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A Representation Model of Collaboration in Design Process

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Declaration

I hereby declare that this thesis is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they have been acknowledged.

Muroran, March 2016 Patchanee PATITAD

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Abstract

This thesis presents a novel method to construct a mathematical model of collaboration mechanism in context of collaborative design. In design process, miscellaneous knowledge is required for achieving desirable goal. Collaboration is a crucial method that contributes designers to create prime solutions by sharing their knowledge within a team.

During a collaboration, valuable novel knowledge that is not held by the members could emerge due to synergistic effect. Hence, collaborations which derive powerful synergistic effects are required in teamwork. However, the way to examine increasing knowledge is implicit because some kinds of professional knowledge is intangibles. Thus, a representation model of collaborative design mechanism is proposed to describe the process of generating such knowledge. The model that proposed in this thesis has ability to illustrate all of possible new knowledge which may gain from the collaboration. Hereby, fruitful collaboration can be visualized by using the proposed model.

To achieve the goal of the thesis, Channel Theory with infomorphism is introduced to describe and investigate synergistic effects of collaboration. Besides, Chu space is introduced to represent a scheme of infomorphism as a mathematical construction.

Firstly, current knowledge of a member is extracted and transformed to binary data called classification. Then, infomorphisms between two classifications held by members are calculated. The infomorphisms stand for new knowledge in which the members may obtain from the collaboration. Therefore, the infomorphisms can be use to illustrate effectiveness of a collaboration. To verify the ability of evaluation scheme with the proposed model, a collaboration between layout designer and color designer in a web page design process has been exemplified with the proposed model as a case study.

Abstract

To acquire knowledge of layout designer, layout of web page designed by professional designer on the Internet has been investigated. The effects of layout items on users' impression have been examined through an experiment. Then, a model of web page layout design knowledge has been created. A classification of layout design knowledge is constructed based on the model. The classification of layout design knowledge consists of the layout items that significantly affect on users' impression.

Knowledge of color designer is also acquired in order to structure a classification of color design knowledge. Color design of touch panel interface has been investigated to get knowledge of color design. The effects of colors used in interface on users' emotion and operation have been investigated via experiments. Then, an associate model between interface color design, users' emotion and operation has been generated. To structure the classification of color design knowledge, the color combinations that significantly affect on users' impression are chosen from the result of the associate model.

Subsequently, new knowledge has been deduced from the model consists of the two classifications. An algorithm to generate all possible infomorphisms has been developed for investigating effective collaboration. The algorithm has been implemented as a tool on MATLAB environment.

Based on the case study, the designers could have much new knowledge as a result of the collaboration. In this way, the proposed model can represent explicitly several situations which may occur in the collaboration of web page design process.

According to advantage of the proposed model, a team performance can be estimated by constructing the model with classifications of the members. Moreover, it is expected that the team manager can utilize the proposed model as a decision making support tool when constructing a team members.

Keywords: Collaboration, synergistic effect, Channel Theory, design process

概要

コラボレーション（協調作業）は創造的な成果を生み出すための効果的な手法の一つである。コラボレーションでは、さまざまな分野の専門知識をもつメンバーによって構成されたチーム内で知識やアイデアを共有することによって、新しい知識を導き出すことを目指す。良いコラボレーションでは、チーム内で様々なアイデアが交換され、それによって個人では生み出すことのできない新たな知識が生み出される。そしてこの新たな知識が革新的な成果につながる。しかしながら、多くの専門知識は暗黙的であり、またコラボレーションによってどのようなあらたな知識生み出されるかを知る方法は明らかにされていない。そこで本論文では、協調作業環境における知識導出を、数学的モデルで表現する手法を提案する。
本論文は（1）数学モデルの提案、（2）レイアウトデザイナーの知識の可視化、（3）色彩デザイナーの知識の可視化、（4）提案モデルを用いたケーススタディと考察の4つの内容から構成される。（1）では、状況理解や言葉の意味伝達の記述に用いられるチャネル理論を使って、共同作業における知識の拡張を表現する新しい手法を提案する。チャネル理論で情報の流れを表現するために用いられる情報射を用いて、相乗効果によって得られる新しい知識を表現することで、さまざまな可能性について検証することが可能になる。（2）（3）では、一般的に文章として書き下すことが難しいとされる、専門家が持つ暗黙的な知識を数理モデル化するための手法を提案する。（3）では、ケーススターディを用いて提案モデルを検証し、その有用性を明らかにする。
本研究の成果は、プロジェクトチームの編成支援や、チームのパフォーマンス予測、チーム内で起こりうる誤解の予測などへの活用が期待できる。

キーワード: コラボレーション、相乗効果、チャネル理論、デザインプロセス

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1 Introduction

This chapter provides an introduction to the research covered in this study. It starts by explaining backgrounds of the study, followed by the objectives and related researches. Then, the details of the structure and outline of this thesis are shown.

1.1 Background of the study

In today's highly competitive and dynamic environment, an organization have to increase their competence for achieving sustainable competitive advantages. Knowledge is now being considered as one of the most important issue in many types of organizations, and the management of this knowledge is also appraised as the key to success [1]. To capitalize on the knowledge, it is necessary to understand knowledge's features, how it is created, shared, and utilized.

Knowledge sharing (KS) is defined as individual behaviors that involve sharing task-related ideas, information, suggestions, and tacit knowledge among co-workers and supervisors at workplace [2].

Many researches have shown that knowledge sharing and fusion are positively related to reductions in production costs, faster completion of new product development projects, team performance, firm innovation capabilities, and firm performance [3]. Due to the advantage of knowledge sharing, many organizations are trying to introduce several methodologies of supporting knowledge sharing to their research and development processes. On the contrary, a lack of knowledge transfer and sharing lead to a situation where knowledge becomes isolated and is not taken advantage extremely.

Collaboration is one of the effective approaches that help us to share knowledge together and exchange ideas during members of a team. Collaboration is a communication process that refers to how and why information is shared within two or more people from different disciplines participate to achieving a common goal [4]. Team members are required to share their expertise, ideas, resources, or responsibilities within the team during collaboration [5]. Thus, a team in which each member has diverse experiences should lead to high possibility to create various viewpoints more creative, instantly creating efficiency and improving productivity.

In design process, viewpoints of designer teams on the corresponding task play an important role to bring about a novel design solution [6]. Because different experiences and knowledge bring different viewpoints, each designer has his/her own viewpoints on the works [7].

It is widely acknowledged that design teams in which comprise participants from different areas must explore and integrate their specialized knowledge and viewpoints in order to create progressively innovative and ideas [8]. Hence, the collaboration that includes communication and integration of specialized knowledge from multi-disciplines, has been revealed as one of important component of this step to contribute what they can in different domains.

During collaboration process, such cross-combinations may generate a "synergistic effect" that effects among a team members may contribute to generate valuable novel knowledge [9]. Thus, effective collaborations which can derive fruitful knowledge are expected in a team. In this thesis, a synergistic effect refers to knowledge arising between two designers viewpoints that produces a knowledge greater than the sum of their individual knowledge.

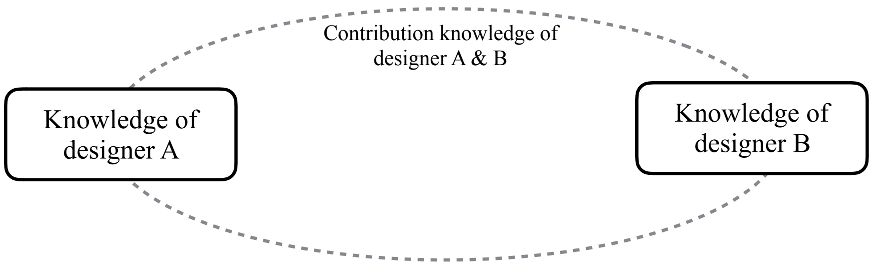


Figure 1.1 – Collaboration in design process.

Figure 1.1 illustrates an example of collaboration in design process. There are two designers in this process; A and B. Both of designers have their own specialized knowledge and viewpoints. After collaboration and sharing their knowledge and experiences, there will be combination knowledge of A and B. This could be new knowledge or contributions. The collaboration that constructs many new knowledge and synergistic effect can be called an effective collaboration. To confirm that the collaboration is effective, amount of new knowledge must be evaluated. However, there are difficulties to evaluate due to knowledge is intangibles and abstraction.

According to above discussion, there are still lack of the method to evaluate such new knowledge and validate an effective collaboration. Therefore, in this research, a mathematical model to investigate and evaluate novel knowledge that may occur in collaboration is considered.

Channel Theory [10] is adopted to investigate synergistic effects of collaboration by considering through a scheme of infomorphism. Besides, Chu space [11], is introduced to represent a scheme of infomorphism as a mathematical construction. To show usefulness of the proposed model, a collaboration between layout designer and color designer in a web page design process is exemplified as a case study. An algorithm of generating all possible infomorphisms has been developed for investigating synergistic effects in a collaboration. The algorithm has been implemented as a tool on MATLAB environment.

1.2 Objectives

From the above mentioned, the method to distinctly identify a productive collaboration is essential. Thus, this research aims to investigate synergistic effects of a collaboration process by using a mathematical model of collaboration mechanism.

1.3 Research Contributions

This thesis aims to proposed a method to investigate and evaluate the knowledge that may occur in collaboration of design process. The theoretical and practical contributions of this thesis can be summarized as follows.

1.3.1 Theoretical contributions

The novel mathematical model for investigate synergistic effects of a collaboration process is proposed. By using this model, the amount of knowledge that is possible to exist in the process is displayed.

1.3.2 Practical contributions

The proposed model have been applied to investigate new knowledge in actual design process. A layout designer and a color designer for the web page is brought as a case study. The proposed model can investigate and evaluate new knowledge by including knowledge from both layout and color design process. The result of the calculation shows infomorphisms which describe amount of new knowledge.

1.4 Related researches

There are many researches have found that a team which consists of different disciplines members have succeeded to create abundant new idea [12, 13]. According to these researches, it should be indicated that the combination of diverse backgrounds members play an important role to bring about the new ideas. Thus, the collaboration which features the team with the members from different backgrounds may lead to create effective collaboration.

During collaboration process, synergistic effects among team members contribute to generate novel knowledge. However, there are a few researches which focus on qualitative analysis in collaboration process. Thus, a representation model of collaboration mechanism is proposed in order to support the qualitative analysis. The model is built based on Channel Theory. Channel Theory provides a logical framework to discuss transition of meaning through a collaboration.

Channel theory has been used in various fields. For example, Suto et al. have proposed a representation model for communication medium with Channel Theory [14]. This model is used to describe semantic information flow, which is corresponding to a kind of medium. Kawakami et al. have proposed a framework of modeling that involves diversity and context dependencies base on Channel Theory [15]. It has the potential to describe diverse understanding of a situation based on the information flows. Moreover, Channel Theory has been also adopted to carry out a theoretical analysis of musicians' awareness for musical expression in order to show difference of musicians' skills between experts and beginners [16].

Furthermore, Channel Theory and Chu spaces have been also utilized in the researches on knowledge sharing field. For instance, Schorlemmer [17] has proposed a formalization of knowledge sharing scenarios by using diagram in the Chu category as well as Kalfoglou and Schorlemmer [18] have proposed an Information-Flow-based method for ontology mapping by adopting Channel Theory.

1.5 Structure and Outline of the Thesis

This thesis consists of seven chapters in which shown in figure 1.2.

Chapter 1 : A main area of study is addressed in this chapter. I show background and signification of the research problem. After a broad overview of the thesis has been given, objective of research related researches and research methodology have been described.

Chapter 2 : The background of related theories are provided in this chapter for the understanding of an interested area. I describes six themes: knowledge sharing, collaboration in design process, Kansei engineering, Channel Theory, Chu space, Kobayashi's Color image scale and Skill Rule Knowledge Model to inform my thesis work for utilizing them for achieving the goal of the thesis.

Chapter 3 : The backbone of this thesis is described here. I show a representation model of collaboration mechanism that could be used to investigate synergistic effects in the collaboration. Furthermore, the way to transform the tangibles like knowledge to be numerical data is also explained. To verify the proposed model, the example of collaboration between layout designer and color designer is discussed in chapter 6. The example model is generated based on the results from chapter 4 and chapter 5.

Chapter 4 : Layout design knowledge is investigated through a modeling of web page layout design knowledge. The procedure to extract knowledge of layout designer is exhibited. Layout design on a web page is exemplified as a case studies. The relationships between the layout items and users' impressions are examined through a experiment. A modeling of web page layout design knowledge was proposed in order to provide operative expert's layout design knowledge.

Chapter 5 : Color design knowledge is investigated through an associate model between interface color design, user's emotion and operation. The effects of color decoration on user's performance and emotion is examined. To obtain knowledge of color designer, interface color design in touch panel device is used to be a representation of color design knowledge.

Chapter 6 : Model of collaboration between layout designer and color designer is discussed. classification of layout design knowledge is extracted from the result in chapter 4, while classification of color design knowledge is extracted from the result in chapter 5. Then, new knowledge that can be obtained from the collaboration is clarified.

Chapter 7 The thesis is concluded and future research is also discussed in this chapter.

1.6 Conclusion

This paper aims to represent the process of generating such knowledge by using a mathematical model under principle of Channel Theory and Chu spaces. Channel Theory is adopted to investigate synergistic effects of collaboration by considering through a scheme of infomorphism. Besides, Chu space is introduced to represent a scheme of infomorphism as a mathematical construction. The basic ideas of Channel Theory and Chu spaces are described in chapter 2. The representation model of collaboration mechanism is elaborated on chapter 3. To verify the proposed model, collaboration between layout designer and color designer is employed as a case study as shown in chapter 4, 5 and 6. Moreover, an algorithm of generating all possible infomorphisms has been developed for showing the usefulness of the model. The algorithm has been implemented as a tool on MATLAB environment. The source code is shown in appendix A.1. Finally, summing-up, limitation and future work of the thesis are discussed in chapter 7.

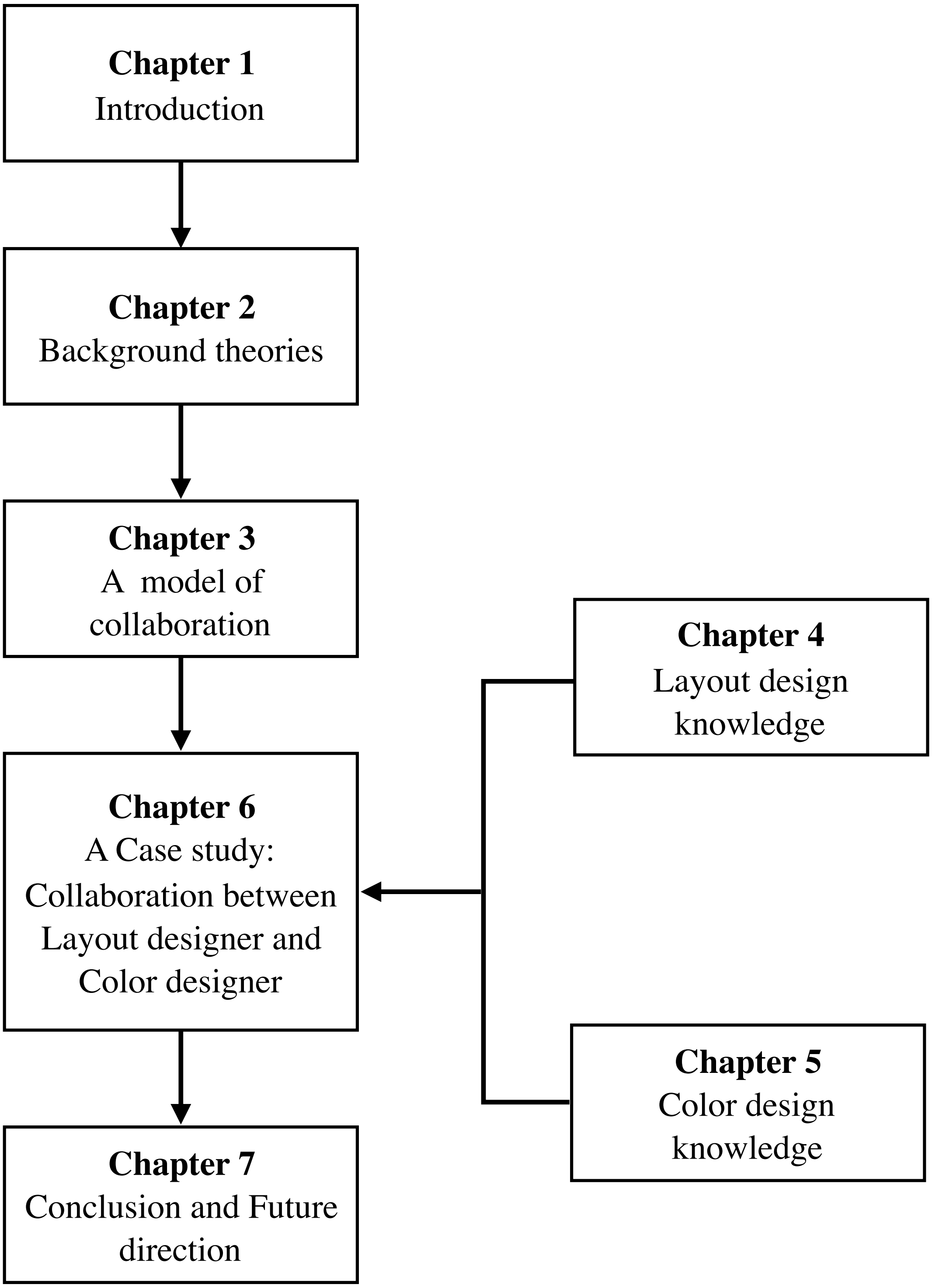


Figure 1.2 – Structure of the thesis.

2 Background theories

2.1 Introduction

In this chapter, key concepts and approaches which are used in this study are described. The following six topics, Knowledge sharing, Collaboration in design process, Kansei engineering, Channel Theory, Chu spaces, Kobayashi's Color image scale and Skill Rule Knowledge (SRK) Model are mentioned.

In section 2.2, the importance of knowledge sharing is explained. Knowledge sharing is the main keyword that engenders this thesis. As knowledge is abstract, there are many difficulties to execute and assess achievement of knowledge sharing especially if it is tacit knowledge. Thus, one of the problems that challenges us is how to share and evaluate success of the tacit knowledge sharing.

In order to research on knowledge sharing, collaboration is one of the promising methods that provides us to share knowledge within team members. To focus on aspect of tacit knowledge, a web page design process is employed because knowledge used in a design process can also be considered as tacit knowledge. Therefore, the concept of collaboration in design process is discussed in sections 2.3. Moreover, Kansei engineering is the important topic that we should consider in design phase. The basic concept of Kansei engineering is explained in section 2.4.

To fulfill the gap of the research problems, a model of collaboration in web page design process is proposed to evaluate the effective of the knowledge sharing. Channel Theory and Chu space is employed to investigate abundant knowledge that may procure from the collaboration. The basic concepts of Channel Theory and Chu space are described in section 2.5 and 2.6.

To show usefulness of the proposed scheme, the example of collaboration between layout designer and color designer is used as a case study. To obtain knowledge

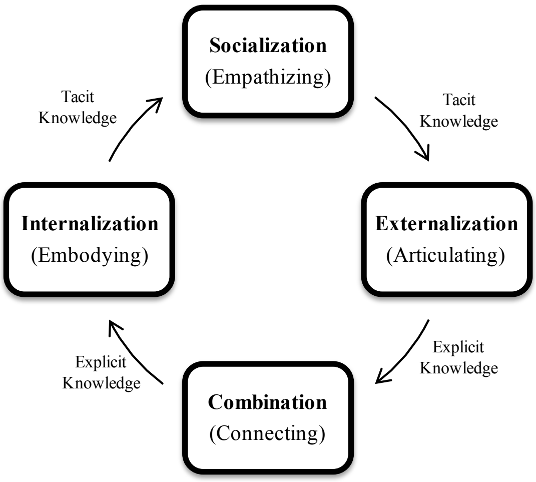


Figure 2.1 – Model for creating organization knowledge: SECI model [21].

of the designers Kobayashi's Color Image Scale is adopted to design experiments. The detail of the scale is explained in section 2.7. Furthermore the notion of Skill Rule Knowledge (SRK) Model as explained in section 2.8 is adopted to design the calculation task of the experiment of investigating color design knowledge.

