

**UNDERSTANDING AND MODELING OF AESTHETIC RESPONSE TO SHAPE AND  
COLOR IN CAR BODY DESIGN**

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In the Department of Mechanical Engineering  
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Saskatoon

By

CHEN WANG

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## ABSTRACT

This study explored the phenomenon that a consumer's preference on color of car body may vary depending on shape of the car body. **First**, the study attempted to establish a theoretical framework that can account for this phenomenon. This framework is based on the (modern-) Darwinism approach to the so-called evolutionary psychology and aesthetics. It assumes that human's aesthetic sense works like an agent that seeks for environmental patterns that potentially afford to benefit the underlying needs of the agent, and this seeking process is evolutionary fitting. **Second**, by adopting the framework, a pattern called “fundamental aesthetic dimensions” was developed for identifying and modeling consumer’s aesthetic response to car body shape and color. **Next**, this study developed an effective tool that is capable in capturing and accommodating consumer’s color preference on a given car body shape. This tool was implemented by incorporating classic color theories and advanced digital technologies; it was named “Color-Shape Synthesizer”. **Finally**, an experiment was conducted to verify some of the theoretical developments.

This study concluded (1) the fundamental aesthetics dimensions can be used for describing aesthetics in terms of shape and color; (2) the Color-Shape Synthesizer tool can be well applied in practicing car body designs; and (3) mapping between semantic representations of aesthetic response to the fundamental aesthetics dimensions can likely be a multiple-network structure.

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## LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
ANN	Artificial Neural Network
ANOVA	Analysis Of Variance
B/S	Browser/Server
C+/-	Cuteness (positive/negative)
CAAD	Computer Aided Aesthetic Design
CAD	Computer Aided Design
CAID	Computer Aided Industrial Design
CASD	Computer Aided Style Design
CIE	Commission Internationale de l'Eclairage (International Commission on Illumination)
CMY(K)	Cyan, Magenta, Yellow (and Key)
TF	Term Frequency
DF	Document Frequency
E-chain	Egoism aesthetics chain
EA	Evolutionary Aesthetics
EID	Ecological Interface Design
EP	Evolutionary Psychology
Emocards	A non-verbal emotion measurement
F+/-	Functional cue (positive/negative)
FBPSS	Function Behavior Principle State and Structure
FBS	Function-Behavior-Structure
G+/-	Gender metaphor (positive/negative)
G-chain	Gender metaphor aesthetics chain
HSL	Hue, Saturation and Luminosity
HTML	Hyper Text Markup Language
ID	Identity (of Kansei word)
IE	Information Extraction
IR	Information Retrieval

KE	Kansei Engineering, an engineering method for translating feelings and impressions into product parameters
Kansei	Japanese word which stands for consumer's psychological feeling and image
LSD	Least Significant Difference
MDS	Multi-Dimensional Scaling
MVC	Model-View-Control design pattern
NLP	Natural Language Processing
NURBS	Non-uniform rational B-spline
P	Probability
P+/-	Personality (friendly/aggressive)
P-chain	Parental aesthetics chain
Perl	A Computer Programming (Scripting) Language
PrEmo	Product Emotion Measurement tool
RCBD	Randomize Complete Block Design
RGB	Red, Green and Blue
S-chain	Social Aesthetics Chain
SAM	Self Assessment Manikin
SAS	Statistical Analysis System
SD	Semantic Differential
SPSS	Statistical Package for the Social Sciences
SQL	Structured Query Language
SVM	Support Vector Machine
T+/-	Trend (positive/negative)
TF-IDF	Term Frequency – Inverse Document Frequency matrix structure
UI	User Interface
VSM	Vector Similarity Measure
XML	eXtensible Markup Language

## CHAPTER 1 INTRODUCTION

### **1.1 General Motivation**

This study is motivated by an industrial design project in which the author participated as a member of the design team of a major European car manufacturer (appendix A). During the design practices, it was noted that (1) a consumer's preference on car body color may vary depending on its shape; (2) the quality of design in terms of color and shape of car body largely relies on designer's personal knowledge and experience; and (3) it was still unclear how to design color(s) given a shape, and vice versa.

Typically, a consumer's initial impression on a new car is derived from his or her appraising the car's exterior. As such, the shape and color of car body are not only confined to influencing the consumer's aesthetic judgment but also have extended impact to the consumer's early perception of the car's functionality and comfort. In order to count this fact in the industrial design processes, it is important to identify the relationship among shape, color and consumer's feelings, and take advantage of such knowledge in the design of car body.

### **1.2 Problem Statement**

Design of car body shape and color differs from creation of pure art products, as the former is in the contexts of engineering, which implies that functionality and ergonomics of a product (i.e., car body) cannot be ignored and they are intertwined with aesthetic design. A common challenge

of dealing with aesthetics issues in the engineering context is how to measure human's feelings; in other words, how to quantify and measure consumer's aesthetic response to a product.

As soon as measurement comes into concern, three questions have to be answered, which are: (1) what to measure; (2) how to measure; and (3) the (quantitative) representation of the measurement results. Unlike in many other design fields (i.e.: functional design and ergonomic design), the three questions can hardly be answered in the aesthetic design field at a first glance. There are a couple of reasons behind the situation. **First**, a common belief is that human mind is “intangible”; any attempt to quantify and measure human aesthetic sense is considered futile. **Second**, although aesthetics has been qualitatively studied in many non-engineering fields, such as psychology, sociology, philosophy and even anthropology, the actual benefits to engineering field are very limited (due to the incompatible ontological assumptions, as discussed later). **Third**, there are also challenges in dealing with race, culture, religion, age, gender and so on. **Fourth**, a consumer’s aesthetic preference contains dynamic patterns which change over the time; they are called “trend” which are difficult to measure and predict in an accurate manner.

Nevertheless, the role of aesthetics and appearance increases as the manufacturing technology becomes more developed and the market becomes more sophisticated. There is growing demand for measuring consumer's aesthetic responses to car body shape and color in the automobile industry, which calls for new solutions to overcome the obstinate problems:

- (1) Identifying fundamental attributes to be measured;
- (2) Developing means to support the measurement;
- (3) Relating the aesthetic measurement to the engineering measurement.

## **1.3 Objectives, Scope, and Method**

### **1.3.1 Objectives**

*Objective 1:* Investigate a general framework for engineering aesthetics.

*Objective 2:* Develop an understanding of how car body shapes evoke affective responses and propose an approach for characterizing car body shapes in terms of aesthetics.

*Objective 3:* Develop an effective means for capturing consumer's color preferences on a given car body shape.

*Objective 4:* Investigate whether and how shape features and color attributes can be represented within a general aesthetic expression framework.

### **1.3.2 Scope**

Modern product design is a seamless integration of functional design, ergonomic design and aesthetic design [Lin and Zhang, 2006]. This study focuses solely on the aesthetic design yet complement functional and ergonomics designs. The aesthetic design aims to design a product (car) for mass production, which means, it intends to satisfy the aesthetic preference of the targeted population, society or human being rather than satisfying individual's aesthetic preference. It is therefore assumed that aesthetic preferences are either homogenous or idiosyncratic, which means, there are common aesthetic preferences that are universal across all members in a group, whereas each member in the group has its distinctive aesthetic preferences in addition to the common aesthetic preferences. The common aesthetic preferences are focused in this study. They are considered in such a way that each pattern of aesthetic preferences can be eventually satisfied by one or more feature(s) of car body shape or color. On the other hand, the

distinctive aesthetic preferences which vary upon an individual consumer's profile (race, culture, religion, age and gender) are temporarily excluded in this study but will be considered in future work.

Regarding the experiment, it was conducted within a maximum allowance of time and resource available.

### **1.3.3 Method**

The general methodology adopted in this study is a combined subjective learning and objective reasoning techniques. Fruitful results about aesthetics from philosophy and psychology were learned and assigned with engineering senses; the feature of the methodology is thus interdisciplinary. In particular, some well known paradigms in philosophy and psychology about aesthetics were closely examined and employed to the work here. Scientific measurement follows statistics due to the inherent nature of humans – i.e. uncertainty and non-deterministic.

### **1.4 Organization of the Thesis**

**Chapter 2** reviews literature resources available in the relevant works, aiming at finding a high-level framework that is suitable to sustain this study as well as low-level details that may facilitate the implementation. Meanwhile, the precedent researches and findings are converged, categorized and lined up with the vision of this study, revealing valuable solutions to adopt and open issues on which to work.

**Chapter 3** discusses the need and acquisition of Kansei (feeling) vocabulary as a tool for grasping consumer's affective responses. In compiling a quality Kansei vocabulary, a Web-



mining based method is proposed; its principle is explained in terms of technology, data structure and software tools.

**Chapter 4** addresses how product shapes evoke affective responses. A domain specific framework is established by adopting the (evolutionary-) psychology and aesthetics principles along with the FBPSS design methodology. This framework is then applied to the fundamental dimensions of human aesthetic sense in terms of appraising cars.

**Chapter 5** describes and discusses the development of an effective means for capturing and accommodating consumers' color preferences on car body shapes. An instrument, called "Color-Shape Synthesizer" is devised by combining classical color theories and the advantages of modern digital technologies.

**Chapter 6** presents an experiment in which some theoretical findings described in the previous chapters are verified.

**Chapter 7** concludes this thesis by summarizing the research findings, suggesting future works, and specifying the contributions.

## CHAPTER 2 BACKGROUND AND LITERATURE REVIEW

### **2.1 Introduction**

In this chapter, the literature review is given at two levels: (1) framework level and (2) implementation level. At level (1), contemporary aesthetics design frameworks such as Kansei Engineering and Dual-Process Methodology are investigated. At level (2), four categories of distinctive approaches toward shape-oriented aesthetic models are discussed, respectively. Upon the objectives of this study, the advantages and limitations of existing studies are concluded at both level (1) and (2).

### **2.2 Aesthetic Design Frameworks**

This section aims at getting a conceptual view from the literature in order to land a proper framework for sustaining this study. Implementation details are temporarily excluded.

#### **2.2.1 Kansei Engineering**

The quality of contemporary industrial design relies more and more on sophisticated design framework. Any framework that intends to incorporate aesthetics and engineering must be capable to deal with the challenge of grasping intangible human aesthetic sense. Kansei Engineering is such a state-of-the-art framework that is originally proven practical in the automotive industry and getting recognized by the other application domains such as the electrical product design and fashion design.

"Kansei" is a Japanese word (感性) which stands for consumer's psychological feeling and image regarding product's shape, color, texture as well as functions, usability and so on. According to Nagamachi [1995], if a product manufacturer intends to influence consumers' decision of purchasing, they have to identify the Kansei of consumers and implement it in the product. Therefore, there seems to be a common agreement among designers of the importance of Kansei and the need for practical methods within this field [Grimsaeth, 2005].

Kansei Engineering was developed as an engineering method for "translating feelings and impressions into product parameters" [Wikipedia, 2007]. Since devised in the early 70's at Hiroshima University, Kansei Engineering has spread over Japanese industries [Nagamachi, 1995]. According to Nagamachi [2001] and Schütte [2005], Kansei Engineering has three focal points that are commonly considered in design for aesthetics: (1) How to accurately understand customer Kansei; (2) How to translate the Kansei understanding into product design features; and (3) How to create a system and organization for conducting Kansei orientated design.

Based on multidisciplinary techniques of psychological assessment, artificial intelligence and computer science [Schütte 2005], Kansei Engineering (KE) proposed general procedures to guide product designers to obtain relations between Kansei and design features (see Figure 2-1). For example, Lin et al [2006] summarized the KE steps to grasp consumer's feeling as follows: (a) A set of words that describe consumer's feeling is compiled from various sources; (b) The words are then assessed by design engineers based on a subjective rating method; and (c) The factor analysis is applied to achieve a reduced set of words. Lin et al. [2006] also summarized the

KE procedure to identify design characteristics of the product from consumer's feeling as: (a) The design parameters of a concerned product are classified into levels; (b) The subjective rated assessment is conducted on the relationship between the feeling words and design parameters; and (c) A multiple-regression analysis is conducted to establish the relationship between the feeling word and the design parameter.

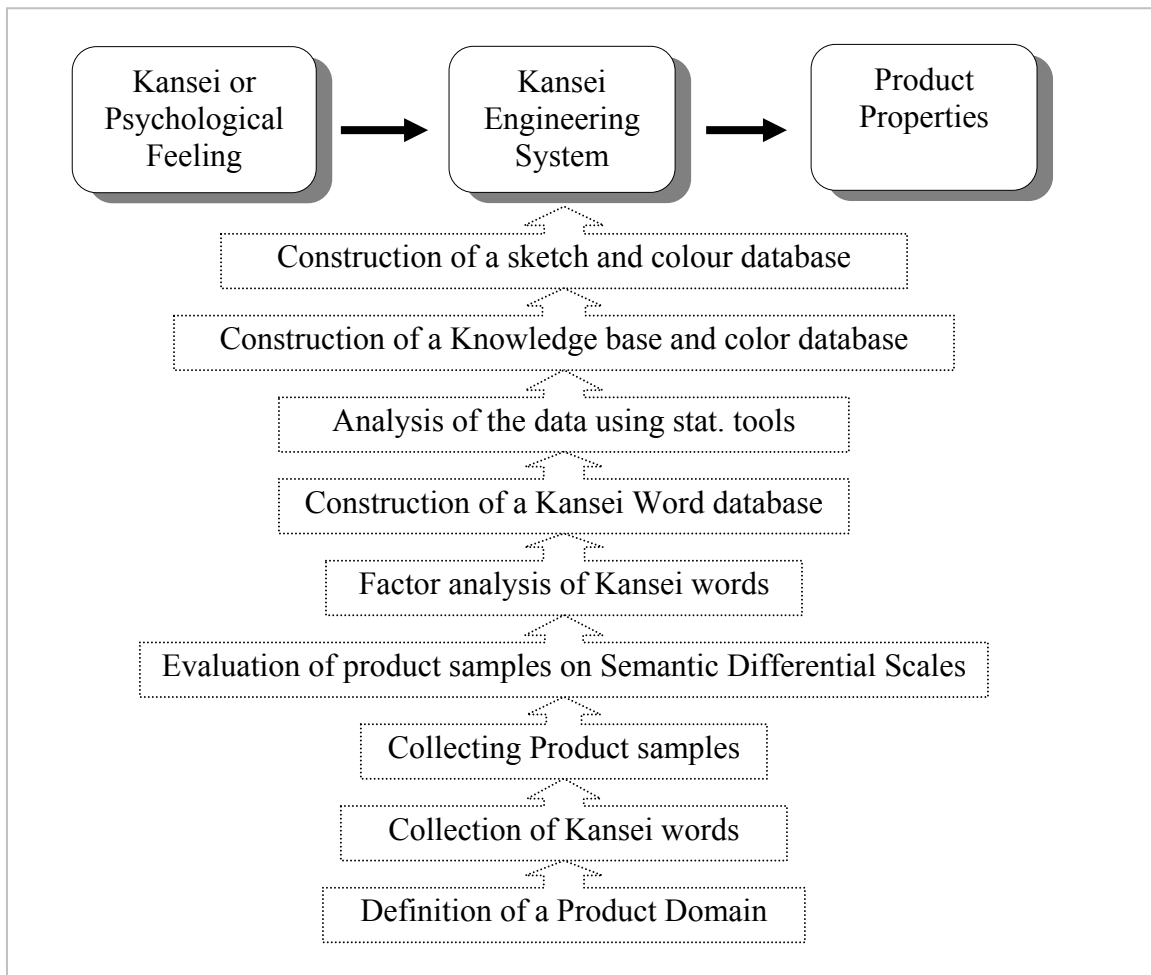


Figure 2-1 Principle and procedure of Kansei Engineering

Further, according to Nagamachi [1995], there are three styles of Kansei Engineering - Type I, II and III (see Table 2-1). In the recent literature, it is seen that up to six types of Kansei Engineering have been developed [Schütte 2005]:

Table 2-1 Kansei Engineering Types

KE Type	Description
Type-I	Category Classification
Type-II	Kansei Engineering System KES
Type-III	Hybrid Kansei Engineering System
Type-IV	Kansei Engineering Modeling
Type-V	Virtual Kansei Engineering
Type-VI	Collaborative Kansei Engineering Designing

Although Kansei Engineering is recognized as an innovative and valuable approach for translations between consumer's feelings and design elements, it is however not the only approach found noteworthy in literature.

### 2.2.2 Dual-Process Methodology

Liu [2003] proposed a methodology called “dual-process engineering aesthetics research methodology”. This methodology consists of two processes and is intended to achieve a comprehensive, precise, and quantitative understanding of aesthetic responses in a design context [Mokarian, 2007].

In Liu’s dual-process framework (see Figure 2-2), the first process (top-down process) is called “multidimensional construct analysis or multivariate psychometric analysis,” whose goal is to establish a “global” and qualitative view of the critical dimensions involved in a specific aesthetic response. The second process (bottom-up process) is called “psychophysical analysis,” whose objective is to establish a “local” and quantitative view of an individual’s perceptual

abilities and characteristics in making fine aesthetic distinctions along the selected dimensions. It identifies how keen the perceivers' senses are in detecting variations along the critical aesthetic dimensions and how their preference levels vary with changes in specific design parameters or aesthetic variables.

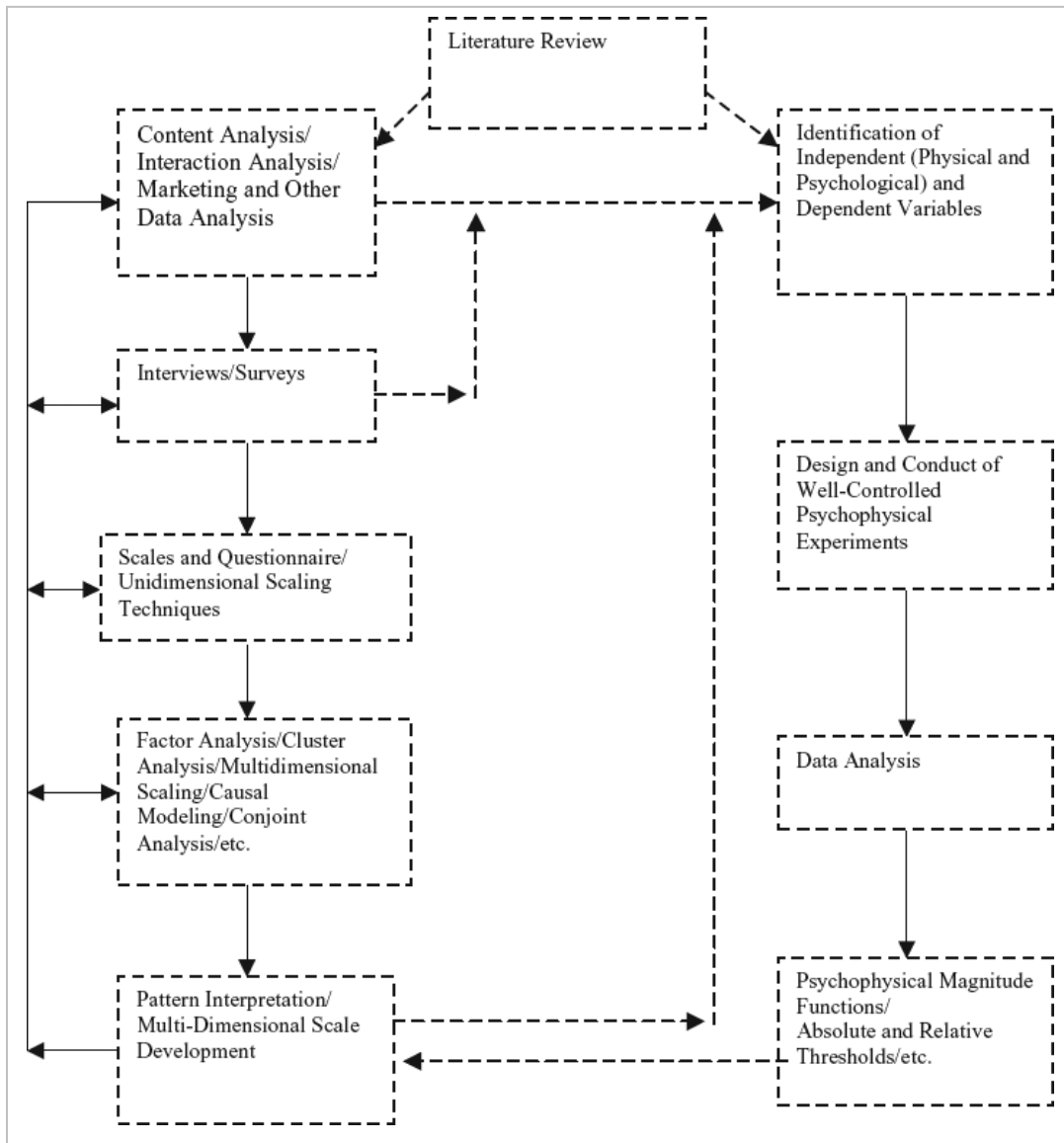


Figure 2-2 Dual-Process Methodology [Liu, 2003]

It seems that Kansei Engineering (discussed in the last section) can be placed into the first “multivariate psychometric analysis” of the dual-process methodology [Mokarian 2007]. The differences of these two are that in the dual-process methodology, the initial list of product attributes is not proposed by designers or researchers but is constructed on several sources, one of which is "content analysis" of carefully elicited texts from the consumer subjects [Liu 2003]. Nevertheless, the most outstanding advantage of dual-process methodology is, as Liu [2003] pointed out, the integration of the psychometric research process and the psychophysical research process.

Both Kansei Engineering and dual-process methodology are well documented at the conceptual level in the literature. However,, their implementation details are less (if not at all) discussed. The details, such as what are the concrete principle components or critical dimensions, are not answered but are critical to this study. Thus, a further literature review has to be conducted in a wider scope, as given in the next section.

### **2.3 Shape Aesthetic Models**

This section moves the literature review down to the implementation level and zooms-in to modeling shape-induced aesthetic responses, which is the major open issue in this study. The topics in the subsequent sub-sections are organized in a bottom-up order in order to determine what is the best level (e.g., geometrical, phenomenological, or empirical) the shape-induced aesthetic features can be accurately identified, captured and measured for research purposes.

### **2.3.1 Computational Aesthetics Model**

The motivation of reviewing computational aesthetics model is to figure out if it is possible to quantify human aesthetic preferences and systematically translate them into geometrical parameters. Ideally, if such a technology exists, can it be applied in a reversed manner, say extracting aesthetic features out of geometrical data of a given car body shape?

The concept of computational aesthetics is contextually polymorphous. In the industrial design context, there is by far no clear definition given to computational aesthetics. Instead, a term called Computer Aided Aesthetic Design (CAAD) [Brunet et al., 2002] has been intentionally introduced in order to differentiate itself from CAID (Computer Aided Industrial Design) and CASD (Computer Aided Style Design). Unlike CAID and CASD that aim at releasing the designers from tedious geometrical operations, CAAD is dedicated to communicating with designers in designer's language for expressing aesthetics. It assumes that designer's aesthetic intensions could be systematically interpreted into quantitative values for "driving the deformation of geometrical curves/surfaces. An ideal model of computational aesthetics should be capable to translate aesthetic preferences to shape geometry parameters by employing dedicated mathematical algorithms or artificial intelligence. According to Cappadona et al. [2003], the formalization of these translations as items of knowledge to be processed by a computer system may allow the designers' aesthetic intent to be communicated and/or preserved throughout a product industrial process.

However, it is found that computer support of industrial design is still in its infancy, especially of design for aesthetics which lacks proper theoretical fundamentals [Breemen et al., 1998], and without objective formal criteria for evaluating aesthetic shape properties [FIORES, 1999]. To



date, a few pioneering attempts have been made to achieve low level, simple element based or domain specific solutions rather than sophisticated, universal methodology for embodying high-level aesthetic concerns into design.

FIORES & FIORES-II for example, are projects that funded by the European Commission aiming at a new generation of computer aided aesthetic design (CAAD) system. By using case-based reasoning (CBR) techniques across thousands of examples, they extracted correlations that determined what certain styling properties literally meant to the eye. The styling properties investigated included tension, acceleration, sharpness, softness, crispness, convexity, concavity and lead in. These properties were then mathematically formalized with geometrical parameters such as curvature and NURBS/B-Splines control points. The outcome of this work included a software prototype providing free-form modeling tools for curve modification driven by aesthetic properties [FIORES and FIORES-II, 1997 - 2003].

$\delta$ -F<sup>4</sup>, as another example, has achieved computational aesthetics at a higher level where multiple geometric entities were grouped together to form a functionally meaningful element (e.g., door handle cavity). By introducing so-called Fully Free Form Deformation Features method, all member surfaces of elements were under the control of minimum number of characteristic curves, say target line and limiting line. Aesthetic features of this high-level element were therefore determined by shape features of a few low-level character curves, allowing a direct manipulation of surfaces through a restricted number of intuitive parameters [Cheutet et al. 2004].

The next example "BRIDGER" developed by Reich [1993] demonstrated a different type of computational aesthetics targeting aesthetic judgment. This system has an adaptive iteration workflow which runs through learning - redesign - evaluation processes. By using an incremental hierarchical clustering technique, the rationalistic learning engine captures property-value pairs (called aesthetic knowledge) from the structural components of proven successful products. The learned knowledge is then applied to synthesize new candidates (products) according to given specification. Each predicted candidate is then redesigned upon aesthetic evaluation in romanticist view followed by an analysis against specification until either aesthetic or engineering requirements are satisfied. The winning product is assimilated as new knowledge. Although BRIDGER limits itself to preliminary design of the cable-stayed bridge, the model it implements is more general for aesthetic judgment in industrial design [Reich, 1993].

The final example given by Tsai [2006] is valuable for its experimental quantification of product forms and colors during an industrial design process. A feature-parameter-based hierarchical model was used to construct the geometric shape of a product by specifying a series of feature operations, e.g., extrude, sweep, cut, fillet, etc. Each feature operation may involve one or more corresponding form parameters. Meanwhile, CIE-based color model was adopted for representing product color with R.G.B values. By using a gray clustering and fuzzy neural network, computational aesthetic models have been trained in a supervised manner, offering designers with aesthetic prediction capability for creating new product [Tsai, 2006].

After carefully looking into the above examples, it can be summarized that despite the significant progresses, computational aesthetics is still in its groundbreaking stage as a new discipline. By

far, it is typically applied to solve local and elementary aesthetic issues. Its current algorithms must rely on limited domain knowledge to achieve acceptable results [Catalano et al., 2007]. There are still theoretical issues to be addressed before it achieves a practical model suitable for "computing" human's high-level psychological response to a complex-shaped artifact like a car.

### **2.3.2 Ontological Model**

Since computational aesthetics has to work with simple, local, low-level aesthetic properties, the ontological model is reviewed in order to determine if it could be helpful to decompose a complex-shaped product into simpler entities until computational aesthetics becomes applicable.

The ontological model assumes that a complex-shaped artifact (like a car) is a harmonious integration of design elements which contribute to corresponding parts of the artifact's holistic appearance. In short, a complex-shaped artifact is aesthetically decomposable [Lin et al., 2006; Nagamachi, 1995]. A formal ontological model is a hierarchical taxonomy where the product itself is regarded as the zero-level design element on top of all other design elements. Along this hierarchy, a higher level element could be broken down (through one or more layers) into clearly, meaningful sub-elements to get the design details which are typically mean physical traits<sup>1</sup> [Nagamachi, 1995].

A recent study conducted by Catalano et al. [2007] resulted in a formal framework for extracting aesthetic elements from holistic car style (see Figure 2-3). Relying on domain knowledge gathered during several years of cooperation with designers of major European car manufacturers, car aesthetics ontology was conceived to formalize car aesthetics decomposition.

For a given car, the explicit and implicit elements contributing to the definition of car aesthetics will be captured and can be further realistically tackled down through digital models and methods.

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<sup>1</sup> .. which typically mean physical traits – commented by the author.

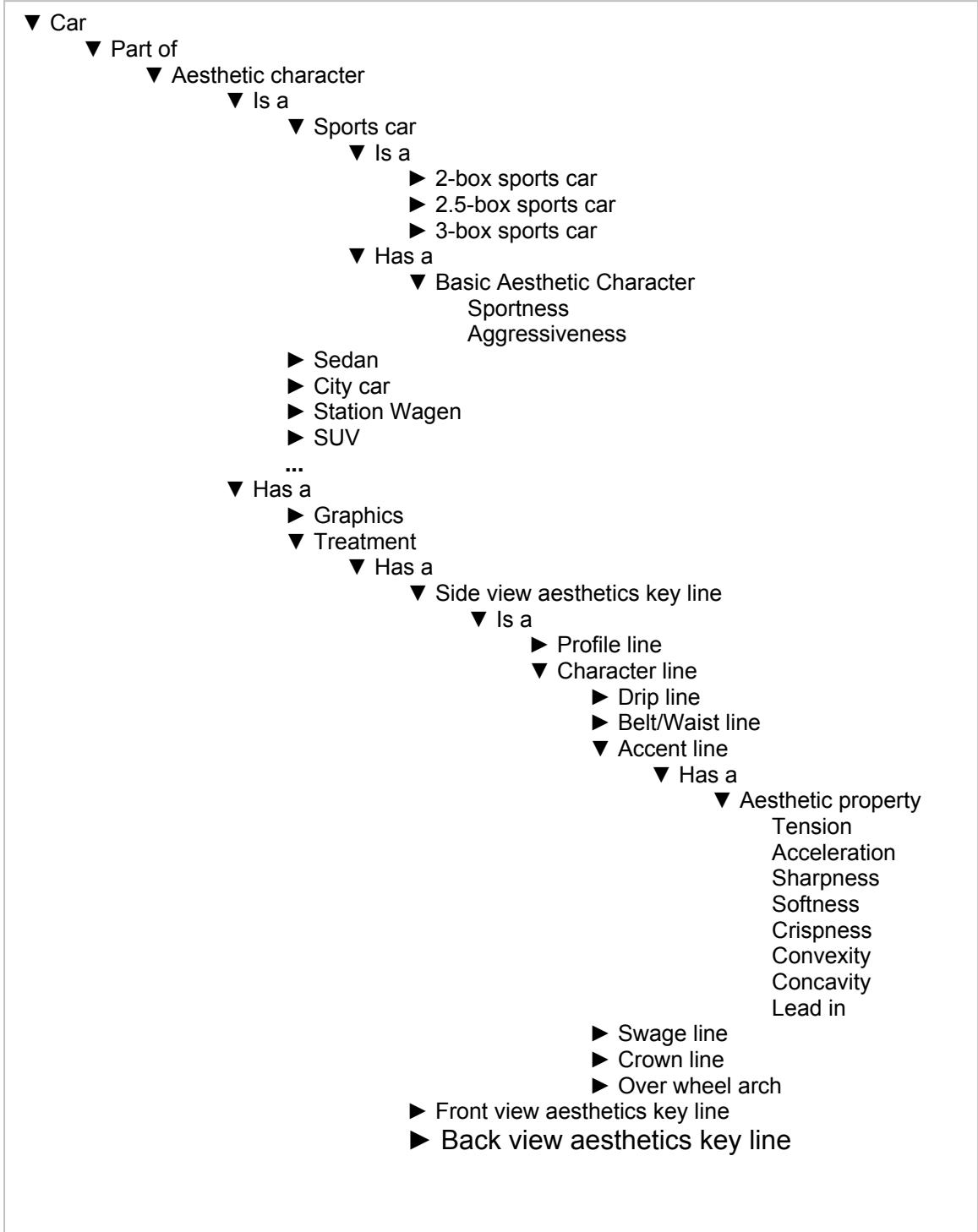


Figure 2-3 Car body shape ontology in hierarchical layout (“A is-a B” means A is a kind of B or B is more generic than A; “A has-a B” means A has an attribute of B)

However, there are several major limitations in the ontological model approach:

- (1) The ontological model is top-down-only, implying that it is with high likelihood that a good product can be aesthetically decomposed down to a collection of good design elements, but it is with low likelihood that an attractive product can be made up by just gathering good design elements together.
- (2) The ontological model is designer oriented but not customer oriented. Since customers do not necessarily have the expertise in conducting decomposition, Ontological model is not very practical in predicting a customer's feelings about a product design.
- (3) The ontological model is inherently harder to be used in this study because too many attributes (dimensions) are required to fully specify a complex product shape.

