PAPER • OPEN ACCESS

The Summary of Product Gene Network Theory

View the article online for updates and enhancements.

The Summary of Product Gene Network Theory

Lun Sun[1] *

[1] School of Media & Art Design, Wenzhou Business College, Wenzhou, Zhejiang, 325100, China

Abstract. Product gene network is a new research field of product morphology. This paper reviews the development and theoretical basis of product gene network and summarizes the method of the construction and application of product gene network. Borrowing some concepts of gene regulation network, product gene network takes product morphological gene as the node of network and the correlation of each gene as the edge of node to construct the complex network model of product morphological. On the basis of the product morphogenetic network, different node types in the product morphogenetic network are identified, and the node groups are obtained, which are ultimately transformed into design strategies. According to their own needs, designers can selectively combine the node types / node groups and other information to design the product form.

1. Introduction

These In recent years, the application of the concept of product genes in products has become a hot topic of morphological research. Many scholars have expanded the research field of product genes in product design from different perspectives, from the operation mechanism of DNA in product design to the mapping relationship between product genes and human perception images. The concept of gene network is formed by the microscopic study of genes contained in products. The purpose of product gene network is to form gene network by decomposing products, and to analyze and obtain gene nodes and node groups that need priority processing, so as to guide the actual product design.

2. Development of product gene network theory

Product gene network theory is derived from complex network theory. At the end of the 20th century, the research of complex networks began to be involved in many different disciplines such as engineering science, mathematical science and biomedical science. The complex network theory is to find out the commonality of different complex networks by analyzing the complex network system of these irrelevant disciplines, and to obtain the general rules for dealing with complex networks[1], then gradually form a number of classical models of complex networks. The complex network theory analyzes the characteristics of the whole network in these network models and studies the propagation path and variation of different information elements in the complex network. Therefore, the complex network has gradually become the main model to describe the principles of the organization of the objective world. By constructing the complex network, the internal topology is analyzed, and it has also become one of the main means to study the complex system in various fields.

The application of complex networks in the field of industrial design is still in its infancy, but the connection between complex networks and industrial design can be traced back to the 1980s. In 1981, Steward proposed the DSM model of design structure matrix to express the relationship between design elements[2], which first introduced the concept of complex network into the process of industrial design. With the establishment of complex network model and relevant statistical

knowledge, scale-free characteristics of industrial product network are also confirmed[3]. Then a lot of research appeared in the field of mechanical products, the main theoretical application is mainly in the study of the relationship between the parts of the mechanical product family. It is found that the characteristic of typical complex network exists in mechanical products.

In recent years Xiaojian Liu[4] and other scholars used the theory of complex network research in the form of products, and found that the shape elements of product formed between gene networks, at the same time, defined the important characteristics of product gene nodes and node group which is formed by the identification method, and based on analysis of product gene networks results assist designer in product design. Since the concept of product gene network was proposed, the research objects involved water bottles, thermos cups, office chairs, product color matching and so on.

3.The theoretical basis of product gene network

Gene network is a complex network formed by genes. In biomedicine, genes are the basis of regulating cell behavior and completing biological operation. The interaction and expression of genes is the basis for the operation of biological systems. The interrelationship of genes can form gene networks by analyzing data and embody the characteristics of complex networks. Topological graph of the network is composed of many nodes and the edges between related nodes. If the nodes have no ownership relationship, the edges of the nodes are not directional. For gene network, the nodes of the network are genes, and the edges of the network are the graphical representation of the information transmission relationship between related genes.

The topological characteristics of complex networks are important indicators to determine the types of networks. In the existing complex network research, the clustering coefficient of nodes, the length of characteristic path, node degree and degree distribution of the network are analyzed. According to these three index characteristics, modern complex network theory forms complex network models such as regular network, random network, small-world network and scale-free network, and summarizes the characteristics of different network models.

Product gene network (PGN) applies the concept of gene network to products and abstractly represents product differentiation into a complex network form. As an artifact, the gene of a product is the smallest feature unit with the characteristics of heredity and variation, which determines the transmission of information in the iterative process of product morphology and determines the recombination and optimization of -morphology [5]. High recognition product morphological genes can be separated to further transfer and inherit excellent morphological genes, and more competitive product morphological genes can be formed through effective variation. The most basic components of a complex network are nodes and edges. The product gene network takes the modeling elements and parts of a product as gene nodes, and forms a network based on the correlation and dependency between genes as edges, and studies the topological characteristics of the network. Therefore, to construct the product gene network, the primary task is to determine the node and node edge of the product gene network, and then identify the node group and the central node through technical analysis, so as to guide the subsequent product design process.