2.2 Knowledge sharing

Organizational knowledge creation involves a continuous interplay between explicit and tacit knowledge [19]. Explicit knowledge is systematic and easily communicated in the form of hard data or codified procedures. On the other hand, tacit knowledge is hard to formalize, making it difficult to communicate or share with others. It involves intangible factors embedded in personal beliefs, experiences, and values. Thus, tacit knowledge is difficult for us to obtain and share [20]. Here, if tacit knowledge can be visualized, it becomes easy to comprehend. Several studies have been conducted to visualize tacit knowledge. The SECI (Socialization, Externalization, Combination, and Internalization) model represents the process of creating new knowledge and sharing it through transition between tacit and explicit knowledge. Through the transition process, tacit and explicit knowledge expand in terms of both quality and quantity [21]. Figure 2.1 illustrates the SECI model. There are four steps of knowledge conversion as follows:

1. **Socialization** in which individual tacit knowledge is shared to create public tacit knowledge.

2. **Externalization** step describes how tacit knowledge is articulated in an explicit form.

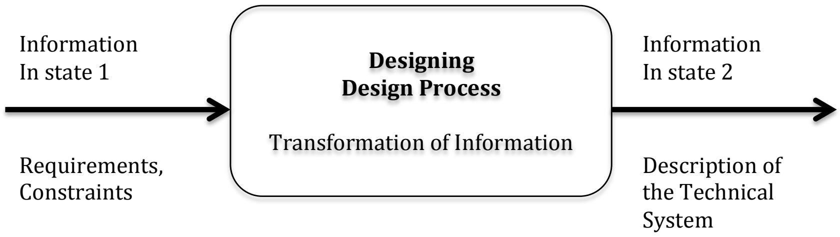


Figure 2.2 – Diagram of black box of the design process by Hubka and Eder [26].

3. **Combination** step, the explicit knowledge is systematized.

4. **Internalization** in which the new tacit knowledge is crystallized

The SECI model clarifies procedures to share tacit knowledge clearly. The knowledge sharing among individuals in an organization is required fundamentally to achieve innovation and organizational success. It also promotes the creation of values within a company [22, 23]

Knowledge used in a design process can also be considered as tacit knowledge. Of course, some such knowledge can be regarded as explicit knowledge. For instance, some kinds of knowledge of design can be represented by rules and definitions, such as natural language or symbols, called "design language [24]" in design education. However, general design skills can be called a type of tacit knowledge.

In a design process, a designer uses various kinds of design knowledge, from common sense knowledge about the physical world to domain of specific knowledge like theories in physics [25]. Hubka and Eder [26] have introduced the block diagram that they called "Black box of the design process." Figure 2.2 represents the ideas of Hubka and Eder. Design process consists of thinking ahead and describing a structure, which appear as potential carrier of the desired characteristics, such as properties and product functions. In this stage the designing can be defined as "the transformation of information from the conditions of needs, demands, requirements and constraints into the description of a structure which capable of fulfilling customer's demands." To speed up the product design efficiency, product designers would like to utilize the past experience and know-how to assist the design of new products or in the enhancement of existing one [27].

However, the design know-how including such functional knowledge used in the design phase is usually left implicit because each designer possesses it. There are main three causes of inconsistency, non-re-usability, and improper categorization in the design process [28]. The first one is that different frameworks for conceptualization are used when people try to describe knowledge in different domains. The second cause is there are several functional concepts without clear definitions as pointed out. The last cause is that structure (organization) of viewpoint-independent and consistent modeling of functional knowledge is not fully investigated yet. From the causes mentioned above, it shows that all causes are from lack of knowledge and information transfer and sharing. Meanwhile, it is the lack of formal representations of the existing design knowledge that makes it extremely difficult to trace the past design routines [27]. Besides, there is a gap between the theoretical and practical work being done [29]. Various kinds of technical reports/documents have regularly brought to use for cooperate from each department. Unfortunately, however, it has been difficult for them to understand documents written by other worker from difference knowledge areas. Current business trends that points to the importance of knowledge transfer includes the increased use of joint ventures and strategic alliances [30, 31]. Hence, the term of “Knowledge Transfer” is becoming increasingly important in organizations. Knowledge transfer is conceived as an event through which one organization learns from the experience of another [32].

New knowledge can promote innovations in new methods and practices, which can then be absorbed into the routines and culture of an organization [32].

To provide knowledge transfer in design process, a method for modeling a tacit knowledge by using web page layout design as a case study is developed. The method to create a model is detailed in chapter 4.

2.3 Collaboration in design process

The term of collaboration is described by Gray [33] as “a process through which parties who see different aspects of a problem can explore constructively their differences and search for solutions that go beyond their own limited vision of what is possible.” It comes up with a significant value of collective co-work among groups of stakeholders who share with and learn from one another. These stakeholders exercise their expertise and work autonomously in their own work patterns [34]. Collaboration solutions are tools, culture, and processes that allow people to work together. It is also considered to embrace an ability of two or more groups to transfer data and information [35]. It has the capacity to bring previously separated organizations into a new structure with full commitment to a common mission [36]. Collaboration can be beneficial when the technology is applied within the context of an enterprise culture that encourages sharing and open interactions between people.

Complex design problems require more knowledge than any single person possesses because knowledge is relevant to a problem is usually distributed among stakeholdersTraditional product design systems use a sequential mode of design generation, which breaks a design task into a number of sub-tasks that can be sequentially executed in a predefined work flow. However, this method often requires numerous iterations, which makes design expensive and time-consuming, and also limit the number of design alternatives that can be examined. Hence, such a sequential design mode has been found to be brittle and inflexible [37].

For effective design, the collaboration among design teams is necessary. Collaborative design is one of key challenges for a design department as more engineers or other specialists are involved in the design process of a product [38]. It is performed by multiple participants (representing individuals, teams or even entire organizations), each potentially capable of proposing values for design issues and/or evaluating these choices from their own particular perspectives [39]. This includes those functions such as preliminary design, detailed design, manufacturing, assembly, testing, quality control, and product service as well as those from suppliers and customers [37, 40]. By using this method, the insufficient or even absent manufacture-ability checks concurrently by detecting and considering conflicts and constraints at earlier design stages are pointed out. Although the collaborative design approach provides considerable contributions in design, it is challenging because strong inter-dependencies between design decisions make it difficult to converge on a single design that satisfies these dependencies and is acceptable to all participants [39].

The power to combine the perspective, resources, and skills of group of people and organization has been called *synergy* [41–43]. The synergy is used to achieve through collaboration is not only a mere exchange of resource, but also a combination the individual perspectives, resources, and skills. The results of combination is a creation of something new and valuable that is greater than a sum of it individual parts [44, 45]. As such, synergy is manifested in the thinking and actions that results from collaboration, and also in the relationship of partnerships to the broader community [41]. To create synergy, the group of people need a process that make a good use of different perspectives, knowledge, and skills. Thus, the whole group can develop better way of thinking about the problems and addressing them.

The aim of collaboration is to produce synergy, that is, outcomes that are only possible by working with others. It is clearly that the synergy created by collaboration can be very powerful. The raw components for synergy are that people and organizations that come together as the same team. However, effective collaboration that creates high level of synergy is hard to achieve, because various institutions, departments and professionals have different aims, traditions, styles of working and mandates [46]. Since the focused objectives result in high synergistic effects for the collaboration, considering the difficulties involved, it is likely that many organization do not achieve an effective collaboration that can create high levels of synergy. However, it is still not possible to determine the extent of knowledge after the synergy happened in collaboration since there is a lack of the way to measure synergy [41]. Thus, this thesis proposes a representation model of collaboration mechanism to investigate synergistic effects in collaboration process. The notion of the proposed model is described in chapter 3.

2.4 Kansei engineering

The customer-oriented becomes the main factor of product development. To implement the customer's feeling and demands into product function and design, Kansei engineering is introduced [47]. Mazda Motor Company manager K. Yamamoto used the term Kansei Engineering for the first time when he delivered a speech at Michigan University in 1986 [48,49]. However, in academic field, Kansei engineer is pointed out by Nagamachi in 1995 [50]. It is one of the main areas of ergonomics (human factors) [51]. Kansei, a term for human emotion in Japanese, is a concept of sensing a phenomenon or an artifact that builds impressions [52]. According to Nagamachi [50], Kansei is defined as "a translation system for translating images or feelings into real design components" or "customer psychological feeling and image of a new product." As its definition, Kansei engineer focuses rather on the customer's feeling and needs more than the manufacturer's intention. It is the first and foremost product development methodology that translates customer impressions, feelings and demands on existing products and concepts into concrete design parameters [52].

There are many researchers that have worked in the Kansei engineering area and made their contribution to the development of Kansei engineering. Moreover, Kansei engineering is expanding in many new areas including new innovative tools which are added to the original methodology [48]. In 1997, applications on Kansei engineering are collected and grouped according to tools and task areas [53]. There are six groups of Kansei engineering as follows:

I- Category Classification In this type, a tree structure methods is used to identify the customer's affective needs from a product strategy and a market segment.

II- Kansei Engineering System In this type, a computer aided system using interference engines and Kansei databases is often used. The mathematical statistical tools are brought to connect Kansei and product properties.

III- Hybrid Kansei Engineering System For hybrid Kansei engineering, a computer database system similar to the second type. Not only recommending a suitable product proprieties but it is also predict the Kansei that product properties elicit.

IV- Kansei Engineering Modeling For the forth type, building mathematical prediction models is concerned.

V- Virtual Kansei Engineering In the fifth type, Virtual Reality (VR) techniques is included with standard data collection systems.

VI- Collaborative Kansei Engineering Designing In Kansei Engineering Type VI, the Kansei database is accessible via Internet. Such design supports group work and concurrent engineering [48, 53].

To apply Kansei engineering, there are three main steps that typically use; (1) spanning the semantic space: defining the responses, those emotions that will be studied; (2) spanning the space of properties: deciding on the technical properties of the products that can be freely changed and that might affect the responses (factors in a factorial design) and (3) the synthesis phase, where both spaces are linked (that is, how each factor affects each response is discovered) [48, 54].

Due to strong benefit that Kansei engineering method can link the customer feeling and product properties, there are many products especially in Japan which have applied Kansei engineering, for example, automotive industry, construction machine industry, electric home appliance industry, office machine industry, and house construction industry [47]. Not only on business sides, in academic sides, Kansei engineering has been also applied for many research works. There are many technique that are adopted to analyze Kansei such as regression analysis, quantification theory, neural networks, genetic algorithms, fuzzy logic, and rough sets [48, 55–57]

In this thesis, the concept of Kansei Engineering System is utilized in order to fulfill a user's demand, the emotion that the test screens provided to the participants is investigated. In chapter 4, users' impression on the layout of web page is examined. Then, the model of layout design knowledge is created by using the mathematical statistical tools. Moreover, in chapter 5, the concept of Kansei engineering is also used to identify users' emotion on interface color design.

2.5 Channel Theory

Channel Theory provides a mathematical framework of qualitative theory of information. The basic idea of Channel Theory consists of classification, local logic, infomorphism, and information channel.

A classification $A = \langle tok(A), typ(A), \models_A \rangle$ consists of the following items:

1. A set of objects to be classified, called “tokens of A” ($tok(A)$)
2. A set of objects used to classify the tokens, called “types of A” ($typ(A)$)
3. A binary relation between $tok(A)$ and $typ(A)$ ($\models_A$)

A classification indicates that each token is classified into which type.

Infomorphism is important relationship between two classifications. It provides a way of moving information back and forth between them. Infomorphism:$\langle f^\wedge, f^\vee \rangle$ is a pair of functions, of which $f^\wedge$ is a function from the types of one of these classifications to the other, and $f^\vee$ is a function from the tokens of one of these classifications to the tokens of the other. Given two classifications A and B, an infomorphism from A to B written as $A \rightleftharpoons B$ satisfies

$$f^\vee(b) \models_A \alpha \text{ iff } b \models_B f^\wedge(\alpha) \tag{2.1}$$

for $\forall \alpha \in typ(A), \forall b \in tok(B)$, where $f^\wedge$ and $f^\vee$ are whole-part relationships. Figure 2.3 shows a diagrams of a relationship between two classifications.

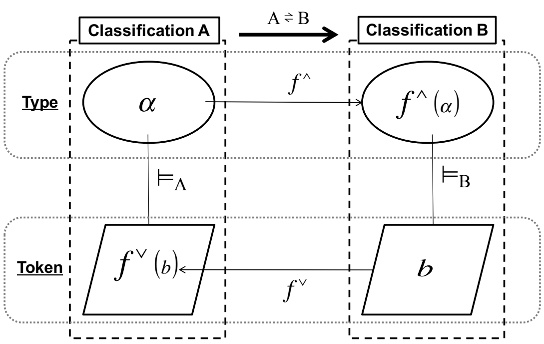


Figure 2.3 – Relationship between two classifications.

2.6 Chu space

Category Theory has provided a unified language for managing conceptual complexity in mathematics and computer science. Chu spaces, which derived from category theory, has been brought to use in computer science through the work of Barr as constructive models of linear logic. Pratt's [58] has applied Chu space for several areas, e.g. the model for concurrency and philosophy of logic, information and computation.

A Chu space A over a set S is a triple (A, r, X), consists of a set of tokens(A), a set of types(X), and a function $r : A \times X \to S$, constitutes the matrix. In the Chu space context, tokens are usually called points, while types are called states. The alphabet is a binary number which represent numeric value using two different symbols: typically 0 and 1 or $S = \{0, 1\}$. It becomes possible to represent a variety of structured objects.

Let $A = (A, r, X)$ and $B = (B, s, Y)$ be two Chu spaces. A Chu transform from A to B is a pair (f, g) consisting of functions $f : A \to B$ and $g : X \to Y$ such that $s(f(a), y) = r(a, g(y))$ for all a in A and y in Y.

It can be seen that the notion of classification coincides with the notion of Chu space as well as a scheme of infomorphism is similar to a kind of Chu transform.

However, those Chu transforms (f, g) for which f and g are both bijections, while fundamental property of infomorphism is pair of functions. This means Chu transform cannot perform all infomorphisms. Thus, the authors have proposed a new method to find all of infomorphisms that are possible to happen in a communication. Detail of the method is described in chapter 3.

2.7 Kobayashi's Color image scale

Color in one's environment is known to bring emotional, social, and physiological reactions to people. An example is the relationship between colors and human emotions that has a strong influence on how we perceive our environment [59]. Despite its significance, understanding meaning of color in environments is challenging mainly because of the difficulty in testing real color environments with virtually unlimited possible color combinations [60]. As the context of color usage changes its impact on human responses, studying color and human responses has limited value if colors are isolated from actual environments [61].

In 1981, Shigenobu Kobayashi and his team [62, 63], from the Nippon Color and Design Research Institute (Japan), has introduced and developed color theory focusing on the association of colors and words (i.e., adjectives) describing feelings and psychological emotions called “Kobayashi’s Color Image Scale.” This method is useful for describing the similar, contrasting images of colors, classifying the correlation of various objects such as shapes, patterns, clothing, foods, etc. Psychophysical experiments was used to match 130 basic colors and 1170 three-color combinations to 180 keywords, or image words, belonging to high-level semantic concepts related to the ways in which people perceive colors [59, 62].

Kobayashi’s Color Image Scale provides a powerful tool for designers to generate and search for all relevant color combinations related to a given theme and interesting methods for image indexing based on high-level color semantics [59, 64]. Hence, during the last four decades, Kobayashi’s color image scale has been widely adopted throughout major industries and researches.

In this thesis, Kobayashi’s Color image scale is adopted to design the experiments in two chapters. KeyWord Image Scale is utilized to represent the impression of an user in chapter 4. Moreover, each color combination from Color combination Image Scale is employed to decorated in the experiment in chapter 5.

2.8 Skill Rule Knowledge (SRK) Model

The Skill, Rule and Knowledge (SRK) model is developed by J. Rasmussen of the Riso Laboratory in Denmark to deal with a rapidly growing interest in the analysis of human error caused [65, 66]. This scheme provides a useful framework for identifying the types of error likely to occur in different operational situations, or within different aspects of the same task where different types of information processing demands on the individual may occur [67].

The SRK Model advocated by Rasmussen is shown in figure 2.4. The briefly explanation of 3 different levels of SRK model are shown as follows [38]:

Skill Based Level: Performance and decision making is at the subconscious level and is more of an automatic response to a particular situation. People who usually make skill based decisions are very experienced with the task at hand.

Rule Based Level: People will operate on this level when they are familiar enough with the task but do not have enough experience and will look for cues or rules that they may recognize from past experience to make a decision.

Knowledge Based Level: When the task at hand is novel and when people do not have any rules stored from past experiences, people will resort to analytically processing using conceptual information which involves problem definition, solution generation and determining the best course of action or planning before making a decision [68].

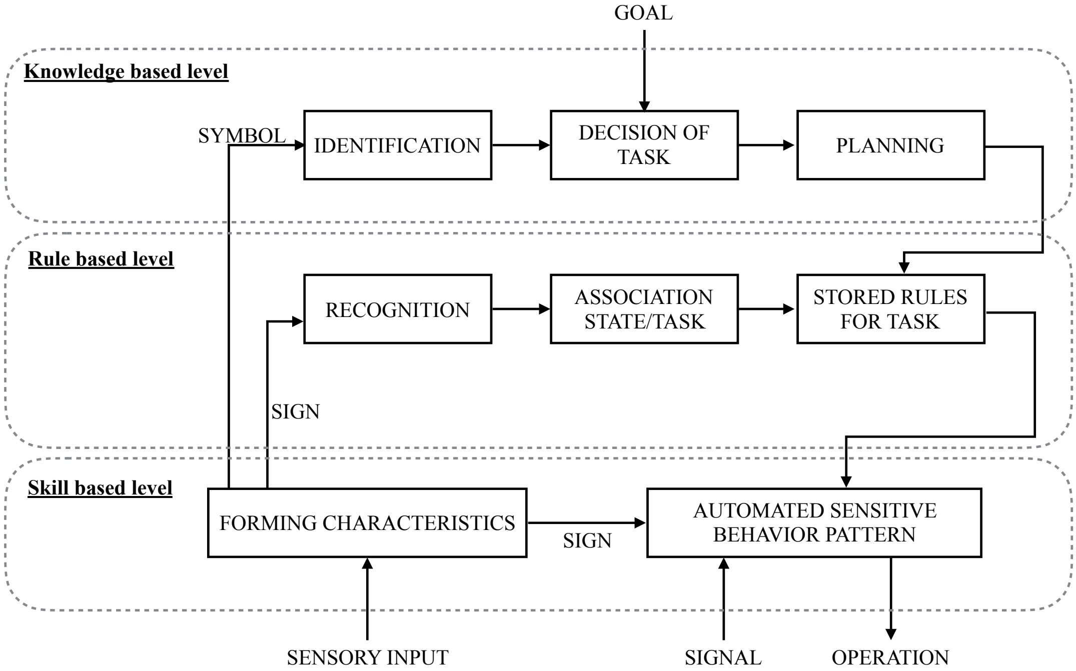


Figure 2.4 – The SRK model [65].

In chapter 5, knowledge of color designer is extracted by conducting an experiment. In order to examine effect of coloration, the experiment is designed based on the Knowledge Based Level of SRK model.

