CONCEPTUAL RECOMBINATION: A SUB-CONCEPTUAL DESIGN THEORY FOR CULTURAL PRODUCT CREATION

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_______________________________________ (Signed)

HUNG, Chor Kin _______________________ (Name of student)

To my wife Nicole who pledged her whole-hearted support for my part-time Ph.D. study in the past four years, while I was working full-time as a lecturer. I will never forget your tolerance, consideration, and love.

To my parents who gave me wisdom and determination, I am proud to be your son.

Abstract

In view of the popularity of conceptual design theories and the lack of a mutually agreed creative method for cultural product creation, this research study attempts to borrow the concepts of conceptual design theories to form a design theory for cultural product creation. It explores the nature of cultural products and concludes that there are commonalities in them at an ontological level, giving rise to cultural product ontology. Such an ontology provides a solid foundation for the development of the expected design theory. On the other hand, this research study regards functional reasoning of conceptual design as the theoretical reference for the formation of the expected design theory. This is because its design process is very similar to the creative processes of different cultural products that can also be described by the concepts of homeomorphism, a scientific account. Furthermore, the expected design theory works at a domain level, while conceptual design theories operate at a conceptual level. This research study, therefore, refers to Sloman's two systems of reasoning and defines the expected design theory as a sub-conceptual design theory, namely, Conceptual Recombination.

To connect Conceptual Recombination with cultural product ontology, this research study refers to the task model of application ontology to define their working relationship, since there is no method ontology in cultural product ontology due to the fact that there is not yet a commonly agreed creative method for different cultural product creations. Furthermore, there is a computational representation of Conceptual Recombination to demonstrate the operations and contributions of Conceptual Recombination as well as to provide a reliable creative method for the generation of exploratory and transformational creativity (ET-creativity) in the different parts of cultural products through a single-user Creativity Support Tool that takes in user unfinished work and produces representational and creative system outputs as continuations to the user input. Such a computational representation clearly explains the three levels of prediction of Conceptual Recombination that are in response to the concepts of functional reasoning.

In addition, since Conceptual Recombination is also a prescriptive model, there is no proof of it. Instead, this research study uses cases to demonstrate its operations to reveal its contributions to cultural product creation. It concludes that Conceptual Recombination defines a new research area as regards sub-conceptual design theory and an objective creative method for different cultural product creations and the above-mentioned single-user CSTs.

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Chapter 1

Introduction

> "Investigation into how the knowledge of functionality (of design problems and possible solutions) can be used to guide, constrain and shape the design activity, is an important strand of present design research" (Chakrabarti and Bligh, 2001, p. 493).

In engineering design, the theories of conceptual design, which aim at identifying the desired functions of a design problem and directing the relevant mapping process to acquire the necessary attributes to solve the problem, have a long history. Some of them such as Advanced Systematic Inventive Thinking (ASIT) (Maimon and Horowitz, 1999), C-K design theory (Hatchuel and Weil, 2009), and axiomatic design (Suh, 1990) are well known among engineers. These conceptual design theories provide a solid foundation for engineers to produce innovative design. For example, ASIT has one condition, one principle, and five operators to guide engineers to forge a creative solution to an engineering problem. General design theory (Yoshikawa, 1981) focuses on the dynamic mapping process between functions and structures. C-K design theory owns a creative model to explicitly explain the generative process of new concepts and new knowledge. Conceptual design theories are well recognized among engineers.

On the other hand, there are cultural product theories such as tonal music theory for popular music (Ewer, 2010), architectural theory (Maier et al., 2009) for architecture, and fashion theory (Miller et al., 1993) for clothing fashion that describe certain creative processes of cultural products. Herein, cultural products are "conceived as nonmaterial goods, directed at a mass public of consumers, for whom they serve an esthetic, rather than a clearly utilitarian purpose" (Hirsch, 1972, p. 639). Referring to Deinema (2008) and Peterson and Anand (2004), cultural products possess variants and invariants especially when they belong to a specific culture. The invariants contribute to their retardation (stable structures such as the harmonic structures of popular music) in a period of time, while the variants define their changing expressions (e.g. melodies of popular music) in that period of time. Note that this research study focuses on the cultural products relating to the mainstream of a culture. There is a detailed discussion on cultural products in 2.2. In view of the maturity and popularity of conceptual design theories, is it possible to refer to them and form a design theory for this research study that describes the creative processes of different cultural products? Do cultural products have anything in common that gives rise to such a design theory? Further, since conceptual design theories are abstract and cultural product theories are more practical, how to form a design theory based on conceptual design theories for cultural product creation?

In fact, this research study not only investigates the possibility of referring to conceptual design theories to form a design theory that describes the creative processes of different cultural products, but also focuses on the situation in which a cultural product creator has an unfinished work but no clue about completing it satisfactorily. Such a situation can be described as design fixation, referring to the time when a cultural product creator cannot finish his work due to his blind adherence to a set of ideas (Jansson & Smith, 1991). Sapp (1992) names this point in time during a human creative process as the point of creative frustration, referring to "a sense of stagnation or frustration" of a designer. This point of creative frustration can bring out "crucial and conscious decisions" affecting the manifestation of a creative work. Sapp claims that "[i]t is at this point that the individual chooses how to proceed; he or she makes choices which will determine whether or not the problem will be solved and whether or not the product will acquire creative significance" (Sapp, 1992, p. 25). This research study aims specially at this difficult time of cultural product creators though not stepping into cognitive science, trying to define a design theory with reference to conceptual design theories to assist cultural product creators in completing their works.

Mumford et al. (1996a, 1996b, 1997) suggest a cognitive approach in their discussions of the process-based measures of creative problem-solving skills. They claim that problem construction on an ill-defined problem based on certain categorical structures can help us derive a creative solution. In this research study, an unfinished cultural product is also an ill-defined problem to its creator, giving him/her the point of creative frustration. Then, problem construction is followed by information encoding, category search, specification of best fitting categories, and combination and reorganization of category information in the process-based measures of creative problem-solving skills (Lubart, 2000-2001).

Most importantly, Mumford et al. claim that problem construction provides a new way of understanding the ill-defined problem and a ground for new ideas. To a certain extent, this is similar to the objective of a conceptual design theory: to identify the desired functions of a design problem and direct the mapping process from a function space to an attribute space under certain constraints to acquire the necessary attributes to solve the problem (Chakrabarti and Bligh, 2001; Yoshikawa, 1981). Nevertheless, it is difficult to implement a conceptual design theory into a domain due to its abstraction. Therefore, this research study is to explore the possibility of forming a new design theory for cultural product creation that tackles the abstraction.

On the other hand, since there is a lack of a reliable computational creative method in a single-user Creativity Support Tool (CST) that takes in a user unfinished cultural product and produces representational (representing the user intentions implied in the user input) and creative system outputs as continuations to the user input as shown in Figure 1.1, this dissertation also includes a computational form of Conceptual Recombination to be deployed into such a CST which is a computer system aiming at enhancing human creativity by assisting users in producing and organizing ideas (Chen, 1998). It specially highlights the use of computational creativity to derive a creative solution.

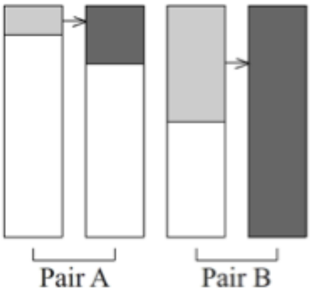


Figure 1.1: Two cases of user unfinished cultural products to be developed by a single-user CST. There are two pairs of blocks in the figure. Each block is potentially a complete cultural product. Each pair consists of a block with a grey area representing a user input and a block with a darker area referring to a partial or complete cultural product inclusive of both the user input and continuation derived from the CST in, probably, similar length, weight, or proportion. For instance, pair A describes two parts of a narrative represented by the black area. Initially, the first part in grey was written by the user. The CST has produced the second part as the continuation to the first part. However, the narrative is not yet complete with only these two parts. Pair B is applicable to a popular song with the grey area representing a verse written by a user and the black block describing a complete song inclusive of a chorus happens right after the verse.

1.1 The Problem Domain and Approach

The problem domain of this research study is mainly about the lack of a design theory that can describe the creative processes of different cultural products and guide cultural product creators to complete their partial works. This problem can be interpreted into two questions:

i. Do cultural products have anything in common that contributes to the rise of such a design theory?
ii. What are the references for the formulation of this design theory?

Superficially, all cultural products are different. In what perspective can we explore their possible commonalities? If this is not about their appearances, what are they intrinsically? Can we describe them ontologically? Based on the existing literature including the dance ontology by Blades (2008), guitar ontology by Bandini et al (2008), Japanese architecture ontology by Lopes (2007), etc., how should we study cultural products at an ontological level. Do they share the same set of ontological properties? Is this possible? Can this contribute to the rise of the expected design theory?

On the other hand, engineering design also owns a substantial amount of work utilizing ontologies such as PhysSys ontology (Borst and Akkermans, 1997) and application ontology (van Heijst et al., 1997). An example that sheds light to this research study is that when there is no method ontology in an ontology, it is possible to use the task model in application ontology to describe the role of a method for an ontology. If there is no commonly agreed creative method for cultural products, can the expected design theory be a task model? Do the ontologies in engineering design have any linkages with the ontologies of cultural products? Should they be relevant to each other, can we refer to conceptual design theories to form a new design theory that describes the creative processes of different cultural products?

In this research study there is a sub-problem concerning the implementation of the expected design theory computationally as there is a lack of a reliable computational creative method in a single-user CST that takes in a user unfinished cultural product and produces representational and creative system outputs as the continuations to the user input. The well-known academic examples of such a CST include Aaron (Cohen, 1995) for drawing, BRUTUS (Bringsjord and Ferrucci, 2000) for storytelling, and Continuator (Pachet, 2006) for music composition. Is it possible to implement the expected design theory into these creative systems to do so? How can we translate it into a computational creative method? How can this method take in a user input and produce a creative and representational output accordingly?

In order to create the expected design theory, this research study refers to the methodologies of certain conceptual design theories especially those that focus on prescriptive model to define its own methodology. This is because the expected design theory is to describe the phenomena revealed by many different theories for cultural product creations. Furthermore, since the existing theories have already explained the phenomena, there is no need to create another proof of their validity. As for the computational representation of it, there will be a demonstration of its validity in accordance with certain computational creativity theories and mathematical models. There is also a case study about its possible practical use. There will be a thorough discussion on the methodology of this research study in Chapter 3.

1.2 Motivations and Applications

The motivations of this research study are as follows:

i. Is it possible to have a design theory that can describe the creative processes of different cultural products and guide cultural product creators to complete their partial works?

ii. How can we make ourselves more creative when designing cultural products such as a watch, a poster, or a popular song?

iii. How can a single-user CST take in a user unfinished cultural product and produce representational and creative system outputs as continuations to the user input?

iv. Are there any existing design theories that can answer the first two questions and allow a single-user CST to perform in the way described in the third question?

Should the expected design theory be available, it will help solve the creative paradoxes of cultural product creations, defining their creative processes and so revealing the relevant tacit knowledge. This will also provide a set of guidelines for cultural product creators when they are stuck with their partial works in hands.

The computational representation of the expected design theory will assist the CST community in achieving a reliable creative method that can read user inputs and produce creative and representational outputs as continuations to the inputs. This should be greatly different from other computational creative methods such as fractal and hidden Markov model that can only produce limited variations of the inputs.

1.3 Thesis Statement

The thesis proposed in this dissertation is to create a design theory that describes the creative processes of different cultural products. In particular, it seeks answers to the below questions:

i. What are the commonalities shared by different cultural products that allow such a design theory to describe cultural products collectively?

ii. What is the theoretical background of such a design theory?

iii. How to use this design theory?

iv. How to apply this design theory in a computational environment?

v. How to evaluate this design theory and its computational representation?

1.4 Research Objectives and Scope

Given the motivating factors discussed in 1.2 and the research questions stated in 1.3, this research study has the below objectives:

i. To define the commonalities of cultural products and base on this finding to define a design theory that describes and explains the creative processes of different cultural products as well as guiding cultural product creators to complete their partial works.
ii. To define a computational representation of the design theory that applies to single-user CSTs that read user unfinished works and produce representational and creative outputs as continuations to the user inputs.
iii. To define the evaluation methods for the design theory and its computational form.

