or measures in design competitions is much vaguer.

There are available tools for the vagueness of vague data. Rough set theory (RST), introduced by Pawlak [1982], provides approximations of concepts in the presence of incomplete information and have been successfully applied in data mining, concept generation, induction, and classification. A rough set is a formal approximation of a set in terms of a pair of sets which give the lower and the upper approximation of the original set. RST-based data analysis starts from a decision table, containing data about objects of interest characterized in terms of condition and decision attributes. A set of decision rules can be induced from the analysis of decision table. For formal definitions of primary concepts, refer to ([Pawlak 2002]). For a decision table of entries for design competitions, for instance, the condition attributes could be form, colour, structure, and scene, while the decision attribute could be winning prizes. Decision rules induced from decision tables are represented as logical expressions of the following form.

$$\text{IF (conditions) THEN (decision)} \quad (1)$$

where conditions are formed as a conjunction of elementary tests on values of attributes.

The decision rule is a popular type of design knowledge, which is used in practice. There are many successful applications of rough set theory. Among them, ROSE2 (Rough Sets Data Explorer), developed by the Laboratory of Intelligent Decision Support Systems of the Institute of Computing Science, Poznań University of Technology, is a software implementing basic elements of the rough set theory and rule discovery techniques [ROSE2 n.d.].

3. Deriving winning formulas

The approach to derive the winning formulas is twofold. One is hypothetico-deductive model (see [Godfrey-Smith 2003]) while the other is falsification about hypothesis testing (see [Popper 1968]). The former is described as the following. First, the author used his experience about industrial design, structure-mapping theory (SMT), and rough set theory to think of the analogy used by winners in design competitions. Reviewing some literature, I found this topic is worthwhile. Second, he transformed some notions of SMT to design principles as conjectures (i.e., hypotheses) to test. The major hypothesis is that a set of design-by-analogy formulas can be derived from a decision table consisting of specific elements and relations about the winners. If these hypotheses are true, the author predicted the formulas would be consistent with the SMT principles. Third, a sample of one-hundred winners was chosen to test the predictions from the hypothesis. The latter approach, falsification, is to maintain hypotheses are testable, and cannot be 'proven to be true' forever. Therefore, the hypotheses of this study are rejected if inconsistent with the results. Otherwise, it is temporally not rejected if consistent.

3.1 Decision table

One hundred entries of product design from nine renowned design competitions in Taiwan, including Braun Campus Prize Taiwan, Taipei International Design Award, and Taiwan International Student Design Competition, are selected as the subjects to derive winning formulas. This study does not consider any entry that is not a finalist because its design boards or related information is not available. All of the entries were assessed by a focus group to build a decision table. The focus group comprises two experienced industrial designers and three graduate students of industrial design of Taipei Tech. They all have taken part in a one-week orientation workshop on analogous design. To build the decision table based on rough set theory, the focus group started to decide the data representation for all of the entries in the following steps.

First, the decision attribute in the decision table is 'Prize'. Its value is either 'Prize Winner' or 'Honourable Mention'. Thirty-five entries that are gold, silver, or bronze prize winners, are classified into prize winner group. The remainder sixty-five finalists, without any prize after the preliminary selection session in design competitions, are classified into honourable mention group.

Second, according to conceptual metaphor model [Ortony 1979, 1993], category similarity (also called domain similarity) between the target and source is supposed to be lower to make a better metaphor or analogy. Category describes to what classification an object belongs. Four target categories and five source categories are concluded by specifying the target and source of each entry, as shown in Table 1. Additionally, the element similarity between the target and source is supposed to be higher for a better metaphor. The elements are divided into object-oriented elements, including 'Form', 'Colour', 'Texture', and relation-oriented elements, including 'Interaction', 'Environment', and 'Structure'. The interaction refers how the user (or any kind of 'actor') interact with the object. For example, the interaction in which 'a housekeeper draws a toilet brush from its holder' is similar to that 'King Arthur drew the sword from the stone' in Excalibur legend. The environment is the contexts where the interaction occurs. For instance, the environment in which a designer uses a pencil holder could be the desktop in his or her office. In this sense, the environment similarity between a pencil holder and a mug is higher than that between the pencil holder and a tin can, because the latter is seldom present on the desktop in the office. The structure represents the spatial relations among the object's components. Finally, all data types for these attributes are of nominal values.