### **2.3.3 Phenomenological Model**

Following the consumer-oriented thinking, the phenomenological model was investigated as a potential tool for grasping consumer's aesthetic response to product.

Phenomenological techniques work on a customer-oriented intuitive level and do not strive after a deep understanding of the role of shape features in controlling feelings evoked [Breemen et al., 1998]. Emotion, a phenomenological meaningful aspect, is an important component of customer response to product [Desmet et al., 2000]. Emotions elicited by product influence both the decisions to purchase the product and the pleasure of owning and using it after the purchase [Desmet et al., 2001]. Designing attractive products is therefore guided by in-depth knowledge about emotions the products evokes in the customer. Integrating such affective values in product design requires the introduction of suitable methods which can capture and convert subjective and even unconscious feelings about a product into concrete design parameters [Schütte, 2005].

Discussing emotional responses to products with users is difficult. First, emotions are difficult to verbalize, especially the type of subtle, low intensity emotions elicited by products [Desmet 1998]. Furthermore, asking users to describe their emotional response will require cognitive involvement, which may influence the response itself [Desmet, 2001]. Special tools, called non-verbal self-report instrument, have been developed that can support users in expressing their emotional responses without the use of words.

Lang devised a series of pictograms to judge the emotional quality of stimuli [Lang, 1980]. It is later called Self Assessment Manikin (SAM) [Lang, 1985], as shown in Figure 2-4. It is a nonverbal, culture fair rating system based on a three-dimensional system of emotion consisting of valence, arousal, and dominance. The SAM rating scale is comprised of three sets of graphic figures, respectively representing the three dimensions [Suk, 2006].

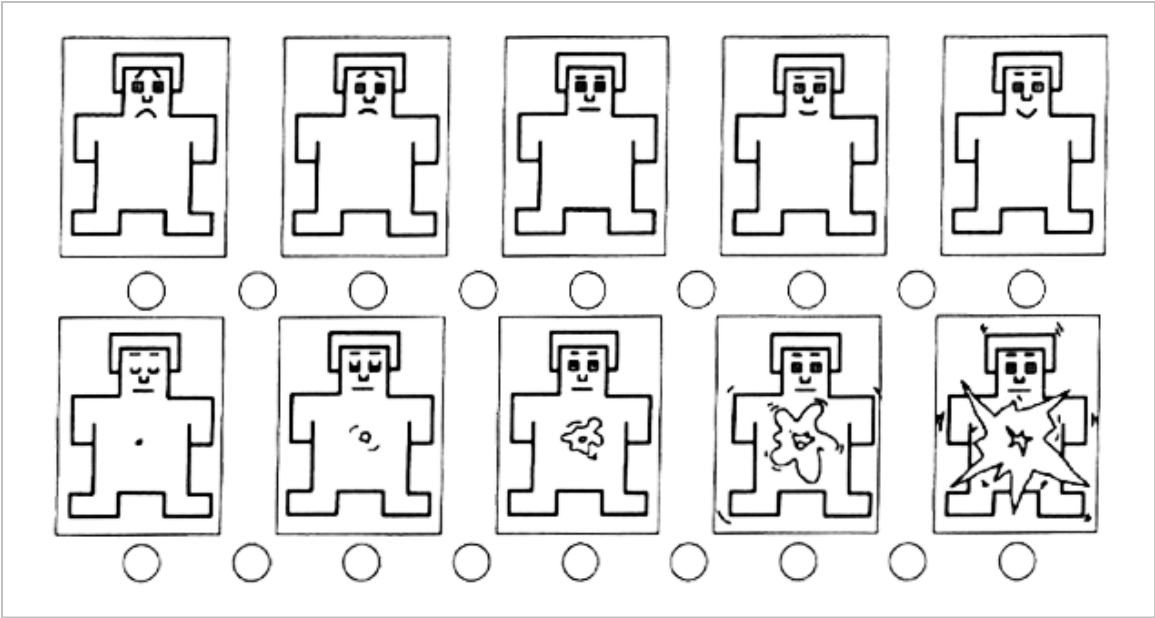


Figure 2-4 Self-Assessment Manikins (SAM) [Lang, 1980]

Emocards, another instrument proposed by Desmet, consists of 16 cartoon faces with eight distinct emotional expressions (8 male faces and 8 female faces) (see Figure 2-5). In a discussion, the emocards help the subjects to express their emotional response. For example, a subject can select a card that best expresses his or her emotional response to a product or put the cards in order of relevancy. In this way, the cards can be used both as an aid to objectify emotional responses and as an aid for starting a conversation on these responses with a designer or researcher [Desmet, 2001]. Comparing to just measuring general underlying dimensions of emotions, this method can obtain additional values of measuring specific emotions that provide clues on why these emotions are elicited.

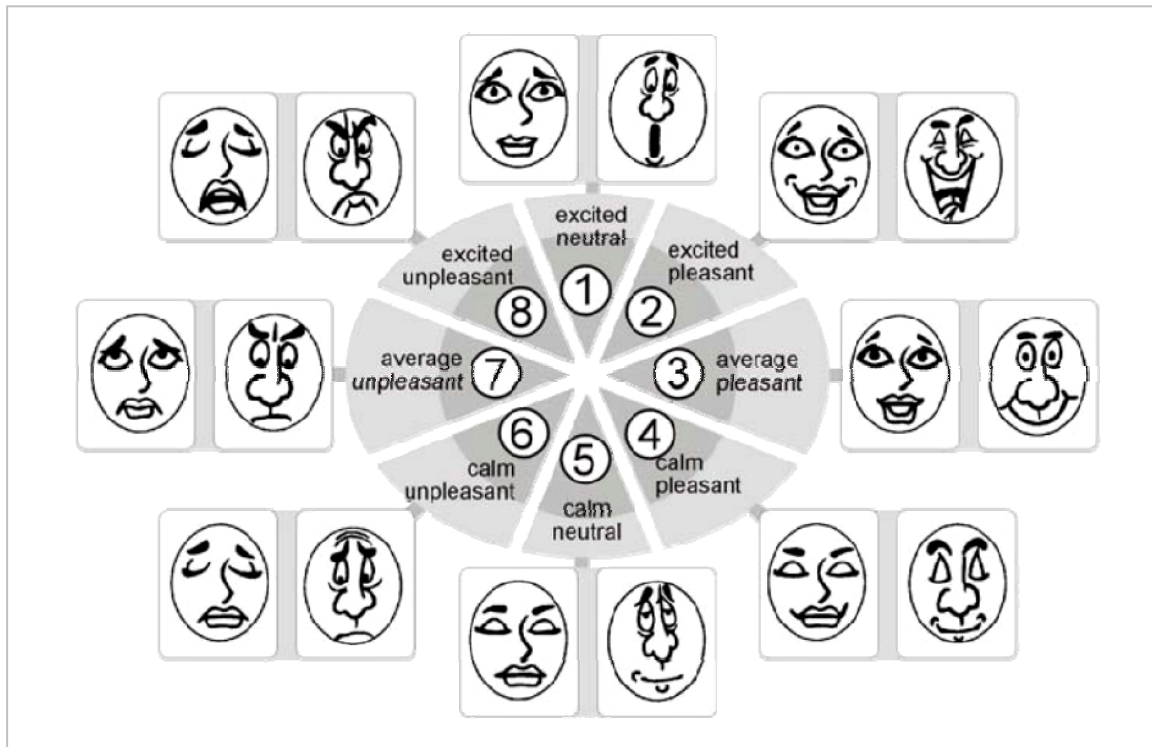


Figure 2-5 Eight emotional categories and Emocards [Desmet, 2001]



PrEmo (Product Emotion Measurement tool), also developed by Desmet, is based on a set of 14 product emotions (see Figure 2-6). These 14 emotions are visualized by animations of cartoon character and can be presented on a computer interface by the means of dynamic facial, bodily and vocal expressions. Each animation is accompanied by frames representing (hidden) three-point scale of a particular emotion. Subjects can express themselves by selecting those animations that correspond with their felt emotion evoked by the target product [Desmet, 2000]. The unique strength of PrEmo is that it can be used to measure distinct, rich and mixed emotions.

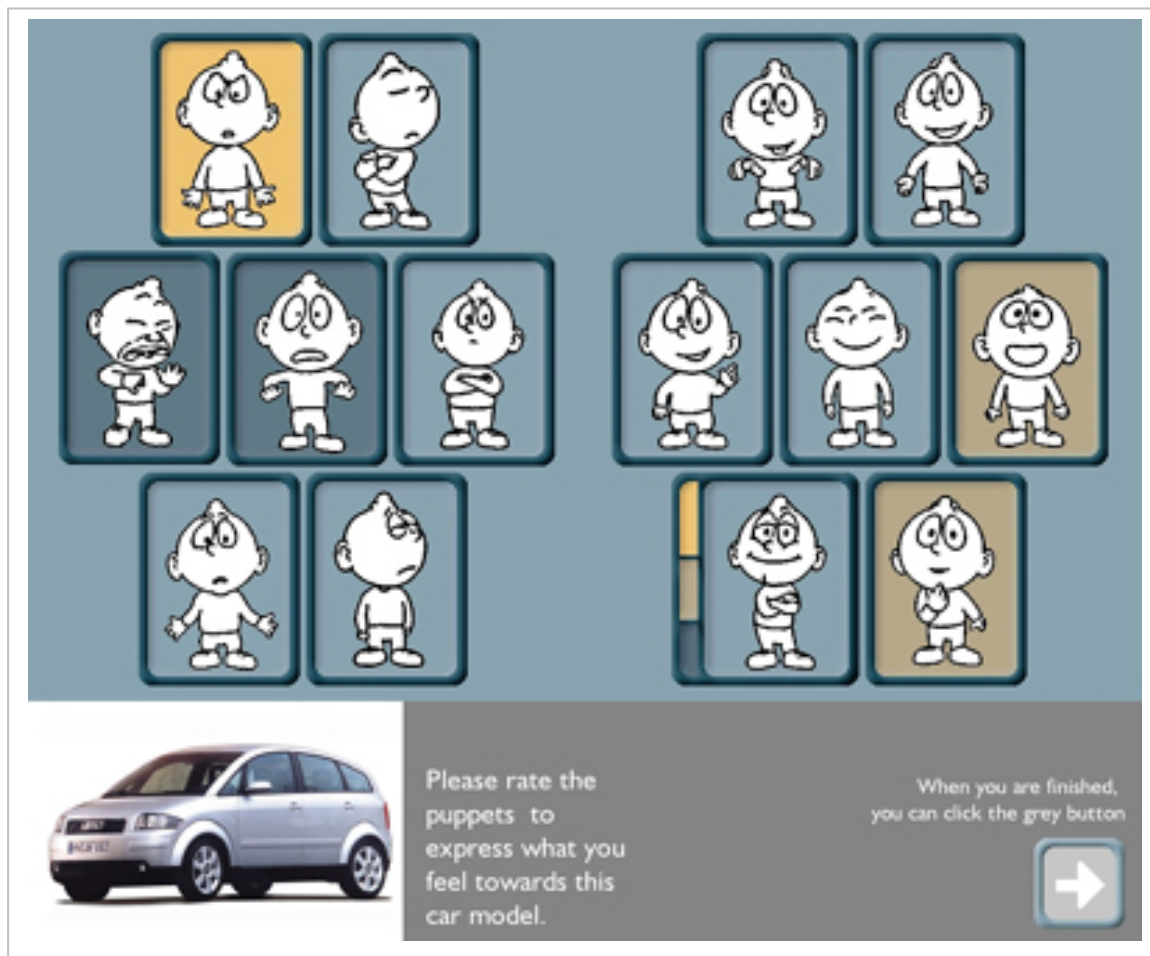


Figure 2-6 PrEmo, a self reporting tool that measures 14 emotions with the help of an animated character [Desmet, 2000]

Pilot studies [Wensveen et al., 2004; Desmet, 2000, 2001, 2004] shows that non-verbal self-report phenomenological models are straightforward, effective and practical in measuring customer emotional responses evoked by a product. It can be used cross-culturally because it does not ask respondents to verbalize their emotions. It is also pleasant or even enjoyable since the operation is fast and intuitive in use, requires neither expensive equipment nor technical expertise.

On the other hand, the phenomenological model obtained by non-verbal self-report instruments has three major limitations to this study:

- (1) The emotions depicted by the faces or drawings may not always be understood or did not match to the users' feelings [Taehti et al., 2005].
- (2) Emotions evoked by products are idiosyncratic, different people can have different feelings towards the same product [Desmet et al., 2004]
- (3) Relationship between unique emotion and unique form feature is not addressed. Instead, it is just assumed that a designer is able to express emotional value in a design [Desmet et al., 2001], which might not always be true.

#### **2.3.4 Empirical Model**

Empirical model bases its findings on direct or indirect observation as its test of reality. Statistics and data mining techniques are often employed by the empirical model in either learning process or evaluation process. Perceptual mapping is a graphics technique originally used by marketers that attempts to visually display the perceptions of customers or potential customers [Wikipedia, 2007]. In recent years, designers often use perceptual maps for visualizing consumers'

perception of different product shapes and the aesthetic factors affecting their decisions [Chen et al., 2003].

A product perceptual map can be constructed by using a number of methods, including multidimensional scaling (MDS) [Kruskal,1978; Schiffman, 1981] along with semantic differential rating [Osgood et al., 1957]. Besides, factor analysis, discriminator analysis, cluster analysis, and logic analysis can also be used [Wikipedia, 2007]. Based on proximities (or, conversely, distances) among the stimulus objects, MDS methods computes a (usually low dimensional) perceptual map such that each point in the map corresponds to a stimulus object, and distance between any two points matches the proximity between the corresponding stimulus objects as much as possible. That is, if two stimuli are perceived to be similar, the points representing them in the map are placed close together. On the other hand, if two stimuli are perceived to be more dissimilar, the corresponding points are placed farther away from each other [Chen et al., 2003]. Figure 2-7 shows an example map of automotive shapes.

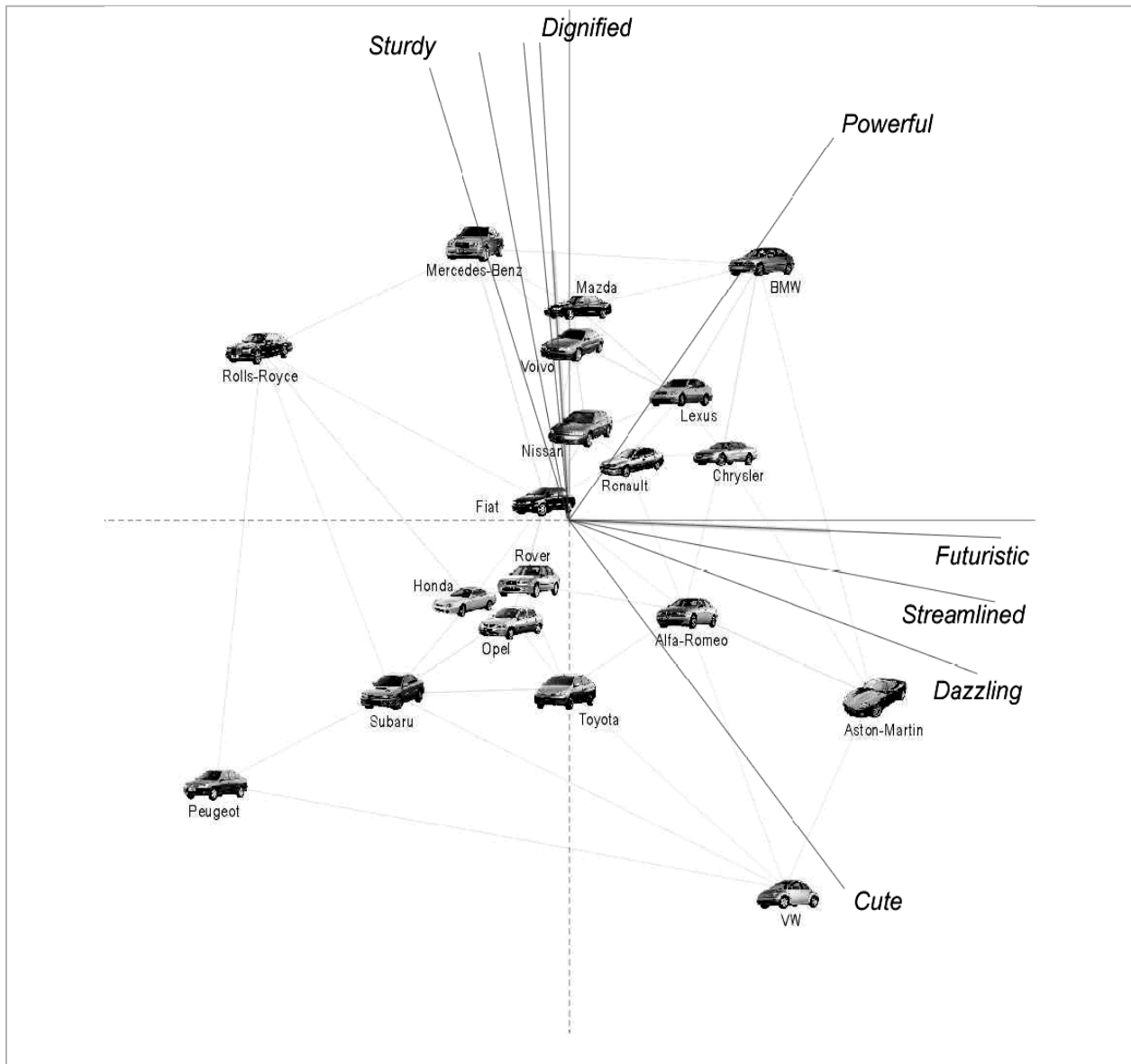


Figure 2-7 A product perceptual map of automotive shapes [Chen et al., 2003]

Although the perceptual mapping method is based on a set of solid statistical techniques (e.g., MDS), the quality of the model still varies according to the two critical preliminary steps which are (1) selection of perceptive words (adjectives) and (2) determination of fundamental dimensions of affective responses. Many examples are found in literature showing that each of

these studies devise its own set of scales for measuring affective responses for automotive product, as demonstrated in Table 2-2.

Table 2-2 Different studies yield different fundamental aesthetic dimensions

Study	Fundamental Aesthetic Dimensions
[Hsiao et al., 2006]	Trend, Emotion, Complexity, Potency
[Chen et al., 2003]	Sturdy, Dignified, Powerful, Futuristic, Streamlined, Dazzling, Cute
[Binh Pham, 1999]	Balance, Proportion, Dominance, Alternation, Gradation, Solidity, Simplicity, Dynamics, Rhythm
[Breemen et al., 1998]	Aggressive, Friendly, Functional, Elegant
[Huang et al., 2006]	Luxury, Personality, Complexity, Trend

Consequently, the lack of reliable, formalized and standard collection of perceptive words and consistent fundamental dimensions of affective responses prevents the empirical model approach from being used as a reliable and rigorous tool.

## 2.4 Conclusion

The survey of literature revealed that Kansei Engineering (KE) [Nagamachi, 1995] addressed the major concerns of this study for considering consumer preferences in the product evaluation and development process. Therefore, this study will be basically guided by KE's principles and procedures, which are: grasping consumers' affective responses by using Kansei words; identifying fundamental factors or principle components of consumers' Kansei; and embodying Kansei in product design by mapping Kansei words to design parameters. In addition, what makes the dual-process methodology [Liu, 2003] extraordinary valuable to this study is that it points out (1) there are critical dimensions underlying consumers' aesthetic responses, and (2) consumers' aesthetic responses should be measured along these critical dimensions. The notion of critical dimensions, fundamental factors, or principle components are basically equivalent,

implying that there are fundamental dimensions underlying human aesthetic senses, as explained in Figure 2-8.

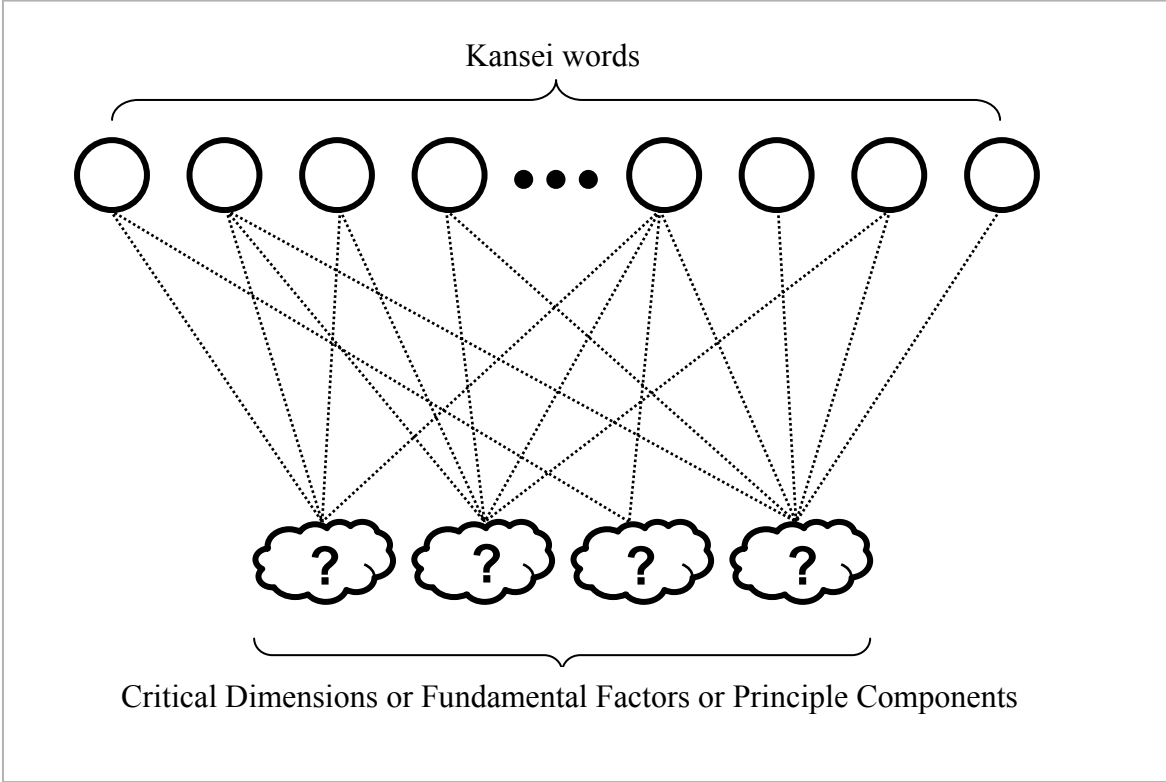


Figure 2-8 Kansei words and underlying dimensions

However, the question about what are the concrete fundamental factors, principle components or critical dimensions is not answered in the literature. It might be true that the question can only be answered with a given category of product and targeted consumer population. But it is also noticed that the successful implementation of a design framework, such as Kansei Engineering, will be largely determined by the concrete tools, domain specific knowledge and even subjective uncertainties. Therefore, complementary literatures were reviewed, aiming at finding implementation details.

At the implementation level, since the computational aesthetics model is still in its infancy, it is currently impractical to establish direct map between shape geometrical parameters and color parameters, although both of them are the parameters in engineering space. As such, some portions of this study have to rely on phenomenological and empirical methods, as shown in Figure 2-9 (a) and (b).

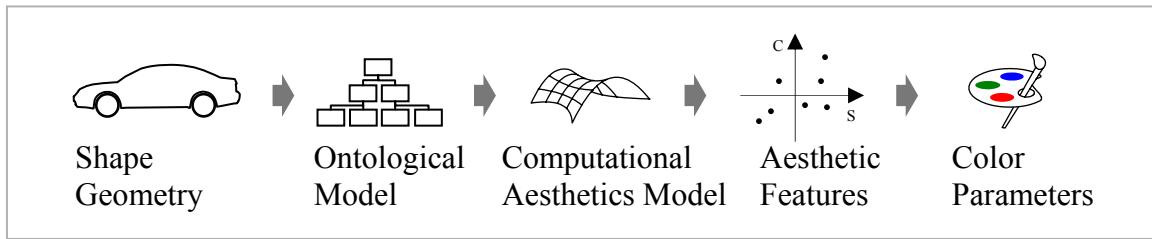


Figure 2-9 (a) Ideal implementation – product aesthetic features are systematically evaluated based on product shape geometry and mapped to color parameters

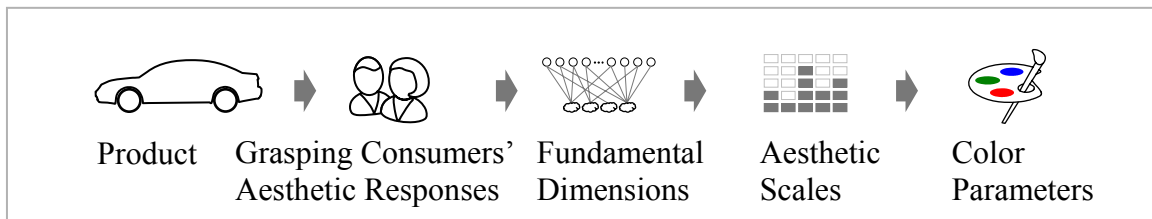


Figure 2-9 (b) Practical implementation – consumers' aesthetics responses are grasped and measured along fundamental dimensions, and mapped to color parameters

It is also noticed in literature that researchers tend to be objective, rational and scientific when dealing with local, simple and design-oriented aesthetic issues, whereas they become subjective, philosophical and empirical when dealing with global, complex and consumer-oriented aesthetic issues. This epistemological polarization makes it extraordinarily difficult to bridge the gap between the feeling space and engineering space. To eliminate the polarization, this study argues that industrial design researches must be sustained by compatible epistemology throughout the entire process.

Finally, the procedures for conducting this study is proposed and shown in Figure 2-10.

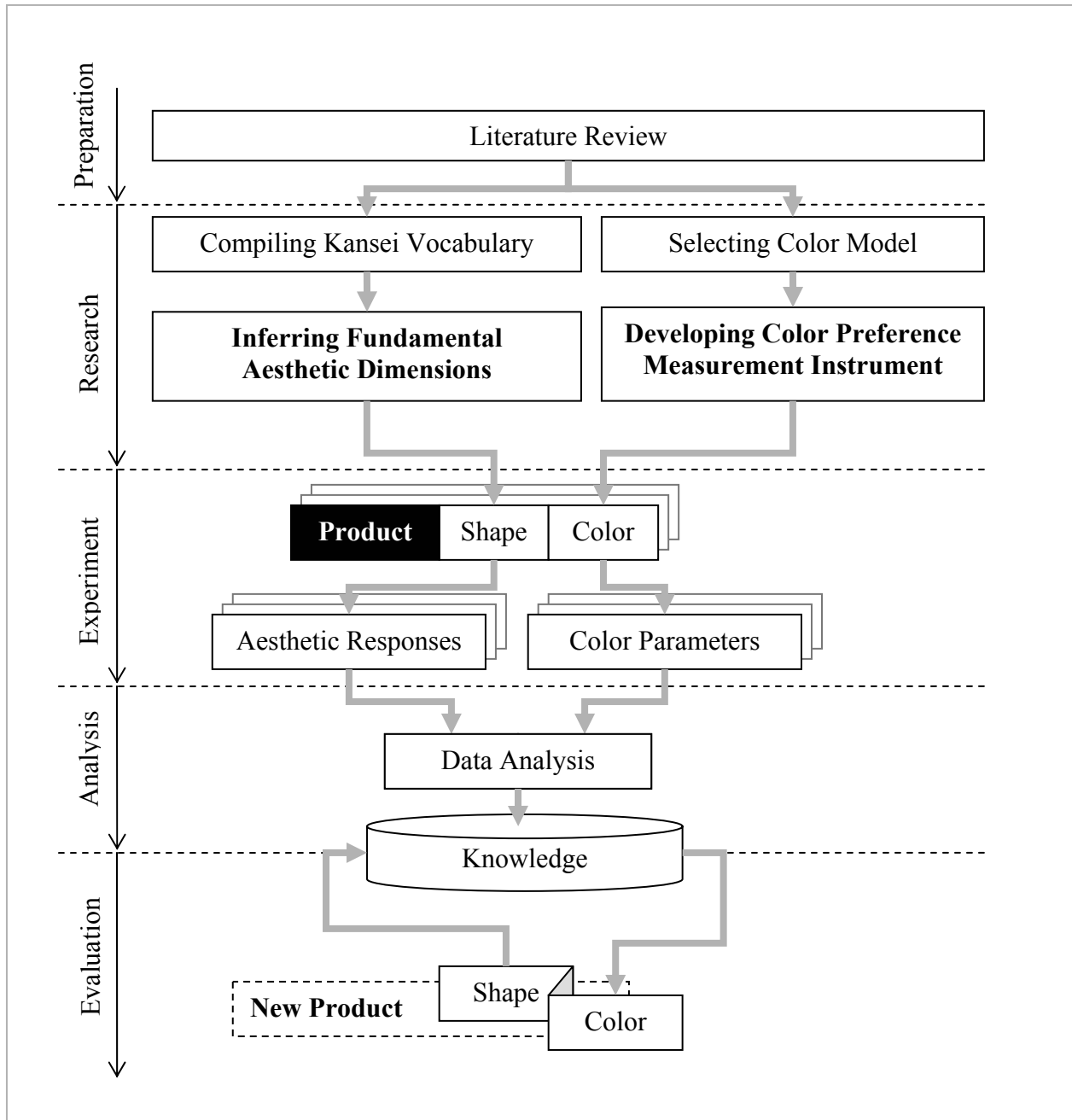


Figure 2-10 Procedural diagram of this study



## CHAPTER 3 COMPILING KANSEI VOCABULARY

### **3.1 Introduction**

Industrial design is often questioned by how a designer is able to grasp consumer's affective feeling to a product being designed. This feeling is called Kansei in the Kansei Engineering context. Since the nature of Kansei is latent, intrapersonal, and intangible, it is measured using external methods such as the one based on the adjectives or adjective words in human natural language [Nagamachi, 2001]. In this study, one initial task is to compile a Kansei vocabulary which contains all adjectives that are commonly used by contemporary consumers for expressing their Kansei while appraising cars.

Traditionally, Kansei vocabulary is developed by product designers in a designer subjective manner or collected by surveying as many consumers as possible. Today, with the popularity of the Internet, rich textual resources are available and accessible electronically and remotely, including a huge amount of dedicated auto reviews and design articles. In this study, a new attempt is given to the Web-mining technology for gathering the Kansei vocabulary from the Internet in a semi-automatic, mission-specific and content-consistent manner.

### **3.2 Web Mining Technology**

By its definition, Web-mining is the application of data mining techniques to discover patterns from the Web. Depending on the purpose of Web-mining, it can be divided into three different

types, namely Web usage mining, Web content mining, and Web structure mining [Wikipedia, 2008].

Web content mining, sometimes also called Web text mining, is the process of discovering useful information from the content of single web page. Web structure mining is the process of analyzing web pages (nodes) and their relations (connections). It is usually performed by means of parsing the HTML (Hyper Text Markup Language) or XML (eXtensible Markup Language) tags [Wikipedia, 2008]. Web usage mining is the type of Web mining activity that involves the automatic discovery of user access patterns from one or more Web servers [Cooley, 1997].