Note that this research study does not delve into cognitive science regarding creativity and human perception towards system outputs as well as the philosophical question about the possible existence of thought processes in a machine simulating human creative behaviors. This study remains in the fields of design and artificial intelligence.

1.5 Original Contributions

The contributions of this research study are threefold. Firstly, it provides a design theory that describes the creative processes of different cultural products and assists cultural product creators in developing their unfinished works. Secondly, it provides a reliable computational creative method for different single-user CSTs that read user unfinished cultural products and produce representational and creative outputs as continuations to the user inputs. This unique method never existed in the past. Thirdly, this research study defines the commonalities of different cultural products that allow the expected design theory to explain the creative processes of cultural products in a new way.

1.6 Dissertation Outline

Chapter 2 reveals four cultural product components – rules, structures, features, and biases – that can also be the ontological properties of the different cultural product ontologies. This revelation paves the way to the development of the expected design theory in this research study that describes the creative processes of different cultural products. Further, its discussion on conceptual design theories has identified functional reasoning approach as the core of the expected design theory. It also highlights the importance of an explicit creative model in such a design theory. In addition, it specifies the creativity in this research study that requires a balance between novelty and appropriateness, leading to the question about how a conceptual design theory can offer appropriateness when solving a design problem – a crucial aspect of the expected design theory. Lastly, it introduces computational creativity and CSTs for the sub-problem of this research study.

Chapter 3 defines the methodology of this research study. It first explains why the expected design theory is prescriptive and abductive. Since the expected design theory is supposed to be derived from conceptual design theories, it further explores the conceptual design theories that are also prescriptive and abductive to be the references for the development of the methodology. The latter part of Chapter 3 lists down the four major parts of the methodology in view of TRIZ, and suggests using cases to evaluate the operations of the expected design theory. Lastly, it discusses the computational representation of the expected design theory.

Chapter 4 investigates the deployment of the concepts of conceptual design theories at a domain level for cultural product creation. It refers to Sloman's conceptual and sub-conceptual systems to form such a design theory, namely, Conceptual Recombination.

There are two parts in Chapter 5. The first part details the relations between Conceptual Recombination, a sub-conceptual design theory, and cultural products. It first defines a cultural product ontology to describe cultural products ontologically, emphasizing their commonalities that give rise to Conceptual Recombination. Then, it points out that the lack of method ontology in the cultural product ontology, and therefore, any creative method, including Conceptual Recombination, that describes the creative processes of cultural products is a task model for the cultural product ontology when referring to engineering design. The second part provides additional theoretical information for the computational representation of Conceptual Recombination. This involves i) the role of the cultural product ontology in a single-user CST, giving information about the transformation from a user unfinished cultural product to a system generated complete work; ii) the working relation between the cultural product ontology and Conceptual Recombination; iii) the conceptual space for the generation of computational creativity; iv) the application of ET-creativity to the structures and features of cultural products respectively.

Chapter 6 explains how Conceptual Recombination operates as a task model for the cultural product ontology. In 6.2 Conceptual Recombination is divided into two stages – deconstruction and reconstruction – to analyze and breakdown a user input, and to convert it into a system output through its three levels of prediction concerning cultural preferences, a system's conceptual space, and homeomorphism in topology. The most important finding of this chapter is the utilization of topology of the cultural product ontology that allows objective measurement of productive aberration – the second prerequisite of T-creativity in Wiggins's Creative System Framework. This chapter gives a detailed account of the computational representation of Conceptual Recombination that is a sub-conceptual design theory with ET-creativity.

Chapter 7 defines the computational model of Conceptual Recombination in view of Wiggins's Creative Systems Framework (CSF) and Ritchie's interpretations of its search mechanisms. It pinpoints the problems of CSF in a single-user CST and concludes with a 7-tuple computational model for Conceptual Recombination.

Chapter 8 uses three cases to demonstrate the operations of the computational representation of Conceptual Recombination and explain how cultural product creation may happen to assist cultural product creators in completing their partial works creatively.

Chapter 9 concludes this dissertation with a discussion about its main contributions regarding six major aspects. Firstly, it explores the nature of cultural products ontologically, giving rise to the cultural product ontology and providing a foundation for the development of Conceptual Recombination. Secondly, it borrows the concepts of functional reasoning to form such a new design theory. Thirdly, it refers to Sloman's two systems of reasoning and coins this new design theory a sub-conceptual design theory, a brand new design research area emphasizing associative reasoning for designing. Fourthly, it gives a scientific prescriptive account of the creative processes of cultural products by referring to the concepts of homeomorphism. Fifthly, it defines the working relationship between Conceptual Recombination and the cultural product ontology. Lastly, it defines a creative method for the single-user CSTs that take in user unfinished cultural products and produce representational and creative system outputs as continuations to the user inputs.

Moreover, there is a discussion in Chapter 9 about the future work of this research study. It covers the possibilities of having Conceptual Recombination as the method ontology for the cultural product ontology and a standard for all the similar CSTs working on the sub-problem of this dissertation. In addition, it suggests several future research directions concerning ET-creativity life cycle, Conceptual Recombination as a design method, and Conceptual Recombination in ethnocomputing.

Chapter 2

Literature Review

2.1 Overview

This chapter provides a literature review on the major elements of this research study regarding cultural product components and ontologies, conceptual design theories, CSTs, and computational creativity. They are also presented in this order to let readers firstly understand the nature of cultural products followed by the possibility of having conceptual design theories to describe their creative processes. Since there will be a discussion on the computational form of the expected design theory in this research study, there is also a review on CSTs and computational creativity to state the computational environment of the expected design theory and the types of creativity it requires to generate representational and creative solutions. In a nutshell, this chapter lays down a foundation about the relations between cultural products, conceptual design theories, CSTs, and computational creativity, contributing to the formation of the expected design theory in this research study.

2.2 Cultural Products

As stated in Chapter 1, cultural products are nonmaterial goods embodying lives, aesthetic and utilitarian purposes, one-of-a-kind performances and / or unique sets of ideas (Hirsch, 1972). These cultural products include architecture, clothing fashion, furniture, narrative, and popular music. Superficially, they all appear differently. Referring to the work by Maier et al. (2009), architectural theory is a set of rules that define form, function, and architectural style. According to their explanations, form is structure; function is user behavior that can be interpreted as the need of a utility such as an operable window or a feature of a building. "The fundamental relation between these categories is that systems afford behaviors via their structure for a purpose"(p. 398). They also claim that affordance is an important concept in architecture affecting the manifestation of a building. They state that:

> "Buildings have many high-level affordances, including affording shelter to occupants from the exterior environment, affording aesthetics to occupants and passers-by, affording storage of goods, affording comfort to occupants through climate control, etc. More detailed affordances can better be analyzed by looking at specific building elements" (p. 396).

It is possible to conclude that affordances form a particular architectural style, supporting the discussions on biases in cultural products in this section.

On the other hand, Peterson and Anand (2004) claim that there are societal and institutional views on cultural products. The former concerns the values of cultural products and their retardation over time. The latter focuses on their production aspects and rapid changes in expression. In other words, there are changing expressions in the retardation of cultural products. It is possible to further interpret the retardation as having stable structures in cultural products. These structures support different expressions, as institutionalization is part of a society that allows tautology in cultural products such as the co-existence of retardation and rapid changes in expression. Also, the different expressions are like features running on structures.

Moreover, referring to the typology of cultural products by Deinema (2008), cultural products can be universal, culturally inclusive, or culturally exclusive. A universal cultural product is “widely used, recognized and understood around the world.” The use of English in a cultural product is an example. A culturally inclusive cultural product requires “culturally-specific heritages, knowledge and tastes,” but not limited to a particular culture. It encourages cultural hybridity. World music is a culturally inclusive product. Lastly, a culturally exclusive product is produced, understood, and appreciated by a specific culture. It involves “intricate and refined expressions of traditions” developed through a long period of time. In the production of such a culturally exclusive product, the intricate and refined expressions are similar to biases that shape the product to fit the relevant culture. Cantopop (popular music in Cantonese) is an example of a culturally exclusive product.

According to the analyses by Deinema, Peterson and Anand, cultural products do consist of structures, features, and biases. They are all bounded by rules, a more general term for Zeigeist. Readers can further refer to 5.2.1 for the definitions of rules, structures, features, and biases in this research study regarding the formation of the expected design theory. In fact, this view on cultural product components is also supported by an older literature by DiMaggio.

DiMaggio (1987) suggests using the four dimensions of his artistic classification systems (ACSs) to study the relations between arts and societies. The first dimension concerns the differentiation of arts that are institutionally bounded. In other words, this type of arts is bounded by the particular cultures. The second dimension is about hierarchicalization, ranking arts by prestige. The third dimension is universality, classifying arts in a universal manner. The fourth dimension is ritual potency concerning how we define institutionalization. DiMaggio further explains this dimension that, “strongly bounded ACSs are characterized by the clustering of tastes within ritual boundaries” (p. 441).

It is possible to interpret DiMaggio’s first dimension as arts categorized by cultures; second dimension as arts categorized by prestige; third dimension as arts classified at a meta-level leading to the rise of universality in classifications; fourth dimension as arts shaped by tastes that might be ephemeral as they are ritual or simply “a means of constructing social relations.” They do change over time. Since the arts in Dimaggio’s concern are cultural, and there is aesthetic consideration in a cultural product according to Hirsch’s definition, DiMaggio’s ACSs can be projected onto the study of cultural product. For example, cultural products can be classified at a meta-level (or ontological level). The “tastes” factor can be interpreted as biases, functions of rules that define a culture, that set a particular style of a cultural product. He also states that, “questions of style are independent of the structure of artistic classification systems insofar as works within the same genres may vary substantially in their thematic content” (p. 442). Based on the findings of DiMaggio, cultural products can have rules that define which cultures they belong to, biases that form their styles, and structures as foundations that support the existence of styles inclusive of features. In other words, the structures of cultural products are stable over time and form a foundation for the development of different cultural products in the same category. Moreover, a style of a cultural product is mainly defined by its features, which are shaped by the biases. Table 2.1 shows the different components of different cultural products with different naming conventions that can all be grouped under rules, structures, features, and biases.

Table 2.1: Examples of Rules, Structures, Features, and Biases of Cultural Products

Cultural Products	Rules	Structures	Features	Biases
Architecture (Maier et al., 2009)	Architectural theory	Form	Function	Architectural style
Clothing fashion (Robinson, 1958)	Fashion theory	Fabric combination, cutting	Color, weight, texture	The age group, social class, and occupation of a target market
Furniture (Wielinga et al., 2001)	Furnishings by form or function (This affects how a piece of furniture is made.)	Components such as a drawer of a chest	Physical descriptors such as color and material	Functional descriptors such as intended location and functional context
Narrative (Lavandier, 2005)	Narratology	Three-act structure	Actors, events	Genre
Popular music (Shave, 2008; Ewer, 2010)	Tonal music theory	Harmonic and rhythmic structures	Melody	Musical style

This research study focuses on the cultural products that are under the strong influence of the mainstream of a culture. Examples are clothing fashion, movies, and popular music. Referring to the definition of cultural products by Hirsch (1972), these examples have both the aesthetic and utilitarian purposes. In other words, products like a pair of scissors that only carries utilities but not beauties (representing the trend of a culture in a specific period of time) as well as a brooch that only has beauties but no utilities do not fall into the discussions of this research study.

2.2.1 Ontologies in Cultural Products

Referring to Table 2.1, architectural theory, fashion theory, narratology, and tonal music theory do describe certain creative processes (processes that create) of the respective cultural products. However, they are not meant for the whole processes. For instance, there is no music theory that describes how a piece of music is composed. In order to find out whether it is possible to use a theory to describe the different creative processes of different cultural products, this research study investigates them at an ontological level (a meta-level) to search for their commonalities, especially with reference to the above-mentioned rules, structures, features, and biases that can become the possible ontological properties of cultural products.