2.9 Conclusion

In this chapter, the six topics that concerned in this research have been mentioned such as Knowledge sharing, Collaboration in design process, Kansei engineering, Channel Theory, Chu spaces, Kobayashi's Color image scale and Skill Rule Knowledge (SRK) Model. The basic concept and advantages of each topic have been shown.

The notions of Knowledge sharing, collaboration in design process and Kansei engineering are the background theories and manipulate the main objective of this research.

A representation scheme that used to investigate effective collaboration in design process is proposed. Abundant knowledge that may procure from the collaboration will be taken an account by using Channel Theory and Chu space as described in section 2.5 and 2.6. To show usefulness of the proposed scheme, the example of collaboration between layout designer and color designer is used as a case study.

The Kobayashi's Color Image Scale as explained in section 2.7 is deployed to design the experiments of both chapter 4 and chapter 5. It is used to express users' impression on layout of each test page of the experiment in chapter 4. Moreover, it is employed to design color decorating on test screen of the experiment in chapter 5.

Then, in chapter 5, knowledge of color designer is extracted by conducting an experiment. In order to examine effect of coloration, the task of the experiment is designed based on the Knowledge Based Level of SRK model as explained in section 2.8.

3 A representation model of collaboration mechanism

In this chapter, a representation model of collaboration mechanism is proposed by adopting Channel Theory. The conceptual of the proposed model is explained as following sections:

3.1 Introducion

The integration of viewpoints is the heart of the cooperative mechanisms implemented in multidisciplinary co-design [6]. Because different experiences and knowledge bring different viewpoints, each designer has his/her own viewpoints on the works [7]. During solution development, sharing different viewpoints that corresponds to the task within the team leads to bring about a novel design solution. Capacity of design proposal becomes richer because of the wider viewpoints which can get from collaboration of designers. Thus, collaboration is a promising method, which assists a design team to create more outstanding solutions and increase ability to fulfill client requirement more perfectly. Especially, in a multidisciplinary design process, roles of collaboration become more important [69].

Collaboration requires team members to share their expertise, ideas, resources, or responsibilities in a team [4]. In a design process, designers collaborate to exchange useful information that supports the team to accomplish the project goal. In addition, Amir et al. [70] have argued that effective communication is critical to the project members of collaborative design, and the designers have spent almost half of their time focusing on communication.

During collaboration process, synergistic effects among members of a team may contribute to generate novel worthy knowledge. Thus, effective collaborations which can derive much knowledge are expected in a team project. However, the way to generate new knowledge through a collaboration is implicit. Thus, this paper aims to represent the process of generating such knowledge by using a mathematical model. By using the proposed model, synergistic effects in a collaboration process are examined. The model can illustrate the increasing knowledge which may gain from the collaboration distinctly.

3.2 Synergistic effects within collaboration process

Collaboration is a process where two or more people work together by sharing their useful knowledge within the team members. The goal of collaboration is to broaden the members' knowledge in which lead to cultivate abundant ideas. Then, the team performance is raised due to increasing a chance of achieving a common goal more completely. Especially in design process, various ideas lead to widen a possibility domain of design solution, then encourage the team to launch an innovation. We imply this phenomena as there are synergistic effects within collaboration process. When two people who have different backgrounds team up in a design process, synergistic effects within the collaboration process can express as figure 3.1.

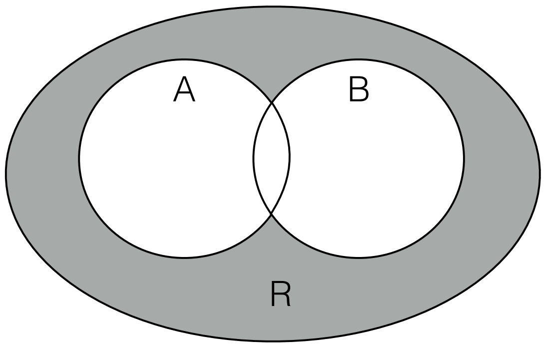


Figure 3.1 – Possibility domain of collaboration in design process.

In figure 3.1, each circle indicates the sets of solutions as an innovation which can be reachable by a person. In this case, A and B have different background such as different experiences, different knowledge and different skills respectively. Therefore, the expected outcomes of them are different with individuals, so the sets of reachable solutions are also different. This is a reason that the two circles do not overlap entirely with each other.

Due to synergistic effect within the process, team performance cannot be calculated as simple union of the abilities of each member. Possibility domain of collaboration will be broaden. The areas which indicated by white area $(A \cup B)$ means normal solution of designer A and designer B. While grey area $R-(A \cup B)$ indicates additional knowledge that the team members may gain from synergy. Eventually, domain of design solution of the team is expanded as shown in R area.

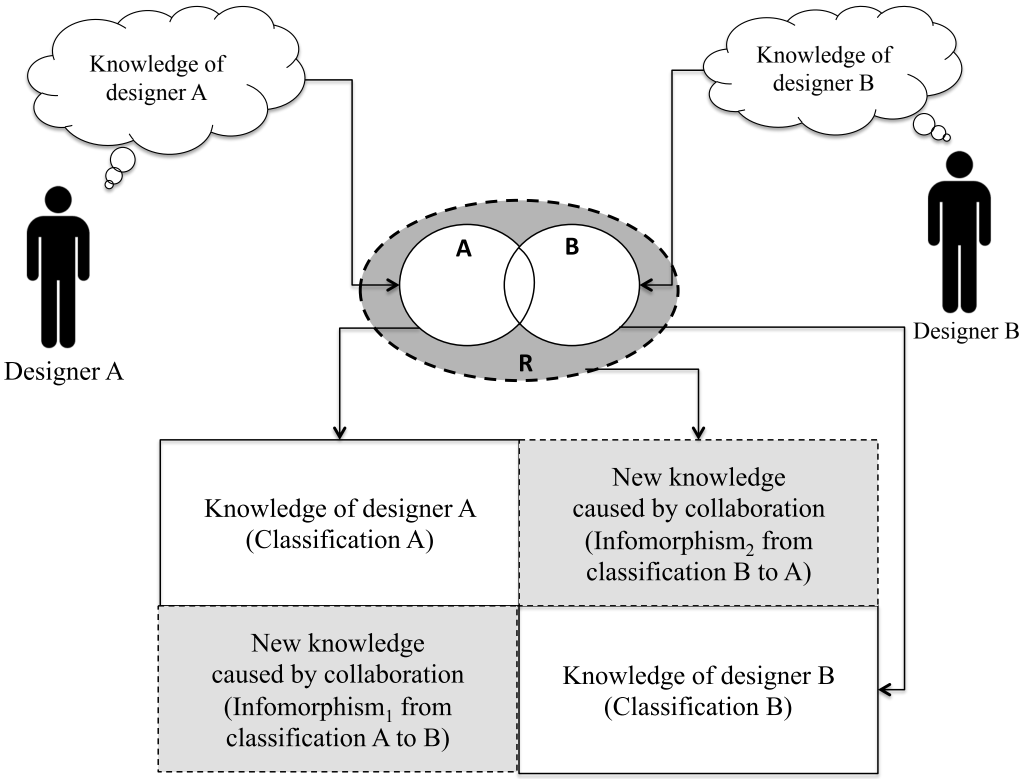


Figure 3.2 – Collaboration mechanism in a design process represented by using Channel Theory.

3.3 A model of collaboration mechanism

Due to benefit of synergistic effects, the effective collaboration is expected in team work. However, it is hard to investigate effective collaboration because the mechanism of generating such a new knowledge is implicit. Thus, the scheme for inspecting a collaboration mechanism is required. A representation of collaboration mechanism is proposed in order to investigate synergistic effects of a collaboration. The proposed model is adopted Channel Theory and Chu space to accomplish the goal. Channel Theory [10] is adopted to investigate synergistic effects of collaboration by considering through a scheme of infomorphism. Besides, Chu space [11], is introduced to represent a scheme of infomorphism as a mathematical construction. Based on the context of collaboration between two designers who have different backgrounds, the outline of the proposed model is illustrated in figure 3.2.

In figure 3.2, each solid line circle indicates a set of knowledge held by a designer. Due to synergistic effects of collaboration, team performance cannot be calculated as simple union of the abilities of each member. Possibility domain of collaboration can be described as dashed line circle. In order to examine effective collaboration, this situation can be represented by using classifications as shown below the circles in the figure. The left top solid line square stands for knowledge of designer A, and the right lower solid line square expresses knowledge of designer B. Thank to ability of Channel Theory, we can deduce new knowledge which can be obtained from the synergy by manifesting as the dashed line squares shown between the classifications. The left lower dashed line square stands for new knowledge which gained from the collaboration in which designer A shared his/her knowledge to designer B and we call it Infomorphism_1. On the contrary, the right upper dashed line square expresses new knowledge which gained from the collaboration in which designer B shared his/her knowledge to designer A and we call it infomorphism_2.

For the reason that each infomorphism has the direction as we can find from figure 2.3. Thus, when we discuss a collaboration between two persons, infomorphisms that are obtained from the both directions should be considered. That is why, the model has two sets of infomorphisms.

3.4 Investigation of synergistic effects in collaborative process

To utilize the proposed model to identify the effective collaboration in design process, there are the steps as shown in figure 3.3. The detail of each step can be descried as follows:

3.4.1 First step: Explore the current knowledge of the designers

Design knowledge is one kind of tacit knowledge. Generally, a designer gains his/her design knowledge through the experience. Sometimes the designer cannot convey their knowledge easily. For this reason, it is quite difficult to obtain design knowledge by making an inquiry to the designer directly. Thus, to explore their knowledge, we may necessary to observe their works, conduct an experiment as well as ask a questionnaire. The explored knowledge may be formed as qualitative data or quantitative data. These knowledge stand for the designers' domains of design solution.

3.4.2 Second step: Structure the classifications of the designers' knowledge

To adopt Channel Theory to investigate synergistic effects in collaborative process, the current knowledge of the designers is transformed to be the classifications of

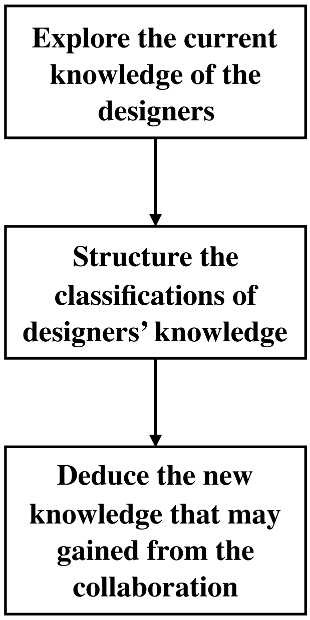


Figure 3.3 – The procedure of applying the proposed model to investigate the effective collaboration.

the knowledge. A classification is a matrix which contains a meaningful binary data. Chu space is adopted to structure the classifications. Thus, the current knowledge of the designers is changed to be a binary numerical data and positioned as a matrix based on the notion of Chu space. The matrices are called the classifications of knowledge of the designers. A classification consists of three main features that are a type, a token and a binary relationship between type and token. The details of the classification has been described in section 2.5. Types stand for the concepts in the knowledge, and tokens stand for a set of attributes. Each type of a classification corresponds a column of the matrix, and each token corresponds to a row of the matrix. With using proposed scheme, the values in each row of the classification matrix is not duplicate with each other. If a token can be classified as a type, the value of the cell indicated by the token and the type is equal to one. For example,

$$\begin{aligned}
classification\ A &= \langle tok(A), typ(A), \models_A \rangle \\
where & \\
tok(A) &= \{a_1, a_2, a_3\}, \\
typ(A) &= \{\alpha_1, \alpha_2\}, \\
\models_A &= \{a_1 \models_A \alpha_1, a_2 \models_A \alpha_2, a_3 \models_A \alpha_1, a_3 \models_A \alpha_2\}
\end{aligned}$$

This classification can be illustrated as a matrix shown in figure 3.4.

	α_1	α_2
a_1	**1**	**0**
a_2	**0**	**1**
a_3	**1**	**1**

Figure 3.4 – An example of Chu space matrix which represents a classification.

3.4.3 Third step: Deduce the new knowledge that may gained from the collaboration

After the classifications were constructed, new knowledge that may gained from the collaboration is deduced and expresses through the infomorphisms.

According to the notion of Channel Theory, when an infomorphism from classification A to classification B is obtained, function from $typ(A)$ to $typ(B)$: $f^{\wedge}$ and function from $tok(B)$ to $tok(A)$: $f^{\vee}$ must exist as shown in figure 2.3.

This is say, each column of the matrix which represents the infomorphism must be same as one of the columns of the matrix which represents classification A. Meanwhile, at least one line of the matrix of the infomorphism must be similar to one of the lines of the matrix which represents classification B. The example of infomorphism is shown in figure 3.5.

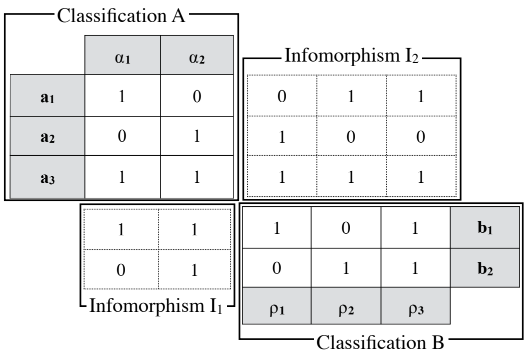


Figure 3.5 – An example of infomorphisms which represent the new knowledge.

In figure 3.5, the upper left matrix stands for the current knowledge of designer A called classification A. The lower right matrix stands for the current knowledge of designer B called classification B.

Then, infomorphism I_1 which is generated from the classification A to classification B stands for the sets of new knowledge which gained from a collaboration as shown in the lower left matrix. From the infomorphism I_1, we can notice that

- the first column of matrix of infomorphism I_1 has the same element of the first column of matrix of classification B. It means that the leftmost column of matrix of classification A: α_1 is mapped to the first column in matrix of classification B: ρ_1 by function $f^\wedge$.

- the second column of matrix of infomorphism I_1 has the same element of the third column of matrix of classification B. It means that the second column of matrix of classification A: α_2 is mapped to the third column in matrix of classification B: ρ_3 by function $f^\wedge$.

- the first line of matrix of infomorphism I_1 has the same element of the third line of matrix of classification A. It means that the first line of matrix of classification B: b_1 is mapped to the third line in matrix of classification A: a_3 by function $f^\vee$.

- the second line of matrix of infomorphism I_1 has the same element of the second line of matrix of classification A. It means that the second line of matrix of classification B: b_2 is mapped to the second line in matrix of classification A: a_2 by function $f^\vee$.

The infomorphism I_1 shows:

$$
\begin{aligned}
f^\wedge(\alpha_1) &= \rho_1, \\
f^\wedge(\alpha_2) &= \rho_3, \\
f^\vee(b_1) &= a_3, \\
f^\vee(b_2) &= a_2.
\end{aligned}
$$

As each infomorphism has the direction, infomorphisms from classification B to classification A should be also examined. The infomorphism I_2 which is generated from the classification B to classification A as shown in the upper right matrix can be described as follows:

- the first column of matrix of infomorphism I_2 has the same element of the second column of matrix of classification A. It means that the leftmost column of matrix of classification B: ρ_1 is mapped to the second column in matrix of classification A: α_2 by function $f^\wedge$.

- the second and third columns of matrix of infomorphism I_2 have the same element of the first column of matrix of classification A. It means that the second and third columns of matrix of classification B: ρ_2 and ρ_3 are mapped to the first column in matrix of classification A :α_1 by function $f^{\wedge}$.

- the first line of matrix of infomorphism I_2 has the same element of the first line of matrix of classification B. It means that the top line of matrix of classification A: a_1 is mapped to the second line in matrix of classification B :b_2 by function $f^{\vee}$.

The infomorphism I_2 shows:

$$\begin{aligned} f^{\wedge}(\rho_1) &= \alpha_2, \\ f^{\wedge}(\rho_2) &= \alpha_1, \\ f^{\wedge}(\rho_3) &= \alpha_1, \\ f^{\vee}(a_1) &= b_2. \end{aligned}$$

In order to practical use, the authors' team has developed a tool which can calculate infomorphisms of two classifications by using MATLAB programming language. The source code has been shown in Appendix A.1.

3.5 Apply the proposed model in a case study

By using the proposed scheme, we can evaluate the effectiveness of a collaboration by representing how new reachable knowledge broadens. In order to show the usefulness of the proposed scheme, a collaboration between Layout designer and Color designer are represented with the proposed model as case study. The procedure of creating the example model is shown in figure 3.6.

The proposed procedure begins with exploring knowledge of the designers. For this case, layout design knowledge on a web page design is exemplified to represent knowledge of layout designer. Layout design knowledge is extracted through the model of layout design knowledge. The procedure of creating the model is explained thoroughly in chapter 4. Then, to extracted knowledge of color design, the association model between interface color design, users' emotion and operation is created. The effect of interface color design on users' emotions in touch panel device is clarified to represent knowledge of color designer. The detail of the association model is described in chapter 5. Subsequently, knowledge of two designers is transformed to be classifications of knowledge. Finally, new knowledge that may gained from the collaboration is deduced. The results are discussed in chapter 6.

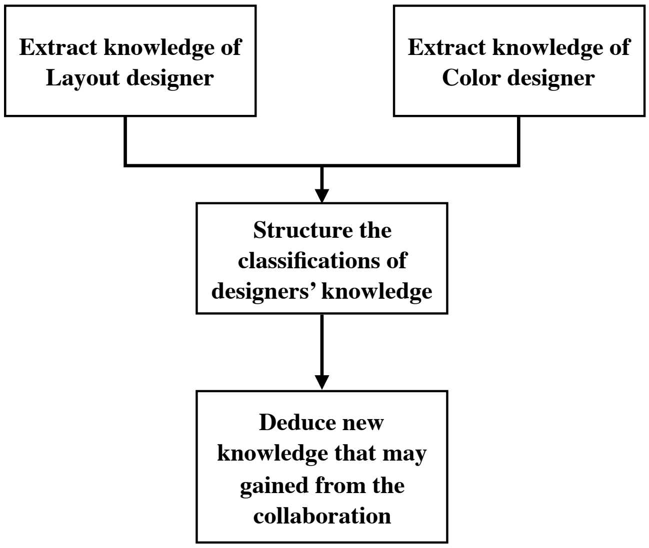


Figure 3.6 – The procedure of creating the example model.

3.6 Conclusion

A representation of collaboration mechanism is proposed in order to investigate synergistic effects of a collaboration. The proposed model is adopted Channel Theory and Chu space to accomplish the goal. Channel Theory is adopted to investigate synergistic effects of collaboration by considering through a scheme of infomorphism. Besides, Chu space is introduced to represent a scheme of infomorphism as a mathematical construction. By using the proposed scheme, we can evaluate the effectiveness of a collaboration by representing how new reachable knowledge broadens.

Based on the context of collaboration between two designers who have different backgrounds, the outline of the proposed model is illustrated. Current knowledge of designers are expressed in the form of classifications. Then gaining knowledge is deduced and expressed through infomorphisms. In order to show the usefulness of the proposed scheme, a collaboration between layout designer and color designer are represented with the proposed model as case study. The process of investigating layout design knowledge is shown in chapter 4 and the method to investigate knowledge of color designer is given a detail in chapter 5. In addition, an algorithm of infomorphisms generating tool has been developed based on the proposed model. We can compute all possible situations that may occur during a collaboration by using the tool.

4 Layout design knowledge: Model of web page layout design knowledge

To acquire knowledge of layout designer, layout design on a web page is adopted to be a representation of layout design knowledge in this study. The effect of layout items on user's impression is examined through a experiment. A modeling of web page layout design knowledge is proposed in order to provide operative expert's layout design knowledge.