4.The construction process of product gene network

4.1 Identification of product genetic nodes

The node of product gene network is the morphological gene obtained by product decomposition. Form is the visual characteristics of the external appearance of existence, and it is the overall cognition formed by observing the physical characteristics of the external appearance of existence and through psychological processing. Different scholars have proposed different classification dimensions for product genes, including the idea of life cycle gene classification, the idea of product gene classification based on information storage, and the classification of identifiable explicit and recessive genes. Product genes based on visual recognition should be objective, stable and operable, so recessive genes such as emotion, management genes and technology genes are not considered.

In different studies, different scholars have different decomposition and gene classification of the subjects. For basic morphological products, 3d modeling was carried out by parameterization method, and continuous numerical values were used for gene coding and subsequent research. Xiaojian Liu [4] studied the water bottle and established a parametric 3d model of the water bottle to obtain several continuity genes. Zhen Sheng defines the design parameters of automobile shape and establishes the continuous gene network model of automobile shape based on sample data statistics.

However, in the study of gene morphology with complex morphology, there are morphological contents that cannot be continuously encoded, so morphological decomposition is required. Product morphology is formed by the orderly combination of morphological genes. Therefore, the decomposition of product morphology can reasonably and orderly decompose the existing products in a reverse manner, and the morphological genes of the products can be obtained after peeling layer by layer. Based on functional logic analysis, a morphological analysis method of "mode module unit" is proposed in the genetic network research of office chair. Morphological analysis decomposes the product from the logic level and divides the product into single modules with different functions. Each module can be further subdivided into molecular modules according to functions. The basic elements of the product are mainly composed of three parts, namely, modeling, color and material. The product form is the ordered combination formed by the coordination and connection of these three parts. Therefore, each module is decomposed from the categories of modeling, material, color and combination to finally obtain product morphological genes and carry out operable coding for product genes. The partial discontinuity genes obtained by decomposition and digital coding of office chair morphology are shown in table 1.

Table 1. Part of the classification variable gene induction table.

Form of seat headrest	0 not obvious 1 separation 2 in the middle 3 The whole top

In the product gene network, the edge between gene nodes is the topological expression of the correlation between genes, that is, the existence of the edge between nodes means that the connected gene nodes have certain connections. The calculation of correlation between genes requires the numerical value of morphological gene coding and the retrograde calculation. For continuous genes, Pearson correlation coefficient was adopted for calculation, and Spearson correlation coefficient was adopted for calculation of genotype genes and the cross calculation of two genes. After the calculation is completed, the edges of the gene network under the corresponding threshold can be obtained by taking different thresholds.

4.2 Construction of product gene network

The purpose of building product morphogenetic network is to study the correlation between morphogenes from a micro perspective. By grasping the relationship between different morphogenes, it can be transformed into a design strategy that can be applied in the design to help designers carry out actual product design. The grasp of the correlation between different morphological genes is mainly from the two perspectives of node priority and node group in product gene network.

In bioinformatics, edge has directivity in biological gene network, and high-level gene node with regulation has important position. For product genes, the priority of gene nodes can also be identified through coding and mathematical processing, and transformed into the form of priority processing in design. The priority of a node is reflected by its centrality and sensitivity. The centrality of a node can be represented by its degree, that is, the number of other nodes associated with the node. Node sensitivity refers to the degree to which a gene is affected by other genes and is a feature of gene stability.

4.3 Node type and node group of gene network

The type of gene node can be identified by calculating its centrality and sensitivity[6]. (1) key nodes. (2) independent nodes. (3) passive node. (4) secondary node. Through the identification of genetic network nodes, it can effectively grasp the importance of the nodes in the genetic network, and tell the designer which morphological genes should be dealt with first.