In fact, there are various existing ontologies of art forms and cultural products that support this investigation. Firstly, there is art works ontology by Wolterstorff (1975) with an emphasis on cultural influences on the creations of art works. Vaggione (2001) interprets such influences as constraints in his study of ontology for music composition processes that may become rules "if they exceed their use within a particular musical work to become part of a common practice" (p. 59). Furthermore, there is also ontology of art by Thomasson (2004), ontology of architecture in Japan by Lopes (2007), guitar ontology by Bandini et al. (2008), and dance ontology by Blades (2008). Their different ontological signatures can be categorized into rules, structures, features, and biases. For example, Bandini et al. use simple aggregation or specification of parts and complex characteristics derived from the combinations of different parts to define guitar features. Meanwhile, one of the explorations by Blades (2008) is about the impact of Choreographic Language

Agent on the interpretation of choreographic structures in a dance ontology. With an appropriate ontology mapping, it is possible to merge all these individual ontologies into a global ontology. Readers can refer to the paper "Ontology Mapping: The State of the Art" by Kalfoglou and Schorlemmer (2003) for details about the different ontology mappings.

If cultural products can share the same set of ontological properties, they are the same ontologically. In this way, it is possible to have a design theory to be shared among them to describe their creative processes. Readers can further refer to 5.2.1 for details about these ontological properties in this research study regarding the formation of the expected design theory. In the next subsection, this research study will further explore the possible references for the development of such a design theory.

2.3 Conceptual Design Theories

At the beginning of Chapter 1 this research study has raised a question about the possibility of referring to conceptual design theories to form a new design theory that describes the different creative processes of different cultural products due to their maturity and popularity. In this subsection, it firstly provides an overview of conceptual design theories then explores this possibility.

Generally speaking, conceptual design owns many conceptual design theories in which different conceptual design processes are found. Referring to the well-known general design theory (Yoshikawa, 1981), conceptual design is a mapping from a function space (problem) to an attribute space (solution) under certain constraints. According to Chakrabarti and Bligh (2001), conceptual design process is about "how functional requirements of a design problem are transformed into schematic descriptions of design solution concepts" (p. 494). *C-K* design theory, ASIT, and axiomatic design (Suh, 1990) are some of the well-known conceptual design theories equipped with the conceptual design process discussed by Chakrabarti and Bligh. In fact, the objective of a conceptual design theory is to identify the desired functions of a design problem and direct the mapping process to acquire the necessary attributes to solve the problem. Its conceptual design process includes functional modeling, concept generation, combination, and evaluation (Woldemichael and Hashim, 2011).

According to the study by Woldemichael and Hashim (2011) regarding a function-based conceptual design support system, a simple example of a conceptual design process (as shown in Figure 2.1) is first to analyze the requirements listed in a design specification and convert these requirements into a function. Second, a designer divides the function into a set of less complex sub-functions for an easier execution. Third, the designer brainstorms concepts for the sub-functions. Fourth, he summarizes the concepts for each sub-function to get a set of concept variants that fulfill the requirements listed in the design specification. Lastly, the designer evaluates the different concept variants under certain constraints such as the available technology and budget and chooses one or a few of them for further development.

Chakrabarti and Bligh (2001) name the function-based conceptual design process as a functional reasoning approach consisting of a functional representation that allows a designer to describe a design problem and its solution in terms of their functions, and a reasoning scheme that reasons at a functional level to produce a solution to the design problem and to evaluate the solution.

When the expected design theory in this research study is to guide a cultural product creator to complete his unfinished work, it is very similar to the functional reasoning approach. This is because it needs to help the cultural product creator to understand the ill-defined problem implied in his unfinished work that hinders him, interpret the problem into a set of functions, generate concepts for the required functions, and evaluate the concepts to form a solution to the problem. The similarities between functional reasoning and the expected design theory are summarized in Table 2.2.

Table 2.2: The Similarities between Functional Reasoning and The Expected Design Theory

Functional Reasoning	The Expected Design Theory
Functional Representation	To understand an ill-defined problem in an unfinished cultural product through problem redefinition in terms of a set of functions
Reasoning Scheme	• To generate concepts for the required functions • To evaluate the concepts to form a solution to the problem

This subsection will further continue with Chakrabarti and Bligh's discussions about the three most influential functional reasoning approaches that give readers a better understanding of conceptual design. However, since their proposed model only plays a supporting role to conceptual design but is not a conceptual design theory, this research study does not discuss it.

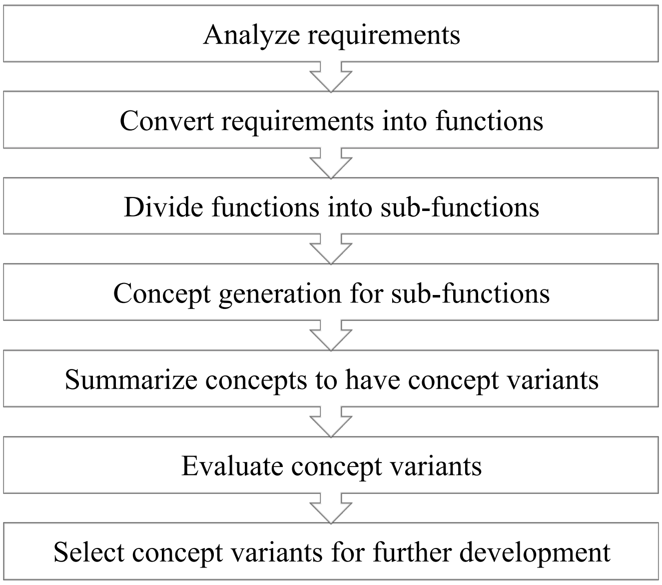
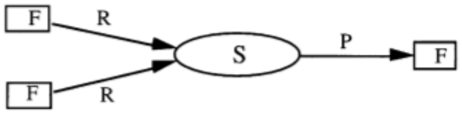


Figure 2.1: A simple example of conceptual design by Woldemichael and Hashim (2011).

The first approach is Freeman and Newell's model (1971) using known structures to identify a design problem (desired functions), and new structures to provide a design solution (required functions). In other words, the required functions fulfill the needs of the desired functions through the transformations of known structures into new structures. All these structures have attributes to enable them to provide different functions. The new structures are formed when there is a new combination of known structures. The search on the known structures to produce the necessary new structures will continue until all the required functions are present. Note that in Figure 2.2 Chakrabarti and Bligh highlight that this model does not design well at a specific given level. The solution S7 is not able to provide all the desired functions for F7.

(a)The Functional Description of a Structure S



(b)The Reasoning Scheme

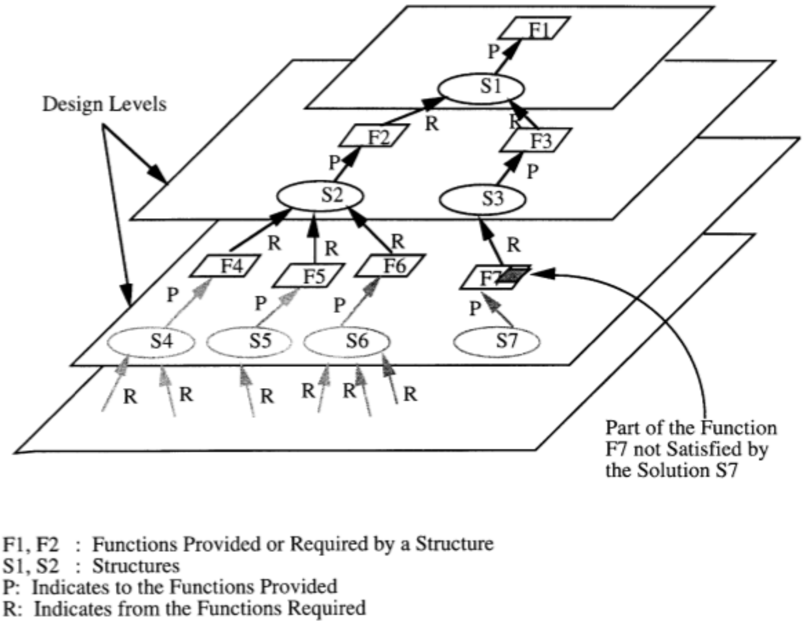


Figure 2.2: Freeman and Newell's functional reasoning model (Chakrabarti and Bligh, 2001, p. 496).

The second approach is Yoshikawa's paradigm model derived from his general design theory. In this model, a design problem is a set of functional requirements, whilst a design solution is a set of attributes. A designer proposes an initial solution and identifies the wrong components in it to find out the differences between the design specification of the design problem and the solution in hands. He further searches for the right components to reduce the differences until there is a satisfactory solution.

The third approach is Pahl and Beitz's systematic model (1995). In this model, a design problem is a set of solution-neutral functions, while a design solution is a set of solution concepts. The whole process starts with combining the solution-neutral functions into sub-functions called function-structures. These sub-functions will be simplified repeatedly until they are sufficiently simple. Then, an optimum function-structure is chosen wherein solution-alternatives are identified.

These solution-alternatives are further combined into alternative solution concepts. The best solution concepts will go tackling the design problem.

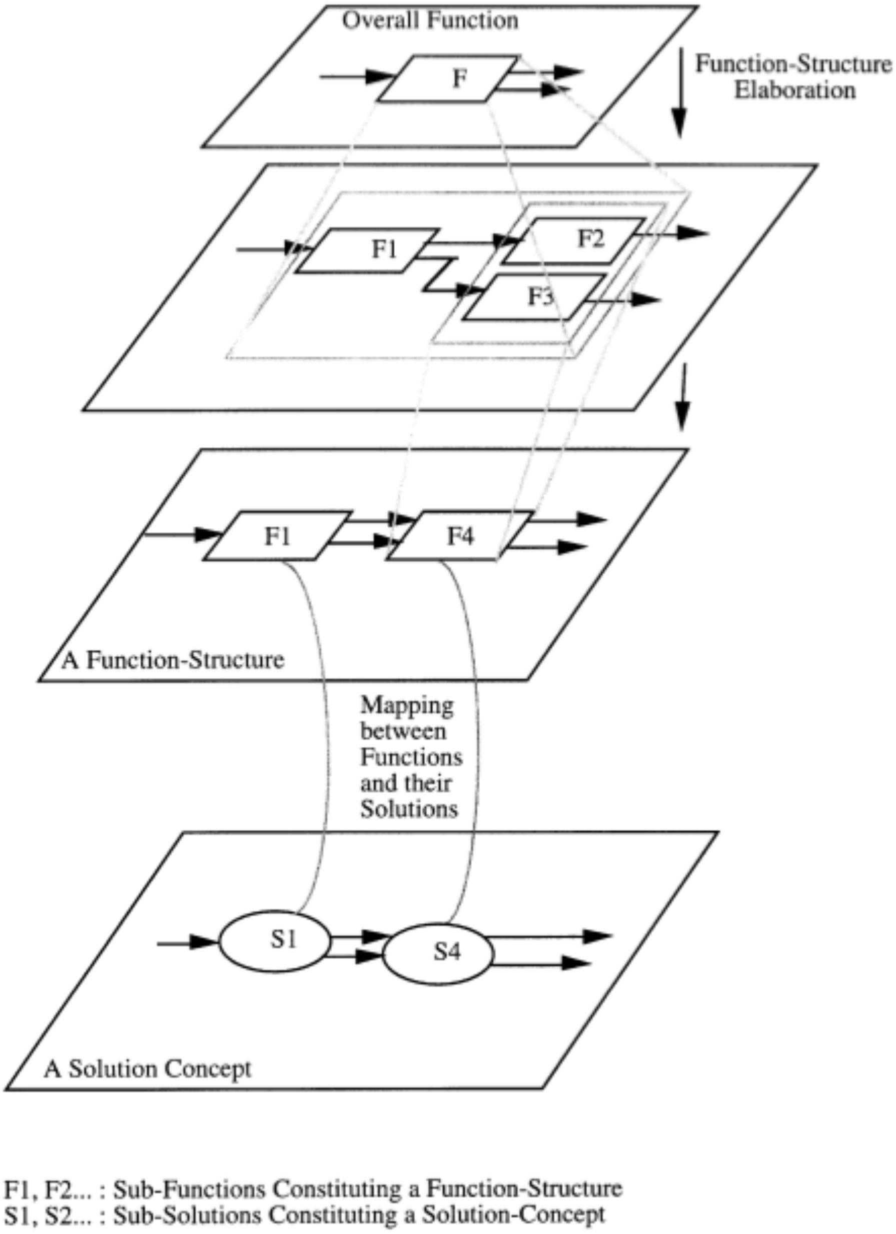


Figure 2.3: Pahl and Beitz's systematic model (Chakrabarti and Bligh, 2001, p. 497).