4.1 Introduction

Nowadays, many companies encounter strong global competition, so they have to increase their competence. Knowledge sharing is one crucial factor for organizations to survive intense competition [71]. It has also been pointed out that knowledge sharing practices in an organization are very important for facilitating innovation and improving performance [72]. Thus, knowledge sharing should be prioritized in organization activities. Tacit knowledge is a significant chapter of the knowledge theories. It can be described as personal knowledge and difficult to formalize. This type of knowledge is acquired through experience, observation and imitation, and it cannot be transmitted easily with language [73]. Thus, this type of knowledge is difficult for us to obtain and share. Here, if tacit knowledge can be visualized as a model, it becomes easy to comprehend. A visual designing process is a good example that requires tacit knowledge. Usually, the client expects the result of designing to look a certain way. Capable designers can easily create appropriate designs that reflect clients' requirements but this is not simple for novice designers. Thus, to create an effective design, the creator has to implement his/her intended impressions in the correct form. Then, the users can feel the intended impression from the artifact. This scheme can be represented as an analogy of the communication process model proposed by Shannon and Weaver [74]. The transmission processes of general information and a design image are shown in figure 4.1 and figure 4.2, respectively.

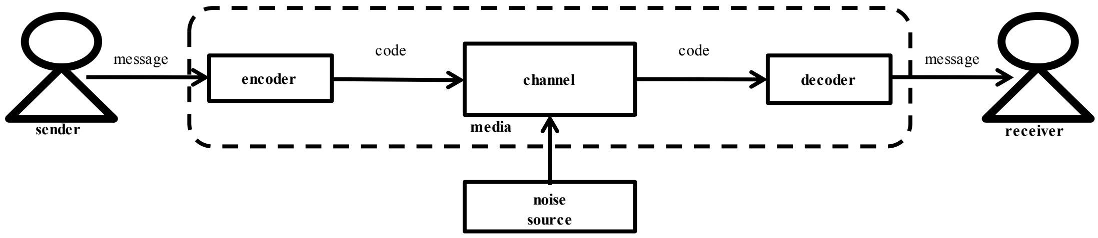


Figure 4.1 – Schemata of communication showing how general information is transmitted and processed.

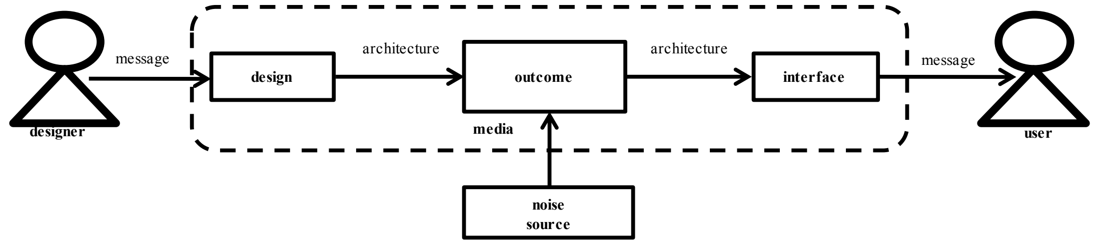


Figure 4.2 – Schemata of communication showing how design image is transmitted and processed.

For successful communication, a sender must transmit information to a receiver precisely. In a communication system, the sender encodes a message into codes that consist of a series of symbols based on their own inherent knowledge. The symbols may be written or spoken words, pictures, music, etc. The symbols reach the receiver via a channel. Then the code is decoded, and the receiver can understand the information. In this process, the information channel is influenced by several noises and the noises may distort the original information. Usually, many digital communication channels have mechanisms to reduce the effects of noises. Meanwhile, in the transmission process of a design image, such a noise reduction system cannot be put between designer and user. Thus, the design process is more difficult than the encoding process in verbal communication, so a support system is required. In order to extract knowledge of layout designer, a layout design process for web pages is employed as a representation knowledge of layout designer.

In this chapter, we focus on knowledge of layout designer, then other elements such as colors, pictures, etc. are ignored. An experiment is conducted to investigate how the collected web pages reflect the images. Then, models of design knowledge were created by using Bayesian network theory. These knowledge models can restrict the amount of noise in the communication system. Moreover, the knowledge model may help inexperienced designers to conveniently create a web page at an expert level.

Based on the notion in section 3.4.2, the classification of knowledge of layout designer is constructed by employing the results from the experiment.

4.2 Effect of layout of web page on a user's impression

The relationship between impression and layout items of a web page is investigated. Then, the associated models are created by using a Bayesian network to visualize the tacit knowledge. Since outcomes of expert designers should reflect their intentions, the relationship between design and the intention should be clarified. To obtain an expert's design knowledge, we assume that web pages, created by capable designers contain the designers' intentions. Such intentions are especially reflected in the elements of the web pages such as font style, font size, text margin, etc.

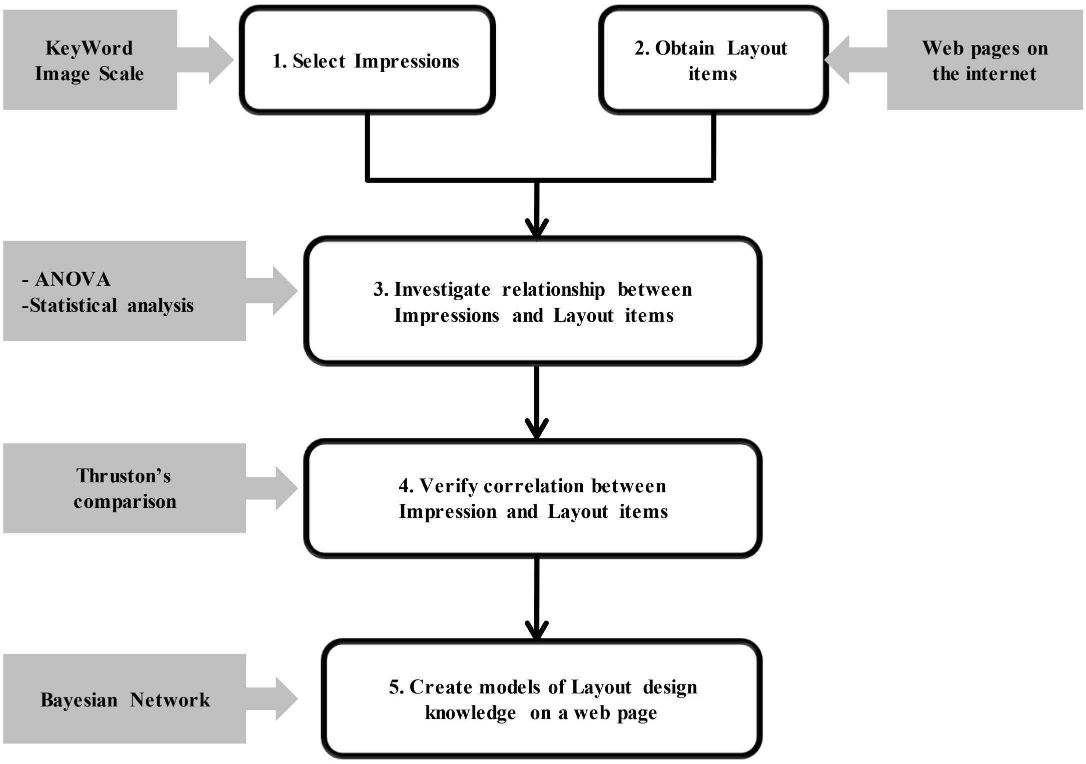


Figure 4.3 – Procedure of extracting layout design knowledge.

The outline of the proposed method is shown in figure 4.3. The first step is selecting impression words that represent designers' intentions and collecting representative web pages of the impressions. Then, the layout information is extracted from these web pages. Subsequently, the relationship between impressions and layout items is investigated and verified through experiments. Afterward, the knowledge models of the web page's layout design are created. The optimal model

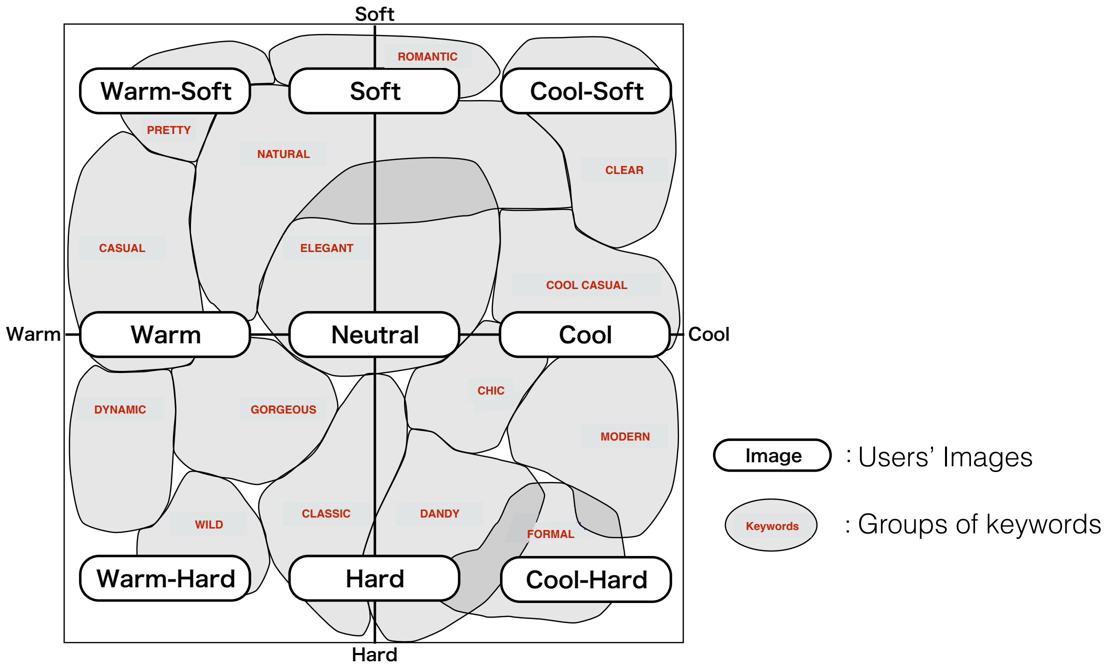


Figure 4.4 – KeyWord Image Scale.

is chosen to be the representative model. The detail of each step is explained as follows:

Step1: Select Impressions

The first step is selecting impressions that explain a designer's intention. The Japanese Color and Design Research Institute developed a cluster of impressions called KeyWord Image Scale [63], which has two axes: the Warm-Cool axis and the Soft-Hard axis. Nearly 180 adjectives are located on the scale. Each word expresses an impression associated with a color. The space represented by the language image scale can be divided equally to nine domains as shown in figure 4.4 Warm, Cool, Soft, Hard, Warm-Soft, Warm-Hard, Cool-Soft, Cool-Hard, and Neutral. In this study, these nine keywords are used for representing impressions of web pages.

Step2: Obtain Layout Items

The second step is collecting layout items. Ninety web pages were selected from the Internet. Each web page reflects an impression that corresponds to a position on the KeyWord Image Scale. The data of layout items were extracted from contents of the ninety web pages. The structure of a web page is shown in figure 4.5

Figure 4.5 – Structure of a web page.

Generally, contents on web page are marked up with HTML. Meanwhile, elements of a web page, layout, colors, and fonts are defined with a CSS (Cascading Style Sheet). A CSS file is embedded into an HTML document, and it defines the layout of the page. A content of a page can be divided into three domains, as follows:

- **Title** ⟨*h*1⟩ means a short sentence located above content. Usually, the letters are the biggest of all the elements. This part always displays the subject topic and appears just once.
- **Subtitle** ⟨*h*2⟩ means a short sentence located below the title. Usually, the letters are bigger than those in the body. This part summarizes the meaning of content in the body and may appear multiple times.
- **Body**⟨*p*⟩ A set of sentences located below a subtitle. This part occupies most of the content area and represents the details of the topic.

Usually, a web page is constructed by using many layout elements such as letter characteristic, text margins, color schemes of the image, etc. To focus on the relationship between the impressions and layout items, color scheme of the web page and image data were ignored.

The layout elements used in the experiment are shown in figure 4.6 and defined as follows:

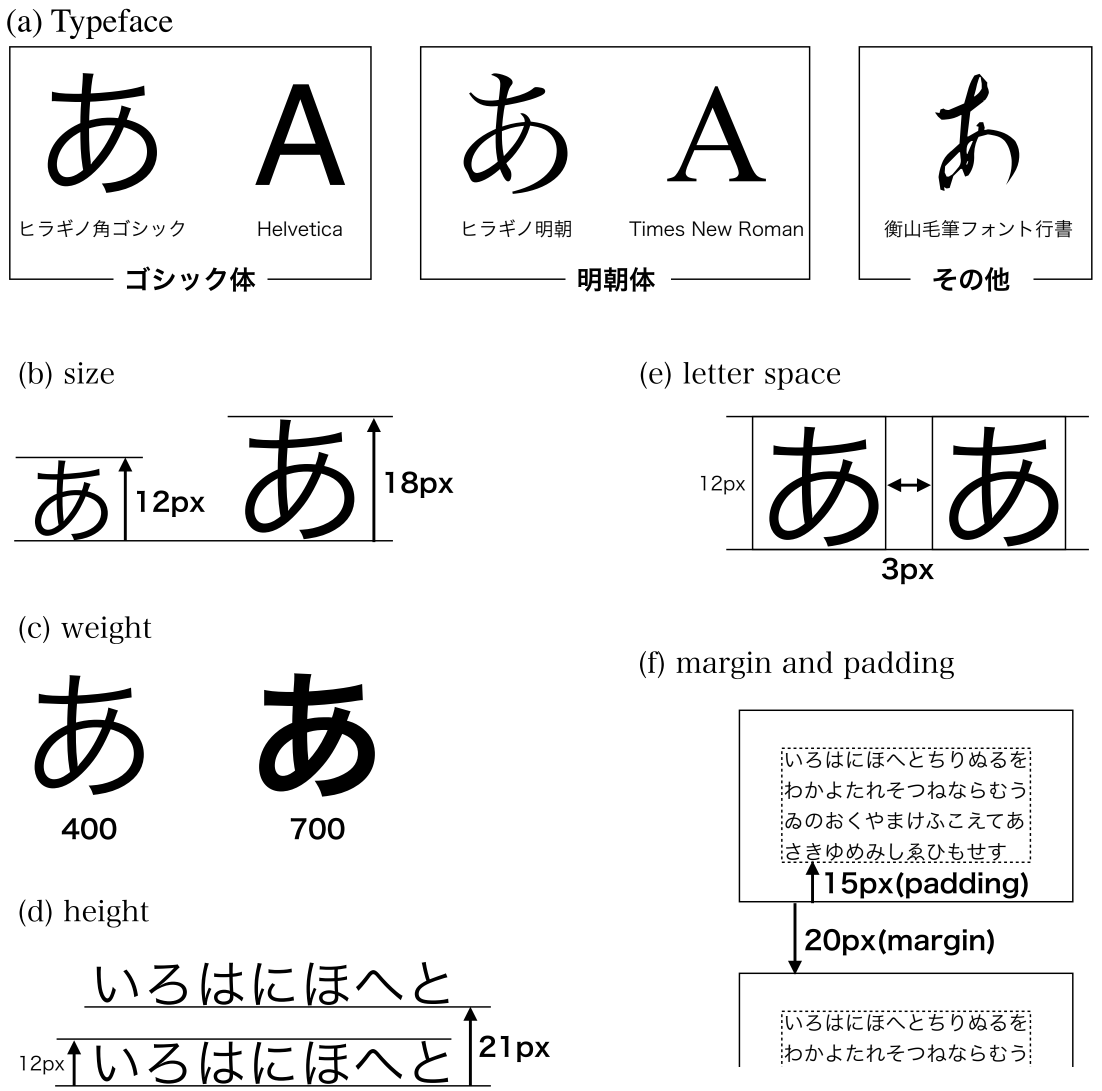


Figure 4.6 – Layout items used in the experiment.

- **Typeface** means the style of the letters. Fonts can be classified into two font families: Japanese and Latin. The Japanese font family includes Gothic, Ming, and Cursive styles. Meanwhile, the Latin font family includes Sans-Serif, Serif and Script styles.
- **Font size** means the size of the letters that is a vertical measurement from the reference base line.
- **Font weight** means the weight or the boldness of the letters.
- **Line height** means the distance between the base line and the next adjacent line.

- **Letter spacing** means the distance between the regions of adjacent letters.
- **Margin** means the space between the text boxes.
- **Padding** means the distance from the box frame to the letter domain in the box.

The example of CSS code of layout elements is described in table 4.1.

p3cm p10cm

Table 4.1 – The example of CSS code of layout elements used in the experiment.

Layout element	Example of CSS code
Typeface	$h1$ {font-family: serif}
Font size	$h1$ {font-size:12px}
Font weight	$h1$ {font-weight:400}
Line height	$h1$ {line-height:21px}
Letter spacing	$h1$ {letter-spacing:3px}
Margin	$h1$ {margin-top:20px; margin-bottom:20px; margin-right:20px; margin-left:20px;}
Padding	$h1$ { padding-top:15px; padding-bottom:15px; padding-right :15px; padding-left: 15px;}

Many web pages are used for advertising products or providing services. Usually, the impression of a web page depends on the category of such products and services. For example, the website that advertises soft drinks should provide a cool image, and a page providing a financial service should have a hard image. Thus, the genres of products and services can be classified in accordance with the expected impression. Therefore, genre can be employed as a criterion for classifying web sites that represent each impression. Eighty-five web pages were selected to be the sample web pages. Brainstorming was conducted to class product genres by considering the impressions. The product genres were arranged on the language image scale as shown in figure 4.7.

Step3: Investigate relationship between Impressions and Layout items

The third step is investigating the relationship between impressions and layout items. The web pages that reflect the nine impressions mentioned above were collected from the Internet. Ten pages for each category, thus the ninety web pages, were obtained. Ratios of the web pages in each product genre which divided by typeface are shown in figure 4.8.

Then, ANalysis Of VAriance (ANOVA) was conducted to investigate the differ-

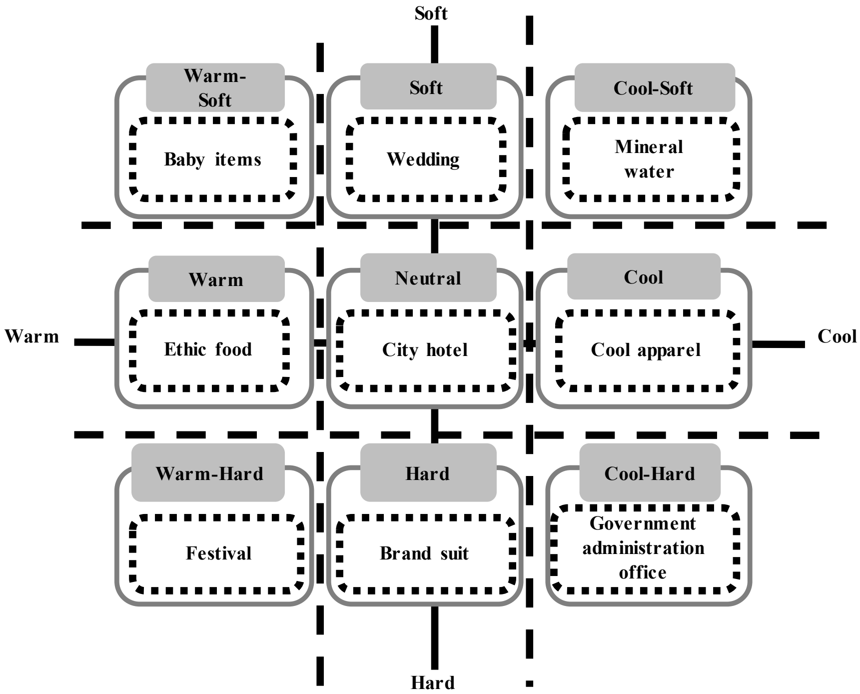


Figure 4.7 – Genres that represent each impression.

ences layout information between each product genre as shown in table 4.2 and table 4.3.