Normally, information on the Internet is massive, overloaded, distributed, heterogeneous, unstructured, and mixed with noises. Thus, a number of advanced and multidisciplinary technologies are often required for automatically distinguishing the valuable information from the background noises, such as NLP (Natural Language Processing), IR (Information Retrieval), IE (Information Extraction), and so on. These fully automatic systems are usually expensive and need a significant amount of time to develop. On the other hand, an ad-hoc system is sometimes more practical and effective in solving specific problems – in particular when a proper balance can be made between the use of computer and use of manual work. In this study, an ad-hoc Web mining approach is proposed for compiling Kansei vocabulary from the Web. The approach is a hybrid yet simplified type of Web mining approach which mixes Web content mining and Web structure mining. This approach has three steps: (1) Raw Data Collection, (2) Data Structuring, and (3) Noise Reduction, as respectively described below.

### 3.3 Raw Data Collection

A general purpose search engine, such as Google and Yahoo, usually uses an automatic tool for collecting huge amount of data from the Web quickly. This category of tool is called "crawler" or "spider". In the early stage of this study, a simple experimental crawler was developed by using Perl. It has an interface to Google in order to take advantage of Google's ranking mechanism for obtaining high-quality car reviews based on carefully selected keywords. By parsing the underlying HTML code of the Web pages returned from Google search, the contents of each car review can be extracted and saved as plain text. But in practice, it is found that the data captured by this way could not meet the quality requirements due to two reasons. First, no matter how the keywords are selected, the Web pages returned by the general search engine (Google) are often mixed with few content-relevant pages and many content-irrelevant pages. Second, it is unrealistic for a simple and non-semantic enabled crawler to identify valuable content from dynamic page layouts by merely parsing HTML tags.

Since the quality of raw data has direct impact to the quality of the Kansei vocabulary, a computer aided manual data collection procedure was eventually employed in this study. The procedure had three steps. **First**, a complete list of auto manufacturers and their major car models were compiled by traversing the catalog indices of commercial automotive websites. **Second**, car review articles were browsed from renowned automotive websites where each review article focuses on one car model in the list. The car model and content were manually identified, selected, and saved as plain text from the containing Web page. Noises, such as navigation bars, embedded commercials and other content-irrelevant texts were therefore excluded. **Third**, an ad-hoc assistive tool, called "clipboard sniffer" was developed to facilitate

this process with an impressive productivity of less than 30 seconds per article per person. The clipboard tool is described in Appendix B of this thesis.

As the number of articles increases, another automatic utility was used to check whether the number of collected adjectives was approaching saturation. The utility scanned the already-collected articles, drew a curve with a number of adjectives versus a number of articles, and meanwhile, conducted a logarithmic linear regression to come up with a formula which can be used to predict how many new adjectives could be added if a number of additional articles were collected, as illustrated by Figure 3-1.

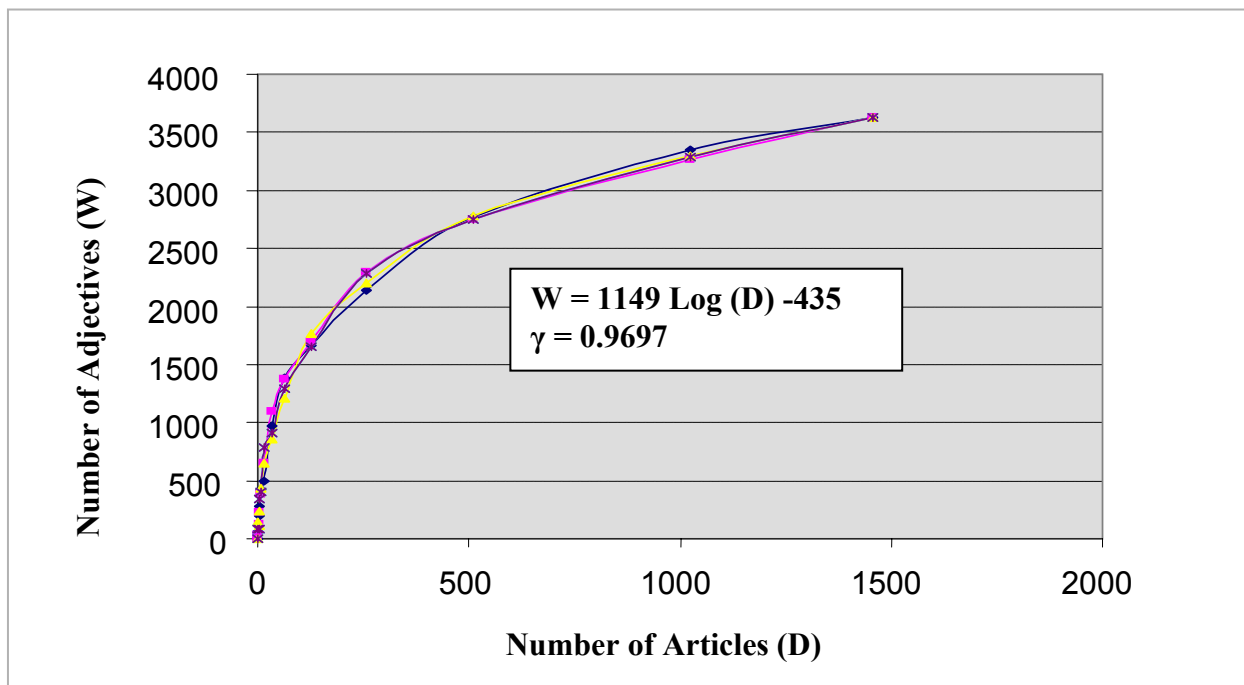


Figure 3-1 Number of Kansei words vs. Number of articles

When approximately 85% of the predicted number of adjectives was collected, the process ended. It was noted that the increasing the number of collected articles may not always result in a

better Kansei vocabulary, because more noises could be introduced as well. As the result, a total of 1457 car reviews were collected in this study (see Appendix E).

### **3.4 Data Structuring**

When adequate number of car reviews had been collected, they were temporarily stored as unstructured raw text files that may not be effectively analyzed by using Structured Query Language (SQL). Textual elements (adjectives in this study) must be extracted from the text files and then re-organized in order to be loaded into a relational database system for further process.

Since Kansei words are actually adjectives, the first step of data structuring is to automatically identify adjectives that are used in the car reviews. This raised the need of electronic dictionary of all adjectives in the target language (English). The dictionary can be compiled by using shared lexical databases from open source projects, such as WordNet or WordWeb. In English, there are approximately 20,000 adjectives found in WordNet.

During the scanning, once an adjective was identified and captured from a review text associated to a car model, it was picked up into a well organized data structure where relationships between adjectives and their originated car models are properly preserved. Among various existing text structure models, the TF-IDF [Wikipedia, 2007] matrix was selected in this study for its simplicity and efficiency (Figure 3-2). In short, in a TF-IDF matrix, each adjective has a property called TF (term frequency) which represents how often it is used within a specific car model. Meanwhile, the adjective has another property called IDF (inverse document frequency) which represents how unique it can distinguish a car model from others. Many software tools, such as SAS Text Miner, SPSS LexiQuest and WordStat, are capable in building a TF-IDF matrix. The

result matrix can be loaded to a relational database system (such as MySQL) via CSV format (Figure 3-3). Consequently, 3574 adjectives were extracted and loaded into database.

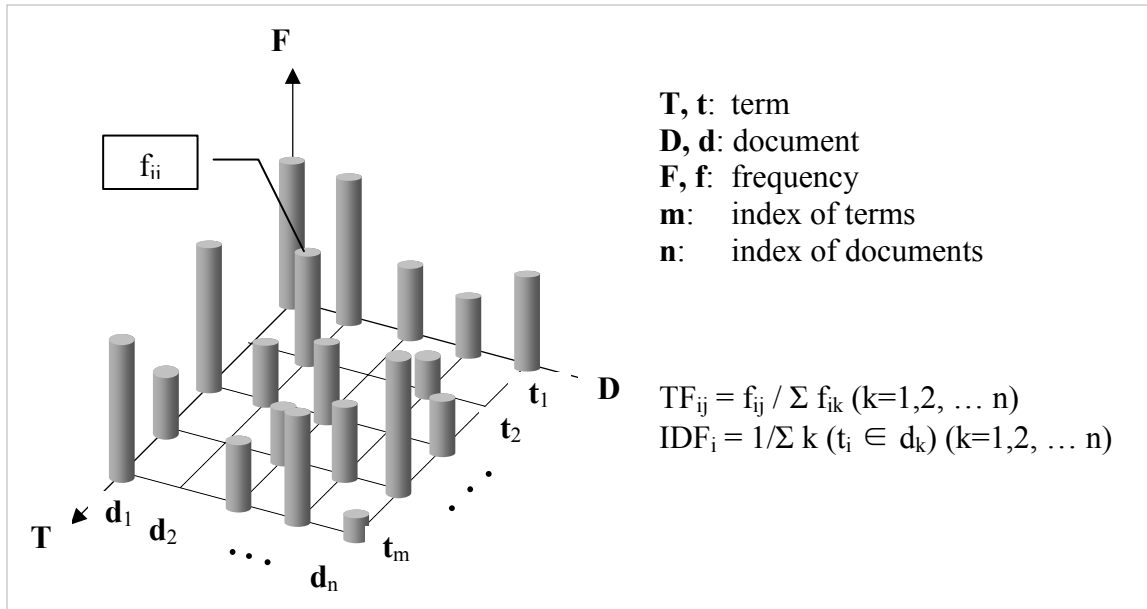


Figure 3-2 TF-IDF matrices

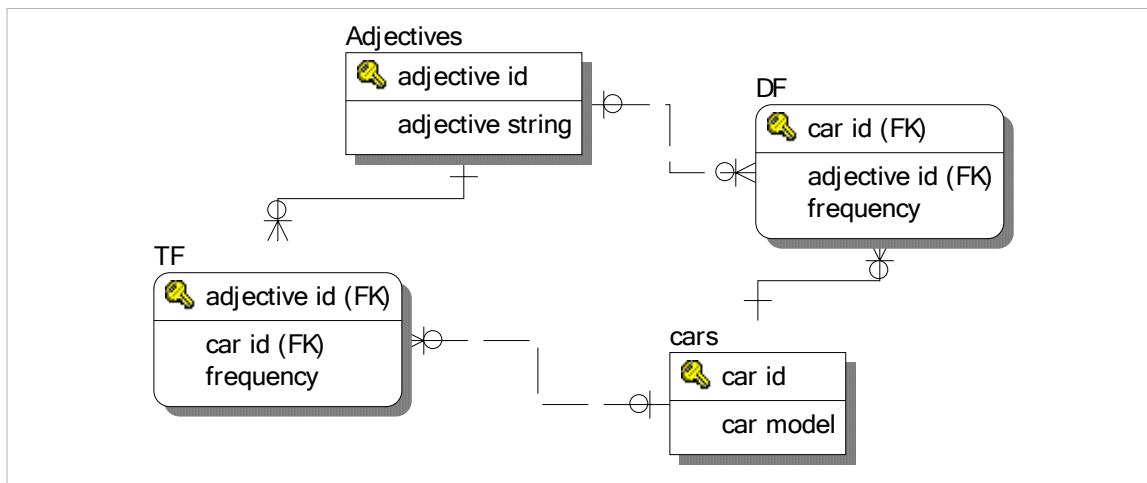


Figure 3-3 ER diagram representing TF-IDF matrices in RDBMS

### **3.5 Noise Reduction of Raw Data**

Apparently, not all adjectives extracted automatically from the car reviews are Kansei words dedicated to expressing shape-induced feelings. Actually, only a minority of them are valuable Kansei words, the remainder are just noise. In this study, two steps were conducted to identify and eliminate the noise.

In the first step, the IDF property is used to evaluate the commonality of an adjective. An extremely low IDF value indicates that the adjective in question is commonly used by most of the car models; therefore, this adjective is not qualified enough to distinguish car models. At the other end of the scale, an extremely high IDF value means that the adjective in question is rarely but only occasionally used in the target context. Consequently, 10% adjectives were cut off by applying the IDF threshold.

In the second step, valuable adjectives which have direct association to shape-induced feelings (the real Kansei words) need to be distinguished from the others. To accomplish this goal, a keen sense in emotion and design expertise are required. Therefore, a design team from a major European auto manufacturer was involved. Through a survey, the experienced designers ranked each adjective by evaluating its semantic relevance to aesthetics features of car shape. The results were collected, summarized, and a total of 387 adjectives were finally taken into the Kansei vocabulary. These adjectives were then ranked into two groups: (1) frequently used adjectives and (2) infrequently used adjectives, according to their TF-IDF values.

### **3.6 Conclusion**

In this study, a high quality and well structured Kansei vocabulary database was compiled by using the Web-mining technology. Through this process, it was noticed that although the electronic information on the Internet is rich and easy to access, identifying and extracting valuable information is still a challenge. The key to success is to select, develop and integrate proper methods and tools for achieving the given goal. The ad-hoc tool and semi-automatic procedure proposed in this study are proven to be a practical fit to mining Kansei vocabulary from the Web.



## CHAPTER 4 FUNDAMENTAL AESTHETIC DIMENSIONS

### **4.1 The Problem**

Apparently, Kansei vocabulary is limited to expressing the consumers' Kansei. Since the purpose of Kansei vocabulary is to measure consumer's Kansei, it is important to identify the relationship between Kansei words and their originated Kansei. In general, such a relationship is a many-to-many one in the sense that a particular Kansei may be expressed by more than one word; yet a word can express, particularly, more than one Kansei. This is especially true for a complex product such as car.

In Kansei Engineering [Nagamachi, 1995], it is assumed that there are principal factors underlying Kansei words. Liu [2003] also clearly pointed out that perceivers' senses should be measured along the principal dimensions, implying that the nature of Kansei is discrete, modular and heterogeneous. Since Kansei has to be measured in a multi-dimensional vector space, the difficulty is to determine the principal or fundamental dimensions of Kansei space (Figure 4-1). Since consumer's aesthetic response is considered a subset of Kansei, in this study, the fundamental dimensions of Kansei space is also called "fundamental aesthetic dimension".

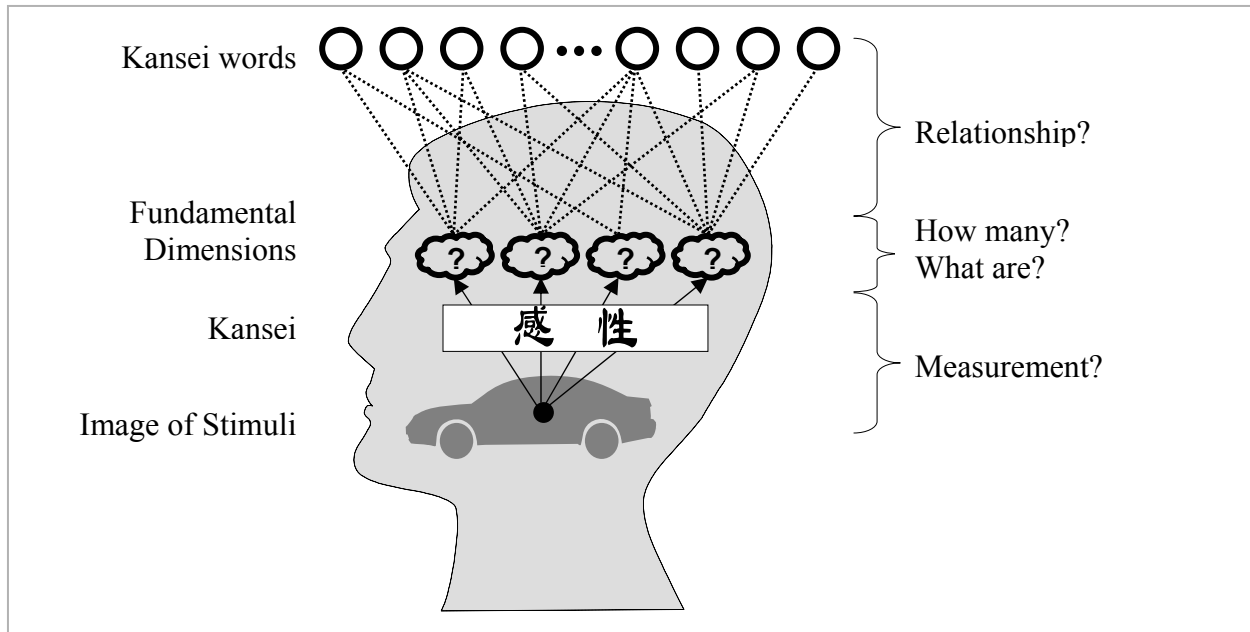


Figure 4-1 The intangible, discrete, modular and multi-dimensional nature of Kansei

Basically, there are two approaches to infer the fundamental aesthetic dimensions: (1) the axiomatic approach and (2) the learning approach. In (1), the fundamental dimensions are deducible by means of the theoretical framework such as philosophy, psychology, neurophysiology, anthropology, and so on; while in (2), the fundamental dimensions are found through analysis of phenomenological, empirical or experimental observations. The dominance of (2) is revealed in the current literature. For instance, one widely used learning approach is to identify a representative word among a group of Kansei words that are considered "similar" in accordance to certain criteria. Many studies (refer to Section 2.3.4) are to identify "similarities" among Kansei words by conducting subjective rating followed by statistics, such as principal component clustering or factor analysis. Each of these studies concludes its own finding of fundamental dimensions. However, once the results from the studies are put together and compared, these results are found mutually inconsistent (as previously shown in Table 2-2),

although they are associated with a common category of product. In this study, the pure learning approach is questioned by such a repeatability problem.

The argument between the axiomatic approach and the learning approach can be traced back to the age-old argument between two epistemological schools in the aesthetic design domain. According to Reich [1993], there are two major epistemologies that seem to contribute to aesthetic design. The first one is objective, intellectual, instrumental and functional called *rationalism*; the second one is subjective, passionate, intrinsic and emotional called *romanticism*. There are radical differences between rationalism and romanticism. The ontology embedded in rationalism is realism. It asserts that beauty exists outside of the human mind. The epistemology of rationalism is objectivism. According to objectivism, beauty is a quality of objects [Reich, 1993] and it exists in objects independently of the consciousness of humans who interact with the object. The ontology embedded in romanticism is idealism. It asserts that beauty solely exists inside the human mind [Reich, 1993]. The epistemology of romanticism is of subjectivism. According to subjectivism, beauty is dependent on the consciousness of humans.

Back to the original problem, it seems that the learning approach is backed by romanticism, as it asserts that Kansei is individual's consciousnesses and therefore it is not necessary to be universal. This is indeed acceptable in the pure art domain such as fine art. However, in the industrial design domain, aesthetic design has to be seamlessly integrated into an entire design chain where some of the downstream activities may assert that Kansei are the properties attached to a product. As soon as they try to map Kansei from the romanticist view to design parameters, problem occurs.

A significant difference between aesthetic design and fine art creation is that aesthetic design will be eventually integrated with ergonomic design and functional design [Lin, 2006]; as such, any design decision made on an element of a product may eventually influence consumers' comprehensive satisfaction in functionality, usability and aesthetics. Therefore, it seems to be a good idea to force aesthetic design to fit to austere rationalism so that the product structural parameters can be directly used as the reasons of consumers' Kansei. However, in practice, Kansei is intangible and complex and can only be indirectly observed by using Kansei words. It is just hard for the austere rationalism to infer consumers' Kansei from the vast Kansei words. Yet, the pure romanticism has its inherent weakness in relating Kansei to engineering features. Consequently, neither the austere rationalism nor the pure romanticism is solely defended when facing to the integrated design challenge<sup>2</sup>.

In summary, Kansei must be measured along the fundamental dimensions. Two approaches, rationalism based reasoning and romanticism based learning, are investigated upon the goal of determining how many and what are the fundamental dimensions underlying consumers' Kansei. Neither of them is considered to be fully practical, leaving a major puzzle in this study.

## **4.2 Kansei and Human Needs**

The lack of methodological support in determining the fundamental dimensions of Kansei forces this study to look into the nature of consumers' Kansei.

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<sup>2</sup> This also explains the phenomenon revealed in a literature review that researchers tend to be rationalism while dealing with local, simple and design-oriented aesthetic issues, whereas they become romanticism while dealing with holistic, complex and consumer-oriented aesthetic issues. This (epistemological) polarization is backed by the thinking that design problems have to be isolated in order to arrive at straightforward solutions along specialized epistemologies. An interdisciplinary gap is therefore introduced between the aesthetic space and the engineering space. In contrast, this study argues that epistemological compatibility must be concerned throughout the integrated design process.

### 4.2.1 The Etymology of Kansei

Kansei is a transliteration of two-character Japanese words (感性) which share identical characters and semantic meaning in Chinese. Figure 4-2 shows the etymological interpretation of Kansei. The two characters are processed in human minds when they receive the information from the external world [Lee et al., 2000].

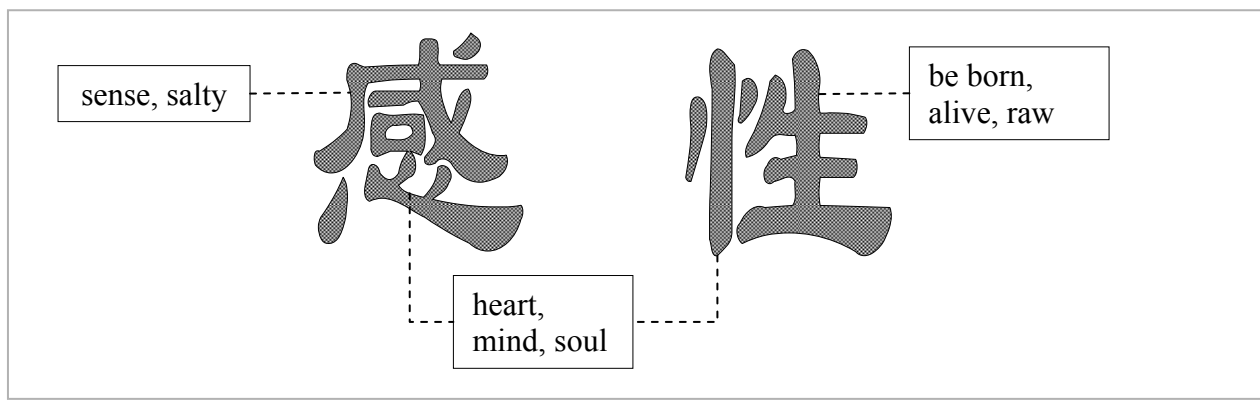


Figure 4-2 The etymology of Kansei

### 4.2.2 The Definition of Kansei

In practice, Kansei is interpreted in various ways and has been used in many studies in not only design but also other research fields [Lee et al., 2000]. In 1998, Prof. Akira Harada collected 60 definitions provided by researchers involved in the research related to Kansei and analyzed the responses statistically. This yielded five major interpretations of Kansei [Wikipedia, 2008]:

- (1) Kansei is a subjective and unexplainable function.
- (2) Kansei, besides its innate nature, consists of the cognitive expression of acquired knowledge and experience.
- (3) Kansei is the interaction of intuition and intelligent activities.
- (4) Kansei is the ability of reacting and evaluating external features intuitively.

(5) Kansei is a mental function creating images.

#### **4.2.3 The Unity versus Variety of Kansei**

Since Kansei exists in every body's mind, one may ask how much an individual's Kansei equals or differs from those of others while appraising a product. As Desmet [2004] states, although Kansei are idiosyncratic (i.e. different peoples may have different feelings towards the same product), universal patterns can be identified in the underlying process of how these Kansei are evoked. The universal pattern is largely concerned by studies in the industrial design context because design of a product for mass production, such as automotive, needs to identify and to focus on the common Kansei shared by target population rather than individual's distinctive Kansei. Therefore, this study will devote to the cross-cultural and universal aspect of Kansei while considering the variety and diversity aspect of Kansei for the future works.

#### **4.2.4 Kansei and Needs**

The last yet crucial question is how products evoke Kansei and why different designs will result in different Kansei. Since Kansei mainly works instinctively and intuitively without explicit awareness, tracing the origination of Kansei is not as easy as it was anticipated to be. Multidisciplinary efforts have been paid in philosophy, psychology, sociology, neurophysiology, anthropology, and so on. Despite the promising endeavors, it is still very difficult to understand why, when, and how products evoke particular Kansei in a human's mind, body, and perhaps soul [adapted from Desmet et al., 2004].

However, it may well be true that a contemporary consumer experiences a product in relation to a variety of needs, both functional and emotional. The question “why a product is attractive to a

consumer” can also be asked in an equivalent way, say “what sorts of consumer’s needs are addressed by the product”. Unsurprisingly, many (if not all) contemporary consumers are able to answer the question by just watching a TV commercial of a car. Adjectives, such as “powerful”, “comfortable”, may easily appear in their answers without having sat inside the car and having a test drive. So, how a functional need (such as “power”) can be addressed by visual sense? Is “powerful” a Kansei word with aesthetic value? If so, how about another Kansei word “graceful”, does it (in opposite) address any sort of functional need?

Nevertheless, it is indiscreet to assert any causal connection between aesthetic values and functional needs without understanding how an object in environment is visually perceived. In 1979, the perceptual psychologist James J. Gibson initiated the ecological approach to visual perception [Gibson, 1979] in which organism and its environment is considered as an ecologically reciprocal pair. According to Gibson [1979], the environment not only serves as the surfaces that separate substances from the medium in which the organism lives, but also offers perceivable information about what it possibly affords the organism in terms of shelters, foods, tools, social relationships, and so on. Since the English verb ‘to afford’ is found in the dictionary but not its corresponding noun, Gibson coined a new term called “affordance” to represent this concept. Donald Norman further appropriated the term affordances in the context of Human–Machine Interaction to refer to just those action possibilities which are readily perceivable by an actor [Norman, 1998]. In the affordance concept, the individual’s (visual) perception plays an important role. To better illustrate the concept, think about Toyota Matrix as a typical example (Figure 4-3). The car tends to embody a “powerful” look because the characteristic line throughout both sides of the body visually exaggerates the pushing power of its rear wheels,

making it “propulsively affordable”. But in fact, the car is merely pulled by a 1.8L economical engine through its front wheels.

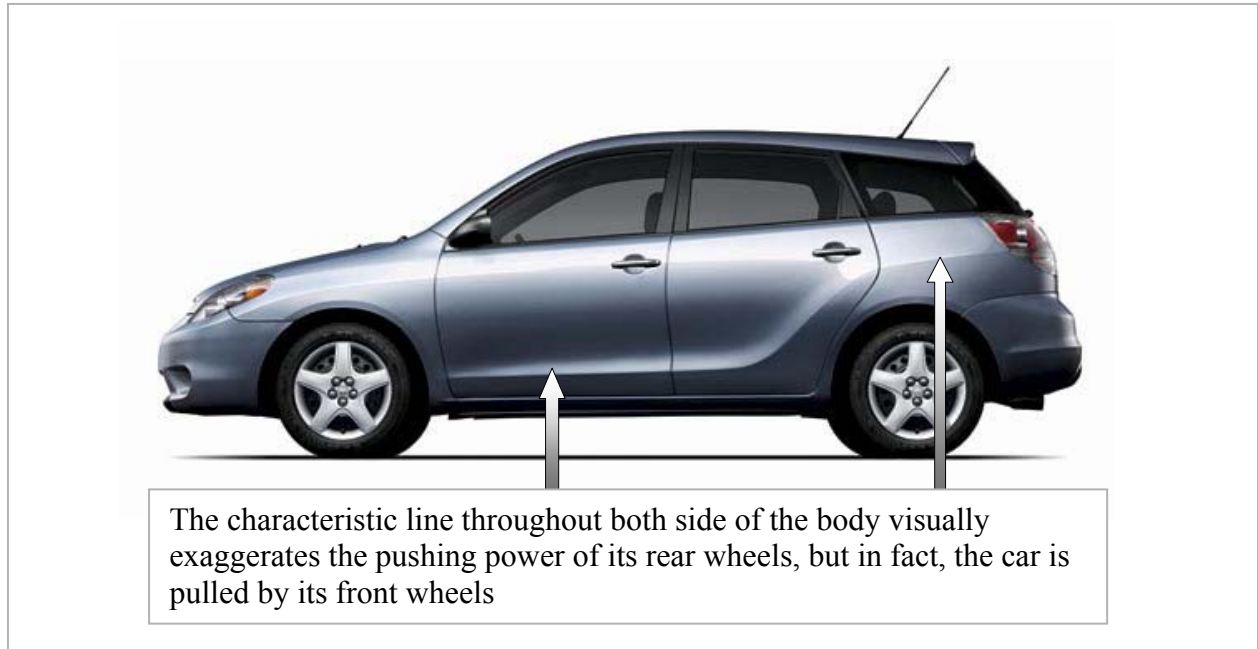


Figure 4-3 Illustration of the concept “affordance”

In this example, although the characteristic line has a zero contribution to the vehicle’s propulsive power, the human visual sense, via the process in the brain, assigns a functional metaphor to it. The process can be adapted to Gibson’s illustration [Gibson, 1966] (Figure 4-4) where affordances can be traced down to human motivations and needs.



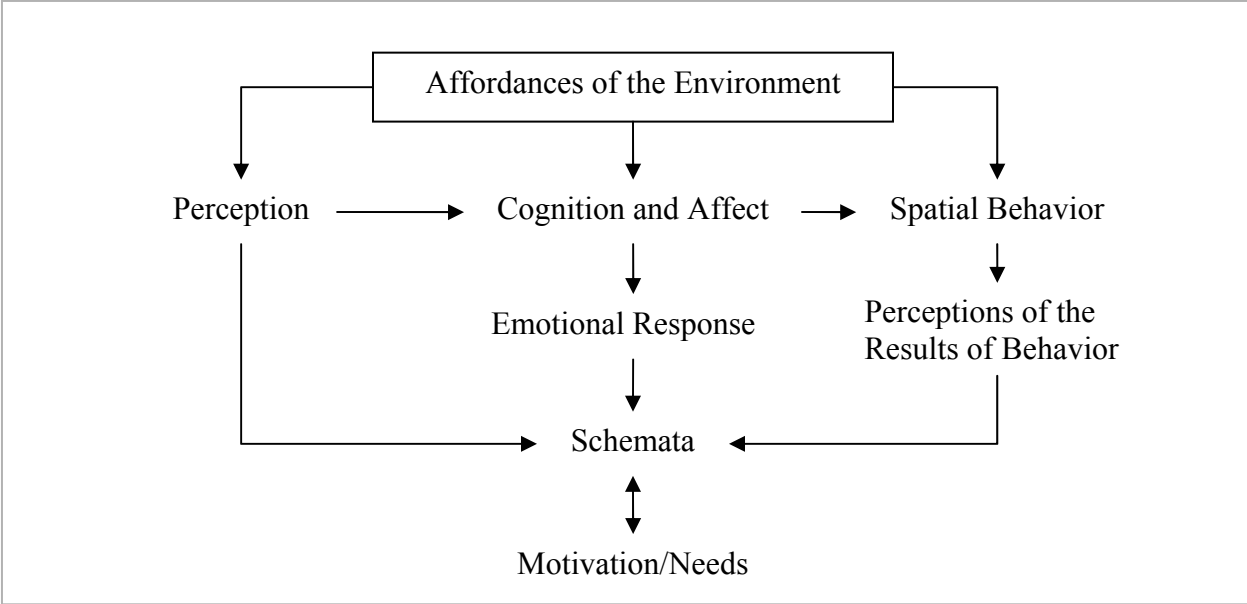


Figure 4-4 The fundamental processes of human behavior [Gibson, 1966]

The notion of affordance is adopted here as a clue to trace into consumer’s perception and to understand what are the motivations behind human visual senses. It seems that the role of visual sense is seeking environmental patterns that possibly afford to fulfill its underlying motivations. If such a pattern is matched, the visual sense is pleased, regardless of the actual fulfillments of the original motivations. Apparently, the motivations here refer to the functional intentions for satisfying the observer’s needs. This logic does not automatically fall into the austere functionalism. Instead, it suggests that visual pleasing can be reinforced by incorporating aesthetic features and functional cues in design elements. As it is learned from many former products that neither pure decorative elements nor pure functional elements solely worked well (Figure 4-5), design elements on modern products have to be both *aesthetically valuable* and *functionally meaningful*. This logic is also advocated by the thesis of contributory aesthetic duality [Hansson, 2005] where it holds that aesthetic valuations that refer to a practical function are in most cases positively correlated with satisfaction of that function. Following the axiom

that functions serve to human needs, it can be inferred that there is reciprocal (rather than causal) relationship between consumers' Kansei and consumers' needs, and within the industrial design context, the fundamental dimensions underlying consumers' Kansei and consumers' needs are supposed to be parallel. Therefore, Kansei elicited by products can be indirectly measured along the fundamental dimensions of consumers' needs<sup>3</sup>.