Table 2 shows the entry number one, Pebble-stone Erase, for example. The value of source category is a2 (Natural materials), to which pebble stone belongs to, whereas the value of target category is b2 (Living goods), to which erase belongs to. The attributes of form, colour, and interaction are valued by 'yes' (i.e., similar), but the attributes of texture, environment and structure are valued by 'no' (i.e., dissimilar).

Table 1. Nominal values of attributes

	STM terminology	Decision Table Attributes	Nominal Values
Condition Attributes	Domain	A. Source category	a1. Artefact, a2. Nature materials, a3. Animal, a4. Plant
		B. Target category	b1. 3C products, b2. Living goods, b3. Furniture, b4. Medical products, b5. Public facilities
	Element	C1. Form	yes, no
		C2. Colour	yes, no
		C3. Texture	yes, no
	Relation	D1. Interaction	yes, no
		D2. Environment	yes, no
		D3. Structure	yes, no
Decision Attributes	Element	E. Prize	yes, no

Table 2. Decision table example

No.	Photo	A	B	C1	C2	C3	D1	D2	D3	E
1		a2	b2	yes	yes	no	yes	no	no	yes

3.2 Rules induction

The above decision table is exported into ROSE 2 Version 2.2 for rule induction. Results indicate the high quality of classification (0.8000), and acceptable accuracy (0.5833 for the prize winner group, 0.7222 for honourable mention group), as displayed in Table 3. The average accuracy of classification using K-fold cross validation with 10 passes is 73.00%. The core attributes based on quality loss are, in priority order, structure (D3, 0.17), scene (D1, 0.10), setting (D2, 0.08) and form (C1, 0.08), colour (C2, 0.05), and texture (C3, 0.05). The results indicate relation similarity is more significant than element similarity in general.

There are twenty-six rules induced by basic minimal covering, in which eight rules satisfy the strength of 12.5% or higher, as shown in Table 4. The rules 1, 2, 3 and 4, for the prize winner group are defined as the winning formulas, whereas the remainder rules are for the honourable mention group. It is interesting that several critical entries appear at least three times in these rules. The set of critical entries for prize winner group is {3, 10, 33}. For example, the number 3 object in the prize winner group is a box of birthday candles with the metaphor of matchbox. This metaphor is based on high similarity of the element (form) and relations (scene, setting, and structure) between traditional birthday candles and matches. When someone shows how to light the candles like quickly dragging the match head along the striker, all participants in the birthday party likely feel very surprised and happy, enriching the pleasure of celebration. Moreover, missing matches or lighter is no longer a trouble at a birthday party.

Table 3. Approximations and accuracy of the two groups

Approximations				
Group	# of objects	Lower approximations	Upper approximations	Accuracy
Prize winner	35	28	48	0.5833
Honourable mention	65	52	72	0.7222

Table 4. Decision rules derived

Rule	Description	Strength	Satisfactory entries
1	IF source category is artefact AND scene is similar AND structure is similar THEN the entry belongs to prize winner group.	20.00%	3, 5, 6, 8, 10, 20, 33
2	IF source category is artefact AND target category is living goods AND structure is similar, THEN the entry belongs to prize winner group.	17.14%	3, 6, 10, 20, 30, 33
3	IF source category is artefact AND form is similar AND structure is similar THEN the entry belongs to prize winner group.	14.29%	2, 3, 5, 10, 33
4	IF target category is living goods AND colour is similar AND scene is similar THEN the entry belongs to prize winner group.	14.29%	1, 10, 13, 14, 32
5	IF form is similar AND colour is dissimilar AND structure is dissimilar THEN the entry belongs to honourable mention group.	24.62 %	47, 52, 53, 58, 61, 62, 66, 69, 70, 75, 86, 89, 91, 93, 98, 99
6	IF form is similar AND scene is dissimilar AND structure is dissimilar THEN the entry belongs to honourable mention group.	18.46%	44, 47, 49, 53, 58, 66, 69, 75, 89, 91, 93, 98
7	IF source category is artefact AND form is similar AND texture is dissimilar AND structure is dissimilar THEN the entry belongs to honourable mention group.	16.92%	47, 49, 58, 66, 69, 75, 86, 89, 91, 98, 99
8	IF colour is dissimilar AND scene is dissimilar AND setting is dissimilar AND structure is dissimilar THEN the entry belongs to honourable mention group.	13.85%	38, 47, 53, 58, 66, 89, 93, 96, 98

