机械产品
创新设计方法与实践

张涛　刘建华　赵伟　主编

机械产品创新设计方法与实践
The Method and Practice of Mechanical Product Innovative Design

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前　言
Preface

　　产品设计作为工业设计的核心，对企业的生存和发展至关重要。为培养国际化的设计理念，了解更多的新知识、新理论，培养高水平的设计人员，促进工业设计专业的国际化，以实现我国自主设计的目标，适应经济全球化和科技革命的挑战，在工业设计专业课程中开设了"产品设计"课程的双语教学环节。

　　本书是根据国家教育部"大力推广使用外语讲授公共课和专业课"精神和高等学校开展双语课程改革和实践的要求，并结合多年教学实践经验编写而成的。在编写过程中，突出了以下特点：

　　(1)本书采用了中英文相结合方式，通过不同表述方式，释放语言限制，突破传统思维，转换思维模式，开启思路，挖掘潜能，以全新思维构架，从不同角度认识设计基本原理及思路。其中设计理论、思想及方法采用英文撰写；创新设计案例及实践则采用中文撰写，保证设计构思的清晰准确实现，加强对设计理论的认知和理解。

　　(2)本书内容以"设计方法—设计实例—设计创新—设计实践"为主线，阶梯递进，逐步深入，注重理论与实践紧密结合。论述语言通俗浅显、清晰简洁、条理明朗，应用实例贴近生活、易于对比和理解。

　　(3)本书包括国内外先进的设计理念、设计成果，可以开阔读者的视野，激发其设计与创作的欲望。

　　(4)本书产品设计实例范围全面，包括交通工具、家具、家电、公共设施、老年和儿童产品、日常用品、机电产品设计、健康产品等各类产品。

　　(5)本书的适用面广，既适用于机械类各专业，如工业设计、机械设计制造及自动化、车辆工程等专业，也适用于近机械类专业，如工业工程、电气工程及其自动化等专业。

　　本书的编写分工如下：刘建华负责第1章中1.1～1.4节的编写，张涛负责第1章中1.5节的编写，朱蕾负责第2章的编写，赵伟负责第3章的编写，李珂负责第4章的编写。本书由张涛、刘建华和赵伟任主编；张伟社教授负责审阅，其在审阅后提出了许多宝贵意见。在编写过程中，得到了西北工业大学出版社雷军等同志的大力支持和热忱帮助，在此一并表示感谢！

　　由于水平有限，书中难免会有不妥之处，恳请读者批评指正。

<div align="right">

编　者

2013 年 3 月

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Universal Design Principle

1.1 可视性设计准则 Perceived principles

1.1.1 外观式设计准则 The aspect

1. Color combinations

Color defines the world and gives different from the objects. Color is the one of the most useful and powerful design tools.

（1）Physics of color

Where does color come from? Color derives from the spectrum of light interacting in the eye with the spectral sensitivities of the light receptors. Color can only exist when three components are present: a viewer, an object and light. Pure white light contains all colors in the visible spectrum, but it is perceived as colorless. When white light hits an object, it reflects some colors which contribute to the viewer's perception of color.

And color has three components, they are hue, saturation, brightness to show differences between things in the world. For instance, hue can tell the ripe tomato or not, and saturation can tell the milk coffee or not, and brightness can tell the difference between the sun and the moon (see Fig. 1-1).
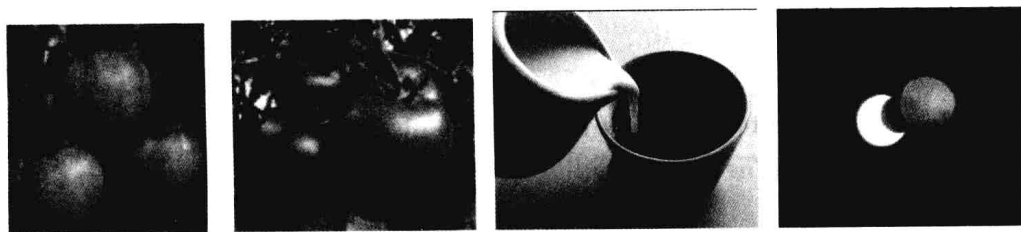

Fig. 1-1 The examples about three components

1) Hue

In general, "color" often is talked about hue, which is a component of color to be talked about most. It indicates that a color looks red, green, blue, yellow, orange, etc, appeared on the color wheel. As an example, look at the line of different hues in Fig. 1-2. It looks like colors from a rainbow.