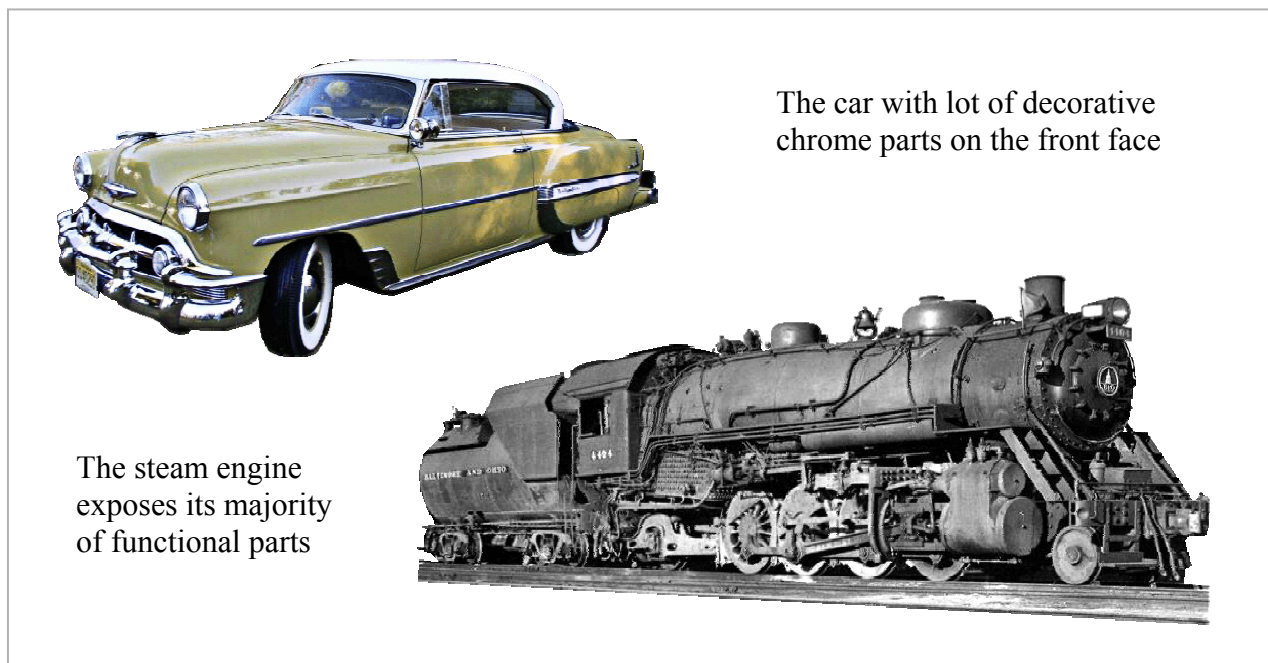


Figure 4-5 Pure decorative or pure functional exterior elements that were often found on outdated products may not be attractive to the contemporary consumers

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<sup>3</sup> Pending discussion in the next section will further prove that aesthetic senses are also derived from the needs of prehistoric humans

#### **4.2.5 Maslow's approach versus Darwin's approach**

The fundamental dimensions of human needs are well studied in multiple domains. Two approaches seem to be valuable to this study: (1) the Maslow's hierarchy of needs [Maslow, 1943]; and (2) the Darwinian approach leading to Evolutionary Psychology (EP) [Cosmides et al., 1997] from which the Evolutionary Aesthetics (EA) is recently derived [Thornhill, 2003]. In (1), the fundamental dimensions of human needs are given by a hierarchical pyramid model based on humanistic psychology. The model has five basic levels and two extended levels where lower levels are associated with physiological needs, and the higher levels are termed growth needs associated with psychological needs. If the lower level of need is not met, the higher level will not come into concern. In (2), the fundamental dimensions of human needs are not explicitly given; instead, it emphasizes the ultimate goals and mechanisms underlying the needs, say, survival success, adaptation, and natural selection. The human needs can be logically induced from the goals and mechanisms. In short, (1) offers what and when, and (2) provides why and how. In fact, (1) and (2) are compatible rather than exclusive. Finally, (2) is adopted in this study for the following reasons:

- (a) The relationships between aesthetic senses and human needs are directly addressed by (2); yet in (1), aesthetic senses are isolated into an extended level of needs, preventing it from being related to other levels of needs.
- (b) It seems that (1) is often questioned by other studies for its hierarchical organization of needs. Indeed, in the consumer product design context, consumers' needs are observed more in a casual flat manner rather than in a strict hierarchical manner.
- (c) The epistemology behind (2) is rationalism with a nature science basis, which is essentially compatible with the epistemology used in engineering, including the ergonomic design, functional design process and the aesthetic design.

### **4.3 Review of Evolutionary Psychology and Aesthetics**

The basic idea of the evolutionary approach is that the environment in which human lives is chaos and overloaded with massive information but short in resources. There must be a mechanism evolved for humans to invest a minimal amount of means, such as effort, resources, brain capacity, to attain the highest possible effect, in terms of survival, reproduction, learning or explaining [Hekkert, 2006]. Therefore, the visual senses, or the specific aesthetic senses, evolve to serve for the short cut between forms and survival goals by eliminating frequently repeated contents that often require costly cognitive processes. To this study, if the goals are identified, the forms that appeal to visual senses are supposed deducible from the goals by using the principles provided by evolutionary psychology.

In this section, evolutionary psychology and evolutionary aesthetics are briefly reviewed in order to identify the basic principles that can be applied in the next two sections for inducing the fundamental dimensions of human aesthetic senses in case of appraising artifact such as car.

Understanding consumer's aesthetic responses (Kansei) to products requires theoretical propositions about how these aesthetic responses are related to products [Desmet, 2004]. In recent years, a novel concept based on evolutionary psychology (EP), namely evolutionary aesthetics (EA), is recognized to be a reasoning approach to identify the nature of human aesthetic senses from the rationalistic perspective. Evolutionary psychology (EP) is a hybrid discipline that draws insights from modern evolutionary theory, biology, cognitive psychology, anthropology, economics, computer science, and paleoarchaeology. The discipline rests on a foundation of core premises [Wikipedia, 2008]. There are five basic principles that EP may be

adoptable in the research which attempts to understand the “design” of the human mind [Cosmides, 1997]:

**4.3.1 EP Principle 1** - The brain is a physical system. It functions as a computer. Its circuits are designed to generate behavior that is appropriate to the environmental circumstances.

One question that many philosophers fail to address is why humans have aesthetic preferences (e.g. beauty) and where beauty resides - in the object, the beholder’s mind, or the interrelationship of object with mind [Volland et al., 2003]. It may well be true that human aesthetic preferences are based on the mental pleasure produced by certain features of things [Volland et al., 2003], but why humans can get pleasure from these features? According to [Chris<sup>4</sup>, 2005], beauty is seen as the product of perceiving rewarding features in stimuli. Rewarding, in this case, means that the visual system (or other sensory system), when it processes certain types of features or combinations of features, sends a signal to the limbic system (emotional brain), which then releases rewarding chemicals (e.g., dopamine). In order to understand the human aesthetic sense (Kansei) from the evolution specific perspective, it is essential to understand that the nature of the brain as a physical system whose operation is governed solely by the laws of chemistry and physics [Cosmides, 1997].

**4.3.2 EP Principle 2** - The neural circuits were designed by the natural selection to solve problems that ancestors faced during the species' evolutionary history.

Since any mechanism is designed for solving problems at hand, it can be inferred from a point of view of evolutionary psychology that the logic of human's aesthetic pleasure or inclination to

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<sup>4</sup> Last name is missing in original document

pursue beauties is engineered to address certain concerns in human evolution. As Thornhill [2003] states, beauty is a promise of function in the environments in which humans evolved, i.e., of a high likelihood of survival and reproductive success in the environments of the human evolutionary history. According to Voland et al. [2003], the aesthetic preferences of humans and their spontaneous distinction between "beauty" and "ugliness" can be posited in a (modern-) Darwinian framework as a biologically adapted ability to make important decisions in life. Based on this framework, all features of a species' cognitive or neural architecture are either adaptations, byproducts, or genetic noises [Tooby, 2001]. Adaptations are present because they were selected to perform a function that ultimately contributed to genetic propagation [Tooby, 2001]. The drive power behind the formation of human's aesthetic senses, according to [Fisher, 1958], is evolution driven by natural selection.

Generation after generation, for 10 million years (Figure 4-6), natural selection has slowly sculpted the human brain, favoring circuitry that is good at solving the day-to-day problems of our hunter-gatherer ancestors [Cosmides, 1997]. Through a slow process of natural selection, psychological mechanisms (e.g., aesthetic sense) have evolved that are perfectly fit to solve these problems [Hekkert, 2006]. "Human nature", including the nature of aesthetic senses, refers to the accumulated specialized neural circuits that are common to every member of a species [Galambos, 2006]. Those whose brain circuits were better designed for solving these problems, such as gathering nutritious food, avoiding predators, finding mates, understanding the intentions of others, and so on, left more children, and the contemporary people are descended from them [Hekkert, 2006; Cosmides, 1997].

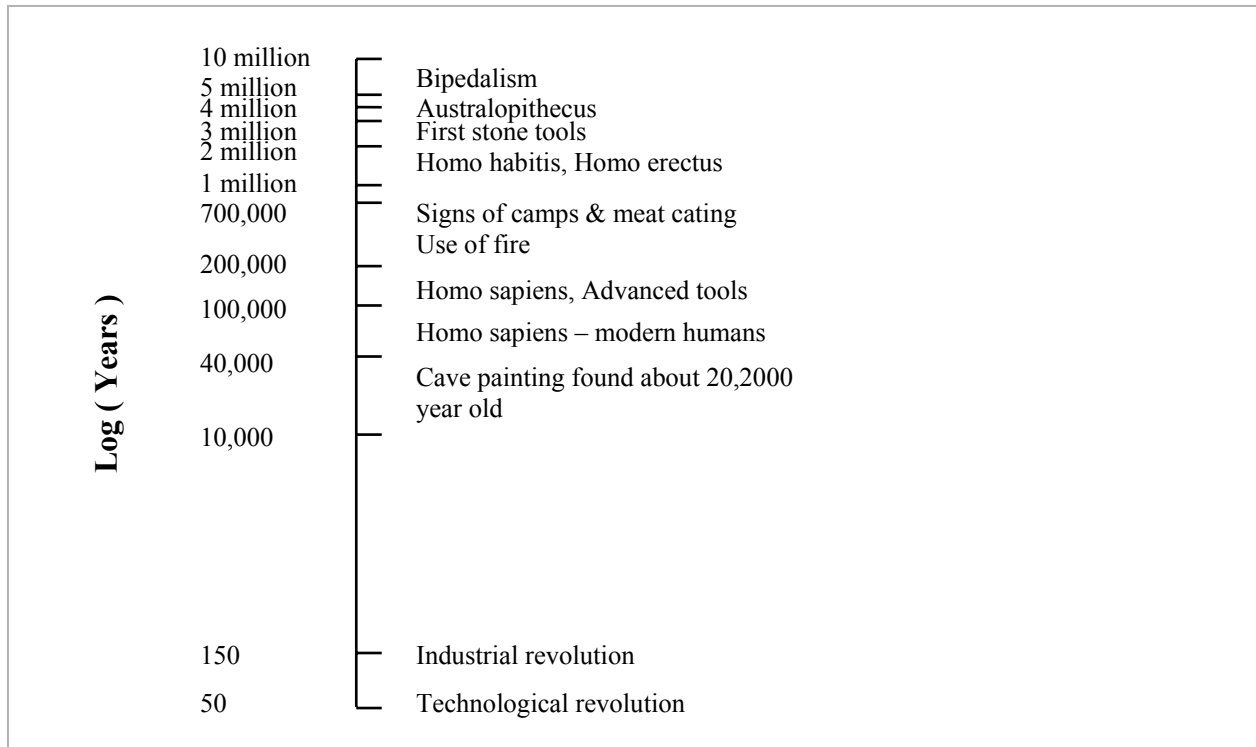


Figure 4-6 Milestones in 10 million years of human revolution [Kenyon, 1994]

**4.3.3 EP Principle 3** - Most of what goes on in the mind is hidden; thus, most problems that seem easy to solve are actually very difficult to solve -- they require very complicated circuitry.

In applying the evolutionary approach, it is speculative to hypothesize the origin of aesthetic sense by conscious experiencing intuitions and instincts. As Cosmides [1997] points out, consciousness is just the tip of the iceberg; most of what goes on in human's mind is hidden from the beholder. As a result, the conscious experience may mislead the researcher into thinking that the brain circuitry is simpler than it really is. Most problems that are experienced as easy to solve are actually very difficult to solve; they require very complicated neural circuitry. For example, vision is effortless, reliable, and precisely fast because all the complicated, dedicated mechanisms are involved and operated automatically in producing coordinated functional outcomes, making the high-level activity, e.g., aesthetic adjudgement, easier for the beholder.

But in fact, it is still challenging enough for a modern computer to simulate or duplicate the same functionalities, e.g., complex object recognition in a natural background.

**4.3.4 EP Principle 4** - Different neural circuits are specialized for solving different adaptive problems.

Unlike most cognitive psychologists who regard the human mind as a general-purpose problem-solver, evolutionary psychology argues that the human mind consists of a large number of special-purpose devices, which are usually referred to as "modules" [Evans, 1999]. This view has since become known as the "Massive Modularity Hypothesis" [Murphy et. al., 1998; Samuels, 1998], where each module is called "Darwinian Module" [Evans, 1999]. According to Evans [1999], a Darwinian module is a computational mechanism that is domain-specific, informationally-encapsulated; it is designed by natural selection as part of the universal species-typical design, and is thus innately specified and genetically determined. Darwinian modules have a typical ontogenetic pace and sequencing, and are often associated with characteristic breakdown patterns. The massive modularity hypothesis maintains that the mind contains a large number of distinct thought interconnected information processing systems [Galambos, 2006].

**4.3.5 EP Principle 5** - Modern skulls house Stone Age minds

One may hereby ask, what Darwinian module(s) is (are) used by contemporary people to appreciate the modern artifact such as car? The point behind this question is that there is just no adequate time for humans to evolve into new Darwinian module(s) dedicated to appreciating every novel objects such as motor vehicles. Since their ancestors spent well over 99% of the species' evolutionary history living in hunter-gatherer societies, the environment that humans



(and therefore human minds) evolved in was very different from the modern environment [Cosmides, 1997]. The most significant human adaptations evolved over the past 100,000 generations (2-3 million years) and so have not changed much since the dawn of modern civilization [Ulrich, 2006]. The key to answer this question is to understand the cognitive ability of human brain called "transcendental abstraction" where memory plays an important role. According to Baharmast [2007], a single memory by itself is of little use, but when strung together with other memories and actions and logic that turns out to be rewarding, then abstractions become tools for survival. While discerning novel entities and phenomenon, abstraction (also refers to knowledge) that is affirmed, confirmed, corroborated and incorporated in a functionality offers the power in making decisions that are likely correct for survival. According to Baharmast [2007], the accumulation of abstraction (knowledge) works with a hierarchical model where the brain classifies similar knowledge in related classes, and then it goes about defining the sub-classes or the super-classes. This mechanism reinforces the ability to see things that are close together, discover relations, detect objects or meaningful wholes, and helps to make a most likely and economically efficient decision within a very limited time for capturing resource or avoiding hazard in a highly dynamic and chaotic environment [Hekkert, 2006]. Back to the original question, while appraising a car, the evolved cognitive architecture quickly resembles a confederation of functionally dedicated Darwinian modules and attempts to classify or derive the vehicle to or from related classes, say, a human, an animal, a facial expression, a bodily gesture, a motion, and so on, and tries to arrive at intuitive and subjective judgment in just seconds or shorter, and then, may or may not turn to the slow reasoning process by applying educated knowledge, e.g., mechanical engineering.

### **4.3.6 Additional Discussion**

Although evolutionary psychology (EP) is widely recognized as a logical extension of Darwin's work, one of its promising application branches in the aesthetics domain, evolutionary aesthetics (EA), is still in a ground-breaking stage. Especially in the industrial design context, the EA application paradigm is hardly reported in the public literature. In this study, a major effort is given to use EA for inferring a novel method, namely Evolutionary Aesthetics Chain and Network. The method is then applied for inferring human aesthetic senses, ascertaining the fundamental dimensions underlying the aesthetic senses in terms of appraising cars.

## **4.4 Evolutionary Aesthetics Chain**

### **4.4.1 Introduction**

In the evolutionary view, aesthetic senses are the products of natural selection (EP principle 1) – only those that contribute to the survival probability of its possessing gene are selected and retained (EP principle 2). Yet, the aesthetic sense itself is seldom the direct cause of survival success. To the beholder, the aesthetic sense serves as an agent which hides all the complexities of the underlying mechanism (EP principle 3). But it is important to understand how survival success connects, step by step, to specific aesthetic sense. The connection is supposed to be a multi-layer chain where the bottom layer is the indicator of the gene survival likelihood and the top layer is the aesthetic preference, in between, there will be a number of hidden layers where each layer has an indispensable contribution to the successful probability of the entire chain.

### **4.4.2 A Simple yet Typical Example**

To illustrate the concept, think about a simple yet typical instance (thanks to Gengzhou Jin). Suppose that there is a simple species that lives on a kind of green algae (as food) and has a

simple sensor that is able to distinguish colors. At the very beginning, different members in this species tend to move to different colors for whatever random reasons such as genetic mutation. Those who move to green color may gain a better chance to find food and therefore get higher survival probability. Eventually after chronic natural selection, a firm connection between green and genetic survival evolves as an inheritable trait of this species. Green holds common appeal for all members in this species. On this simplest chain, four layers are revealed: (1) health; (2) need of food; (3) color of food (green); (4) preference of green, where layers from (1) to (3) are hidden layers that are not detectable by the organism itself. As long as the organism pursues (4), the rest things work for it in an automatic and self-regulating manner, no matter whether the organism is aware of other hidden layers. If (4) is called aesthetic preference, then the sum of the layers and relationships between the layers will be coined "Aesthetics Chain".

#### **4.4.3 Generalization and Formalization**

The notion of Aesthetics Chain is introduced here for representing the internal structure and state of the aesthetic sense that is "designed" by natural selection. One may disagree with the likeness between the natural selection process and artifact design process. But both of the processes are aiming at solving practical problems, and the analogy between their products – human mind versus computer system – is supported by evolutionary psychology (EP principle 1 & 2). Thus, the original design logic is supposed to be deducible by reverse-engineering the product. Contemporary design methodologies, such as EID or FBS, can be applied for understanding how the human aesthetic sense is "designed" by natural selection based on the basic principles provided by EP and EA. In this study, a novel design model elaborated by Zhang et al. [2005], namely FBPSS, is selected for its enhancement on top of the FBS model, and the result will be presented with a generalized Aesthetics Chain.

To be brief, five points need to be clarified: **First**, the Aesthetics Chain itself is not a design model but rather a blue-print that presents the structure and state of the product (aesthetic sense). **Second**, function and behavior are the elements in the FBPSS design model, and they will not come into the Aesthetics Chain. **Third**, layer and entity are two equivalent terms used, respectively, in the FBPSS space and in the Aesthetics Chain space. **Fourth**, any Aesthetics Chain "designed" by natural selection serves to a common function, which is, "enhancing gene survival success". **Fifth**, suppose that the dependency probability between any two out of  $n$  layers is denoted by  $P_i$  ( $i=1\dots n-1$ ), the reliability of the entire Aesthetics Chain will be:  $P = P_1 P_2 \dots P_{n-1}$ . Thus, the principle of the Aesthetics Chain is to maximize  $P$ .

In the previous example, the health and the preference of green are the two end layers in the Aesthetics Chain view as well as the two end entities in the FBPSS view. There is an argument about which one should be selected as the independent variable and which one would be then the dependent variable. It seems that the aesthetic preference should be selected as the independent variable because it is the only one entity that is able to receive external stimuli (color of food), implying that it is the trigger entity of its related behavior. On the other hand, consider that if an organism has taken an adequate amount of food (and is therefore not in hungry), its preference of green will be accordingly inhibited to avoid potential hazard of over nutrition, suggesting that the health should be selected as the independent variable. Either of the two scenarios sounds reasonable. In fact, it depends on what behavior is in question. There are actually two behaviors in this example: the first one is physical, external, and driven by color, say approaching to green for food. Another one is mental, internal, and driven by health, say activating or inhibiting color

preference. As such, the two B-S (behavior-state) relationships can be illustrated with a circle (Figure 4-7) where the health state activates the preference of green, and the preference of green satisfies the health state by approaching to green for food. Since the closed loop is typically initialized by the health state, the health state is hence selected as the ultimate independent variable.

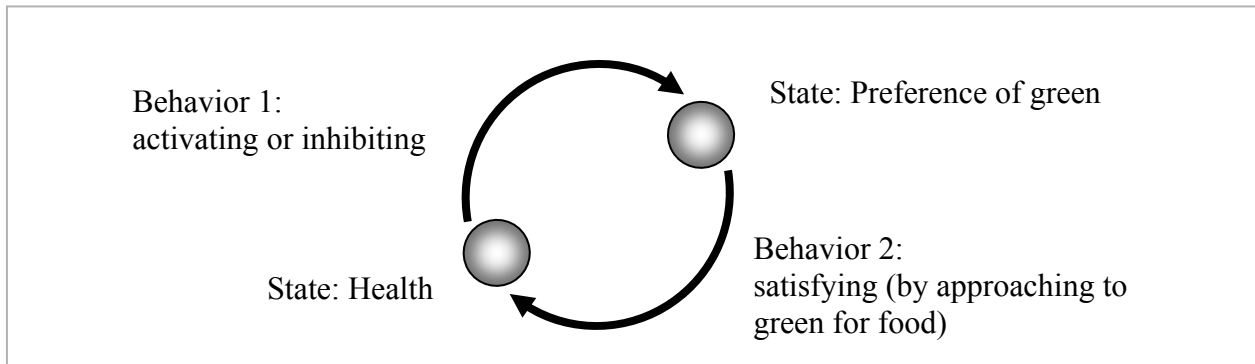


Figure 4-7 The circular B-S (behavior-state) relationship

This activation–satisfaction–inhibition/deactivation process of aesthetic sense can also fit to the psychodynamics framework in which human mind is considered to be an energy-system governed by the principle of the conservation of energy. According to Freud’s argument about Ego and the id, id was the source of the personality's desires, and therefore of the psychic energy that powered the mind [Wikipedia, 2008]. It can be inferred that if an object or environment pattern is perceived to afford freeing the psychic energy, it will generally appeal to the visual sense.

Given the above, a tentative definition of the basic and multipurpose template of Aesthetics Chain could be derived from this simplified example by generalizing all concrete layers on this particular aesthetic chain. But first of all, the layer “color of food” should be excluded because it

is the character of object or pattern of environment (affordance) which is actually the external stimuli. Now beginning with the top layer, the preference of color can be the preference of texture/shape/sound/smell/touch etc., therefore, this layer should be generalized as aesthetic sense. Below it, the need of food, is an instance of general needs of resource/shelter/safety/relationship, etc., for enhancing the perceiver's adaptation; as such, the particular need can be generalized to be the fitness concern. On the next layer, since health is often a strong and comprehensive indicator about how well an organism adapts itself to its environment, so the layer representing health can be generalized as the fitness state. Finally, as suggested by EP, the gene survival is the ultimate goal of all; therefore it needs to be included in every aesthetic chain at the bottom-most level as the root layer. The result template of Aesthetics Chain is shown in Figure 4-8 (b). Along activation behavior, each lower layer activates/sets its direct upper layer, and along satisfaction behavior, each upper layer satisfies its direct lower layer. The balance between each two layers is maintained by the activation/satisfaction pair between them, each pair is the major principle contributing to the probability of successfully performing the corresponding behavior. Once the two behaviors are successfully conducted, new balance is achieved, means, the function for enhancing the gene survival is fulfilled, as shown in Figure 4-8 (a).

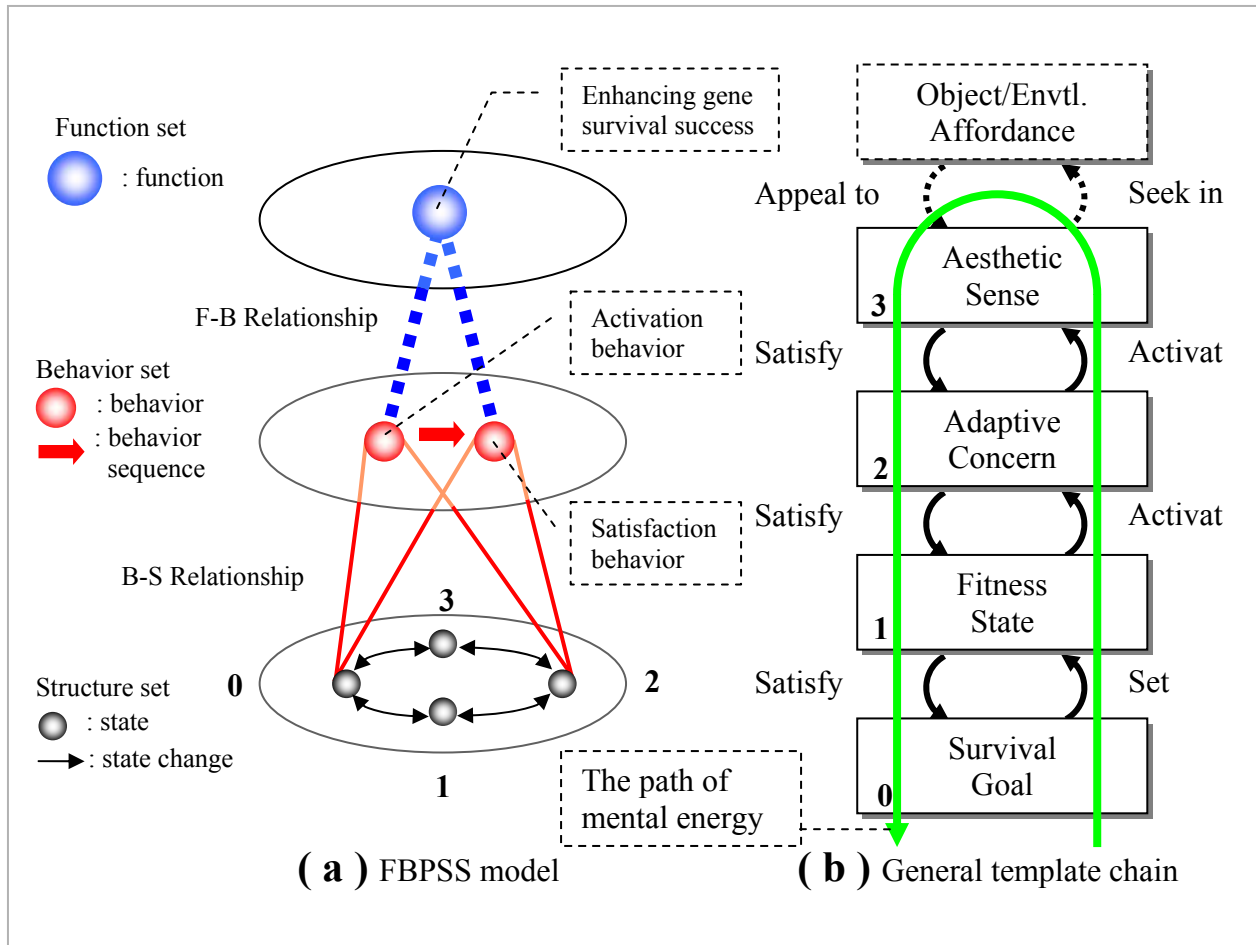


Figure 4-8 Basic aesthetics chain

## 4.5 Evolutionary Aesthetics Network

### 4.5.1 Introduction

Going back to the previous example (the simple organism that eats green algae), suppose that the simple species has a natural enemy whose color is red. It is logical to infer that through chronic natural selection, another Aesthetics Chain will be evolved, say dislike of red. Consequently, a practical case often involves multiple aesthetics chains, different chains consist of different layers, and layers from different chain may be interconnected, making up of a network, called Aesthetics Network.

Generally, there are two ways of using the evolutionary approach for reasoning aesthetic senses. One is the easy, determined, convergent, and backward way starting from given aesthetic preference and tracking back to the ultimate goal -- the gene survival success; whereas the other is the difficult, undetermined, divergent, and forward way starting from survival success and seeking after all meaningful aesthetic senses. The backward way usually carries out a single Aesthetics Chain (as exemplified in last section), whereas the forward way typically achieves multiple and sometimes interlaced aesthetics chains, say, Aesthetics Network. In this study, since the fundamental aesthetic dimensions are the unknown yet pursued targets, the forward way applies.

#### **4.5.2 Claim of Imperfection**

In the last section, a simple Aesthetics Chain has been worked out by the backward way. It was then generalized and formalized by the FBPSS approach. Yet it does not automatically imply that the resulting template can be directly applied for guiding the forward exploration of human aesthetic senses. Human mind has the most complex mechanism of all. It is extremely hard (if not impossible) to represent human aesthetic senses merely by limited aesthetics chains with limited layers. According to the massive modularity hypothesis suggested by EP, the human mind contains a large number of distinct thought (dynamically) interconnected information processing systems [Galambos, 2006], implying that the topology of human Aesthetics Network tends to be infinitely complicated and incognizable.

However, the complexity is not a trap of agnosticism. Human aesthetic senses are not arbitrary, but lawful. As discussed in the previous sections, all aesthetic senses are ultimately dedicated to, and therefore, rooted by gene survival success. As such, the topology of human Aesthetics



Network is considered like a tree -- except that many branches in the crown are interconnected, only a few main branches supporting the crown are relatively independent. These main branches are supposed to be the fundamental dimensions behind the human aesthetic senses, and have been well addressed by EP or EA.

#### **4.5.3 Two Sub-root Branches Derived from Gene Survival Goal**

In EP, a frequently repeated phrase is: the main goal of humans is to "survive in order to reproduce" [Hekkert, 2006]. It draws out two equally important implementations of human's gene survival success, which are: (1) the survival success of human individuals as the gene carriers; and (2) the reproductive success of the gene carriers for sustaining the continuity of the gene. Based on this dualistic concept, EP argues that the logic behind human mind have to be both egoism and altruism. The duality also applies to aesthetic senses where aesthetic pleasing could be produced not only by intuiting beneficial cues to individual's survival goal, but also by associating latent welfare to others, or by perceiving the contributive features related to the propagation of the human being. To further unfold what are the purposeful and discriminative aesthetic senses and when they are activated or inhibited, it will be forced to look into the crucial EP thinking - the notion of adaptation (fitness).

#### **4.5.4 The Four Fitness Branches**

As discussed in the previous section, the aesthetic sense serves as an agent which efficiently hides all the complexities of the underlying mechanisms that evolve for solving the adaptive problems (EP principle 3). These adaptive problems are identified and discussed in EP in order to discover what and how psychological mechanisms have been evolved that is perfectly fit to solve the problems. By surveying the EP literature, it is found that although different studies

addressed different adaptive problems, an universal agreement is revealed that adaptive problems have the impact on limited fundamental dimensions of human fitness, which are: (1) individual fitness, (2) inclusive fitness, (3) reproductive fitness, (4) offspring fitness, and (5) parent-offspring conflict. In EP based studies, the five fundamental fitness dimensions are considered as distinctive clues for reasoning the extensive human psychological phenomena.