3.3 Data analysis

As a whole, the frequency distribution of values of source category and target category is similar, as shown in Table 5. For both of the prize winner group and honourable mention group, the major source category is 'artefact' (a1, 63~69%), and the major target category is 'living goods' (b2, 54~55%). Compared to the category values, the frequency distribution of similarity types reveals much more diversified. As shown in Table 6, the prize winner group keeps a certain balance to focus on the similarity of form (C1, 13%) and texture (C3, 13%), but the honourable mention group tends to pay attention to form (C1, 19%). Likewise, in the relation similarity, the prize winners simultaneously focus on scene (D1, 28%) and structure (D3, 22%), yet the honourable mention group focuses on interaction (D1, 31%) and environment (D2, 24%) together. This result supports Gentner's [1983] assertion on the importance of structure mapping for creative thinking. However, in overall average, interaction similarity occurs most frequently (D1, 29%). This result is also consistent with Nagai, Taura, and Mukai's [2009] approach of thematic relation similarity for creative design.

Table 5. Frequency of category values

	Source category				Target category				
E. Prize	a1. Arte.	a2. Nat.	a3. Ani.	a4. Plant	b1. 3C	b2. Living	b3. Furn.	b4. Med.	b5. Pub.
yes (35)	24 (69%)	2 (6%)	5 (14%)	4 (11%)	12 (34%)	19 (54%)	1 (3%)	2 (6%)	1 (3%)
no (65)	41 (63%)	4 (6%)	8 (12%)	12 (18%)	14 (22%)	36 (55%)	9 (14%)	1 (2%)	5 (8%)
Sum. (100)	65	6	13	16	26	55	10	3	6

Table 6. Frequency of similarity types

	Element similarity			Relation similarity		
E. Prize	C1. Form	C2. Colour	C3. Text.	D1. Scene	D2. Setting	D3. Structure
Yes (83)	11 (13%)	8 (10%)	11 (13%)	23 (28%)	12 (14%)	18 (22%)
No (107)	20 (19%)	8 (7%)	11 (10%)	33 (31%)	26 (24%)	9 (8%)
Sum. (190)	31 (16%)	16 (8%)	22 (12%)	56 (29%)	38 (20%)	27 (14%)

3.4 Rule deduction for test

To test the winning formulas, the focus group selected 14 prize winners and 16 honourable mentions from available information on the official website of National Treasure Derivative Product Design Competition design during 2011 through 2014 [National Palace Museum n.d]. The focus group used the same method described in Section 3.1 to build the decision table and then employed the conditional attributes as premises to fire as many rules as possible. Inference consequence for each entry is the classification of either prize winner group or honourable mention group. Each classification is compared with that entry's decision attribute value in the decision table. The inference consequence is correct for 23 of the 30 entries, indicating high accuracy (76.7%). That implies the winning formulas are reasonable to a certain degree and is rather practical for design competition entrants.

However, the formulas remain some restraints. The maximal strength value of the decision rules derived is 20.00%, and only 8 decision rules with strength value that is 13.85% or more. The accuracy rate of prediction for the 30 testers is 76.7%, less than expected. Further study on identifying more critical attributes for decision table might improve the prediction. However, some tacit attributes, such as the aesthetic quality of the winners, are hard to explicitly express. In a word, the formulas are strategic, rather than of tactic.