Table 4.2 – Results of analyzing variance of layout items for $p-value < 0.05$.

Layout items	P-value
Title-Text size	0.018
Title-Font weight	0.017
Body-Text size	4.4×10^{-6}
Body-Line height	0.026
Body-Letter spacing	0.011
Body-Left margin	0.018

The following six items are significantly different in each genre ($p-value < 0.05$): Title-Text size, Title-Font weight, Body-Text size, Body-Line height, Body-Letter spacing, and Body-Left margin. The following four items show a marginally significant difference in each genre ($0.05 \leq p-value < 0.1$): Title-Letter spacing, Title-Left padding, Subtitle-Font weight, and Subtitle-Line height. In the results, the mean values of these layout items were different in each product genre.

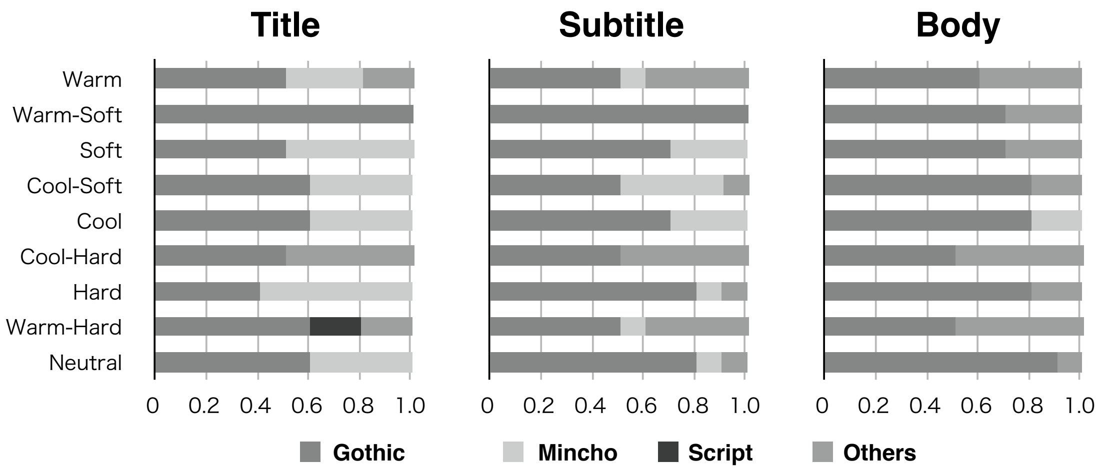


Figure 4.8 – Ratios of the web pages divided by typeface.

Table 4.3 – Results of analysing variance of layout items for $0.05 \le p - value < 0.1$.

Layout items	P-value
Title-Letter spacing	0.077
Title-Left padding	0.077
Subtitle-Font weight	0.076
Subtitle-Line height	0.093

Step4: Verify correlation between Impressions and Layout items

The fourth step is conducting an experiment to verify if the layout information extracted from the collected web pages reflects the expected images correctly. The outline of the method for creating web pages that are used in the verification step is shown in figure 4.9. Two web pages are selected from the samples for each impression. Eighteen web pages are obtained in this way. The CSS files are extracted from the selected web pages. Then, eighteen test pages are created with a test HTML file and eighteen extracted CSS files.

Twenty participants took part in this experiment. Four participants were students from a design department of university. Thurston's method of paired comparisons **??** was used to verify the image of the sample pages. Thurston's method of comparisons is a very useful method to measure human feelings among many objects.

In this procedure, the participants were shown a pair of pages, and asked to compare the pages on the basis of their impressions, and this was repeated until all combinations had been shown. Thus, a participant compared $({}_{18}C_2)$ times. The example of test screen shown in figure 4.10.

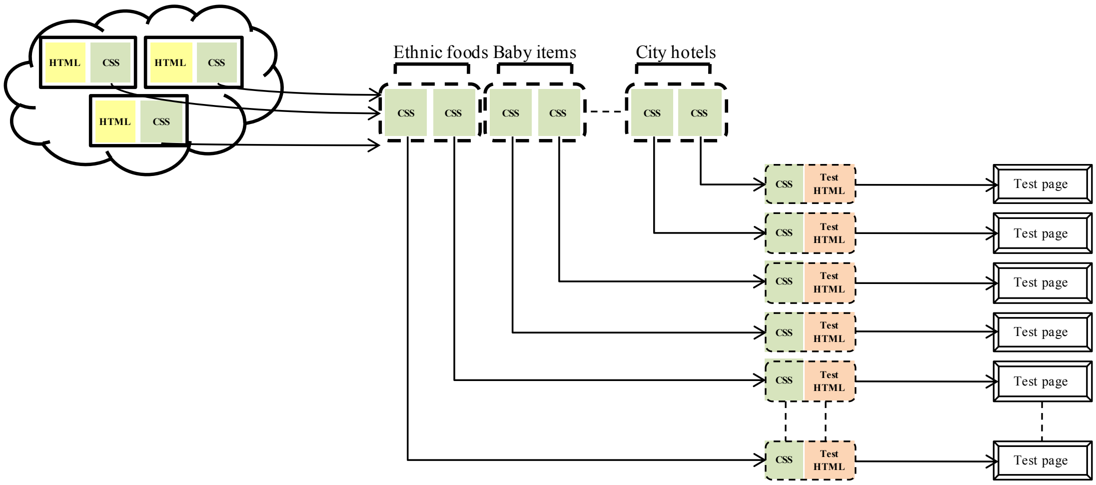


Figure 4.9 – Procedure of making sample pages for the experiment.

The process started with participates were asked which page was harder on the **hard-soft** scale. After all web pages were judged, the same procedure was conducted again on the **warm-cool** scale. Participates judged all web pages using two images scales such as **hard-soft** and **warm-cool** images. Figure 4.11 and 4.12 show the results on the **hard-soft** and **warm-cool** scales, respectively.

From figure 4.11, we can see that many web pages categorized into soft groups are located on the soft side. Meanwhile, from figure 4.12, we can see that some web pages categorized into cool group are located on the cool side. This means that the **soft** and **cool** axis is trustworthy.

Step5: Create models of Layout design knowledge on a web page

The last step is generated the models that represent the relationship between two impressions (**soft** and **cool** images) of page and the layout items. The Bayesian Network is used to structure the models. A Bayesian networks is a graphical model that encodes probabilistic relationship among variable of interest. This can be used for data analysis, and is widely used in data mining applications [75]. Several algorithms for learning the structure of a Bayesian network have been developed. In this study, two kinds of techniques for scoring-based structure learning algorithms, which are Hill Climbing (HC) and Tabu Search (Tabu), are employed. Besides, the scoring functions that used in this study are the Akaikes Information Criterion (AIC) and the K2 evaluation value. Then, the suitable model is distinguished by using the leave-one-out cross validation (LOOCV) method.

Usually, input data of Bayesian network should be discrete values. Discretization of the layout items was performed because the raw data obtained in the previous

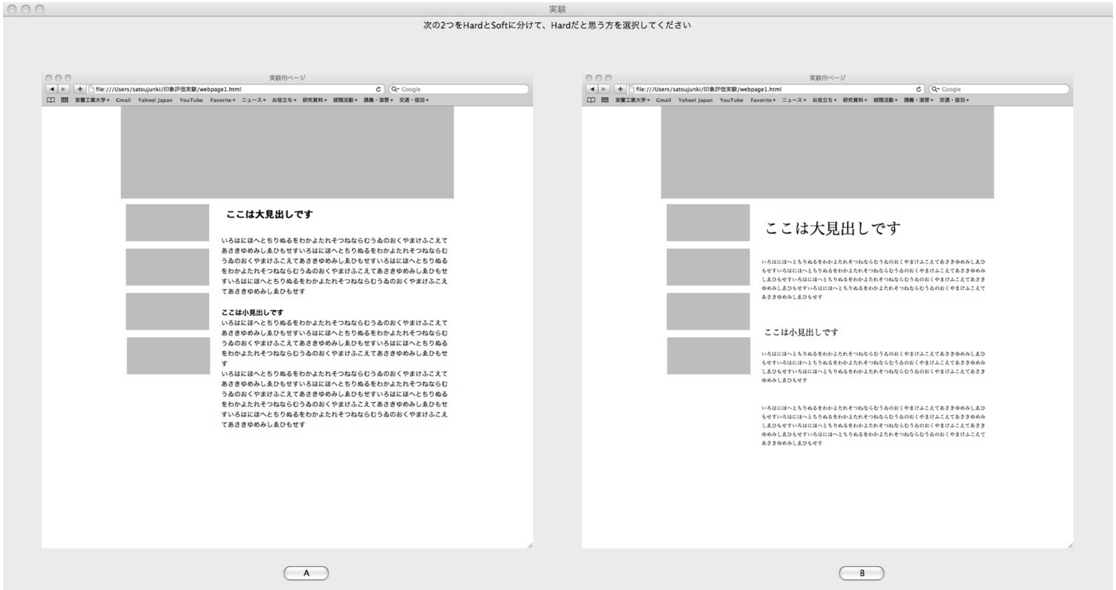


Figure 4.10 – The example of test screen used in the comparison analysis.

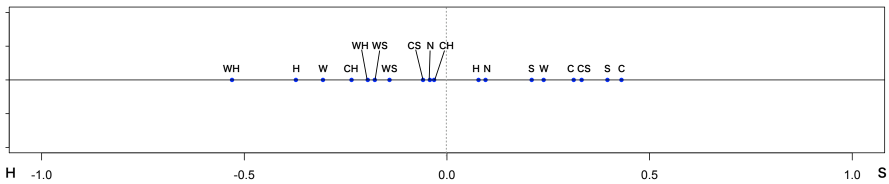


Figure 4.11 – Scatter diagram of comparison results in **Hard-Soft** scale.

steps were continuous values. Then, the associated models were structured by using Bayesian network techniques. The data analysis software “R” was utilized for generating the models.
Four models were created with the algorithms listed in table 4.4. These models are shown in Appendix A.2.

Table 4.4 – Structure learning algorithm and network scores in each model.

Model	Structure learning algorithms	Network scores
1	Hill Climbing	Akaike’s information criteria (AIC)
2	Hill Climbing	K2 evaluation value
3	Tabu Search	Akaike’s information criteria (AIC)
4	Tabu Search	K2 evaluation value

From the model structures, we can notice that there are six nodes that involve two impression nodes (**soft** and **cool** images). As a result, the eight crucial nodes were assessed in order to evaluate the accuracy of models:

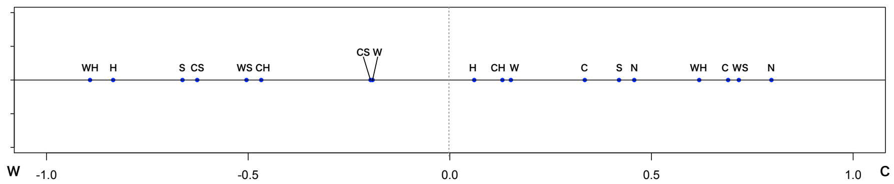


Figure 4.12 – Scatter diagram of comparison results in **Warm-Cool** scale.

Table 4.5 – The meaning of nodes that appear in the models.

Node	Meaning	Options
IC	Impression of Cool	Cool, Neutral, Warm
IS	Impression of Soft	Soft, Neutral, Hard
TW	Weight of the letters in title domain	1, 1.75
SW	Weight of the letters in subtitle domain	1, 1.75
SPT	Top padding of subtitle domain	0px, 4px, 10px, 20px
TF	Font family of title domain	1; Gothic, 2; Mincho, 3; Others, 4; Not specify
BS	Font size of body domain	8.82px, 11px, 12px, 14px, 16px
BML	Left margin of body domain	0px, 15px, 30px, 40px, 55px

- Two impressions: **cool and soft**
- Three layout items that closely correlated with cool and soft impressions: **title-font weight, subtitle-font weight, and body-padding-top**
- Three layout items that connected with the cool and the soft impressions: **title-font family, body-font size, and body-margin-left**

The LOOCV was adopted to assess how well models perform. The results show that the ratios of correct answers of model 4 are higher than the chance levels for seven nodes as well as being the best for all models overall. Therefore, the model 4 represents knowledge of web designers best in these models. The fitness was also evaluated by using four information criteria tools: AIC, BIC, Log-likelihood, and K2. As a result, we can see that model 4 is the most suitable model to visualize the knowledge of the layout design. The results of evaluation are shown in table 4.6.

From the results, the model created with the K2 evaluation level and the Tabu search algorithm was the most appropriate. However, concerning the attributes of cool and soft, the ratios of correct answers are quite low. This indicates that this model is not suitable to estimate impressions of cool and soft. On the other hand, this knowledge model may be superior to estimate style of font and text size because the percentage of correct answers is rather high. The models created with the proposed method could be used for developing a design support system for web pages, which would work like an expert system. Such a system would be

Table 4.6 – Results of LOOCV analysis.

Node	Ratio of correct answer				Chance level
	Model 1	Model 2	Model 3	Model 4	
IC	0.400	0.189	0.200	0.200	0.333
IS	0.300	0.322	0.389	0.389	0.333
TW	0.467	0.467	0.644	0.644	0.500
SW	0.811	0.800	0.678	0.678	0.500
SPT	0.622	0.622	0.433	0.444	0.250
TF	0.600	0.522	0.722	0.722	0.250
BS	0.478	0.478	0.600	0.600	0.200
BML	0.900	0.878	0.867	0.889	0.200

beneficial for inexperienced designers because they could receive useful advice from the system just like from expert designers. In addition, this system would infer the duplication of expert knowledge. From this function, the implicit knowledge could be transmitted to and shared with the public. Moreover, organization intellect in the field of design would be developed by utilizing our methodology.

4.3 Conclusion

In order to extract knowledge of layout designer, the knowledge algorithms of a web page layout design by using Bayesian networks have been evaluated. Four models were generated with a different algorithm. From the models, we can find that there are eight crucial nodes which are considered to evaluate the accuracy of model: Impression of Cool, Impression of Soft, Typeface of title domain, Left margin of body domain, Font size of body domain, Top padding of subtitle domain, Weight of the letters in subtitle domain and Weight of the letters in title domain. Subsequently, a comparison of learning algorithms was carried out by using LOOCV technique. As the model structured with Hill-climbing technique and the AIC score (HC&AIC) and the model structured with Tabu Search and the AIC score (Tabu&AIC) can represent all of layout element and soft-hard impression well whereas it is not suitable to estimate impression of Cool. Regarding to the networks structured with Hill-climbing technique and the K2 (HC&K2), the result reveals that ratios of correct answer of all nodes of impressions (IC, IS) are lower than chance level. It implies that this method is not suitable to represent impression of Cool and Soft. The result of analyzing the model structured with Tabu search and the K2 (Tabu&K2) reveals that ratios of correct answer of all nodes of impressions (IC, IS) are higher than chance level. It implies that this method is suitable to represent knowledge of web page layout design. Thus, we can argue that the model created with Tabu search and the K2 is the most appropriate. However, the ratios of correct answers of Cool impression node (IC) and Soft impression node (IS) are quite low. This indicates that the model created with Tabu search and the K2 is not suitable to estimate impression of Cool and Soft. On the other hand, this knowledge model may be superior represent style of other layout items because the percentage of correct answers is rather high.

The models created with the proposed method could be used for developing a design support system for web designers, which would work like an expert system. The support system provides alternative of web page layout design by illustrating layout template options to a user. In order to generate the most suitable model, model structured with Tabu search and the K2 algorithms are selected. These structure learning algorithms can visualize the knowledge of the layout design accurately. Such a system would be beneficial for inexperienced designers to create a web page at an expert level more conveniently because they could receive useful advice from the system just like from expert designers. In addition, this system would infer the duplication of expert knowledge. From this function, the implicit knowledge could be transmitted to and shared with the public. Moreover, organization intellect in the field of design would be developed by utilizing our methodology.

5 Color design knowledge: a model of interface color design knowledge

To obtain knowledge of color designer, interface color design in touch panel device is used to be a representation of color design knowledge. The effect of interface color design on users' emotions is clarified through an associate model between interface color design, user's emotion and operation.

5.1 Introduction

Recently, the demand of using electronic appliances with touch panel interface has been rising more and more. Touch screen technology is widely used for ATMs (Automated Teller Machines), ticket vending machines, interactive kiosks and so forth. Many personal devices such as smart phones, tablets PC, also use this technology. These devices are used in several fields e.g., service and health care [76]. Touch panel interfaces enable a user to interact directly with a device by using his/her fingers. Users can retrieve target information by touching the screen [77]. Many researches claim that operation time of touch screen usage is significantly less than physical input devices such as keyboard and mouse on a same task [78, 79]. Furthermore, touch interfaces are easy to adjust the interface design; size, color, and location of items on a screen [80]. Due to the above advantages, i.e., easy use, flexible design, and better performance, touch screens have became popular, and user-friendly touch panel interfaces are required. Thus, a touch panel device was used in the experiments.

Color information is one of the most influential factors which affects users' perceptions, physiological reactions and emotional reactions [81]. Thus, appropriately using of colors in an interface can lead to better performance of the operators. Conversely, poor use of color might lead to decrease in performance and increase the ability of visual fatigue [82]. There are many studies which inquired into relationships between color interfaces design and the operations. The results revealed that color affects users' working performances. However, users' perceptions for a coloration are difference depend on the individual. Consequently, it can be assumed that the difference might cause differences of users' feelings. Several studies have provided evidences of relationships between colors and emotions. They have found that each different color has an individual impact on human. According to Pastoor [83], subjective measure can be more sensitive to distinguish a difference in color display on monitors than measures with instruments. In addition, many previous researches have used emotional evaluation rather than physiological evaluation [84]. Therefore, it is expected that colors which decorate an interface design, the users' emotions and the task performances are related each other. Unfortunately, almost of the previous researches were done in which impacts of colors on emotions or task performances were investigated independently as shown in figure 5.1. However, design cognition might vary from a person to a person and the relationships also may change depend on an individual. Thus, a novel representation model of relationship between interface color design and operation is proposed as shown in figure 5.2. In this scheme, an interface design is recognized by an operator, and he/she has some feelings about the design. Then, his/her operations are influenced by the feelings. This scheme is expected to represent the effects of interface design on the user more clearly. This chapter aims to demonstrate advantage of the model which is generated based on the proposed scheme in comparison with a model based on the traditional one. In order to achieve the research goal, correlations between coloration interface and users' emotions have been investigated. Moreover, the relationship between users' emotions and operational performances are also verified. Two method approaches which are user experiments and questionnaires are conducted to obtain data. Then, Structural Equation Modeling method is employed to verify the proposed scheme and the traditional one.e validity of the proposed scheme by comparing the models that generated based on the

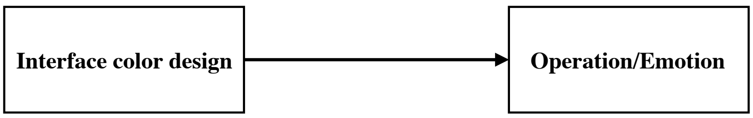


Figure 5.1 – Traditional scheme of effect of interface color design.

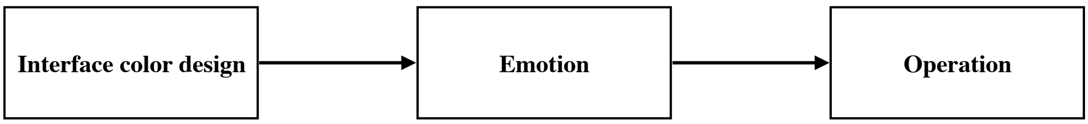


Figure 5.2 – Proposed scheme of effect of interface color design.