2)Saturation

Saturation(see Fig. 1 - 3) is the amount of grey in a hue and represents how pure a color is. As an example of saturation, think about what happens to add milk in coffee. Just add a little milk and stir it up. It's deep brown. Then add more milk, it's still brown, but not as deep. Add more and more milk, the mix would get more faded until it looks almost white.

Fig. 1 - 2   Hue

Fig. 1 - 3   Saturation

The saturation increases, the amount of gray decreases. The color wheel in the middle is the purest color. A color with more gray is considered less saturated, while a bright color with very little gray, is considered highly saturated.

The saturation of a color can affect our emotion. More saturated colors are considered more bold and tied to emotions, and are perceived as more exciting and dynamic. In advertisements, saturated colors could be often used in order to catch the attention of readers and viewers. Unsaturated colors are considered softer and less striking, and are perceived as more restful and peaceful.

Then using saturated colors could attract attention, and using desaturated colors should be more performance and efficiency. Generally, desaturated dark colors are perceived as serious; and desaturated bright colors are perceived as friendly.

3)Brightness

Brightness (see Fig. 1 - 4) is the amount of white in a hue and shows how strong a color is. For example, the sun has a high brightness, while a birthday candle has a low brightness. Colors like whites and yellows have a high brightness. Colors like browns and grays have a medium brightness. Colors like black have a low brightness.

Fig. 1 - 4   Brightness

Among three components, hue is most important to seeing color. People should be more sensitive to changes in hue than to changes in brightness, and more sensitive to changes in brightness than to changes in saturation. Traffic lights use the different hues of green, yellow, and red instead of a dark red, a medium red, and a bright red.

4）Meaning of colors

Colors are non-verbal communication. Over 80% of visual information is related to color. In design, it is helpful to know how a person perceives certain colors and the color meanings.

Symbolism of color is varying from culture to culture. And different cultures attach different meanings to colors. For example, in European culture white is believed to signify marriage, angels and peace, but in the Orient white is the traditional color of mourning and death.

（2）Guidelines about Color combinations

There are the four ways to combine with colors.

1）Analogous — adjacent color

Analogous color combinations (see Fig. 1-5(a)) use colors that are next to each other on the color wheel.

2）Complement — opposing color

Complementary color combinations (see Fig. 1-5(b)) use two colors that are directly across from each other on the color wheel. These opposing colors create maximum contrast and maximum stability.

3）Quadratic

Quadratic color combinations (see Fig. 1-5(c)) use colors at the corners of a square or rectangle circumscribed in the color wheel.

4）Triadic

Triadic color combinations (see Fig. 1-5(d)) use colors at the corners of equilateral triangle circumscribed in the color wheel.

(a)　　　　　　　　　　　　　　(b)

(c)　　　　　　　　　　　　　　(d)