Among these three reasoning schemes, the systematic model is the most popular. It can be easily found in our daily design routines such as the one mentioned by Woldemichael and Hashim. However, all these reasoning schemes do not have a creative model that explicitly explains the generative process of new concepts and new knowledge (Hatchuel and Weil, 2009). C-K design theory to be discussed in the next subsection provides a solution to this problem.

2.3.1 C-K Design Theory – A Conceptual Design Theory with a Creative Model

C-*K* design theory (Hatchuel and Weil, 2003, 2009) is a model for creative design. Many scholars have applied it to their studies (Le Masson and Magnusson, 2002; Ben Mahmoud-Jouini et al., 2006; Elmquist and Segrestin, 2007; Salustri, 2012). It is considered as a good representation of conceptual design theories with creative models and all design theories due to its powerful modeling capacity and generality (Hatchuel and Weil, 2009). It is unique in the way that it regards creativity as a "constitutive part of the design process" (Reich et al. 2012, p. 143), and therefore incorporates a model of creative thinking in the form of the modern Set theory. Since "dynamic mapping is not sufficient to describe the generation of new objects and new knowledge which are distinctive features of Design" (Hatchuel and Weil, 2009, p. 181), *C*-*K* design theory has two spaces and four operators to combine the dynamic mapping process between functions and structures with the generative process of new concepts and new knowledge (as shown in Figure 2.4), making it significantly different from the other conceptual design theories such as general design theory (Yoshikawa, 1981) and axiomatic design (Suh, 1990) that only focus on the mapping process. Most importantly, *C*-*K* design theory "establishes necessary conditions that should be verified by any creativity method" (Reich et al., 2012, p. 145) giving it a paramount status representing conceptual design theories with creative models.

The two spaces of *C*-*K* design theory are concept space *C* and knowledge space *K*. Space *K* provides knowledge and logics for reasoning about the relations between concepts of space *C*, and is responsible for passing a property to space *C* to trigger partitioning of an initial concept to create new concepts. If that property is known to space *K*, there will be restrictive partitions in space *C*. Otherwise, there will only be expansive partitions where creativity happens. One can imagine that space *K* represents a designer that may possess a known property such as a basic component of a chair and an unknown property such as a design brief that cannot be understood with his current knowledge. Due to the different natures of space *C* and *K*, a design or design solution must go through the path of the type $K \rightarrow C \rightarrow K'$ to acquire new concepts and reason about the new concepts (Shai et al., 2012). All the activities in space *C* and *K* are categorized as the below four operators:

i. $K \rightarrow C$ starts off the generation process of a design solution.

ii. $C \rightarrow C$ partitions an initial concept and the subsequent concepts either in a restrictive or expansive way.

iii. $C \rightarrow K$ connects a new concept with the knowledge in space *K* for reasoning.

iv. $K \rightarrow K$ reasons about a new concept from space *C*.

Note that space *C* only performs partitioning to generate concepts for space *K* because it is defined within a restricted axiomatic of set theory, and is unable to verify the axiom of choice and the axiom of regularity with its nature of undecidability (Hatchuel and Weil, 2003, 2009). That is, it only classifies a new concept after partitioning as true, false, or undecidable. It ignores any logical status that space *K* may have for each concept. On the other hand, space *K* may represent a designer to reason about the different concepts in a new design. This is in fact a complicated cognitive process that involves different cultural values that are not in the discussions of this research study.

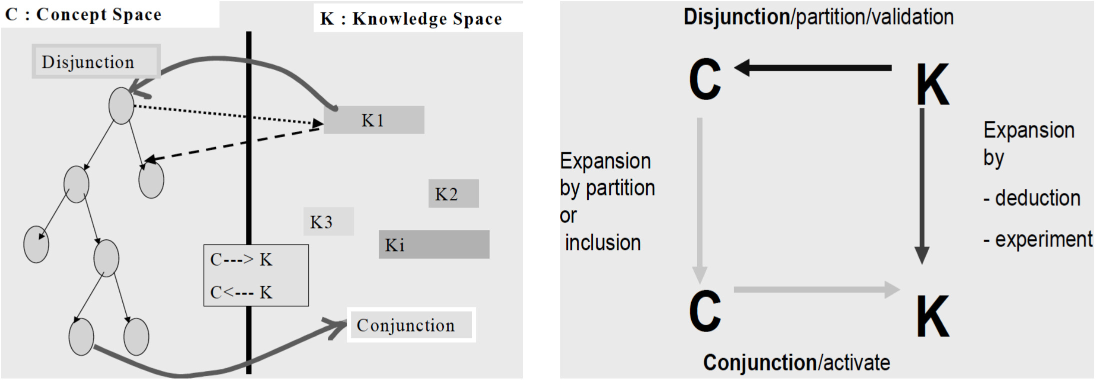


Figure 2.4: The two spaces and four operators of *C-K* design theory (Hatchuel and Weil, 2003, p.118).

2.3.2 Creativity in Conceptual Design

This research study does not discuss the different creativity theories in the fields of psychology and cognitive science. It uses a simple description to explain the role of creativity in conceptual design.

Goel and Singh (1998) state that, “Creativity researchers, mostly from the field of psychology, usually claim that being creative means being novel and appropriate” (p. 6). Gomes et al. (2006) also emphasize that novelty and appropriateness are the two main properties of creative design. This balance of novelty and appropriateness is of utmost importance because it facilitates the practical use of any conceptual design theory. That is, on the one hand, we need such a theory to make ourselves more creative; on the other hand, we expect the theory to help us produce appropriate results for a particular task. Readers can further refer to 5.2.2 about the key axiom of cultural product ontology in this research study for more information about the balance. Dorst and Cross (2001) provide an interesting view on such a balance:

> “So it may be that creativity is normally regarded as a significant aspect of an overall ‘good’ design. However, ‘creative’ design is not necessarily ‘good’ design … It therefore provides an interesting observation on the role of creativity within the total set of design goals. A designer’s aim normally is to achieve a high-quality design, with newness, novelty or

> creativity being treated as only one aspect of an overall, integrated design concept" (Dorst and Cross, 2001, p. 431).

The other aspects of the integrated design concept could be mostly about appropriateness to acquire a 'good' deign. Conceptual design theories with creative models like *C-K* design theory have already addressed the novelty of the balance (Le Masson and Magnusson, 2002; Ben Mahmoud-Jouini et al., 2006; Elmquist and Segrestin, 2007) but not yet the appropriateness, which must refer to a specific context for users to easily understand and practice the relevant theory, contradictory to the broad meanings of conceptual design theories. Consequently, this imbalance hinders them from being easily implemented in design problems. For example, *C-K* design theory has two spaces and four operators to combine the dynamic mapping process between functions and structures with the generative process of new concepts and new knowledge. However, there is no guidance about how a designer of a particular domain should use it to solve his design problem. This research study will pay special attention to this issue when formulating the expected design theory regarding the creative processes of cultural products.

2.4 Creativity Support Tools

As discussed in 1.1 there is a sub-problem in this research study regarding the lack of a reliable computational creative method in a single-user CST that produces creative and representational system outputs as continuations to a user unfinished creative work. In this subsection this research study will first continue its discussion on creativity computationally. Then, it will provide an overview of CSTs followed by a discussion on the use of computational creativity in them and so the problems to be solved in this research study.

2.4.1 Computational Creativity

In 2006 Wiggins (2006a) presented his definition of computational creativity:

> "The study and support, through computational means and methods, of behavior exhibited by natural and artificial systems, which would be deemed creative if exhibited by humans" (p. 451).

In the same year Ritchie (2006) also presented his mechanisms rather than a formal definition of computational creativity, which stated that:

> "the artefacts [caused by computational creativity] are intended to be, or to directly represent, objects or concepts (e.g. melodies, poems, pictures) which, if produced by a human, might – if good enough – be classed as demonstrating creativity … [and their classifications and qualities] may be a matter of subjective (human) judgment" (p.242).

In 2009 AI Magazine had a special issue about computational creativity. In that issue, many recognized scholars including Boden, Colton, Gervas, Ritchie, and Wiggins expressed their viewpoints about the roles and evolutions of computational creativity in artificial intelligence. Colton, Mántaras, and Stock (2009) presented their definition of computational creativity in that issue:

> "[C]omputational creativity is the study of building software that exhibits behavior that would be deemed creative in humans … However, computational creativity studies also enable us to understand human creativity and to produce programs for creative people to use, where the software acts as a creative collaborator rather than a mere tool" (p. 11).

Compared to the definition by Wiggins and mechanisms by Ritchie, the definition by Colton et al. further investigates the applications of computational creativity – creative collaborator – and the thought process behind. It is preferred in this research study.

On the other hand, Newell et al. (1963) define the type of computational creativity that a creative system should possess. They claim that a creative system output should be novel, useful, innovative and therefore exclusive of the previously accepted ideas, insightful about the relevant problem domain, and reflective about a user's passion and determination to succeed. Cardoso et al. (2009) state that their definition of creativity is the most commonly used in artificial intelligence. However, it does not include any mechanism about generating computational creativity. This research study further refers to Boden's theory for an answer.

Boden (1998, 2009) suggests three types of computational creativity for a machine to imitate human creativity. Firstly, there is combinational creativity that uses familiar ideas to generate new ideas in the form of unfamiliar juxtapositions. Secondly, there is exploratory creativity (E-creativity) that explores the potential of a conceptual space to create new and unexpected ideas. It is culturally dependent. Thirdly, there is transformational creativity (T-creativity) that requires a transformation of one or more dimensions of a conceptual space to generate exceptional ideas. Wiggins (2001, 2003, 2006a, 2006b) adds onto Boden's definition of T-creativity that a creative system must be able to search beyond its conceptual space, produce perfect or productive aberration (an idea that is perfect to a user or partly acceptable), and facilitate user self-awareness to make a new rule or rule change so as to transform a dimension of a conceptual space. These three types of computational creativity can be evaluated by personal creativity (P-creativity) concerning judgments of an individual or historical creativity (H-creativity) requiring recognitions of a society. Boden's theory is well recognized among scholars (Ram et al.; Schank and Foster; Turner, 1995; Ritchie, 2006; Colton et al., 2009), and has laid down a solid foundation for the study of creative systems (Perkins, 1995; Pease et al., 2001; Ritchie, 2001; Wiggins, 2003; Peinado and Gervás, 2006).

According to Boden, the exceptional T-creativity should be novel and innovative enough to let a creative system to achieve the type of computational creativity that it should possess as discussed by Newell et al. Boden says, “novel ideas gained by exploring an unknown niche in a pre-existing conceptual space are regarded as less creative than ideas formed by transforming that space in radical ways” (Boden, 1995, p. 125). However, it is difficult to prove that T-creativity is inspiring and useful for a problem domain without applying it to a particular situation.

In addition, it is important to learn about another school of computational creativity – Gärdenfors’ theory of conceptual space (1995, 2000, 2007) – to better appreciate Boden’s theory. Basically, it is about Gärdenfors’ interpretation of a conceptual space but not the generation of creativity. However, some scholars such as Forth, Wiggins, and McLean (2010) regard it as a new horizon of instantiating the abstractions in Boden’s theory and therefore a mechanism of computational creativity. This theory regards a conceptual space as a multidimensional space and renames it as betweenness, a conceptual level of which conceptual structures are located. This conceptual level is between a symbolic level, such as a formal grammar, and a sub-conceptual level, for example, a neural network. Gärdenfors regards the relations between the symbolic and sub-conceptual levels as an irreconcilable dichotomy. They can only be united at a conceptual level. Most importantly, it defines criterion *P* for the development of a natural property, and criterion *C* for a natural concept. Criterion *P* is a convex region of a domain in a conceptual space in which natural properties can be found, while criterion *C* is a set of regions of different domains forming a natural concept. Such a natural concept contains the interrelations between the different domains in a conceptual space. Since these different domains govern different sets of regions, a natural concept also owns the natural properties in these regions. Furthermore, the boundaries between the different regions of a natural concept give rise to combinational and E-creativity. T-creativity may appear in one, two, or many of the domains.