5.2 Relationship between color interface of touch panel on a user's emotion and operation

In order to comprehend how design affects users' cognitions and behaviors, novel scheme of association between design and operation performance has been proposed as described in the previous section. In order to verify the validity of the proposed scheme, a representative model is generated by using Structural Equation Modeling method based on the scheme and the model is analyzed. Eventually, the result of proposed scheme is compared and discussed with the model based on the traditional one. The outline of the process is shown in figure 5.3. The first step is the designing of experiments. In this step, an experimental equipment and tasks are designed. Next, the experiments are conducted in order to obtain data for generating models. In the experiments, participants are asked to do simple tasks and answer questionnaires. Afterward, a proposed scheme and a traditional scheme are applied to generate two models, i.e. a proposed model and a traditional model, with the results of the experiments. Structural Equation Modeling is utilized for the generating model process. Finally, correlation results are compared in the models which generated based on the traditional scheme and the proposed scheme.

5.2.1 Step1: Design of experiments

Outline of experiment

Two methods are adopted to obtain data: observing task performances and questionnaires. Relationship between users' feelings and operation are investigated through the experiment. The participants were asked to work arithmetical tests (single digit ones). Then, questionnaires were prepared in order to examine users' feelings on each screen. Afterward, experiments data and questionnaires data were fit in order to generate proposed model. The participants were males and females students in their twenties to thirties.

Equipment

To get performance data, a simple computer application which quizzes addition questions was used. The bottom of the screen of this application is decorated by a color schemes. This color scheme can be chosen from the color sets on a color combination image scale [63]. The color combination image scale is an image map which transforms color schemata into impressions. This scale has two axes, "soft_ hard" and "cool_ warm." Twelve major descriptive phrases were selected as representative color schemes; "casual," "cool_ casual," "romantic," "modern,"

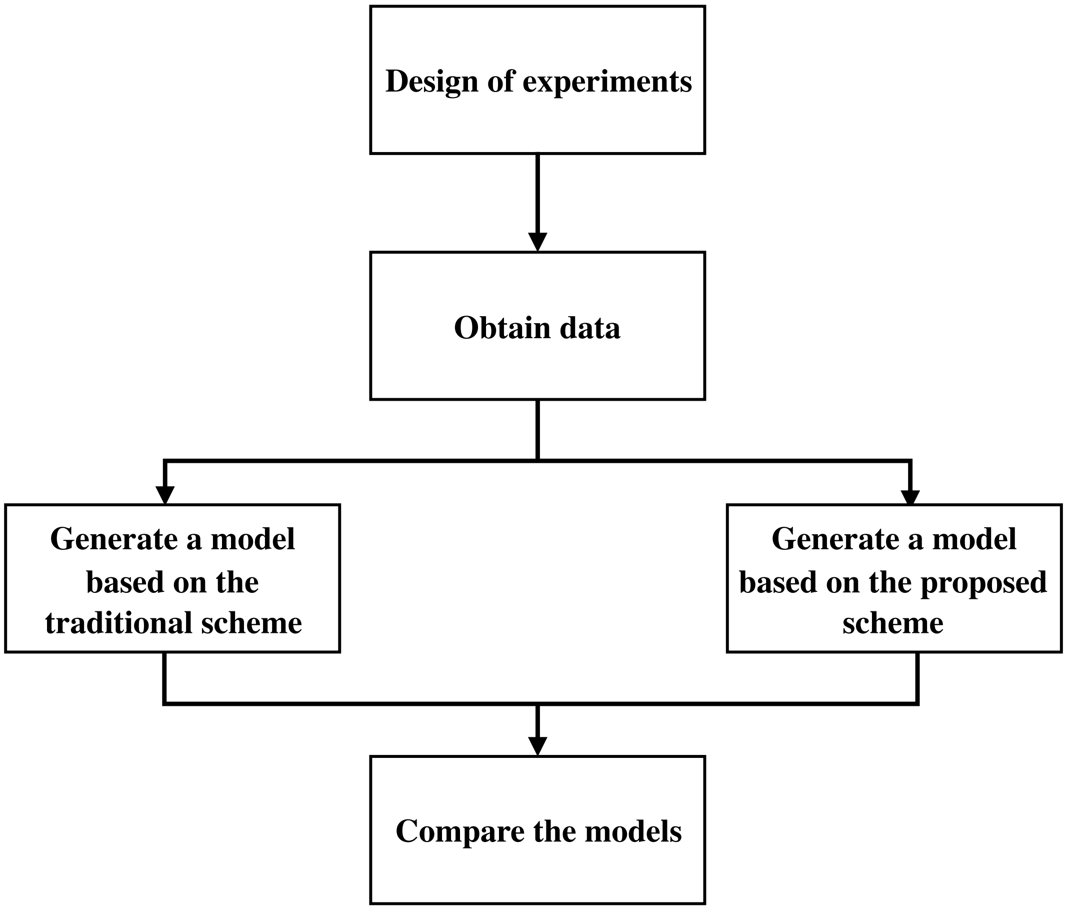


Figure 5.3 – Outline of the study of interface color design.

“elegant,” “classic and dandy,” “formal,” “clear,” “natural,” “chic,” “gorgeous,” and “wild.” Each color scheme consists of three to five different colors. The representative color schemes are shown in figure 5.4. The components colors used in each color scheme are shown in figure 5.5 by using Munsell color system.

An example of screen which is used in this research is shown in figure 5.6. The background of the screens are colored by pale gray (N8), and the push panels’ color are white (N9.5). The color of characters are dark gray (N3). The colors of these components were chosen by considering visibility of characters in the screen. The three alternatives are placed for each problem.

In the experiments, the decoration color scheme was chosen from representative color schemata which mentioned above. Each screen was displayed with a different color scheme without changing other components. Thus, the experiments have been conducted under twelve different conditions.

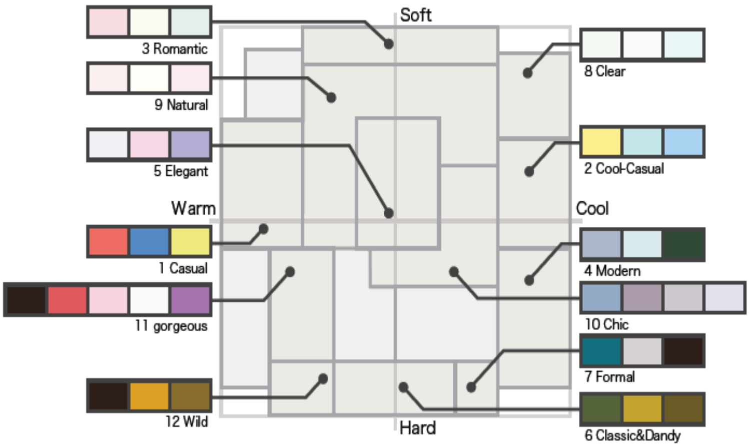


Figure 5.4 – The twelve color schemes which were used in the experiments.

Image word	Color 1	Color 2	Color 3	Color 4	Color 5
01.casual	5R 5/12	5PB 4/10	10Y 8/12	—	—
02.cool-casual	6Y 8/10	5B 7/6	5PB 6/8	—	—
03.romantic	7.5R 8/4	7.5Y 9/6	2.5G 8.5/2	—	—
04.modern	6.25PB 5.6/6	5B 8/4	5BG 3/2	—	—
05.elegant	10PB 8/4	2.5RP 8/4	2.5P 6/6	—	—
06.classic&dandy	10GY 3/2	2.5Y 6/8	2.5Y 3/2	—	—
07.formal	5B 4/4	7.5PB 8/2	5PB 2/2	—	—
08.clear	10BG 9/2	10Y 9/0.5	10BG 7/4	—	—
09.natural	3RP 8/4	5Y 9.2/1	5P 8/4	—	—
10.chic	5PB 6/4	5P 6/2	5P 7.5/0.5	5PB 8/1	—
11.gorgeous	5P 2/1	3R 4/12	5RP 8/4	7R 9.2/1	2.5P 4/10
12.wild	N1	8YR 5/8	10YR 4/4	—	—

Figure 5.5 – Colors which are used in the experiments.

Tasks

In the experiments, the participants tried single-digit mental arithmetic tests. The participants were requested to select one correct answer from three choices by touching one of three push panels. If a participant does not touch any buttons within 1.5 seconds, the system moved on the next problem automatically. Thirty different problems were contained in each condition. The spending time and the accuracy rate were chosen as indicators to measure working performances, and recorded.

Evaluation of users' feelings

Questionnaires have been conducted to obtain participants' feelings data for each screen. Questionnaire comprised fifth-teen sensations query in which chosen from web usability indicators in Japan [85] and four emotional indicators were developed by intense brainstorming session. The details of each sensation are described as follows:
Fifth-teen sensations which chosen from web usability indicators in Japan:

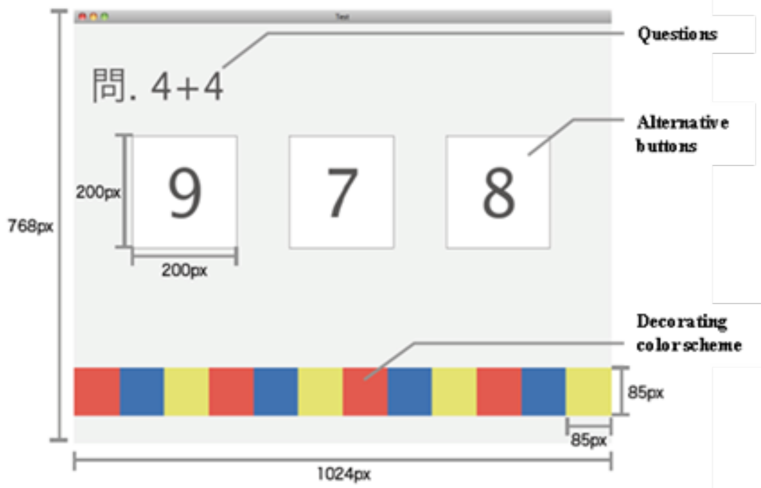


Figure 5.6 – An example of screen which used in the experiments.

- **Preference** : The state of being preferred
- **Luminous**: Easily understand
- **Visibility**: The degree of being visible
- **Steadiness**: To be fast to acting or deciding
- **Familiarity**: The state of being familiar
- **Eye strain**: The degree of fatigue of the eyes when a user look at the test screen
- **Legible**: Capable of being read
- **Beauty**: The quality that give a pleasure to the mind or sense
- **Comfortableness**: Free from stress or anxiety
- **Impressive**: The act of impressing
- **Safety**: Free from danger

Four emotional indicators were developed by intense brainstorming session:

- **Ease**: The feeling as though workload is few
- **Concentration**: The state of being concentrated on the task

- **Volition**: The capability of conscious intention to do the task
- **Relieve**: To have relieve from a mental strain

The participants were asked to assess their sentiment on each screen by adopting Visual Analog Scale (VAS) method for the scoring. A part of questionnaire is shown in figure 5.7.

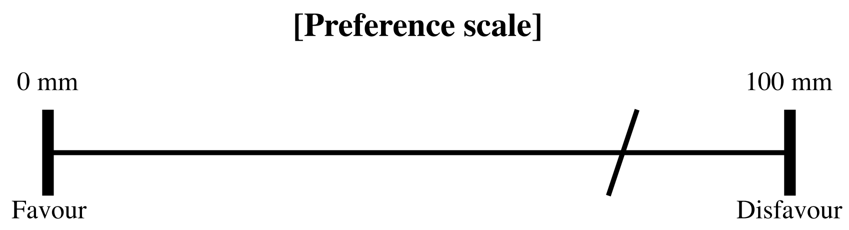


Figure 5.7 – A part of questionnaire for evaluating users' feelings.

5.2.2 Step2: Obtain data

The experiments ran under the twelve different conditions as described in last step. In each condition, each participant was requested to do calculation tasks and ask the questionnaire. Figure 5.8 illustrates the procedures of the experiments.

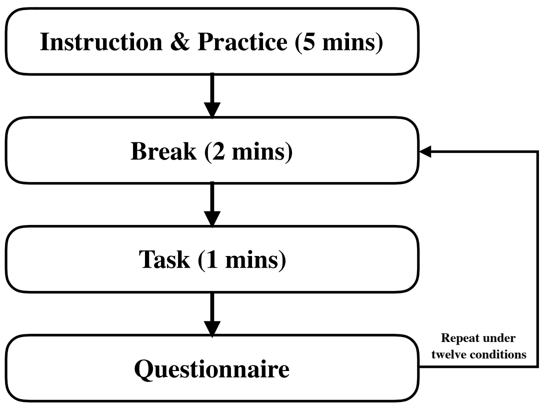


Figure 5.8 – Procedure of the experiments.

On the beginning, each participant got the instructions and trialed a training task. Secondary, the training task was conducted on a screen that had no color decoration. Following a practice step, the participant tried the tasks on the twelve screens. Afterward, the participants had to answer the questionnaires to evaluate their feeling with each decorated color scheme. A two minutes break was given between each condition for resting and decreasing the effect by previous screen.

5.2.3 Step3: Generate the representative models

After the experiment process, Structural Equation Modeling (SEM) approach is adopted to generate representative models. SEM is a technique to express a complicated statistical model by a path diagram which expresses causation between variables with an arrow line clearly. SEM model can be represented as a diagram by using squares and arrows. A square represents variable and an arrow means causation between two variables. A numerical value added to an arrow expresses a degree of effect [86]. The results from SEM method were shown by using comprehensible graphic. Sample models were generated from data which obtained from the experiments and the questionnaires which mentioned in the previous step.

Initially, input data was prepared by using Discretization method and Pruning method in order to improve the fit of the models. Consequently, two models have been generated based on types of scheme, traditional scheme which is shown in figure 5.1 and proposed scheme which is shown in figure 5.2, have been generated by using the SEM method. A diagram of generated model which based on the traditional scheme is shown in figure 5.9.

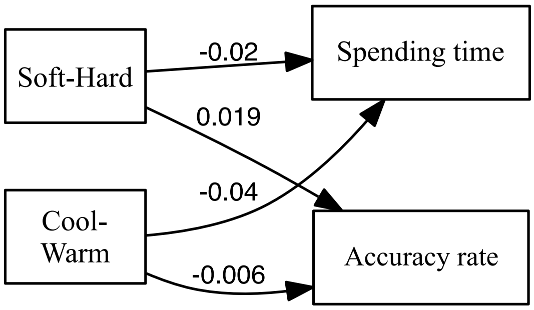


Figure 5.9 – A SEM diagram based on the traditional scheme.

The model which is generated based on the proposed scheme showed that there are five emotions which linked up operations; steadiness, ease, safety, beauty, and luminous. Thus, the emotion nodes which are not connected with operation nodes were eliminated and the model has been re-generated. The re-generated model is exhibited in figure 5.10.

As shown in figure 5.10, there are fifth emotions connected with working performances in the model based on the proposed scheme. Steadiness quicken spending time to complete work whereas sensation of Ease effects negatively on the spending time index. For accuracy rate indicator, Luminous tends to increase number of correct answers in the tasks. Moreover, there are positive correlations with both of working performance and Safety. On the other hand, there are negative correlations between the performances and Beauty. Therefore, it can be confirmed that

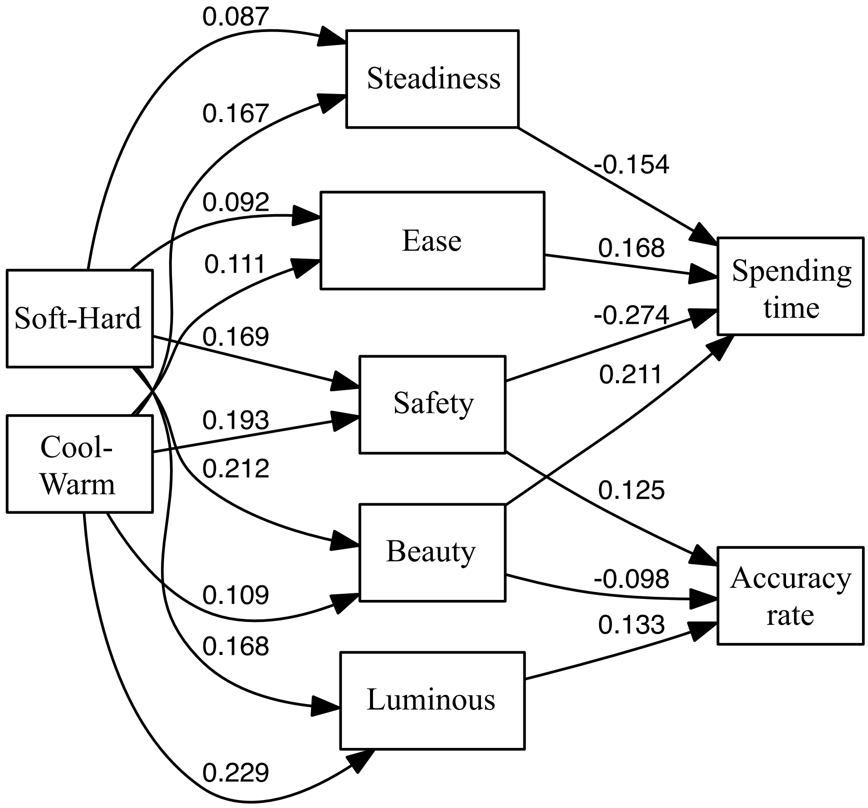


Figure 5.10 – A SEM diagram based on the proposed scheme.

the operational performances and the users' feelings have a causal association. Following, the Soft-Hard node and the Cool-Warm node are connected with all nodes of emotions positively.

5.2.4 Step4: Compare the models

In this section, the efficiency of the proposed scheme is clarified and discussed by comparing two models, generated based on the proposed scheme and based on the traditional scheme. In the case of the model based on the traditional scheme, the result shows that the **soft-hard** value has negative effect on **working time**, whereas has positive effect on **accuracy of operation**. Meanwhile, both of operation indicators were affected negatively by the **warm-cool** value. However, coefficient of each path is quite low as shown in figure 5.9. Thus, we cannot find any significant effects of the interface design on working performance indicators when investigating through the model which is generated based on the traditional scheme. This is to say, the analysis with this model cannot clear up effects of the interface color design on the users' operation.

From the results of correlation analysis, we can notice that the model based on the traditional scheme is hard to explain that how coloration takes an effect on users' working behaviors. While the model based on the proposed scheme can assist us to better understand about how colors decoration of interface design influence operational performance through users' emotion perspective. The results show how coloration has effects on users' feelings and how operational performance was affected by users' feelings. Furthermore, the proposed scheme can illustrate the effect of colors interface design on users' operation more precisely than the traditional scheme.

5.3 Conclusion

In order to obtain knowledge of color designer, knowledge of color designer has been extracted through the proposed associate model between interface color design, user's emotion and operation. The new scheme has been proposed for better understanding how colors interface design influence users' operational performances. The new scheme represents relationship between design, user's feeling and operation. While, the traditional scheme considered only relationships between interface color design and operation or interface color design and emotion. To demonstrate advantage of the proposed scheme, the experiments and the questionnaires have been conducted to generate example models. Then, SEM method was adopted to construct the models based on the proposed model and traditional model. Finally, the results from two models were compared. It has been revealed that the proposed scheme can illustrate the relationship between interface color design and the operations more accurately than traditional scheme as a result of analysis of the models. Therefore, we can understand the mechanisms in which how an operator feels about an interface design, and how the operations get effects from the feelings with the proposed scheme.

The results have shown that there are causal relationships between interface colors design, users' feelings and operational performances. When the scheme is introduced into a practical system, the relationship between coloration and each operator should become clear. However, it is difficult to know how coloration effects on each person. An efficient method to find the relationship is expected to develop a design support system based on the proposed scheme.