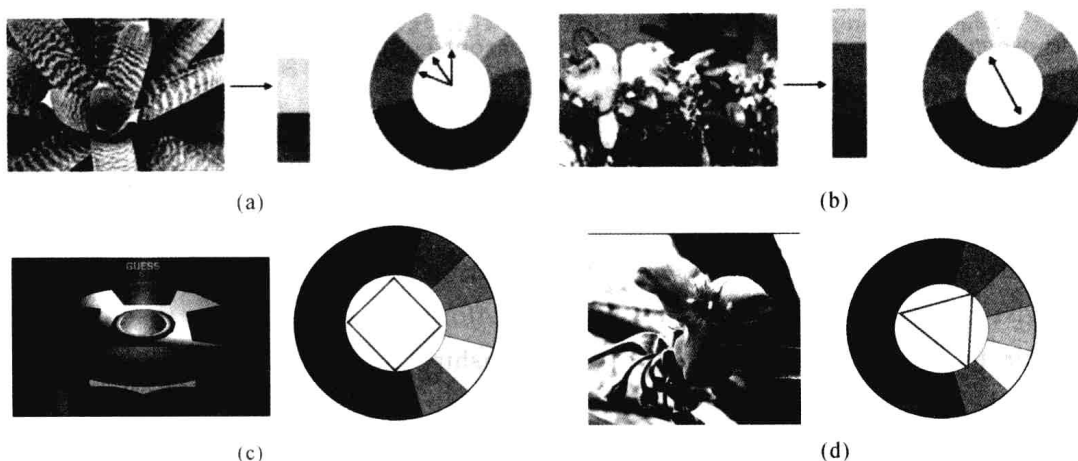Fig. 1-5　Color combinations

（3）Epilogue

Color can attract attention, convey feeling and enhance aesthetics. And colors can also cause fatigue, increase stress, damage eyesight, increase possible worker errors. So if

applied improperly, colors can seriously harm the intention of a design.

2. Rules of visibility

(1) Definition

The efficiency of a system should be improved if the users are allowed to see the information and the performing status. In general, a green light indicates that the status of the device is very well, and a red light indicates that there is failure. For example, red light shows that the printer is out of paper (see Fig. 1-6(a)); illuminated controls could be used to indicate controls that are currently available (see Fig. 1-6(b)).

In simple systems, the rules of visibility is easily realized that all controls and status are visible, but it should be perhaps difficult in complex system.
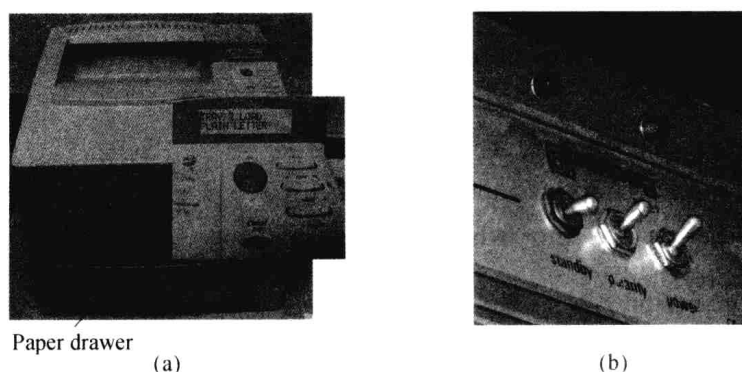
Paper drawer
(a)   (b)

Fig. 1-6   Rule of visibility

(2) The solutions

In a complex system, there are three steps for the maximize visibility. At first, the designer must consider the number of controls and information, then puts controls and information into logical categories, in final, hides some controls within a parent control, where these controls remain concealed until the parent control is activated.

3. Affordance

(1) Deduction

Afford is verb, be able to spare or give up something or be the cause or source of something. Then what is affordance?

And in 1979, Mr. James Jerome Gibson, who was an American perceptual psychologist, brought about Affordance theory. Affordance theory states that the world is perceived in terms of object shapes, spatial relationships and possibilities for action.

Mr. Gibson said, a possibility for action afforded to a perceiver by an object. And the affordances of an object depend upon the perceiver and the characteristics of the object. For example, a small stream affords such actions as crossing to an adult, but to an infant it affords jumping.

Then in 1988, Mr. Donald Norman introduced the term affordance to design in his book *Psychology of Everyday Things*. He said, "An aspect of an object which makes it obvious how it should be used" and "Keep the perceptions of the user in the mind." And that is to let

object talks.