#### **4.5.5 The Result Aesthetic Network**

However, in EA based studies, the use of the five fundamental fitness dimensions are typically restricted in understanding specific human aesthetic judgments in the area of natural beauty and in sexuality. In contrast, its application in industrial design domain is hardly reported. One possible reason is the misunderstanding that artifact appraising relies on cognitive process which may easily shield the importance of intuitive perception. Another reason could be the lack of a rational method to infer aesthetic dimensions from the fitness dimensions. In this case, the template of Aesthetics Chain developed in the last section applies. As previously discussed, the notion of Aesthetics Chain is imperfect and unsophisticated, it is currently used in this study within a limited scope and within specific context, say fundamental aesthetic dimensions for appraising cars. There are two unknown layers to be addressed: (1) what is the human concern and (2) what is the aesthetic sense. In the coming sections, the questions are addressed along each of the dimensions.

Along dimension (1), EP states that the most basic human concern is to access to live resources - by hunting or gathering. The resource here is the abstraction of any kind such as food, shelter, money, time, information and so on. If the appearance of an object elicits functional cues that may facilitate the access to resources, such as power, speed, and capacity, this object would

generally appeal to the observer. On the other hand, safety is equally important and must be concerned as well. The psychological mechanism of safety judgment works as elegant as simple: the most typical prototype of a category is often the most adaptive one, whereas novel things usually mean risking the unknown for change (better or worse). Therefore, the sense of trend is considered fundamental for security. Consequently, since dimension (1) solely addresses the fitness of each individual, the Aesthetics Chain on this dimension is named Egoism chain (or E-chain for short). There are two branches in it, one lead to functional cues; the other lead to trend.

Along dimension (2), EP offers a biological principle to human's altruism behavior where society plays important role in retaining the maximum number of copies of the most similar gene in the population. The underlying psychological mechanism not only assigns every social member with the concern about its sociability in building reciprocal relationships with others (such as belonging, friendship, leadership, respecting, and so on), but also provides useful senses in judging other's sociability by identifying its character and personality (such as friendly, gentle, arrogant, aggressive, etc.). Yet, the complexities of human pro-social or anti-social behaviors are far beyond the scope of this study. Instead, the theory of inclusive fitness is used here in a largely simplified manner in order to explain the fact that one often intuitively attempts to identify other's personality based on the car it drives, or tries to express itself to others through its owning car. In this case, if the beholder's sociability needs are matched, visual pleasing is produced. Thus, the Aesthetics Chain derived along this dimension is named Social chain (or S-chain for short).

Along dimension (3), the relationship between human aesthetic sense and sexuality is extensively explored either by both EP and EA. To be brief, the success of human reproductive fitness is largely determined by the strategy of mating, which is also called sexual selection. In this context, a candidate's appearance offers rich information about its genetic quality and breeding value which determines its degree of attractiveness to a mate seeker who has mating concern. It is well recognized that gender metaphors associated to high reproductive values can also make an artifact attractive -- if the sexual traits are utilized in an appropriate, implicative and reasonable way. Eventually, the aesthetics developed along this dimension is named Gender metaphor chain (or G-chain for short).

Along dimension (4), the human's epimeletic behavior can be tracked back to the fundamental human concern for nurturing the offspring, which is also the motivation of parental investment in EP's view. Things that exhibit pedomorphosis or cuteness, which are kind of attractiveness commonly associated with youth and appearance. They are usually characterized by (though not limited to) some combination of infant-like physical traits, especially small body size with a disproportionately large head, large eyes, a small nose, dimples, and round and softer body features [Wikipedia, 2008]. Infantile personality traits, such as playfulness, fragility, helplessness, curiosity, innocence, affectionate behavior and a need to be nurtured are also generally considered cute [Wikipedia, 2008]. As Konrad Lorenz argued in 1949, infantile features triggered nurturing responses in adults and that this was an evolutionary adaptation which helped ensure that adults cared for their children, ultimately securing the survival of the species [Wikipedia, 2008]. Hence, the Aesthetics Chain rolling out along this dimension is named Parental chain (or P-chain for short).

Along dimension (5), the (re-)allocation of limited resources between parents and offspring, offspring and offspring, and the difference in influences owned by each of the parents are addressed. Since this dimension is less relevant to the context in this study, it is excluded in the result.

Conclusively, the entire Aesthetics Network is illustrated in Figure 4-9. Four aesthetics chains are constructed, which are: (1) Egoism chain (E-chain); (2) Social chain (S-chain); (3) Gender metaphor chain (G-chain); and (4) Parental chain (P-chain). Furthermore, five fundamental aesthetics dimensions are inferred, they are: (1) Functional cue; (2) Trend; (3) Personality; (4) Gender metaphor; and (5) Cuteness. In Figure 4-9, the five fundamental aesthetic dimensions are drawn in a nebulous shape, implying that the dimensions could not be, in case of have to be, simply represented by a single word.

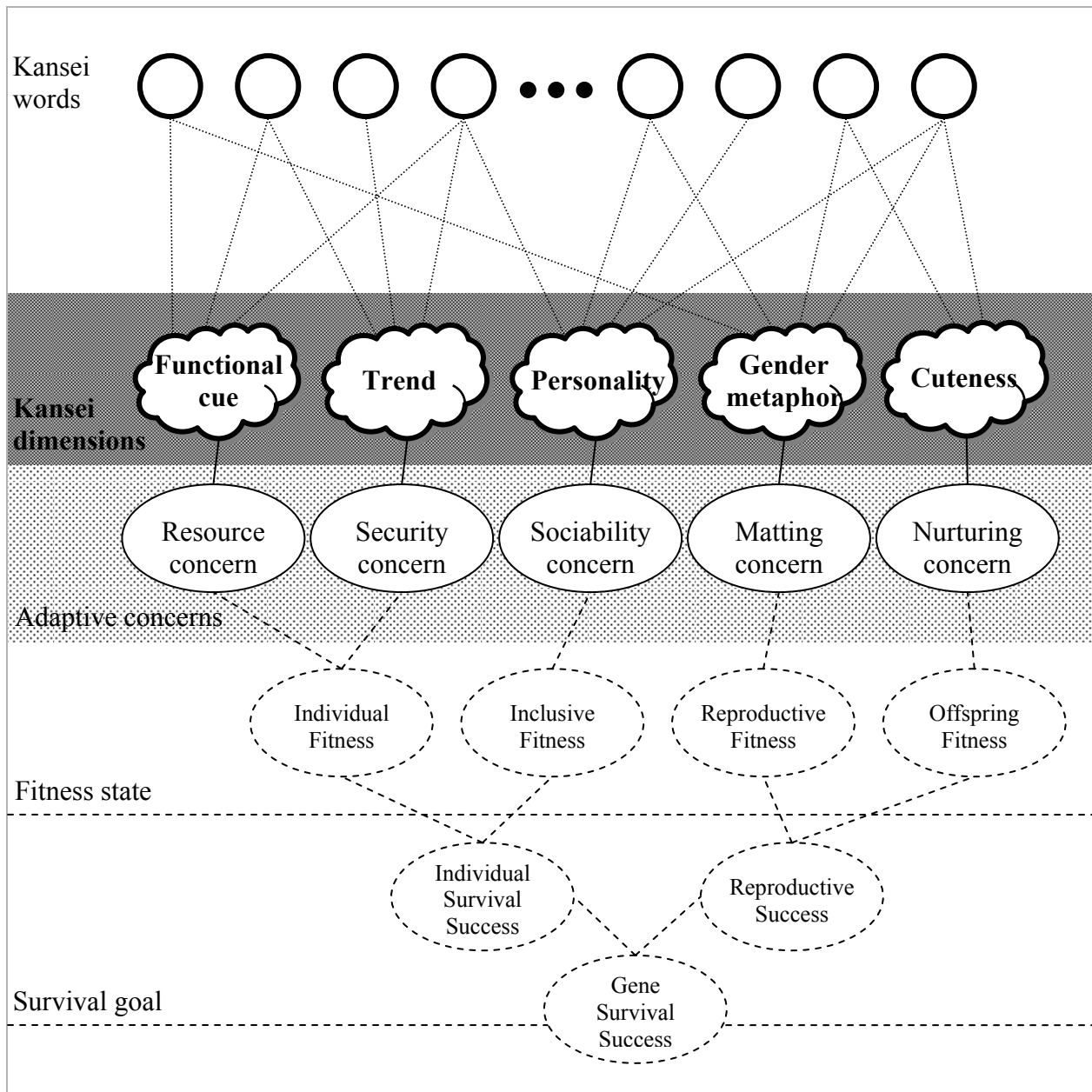


Figure 4-9 Evolutionary Aesthetics Network for appraising cars

#### 4.5.6 Discussion

With respect to the massive modularity hypothesis of EP (EP principle 4), the Aesthetics Chain and network approach is currently impossible in reasoning the extensive human psychological mechanisms, including those high-level, intangible aesthetic senses. The task for identifying the higher portion of Aesthetics Network – the layers between the fundamental aesthetic dimensions

and Kansei words – have to rely on a complementary learning approach, such as subjective rating or subjective conjecture. However, the current result may provide valuable guidance to the subjective learning, especially, once the fundamental human concern could be captured, or in other words, if consumers’ fundamental needs are measurable, the unsupervised learning could be then replaced by a supervised learning, yielding more reliable, stable and rational results with enhanced objectivities and engineering values.

By far, although human emotion is not addressed in this approach, it is considered to be added into future work where emotion represents the balance of states of the human fitness concerns, and facial expressions are the indicators of the balance state.

In the current result, similarities are revealed between fitness concerns and Maslow’s needs. For example, the concern of resource is addressed by Maslow’s model at the physiological level; the security concern is also addressed by Maslow’s model at the safety level; the sociability concern is also addressed by Maslow’s model at the love/belonging level; and the matting concern can be mapped back to Maslow’s model at the physiological level. The compatibilities are the indication of robustness, whereas there are still non-overlapped portions, leaving considerable headroom for future improvements.

Finally, it is important to note that the evolutionary approach proposed in this study does not intend to replace any of the existing car body design methodologies or deny designer’s expertise and experiences. In addition, the approach focuses only on the low level instinctive responses

which may come first but the effects could be easily overridden by the subsequent cognitive processes and knowledge recall. Therefore, use of the approach should be carefully limited.



## CHAPTER 5 COLOR MODEL AND INSTRUMENT

### **5.1 Introduction**

Color is considered to be the most salient, resonant, and meaningful visual feature of those seen in early vision. This makes color a compelling visual cue for persuasive communication purposes such as conferring identity, meaning, or novelty to an object or idea [Suk, 2006]. In appraising a product, the image sensation of the product is typically formed by aggregating the overall perception of form, color, and texture [Tsai, 2006]. When considering the overall image sensation of a product, a mutual dependency exists between a product's form and its color [Tsai, 2006]. Thus, color cannot be disassociated with the shape that upholds it or has a border that limits it. According to Suk [2006], color contributes to the appreciation of and preference to products and plays an essential communication role for the products, improving the efficacy of messages and increasing the likelihood of purchasing. When selecting a new car, color ranks among the high priority features consumers look for. In many cases, consumers choose to either wait for the availability of cars with their desired color or even shop another brand of cars that have their desired color.

Obviously, when a new car body is shaped, body color is an additional yet critical property that may further enhance its attraction to consumers and therefore has a considerable influence to the market coverage. In general, offering more selectable colors for a car has always a positive contribution to its market coverage. In practice however, the fact is that the number of available

colors has to be limited by the cost of producing the car of an additional color. The reason behind this limitation has less connection to the pigment itself but is more associated with manufacturer's paint shop efficiency and supply chain management, as illustrated in Figure 5-1.

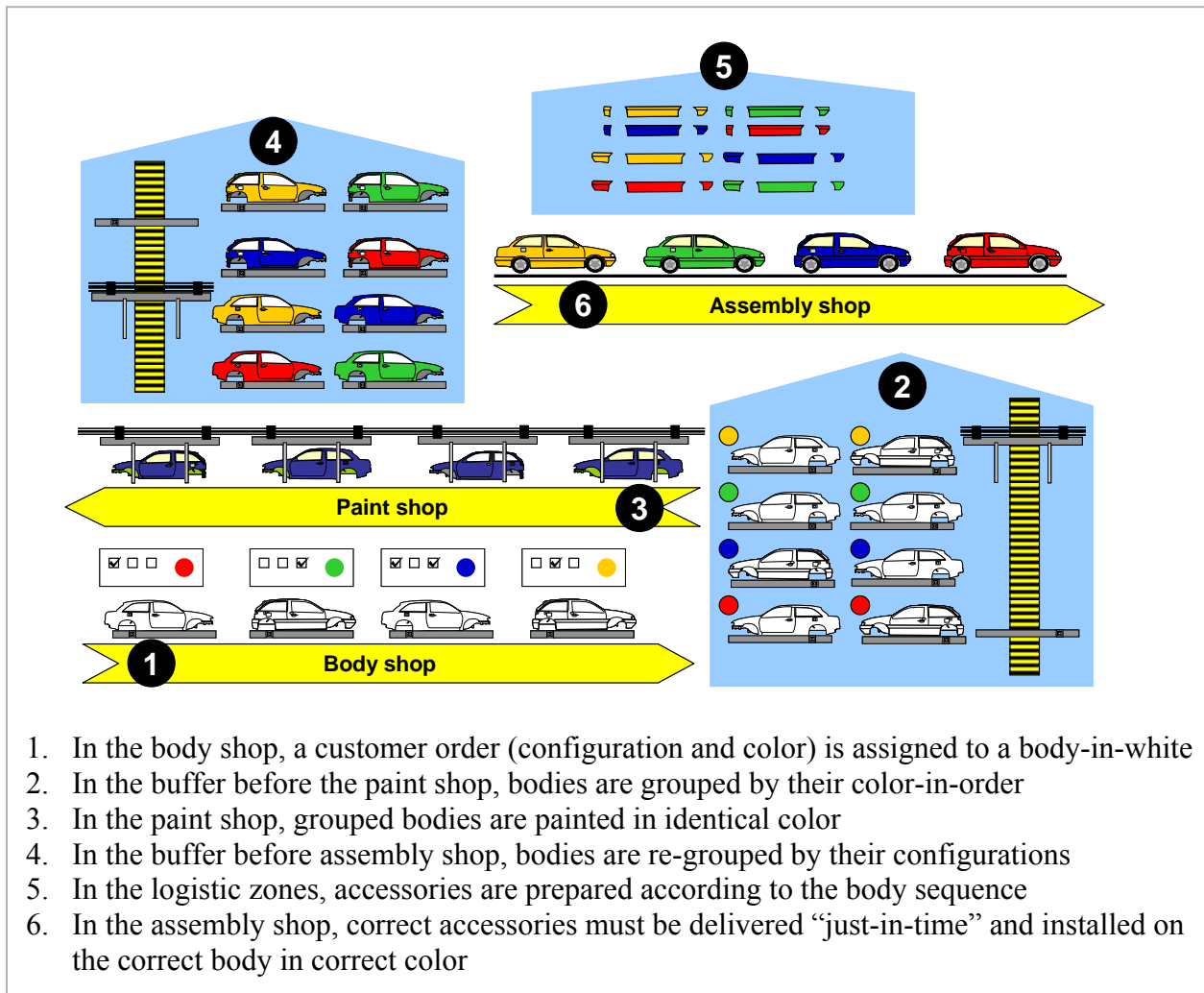


Figure 5.1 A typical “order-driven” flexible manufacturing process

Using the minimum number of colors for attaining the maximum market coverage poses a great challenge to car body color design. This requires not only a keen sense in color but also a deep

understanding of target consumers' color preferences. This chapter studies modeling of customers' color preferences.

In the remaining part of this chapter, section 5.2 will review and compare different color models in literature to select a suitable color model for the purpose of this study. In section 5.3, an instrument, named "Color-Shape Synthesizer", is presented which allows grasping a consumer's color preference to a specific car shape and represents the captured color preference.

## **5.2 Selection of Color Model**

### **5.2.1 Qualitative Color Models**

#### *5.2.1.1 Marketing color model*

Humans are generally used to describing color by using basic colors (or color primitives) such as red, green, blue, yellow, white, and black. Since car body color in the automobile industry varies from manufacturer to manufacturer and (car) model to (car) model, it is hard to uniquely distinguish a color by merely using the color primitives. In fact, color is often used as a means to induce emotions in humans. Therefore, there must be words (adjectives and / or nouns) that can represent emotions induced by colors. The power of these words not only helps to distinguish a color but also to leave an incredible headroom for the car manufacturer to promote a potential buyer's imagination about the product. Table 5-1 shows a few examples of color models of cars found in the public websites of major north-American, European and Asian car manufacturers.

Table 5-1 Color primaries and their descriptive words in marketing color models of cars

Primaries	Descriptive adjectives or nouns
White	Campanella, Polar, Crystal, Cool-Vanilla, Diamond, Oxford, Calcite,
Black	Sapphire, Flint-Mica, Brilliant, Cherry, Super, Magic, Graphite
Red	Salsa, Barbera, Barcelona, Radiant, Copper, Brilliant, Misano, Inferno, Crystal, Merlot, Fire-opal, Carneol
Green	Jade-Sea, Periclase, Sage
Blue	Laser, Monaco, Pacific, Nautical, Stormy, Icy, Ocean, Cleanwater, Chip, Sunset, Light-Ice, Tanzanite, Venetian, Azure
Yellow	Olive-Mist, Golden-Sand, Mist-Gold
Grey	Platinum-Bronze, Galaxy, Meteropolitan, Lava, Dark-Titanlum, Sandstone,
Silver	Thunder, Radiant-Bronze, Light-Platinum, Light-Tundra, Tenorite Reflex, Titanium, Streak-Mica, Sunlight, Bright-Metallic, Birch, Palladium, Cubanite, Frost, Radiant, Winter-Forst

Although the popularity of these color models listed in Table 5-1 indicate their success in the business community, they are not suitable for this study due to their inexact, ambiguous, and sometimes exaggerated nature.

#### 5.2.1.2 Psychological color model

The psychological function of color has been long noticed, studied and used. It is known that humans carry a sort of hereditary recollection of nature's meaning behind each color. Over time, people begin to recognize specific colors as specific signs and adhere to their message, resulting in distinctive ideas and emotions attached with each other. Despite a large deviation in an individual's sensitivity level, qualitative yet universal patterns have been retrieved, summed up, and adopted as aesthetic, ergonomic, or even clinical principles in evoking specific psychological responses. They are briefly discussed as below:

- (1) Colors convey emotional values, in terms of valence, arousal, and dominance. For example, as verified by Suk [2006] within his framework and experiment, chroma was found positively correlated to all emotion dimensions.
- (2) The emotional effects elicited by colors are also perceivable in humans' day-to-day life in terms of feeling, mood and subjective well-being. Different colors are used for stimulating or expressing different (either positive or negative) emotions such as happiness, excitement, sadness, fear, anger, and so on.
- (3) Different colors have different visual weightiness in human eyes. As experimentally verified by Mokarian [2007], colors may alter the perceptual weightiness of an area or an object, which is used to achieve or break visual balance of a product. This visual balance was used as a principle for product aesthetic design with consideration of ergonomics and functionality [Mokarian, 2007].
- (4) Colors often produce illusions in terms of motion such as advancing color and receding color; and in terms of volume such as expansive color and contracting color. This phenomenon is also known as "color stereoscopy" or "chromostereopsis".
- (5) Colors can also be described in temperature terms, such as "warm" or "cool" as related to the dominant wavelength of the color.
- (6) Other recognized psychological attributes of a color include (but not limit to): humidity (dry-wet), rigidity (hard-soft), purity (clean-dirty), and so on.

In summary, the qualitative color models phenomenally address an observer's responses to colors and express the feelings using semantic representations. However, for engineering applications, a quantitative color model is needed.

## 5.2.2 Quantitative Color Models

### 5.2.2.1 RGB color model

The RGB (abbreviation of red, green, blue) color model is an additive color model (Figure 5-2) in which red, green, and blue light are added together in various ways to reproduce a broad array of colors [Wikipedia, 2008]. The main purpose of the RGB color model is for sensing, representation, and display of images in electronic systems, such as televisions and computers [Wikipedia, 2008]. In the digital age, the RGB model is progressively implemented by using 3, 8, 16 and 24 bits of memory; each additional bit may significantly increase the coverage and accuracy in representation of color. A modern computer uses at least 24-bit for each pixel, and this means that each pixel is capable of representing up to 16 million different colors.

### 5.2.2.2 CMY(K) color model

CMY (abbreviation of cyan, magenta, yellow) is a subtractive color model (Figure 5-3) which is used in color printing [Wikipedia, 2008]. Theoretically, mixing of cyan, magenta and yellow can generate the black. Due to practical restrictions, black (also called “key”) has to be introduced as the fourth independent component, leading to a modified CMY color model called CMYK which is better known than CMY. Since RGB and CMYK models are both device-dependent, there is no simple or general conversion formula between them [Wikipedia, 2008].

### 5.2.2.3 HSL color model

HSL (abbreviation of hue, saturation, lightness/ luminosity) is a representation of points in an RGB color space, which attempts to describe perceptual color relationships more accurately than RGB while retaining the computational ease with RGB [Wikipedia, 2008]. Based on the HSL model, each color can be presented by its Hue, Saturation, and Luminosity. Hue refers to a

special wavelength of color to which a name is given. Luminosity points to relative lightness or darkness of the color and its gradation is between black and white. Intensity, also called saturation or chrome, refers to the purity of a hue at its highest saturation that is in its brightest form [Preble and Preble, 1994].

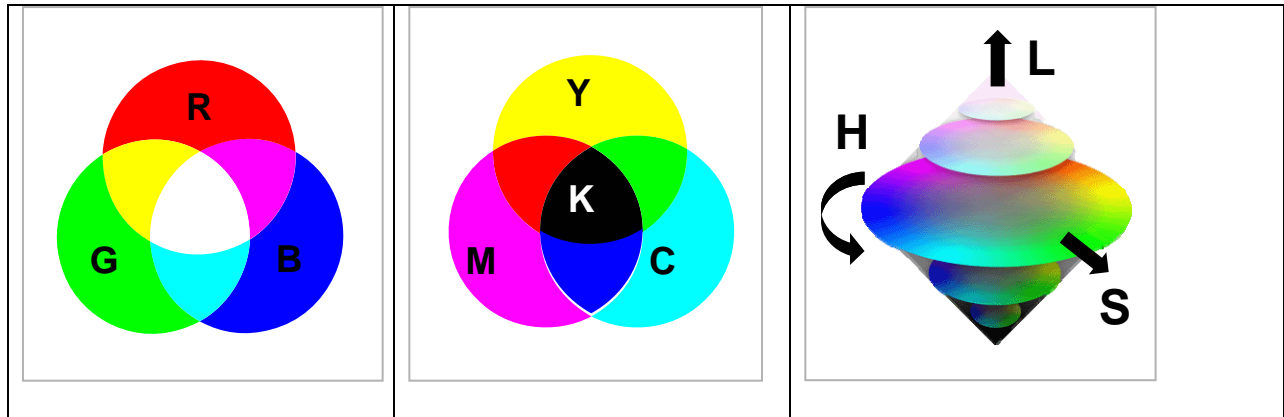


Figure 5-2 The RGB color model as an additive color model

Figure 5-3 The CMY color model as a subtractive color model

Figure 5-4 The HSL color model which is a simple transformations of RGB [Wikipedia, 2008]

#### 5.2.2.4 Color Space

The three quantitative color models discussed above have a common feature that they are represented by three numbers – a triplet of numbers. However, how these numbers are interpreted by a concrete color device is not defined, which causes that different devices sense or reproduce a color differently. This problem is addressed by the notion of color space in which: (1) most color devices including individual's eyes have a limited gamut (coverage of the visible colors defined in CIE 1931 XYZ color space) (Figure 5-5); (2) Given a color, different input devices may result in different triplets of values, or given a triplet of values, different output devices may produce different colors on their corresponding media. In order to obtain a matched (standard) color across devices, a mapping mechanism is essentially needed on each device to

convert between the device-dependent local color space and the device-independent global (standard) color space. The mechanism is also known as profile-based color management.

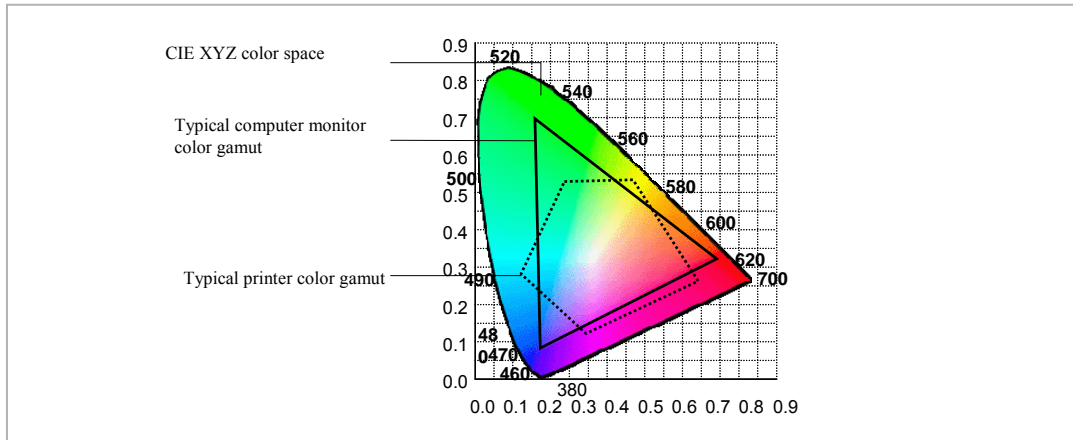


Figure 5-5 CIE XYZ color space and typical color devices' gamut

#### 5.2.2.5 Color Solid

A color solid is a three-dimensional representation of the color space. There are a couple of color solids (Figure 5-6). In general, color solids are useful tools in helping designers quickly navigate the color system, identifying the relationship between multiple colors such as complementary color or concordant color. Since the body of an individual car is not typically painted in multiple colors, color solids are temporarily not used in this study.



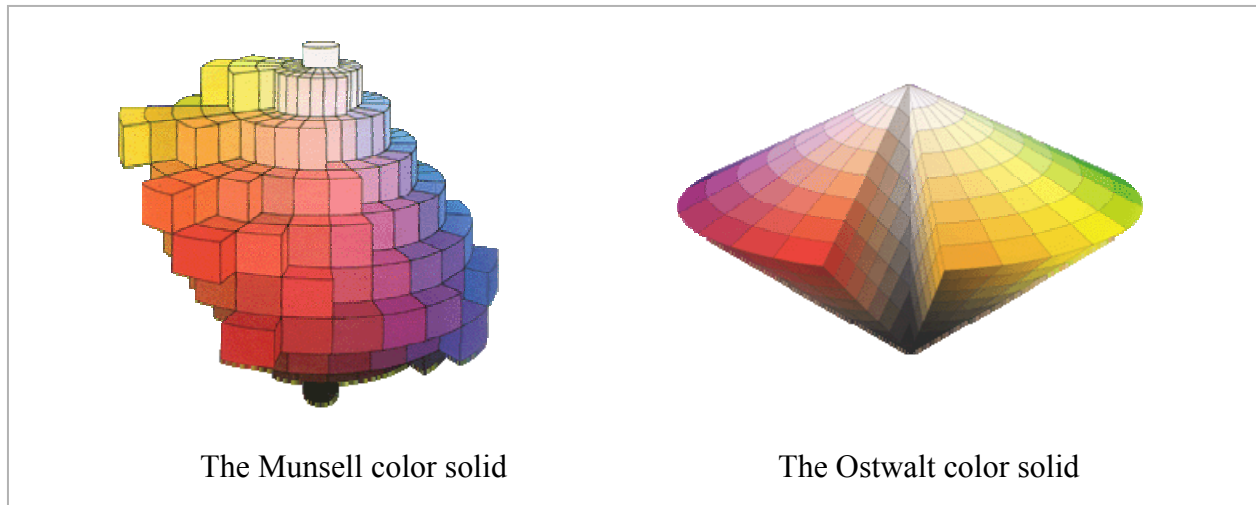


Figure 5-6 Color solids which are a three-dimensional representation of color space [www.icoffice.co.jp]

### 5.2.3 Discussion

In the previous discussion, two categories of color models were revealed: (1) **qualitative** models and (2) **quantitative** models. Qualitative models are consumer-friendly and are specialized in accommodating psychological responses in a semantic approach. Quantitative models are designer-oriented or device-oriented and are capable of capturing, storing, processing, and reproducing color in an accurate and “engineering-able” manner. In the industrial design context, a qualitative model needs to be eventually mapped to a quantitative model.

Quantitative models are found misused in some research experiments. One typical example of such a misuse is the assumption that R(ed), G(reen) and B(lue) are the fundamental and independent dimensions of the consumer’s visual sense. This assumption is likely derived from the fact that most digital equipment systems handle R, G, and B components in three separate and parallel channels. Based on this assumption, the R, G, and B values are often selected as the independent treatments in experiment design as well as the orthogonal variables in analyzing the

experimental observations. However, this assumption is not always true especially when the experiment aims to grasp a human's *mental responses* to color rather than human's *eyesight* to color.

Human mind works more with *relative* proportions among R, G, and B components rather than the *absolute* value of each. For instance, a high R value does not necessarily produce a “fiery” or “bloody” feeling unless G and B values are significantly lower than R value; or a high B value may produce “cold” feeling but may also lead to “silver” if R and G values are as high as B value. Consequently, using R, G, and B as independent variables may eventually weaken the relevance of the results. On the other hand, if human subjects are targeted in a computer-based color experiment, the HSL (or HSV) model is generally a better choice than the RGB or the CMY(K) model, since hue, saturation and lightness are found to have relatively more independent influences on human's mental perception to color. The HSL model can therefore better emulate how humans perceive color. Figure 5-7 demonstrates a television as a typical example: the TV uses the RGB model for its internal signal processes while uses the HSL model to interact with the user.

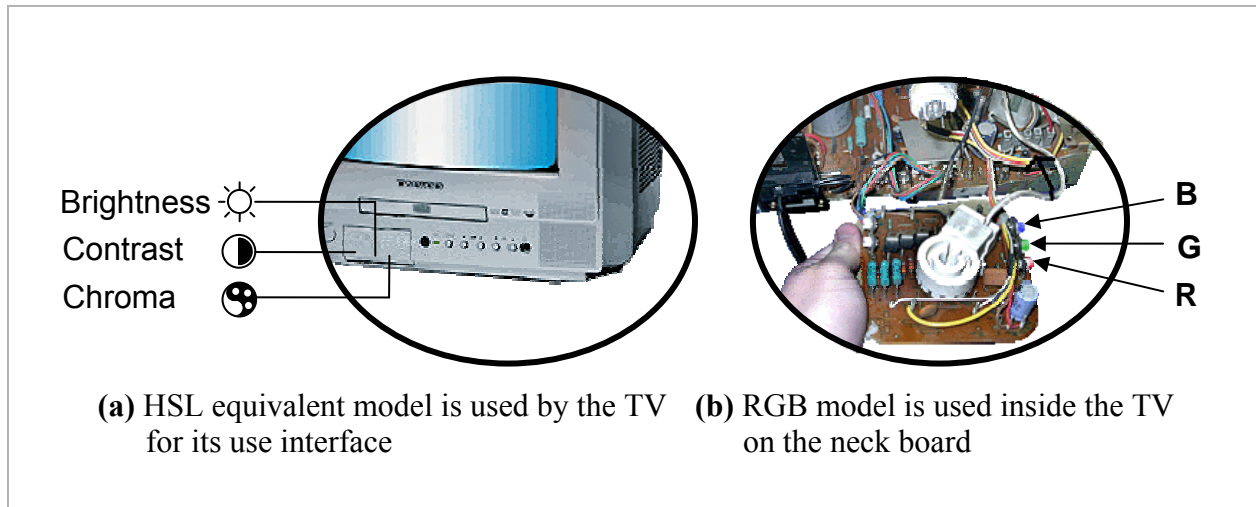


Figure 5-7 Different color models used by television for different purposes

Regarding the color space, if industrial design must be conducted using electronic devices such as computer monitor, color space plays an important role and may have considerable impact to the results. Car color in automotive industry is typically defined in the CMY(K) model and perceived in a natural environment which is a highly dynamic color space; whereas a colored car shown on the computer monitor is typically accommodated in RGB (or HSL) model and perceived in an individual monitor's color space which may have no color management at all or have a default color management that is not properly calibrated. Thus, color distortion is introduced when reproducing a color in a different model and space, leading to subjective judgment deviations. Since the experiment proposed in this study relies on the computer, there will be color distortion. However, the influence of color distortion can be reduced by training the human subjects or participants how to avoid it and by a proper experimental design.