6 Model of collaboration between Layout designer and Color designer

6.1 Introduction

In order to show the usefulness of the proposed scheme, an example of collaboration between layout designer and color designer in a web page design process are represented with the model as a case study. Knowledge of layout designer has been extracted from the model of web page layout design knowledge that we have described in chapter 4. Besides, knowledge of layout designer has been obtained from the model of interface color design knowledge as we have explained in chapter 5. Subsequently, in this chapter, classifications of knowledge of the members are generated based on knowledge of the designers that we have obtained. Afterward, new knowledge that may gain from the collaborations is deduced based on the methodology as depicted in section 3.4. Increasing knowledge is expressed by the infomorphisms. Finally, reasonableness of the results are discussed.

6.2 Classification of Layout design knowledge

Following chapter 4, the knowledge algorithms of a web page layout design by using Bayesian networks have been evaluated. In order to generate the most suitable model, model structured with Tabu search and the K2 algorithms are selected. These structure learning algorithms can visualize the knowledge of the layout design accurately. The results show that there are eight crucial nodes which are considered to evaluate the accuracy of model such as Impression of Cool, Impression of Soft, Font family of title domain, Left margin of body domain, Font size of body domain, Top padding of subtitle domain, Weight of the letters in subtitle domain and Weight of the letters in title domain. In order to structure classification of knowledge of layout designer, the layout items that significantly affect on users' impression are chosen from the result of the model.

In this example, two layout items are chosen from the eight influential items to be representations of knowledge of layout design which are **Font weight** and **Typeface** of title domain. The classification of layout design knowledge is represented with matrix (L) shown in figure 6.1.

(L)		Users' impression			
		Warm	Soft	Cool	Hard
Title : Font weight	W_1	0	0	1	1
	$W_{1.75}$	1	1	0	0
Title : Typeface	Gothic	1	0	1	0
	Mincho	0	1	0	1

Figure 6.1 – A classification of knowledge of layout designer.

Following the way to structure a classification as explained in section 3.4.2, each type stands for an impression and each token stands for a layout item, font weight or typeface of title domain. Tokens W_1 and $W_{1.75}$ mean weights of letters, which are defined as normal and bold respectively. Tokens Gothic and Mincho mean font styles of letters in title part. Gothic style is is a Japanese font features plain strokes similar to sans serif designs. Mincho is a Japanese font that features serifs at the end of its strokes.

The elements in the classification of layout design knowledge are derived from the following fact:

- when boldface and Gothic are used on the title of web page, it gives warm impression to the observers.
- when boldface and Mincho are used on the title of web page, it gives soft impression to the observers.
- when normal font weight and Gothic are used on the title of web page, it gives cool impression to the observers.
- when normal font weight and Mincho are used on the title of web page, it gives hard impression to the observers.

Such knowledge can be described as a classification as follows:

$$
\begin{aligned}
tok(L) &= \{W_1, W_{1.75}, Gothic, Mincho\} \\
typ(L) &= \{Warm, Soft, Cool, Hard\}
\end{aligned}
$$

$$W_1 \models_L Cool, \qquad Gothic \models_L Warm,$$
$$W_1 \models_L Hard, \qquad Gothic \models_L Cool,$$
$$W_{1.75} \models_L Warm, \qquad Mincho \models_L Soft,$$
$$W_{1.75} \models_L Soft, \qquad Mincho \models_L Warm.$$

6.3 Classification of Color design knowledge

Following chapter 5, knowledge of color designer has been extracted through the associate model between interface color design, user's emotion and operation. In this scheme, an interface design is recognized by an operator, and he/she has some feelings about the design. Then, his/her operations are influenced by the feelings. This scheme is expected to represent the effects of interface design on the user more clearly. To demonstrate advantage of the proposed scheme, the experiments and the questionnaires have been conducted to generate example model. Then, SEM method was adopted to construct the models based on the proposed scheme. The result shows that there are fifth emotions which significantly affect on the users' operation performance i.e. Steadiness, Ease, Safety, Beauty and Luminous. Moreover,we found that the color decorating have effect on the emotions positively. In order to structure classification of knowledge of color designer, the color combination that significantly affect on users' impression are chosen from the result of the model.

(C)		Users' subjectivity			
		Steadiness	Beauty	Safety	Ease
Color decorating	Red	0	1	0	1
	Green	1	0	0	1
	Blue	1	0	1	1
	Yellow	1	1	1	1
	Purple	0	1	1	0

Figure 6.2 – A classification of knowledge of color designer.

In this example, four powerful emotions are chosen from the fifth emotions to be representations of knowledge of color designer which are **Steadiness**, **Beauty**, **Safety** and **Ease**. The classification of color design knowledge is represented with matrix (C) shown in figure 6.2. Here, each token stands for an users' subjective term and each type represents a decorating color. The elements in the classification of color design knowledge are derived from the following fact:

- when a screen is decorated with green, blue and yellow, it gives steadiness image to users.

- when a screen is decorated with red, yellow and purple, it gives beauty image to users.
- when a screen is decorated with blue, yellow and purple, it gives safety image to users.
- when a screen is decorated with red, green, blue and yellow, it gives ease image to users.

Such knowledge can be described as a classification as follows:

$$
\begin{aligned}
tok(C) &= \{Red, Green, Blue, Yellow, Purple\} \\
typ(C) &= \{Steadiness, Beauty, Safety, Ease\}
\end{aligned}
$$

$$
\begin{aligned}
Red &\models_C Beauty, & Green &\models_C Steadiness, \\
Red &\models_C Ease, & Green &\models_C Ease, \\
Blue &\models_C Steadiness, & Yellow &\models_C Steadiness, \\
Blue &\models_C Safety, & Yellow &\models_C Beauty, \\
Blue &\models_C Ease, & Yellow &\models_C Safety, \\
Purple &\models_C Beauty, & Yellow &\models_C Ease, \\
Purple &\models_C Safety. & &
\end{aligned}
$$

6.4 Model of collaboration between Layout designer and Color designer

After the classification of the designers were structured, new knowledge that can gain from the collaboration is deduced based on the methodology in section 3.4.3. The matrices in figure 6.3 illustrate the collaboration of this situation by using the proposed model. In this case, the model consists of two classifications (L and C) and two sets of infomorphisms (I_1 and I_2). Classification L means the knowledge of layout designer as well as classification C means the knowledge of color designer. Moreover, two sets of infomorphisms (I_1 and I_2) mean new knowledge that can be deduced from the collaboration.

(L)

		Users' impression			
		Warm	Soft	Cool	Hard
Title : Font weight	W_1	0	0	1	1
	$W_{1.75}$	1	1	0	0
Title : Typeface	Gothic	1	0	1	0
	Mincho	0	1	0	1

(I_2)

1	0	1	0
0	1	0	1
0	1	1	0
1	0	0	1

(I_1)

1	1	0	0
1	0	1	0
1	0	1	1
1	1	1	1
0	1	0	1

(C)

Steadiness	Beauty	Safety	Ease		
0	1	0	1	Red	Color Decorating
1	0	0	1	Green	
1	0	1	1	Blue	
1	1	1	1	Yellow	
0	1	1	0	Purple	
Users' subjectivity					

Figure 6.3 – A model of collaboration in a web page design between layout designer and color designer.

6.4.1 I_1: Infomorphisms from classification L to classification C

Infomorphism from classification L to classification C can be illustrated as matrix (I_1) in figure 6.3. Columns in matrix (I_1) represent function $f^{\wedge}$; a mapping from types in classification L to types in classification C. From matrix (I_1) in figure 6.3, the results show that:

- The leftmost column of matrix (I_1) has the same element of the forth column of matrix (C). It means that the leftmost column of matrix (L): **Warm** is mapped to the forth column in matrix (C): **Ease** by function $f^{\wedge}$.

- The second column of matrix (I_1) has the same element of the second column of matrix (C). It means that the second column of matrix (L): **Soft** is mapped to the second column in matrix (C): **Beauty** by function $f^{\wedge}$.

- The third column of matrix (I_1) has the same element of the first column of matrix (C). It means that the third column in matrix (L):**Cool** is mapped to the first column in matrix (C): **Steadiness** by function $f^{\wedge}$.

- The rightmost column of matrix (I_1) has the same element of the third column of matrix (C). It means that the rightmost column of matrix (L):**Hard** is mapped to the third column in matrix (C): **Safety** by function $f^{\wedge}$.

While, lines in matrix (I_1) represent function $f^{\vee}$; a mapping from tokens in classification C to tokens in classification L. The results show that:

- The first line of matrix (I_1) has the same element of the second line of matrix (L). It means that the first line of matrix (C): **Red** is mapped to the second line of matrix (L): $W_{1.75}$ by function $f^{\vee}$.

- The second line of matrix (I_1) has the same element of the third line of matrix (L). It means that the first line of matrix (C): **Green** is mapped to the third line of matrix (L): **Gothic** by function $f^{\vee}$.

- The final line of matrix (I_1) has the same element of the forth line of matrix (L). It means that the final line of matrix (C): **Purple** is mapped to the final line of matrix (L): **Mincho** by function $f^{\vee}$.

6.4.2 I_2: Infomorphisms from C to L

Infomorphism from classification C to classification L can be illustrated as matrix (I_2) in figure 6.3. Columns in matrix (I_2) represent function $f^{\wedge}$; a mapping from types in classification C to types in classification L. From matrix (I_2) in figure 6.3, the results show that:

- The first column of matrix (I_2) has the same element of the rightmost column in matrix (L). It means that the first column of matrix (C): **Steadiness** is mapped to the rightmost column in matrix (L): **Hard** by function $f^{\wedge}$.

- The second column of matrix (I_2) has the same element of the leftmost column in matrix (L). It means that the second column of matrix (C): **Beauty** is mapped to the leftmost column in matrix (L): **Warm** by function $f^{\wedge}$.

- The third column of matrix (I_2) has the same element of the third column in matrix (L). It means that the third column of matrix (C): **Safety** is mapped to the third column in matrix (L): **Cool** by function $f^{\wedge}$.

- The rightmost column of matrix (I_2) has the same element of the second column in matrix (L). It means that the rightmost column of matrix (C): **Ease** is mapped to the second column in matrix (L): **Soft** by function $f^{\wedge}$.

Likewise, lines in matrix (I_2) represent function $f^{\vee}$; a mapping from tokens in classification L to tokens in classification C. The results show that:

- The second line of matrix (I_2) has the same element of the first line of matrix (C). It means that the second line of matrix (L): $W_{1.75}$ is mapped to the first line of matrix (C): **Red** by function $f^{\vee}$.

- The third line of matrix (I_2) has the same element of the final line of matrix (C). It means that the third line of matrix (L): **Gothic** is mapped to the final line of matrix (C): **Purple** by function $f^\vee$.

- The forth line of matrix (I_2) has the same element of the second line of matrix (C). It means that the forth line of matrix (L): **Mincho** is mapped to the second line of matrix (C): **Green** by function $f^\vee$.

We can compute all possible situations that may occur during a collaboration by using the developing tool. In this case, 120 infomorphisms have been obtained from “classification of layout design knowledge” to “classification of color design knowledge.” Meanwhile, there are 192 infomorphisms have been obtained from “classification of color design knowledge” to “classification of layout design knowledge.” Thus, $(I_1 \times I_2)$ can be considered as new knowledge obtained from the collaboration.

6.5 Results and Discussion

In the example, we can get 120 infomorphisms from “classification of layout design knowledge” to “classification of color design knowledge.” Besides, 192 infomorphisms have been also obtained from “classification of color design knowledge” to “classification of layout design knowledge.” It means we can expect that one of 120 × 192 kinds of situations could be occurred when the layout designer and the color designer collaborate in a design process. Each combination of the infomorphisms explains new knowledge, which they could obtain from the cooperation in the design process. However, we cannot say that all situations are proper understanding in the design context.

In figure 6.3, infomorphism I_1 shows:

$$f^\wedge(Warm) = Ease, \qquad f^\wedge(Soft) = Beauty,$$
$$f^\wedge(Cool) = Steadiness, \qquad f^\wedge(Hard) = Safety.$$

This infomorphism means that the designers can understand as follows;

- the items that give warm impression also provide ease image to observers.
- the items that give soft impression also provide beauty image to observers.
- the items that give cool impression also provide steadiness image to observers.
- the items that give hard impression also provide safety image to observers.

This new knowledge is acceptable because it is consistent in semantics.

On the other hand, infomorphism I_2 shows:

$$f^{\wedge}(Steadiness) = Hard, \qquad f^{\wedge}(Beauty) = Warm,$$
$$f^{\wedge}(Safety) = Cool, \qquad f^{\wedge}(Ease) = Soft.$$

This infomorphism means that the designers can understand as follows:

- the items that give hard impression also provide steadiness image to observers.
- the items that give warm impression also provide beauty image to observers.
- the items that give cool impression also provide safety image to observers.
- the items that give soft impression also provide ease image to observers.

This infomorphism says that the designers can understand that the design that gives warm impression also provides beauty image to observers. This new knowledge is difficult to accept because warm impression is conflict with beauty image according to the theory of science of color [63].

Moreover, we have applied the proposed model in several situations. To more examples in which we have researched are shown in Appendix A.3.

6.6 Conclusion

To verify the usefulness of the proposed scheme, an example of web page design cases has been shown as a case study. The examples illustrated the situation that the designers who have different background collaborated in a web page design process. In the example, a designer who has enough experience of layout design whereas the other designer is proficient in color design. They could have much new knowledge as a result of the collaboration but we cannot say that all increasing knowledge is acceptable because some new knowledge is nonsense.

In this way, we can say that the proposed model can represent situations which may occur in a collaboration of web page design process exactly. By using the proposed model, we can know not only valid outcomes but also unacceptable knowledge which is obtained through a collaboration. Such disagreeable knowledge could be considered as a misunderstanding which should be watched out in the design process. Nevertheless, it is also useful information to consider the effective collaboration.

7 Conclusions and Future directions

7.1 Conclusions

Due to benefit of synergistic effects, the effective collaboration is expected in team work. However, it is hard to investigate effective collaboration because the mechanism of generating such a new knowledge is implicit. Thus, a representation of collaboration mechanism is proposed in order to investigate synergistic effects of a collaboration. Channel Theory is adopted to investigate synergistic effects of collaboration by considering through a scheme of infomorphism. Besides, Chu space is introduced to represent a scheme of infomorphism as a mathematical construction. The proposed model is structured based on the collaboration between two members who have different backgrounds. To verify the proposed scheme, a collaboration between layout designer and color designer have been represented with the proposed model as a case study. Moreover, an algorithm of generating all possible infomorphisms has been developed for showing the usefulness of the proposed model. The algorithm has been implemented as a tool on MATLAB environment.

To acquire knowledge of layout designer, layout design on a web page has been adopted to be a representation of layout design knowledge. The effect of layout items on user's impression has been examined through a experiment. A modeling of web page layout design knowledge have been evaluated by using Bayesian networks in order to provide operative expert's layout design knowledge. Four models were generated with a different algorithm. From the models, we can find that there are eight crucial nodes which are considered to evaluate the accuracy of model: Impression of Cool, Impression of Soft, Typeface of title domain, Left margin of body domain, Font size of body domain, Top padding of subtitle domain, Weight of the letters in subtitle domain and Weight of the letters in title domain. The models created with the proposed method could be used for developing a design support system for web designers, which would work like an expert system. The support system provides alternative of web page layout design by illustrating layout template options to a user. In order to generate the most suitable model, model structured with Tabu search and the K2 algorithms are selected. These structure learning algorithms can visualize knowledge of the layout design accurately. Such a system would be beneficial for inexperienced designers to create a web page at an expert level more conveniently because they could receive useful advice from the system as same as from expert designers.

To obtain knowledge of color designer, interface color design in touch panel device is used to be a representation of color design knowledge. The effect of interface color design on users' emotions has been clarified through the proposed associate model between interface color design, user's emotion and operation. The proposed model has been constructed by using SEM method. As a result of analysis of the model, there are fifth emotions connected with working performances. Following, the hard-soft node and the warm-cool node are connected with all nodes of emotions positively. It has been revealed that the proposed scheme can illustrate the relationship between interface color design and the operations accurately. Therefore, we can understand the mechanisms in which how an operator feels about an interface design, and how the operations get effects from the feelings with the proposed scheme.

Subsequently, classifications of knowledge of the members are generated based on knowledge of the designers that we have obtained. Then, new knowledge that may gain from the collaborations has been deduced. As the results, they could have much new knowledge as a result of the collaboration but we cannot say that all increasing knowledge is acceptable because some new knowledge is nonsense. In this way, we can say that the proposed model can represent situations which may occur in a collaboration of web page design process exactly. By using the proposed model, we can know not only valid outcomes but also unacceptable knowledge which is obtained through a collaboration. Such disagreeable knowledge could be considered as a misunderstanding which should be watched out in the design process. Nevertheless, it is also useful information to consider the effective collaboration.

7.2 Directions for future works

A representation model of collaboration is proposed based on the context of collaborative design that consists of two designers who have different disciplines. Since general collaboration process is not including only two members but always comprises a lots of multi-discipline members. Therefore, further studies should be made to developed the proposed model for general use. According to advantage of the proposed model, a team performance can be estimated by constructing the model with classifications of the members. In this way, a decision making support tool for team formation could be developed based on the proposed scheme. A team manager can utilize the decision making support tool when constructing a team members.