（2）Definition

At first, what is that in Fig. 1 – 7(a)? It is maybe a piece of glass or window? It is not sure and it is lack of affordance. But in Fig. 1 – 7(b), it is a blackboard, and this sure makes it obvious! And this is design with affordance.
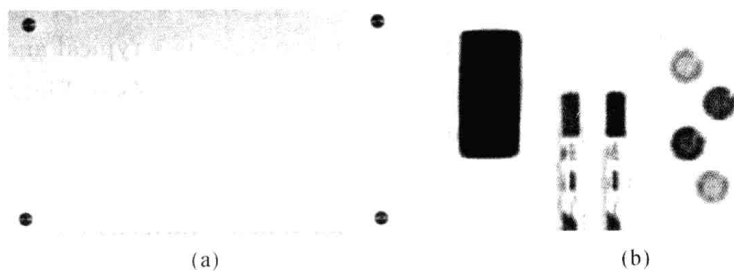

(a)　　　　　　　　　　(b)

Fig. 1 – 7　What is that?

Affordance is a quality in which the physical characteristics of an object or environment afford its function. Physical characteristics are primarily physical in nature, such as area, hardness, smoothness, weight, shape, volume, color, etc.

Firstly, some physical characteristics are better suited for some functions than others. For example, circle is better suited than square for rolling, and stairs are better suited than fences for climbing.

Secondly, the design with affordance corresponding to its function will perform more efficiently and will be good usability. For example, the door with a flat plate affords pushing, and the door with a handle affords both pulling in Fig. 1 – 8(a). If open the door with a plate only by pushing and open the door with a handle only by pulling, the affordance of the designs corresponds to the way in which the door can be conveniently used. Then the sign of "pull" in Fig. 1 – 8(b) is superfluous. But if door with handle is designed to open only by pushing in Fig. 1 – 8(c), the affordance of the design conflicts with the door's function, and it would be not convenient.
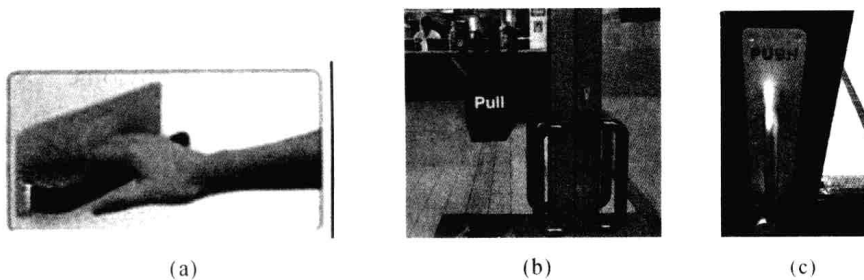

(a)　　　　　　　　　　(b)　　　　　　　　　　(c)

Fig. 1 – 8　The door with the handle

Thirdly, using images of common physical objects and environments can improve the usability of a design. There are many designs of images in computer software. For example, the "desktop" used by computer operating systems has the function of office desk. And on a

computer screen, three dimensional buttons with the physical characteristics of buttons can afford pressing. In addition, other items, such as the file folder, rubbish can, and so on, are same with ones in the real world, and their functions are also the same with those in the real world.

(3) Practical application

Chinese abacus (see Fig. 1 - 9(a)), which is a calculator that performs arithmetic functions by manually sliding counters on rods or in grooves, is a typical ancient design with good affordance. And the another design is the old typewriter (see Fig. 1 - 9(b)) is a mechanical or electromechanical device with a set of "keys" that, when pressed, cause characters to be printed on a medium, usually paper, and it is also a typical ancient design with good affordance. And with opposing male and female surfaces and featureless sides, Legos naturally afford plugging into one another (see Fig. 1 - 9(c)). Besides, there are other designs such as cellphone, faucet, and so on.
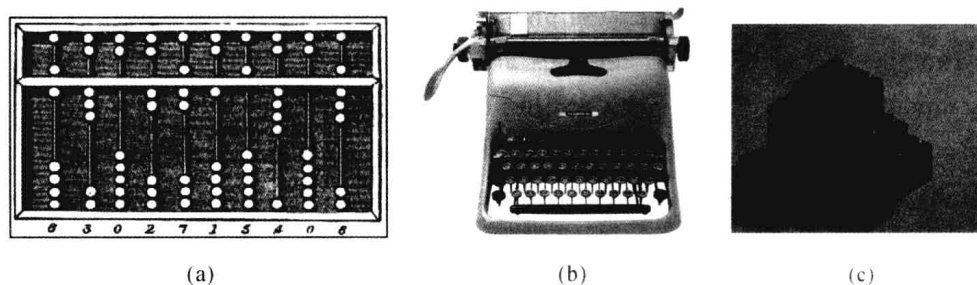

(a)   (b)   (c)

Fig. 1 - 9   Some designs of good affordance

4. Matching

(1) Definition

Matching is a relationship between controls and their functions. Good matching should enhance usability.