When a color is applied on an object, different parts of the object have different lightnesses upon the relative position between the light source(s) and the object in the environment (Figure 5-8). In addition, the gradient distribution throughout the object also varies depending on the surface

material. In other words, altering the gradient distribution may emulate different surface material features. For example, sharpening the gradient may enhance the “metallic” feeling of a painted car body, say grey versus silver.

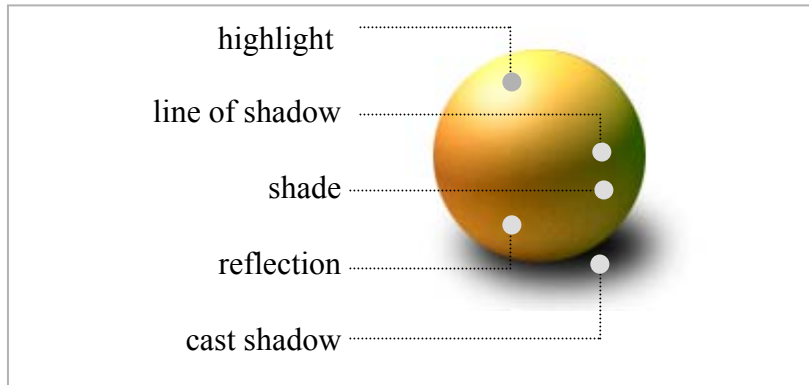


Figure 5-8 Color on shape (sphere)

Finally, given a car body shape, in order to grasp a consumer’s color preference and represent it in a quantitative model such as HSL, an instrument is required, which is discussed in the next section.

### 5.3 Color-Shape Synthesizer

Appraising different colors on a given shape is not always as easy as it was intuitively anticipated. Most people are actually not capable enough to imaginatively synthesize color and shape in mind without deviation and bias. Before the digital age, colors have to be applied on physical models in order to be faithfully assessed. To save cost, a physical model was sometimes scaled down (1:5 or 1:10); each detachable half (say left or right side) of the model was painted in different colors and presented in front of a mirror. More often, real car bodies or parts are used as alternative models during the color assessment process (Figure 5-9).



Figure 5-9 In the former time, colors are applied on parts for assessment [Lee, 2007]

The invention of the computer aided design (CAD) system and ray tracing algorithms provide a revolutionary solution for synthesizing color and shape in a 3D virtual space, eliminating the time spent and effort taken on making physical models. Besides, the graphic manipulation software offers another digital capacity of exchanging color of a car body in 2D (photographic) space. However, only well-trained designers can take advantage of CAD or 2D graphic tools for presenting a car in different color schemes. In contrast with the professionally equipped forward communication from designers to consumers (Figure 5-10), the instrument that enables consumers to express their own color preferences and to communicate with designers in a backward manner is still missing or not matured. This kind of instrument will be useful to any work that attempts to grasp consumers' color preferences on different shapes. The core functionality of such an instrument is to offer the user with almost an unlimited freedom to pick

any color from a continuous color space and virtually “paint” the color on the car body in an image. Ideally, the instrument can be operated in a straightforward, real time, online and interactive manner. The instrument is hereafter called by this study “Color-Shape Synthesizer”.

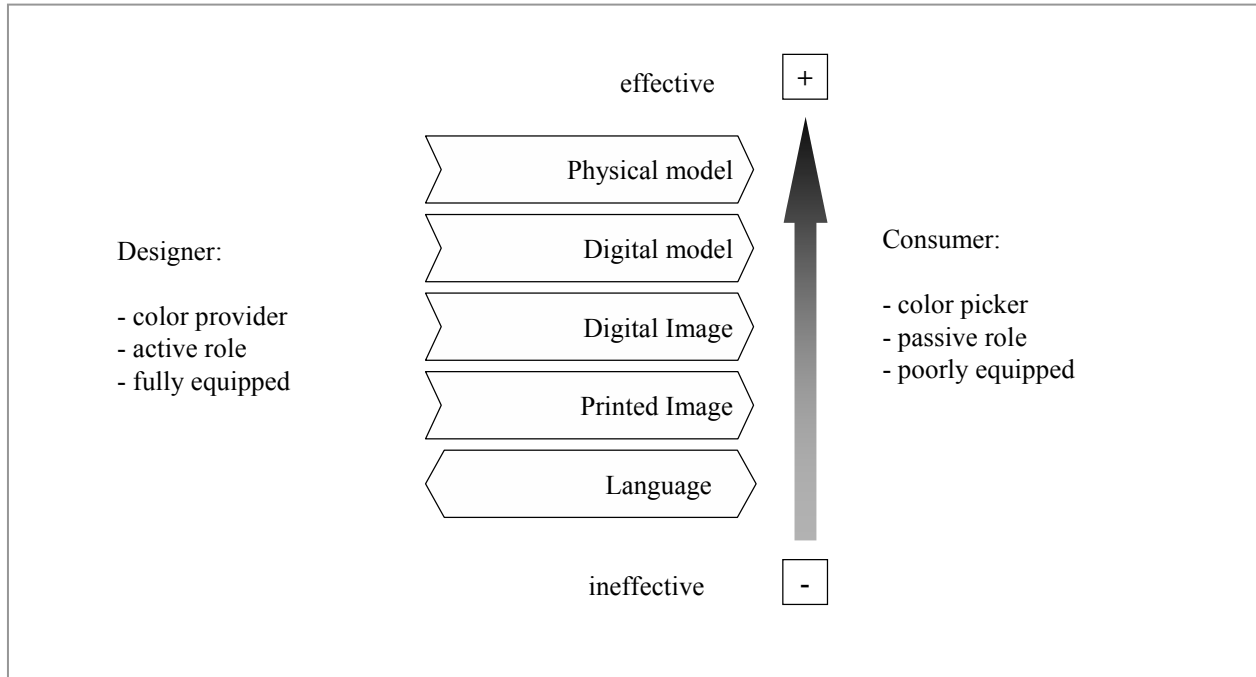


Figure 5-10 Unbalanced color communication between designers and consumers

### 5.3.1 The Criteria of Raw Image Selection

Currently in this study, a Color-Shape Synthesizer was supposed to work with a static 2D car image. In future, a 3D dynamic Color-Shape Synthesizer can be developed by further integrating the 2D synthesizer and panoramic technology. Nevertheless, since the quality of the raw image has direct impact to the practical value of the Color-Shape Synthesizer, it is necessary to select a qualified image upon certain filtering criteria in terms of perspective, lighting, environment, exposure, and so on. Unlike the commercial purposes, the car image selected for this Color-Shape Synthesizer must represent the original information of the car body shape. Any element or

pattern that does not originally belong to the car body is undesirable as it might be misleading, except that a simple background is acceptable if it only serves as a reference to the ground plane. Therefore, a studio photo is normally preferred; otherwise the criteria listed in Figure 5-11 should be followed when filtering quality raw images for use in the Color-Shape Synthesizer.

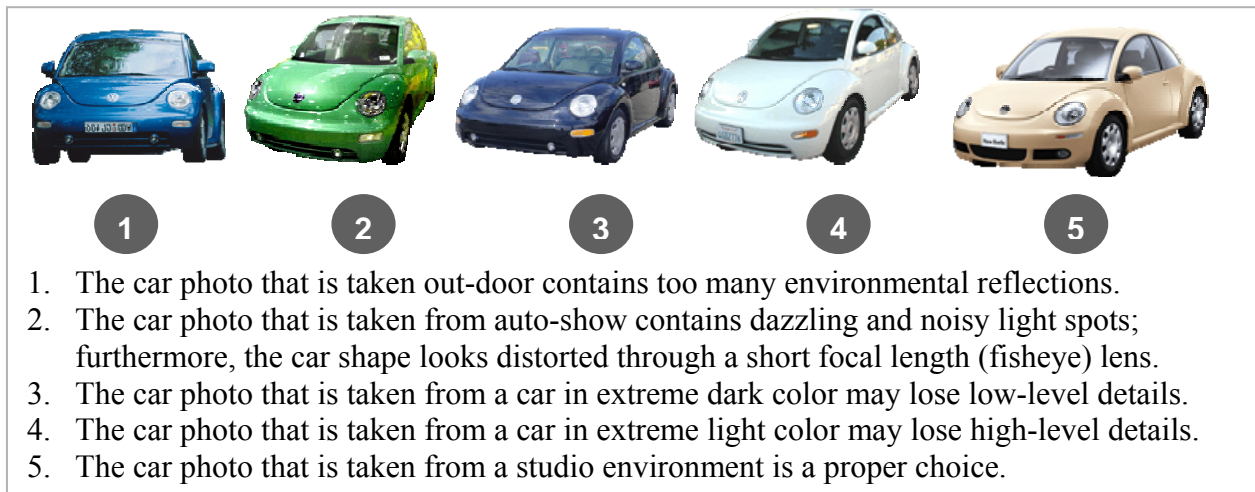


Figure 5-11 Criteria of filtering quality raw image for the Color-Shape Synthesizer

### 5.3.2 Image Decomposition

A raw car image normally consists of three components, which are: **(1)** painted car body, **(2)** non-painted exterior parts, and **(3)** background. The three components are originally integrated together as a whole in the raw image. In order to selectively assign a new color to the painted portion (car body) while maintaining the colors on the other portion (windows, wheels, lights, logo and so on) unchanged, and optionally turn on/off the background upon request, the raw image needs to be decomposed into three overlapped layers where each layer contains only one of the three components, as shown in Figure 5-12.



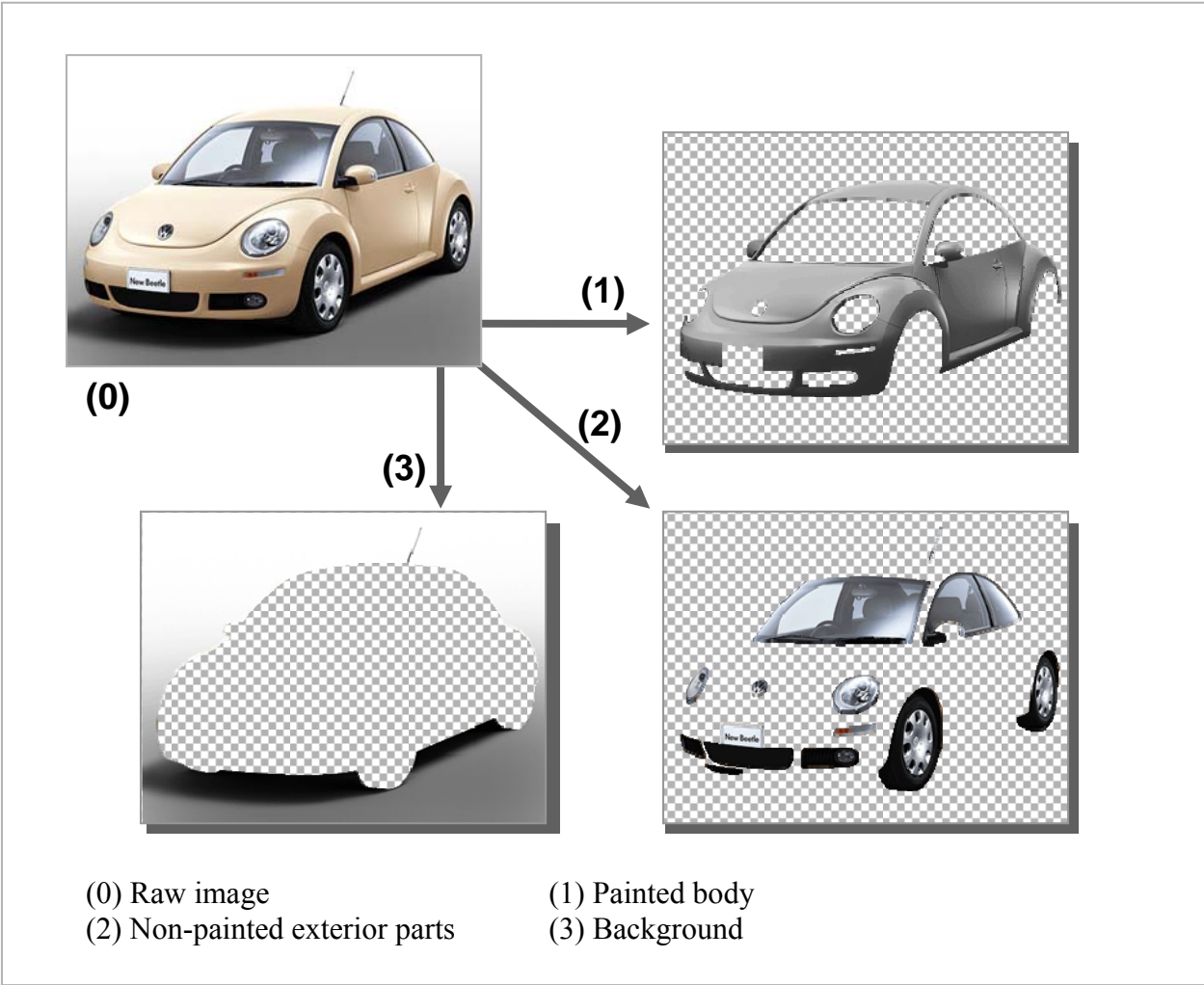


Figure 5-12 Decomposition of raw image

**5.3.3 Non-linear Normalization of Image Levels**

The goal of normalization is to obtain a car body image that only carries information about its shape but not its color. Removing color from a shape is not as simple as an operation of de-saturation. De-saturating a dark-red car and a light-yellow car will, respectively, result in a dark-grey car and a light-grey car rather than two identical middle-grey cars, because the L(lightness) component (of HSL model) can not be properly removed by de-saturation (Figure 5-13). It can be inferred that an ideal color removing method should be able to produce a neutrally



monochromatic car image which is in the middle of the extremely dark (black) and the extremely light (white) tones, regardless of the original color in the raw image. Thus, it is often necessary to further adjust the lightness levels after conducting the de-saturation operation. However, since a car body consists of complex surfaces and therefore its lightness gradient is also complex, tone levels of a car body image can not be ideally adjusted by merely using a linear tool, such as the brightness/contrast function, which may permanently cut-off valuable polar tone levels during the transformation. In order to preserve, at maximum, the original shape information (represented by tone levels), an advanced non-linear level transformation is considered. The power of non-linear transformation not only satisfies the quality requirements of image normalization but also allows producing the extremely dark (black) and the extremely light (white) car body images in a lossless and reversible manner (Figure 5-14).

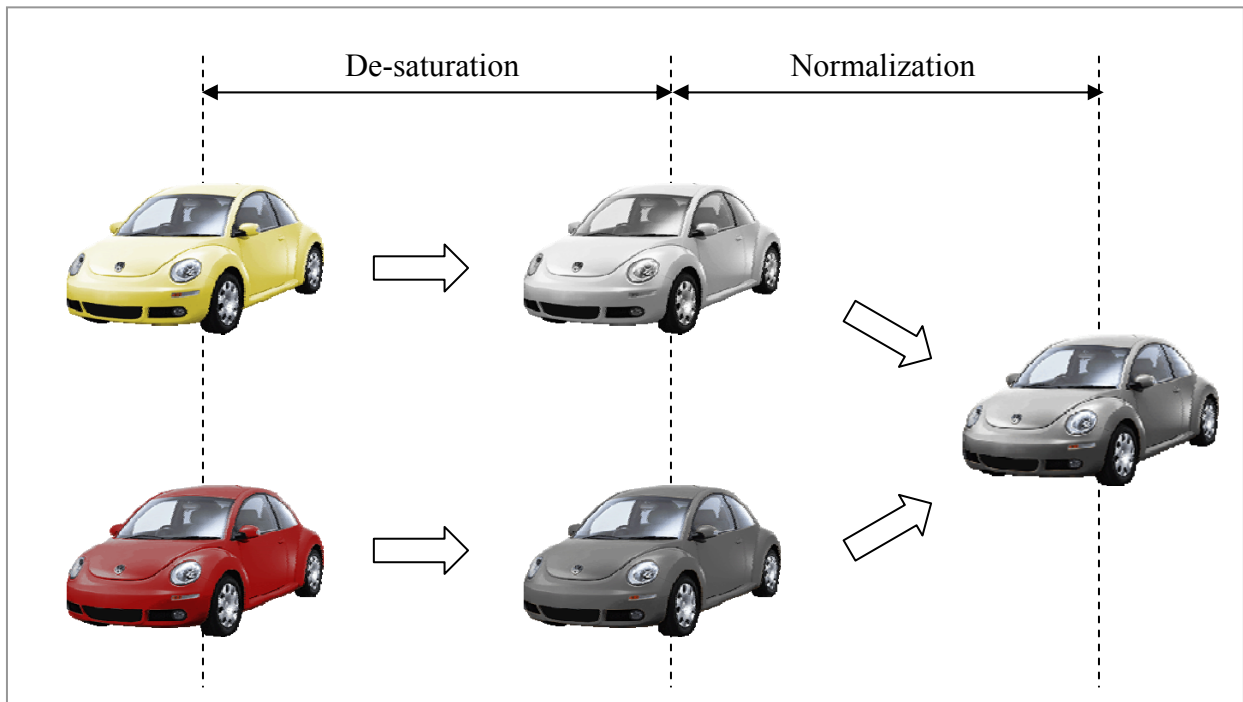


Figure 5-13 Extracting non-color shape image from original color image

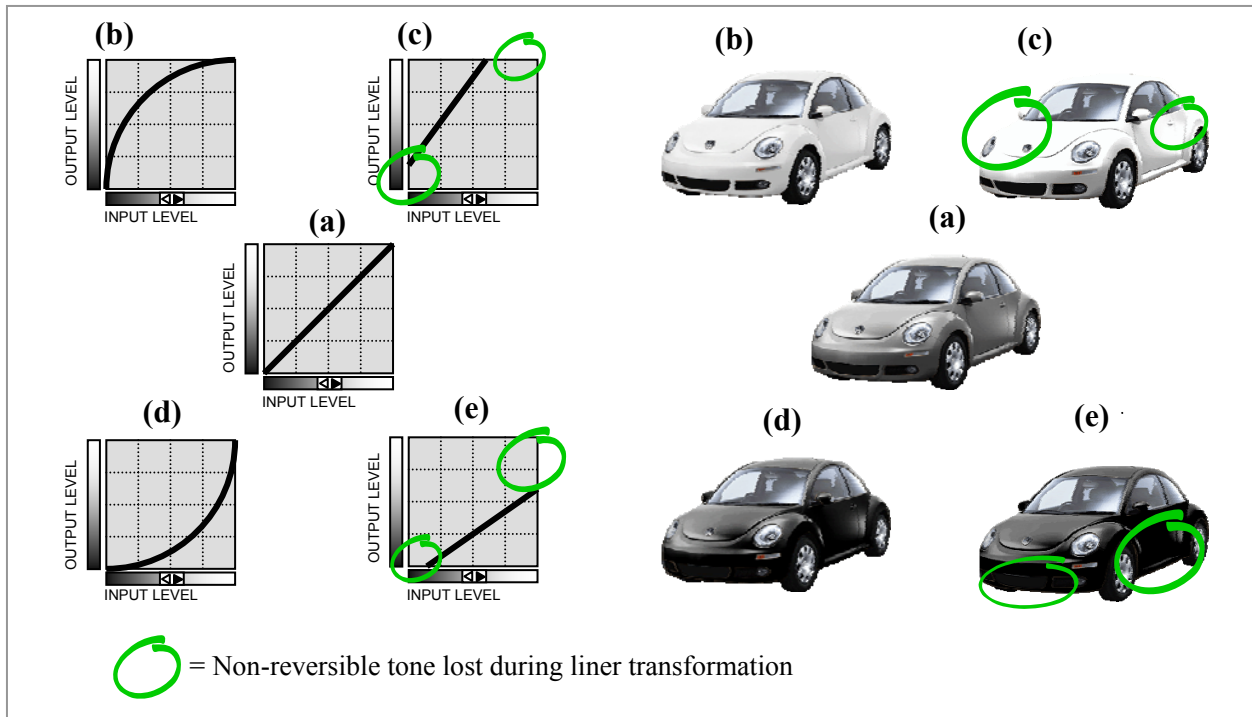


Figure 5-14 The non-linear normalization of levels

### 5.3.4 The Architecture of Color-Shape Synthesizer

As illustrated in Figure 5-15, the Color-Shape Synthesizer architecturally consists of 5 layers. Layer 1 and Layer 2 statically hold the background and all unpainted parts. Above these two layers are Layer 3 which holds the car body in the extreme dark tone and Layer 4 which holds the car body in the extreme light tone. The division of these four levels is dynamic because its R, G and B components can be programmatically changed and the opacity of Layer 4 (white body) is also changeable. On the top is Layer 5 which is a mask layer for emulating metallic styles through the transparency (also called alpha-) channel.

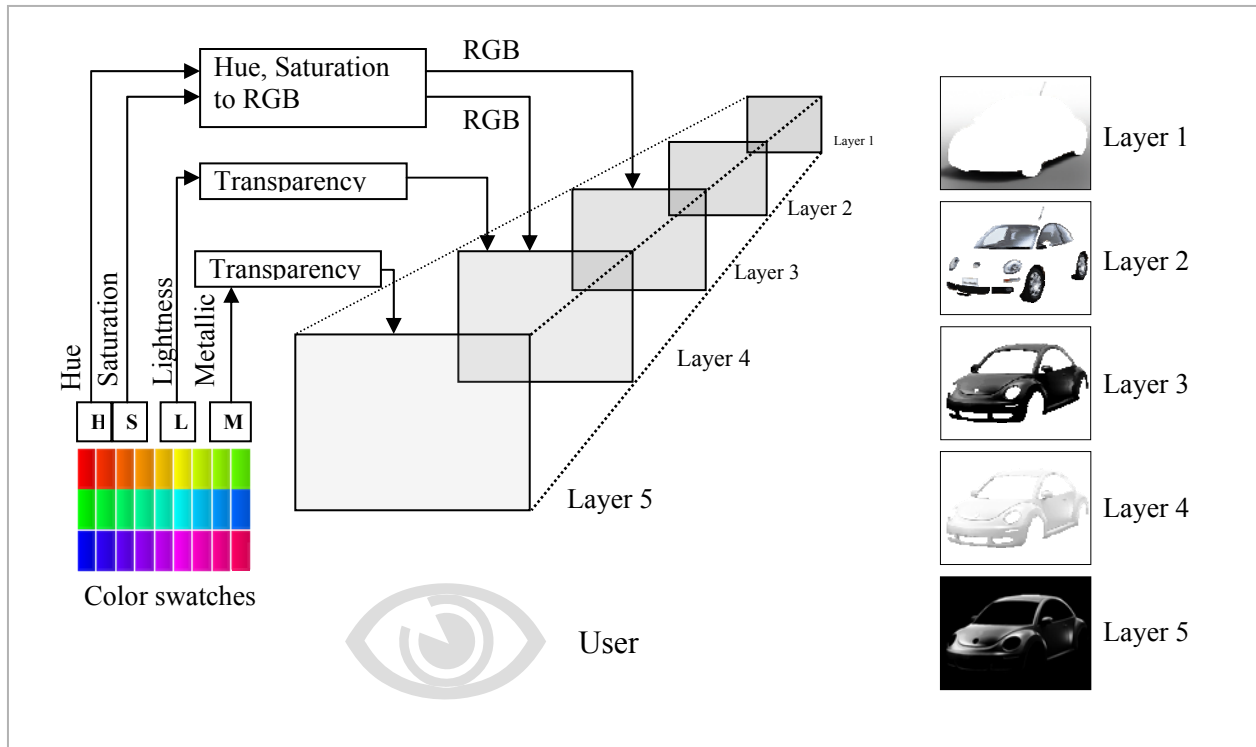


Figure 5-15 The multi-layer architecture of the Color-Shape Synthesizer

All the five layers are overlapped and exactly aligned. As a result, what the user eventually sees is a complete car rather than a bunch of unorganized parts.

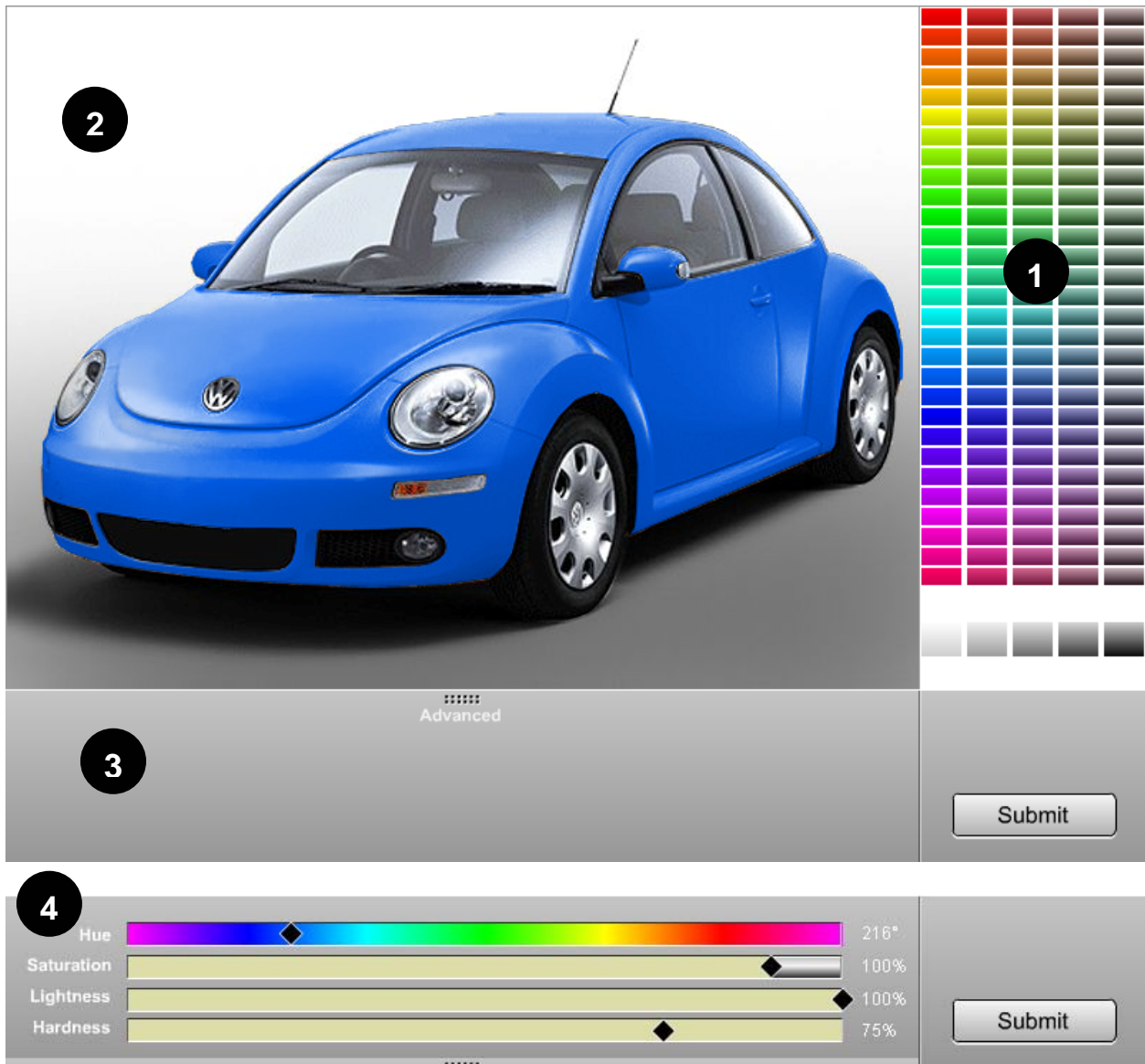
The Color-Shape Synthesizer provides two kinds of UIs (user interfaces), which are: (1) **digital color swatches**, and (2) **advanced HSL sliders**. The UI (1) targets to general users, and it discretizes the HSL model and visualizes HSL values by an array of digital color swatches which emulate the printed color swatches available at auto dealers. The UI (2) is optional for the users who have basic idea about HSL, and it offers advanced and step-less (continuous) capacity to adjust hue, saturation, lightness, and metallic parameters respectively for generating a favorite color that is not found in the swatch array. As the user picks a color by clicking on a color swatch or dragging the advanced color sliders, the algorithms sitting between the color user

interface and the shape layers immediately translate the user selected HSL values to RGB values and dynamically change the RGB values of the group containing layer 3 and 4. Simultaneously, the L component is further used to change the blend ratio among layer 4 (the white body) and layer 3 (the black body) by changing the opaqueness of layer 4, yielding any intended intermediate tone level between white and black. Meanwhile, the non-linear normalization mechanism guarantees that the original shape information (tone levels) is perfectly preserved throughout the entire process.

The above system is eventually implemented by using Adobe Flash<sup>1</sup> (which was Macromedia Flash) and ActionScript. The result Color-Shape Synthesizer is therefore automatically supported by almost all major Web browsers, offering a great potential for conducting a distributed on-line experiment. Figure 5-16 shows the screen shot of the Color-Shape Synthesizer's user interface.

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<sup>1</sup> Although Flash is nowadays broadly used by almost all car manufacturers to showcase their product in different colors, however, the architecture proposed in this study is specified to meet the academic experiment quality requirement, which is different from either the commercial or the entrapment quality requirement.



1. Color swatches
2. Shape layers
3. Advanced color picker (closed)
4. Color sliders in the advanced color picker

Figure 5-16 The user interface of Color-Shape Synthesizer

The prototype of the Color-Shape Synthesizer is enclosed in Appendix C.

The life demo of the “Color-Shape Synthesizer” is also available at:

[http://homepage.usask.ca/~chw346/Color\\_Shape\\_Synthesizer/](http://homepage.usask.ca/~chw346/Color_Shape_Synthesizer/)

## CHAPTER 6 EXPERIMENT

### 6.1 Hypotheses, Assumptions and Scope

An experiment is proposed to verify whether car body shape can be characterized in terms of the fundamental aesthetics dimensions developed by this study and whether a consumer's color preference can be profiled in terms of the fundamental aesthetics dimensions.

The following hypotheses were tested in the experiment:

- [H1] Car body shape can be aesthetically characterized in terms of the fundamental aesthetics dimensions which are: Functional Cue, Trend, Personality, Gender Metaphor and Cuteness.
- [H2] Consumer's color preferences, represented by hue, saturation and lightness, vary according to different shapes in terms of the fundamental aesthetics dimensions.
- [H3] Shape induced Kansei can be captured and inferred by Kansei words along the fundamental aesthetics dimensions.

In order to reduce the experiment complexity at a feasible and reasonable level, the following assumptions were made:

- [A1] Aesthetic sense within a culture group and age group is homogeneous
- [A2] The fundamental aesthetic dimensions are orthogonal – i.e., –dependencies among them can be ignored.

Finally, with consideration of a limited time and limited resource available, only one culture and age group of subjects were tested.

## **6.2 Design of the experiment**

### **6.2.1 Stimuli Collection**

Stimuli are car images to be appraised and evaluated in this experiment. To meet the experimental assumption [A2], the selected car body shapes must be as "typical" as possible in terms of the fundamental aesthetic. Generally, the typicality of a car body shape is determined by its underlying design intention which is not explicit for ordinary people, and only well-trained eyes can grab them. Therefore, experienced designers from a major European car manufacturer were involved to select "typical" stimuli for this experiment. As a result, totally 9 car models were selected and coded by Car#1, Car#2, ..., Car#9, they are shown in Figure 6-1. The criteria of the selection tends to ensure that they were as different as possible in terms of shape features and as similar as possible in terms of body type (i.e.: 2 or 4 door sedan), model year and price. It was noted that the information about the typicality of a particular car body shape with respect to fundamental aesthetic dimensions was acquired during the experiment.

