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概要 Collaboration is one of the effective approaches that help us to share knowledge together and exchange ideas within a team. Sometimes, novel worthy knowledge that is not held by the members emerges because of the collaboration. Such knowledge often contributes to create prime solutions in the collaboration process. However, the mechanism of generating such new knowledge is implicit. In this paper, a mathematical model of collaboration mechanism is proposed. Channel theory is utilized to accomplish this goal. Collaboration between engineering course students and entertainment media course students was represented by using the proposed model. As the results, there are two infomorphisms were deduced from the classifications. It means the students could gain new knowledge from the collaboration process and we can say that the collaboration is effective.

キーワード: collaboration, synergetic effects, Channel Theory, design process

1 Introduction

Nowadays, knowledge has the powerful influence which leads business organization to survive in the competition among firms. Knowledge sharing stands for exchanging and transmitting knowledge among individuals, groups, and organizations for the purpose of improving organizational competitiveness [1]. Knowledge sharing is a fundamental means through which employees can contribute to knowledge creating, innovation, and ultimately the competitive advantage of the organization [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 advantages of knowledge sharing, many organizations pay attention to knowledge management system to support knowledge sharing.

Collaboration is a promised method which provides benefits of knowledge sharing to us. Collaboration is a process in which two or more members from different area participate in knowledge transmitting process for achieving a common task or a goal [4]. During collaboration process, synergetic effects among team members would contribute to generate novel knowledge. So, collaborations which derive powerful synergetic effects are required in teamwork. However, the way to produce effective collaboration is implicit because collaboration is a complex, multi-dimensional process which is characterized by constructs such as coordination, communication, meaning, relationships and trust [5]. Thus, this study aims to propose a mathematical model of collaboration mechanism in order to investigate the process.

Channel Theory [6] is utilized to achieve this goal by considering through a scheme of infomorphism. Besides, Chu space [7] is introduced to represent a scheme of infomorphism as a mathematical construction. To verify the proposed model, an example of collaboration between engineering course students and entertainment media course students is shown.

*This study was presented in HCI2015.

2 Literature reviews

2.1 Related works

There are many researches have found that a team which consists of different disciplines members succeeded to create new idea [8][9]. According to these researches, the combination of diverse backgrounds members played an important role to bring about the new idea. As these examples show, different perspective is an important factor to create effective collaboration.

During collaboration process, synergetic 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 [10]. 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 [11]. It has the potential to describe diverse understanding based on the information flows. Schorlemmer [12] proposed a formalization of knowledge sharing scenarios by using diagram in the Chu category. Moreover, Channel Theory has been utilized to represent effect of collaboration between layout designer and color designer in the design context. The result shows that the scheme can illustrate the new knowledge inclusively [13]. Basic ideas of Channel Theory and Chu spaces are referred briefly in the following sections.

2.2 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

$$f^\vee(b) \models_A \alpha \quad \text{iff} \quad b \models_B f^\wedge(\alpha) \tag{1}$$

for $\forall \alpha \in typ(A), \forall b \in tok(B)$, where $f^\wedge$ and $f^\vee$ are whole-part relationships. Fig. 1 shows a diagrams of a relationship between two classifications.

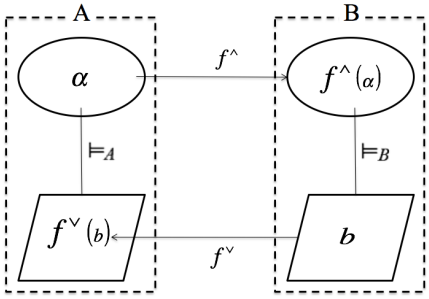

Fig. 1: Relationship between two classifications.

2.3 Chu spaces

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 [14] 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 can be empty or one digit, but starting with $S = \{0, 1\}$. 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.

3 A model of collaboration mechanism

In order to clarify the way to produce an effective collaboration, the mathematical model of collaboration mechanism is proposed based on Channel Theory. The outline of proposed model is shown in Fig. 2. Assume a situation in which two members who have different academic backgrounds work jointly in a group. Each solid circle indicates a set of knowledge held by a member. Due to the different disciplines, each knowledge is different with another. That is why the two circles do not overlap entirely with each other. Due to synergetic effects in the collaboration, team performance cannot be calculated as a simple union of the abilities of each member ($A \cup B$). Possible knowledge domain of the team can be indicated as grey area ($R - (A \cup B)$. This situation can be represented by using classification of Channel Theory as shown below the circles in the Fig. 2.

Here, we can deduce the knowledge, which can be obtained from synergetic effects by using infomorphism. By using this scheme, we can evaluate an effect of a collaboration by representing what new knowledge can be gotten from the collaboration.