Press a button, and twist a knob, some kind of effects should be happen. The effect corresponds to expectation, the matching is considered to be good. For example, a power window of automobiles can be raised or lowered by pressing a switch corresponds to the window. The relationship between the control and the window is obvious.

(2) The pattern

There are three matching modes, they are layout, behavior, or meaning. About the layout, the stovetop in Fig. 1 - 10(a) is a good matching, and conversely, the relationship is not clear in Fig. 1 - 10(b). About behavior, turning a steering wheel left turns the car left; and meaning, an emergency shut-off button is colored red, which is the meaning of stop.

(3) Epilogue

Be sure positions and behaviors of controls correspond to the layout and behavior of the system. Simple matching relationship is easy to use. Avoid using a single control for multiple functions.
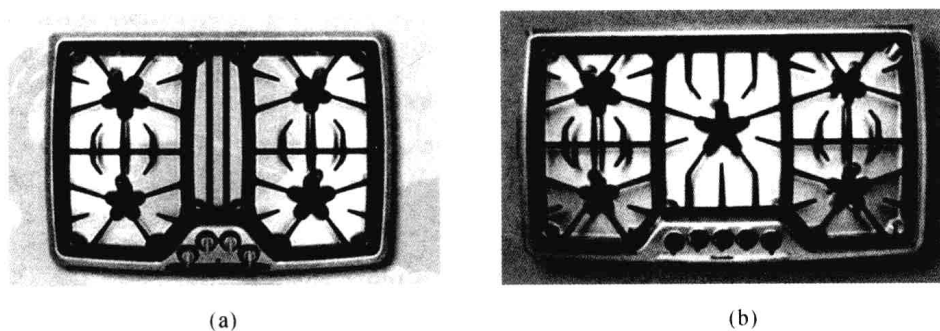
Fig. 1 – 10　Layout
(a) good;　(b) poor

5. Figure-Ground relationship

(1) Definition

The figure-ground relationship is one of Gestalt principles of perception. Every perceived thing contains figure and ground. Figure is objects of focus. And ground is the rest of the field. Elements are perceived as either figures or ground. For example, is it a white circle on a black square or a black square with a round hole in Fig. 1 – 11?

There was an old joke in Soviet Russia about a guard at the factory gate who at the end of every day saw a worker walking out with a wheelbarrow full of straw. Every day he thoroughly searched the contents of the wheelbarrow, but he never found anything but straw. One day he asked the worker, "What do you gain by taking home all that straw?" "The wheelbarrows."
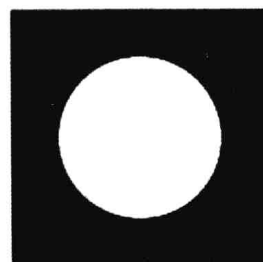

Fig. 1 – 11　Figure and ground

This paper is about the straw and the wheelbarrow, about shifting attention from figure to ground or, rather, about turning into figure what is usually perceived as ground. We are used to think of the load as "figure"; the wheelbarrow is only "ground", merely an instrument. Our default interest is in the act, not in the instrument.

(2) Figure and Ground

The part of a composition paid attention to is called figure. The figure is also called a positive shape. In different composition there may be one or several things to be figure. Everything that is not figure is ground.

This relationship can be demonstrated with both visual stimuli, such as photographs, and auditory stimuli, such as soundtracks with dialog and background music.