3.5 Design with the winning formulas

Wei-Xuan Hung, a member of the focus group, applied the winning formulas to her entry to a metaphor-oriented annual contest, National Treasure Derivative Product Design Competition, in 2015. The main requirements given by the competition is a set of national treasure from which every participant must choose one as the metaphor sources to design a product. Hung started to interpret it into the fact that the source category is 'artefact', and the target category is living goods. Since structure similarity and scene similarity both play key roles in the winning formulas, she chose 'Angling Snow on Frozen River (寒江釣雪)', painted by the Song Dynasty artist Fan K'uan (960-1030), as the source object. The significant relations in the lonely old angler holding a fishing rode in a boat on the river are quite visible, as illustrated in Figure 1.

Figure 1. The source object (38.9cmx80.6cm), adopted from [Angling snow on frozen river n.d.]

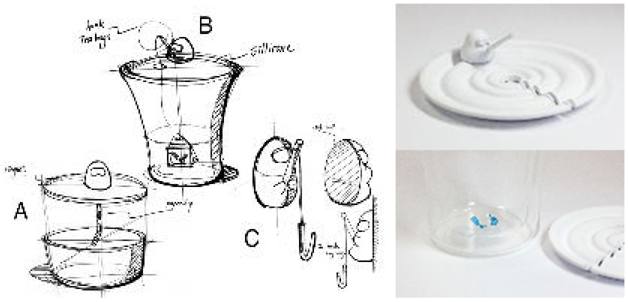

Figure 2. Sketch examples (left) and close ups of final design (right)

Figure 3. Use of the tag bag holder lid

As the source category, source object, and target category were determined, the designer went on exploring the possible target objects by comparing the structure and scene observed in that Chinese Daoist landscape painting. She focused on the issue of connection, based on the holding of fishing rode with a line to propose living goods with a similar issue. One alternative is that an individual pulls a magnet lid of paperclip holder to which a string of paperclips attached. Another alternative is that someone put his or her clothes on a wall hook. Hung finally selected cup lid with tea bag holder as the target object, for it securely holds tea bag string without the drinker holding it. In addition to these concerns, form similarity is considered in her concept development process. Figure 2 illustrates examples of sketches (left) and close ups of the final design (right). The angler sitting on food-grade-silicone cup lid with water wave surface uses a fishing rode to hold the line connecting with the tea bag in hot water through the gap in the lid. At later phases, the design was extended to a Chinese tea cup kit with tea bag holder. To enhance user interaction, Hung added an illustration of a blue fish couple on the inner bottom of the cup. The fish illustration is made of thermo-chromic coating that is sensitive to temperature change. When hot water is poured into the cup, it gradually becomes transparent. Furthermore, as traditional Chinese tea cups commonly have no handle, this design adopts double wall glass for a heat-resisting reason. At the end, the 'Angling-snow-on-frozen-river cup' became the finalist of the competition in May 2015 and won Bronze Prize with NT$ 25,000 (around US$ 800) in July. Also, it was invited to display at the promotion exhibition held at the National Palace Museum, Taipei, in September 2015. Although the formulas are specifically derived from the example of one-hundred entries, their application to the competition is significant.

4. Conclusions

This paper demonstrates description, explanation and prediction of entries in design competitions from the viewpoint of design by analogy. Structure mapping and similarity-based approaches are applied to representing the category, elements and relations of the entries, whereas rough sets are applied to data representation and rule induction. A set of rules, namely, winning formulas, is obtained from a large sample and tested with prize winners at an acceptable prediction accuracy. When initial design problem is given, structure similarity is the key to identifying metaphor target and searching metaphor source, as well as crucial for blending the target and source together to generate good metaphor. The formulas have been applied to a design prize winner for its metaphor created by analogy. It suggests that they are useful for designers, companies, and competition organizers to develop their unique winning strategies for various design competitions. The study also demonstrates a systematic method to derive design formulas from award winners. More comprehensive formulas may be possible, as long as much bigger data of winners and more applications for testing are available.

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