Although Forth, Mclean, and Wiggins (2008) comment that "[i]f the region is extended outwards, preserving convexity, new concepts between the aberration and the previous *P* will be included" and "[whenever] a vector is taken outside of a *P* we have an aberration" (p. 24), it is still very difficult to define the mechanisms for generating different types of computational creativity in Gärdenfors' theory. For example, how can we have an irreconcilable dichotomy between a grammar derived from a conceptual level and a neural network that comes from the same conceptual level? Gärdenfors' theory is too abstract for this research study to implement when compared to Boden's theory that has the clearer explanations about the formations of E-creativity and T-creativity (ET-creativity) and counterparts such as Wiggins's Creative Systems Framework (Wiggins, 2003) and Richie's search mechanisms (Ritchie, 2012). Thus, this research study mainly focuses on Boden's theory to define the mechanisms of generating different types of computational creativity in a single-user CST.

2.4.2 Defining CST

A CST is a computer system that aims at enhancing human creativity by assisting users in producing and organizing ideas (Chen, 1998). It can also be used to enhance the creative process and product quality (Shneiderman et al., 2006). Daily examples of CSTs include Personal Digital Assistant, Wikipedia, and Google Maps (Opas, 2008; Shneiderman et al., 2006). Academic examples are Aaron (Cohen, 1995) for drawing, BRUTUS (Bringsjord and Ferrucci, 2000) for storytelling, and Continuator (Pachet, 2006) for music composition.

According to Sielis et al. (2009), CSTs can be grouped with regard to the creativity techniques they have adopted. mycoted.com offers a simple grouping of them. Generally speaking, these techniques relate to problem definition inclusive of redefinition, idea generation, idea selection converting ideas into solutions, idea implementation realizing ideas, and processes emphasizing the completeness of the overall creative process. Wikipedia, Google Maps, Aaron, and BRUTUS work on idea generation, while Continuator offers both idea selection and idea implementation.

Shneiderman (2009) states that, "The popular and scientific literature on creative processes in business, science, arts, etc. is huge, but the literature on how to design, manage, and use technology to accelerate discovery and innovation is modest" (p. 7). Fortunately, this research study has identified a valuable problem about CSTs. That is, at the time of writing this dissertation, there is still not yet a commonly agreed creative method for CSTs that allows them to read user requirements implied in their unfinished works, to generate creative solutions from the user perspectives, and to evaluate the usefulness and creativity of their outputs objectively. For instance, although Continuator (Pachet, 2006) is a musical instrument capable of producing real-time response to a user input through a variable-order Markov model and a generator module, it can only produce outputs consisting of the characteristics of an input phrase. Sielis et al. coin this problem as the lack of context awareness in CSTs that may exist through system awareness of user and social environment as well as the provision of system recommendations to the user. They stress that context awareness in CSTs can "significantly enhance creativity and learning." Without it there is no appropriate recommendation from a CST to support its user during the creative process. Such recommendation can strongly influence the creative process positively. This research study considers an inclusion of domain information in the design of a CST corresponding to the type of works signified in user inputs is of great importance to the usefulness of a CST. There is a discussion on this matter in Chapter 5.

2.4.3 The Applications of ET-creativity in CSTs

Currently, most CSTs focus on producing ideas with combinational or exploratory creativity. An example of CSTs that produces combinational creativity is Wikipedia. A writer having a writer's block can use its search engine to look for information about a keyword for inspiration. To this writer, the different phrases with the keyword together generated by Wikipedia could be the unfamiliar juxtapositions (the different word combinations that are new to this writer) that become the brilliant ideas to tackle his writer's block. An example about E-creativity is Experiments in Musical Intelligence (EMI) by Cope (1992), which is capable of composing music in the styles of some famous music composers such as Mozart and Stravinsky. The user can further revise the system outputs of EMI to create his music. Boden (1998) states that EMI explores a conceptual space to produce E-creativity.

An example of CST with T-creativity is the open support system equipped with a meta-design approach by Banerjee, Quiroz, and Louis (2011) for the design of floorplans and layouts for brochures and posters. It can generate at least pseudo T-creativity in a collaborative environment. According to Banerjee et al., this is referring to the situation that "the remotely located designers working on the same design problem (floorplan design or editorial design) have the ability to view a set of evolving peer designs and include one or more of these concurrent designs in their own population at any given time" (p. 82). This fits into one of the prerequisites of Wiggins's CSF that there is a search beyond an existing conceptual space resulting in a new concept that forms a new rule or rule change in the existing conceptual space. However, since it is hard to prove that the evolving peer designs must be new concepts, this process may only be able to produce something close to T-creativity. That is, the pseudo T-creativity. Leon (2009) comments on such a meta-design-based collaborative approach in his discussion of computer-aided innovation:

> As long as new optimization methods are not yet fully developed, it has proven useful to allow the interaction of designers with the search process as intermediate steps in the search process [that] may stimulate their imagination and ability to generate new ideas for design variants, which means reducing designers' psychological inertia. (p. 541)

In fact, it is difficult for a single-user CST to generate T-creativity in its outputs, especially when such a CST is supposed to take in a user's unfinished creative work and produce representational and creative outputs as continuations to the user input. According to Wiggins's Creative Systems Framework (CSF) (Wiggins, 2001, 2003, 2006a, 2006b), a creative system must be able to search beyond its conceptual space, produce perfect or productive aberration, and facilitate user self-awareness to produce T-creativity. How can a single-user CST search beyond its conceptual space, read the indications of a user input to produce representational output, and yet possess a mechanism to generate productive aberration to produce T-creativity? This research study will search for solutions to these problems through the expected design theory.

2.5 Summary

This chapter reveals four cultural product components – rules, structures, features, and biases – that can also be the ontological properties of different cultural product ontologies. This revelation paves the way to the development of the expected design theory in this research study that describes the creative processes of different cultural products. Further, its discussion on conceptual design theories has identified functional reasoning approach as the core of the expected design theory. It also highlights the importance of an explicit creative model in such a theory. In addition, it specifies the creativity in this research study that requires a balance between novelty and appropriateness, leading to the question about how a conceptual design theory can offer appropriateness when solving a design problem – a crucial aspect of the expected design theory. Lastly, it introduces computational creativity and CSTs for the sub-problem of this research study.

Chapter 3

Methodology

> “Research in design is truly inter-disciplinary, with influences from engineering sciences, sociology, psychology, and economics” (Teegavarapu and Summers, 2008, p. 1).

3.1 Overview

This chapter defines the methodology of this research study. It first explains why the expected design theory is prescriptive and abductive. Then, it further explores the conceptual design theories that are also prescriptive and abductive to be the references for the development of the methodology, since the expected design theory is supposed to be derived from conceptual design theories. The latter part of this chapter lists down the four major parts of the methodology in view of TRIZ, and suggests using cases to evaluate the operations of the expected design theory. Lastly, it discusses the necessary conditions for the computational representation of the expected design theory.

3.2 Prescriptive Model of Design

According to Finger and Dixon (1989b), the major categories of design research include prescriptive models for design, descriptive models of design processes, computer-based models of design processes, design representations, analysis to support design decisions, and design for X (manufacturing and other life cycle issues). Teegavarapu and Summers (2008) claim that there are five types of design research objectives regarding empirical research, experimental research, development of new tools and methods, implementation studies, and others that include design theory and education. They further summarize the relations between the first four objectives as shown in Figure 3.1. The expected design theory of this research study falls into the third type – development of new tools and methods.

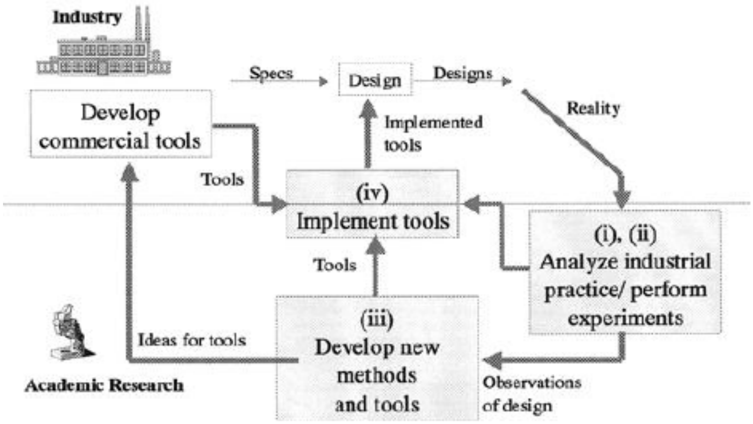


Figure 3.1: The four design research objectives discussed by Teegavarapu and Summers (2008, p. 2).

Finger and Dixon (1989a) further summarize the studies of Cross et al. (1981) and Simon (1969) and conclude that “design is a technological activity” and design theory should be scientific. These two viewpoints greatly affect the direction of this research study, leading to an exploration of the conceptual design theories of engineering design for the formation of the expected design theory that is catered for cultural product creation. They further elucidate in their studies that many researchers have focused on descriptive and prescriptive models of design. The former is about how we design. This involves design process, strategies, and problem-solving methods. The latter is about how a design process should happen and what attributes a design artifact should embrace. They emphasize that prescriptive model could contribute to a better design of a designer.

The expected design theory of this research study is to describe and explain how an incomplete cultural product becomes a complete one with reference to conceptual design theories. Thus, this research study falls into prescriptive model of design. In fact, prescriptive model is one of the three design methodologies regarding decision making as discussed in a recent study by Ng (2011). Its role in design research is prominent. However, there is an outstanding research issue to be solved:

> The mapping between the requirements of a design and the attributes of the artifact is not understood. Because the goal of designing is to create artifacts that meet the functional requirements, more fundamental research is needed on relating the attributes of designs to functional requirements, that is, on prescribing the artifact (Finger and Dixon, 1989b, p. 131).

The nature of this outstanding issue of prescriptive model can be explained with abduction in reasoning. Takeda (1994) and Dorst (2011) have a detailed discussion on the use of abduction in design.

3.3. Abduction in Design

Takeda (1994) claims that when an expected design solution (consisting of the attributes of a design solution) is complex, abduction should be used. This involves a design process that requires a good comprehension and use of the expected design solution (*Ds*) and knowledge for the design (*K*) to generate the required design specifications (*S*) (formula 1). In other words, the design problem is not well defined at this stage. Should it be well defined, deduction can be used to derive the expected design solution based on the required design specifications and knowledge for the design – a common approach when the expected design solution is a routine design (formula 2). Takeda further highlights that the knowledge in an abductive framework is about object properties and behaviors derived from the descriptions of the object, different from the one in the deductive framework regarding how to design. Under these circumstances, abductive inference is to produce feasible solutions but not definite ones.

$$Ds \cup K \vdash S \tag{1}$$

$$S \cup K \vdash Ds \tag{2}$$

Dorst (2011) illustrates the use of abduction in design in an even easier way. He states that inductive reasoning triggers discovery that can be justified by deductive reasoning. Such a discovery should offer a set of values. The inductive reasoning can be further interpreted as serving two different purposes. The first one is to find out what (???) can go through a specific set of working principles (HOW) to produce certain values as shown in formula 3. The second one is to find out both the "what" and working principles that can produce the expected values.

$$\text{???} + \text{HOW}^{\text{leads to}}\ \text{VALUE} \tag{3}$$

The expected design theory of this research study is similar to formula 3 with the missing "what" being partially known. In this way, a problem redefinition is first required to help find its remaining parts to complete it. Then, the expected design theory is the working principles that explain the creative design processes of different cultural products. The expected values refer to the cultural values or even market values the complete cultural product offers. Formula 4 summarizes the objective of the expected design theory of this research study.

$$\text{THE MISSING PARTS OF ??? + THE EXPECTED DESIGN THEORY}^{\text{leads to}}\text{ VALUE} \tag{4}$$

3.4 Conceptual Design Theories with Prescriptive Models and Abductive Reasoning

As discussed in Chapter 1 this research study is trying to borrow certain concepts from conceptual design theories to form the expected design theory. This section is to explore whether there are conceptual design theories that consist of prescriptive models and abductive reasoning so that they can be the references for the development of the methodology of the expected design theory.