(3) The relationship

If the figure and ground of an object are clear, the relationship is stable; the figure element attracts more attention. In unstable figure-ground relationship, the relationship is ambiguous. At times, they could become figure from one to another thing in turn (see Fig. 1 – 12).

Fig. 1 - 12 The unstable figure-ground relationship

In general, the figure has a definite shape, whereas the ground is shapeless. And the figure is perceived to be closer, but the ground is perceived to be farther away in space. Things below a horizon line and the lower regions are more likely to be perceived as figures, whereas elements above a horizon line and the upper regions are more likely to be perceived as ground (see Fig. 1 - 13).
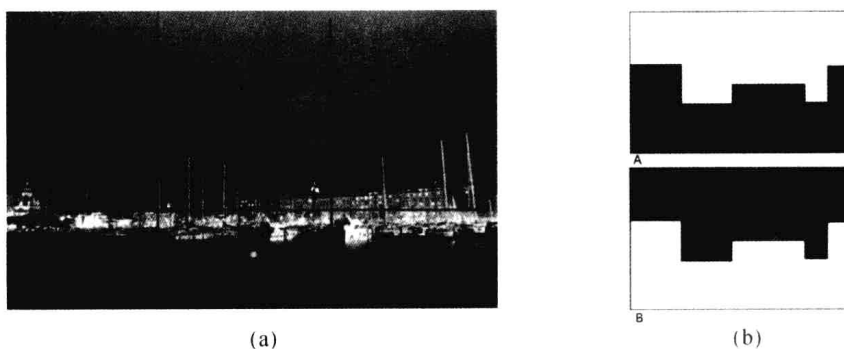

(a) (b)

Fig. 1 - 13 The relationship in the photograph

In addition to, figure-ground reversals (see Fig. 1 - 14) create a delightful "surprise" in the viewer's eye. People are unconsciously influenced by the ground even when they are consciously only aware of the figure.
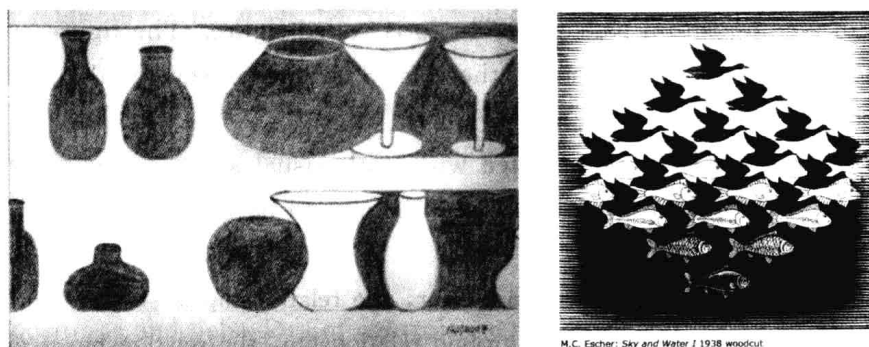

M.C. Escher: Sky and Water I 1938 woodcut

Fig. 1 - 14 Figure-ground reversals

6. Arrangement

(1) Definition

Placement of elements in orderly way is aesthetic and united, such as circular, square, row, column, or spiral. And the rows and columns of people or things can clarify their relationship, for example, a formation of aircrafts in flight, or troops.