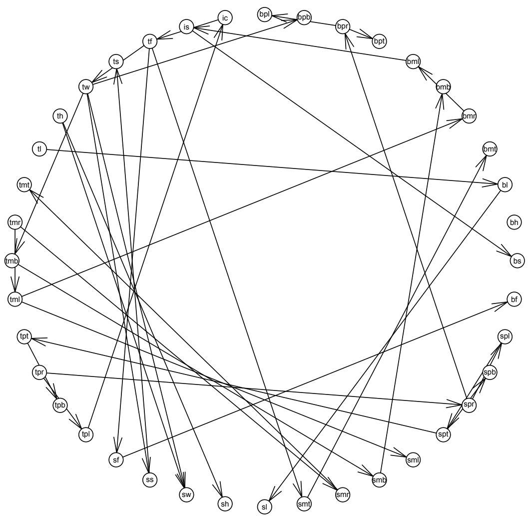
A An appendix

A.1 Source code of infomorphisms calculating tool

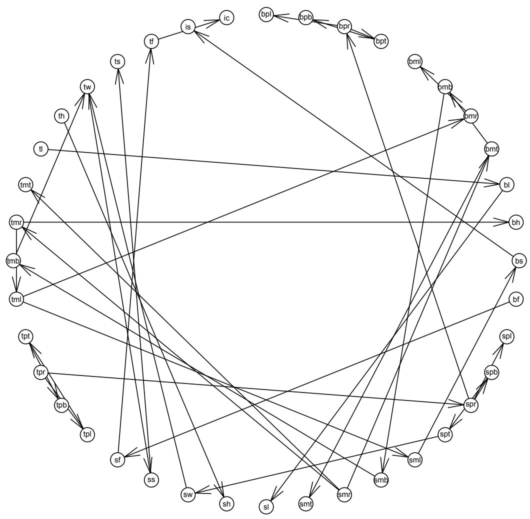
```
a=[classification A]; %%Input element of classification of member A or we call matrix A.
b=[Classification B]; %%Input matrix of classification of member A or we call matrix B

%%Each element of a row can be defined by separating with blank space and using semicolon to terminate each row.

colA = size(a,2); %%Count number of column of the matrix A
colB = size(b,2); %%Count number of column of the matrix B
max = power(colB,colA); %%Calculate amount of all possible infomorphisms
th = max; %% Define variable th equals to set of all possible infomorphisms
M=zeros(max,colA); %%Define index to create all possible infomorphisms
for index = 1:1:colA; %% Define each column of possible infomorphisms with position of column of the matrix A
    cnt = 1;
    rep = max/th;
    th = th/colB;
    for x=1:1:rep
        for y=1:1:colB
            for z=1:1:th
                M(cnt,index)=y;
                cnt = cnt+1;
            end
        end
    end
end
info=zeros(size(b,1),colA);
cnt = 0;

for i =1:1:max %% Define elements in each column of possible infomorphisms
    for j=1:1:size(M,2)
        info(:,j) = b(:,M(i,j));
    end
    stop = 0;
    for rowA=1:1:size(a,1) %%Select infomorphisms by considering if one or more line of the matrix of possible infomorphism similar to one of the lines of the matrix B.
            for row=1:1:size(info,1)
```

```
                if(isequal(info(row,:),a(rowA,:)))
                    cnt = cnt+1;
                    disp(info);
                    stop=1;
                    break;
                end
            end
            if(stop==1)
               break;
            end
     end
end
disp('colA=');disp(colA);
disp('colB=');disp(colB);
disp('rowInfo=');disp(max);
disp('infomorphism=');disp(cnt);
```

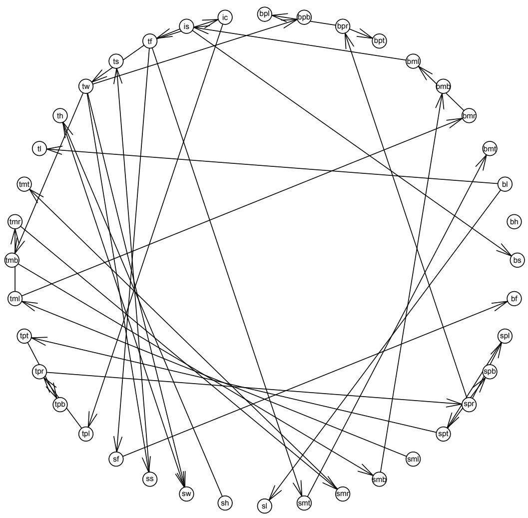
A.2 The models of Layout design knowledge on a web page



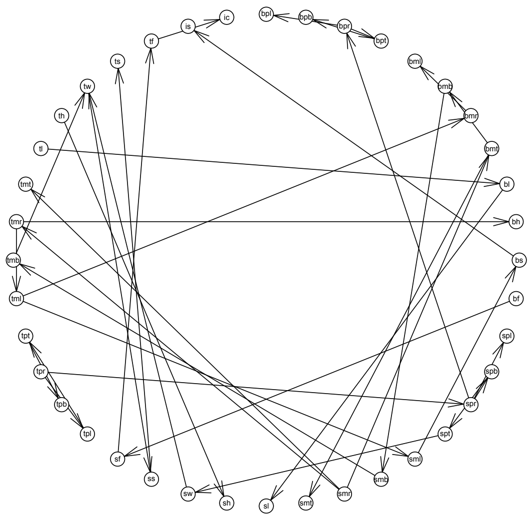
(a) **Model 1**: Hill-Climbing and AIC score



(b) **Model 2**: Hill-Climbing and K2 score



(c) **Model 3**: Tabu search and AIC score



(d) **Model 4**: Tabu search and K2 score

Figure A.1 – Four Bayesian Network models from four algorithms

A.3 Examples of collaboration models by generated based on the proposed scheme

A.3.1 The collaboration between engineering course students and entertainment media course students

An example of collaboration in a design workshop is used for a case study. The collaboration between engineering course students and entertainment media course students is discussed. Knowledge of engineering course students is performed as classification of engineering knowledge. Meanwhile, classification of entertainment media knowledge shows knowledge of entertainment media course students.

Classification of engineering knowledge (A)

A classification of engineering knowledge can be described as a classification as following:

$$tok(A) = \{AR\,code, GPS, Voice\,commands\}$$
$$typ(A) = \{Information\,pull, Interaction, Information\,push\}$$

$$GPS \models_A Information\,pull \qquad Voice\,commands \models_A Information\,pull$$
$$GPS \models_A Information\,push \qquad Voice\,commands \models_A Interaction$$
$$AR\,code \models_A Information\,pull$$

Each token stands for an information technology such as AR (Augmented Reality) code, GPS (Global Positioning System) and Voice commands respectively. Each type stands for a property of the technology. Each type stands for a type of communication. Type of “Information pull” means information is provided when the user requested it. Type of “Interaction” means information is provided through interaction with the system. Type of “Information push” means the system give the user a notification when information is available. For instance, voice commands is suitable for interactive information pull system. The classification can be represented as a Chu map shown in figure A.2(A).

Classification of entertainment media knowledge (B)

Requirements of users are indicated as entertainment media knowledge. The classification of entertainment media knowledge is described as a classification as following:

$$tok(B) = \{Elder, Adult, Child\}$$
$$typ(B) = \{Readability, Entertainment, Simplicity\}$$

$$Elder \models_B Simplicity \qquad Adult \models_B Readability \qquad Adult \models_B Simplicity$$
$$Child \models_B Entertainment \qquad Child \models_B Simplicity$$

Here, each token stands for status of a user. Each type stands for requirement of the users. For example, older declines visualization and they need simplicity design. The classification can be represented as a Chu map shown in figure A.2(B).

I_1: **Infomorphisms from classification** A **to** B

	(A)			(I2)			
	Information pull	Interaction	Information push				
AR Code	1	0	0	0	0	1	
GPS	1	0	1	0	1	1	
Voice commands	1	1	0	1	0	1	
	1	0	0	0	0	1	Elder
	1	0	1	1	0	1	Adult
	1	1	0	0	1	1	Child
	(I1)			Readability	Entertainment	Simplicity	
				(B)			

Figure A.2 – Collaboration model between engineering knowledge and entertainment media knowledge.

An infomorphism from A to B is derived as shown in figure A.2(I_1). Eventually, the collaboration between them can be represented as matrices shown in figure A.2 by using the proposed method. The model consists of three classifications, i.e. A, B, I_1 and I_2. Each column in the matrix I_1 means a combination between a type in classification A and a type in classification B. From matrix (I_1) in figure A.2, the results show that:

- The leftmost column of matrix (I_1) has the same element of the third column of matrix (B). It means that the leftmost column of matrix (A): **Information**

pull is mapped to the third column in matrix (B): **Simplicity** by function $f^\wedge$.

- The second column of matrix (I_1) has the same element of the second column of matrix (B). It means that the second column of matrix (A): **Interaction** is mapped to the second column in matrix (B): **Entertainment** by function $f^\wedge$.
- The third column of matrix (I_1) has the same element of the first column of matrix (B). It means that the third column in matrix (A): **Information push** is mapped to the first column in matrix (B): **Readability** by function $f^\wedge$.

While, lines in matrix (I_1) represent function $f^\vee$; a mapping from tokens in classification B to tokens in classification A. The results show that:

- The first line of matrix (I_1) has the same element of the first line of matrix (A). It means that the first line of matrix (B): **Elder** is mapped to the first line of matrix (A): **AR Code** by function $f^\vee$.
- The second line of matrix (I_1) has the same element of the second line of matrix (A). It means that the second line of matrix (B): **Adult** is mapped to the second line of matrix (A): **GPS** by function $f^\vee$.
- The final line of matrix (I_1) has the same element of the third line of matrix (A). It means that the final line of matrix (B): **Child** is mapped to the final line of matrix (A): **Voice command** by function $f^\vee$.

In figure A.2, infomorphism I_1 shows:

$$f^\vee(Elder) = AR\ code, \qquad f^\vee(Adult) = GPS,$$
$$f^\vee(Child) = Voice\ commands.$$

This infomorphism means shows us as follows;

- $Elder$ is corresponding to $AR\ code$.
- $Adult$ is corresponding to GPS.
- $Child$ is corresponding to $Voice\ commands$

These results provide us a new knowledge for selecting proper information technology device in accordance with the user's generation, i.e. we should provide AR code technology for elder, GPS for adult and Voice commands for child.

I_2: Infomorphisms from classification B to A

Infomorphism from classification B to classification A can be illustrated as matrix (I_2) in figure A.2. Columns in matrix (I_2) represent function $f^\wedge$; a mapping from types in classification B to types in classification A. From matrix (I_2) in figure A.2, the results show that:

- The first column of matrix (I_2) has the same element of the second column in matrix (A). It means that the first column of matrix (B): **Readability** is mapped to the second column in matrix (A): **Interaction** by function $f^\wedge$.
- The second column of matrix (I_2) has the same element of the rightmost column in matrix (L). It means that the second column of matrix (B): **Entertainment** is mapped to the rightmost column in matrix (A): **Information push** by function $f^\wedge$.
- The third column of matrix (I_2) has the same element of the leftmost column in matrix (A). It means that the third column of matrix (B): **Simplicity** is mapped to the leftmost column in matrix (A): **Information pull** by function $f^\wedge$.

Likewise, lines in matrix (I_2) represent function $f^\vee$; a mapping from tokens in classification A to tokens in classification B. The results show that:

- The first line of matrix (I_2) has the same element of the first line of matrix (B). It means that the first line of matrix (A): **AR code** is mapped to the first line of matrix (B): **Elder** by function $f^\vee$.
- The second line of matrix (I_2) has the same element of the final line of matrix (B). It means that the second line of matrix (A): **GPS** is mapped to the final line of matrix (B): **Child** by function $f^\vee$.
- The third line of matrix (I_2) has the same element of the second line of matrix (B). It means that the third line of matrix (A): **Voice command** is mapped to the second line of matrix (B): **Adult** by function $f^\vee$.

In figure A.2, infomorphism I_2 shows:

$$f^\vee(AR\ code) = Elder, \qquad f^\vee(GPS) = Child,$$
$$f^\vee(Voice\ commands) = Adult.$$

This infomorphism means shows us as follows;

- $AR\ code$ is corresponding to $Elder$.

- GPS is corresponding to $Child$.
- $Adult$ is corresponding to $Voice\ commands$.

From this infomorphism, AR code technology can be implied as same as infomorphism (I_1) 1. But GPS is corresponding to child and Voice commands is corresponding to adult.

From the above discussion, we can say that the collaboration is effective because it can provide new knowledge to the members.

In this example, by using the calculating tool that we developed, we can get sixteen infomorphisms from "classification of engineering knowledge" to "classification of entertainment media knowledge." Besides, sixteen infomorphisms have been also obtained from "classification of entertainment media knowledge" to "classification of engineering knowledge." It means we can expect that one of 16×16 kinds of situations could be occurred when the engineering course student and the entertainment media course student collaborate in a design process. Each combination of the infomorphisms explains new knowledge, which they could obtain from the cooperation in the design process.

A.3.2 The collaboration between Layout designer and Color designer in aspect of web page's appearance

The matrices in figure A.3 illustrate the collaboration of this situation by using the proposed model. In this case, the model consists of two classifications (X and Y) and two sets of infomorphisms (Z_1 and Z_2). Classification X means the knowledge of layout designer as well as classification Y means the knowledge of color designer. Moreover, two sets of infomorphisms (Z_1 and Z_2) mean new knowledge that can be deduced from the collaboration.

X: Classification of layout design knowledge

The classification of layout design knowledge is represented with matrix (X) shown in figure A.3(X). Here, each token stands for an impression and each type stands for a layout item, font weight or font style. For example, when font weight is thin and the style is Gothic (Japanese Serif style), it gives cool impression to the observers. Such knowledge can be described as a classification as following:

$$tok(X) = \{Cool, Warm, Soft, Hard\}$$
$$typ(X) = \{W_1, W_{1.75}, Gothic, Mincho\}$$

$$\begin{aligned} Cool &\models_X W_1, & Cool &\models_X Gothic, \\ Warm &\models_X W_{1.75}, & Warm &\models_X Gothic, \\ Soft &\models_X W_1, & Soft &\models_X Mincho, \\ Hard &\models_X W_{1.75}, & Hard &\models_X Mincho. \end{aligned}$$

Types W_1 and $W_{1.75}$ mean weights of letters, which are defined as normal and bold respectively. Types $Gothic$ and $Mincho$ mean font styles of letters in title part, which are defined as sans-serif and serif styles respectively.

Y: Classification of color design knowledge

The classification of color design knowledge is represented with matrix (Y) shown in figure A.3(Y). Here, each token stands for an impression term and each type represent a color. For example, when a web page is decorated with red and blue, it gives classic image to the observers. Such knowledge can be described as a classification as following:

$$tok(Y) = \{Classic, Casual, Clear, Natural\}$$
$$typ(Y) = \{Red, Green, Blue, Yellow\}$$

$$\begin{aligned} Classic &\models_Y Red, & Classic &\models_Y Blue, \\ Casual &\models_Y Red, & Casual &\models_Y Yellow, \\ Clear &\models_Y Green, & Clear &\models_Y Blue, \\ Natural &\models_Y Green, & Natural &\models_Y Yellow. \end{aligned}$$

Z_1: Infomorphisms from X to Y

Columns in matrix (Z_1) in figure A.3 represent function $f^\wedge$; a mapping from types in classification X to types in classification Y. For instance, the leftmost column of matrix (Z_1) has the same element of the second column from the left in matrix (Y). It means that the left most column of matrix (X): W_1 is mapped to the second

	(X)				(Z_2)				
	Title : weight of letters		Title: Font family						
	W_1	$W_{1.75}$	Gothic	Mincho					
Cool	1	0	1	0	1	0	1	0	
Warm	0	1	1	0	0	1	0	1	
Soft	1	0	0	1	0	1	1	0	
Hard	0	1	0	1	1	0	0	1	
	0	1	0	1	1	0	1	0	Classic
	0	1	1	0	1	0	0	1	Casual
	1	0	0	1	0	1	1	0	Clear
	1	0	1	0	0	1	0	1	Natural
	(Z_1)				Red	Green	Blue	Yellow	
					Color decorating				
					(Y)				

Figure A.3 – A model of collaboration in web page design between layout designer and color designer.

column in matrix (Y): Green by function $f^{\wedge}$. While, lines in matrix (Z_1) represent function $f^{\vee}$; a mapping from tokens in classification Y to tokens in classification X. For instance, the first line of matrix (Z_1) has the same element of the fourth line of matrix (X). It means that the first line of matrix (Y): Classic is mapped to the forth line of matrix (X): Hard by function $f^{\vee}$.

Z_2: Infomorphisms from Y to X

Columns in matrix (Z_2) in figure A.3 represent function $f^{\wedge}$; a mapping from types in classification Y to types in classification X. For instance, the third column of matrix (Z_2) has the same element of the leftmost column in matrix (X). It means that the third column of matrix (Y): Blue is mapped to the leftmost column in matrix (X): W_1 by function $f^{\wedge}$. While, lines in matrix (Z_2) represent function $f^{\vee}$; a mapping from tokens in classification Y to tokens in classification Y. For instance, the first line of matrix (Z_2) has the same element of the first line of matrix (Y). It means that the first line of matrix (X): Cool is mapped to the first line of matrix (Y): Classic by function $f^{\vee}$.

In this case, 112 infomorphisms have been obtained from "classification of layout design knowledge" to "classification of color design knowledge." Meanwhile, there are 112 infomorphisms have been obtained from "classification of color design knowledge" to "classification of layout design knowledge." It means we can expect that one of 112 × 112 kinds of situations could be occurred when the layout designer and the color designer collaborate in a design process. Each combination of the infomorphisms explains new knowledge, which they could obtain from the cooperation in the design process. However, we cannot say that all situations are proper understanding in the design context.

For instance, infomorphism Z_1 in figure A.3 shows:

$$f^{\vee}(Natural) = Cool, \qquad f^{\vee}(Casual) = Warm,$$
$$f^{\vee}(Clear) = Soft, \qquad f^{\vee}(Classic) = Hard.$$

This infomorphism means that the designer can understand the followings; a natural style design gives cool impression, a casual style design gives warm impression, a clear style design gives soft impression and a classic style design gives hard impression.

This new knowledge is acceptable because it is consistent in semantics.

On the other hand, infomorphism Z_2 shows:

$$f^{\vee}(Cool) = Classic, \qquad f^{\vee}(Warm) = Natural,$$
$$f^{\vee}(Soft) = Clear, \qquad f^{\vee}(Hard) = Casual.$$

This infomorphism says that the designer can understand that a natural style design gives warm impression. This new knowledge is difficult to accept because warm impression is conflict with natural image according to the theory of science of color [63].

A.3.3 The collaboration between Layout designer and web programmer

This example is a case of collaboration between the layout designer mentioned in the previous section and a web programmer. Classification X means the knowledge of layout designer and classification P means the knowledge of web programmer.

X: Classification of layout design knowledge

The knowledge of the layout designer is explained exactly same as the case in section. A.3.2.

	(X) Title : weight of letters		(X) Title: Font family		(J$_2$)			
	W$_1$	W$_{1.75}$	Gothic	Mincho				
Cool	1	0	1	0	1	0	0	
Warm	0	1	1	0	0	1	0	
Soft	1	0	0	1	1	0	1	
Hard	0	1	0	1	0	1	1	
	1	0	1	0	1	0	0	Ruby
	0	1	0	0	0	1	0	Perl
	1	1	1	1	1	1	1	PHP
	(J$_1$)				Security	Reference	Database	
					Server side service Language			
					(P)			

Figure A.4 – A model of collaboration in web page design between layout designer and web programmer.

P: Classification of web programmer knowledge

The knowledge of the web programmer is indicated as classification P as the matrix (P) shown in figure A.4(P). Here, each type stands for programming languages and each token stands for the typical features of a language, i.e. security, abundance of references, and affinity for database system. For example, there are many references about Perl and PHP programming language, while many references of Ruby are only in Japanese.

Such knowledge can be described as a classification as following:

$$
\begin{aligned}
tok(P) &= \{Ruby, Perl, PHP\} \\
typ(P) &= \{Security,\ Reference,\ Database\}
\end{aligned}
$$

$$
\begin{array}{ll}
Ruby \models_P Security, & Perl \models_P Reference, \\
PHP \models_P Security, & PHP \models_P Reference, \\
PHP \models_P Database. &
\end{array}
$$

J_1: Infomorphisms from X to P

The matrices in figure A.4 illustrate the collaboration of this situation by using the proposed model. Columns in matrix (J_1) represent function $f^\wedge$; a mapping from types in classification X to types in classification P. For instance, the first column of matrix (J_1) has the same element of the first column of matrix (P). It means the first column of matrix (X): W_1 is mapped to the first column of matrix (P): Security by function $f^\wedge$. While, lines in matrix (J_1) represent function $f^\vee$; a mapping from tokens in classification P to tokens in classification X. For instance, the first line of matrix (J_1) has the same element of the first line of matrix (X). It means the first line of matrix (P): Ruby is mapped to the first line of matrix (X): Cool by function $f^\vee$.

J_2: Infomorphisms from P to X

Columns in matrix (J_2) represent function $f^\wedge$; a mapping from types in classification P to types in classification X. For instance, the third column of matrix (J_2) has the same element of the fourth column of matrix (X). It means that the third column of matrix (P): Database is mapped to the fourth column of matrix (X): Mincho by function $f^\wedge$. While, lines in matrix (J_2) represent function $f^\vee$; a mapping from tokens in classification X to tokens in classification P. For instance, the second line of matrix (J_2) has the same element of the second line of matrix (P). It means that the second line of matrix (X): Warm is mapped to the second line of matrix (P): Perl by function $f^\vee$.

28 infomorphisms have been obtained from “classification of layout design knowledge” to “classification of web programmer knowledge.” While, there are sixty infomorphisms have been also obtained from “classification of web programmer knowledge” to “classification of layout design knowledge.” Thus, $(J_1 \times J_2)$ can be considered as new knowledge obtained from the collaboration. Examples of the infomorphisms are described as following:
Infomorphism J_1 in figure A.4 shows:

$$f^\vee(Ruby) \quad = \quad Cool.$$

Meanwhile, infomorphism J_2 shows:

$$f^\vee(Cool) = Ruby, \qquad f^\vee(Warm) = Perl.$$

The infomorphisms J_1 means that the designer can understand the followings; cool impression is combined with Ruby programming. While the infomorphisms J_2 says Ruby programming gives cool impression and Perl programming gives warm impression.

In this way, these new knowledge are difficult to accept because association between two of knowledge is nonsense.

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