TRIZ, the theory of inventive problem solving or in the Russian term "Teoriya Resheniya Izobreatatelskikh Zadatch," was developed by Genrich Saulowitsch Altshuller (1984, 1998). Its aim is to assist in forging systematic innovations. Its formation was based on the comparisons between thousands of patents and the subsequent conclusions regarding the 40 inventive principles of different inventors. Some of the principles are about segmentation, extraction, consolidation, and transformation of states. Moehrle (2005) states that TRIZ is to offer designers an "easy access to a wide range of experiences and knowledge of former inventors, and thus use previous solutions for solving new inventive problems" (p. 4). This is similar to the idea of prescriptive model that informs designers how the design process should happen according to certain instructions. Furthermore, a number of TRIZ tools have been developed. According to Moehrle, a type of TRIZ tools is to assist in specifying how a current state can transform into an intended state. For example, a tool using inventive principles with contradiction matrix (a 39-row and 39-column matrix full of technical systems' parameters about the desired functions and harmful factors of a system in the rows and columns respectively) is about "transferring the desired function and the harmful factor of a problem to the contradiction matrix and applying of recommended abstract inventive principles" to form the intended state (Moehrle, 2005, p. 6). This is akin to abduction that helps define what is needed to go through certain working principles to produce the expected values or even define both the subject and working principles to arrive at the expected values. Savransky (2000) also states that TRIZ is good at defining unknown causes (what) and unknown search directions (working principles). TRIZ has gained an overwhelming popularity in academia. There are TRIZ journals for scholars to discuss their findings on TRIZ.

Another conceptual design theory that embraces prescriptive model and abductive reasoning is C-K design theory (Hatchuel and Weil, 2003, 2009). This model for creative design has two spaces and four operators to combine the dynamic mapping process between functions and structures with the generative process of new concepts and new knowledge, making it significantly different from other conceptual design theories such as general design theory (Yoshikawa, 1981) and axiomatic design (Suh, 1990) that only focus on the mapping process. Most importantly, C-K design theory "establishes necessary conditions that should be verified by any creativity method" (Reich et al., 2012, p. 145) giving it a paramount status representing conceptual design theories with creative models. In this way, its two spaces and four operators are the necessary conditions for all the creativity methods in engineering design. In fact, C-K design theory is good for designers who know the expected values but not the “what” and “working principles” in view of Dorst’s explanation on abduction as shown in the above formula 3. It aims at guiding designers to produce an artifact that can produce the expected values through an explicit creative model.

Other conceptual design theories with prescriptive model and abductive reasoning include the Function-Behavior-Structure model of designing (Gero, 1990; Gero and Kannengiesser, 2004) and Advanced Systematic Inventive Thinking (Horowitz, 1999).

This research study will mainly refer to the methodology of TRIZ to form its methodology due to its popularity and suitability. It will:

- Study cultural products ontologically to have a better understanding of their nature.
- Describe their nature in a systematic and scientific way so that a set of working principles (the expected design theory) can be defined to describe their components, formation, and transformation. Readers can refer to 8.2 for the examples of the working principles.
- Describe and explain the relation between the cultural product ontology and expected design theory of this research study since there is no commonly agreed method for cultural product creation yet.
- Elucidate whether the expected design theory can guide designers to reach the expected values as prescriptive model only suggests how a specific design process should proceed. Under these circumstances, this research study will use a case study to demonstrate the operations of the expected design theory. In fact, this approach has been studied and properly defined as discussed in the next section.

This research study will use cases to demonstrate the operation of the expected design theory. However, since the expected design theory is not yet at a symbolic level that offers rules for designers to design but resides at a sub-conceptual level to consolidate abstract concepts and bring them a step closer to the symbolic level, the cases are not able to test its practicality but operations that should contribute to the missing parts of the subject of a design and the relevant working principles as discussed in 3.3.

3.5 The Necessary Conditions for the Computational Representation of the Expected Design Theory

As discussed in Chapter 1 this research study will also try to define a computational representation of the expected design theory that applies to single-user CSTs. These CSTs read user unfinished works and produce representational and creative outputs as continuations to the user inputs. In this respect it refers to Boden's theory of computational creativity and Wiggins's CSF as discussed in Chapter 2 as well as Richie's search mechanisms regarding Boden's theory to be discussed in Chapter 7 to form the theoretical framework for the generation of ET-creativity in the computational representation of the expected design theory. In other words, the findings of these three scholars will provide the necessary conditions for the generation of ET-creativity in the computational representation of the expected design theory.

3.6 Summary

This chapter reveals the prescriptive and abductive nature of this research study, leading to the exploration of conceptual design theories that own a prescriptive model and abductive reasoning for the development of its methodology since its key objective is to borrow the popular concepts of conceptual design theories to form the expected design theory for cultural product creation. 3.4 lists out the four major parts of the methodology of this research study with reference to TRIZ, a very popular conceptual design theory. 3.5 states the necessary conditions for the computational representation of the expected design theory. There will be propositions drawn from each subsequent chapter to act as guidelines or principles about the formation of the expected design theory as well as how the said CST can be formed to provide a computational representation of the expected design theory. These propositions help define the missing parts of the subject of a design and the relevant working principles.

Chapter 4

Conceptual Recombination as a Sub-conceptual Design Theory

4.1 Overview

As discussed in Chapter 1 this research study is partly to explore conceptual design theories especially those with a prescriptive model and abductive reasoning to formulate a design theory that can describe and explain the creative processes of different cultural products (domain dependent) and guide cultural product creators to complete their partial works. This chapter will investigate how to deploy the concepts of conceptual design theories at a domain level for cultural product creation. It refers to Sloman's conceptual and sub-conceptual systems to form such a design theory, namely, Conceptual Recombination.

4.2 Conceptual and Sub-conceptual Levels

Gärdenfors (1997) suggests that we should reduce the number of dimensions of a piece of information at a sub-conceptual level before sending it to a conceptual level:

> "Given that we are focusing on the representational aspects of cognitive systems, let us then consider the information on the subconceptual level. How do we distill sensible information from what is received by a set of receptors? Or, in other words, how do we make the transition from the subconceptual to the conceptual and the symbolic levels? These questions point to the representation problems that occur on the subconceptual level.
>
> The basic problem is that the information received by the receptors is too rich and unstructured. What is needed is some way of transforming and organizing the input into a form that can be handled on the conceptual or linguistic level. There are several methods for treating this kind of problem. Within the area of ANNs [artificial neural networks], there are systems which are developed to perform this kind of dimensionality reduction, e.g., Kohonen's self-organizing networks" (p. 259).

There are other scholars who have answers for Gärdenfors's questions. Giretti and Spalazzi (1997) claim that the sub-conceptual layer in their *Architectural Symbolic Assistant* (ASA) focuses on the domain-dependent actions, while the conceptual layer "contains descriptive schemata of domain elements and relationships"(p. 104). Regoczei and Hirst (1989) claim that there are three levels of cogniting in their cogniting agent in which the sub-conceptual level focuses on the human cognitive activities, while the conceptual level works on "the construction of conceptual mental models, and the manipulation of these models to understand the external world". Their views on the sub-conceptual level imply that it is tasked to carry out the domain-dependent actions. If a conceptual design theory can also work on a specific domain at a sub-conceptual level, what should it do in order to reach that sub-conceptual level? This research study further investigates Sloman's findings to answer this question.

Sloman's two systems of reasoning (1996), which are well recognized among scholars (Kahneman, 2003; Slovic et al., 2006; Evans, 2008), explain the differences between a conceptual system and a sub-conceptual system. Since conceptual design theories also perform reasoning as discussed in 2.3, his insights guide us to define what we should include in a sub-conceptual design theory (From now on, this research study simply names this type of design theory as sub-conceptual design theory).

Sloman claims that a conceptual system provides rule-based reasoning. In computer science, it can be a rule-based system that encodes an infinite number of propositions (Chomsky, 1968). In Smolensky's terms, such a system processes knowledge in the form of production rules (Smolensky, 1988). These rules imply cultural traits (Sloman, 1996). In other words, a conceptual system describes knowledge for a universe with cultural rules. On the other hand, Sloman states that a sub-conceptual system is about associative reasoning focusing on similarities and temporal structures of a domain for predictions. It does not reason on the ground of an "underlying causal or mechanical structure" but predict based on an "underlying statistical structure" (Sloman, 1996, p. 4). Sloman further stresses that associations in a sub-conceptual system represent elements of a domain while rules of a conceptual system cater to a universe. The below table summarizes the key points of Sloman's analyzes about conceptual and sub-conceptual systems:

Table 4.1**:** A Comparison between Conceptual and Sub-conceptual Systems		
The 3W's & H	Conceptual	Sub-conceptual
What	Rule-based reasoning	Associative reasoning
Where	For a universe	For a domain
Why	Describe, explain, and reason about complex concepts.	Use simpler patterns with features (attributes of concepts) to perform efficient reasoning.
How	• Perform abstraction of relevant features. • Encode an infinite number of propositions. • Describe knowledge with cultural rules (casual, logical, and hierarchical) – hard constraints.	• Identify features and satisfy constraints. • Apply similarities and temporal structures of a domain to predict. • Allow soft constraints to happen and be optional for an entity.

Generally speaking, Sloman's conceptual and sub-conceptual reasoning systems are grouped under dual-process theory of psychology. According to De Neys (2006), these theories consist of two systems with the first one using logical standards for reasoning while the second one using prior knowledge and beliefs to solve problems. Evans (2008) further regards Sloman's two systems as the functional characteristics cluster associated with dual systems of thinking. Furthermore, these two systems can be named as an analytic system for conceptual system and a heuristic system for sub-conceptual system (De Neys, 2006). In addition, some scholars classify Sloman's two systems into two-system theory. Gigerenzer and Regier (1996) and Keren and Schul (2009) have a serious discussion on it and highlight the importance of an ontology for the study of the two-system theory. As discussed earlier, Sloman's two systems are well established and have been adopted for the study of explicit and implicit attitude change (Gawronski and Bodenhausen, 2006) and the development of the theory of implicit and explicit knowledge (Dienes and Perner, 1999).

According to the above different analyses and studies, it is possible to claim that a conceptual design theory is to a great extent similar to a conceptual system. Firstly, it allows designers to use cultural rules to explain how a design solution is derived. Secondly, it is meant for all kinds of designs. Thirdly, it stays at an abstract level to describe, explain, and reason about complex concepts. Fourthly, it also encodes an infinite number of propositions, since it is catered for all designs.

Theoretically, it is feasible to adopt the characteristics of a sub-conceptual system to interpret a conceptual design theory into a sub-conceptual design theory, since the former resembles a conceptual system that can be interpreted into a sub-conceptual system. Referring to Table 4.1, a sub-conceptual design theory in this way has a much smaller scope for associative reasoning, and therefore, allows the use of a simpler coding method to encode only those attributes of concepts that belong to a particular domain leading to an efficient reasoning.

Definition (*Sub-conceptual Design Theory*). A sub-conceptual design theory acts like a conceptual design theory at a domain level and adopts Sloman's sub-conceptual system to perform associative reasoning.

4.3 Conceptual Recombination as a Sub-conceptual Design Theory

This research study proposes a sub-conceptual design theory called Conceptual Recombination to help cultural product creators to adopt the concepts of conceptual design theories to complete their incomplete works. As discussed in 2.3 this new design theory is akin to a functional reasoning approach that allows a designer to describe a design problem and its solution in terms of their functions and uses a reasoning scheme that reasons at a functional level to produce a solution to the design problem and to evaluate the solution. Its computational representation is to be discussed in Chapter 6. Furthermore, it operates on the rules, structures, features, and biases of cultural products as discussed in 2.2 in response to the constraints, similarities and temporal structures, simpler patterns with features, and biases of a sub-conceptual system. Chapter 5 will elaborate on its relations with cultural product ontology.