(2) The pattern

In paper or text, left-aligned, right-aligned or center-aligned text blocks are often used (see Fig. 1 - 15(a)), and justified text is more used than unjustified text. Sometimes to detect different from other text blocks, inclining certain angles of text block could be used (see Fig. 1 - 15(b)).
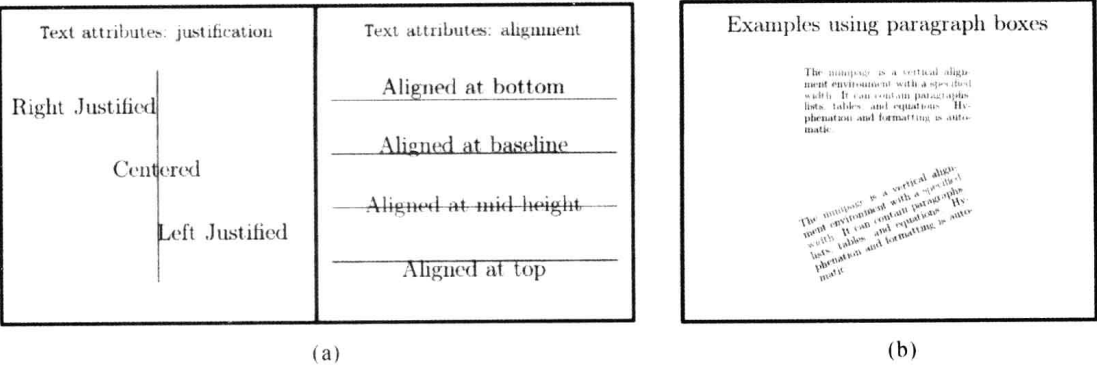

(a)　　　　　　　　　　　　　　　　(b)

Fig. 1 - 15　Aligned text

1.1.2　内涵式设计准则　**The connotation**

1. Consistency

Similar systems are exhibited by similar ways. Then the systems should be easy to know and use. For example, there are the same typefaces, color schemes, menus, staff uniforms, architecture in every Kentucky Fried Chicken (see Fig. 1 - 16).
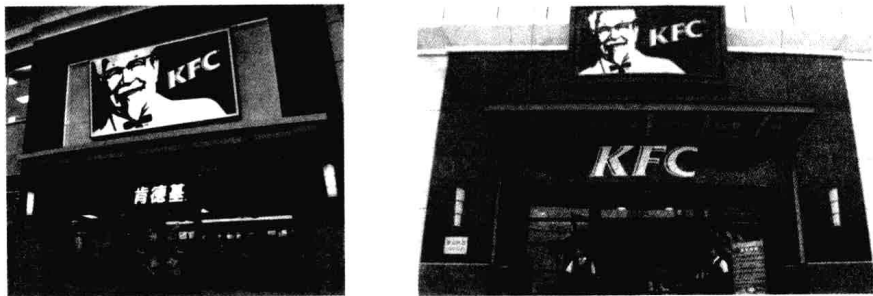

Fig. 1 - 16　Kentucky Fried Chicken

There are two modes of consistency, imagery consistency and applied consistency. Imagery consistency refers to consistency of style and appearance, such as a company logo (see Fig. 1 - 17 and 1 - 18), product brand, and feature of building, etc. Applied

consistency refers to consistency of meaning and action, such as traffic light, buttons of video player, and so on.

Using consistency can simplify usability and ease of learning.

Fig. 1 - 17   Kodak logo

Fig. 1 - 18   Color Gardens logo

2. Good continuation

Good continuation is a Gestalt principle of perception that graphic elements that suggest a continued visual line will tend to be grouped together. Visual patterns with good continuation may suggest to the viewer that the pattern continues beyond the end of the pattern itself. That is, there is an action mentally to "fill in" or "paint in" the rest of the pattern.

Elements arranged in a straight line or a smooth curve are perceived as a group, and are interpreted as being more related than unaligned elements (see Fig. 1 - 19 and Fig. 1 - 20). For example, marks of dial plate are easily interpreted as a group because they are aligned along a circular path. Good continuation is also important in the design of tables, especially in the alignment of columns. Readers should not look down a column to see the good continuation broken by a rule line that is intended to frame a subheading.

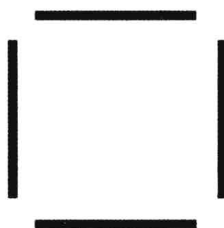Using good continuation in a design, it asserts that relatedness between elements is clear and not interrupted.

Fig. 1 - 19   Corner of square

Fig. 1 - 20   Fold line

3. Five Hat Racks

The term hat racks is built on an analogy, and hats are information and racks are the ways to organize information. In 1976, Mr. Richard Saul Wurman defines the term "information architect", and the concept of the "Five Hat Racks" was originally developed in his book "Information Anxiety", indicating that the information explosion really is dramatic. However, in modern, this is not to mention the extremely dramatic expansion of electronic information on the Internet, which is probably doubling the production of information every

four years. Information may be infinite, however the organization of information is finite. "Five Hat Racks" principle can effectively help to organize information.