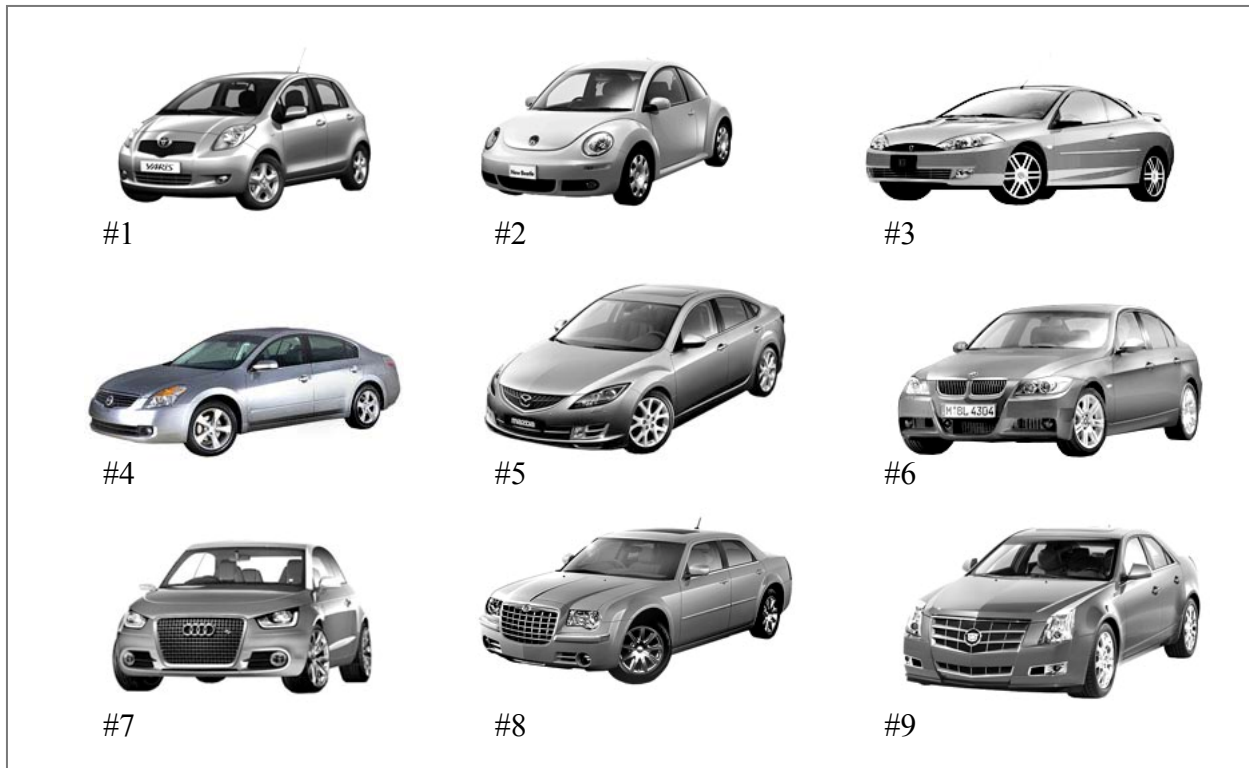


Figure 6-1 The 9 experimental stimuli

### 6.2.2 Experiment Unit

In the experiment, the definition of an abstract car body is a car body without shape. An abstract car will be instantiated while the shape of the car body is being designed. The design process refers to the use of the so-called shape treatment (to be discussed later) on the abstract car to render a shaped car body. The shaped car is then assigned color which is further represented by the HSL model. After the car body is shaped and colored, Kensie words are selected which are specifically tied to that particular car body. The information acquired from the human subject, including (1) shape treatments, (2) colors, and (3) Kensie words, about a particular car body instance is hereafter called experiment unit. The next section will give a more detailed description of the experiment unit – in particular its variables.



### 6.2.3 Variables

The shape treatment is the independent variable of an abstract car body. There are five such variables corresponding to five shape treatment methods which are further derived from the five fundamental aesthetic dimensions. In the experiment, each shape treatment variable was measured by two bi-polar binary levels (see Table 6-1). The reason of using binary levels instead of semantic differential scales was because human aesthetic sense varies in a large range and it is difficult to give an adequate reference scale.

Table 6-1 Independent Variables

Treatment	Level
Functional Cue	F+, F-
Trend	T+, T-
Personality	P+, P-
Gender Metaphor	G+, G-
Cuteness	C+, C-

The color is a dependent variable in the experiment unit in the sense that the shape was determined first and followed by the determination of the color. In particular, for each level of shape treatments, the subject's color preference was captured and measured by hue, saturation and lightness values which are further defined in Table 6-2. Meanwhile, Kansei words which were selected by the same subject to express his/her feeling about the car body after the shape treatment and color assignment, and the Kansei words were treated as another dependent variable of the experiment unit.

Table 6-2 Dependent variables

Name	Range
Hue	0 -360 degree
Saturation	0 - 100%
Lightness	0 - 100%

#### 6.2.4 Experiment Layout

As it was hypothesized (H1, H2, and H3), this experiment only focused on the effects that are produced along the fundamental aesthetic dimensions. Any effects that are introduced by other factors were regarded as unexpected errors, and these nuisance factors are:

- (a) subject profile (culture, age, gender, etc.),
- (b) computer monitor for the experiment, and
- (c) environment where the experiment is conducted.

In order to isolate and reduce the unexpected errors, the blocking technique was used where each subject was regarded as an experimental block, and as such, the concerned effects were grouped within blocks, whereas the unexpected errors were left between blocks. The RCBD (randomize complete block design) layout was employed for the experiment layout...

Normally, it is suggested by the RCBD layout that the minimum sample size should be able to keep the experimental data in a vertically rectangular matrix or at least a square matrix, meaning that the number of blocks should be more than or equal to the number of treatments. In this experiment, the number of treatments was 10, the sample size should not be less than 10. Therefore, 20 was selected as the proper sample size in this experiment.

In addition, there are two types of RCBD layouts: (a) balanced RCBD layout and (2) unbalanced RCBD layout. Before answering which one is better for this experiment, the factor called "mental work load" has to be considered. According to Lin [2003], a subject's mental work load may have impact to his/her performance during the experiment. In this study, a subject was invited to fulfill up to 9 experimental units. It was supposed that the first experimental unit would be processed under the lowest mental work load, and each additional experimental unit would be processed under an increased mental work load. Thus, more experimental errors would be introduced, while more experiment units were processed. As mental work load varies among different subjects, in this experiment, a subject was encouraged but not forced to fulfill all of the 9 experimental units. Upon the actual results, if an adequate number ( $\geq 20$ ) of fully finished blocks were collected, the experimental observation was processed according to the so-called balanced RCBD layout; otherwise, the unbalanced RCBD data analysis (such as lattice design) would be applied.

### **6.2.5 Subjects**

In order to satisfy the experimental assumption [A1], subjects were selected from the same culture and age group. 20 students from Mechanical Engineering Department of University of Saskatchewan were invited to join the so called "controlled" experiment in which their dedications to the experiment were rewarded. More volunteers were also invited to join the "uncontrolled" experiment in order to collect enough data for evaluating the model that was learned from the "controlled" experimental data.

### 6.2.6 Experimental System

Since there is no existing system that can be used or customized to fulfill this experiment, the entire experiment system had to be developed from scratch. The experiment system was in fact a computer system. As shown in Figure 6-2, the system followed the standard 3-tier and MVC conformable design pattern. Meanwhile, the Color-Shape Synthesizer (developed in chapter 5) was used as the core technology for capturing a user's color preference on a given car body shape. The B/S (Browser/Server) architecture allowed the experiment being accessible from anywhere at any time. Figure 6-3 shows the experiment in operation.

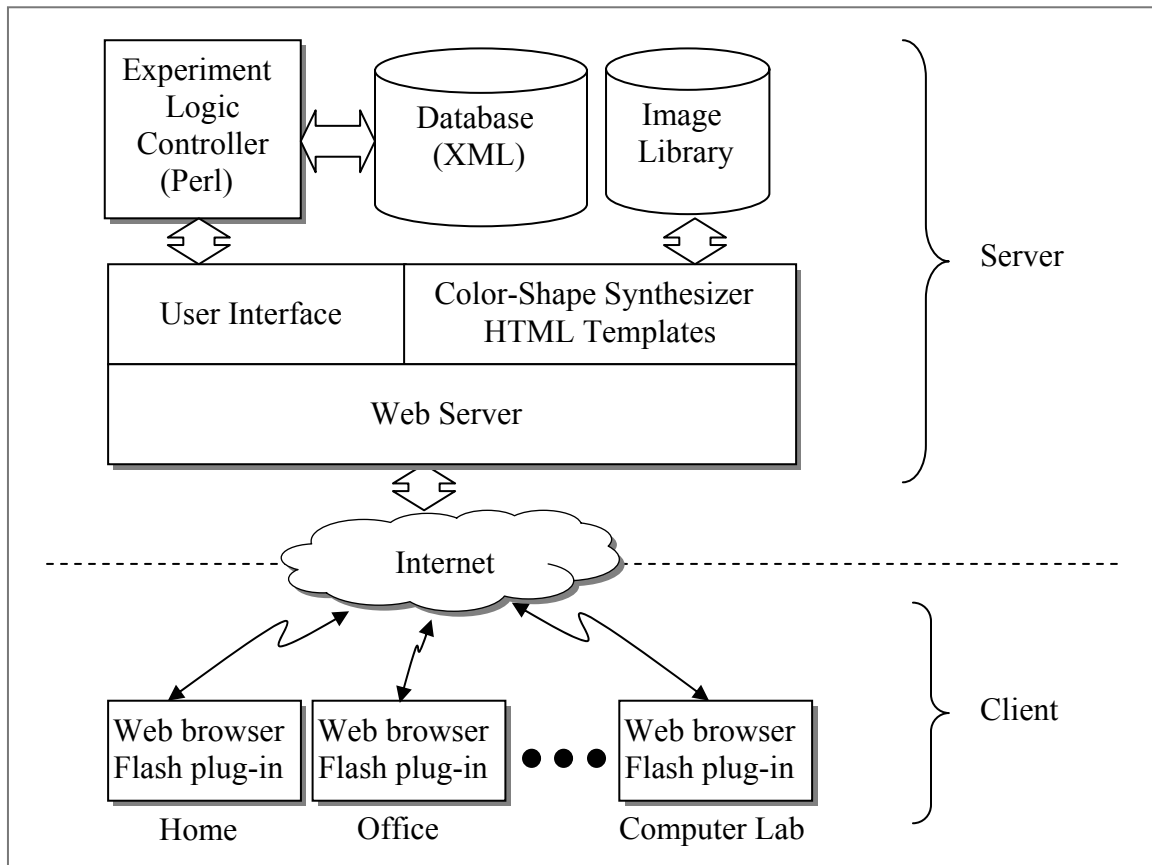


Figure 6-2 The experimental system architecture

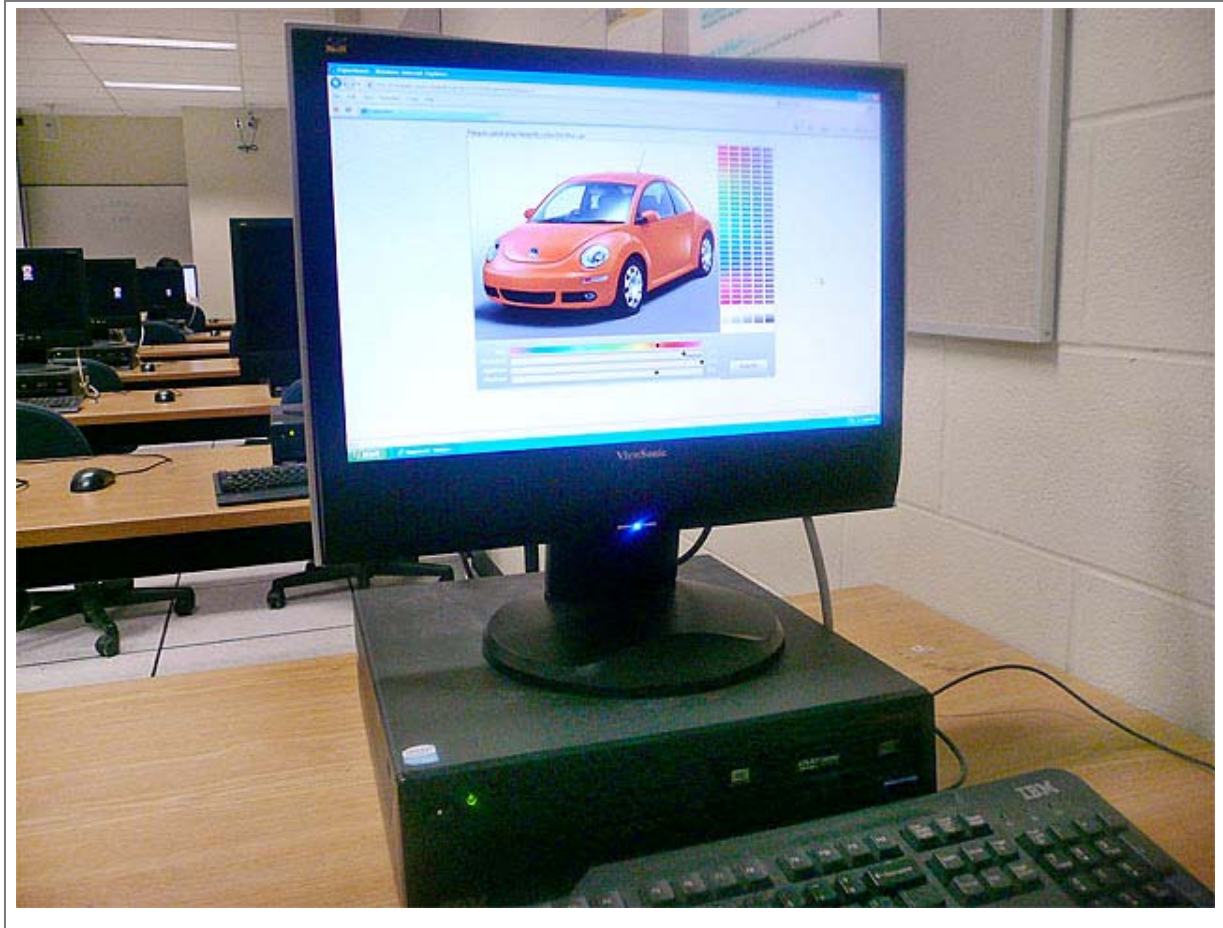


Figure 6-3 The experiment in operation

## 6.2.7 Experiment procedures

The experiment was conducted by two independent parts: **Part (I)** and **Part (II)**.

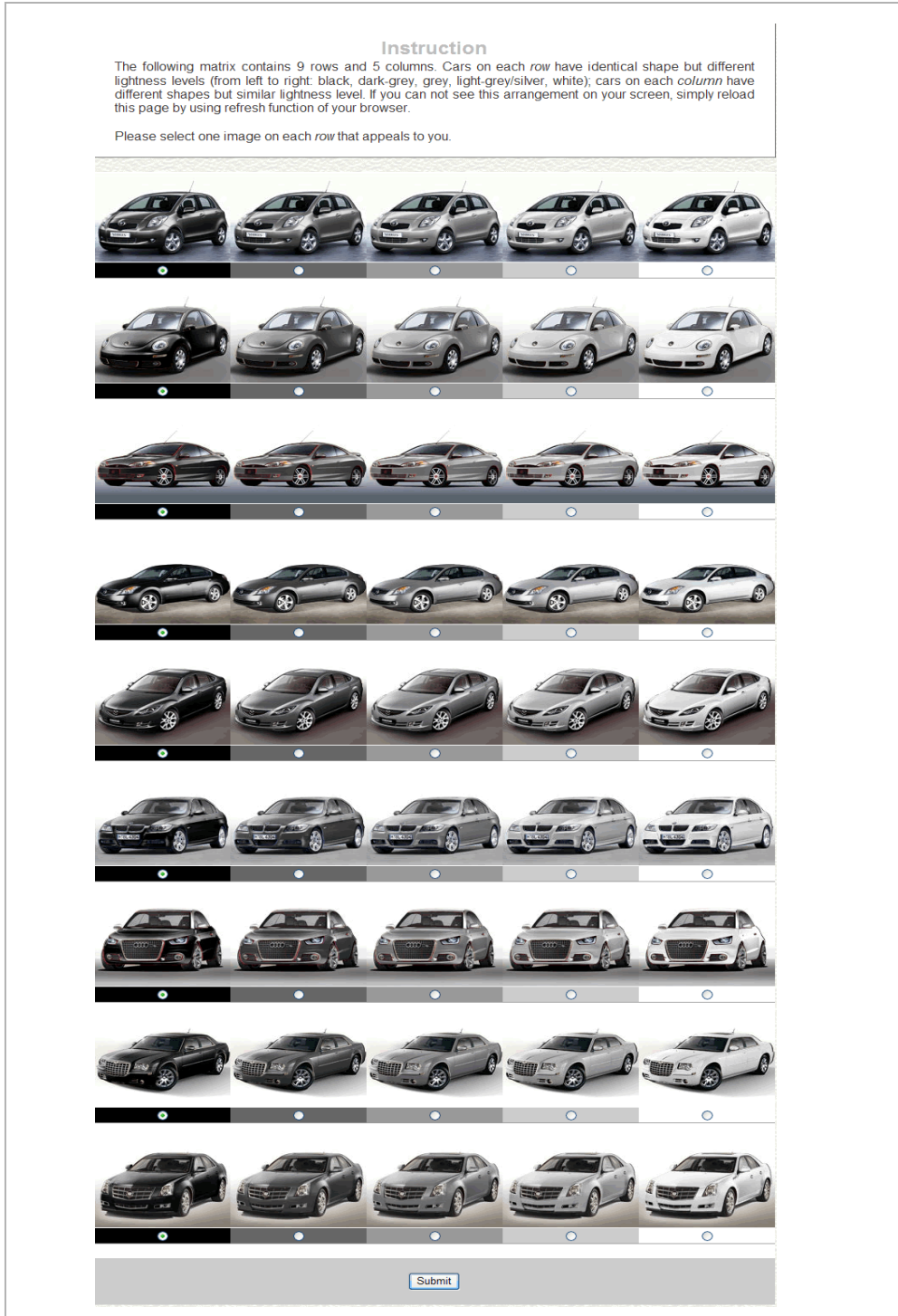


Figure 6-4 Screen shot of experiment part (I) step 2

In **Part (I)**, the 9 cars were always appraised altogether in order to establish an interrelated reference among the cars. In each of the experimental steps in Part (I), the subject was asked to response to one factor per step. For example, the matrix shown in step I-2 contains 9 rows and 5 columns (Figure 6-4). Cars on each row had identical shape but different lightness levels (from left to right: black, dark-grey, grey, light-grey/silver, white); cars on each column had different shapes but similar lightness level. The subject was asked to select one image (representing a lightness level) on each row that appealed to him/her. The steps were repeated for other factors such as hue and saturation.

In **Part (II)**, the 9 cars were appraised individually (separately). The subject could randomly select one of the nine cars to start an appraisal round. During the appraisal round, the subject were asked to create/select/pick-up and "paint" desirable color on the car body by using the Color-Shape Synthesizer, and made his/her best guess about the type of the car's owner (representing the aesthetic dimension), and describe his/her feeling about the car by selecting applicable adjectives (from a sub-set of 55 Kansei words out of the Kansei vocabulary that was pre-compiled in Chapter 3). When finishing and exiting the appraisal round, the subject was navigated back to the beginning of the Part (II) where all 9 cars were displayed together for easy comparison. From there, the subject could start a new appraisal round by selecting a new car, or change his/her answer by selecting a finished car, or decide to quit the experiment. Figure 6-5 shows the major user interface in Part (II).

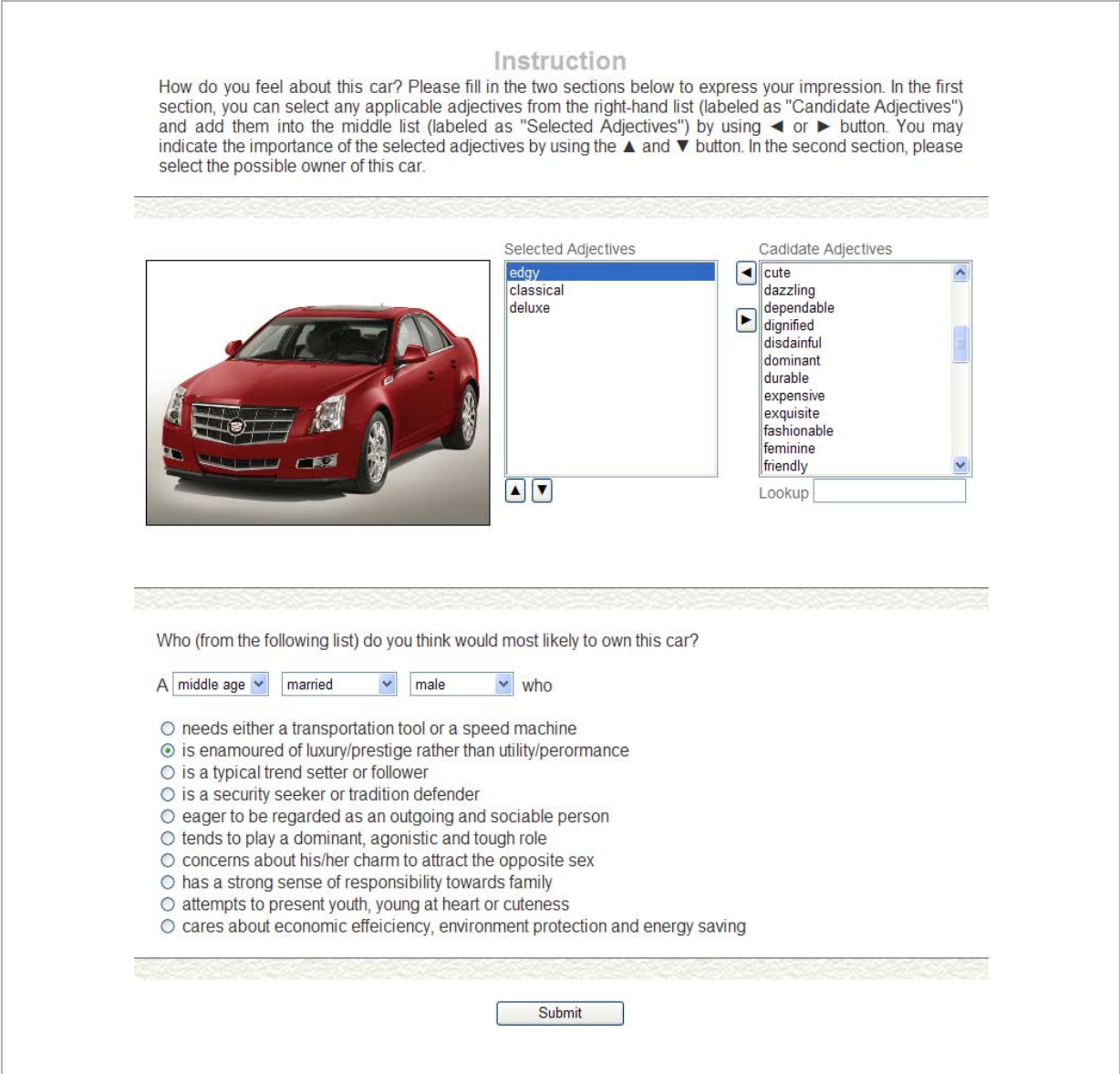


Figure 6-5 The major user interface of Part (II)

Instruction was displayed at the beginning of each major experimental step, explaining the purpose of the step and how to fulfill the step. To reduce the experimental error that might be introduced by different color spaces (as discussed in Chapter 5), before the experiment, a page containing sample color blocks was shown on subject's computer monitor, the subject was asked



to follow a simple step to calibrate his/her color monitor. The subject was also reminded by the following message:

*"People usually use their artistic eyes for appreciating car images on magazine covers or computer screens, but use their practical eyes for judging the real cars on the street or in the showroom. Since this experiment has to be operated via computer screen, please be aware that car colors on computer screen are easily exaggerated beyond the reality this means that the color you pick on the screen may not always be the color you will buy. So, please keep this in mind and try to consciously use your practical sense to avoid this bias."*

Later in the experiment, the interview with a few subjects indicated that the design of the Part (I) was regarded a bit confusing and unnatural, although it was statistically beneficial; whereas the design of Part (II) was better in expressing user's real feeling because of its natural, logical and joyful manner. Therefore, Part (I) was removed from the experiment; the entire experiment had only Part (II).

### **6.3 Data Analysis**

83 records were collected after the experimental system had been published online for 30 days. 38 records which had no Part (II) data were removed from the data pool for analysis, as only Part (II) data will be considered. Eventually, there were 45 records which were valid, among which 20 records were fully completed (all 9 cars were appraised). As such, the 45 experiment data was divided into two sets: (1) the 20 fully completed records were statistically examined based on the balanced RCBD layout, and this data set was called the *training data set*; (2) the rest of 25 (uncompleted) records were used for evaluating the statistical findings, and this set of data was

therefore called the *verification data set*. The data analysis was conducted by using SAS 9.00 for Windows.

### 6.3.1 ANOVA of Shape Data

The 9 car shapes were appraised in terms of the 10 treatment levels (see Table 6-1).  $\chi^2$  test was applied to the observation data at 95% confident level ( $\alpha = 0.05$ ), the result is shown in Table 6-3.

Table 6-3 Car body shape v.s. fundamental aesthetic dimension

	Car#1	Car#2	Car#3	Car#4	Car#5	Car#6	Car#7	Car#8	Car#9
F+	0.112p	0.546y	0.546y	0.546y	1.000y	<b>0.027p*</b>	1.000y	0.218y	0.335p
F-	0.211y	0.631y	1.000y	0.211y	0.289y	0.289y	1.000y	0.771y	0.771y
T+	1.000y	0.384y	1.000y	0.965y	1.000y	0.965y	<b>0.047y*</b>	1.000y	1.000y
T-	1.000y	0.651y	0.651y	0.651y	1.000y	1.000y	0.682y	<b>0.003y*</b>	1.000y
P+	1.000y	0.842y	1.000y	0.341y	1.000y	0.341y	0.631y	0.580y	0.580y
P-	0.191y	0.191y	0.341y	0.191y	1.000y	1.000y	<b>0.003p*</b>	0.341y	1.000y
G+	0.700y	1.000y	<b>0.002p*</b>	0.700y	1.000y	0.233y	0.740y	0.233y	0.687y
G-	0.747y	0.257y	0.747y	0.627y	0.747y	0.257y	1.000y	0.195y	<b>0.012p*</b>
C+	1.000y	<b>&lt;0.001p*</b>	0.880y	0.314y	1.000y	0.314y	0.339y	0.314y	0.880y
C-	0.240y	0.700y	0.687y	<b>0.002p*</b>	1.000y	0.233y	0.255y	1.000y	0.233y

\* significant at  $\alpha = 0.05$   
p: Pearson chi-square test  
y: Yates continuity correction chi-square test  
f: Fisher's exact test

From Table 6-3, 7 out of 9 shapes were found significant at one or more treatment level(s). The result indicated that most ( $7/9 = 78\%$ ) of the selected cars (stimuli) were “typical”, of which, 86% ( $6/7$ ) cars were “typical” at single treatment level, only one car (#7) was “typical” at 2 treatment levels. So, the goal of selecting “typical” stimuli for this experiment was considered well (although not perfectly) accomplished because it was usually not easy to find a real car that

was only “typical” at a single treatment level. As such, the first experimental hypothesis [H1] (defined in section 6-1) was accepted. The success of stimuli selection may bring a significant advantage to the subsequent experiment steps and data analysis. To be straightforward, the 7 shapes were directly denoted by their treatment levels in the subsequent data analysis steps, as shown in Table 6-4.

Table 6-4 Car shapes are directly denoted by their treatment levels

Car#	Treatment Level	Car#	Treatment Level
Cad#2	C+	Cad#7	T+P-
Cad#3	G+	Cad#8	T -
Cad#4	C-	Cad#9	G-
Cad#6	F+		

### 6.3.2 ANOVA of Color Data

Based on the 7 “typically” shaped car bodies, the subjects' color preferences were collected in HSL model. Three color attributes (lightness, saturation, and hue) were averaged, resulting in representative means and standard deviations of the attributes (Table 6-5).

Table 6-5 Color attribute mean v.s. shape treatment

Shape Treatment	N	Lightness			Saturation			Hue		
		Mean	STD	RMSE	Mean	STD	RMSE	Mean	STD	RMSE
C+	20	92.00	18.81	18.33	79.75	37.04	36.10	139.20	118.69	115.69
G+	20	83.75	23.28	22.69	48.25	47.30	46.11	68.40	108.67	105.92
C-	20	61.50	33.33	32.48	31.25	34.98	34.09	76.20	125.81	122.63
F+	20	62.25	42.69	41.61	44.50	45.68	44.52	79.80	111.10	108.28
T+P-	20	48.25	30.88	30.09	19.75	30.28	29.52	81.60	131.89	128.55
T-	20	43.50	38.01	37.05	39.00	37.82	36.86	106.20	112.66	109.80
G-	20	43.50	43.18	42.10	36.50	42.43	41.36	67.80	97.43	94.97

In order to be illustrative, the data in Table 6-5 was further plotted, as shown in Figure 6-6. It was noticed that (1) the means of all three color attributes varied according to different shapes, suggesting that shape treatments may have significant influence to color preferences; and (2)

standard deviations varied across different color attributes, implying that connections between shape and the three color attributes were in different strength. Attribute with lower standard deviation is more likely determined by its shape treatment (e.g.: lightness), and vice versa (e.g.: hue).

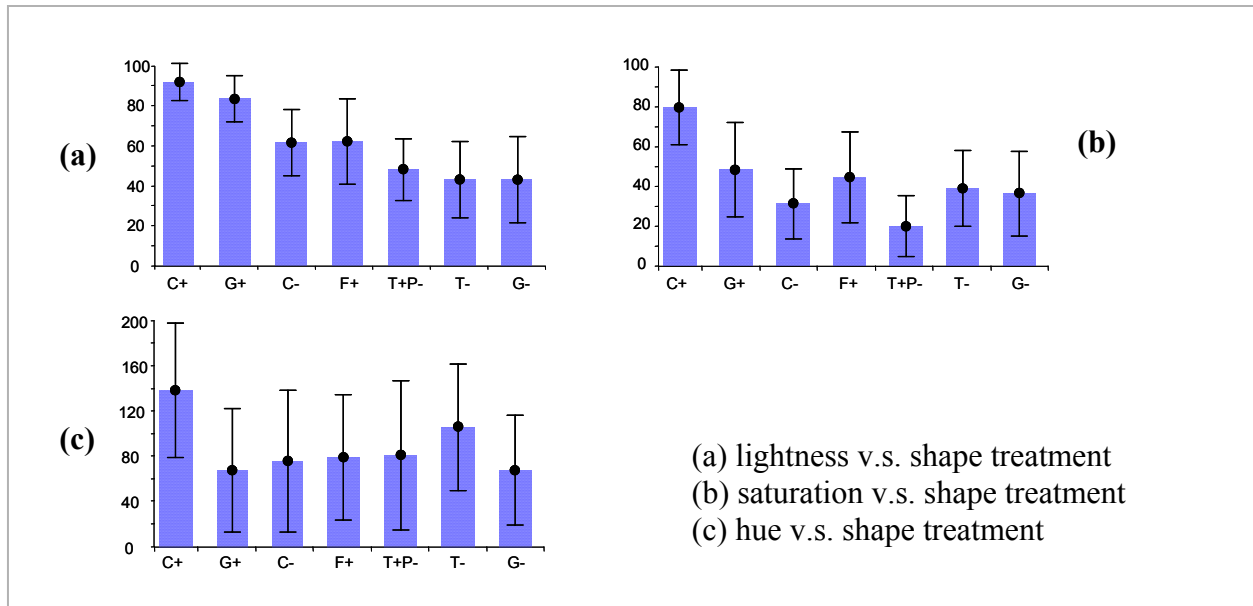


Figure 6-6 Color (HSL) attribute means

To be exact, the means were statistically compared by using student t-test (LSD), the results are shown in Table 6-6 (a), (b) and (c), respectively.