4.4 Summary

This chapter explicates the differences between conceptual and sub-conceptual design theories through Sloman's conceptual and sub-conceptual systems. It further gives the definition of sub-conceptual design theory. Conceptual Recombination as a sub-conceptual design theory is to reveal the creative processes of different cultural products and guide cultural product creators to complete their partial works. Its characteristics include the use of associative reasoning and functional reasoning.

4.4.1 Propositions for the Formation of Conceptual Recombination

- **Proposition 1:** Conceptual Recombination requires a smaller scope defined as a domain for associative reasoning.
- **Proposition 2:** Conceptual Recombination requires constraints, similarities and temporal structures, simpler patterns with features, and soft constraints of a sub-conceptual system in the domain.

Chapter 5

The Theoretical Framework of Conceptual Recombination

5.1 Overview

There are two parts in this chapter. The first part details the relations between Conceptual Recombination, a sub-conceptual design theory, and cultural products. It first defines the cultural product ontology to describe cultural products ontologically, emphasizing their commonalities that give rise to Conceptual Recombination. Then, it points out the lack of method ontology in the cultural product ontology, and therefore, any creative method, including Conceptual Recombination, which describes the creative processes of cultural products, is a task model for the cultural product ontology when referring to engineering design. The second part provides additional theoretical information for the computational representation of Conceptual Recombination. This involves i) the role of the cultural product ontology in a single-user CST, giving information about the transformation from a user unfinished cultural product to a system generated complete work as shown in Figure 5.1; ii) the working relation between the cultural product ontology and Conceptual Recombination; iii) the conceptual space for the generation of computational creativity; iv) the application of ET-creativity to the structures and features of cultural products respectively as shown in the rightmost diagram of Figure 5.1.

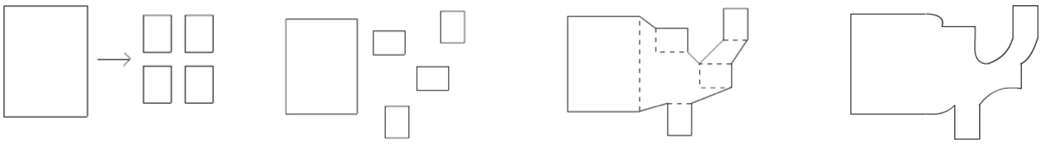


Figure 5.1: A transformation of a user unfinished cultural product (a symmetrical rectangle) into a system generated complete work (an asymmetrical 2D pattern). The first three diagrams from left to

right shows the transformation process by a single-user CST. The rightmost diagram shows the application of ET-creativity to the structures and features of the system output. Readers can refer to 8.3 for details.

5.2 Cultural Product Ontology

This section defines a cultural product ontology in view of the previous discussions on cultural products and the ontologies in them in Chapter 2. It aims at explaining how different cultural products can provide a common ground for the development of Conceptual Recombination.

In 2.2 there are two major conclusions about cultural products and the ontologies in them. Firstly, the grouping of cultural product components[1] consists of rules, structures, features, and biases. Secondly, it is possible to have a global ontology using the four cultural product components as its ontological properties aligning with the different ontological properties of different cultural product ontologies. Such a global ontology should be able to provide a solid foundation for the development of Conceptual Recombination to be shared by different cultural product creators working on different cultural product creations. In this section, this research study further refers to other literature to define such a global ontology, namely, cultural product ontology.

5.2.1 The Four Ontological Properties

As discussed by Batres et al. (2007), an ontology has i) classes with attributes, ii) relations between things in classes such as connected-to and part-of relations, and iii) axioms for these relations. Furthermore, mereology explains part-whole relations in an ontology, while topology explicates the connections between parts (e.g. homeomorphism in 6.2.2). All these characteristics should be found in a cultural product ontology.

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[1] A cultural product component is an element of a cultural product. This research study provides a possible way to group different cultural product components into rules, structures, features, and biases.

Referring to 2.2, this research study defines the ontological properties of the cultural product ontology as follows:

- Features form a class of attributes of a cultural product that a designer can easily detect through his five senses. These attributes include color, melody, taste, and smell.
- Structures form another class of attributes. They are hidden and require our analyses to find them out. These include harmonic progressions of tonal music, grammars of an English composition, and physics. Structures can also be interpreted as organizations of features.
- Rules define a particular culture. They form the axioms directing the organizations of features and structures. Readers can refer to the next subsection about the key axiom of the cultural product ontology.
- Biases are functions of rules preferred by a culture in a specific period of time affecting the manifestation of a cultural product. Referring to Sloman's two systems (1996), they are cultural rules in a conceptual system and soft constraints of a sub-conceptual system. An example about biases is that if there are 100 rules for the construction of a specific type of cultural products and a specific style is expected in this type of cultural products, the biases as functions will select 70 rules out of the 100 rules to form that style. If another style is needed, the biases as functions will choose 62 rules out of the 100 rules to produce that style. In other words, an input for biases as functions is a style for a particular type of cultural products while an output of biases is a subset of the rules for that particular type of cultural products.

Figure 5.2 shows a UML class diagram that depicts the relations between rules, structures, features, and biases. In summary, rules regulate structures and features; biases affect structures and features; structures support features. That is, rules control what structures and features can do. Features will only appear with the existence of structures. Biases define a style of a particular type of cultural products and so affect the formation of structures and features.

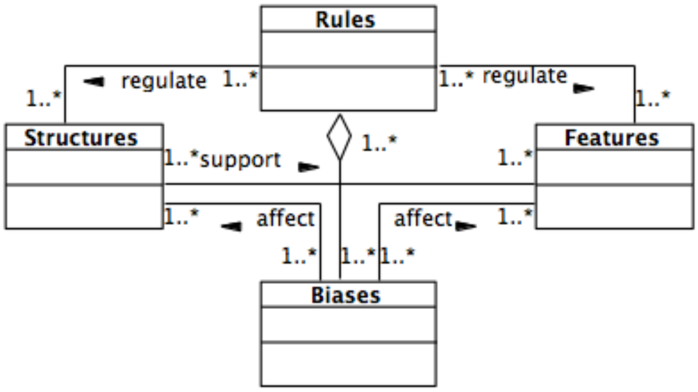

Figure 5.2: A UML class diagram depicting the relations between rules, structures, features, and biases.

Note that the cultural product ontology is not a complete specification of all cultural products in the world. It is a weak ontology (Vrandecic, 2009) that allows other domain ontologies such as narrative or architecture to refer to its ontological properties to develop their ontological properties. An example is guitar ontology (Bandini et al., 2008) for the design and manufacturing of electric guitars. Under these circumstances, the two classes – features and structures – are actually superclasses with rules as axioms.

5.2.2 The Key Axiom

In this subsection this research study especially introduce a key axiom of the cultural product ontology that greatly affects any cultural product creation. It is the balance between novelty and appropriateness. As discussed in 2.3.2 the role of creativity in conceptual design is to achieve this balance and so does sub-conceptual design. In fact, this balance is most often seen in cultural products. That is, cultural products always possess certain values that meet the needs of a group of users, society or culture that exists in a particular period of time. In other words, there are biases in their production processes that shape them into specific forms to meet the requirements of a market. A good balance between novelty and appropriateness is critical to the uniqueness and success of a cultural product.

Axiom (*The Balance between Novelty and Appropriateness*). There is always a balance between novelty and appropriateness in a cultural product. This balance refers to the closed world condition of Advanced Systematic Inventive Thinking (Horowitz, 1999), a well-known conceptual design theory. The condition "restricts the problem solver to variations on existing concepts rather than replacements or the addition of new, formerly nonexistent elements" (Maimon and Horowitz, 1999, p. 357). The condition can be interpreted as thinking inside the box. To have an even better and creative design solution, this research study allows this box to transform over time by including concepts of its designers and excluding poor ideas according to the viewpoints of its designers. The idea of this axiom will be further demonstrated in the computational representation of Conceptual Recombination.

Definition (*Cultural Product Ontology*). A cultural product ontology consists of two superclasses called structures and features with rules as axioms. It is culturally inclined with biases acting as functions of rules, and acts as a weak ontology[2] that allows individual domain such as music, narrative, or architecture to have its own subclasses for further ontological developments.

5.2.3 Yoshikawa's General Design Theory

Since it is possible to borrow the ideas of functional reasoning approach in conceptual design to form Conceptual Recombination, this subsection is to further borrow other important findings and concepts of Yoshikawa's general design theory (GDT) (Yoshikawa, 1981) to confirm the importance of the cultural product ontology and prove the validity of the four ontological properties.

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[2] Generally speaking, a weak ontology requires a domain knowledge engineer to explore it in order to find out the relevant domain ontology. A weak ontology is different from an upper ontology that describes general concepts across all knowledge domains.

GDT is a mathematical theory of design. It is well recognized among scholars (Reich, 1995; Chakrabarti and Bligh, 2001; Wood and Agogino, 2005). It refers to topology to perform predictions. It possesses many valuable insights into the different aspects of design. Firstly, it defines design process as choosing a domain in an attribute space that refers to another domain for specification. In GDT, the domain to be selected in the attribute space is the function space, while there are constraints in the form of a design specification to limit them. In other words, "designing is a mapping from the function to the attribute topology under certain constraints" (Reich, 1995, p. 28). The cultural product ontology also limits a particular domain ontology regarding cultural product. The cultural product creator involved has a specification in the form of an unfinished cultural product stating the desired functions. That is, there is a mapping from the unfinished cultural product (function) to that particular domain ontology (attribute topology) under the cultural product ontology.

Takeda et al. (1990) explains the role of a metamodel in GDT, acting as the central description of the design object. Such a metamodel can further explains the significance of the cultural product ontology. They claim that:

> "A metamodel is a description of the design object that is independent of a context. It contains all entities the design object is composed of, and it includes the relationships and dependencies among these entities" (Takeda et al., 1990, p. 41).

The cultural product ontology provides Conceptual Recombination with a theoretical background that is catered for different cultural products. It is similar to the metamodel in GDT in the way that it provides central descriptions of different cultural products to Conceptual Recombination.

Secondly, GDT supports the existence of the different ontological properties of the cultural product ontology. This research study elaborates this point as follows:

i. GDT includes the use of physical laws describing the relations between object properties and their environments. Reich (1995) provides an example about this respect in his critical review of GDT:

   > "Physical laws include gravity which establishes the *lightweight* property. The remaining artifact description properties in the chairs domain can be determined by observation. These are associated with optics laws which explains how observable attributes are sensed by people" (p. 18).

   The rules in the cultural product ontology are similar to the physical laws in GDT in the way that they also describe the relations between the properties of a user unfinished cultural product and the domain it belongs to.

ii. In GDT an attribute is an observable and measurable property described by a limited number of physical laws. When all attributes come together, an attribute space is formed. In GDT an entity is recognized and described by its attributes. These attributes are similar to the features in the cultural product ontology of which a user can easily detect through his five senses. That is, these attributes are observable and measurable akin to color, weight, and texture in clothing fashion (the features in the clothing fashion ontology). Note that GDT does not specify structures in design akin to the one in the cultural product ontology. However, it does allow organizations of attributes that function like structures as discussed by Reich (1995) in his critical review of GDT: "designing is mainly concerned with synthesis: the generation of artifact structure that will satisfy a desired function" (p. 5).

iii. There are discussions about functions in GDT that imply the importance of the biases in the cultural product ontology. It defines a functional property as a behavior that occurs when an entity is assigned to a situation. A functional description of an entity takes place when there is a collection of functions of different situations. Referring to the cultural product ontology, a bias resembles a functional property fulfilling a cultural need. When the biases work together, they provide a functional description of a cultural product. As stated in a theorem of GDT that a design specification acts as a filter for an entity. The biases in the cultural product ontology are undoubtedly the filters of a cultural product, leading it to a particular direction. The importance of the biases is confirmed.

In fact, GDT not just support the newly designed cultural product ontology but also the use of homeomorphism and T-creativity in this research study to be discussed in Chapter 6. Its insights into design are indispensible for this dissertation.