Five Hat Racks are ways of Location, Alphabet, Time, Category, or Hierarchy. The five hat racks principle asserts that there are a limited number of organizational strategies.

Location refers to organization by geographical or spatial reference. Examples include emergency exit maps and travel guides. Alphabetical refers to organization by alphabetical sequence. Examples include dictionaries and encyclopedias. Time refers to organization by chronological sequence. Examples include historical timelines and TV Guide schedules. Category refers to organization by similarity or relatedness. Examples include areas of study in a college catalog, and types of retail merchandise on a Web site. Hierarchy refers to organization by magnitude. Examples include baseball batting averages and Internet search engine results.

1.2　认知性设计准则　Cognized principles

1.2.1　心智型设计准则　The mental

1. Mental model
(1) Definition
The term "mental model" was first defined by Craik in his book "The Nature of Explanation". In his book, Mr. Craik said that the mind constructs a "small-scale models" of reality that it uses to reason, to anticipate events and to underlie explanation. People understand and interact with environments based on mental representations developed from experience. But the concept couldn't be paid attention to until cognitive science appear. At present, the mental model has been used in many contexts and for many purposes.

Then in design, the use of mental models was popularized in the Human-Computer Interaction design field. Donald Norman in his book *Psychology of Everyday Things* used mental model to describe respectively the designer's mental model and user's mental model. A device is designed on the basis of the designer's mental model, the user forms a mental model through interaction of the device. In other words, the designer materializes his mental model of a given design, which becomes the only means of conveying his mental model to the user. Thus, users do not only interpret the visible parts of the device but also guess what goes on happening (see Fig. 1 – 21). Metal model is mental expression of devices, systems and environments derived from experience. User understands systems and environments, and interacts with them, through comparing the outcomes of his mental model with real-world systems and environments. If the imagine that consciously or unconsciously form from our experiences correspond to with real outcomes, the mental model is accurate and complete, on the contrary, the mental model is inaccurate or incomplete.
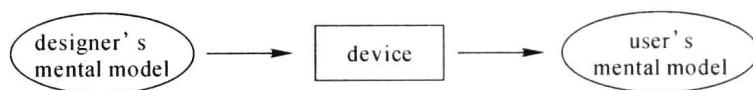
Fig. 1 - 21 Designer's and user's mental model

(2) The different

When a user participates in an event, the user should evaluate his expectations of the event with their realization of the event. Then before the user will participate in an event, there are three questions guide their participation. What does the user want? How does he try to achieve it? What's his action? What does he expect to happen?

At first, the user has an idea about something they want or need. The next, he has an idea about his course of action. Then they have an expectation that his action will let them realize his want. Therefore what the user wants is the goal. Since this is an idea they have, this as a "peak". And he select an approach to be close to the thing he wants, this is "path". Finally, he has an expectation of what will happen, this is "sunshine" (see Fig. 1 - 22). An expectation can't be formulated without a path, and the path can't be formulated without the initial goal. The goal, approach, and expectation constitute the user's mental model.

However, the designer will think more of how the device will perform in this event.

Fig. 1 - 22 Peak, path and sunshine

(3) The expatiation

With regards to design, there are two modes of mental models: design models and use models. Design models is the mental models of how systems work, use models is the mental models of how users interact with systems.

Designers know much about how a system works, and possess very complete and detailed design models. Conversely, users should have more complete and accurate use models than designers through use and accumulated experience. Therefore for enhancing usability of system, designers should obtain accurate and complete use models through personal use of the system, usability testing, or observation of user interacting with the system. The designer using the system or testing will learn the problems of interaction that appear when the system is used by people who are unfamiliar with it. Then the most effective method is to watch people use the design and take note of how they use it. Observing users, designers can acquire accurate information about how people interact with systems.