Table 6-6 (a) Comparison of lightness means across shape treatments

Pr > F	C+	G+	C-	F+	T+P-	T-
G+	0.4264					
C-	<b>0.0038*</b>	<b>0.0334*</b>				
F+	<b>0.0048*</b>	<b>0.0397*</b>	0.9423			
T+P-	<b>&lt;.0001*</b>	<b>0.0008*</b>	0.2024	0.1782		
T-	<b>&lt;.0001*</b>	<b>0.0002*</b>	0.0843	0.0723	0.6467	
G-	<b>&lt;.0001*</b>	<b>0.0002*</b>	0.0843	0.0723	0.6467	1.0000

\* significant at  $\alpha = 0.05$

Table 6-6 (b) Comparison of saturation means across shape treatments

	C+	G+	C-	F+	T+P-	T-
G+	<b>0.0038*</b>					
C-	<b>&lt;.0001*</b>	0.1138				
F+	<b>0.0013*</b>	0.7259	0.2168			
T+P-	<b>&lt;.0001*</b>	<b>0.0087*</b>	0.2834	<b>0.0221*</b>		
T-	<b>0.0002*</b>	0.3878	0.4691	0.6072	0.0738	
G-	<b>&lt;.0001*</b>	0.2731	0.6236	0.4549	0.1192	0.8152

\* significant at  $\alpha = 0.05$

Table 6-6 (c) Comparison of hue means across shape treatments

	C+	G+	C-	F+	T+P-	T-
G+	<b>0.0324*</b>					
C-	0.0564	0.8118				
F+	0.0718	0.727	0.9125			
T+P-	0.0807	0.6871	0.8691	0.9562		
T-	0.3148	0.2499	0.3606	0.4209	0.4532	
G-	<b>0.0310*</b>	0.9854	0.7976	0.7142	0.6737	0.2425

\* significant at  $\alpha = 0.05$

The t-test results indicated that (1) the C+ and G+ shape treatments had significant contribution to the lightness attribute of color; (2) the C+ shape treatment was significantly correlated to the saturation attribute of color; (3) the combined T+P- shape treatment was correlated to saturation at a relatively high confident level; (4) almost no significant relationship was found between the hue attribute value and shape treatments.

### 6.3.3 Relating Shape and Color

Before making any assertion on the above ANOVA results, the verification data set was used to verify the above findings. First, means between the training data set and the verification data set were visually compared in Figure 6-6.

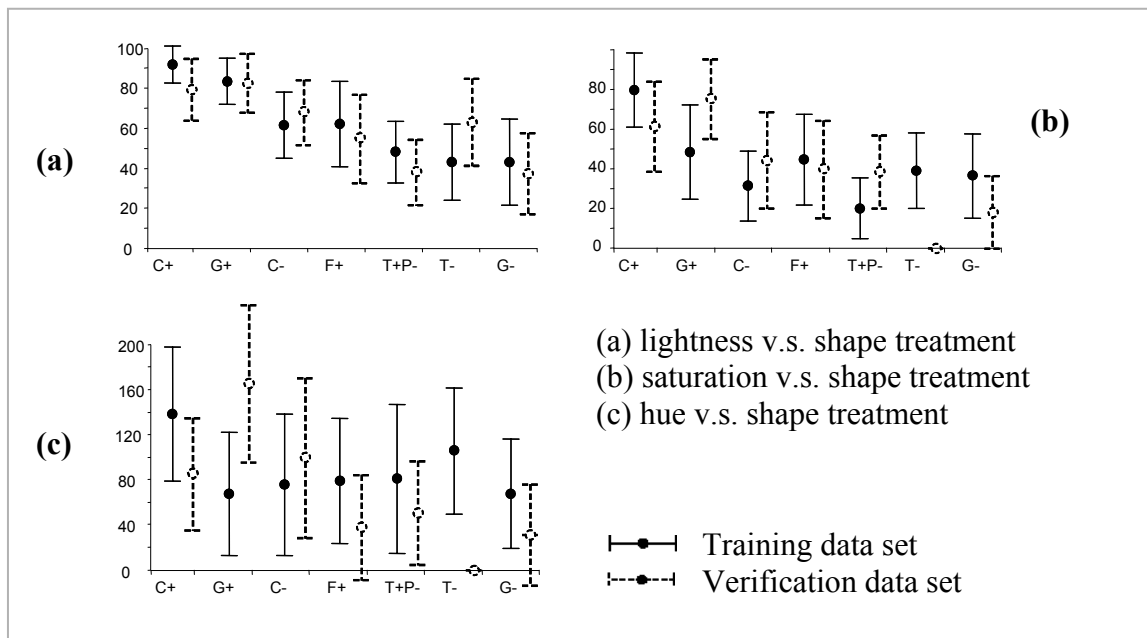


Figure 6-7 Visual comparison of color attribute (HSL) means

Figure 6-7 provided a quick and qualitative indication of similarity between the training data set and the verification data set, especially in terms of the lightness. To be quantitative, multiple regressions were applied to the training data. The regressions were conducted with both a forward and a backward stepwise selection so that only the significantly contributive shape treatment(s) will be taken into the result model, as shown in Table 6-7 (a), (b) and (c), respectively.

Table 6-7 (a) Lightness regression model

Variable	Estimate	Error	Type II SS	F Value	Pr > F
Intercept	45.08	4.36	121950	106.86	<.0001
C+	46.92	8.72	33018	28.93	<.0001
G+	38.67	8.72	22427	19.65	<.0001
C-	16.42	8.72	4042	3.54	0.0620
F+	17.17	8.72	4420	3.87	0.0511

Table 6-7 (b) Saturation regression model

Variable	Estimate	Error	Type II SS	F Value	Pr > F
Intercept	40.00	5.10	96000	61.43	<.0001
C+	39.75	10.21	23701	15.17	0.0002
G+	8.25	10.21	1020	0.65	0.420
C-	-8.75	10.21	1148	0.73	0.3928
F+	-20.25	10.21	6150	3.94	0.0493

Table 6-7 (c) Hue regression model

Variable	Estimate	Error	Type II SS	F Value	Pr > F
Intercept	74.76	11.41	558906	42.95	<.0001
C+	64.44	27.94	69209	5.32	0.0226
T-	31.44	27.94	16475	1.27	0.2625

The regression models were then used to predict color attributes in the verification data set. The one-way t-test result (Table 6-8) showed that the similarities between the training data set and the verification data set should not be rejected (except the hue attribute).

Table 6-8 Evaluation of Shape-Color model

Shape	Lightness		Saturation		Hue	
	Mean	P-value	Mean	P-value	Mean	P-value
C+	92.00	0.112	79.75	0.121	139.2	0.046
G+	83.75	0.890	48.25	0.125		
C-	61.50	0.616	31.25	0.468		
F+	62.25	0.674	19.75	0.140		
T-					106.2	0.309

Furthermore, it was noticed that nearly half (44%) of the total experimental units get achromatous response. The result of logistic regression (Table 6-9) indicated that except the C+ shape treatment (with negative coefficient), achromatic color was suitable for any shape treatment.

Table 6-9 Logistic regression model (achromatous color vs. shape)

Variable	Estimate	Error	Chi-Square	Pr > ChiSq	Pr > F
Intercept	-0.16	0.20	0.64	0.4242	<.0001
C+	-1.57	0.66	5.73	0.0167	0.0226
T+P-	0.78	0.51	2.34	0.1264	0.2625

By combining the result of ANOVA (section 6.3.2) and the result of regression (section 6.3.3), it could be concluded that: (1) the C+ and G+ shape treatments were positively correlated to the lightness attribute of color; (2) the C+ shape treatment was positively correlated to the saturation attribute of color; (3) almost no relationship was found between the hue attribute value and shape treatments. Therefore, the second experimental hypothesis [H2] (defined in section 6-1) was partially tested and partially accepted.

#### 6.3.4 Mapping Kansei Words and Aesthetic Dimensions

To each shape treatment, there were a number of Kansei words attached. These Kansei words were sorted in terms of the importance of the words to the shape treatment; for example, the first Kansei word was the most important word whereas the last Kansei word was the least important one. So, each word could be ranked by the reciprocal value of its order number. In this experiment, there were totally 10 shape treatments and 55 candidate Kansei words. Therefore, each treatment was featured by a Kansei words vector of 55 dimensions which was typically a sparse vector because only few words were selected for each shape treatment by the subject, and the ranks for the rest of unselected words were just zero.

There are multiple approaches to achieve a mapping between Kansei words and shape treatments, as listed below:

- (1) Vector Similarity Measure (VSM),



- (2) Logistic Regression,
- (3) Artificial Neural Network (ANN), and
- (4) Support Vector Machine (SVM)

VSM was selected in this experiment because it is a quick, simple and efficient way in dealing with high-dimensional yet sparse vector problems. VSM is often used as a basic technique in image recognition. Suppose in a coordinate space of rank vs. ID, a vector of Kansei words can be represented by discrete points. Thus, the high-dimensional Kansei words vector problem can be converted into 2-dimensional picture recognition issue. In VSM, the similarity  $S$  between two pictures given by vectors  $A$  and  $B$  can be mathematically calculated by:  $S = A^T B / (|A||B|)$  (where  $A$  and  $B$  are column matrices).

By processing the training data set, the mean (average) Kansei words vectors of the ten shape treatments were learned. The vectors were plotted and observed in different patterns, as shown in Figure 6-8. The ten pre-learned patterns would be tested to see if they can be used as reliable templates for recognizing new vectors.

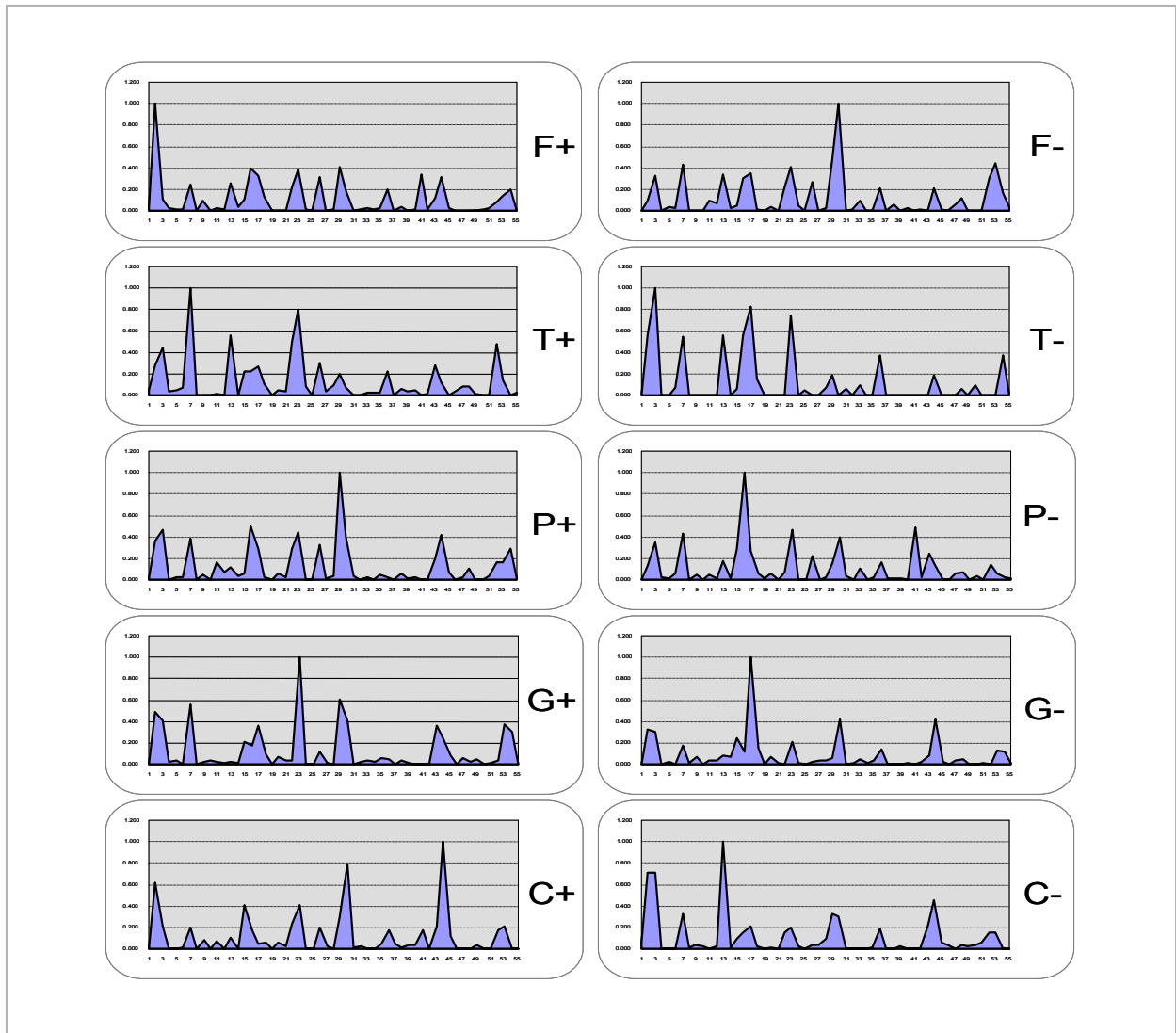


Figure 6-8 Graphs of the ten pre-learned mean Kansei words vectors corresponding to the ten shape treatments

In order to predict the most possible shape treatment corresponding to a given a new Kansei words vector, each of the ten pre-learned vectors would be compared with the new vector, the one which yields the highest similarity value would selected, and its corresponding shape treatment would be taken as the prediction result.

In this study, an ad-hoc VSM utility was coded by using C programming language. 80 vectors found in the verification data set were used for verifying the reliability of the learned patterns.

However, only 16 (out of 80) predictions matched the actual cases, the rest of 64 predictions failed. So, the third experiment hypothesis [H3] was rejected. Hence, it could be inferred that:

- (1) There are no simple mapping functions between Kansei words and the underlying aesthetic dimensions, since the relationships between them are of many-to-many or even with multiple layers.
- (2) The unreliable result for [H3] is also aligned with the phenomenon discussed in section 1.3.4 that different studies yield different fundamental aesthetic dimensions based on the empirical learning approach (see Table 2-2).

## CHAPTER 7 CONCLUSION

### **7.1 Overview of the Thesis**

This study was motivated by industrial design projects and committed to investigating how a consumer's color preference to a car is influenced by the shape of the car body without consideration of the culture, age and gender of the consumer. The goal was to understand and derive new knowledge regarding the relationship between color attributes and shape features with the intention to provide practical guidelines to design of car body shape and color in terms of aesthetics.

Product design is a seamless integration of function, ergonomics and aesthetics aspects of design. This study focused on the aesthetics aspect of product design and aimed to quantitatively measure the aesthetic features of a car body shape and color, in particular answering the essential measurement questions about “what to measure”, “how to measure”. Unlike the measurements in the other two (function and ergonomics) aspects of product design, in aesthetic measurement, the question “what” and “how” are seldom answered. This goal with its four objectives has been achieved. This thesis described the achievement as follows.

**First** in Chapter 2 (section 2.2.1), the state-of-the-art framework for dealing aesthetic issues in engineering context was discussed. In Chapter 3 a more comprehensive approach to compiling Kansei words was presented.

**Second** in Chapter 4, this thesis presented a new theory which assumes that human's aesthetic sense serves as an agent that seeks for environmental patterns that potentially afford to benefit underlying needs of the agent, and this seeking process is evolutionary fitting. A (modern-) Darwinism approach, to the so-called evolutionary psychology and aesthetics, was adopted in this thesis study, and it was further a basis for establishing a fundamental aesthetic inferring framework, namely aesthetic chain and aesthetic network. The application of this framework concluded five fundamental aesthetic dimensions of human aesthetic sense in terms of the appraising of artifacts. In addition, the thesis described a pattern of a consumer's responses to car body shape. This was further conducted within the Kansei (feeling) Engineering framework. In this connection, a TF-IDF (term frequency – inverse document frequency) structured Kansei vocabulary was compiled by using the web-mining technology.

**Third** in Chapter 5, the thesis described how to efficiently and accurately capture a consumer's color preferences on a given shape. Since a color can not be faithfully assessed without a hosting shape, the research will be largely limited by time and cost (in making physical models), or by inexact assumption (e.g.: assuming that consumer can always tell what color he/she likes without seeing the color on the shape) and by feasibility (of preparing sample car images in infinite colors). In the thesis, these issues were addressed with the following ideas. Idea (1): A notion of non-color shape is defined by introducing the non-linear normalization process which is a sophisticated upgrade on top of the simple de-saturation operation. Idea (2): a multi-layer system architecture is proposed to allow virtually “paint” arbitrary color selected from ICE color space on the non-color shape. Idea (3): an extensive review of classic color theories conclude that the HSL color model is the proper quantitative model to accommodate consumer's color preference

on a given car body shape. Idea (4): a software instrument, called Color-Shape Synthesizer, is developed based on the aforementioned principles, ensuring a full meet of the research requirements which may not be solely satisfied by the standard software tools in terms of consumer orientation, and may not be solely satisfied by commercial or entertainment utility as well in terms of research or engineering quality.

**Fourth** in Chapter 6, this thesis described an elaborated online experiment. It was statistically observed that car body shapes can be significantly (at 95% confident level) characterized in terms of the 5 evolutionary inferred fundamental aesthetic dimensions, indicating that the research hypothesis derived from the evolutionary framework should be accepted. It was also observed that among the three color components (Hue, Saturation and Lightness), lightness is found positively correlated to the “cuteness” and / or the “gender metaphor” shape features; and saturation is found positively correlated to the “cuteness” shape feature. As such, models were learned by additional regression procedures. In the subsequent verification tests, the models were not rejected, implying that they can be assimilated into the knowledge base of a prediction tool in car body color design application. On the other hand, hue was observed not sensitive to any of the shape features; leading to an assumption that hue relies more on subjective matter but less on shape features. It is also noticed that almost half (44%) of all experiment units received achromatous response. Further logistic regression revealed that achromatic color was acceptable on most of shape features except cuteness, and this provides advocating to the fact that silver, black and white are favored by many contemporary consumers. Finally, the experiment was conducted to study to the relationship between Kansei words and the 5 fundamental aesthetic dimensions by using the VSM (vector similarity measure) approach. However, the learned model

was rejected by the test, implying that there are no simple mapping functions between Kansei words and the underlying aesthetic dimensions.

The study presented in this thesis concludes:

- (1) Kansei Engineering (KE) is a suitable framework for sustaining aesthetic related study in engineering context only when domain specific implementation is defined. The Aesthetic Chain and Network approach developed in this study are the domain specific addition to KE which address measuring consumer's aesthetic responses to car body shape and color;
- (2) The Fundamental Aesthetic Dimensions inferred based on the Aesthetic Chain and Network are capable of characterizing car body shape in terms of engineering aesthetics;
- (3) The Color-Shape Synthesizer developed in this study is a highly practical tool in capturing consumer's color preferences on given car body shape and facilitating color communication between designers and consumers;
- (4) Persistent patterns are revealed between color components and specific shape features. However, mapping between semantic representations of aesthetic response to the fundamental aesthetics dimensions can likely be a multiple-network structure.

## **7.2 Contributions**

This study is dedicated to an open issue in the industrial design domain: understanding and modeling consumer's aesthetic responses to car body shape and color. Instead of repeating the (less reliable) learning approach, this study presents a thinking that a consumer's fundamental aesthetic sense can be reasoned based on the evolutionary psychology and aesthetics principles. A framework is established with implementation details such as: Aesthetic Chain and Network, TF-IDF structured Kansei (feeling) vocabulary, and the 5 fundamental aesthetic dimensions. A

case study (experiment) demonstrated that the framework is capable of characterizing car body shape in a reasonably low yet orthogonal dimensional space. Future aesthetic studies and design activities that emphasize on aesthetic design may take advantage of this framework.

The next contribution of this study is the instrument called “Color-Shape Synthesizer”. It is an online instrument devised based on the classical color theory and modern digital solutions along with the non-linear normalization process and multi-layer architecture. It eliminates most of the limitations in capturing a consumer’s color preference on a given car body shape, yielding a cost-effective, consumer oriented instrument with engineering quality.

Through the case study (experiment), this study has acquired sharable knowledge that bright colors suit those car bodies with demonstrated “cute” or “sexy” shape features; with increased shape characteristic in “cuteness”, higher chroma (saturation) is often desirable; achromatic colors are safe for most of the shape features; and hue (spectrum) has less connection to shape features but more association to individual’s flavor.

### **7.3 Limitations and Future Work**

It is true that the aesthetic preference is not solely determined by shape and color. Ignoring a consumer’s culture, age and gender sets the major limitation to this study. For example, hue often makes important sense when people talking about color, but it is missed in this study in terms of shape. However, it is assumed that hue has certain connections to culture, age and gender. As such, the first priority in the future work of this study is to take into account culture, age and gender. A series of additional experiments should be conducted in an upgraded



experimental layout call “split-plot” layout, in which multi-factor effects will be observed and analyzed.

Regarding the quantitative representation, in order to work around the difficulty of quantifying human’s mind, this study temporarily used binary levels to drive the numeric based liner statistics methods for quickly testing the research findings. If the results are positive, a better quantification approach will be conducted at a higher resolution. This is planned in the future work in which a more sophisticated data analysis method will be also employed. As such, the combination of subjective scaling and (fuzzy-) neural network could be a good candidate.

By far, the human emotion is not addressed in the evolutionary inferred framework. However, it is considered to be added into future work where emotion represents the balance states of the human fitness concerns, and facial expressions are the manifestation of the emotion.

In mapping Kansei words and the fundamental aesthetic dimensions, a simple VSM method is employed in this study, yielding no valuable pattern(s). A few causes are considered to be responsible for this unexpected result: (1) the dimension of the Kansei words vector is unreasonably high, because synonyms or similar words are treated as different independent words. In future work, language tools need to be involved as part of Kansei vocabulary for categorizing Kansei words into reduced dimensions; (2) the simple VSM approach only offers a simplified work round rather than a dedicated solution in resolving complex mapping issue which may contains many-to-many and multi-layer relationships. In future work, use of more sophisticated approaches, such as (fuzzy) artificial neural network (ANN) or vector support

machine (VSM) will be considered; (3) although the selection of sample cars (stimuli) is considered a success, it is still beyond perfect since not all sample cars are “typical” in all dimensions. Beside, the survey of collecting subjective responses in terms of shape features is also less matured and needs to be improved in future work; (4) semantic differential (SD) measurement will be considered as an upgraded replacement of the current bi-polar measurement in this study in order to achieve better accuracy.

Finally, it is noticed that many subjects who take part of the experiment in this study have less or no driving experiences. In the future work, the experiment should be given to the subjects who are already car owners and / or with long term driving experience.

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## **APPENDIX**

### **Appendix A Additional Background Information**

This study is originally motivated by an industrial design project in which the author participated as a design team member. In this project, an oversea branch of a major European car manufacturer proposed a face-lift surgery to a legacy boxy-shaped sedan. The output of the styling phase was a full-scale clay model demonstrating that the new design has achieved the intended streamlined shape while still able to reuse the original skeleton and door frames for cost-efficiency. However, coating color was intentionally excluded in the project because no negative feedback against the existing color schemes was received from the marketing department. As the project moved on to the prototyping phase, the original colors were inherited and applied to the new shape. However, not all of the painted prototypes passed the final approval because nearly half of the old colors elicited disharmonious emotions on the new shape. The problem was eventually resolved in a supplemental color redesign project which introduced new color swatches, but question was hence raised regarding how to identify and take advantage of the intrinsic relationship between car body shape and color for achieving the best product aesthetic design.

The existence of the color-shape relationship can easily be perceived by looking at cars on the road, in the parking lot, and at dealership. The general phenomenon is also supported by the data in Dupont's 2007 automotive color popularity chart, as illustrated by Figure A-1

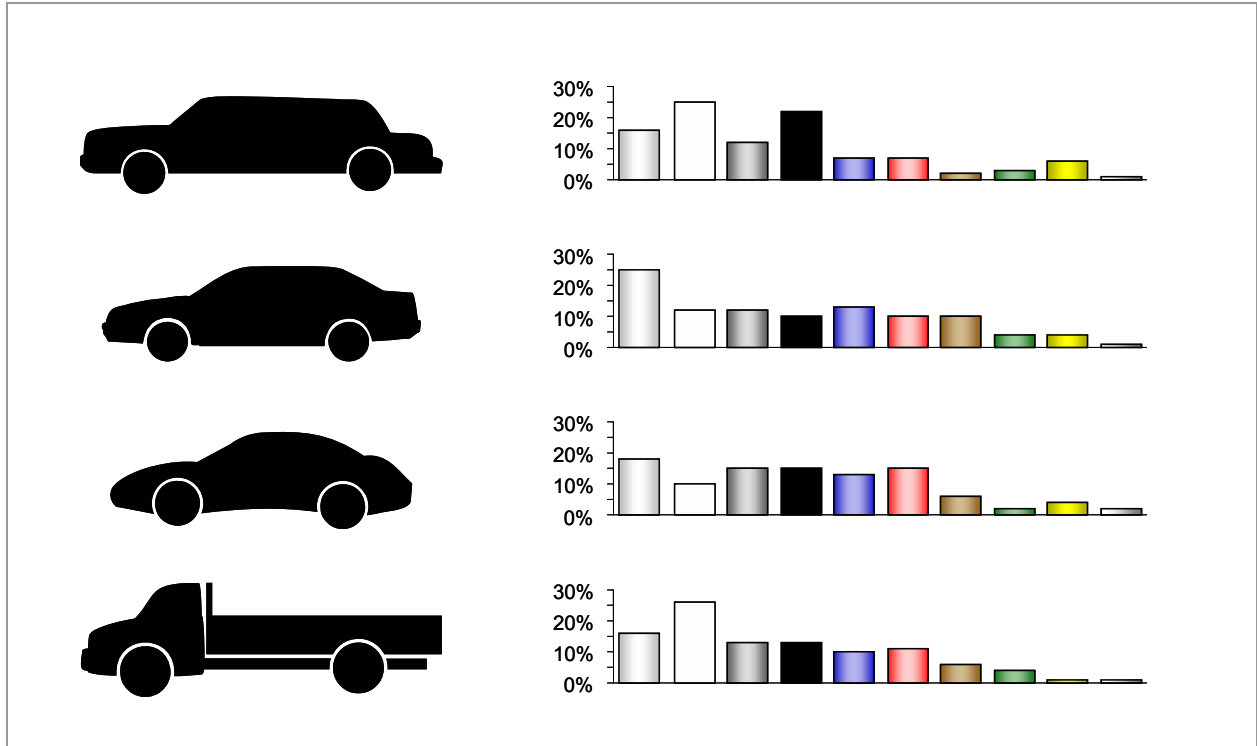


Figure A-1 Consumers' color preferences vary upon different automotive body shapes -- based on Dupont's 2007 automotive color popularity chart

### Appendix B Clip Board Sniffer

Please see the attached disk, or download from:  
<http://homepage.usask.ca/~chw346/Thesis/Appendix.zip>

### Appendix C Color-Shape Synthesizer

Please see the attached disk, or download from:  
<http://homepage.usask.ca/~chw346/Thesis/Appendix.zip>

### Appendix D Experimental Data

Please see the attached disk, or download from:  
<http://homepage.usask.ca/~chw346/Thesis/Appendix.zip>

## Appendix E Kansei Vocabulary

abrupt	bumbling	debonair	featureless
acute	calm	decadent	feisty
adamant	cavalier	defective	feminine
adventurous	chaotic	defiant	feral
affable	charming	delicate	ferocious
aged	chic	deluxe	fetching
aggressive	childish	dependable	fierce
agile	chiseled	depressing	firm
alluring	choppy	dignified	flamboyant
aloof	chromatic	dimmed	flashing
ambitious	chunky	discordant	flashy
angry	circular	disdainful	flattering
angular	classic	distinctive	flawless
antique	classical	dizzy	fledged
arced	classy	docile	fleet
archaic	cleaned	dominant	flexible
aristocratic	coarse	doughty	flimsy
armored	colorful	dowdy	fond
arrogant	commodious	dull	foolhardy
artistic	compact	durable	formidable
astute	complicated	eccentric	framed
asymmetrical	composed	economical	friendly
atmospheric	concave	edged	frivolous
authentic	concise	edgy	funny
awed	conservative	elaborate	futuristic
balanced	contemporary	elegant	galloping
banal	convex	elevated	generous
bizarre	cool	elusive	gentle
blatant	corrugated	energetic	gigantic
blazing	crafty	engaging	glamorous
bloated	crank	exaggerated	glazed
blunt	cranky	exalted	glorious
boastful	crass	exotic	glossy
bony	creaky	expansive	glowing
bouncing	crude	expeditious	gorgeous
bouncy	cubic	expensive	graceful
bowed	cumbersome	exquisite	gracious
brash	curled	exuberant	grotesque
brave	curved	fabulous	happy
brawny	curvy	faddish	harmonic
breezy	cute	faint	heavy
bright	dapper	fascinated	hefty
brilliant	dashing	fashionable	hemispherical
brisk	dazzled	fashioned	hilarious
brittle	dazzling	faulty	hollow

hulking	obtrusive	rounded	stabilizing
humble	orderly	roundish	stark
iconic	organized	rugged	stately
incised	organized	sad	steady
incongruous	ostentatious	safe	stiff
inconsistent	overlarge	scrub	stimulating
inflated	palatial	scruffy	stodgy
inimitable	pale	secure	streamlined
insubstantial	passionate	sedate	striped
intense	peaky	seductive	strung
intricate	peculiar	sensuous	stubby
intriguing	pinched	serene	sturdy
inviting	placid	serpentine	stylish
jarring	planar	serviceable	substantial
knowledgeable	playful	sexy	subtle
lackadaisical	plebeian	shabby	sunken
lackluster	pneumatic	shallow	superb
lethargic	pointed	shaped	superficial
liberal	poised	shapely	surefooted
lightweight	polished	sharp	swank
lively	polite	sharpened	symmetrical
lopsided	ponderous	shining	tacky
lustrous	potent	showy	tallish
lyrical	powerful	skittish	tame
majestic	precarious	slack	tamed
male	presto	slender	tapering
manly	prevailing	slick	tender
mannered	primitive	slippery	tense
masculine	pristine	slithery	tenuous
massive	proportional	sloppy	textured
metallic	proportionate	sluggish	tidy
mighty	pugnacious	smallish	tight
moderate	quaint	smart	tractable
modern	rabid	smooth	traditional
modest	radical	smoothed	trendy
monstrous	ragged	snazzy	tuned
motley	rapid	sober	ultramodern
muscular	reassuring	softish	unadorned
mysterious	rebel	spectacular	unaffected
mystic	recurved	speeding	unappealing
neat	refined	spherical	unbalanced
neutral	resilient	spirited	uncharacteristic
noble	rimmed	sporty	uncommon
oblong	robust	sprightly	unconventional
obscure	romantic	square	undignified
obsolete	roomy	squarish	uneven

unfriendly  
unhurried  
uninspired  
unobtrusive  
unorthodox  
unostentatious

unpopular  
unpretentious  
unreliable  
unsightly  
unwieldy  
unyielding

upscale  
valiant  
velvet  
venerable  
vigorous  
vivid

wavy  
weighty  
wise  
wry  
yielding