3.1 Example of collaboration model between engineering course students and entertainment media course students

To verify the ability of the proposed model, an example of collaboration between engineering course students and entertainment media course students is discussed. Knowledge of engineering course students are 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:

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

$$ARcode \models_A Information\,pull$$

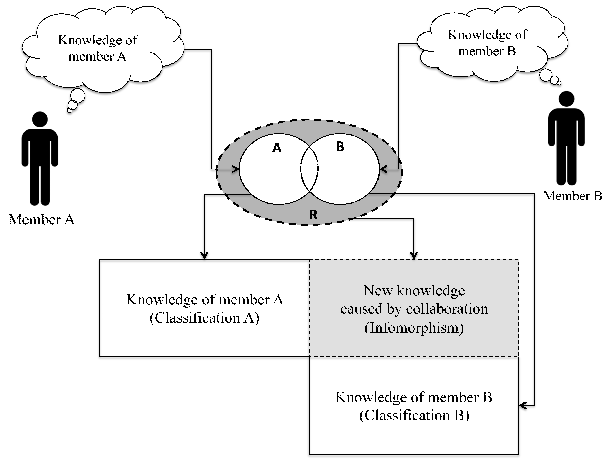

Fig. 2: A representation model of collaboration mechanism

$$
\begin{aligned}
GPS &\models_A Information\ pull \\
GPS &\models_A Information\ push \\
Voice\ commands &\models_A Information\ pull \\
Voice\ commands &\models_A Interaction.
\end{aligned}
$$

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 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 Fig. 3 (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:

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

$$
\begin{aligned}
Elder &\models_B Simplicity \\
Adult &\models_B Readability \\
Adult &\models_B Simplicity \\
Child &\models_B Entertainment \\
Child &\models_B Simplicity.
\end{aligned}
$$

Here, each token stands for status of a user. Each type stands for requirement of the users. For example, elder declines visualization and they need simplicity design. The classification can be represented as a Chu map shown in Fig. 3 (B).

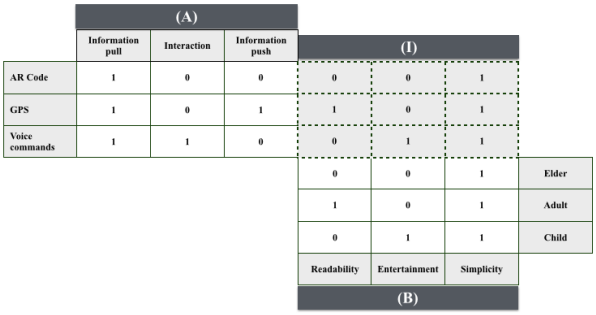

Fig. 3: A representation model of collaboration mechanism.

Infomorphisms from A to B (I)

An infomorphism from A to B is derived as shown in Fig. 3 (I). Eventually, the collaboration between them can be represented as matrices shown in Fig. 3 by using the proposed method. The model consists of three classifications, i.e. A, B, and I. Each line in the matrix (I) means a combination between a token in classification A and a token in classification B. For example, *AR code* in (A) is combined with *Elder* in (B) because the first line of (I) has the same element of the first line in (B). While, each column in the matrix (I) means a combination between a type in classification A and a type in classification B. For example, *Entertainment* in (B) is combined with *Interaction* in (A) because the middle column of (I) and (A) have the same element. In this case, infomorphisms are established from "classification of engineering knowledge" to "classification of entertainment media knowledge." Two infomorphisms have been deduced as shown in Fig. 4.

Each situation explains new knowledge, which engineering course student and entertainment media course student can obtain in the collaboration process. It implies that there are two situations could occur when engineering student and entertainment media student collaborate in a workshop. First in-

fomorphism shows that

$$\begin{aligned} f^{\wedge}(AR\ code) &= Elder, \\ f^{\wedge}(GPS) &= Adult, \\ f^{\wedge}(Voice\ commands) &= Child. \end{aligned}$$

This infomorphism shows us that AR code is corresponding to elder, GPS is corresponding to adult and Voice commands technology is corresponding to child. 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. Meanwhile, second infomorphism shows that

$$\begin{aligned} f^{\wedge}(AR\ code) &= Elder, \\ f^{\wedge}(GPS) &= Child, \\ f^{\wedge}(Voice\ commands) &= Adult. \end{aligned}$$

From this infomorphism, AR code technology can be implied as same as infomorphism 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.

1
0 0 1
1 0 1
0 1 1

2
0 0 1
0 1 1
1 0 1

Fig. 4: Infomorphisms from engineering knowledge to entertainment media knowledge.

4 Conclusion

In this paper, the authors have represented a model of collaboration mechanism based on Channel Theory. Collaboration between engineering course students and entertainment media course students was represented by using the proposed model. In the example, classification A stands for knowledge of engineering student and classification B stands for knowledge of entertainment media student. The result shows that there are two infomorphisms were deduced from the classifications. It means the students could gain new knowledge from the collaboration process and we can say that the collaboration is effective.

As the result, we can say that the proposed model can represent new knowledge which members can obtain from the collaboration. This new knowledge could lead the team to novel solutions. According to advantage of the proposed model, the team performance can be estimated by analyzing the model of the team. Moreover, it is expected that the proposed model can be employed when a new team is organized. The team manager can use the model as a decision supporting tool for organizing a team.

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