Node group refers to the collection of nodes that interact and act together in the gene network, and the influence of these nodes on products has a synergistic effect. The identification of nodal group can help designers grasp the synergistic effect of morphological changes, and take several morphological features of the group into consideration in the design. The identification method of node group: by increasing the correlation threshold of the network, the low-correlation edges are screened and removed continuously, so as to obtain the node group with close relationship. By increasing the threshold (named of [r]) of clustering coefficient in the network, nodes with higher clustering coefficient and their connected node groups form node groups. As shown in Fig.1, it is the office chair gene network graph under different values of [r].

Through the identification of node types and node groups in the genetic network, the importance of nodes in the genetic network can be effectively grasped, and which morphological genes should be given priority to by the designer. It is an important process to transform product gene network into design strategy, and it is a key step to apply gene network to practical design.
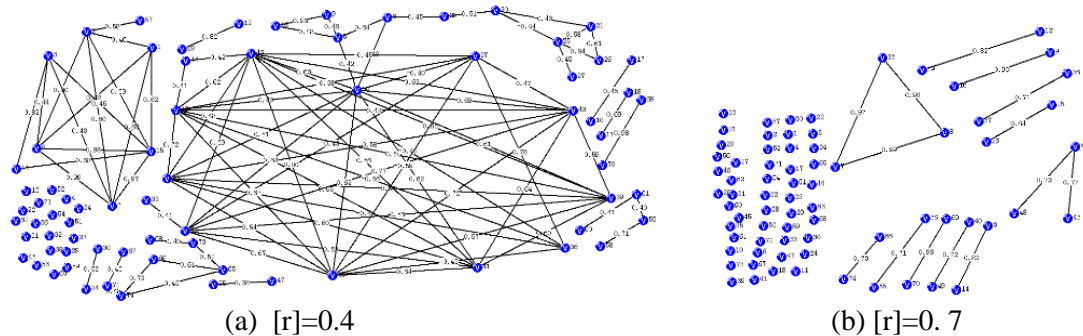

(a) [r]=0.4   (b) [r]=0. 7

Fig.1   gene network diagram in case of different values of [*r*]

4.4 Gene network data processing

After obtaining the product gene nodes and node groups that need priority processing in the gene network, the design strategy transformed into can be applied to the later design. The application of design strategy can be directly referred to the designer for design reference. In particular, for products containing subtype genetic networks, designers give priority to the design of important product forms while dealing with other forms. In the application of gene network to office chair, the evaluation of the design scheme obtained by the designer through the design strategy is superior to the control group in the design experiment.

For the products with continuous parametric modeling in the genetic network, interactive genetic algorithm can be used for further computer-aided design. Interactive genetic algorithm is an extension of genetic algorithm in product design. At the beginning of the interactive genetic algorithm, a number of model groups are generated by the software on the parameterized model, and then displayed to the user step by step. The user selects the displayed model, and the software generates a new model based on the user's choice and the design strategy obtained from the product gene network, and then gives the model to the user for selection until the optimal solution is obtained. By using interactive genetic algorithm, Xiaojian Liu et al. found that the addition of gene network design strategy can effectively reduce the number of iterations and quickly obtain the optimal scheme.

5. Summary

The research of product gene network is an exploratory practice of applying complex network to product gene field. Through the research of many scholars, the preliminary theoretical basis of product

gene network and the construction and application methods of product gene network have been formed. The results show that product genes can form complex networks with effective features, and obtain gene nodes and groups in clusters, which provides new ideas for product shape design.

References

[1]   Xiaofan Wang, Xing Li, Guanrong Chen. (2006) Complex network theory and application. Tsinghua University Press, Beijing.
[2]   Steward D.V. (1981) The Design Structure System: A method for managing the design Of complex systems. IEEE Transactions on Engineering Management, 28 (3):71-74
[3]   Yassien A, Dan B. (2003) Complex concurrent engineering and the design structure matrix method. IEEE Transactions on Engineering Management, 11 (3):165-176
[4]   Xiaojian Liu,Yan Sun, Jianfeng Wu,Shiwei Cheng. (2013) Product's gene regulatory network model and its aiding to design process.Computer Integrated Manufacturing Systems,19(7):1463-1471
[5]   Guanhua Hou. (2014) Establishment and application of product appearance gene intentional model. Journal of Machine Design, 31(3):105-109
[6]   Lufang Zhang, Sheng Zhen, Lun Sun, Xiaojian Liu. (2016) Study of the product form design based on gene network. Journal of Zhejiang university of technology, 44(5):584-590