5.3 Conceptual Recombination as a Task Model for Cultural Product Ontology

The cultural product ontology does not have a commonly agreed method of formulating different cultural products. This issue can be found in many cultural products. For example, there is no rule in tonal music theory about how a songwriter should write a pop song. Similarly, narratology does not provide any method for a writer to create an exciting science-fiction story. In this research study, Conceptual Recombination is to compensate for the missing creative method of the cultural product ontology. In the long run, it contributes to the formation of the method ontology[3] of the cultural product ontology. To better understand its relation with the

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[3] Method ontology happens when there are reasoning methods that require method-specific ontological distinctions.

cultural product ontology, this research study refers to the concepts of application ontology[4] and its task model[5] (van Heijst et al., 1997).

PhysSys ontology (Borst and Akkermans, 1997) as shown in Figure 5.3 is a good example of such interdependences. It is an ontology designed for ontology projection, a form of ontology mapping (Kalfoglou and Schorlemmer, 2003), with an outsourced ontology – EngMath – to handle calculations in complex industrial applications. It also emphasizes the importance of mereology and topology in its operations. Kalfoglou and Schorlemmer (2003) have a good summary of it:

> [PhysSys] is a set of seven ontologies that represents the domain of system dynamics and expresses different viewpoints of a physical system. Interdependences between these ontologies are formalized as ontology projections and included in the *PhysSys* ontology. Three kinds of projections are demonstrated in their work: *include-and-extend*, *include-and-specialize*, and *include-and-project*. The latter was used to link an ontology developed by the authors of *PhysSys* to an outsourced ontology, the *EngMath*. These projections, though, are not computed automatically but defined manually by the knowledge engineer when designing the ontologies. (p. 18)

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[4] Application ontology is an application-specific ontology that requires a knowledge engineer to select the appropriate reusable ontological theories and adjust them to meet the application requirements.

[5] A task model consists of tasks and methods. It goes through different task analyses to divide a real-life task into a number of generic tasks to be associated with the appropriate problem-solving methods.

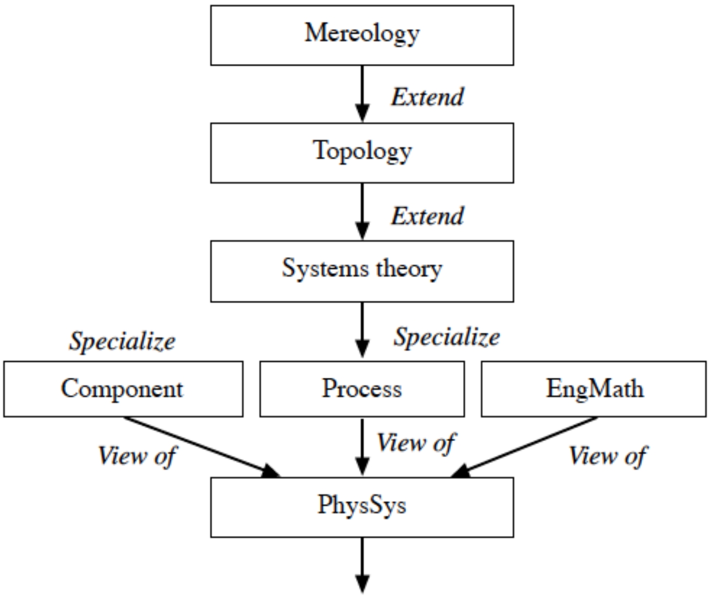

Figure 5.3: Inclusion lattice of the PhysSys ontology (Borst and Akkermans, 1997, p. 368). An outsourced ontology, EngMath, is linked to PhysSys to handle calculations.

The cultural product ontology is analogous to PhysSys ontology in the ways that it represents the domain of cultural products and helps solve prediction problems through its cooperation with Conceptual Recombination, an external creative method akin to EngMath for ontology projections. Furthermore, it also consists of mereology describing the connected-to and part-of relations between different parts of a cultural product, and topology defining the connections. As for systems theory, which provides "the standard system-theoretic notions such as system, sub-system, system boundary, environment, open/closedness, etc" (Borst and Akkermans, 1997, p. 371), and component acting as the carriers of physical processes that can be mathematically described with physical quantities and mathematical relations, this research study will further explain their interactions with the cultural product ontology through the computational model of Conceptual Recombination to be discussed in Chapter 7.

5.4 Preparing for the Computational Representation of Conceptual Recombination

As discussed in Chapter 1 this research study also aims at translating Conceptual Recombination into a computational form that can be deployed in a single-user CST that takes in a user unfinished cultural product and produces representational (user intentions) and creative system outputs as continuations to the user input. This section is to further extend 5.2 and 5.3 to prepare for this computational representation of Conceptual Recombination. Note that high quality computational creativity is required for such a CST.

5.4.1 Cultural Product Ontology in a Single-user CST

This research study refers to the definition of ontology by Schreiber et al. (1995) to explain the relation between cultural product ontology and a single-user CST with Conceptual Recombination:

> An ontology is an explicit, partial specification of a conceptualization that is expressible as a meta-level viewpoint on a set of possible domain theories for the purpose of modular design, redesign and reuse of knowledge-intensive system components. (as cited in Guarino, 1997, p. 298)

This definition states that ontology is not a complete specification of a conceptualization, and implies that it is catered for the design of various knowledge-based systems (KBS) such as a single-user CST. Its insufficiency of representing a full specification of a conceptualization could be due to our limited knowledge about a domain. In this research study, this deficiency may relate to our lack of a commonly agreed method of making cultural products, giving rise to Conceptual Recombination working as a task model of the newly designed cultural product ontology in this chapter, which in return, provides major components for the operations of Conceptual Recombination.

If a single-user CST is capable of generating an output based on a user input, and the output and user input are two consecutive parts of a cultural product, it is possible to state that the output and user input are mereologically related and parts of a cultural product. In topology their connections can be explained by homeomorphism. This transformation is based on the below three assumptions that are critical to the operations of the computational representation of Conceptual Recombination:

i. A single-user CST and its user are both working on the same domain and therefore governed by the same set of rules.
ii. There is no single-user CST that can cover all ideas of all users. As a result, user concepts may become new rules but not contributing to any structural changes in such a CST, since both the CST and user are already constrained by the domain rules. Any changes in rules will only affect the features of a creative work, enabling the transformation.
iii. When a single-user CST interacts with a user, user preferences occasionally reject certain existing superficial features defined by the existing rules. The CST should set aside these rejected features and rules to streamline both system and user evaluations, providing an efficient transformation.

5.4.2 The Relation between Cultural Product Ontology and Conceptual Recombination in a Single-user CST

Figure 5.4 depicts the relation between the cultural product ontology and Conceptual Recombination in view of application ontology and its task model in a single-user CST. The cultural product ontology consists of mereology and topology but lacks a commonly agreed creative method. Conceptual Recombination acts as a task model for it to compensate for this insufficiency. It further requires a computational model to perform exploratory and transformational searches to be discussed in Chapter 7.

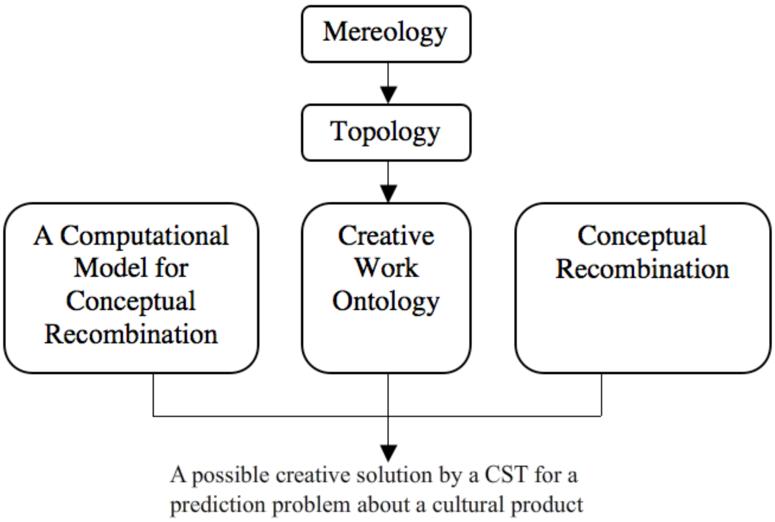

Figure 5.4: A CST with cultural product ontology and Conceptual Recombination.

5.4.3 The Conceptual Space for the Computational Representation of Conceptual Recombination

As discussed in 2.4.1 Boden's theory of computational creativity is adopted for this research study. In 2.4.3 Wiggins's CSF has highlighted the importance of conceptual space for the generation of computational creativity. This subsection is to define the conceptual space in this research study and to prepare for the discussion about the generation of ET-creativity in Chapter 6.

In this research study, the definition of a conceptual space is also following Boden's assertions, consisting of a "particular set of generative principles" of a domain equipped with "established styles of thinking," "distinct structures," and "its own dimensions, pathways, and boundaries" (Boden, 1995, p.124). This definition is preferred because of the newly designed cultural product ontology encompassing rules, structures, features, and biases. The formation of this ontology is firstly in response to the requirement of Conceptual Recombination as a sub-conceptual design theory that a specific domain consisting of constraints, similarities and temporal structures, simpler patterns with features, and soft constraints is needed for associative reasoning. Secondly, the nature of creative works in this ontology allows changing features built upon stable structures as discussed in 2.2. Both features and structures are defined by rules and affected by biases in the form of rules caused by a specific culture. This chapter tries to emphasize that these four components of cultural products are tied to the different parts of Boden's conceptual space. Firstly, the generative principles are similar to rules that are used to define structures, features, biases, and their different combinations forming a specific type of cultural products. Secondly, the established styles of thinking are similar to biases caused by a specific culture affecting the manifestation of a cultural product. Thirdly, the distinct structures are interpreted as structures of cultural products that require our analyses to find them out. An example is grammar in English. Lastly, the dimensions, pathways, and boundaries are similar to features of cultural products. That is, if we use a metric space to represent the features, different cultural products may have different number of dimensions representing the different features. Meanwhile, different combinations of pathways and boundaries deliver rules and limit their activities, affecting the structures, features, and biases in the different areas of a cultural product and giving rise to new structures and features. Readers can further refer to Table 2.1 in Chapter 2 about the rules, structures, features, and biases of different cultural products.

Although there is another school of thought by Gärdenfors (1995) regarding a conceptual space as a multidimensional space and its concepts as different sets of regions of different domains as discussed in 2.4.1, Boden's definition is still chosen due to its appropriateness for this research study. Since the focus of this dissertation does not fall on any conceptual space, there will not be any further investigation of the different definitions of different conceptual spaces.

5.4.4 The Application of ET-creativity

This research study uses E-creativity to limit changes in the foundations, properties or general principles of a cultural product, and T-creativity to free the combinations of its superficial features and form the exceptional ones, in response to the key axiom of cultural product ontology as discussed in 5.2.2. As discussed by Boden, “If the transformations are too extreme, the relation between the old and new spaces will not be immediately apparent. In such cases, the new structures will be unintelligible, and very likely rejected” (Boden, 1998, p. 349). It is vital to have ET-creativity on structures and features respectively to help secure the balance between novelty (expressed in features) and appropriateness (enforced by structures) of a cultural product, similar to achieving both the aesthetic and utilitarian purposes in Hirsch’s definition of cultural product (1972). Readers can further refer to Chapter 7 about the search mechanisms of ET-creativity. Note that appropriateness can also be interpreted as typicality (Ritchie, 2006) regarding a cultural product’s high degree of membership of the category it belongs to.

5.5 Summary

This chapter lays down the theoretical framework of Conceptual Recombination. It explains the commonalities of cultural products through the cultural product ontology consisting of four ontological properties, namely, rules, structures, features, and biases, offering a common ground for the rise of the newly defined sub-conceptual design theory. The key axiom of the cultural product ontology – a balance between novelty and appropriateness – further contributes to the application of ET-creativity to the structures and features of cultural products respectively. Moreover, this chapter also explains the working relationship between Conceptual Recombination and the cultural product ontology. It especially highlights the lack of a method ontology in the cultural product ontology leading to the use of a task model to describe the role of Conceptual Recombination with the cultural product ontology. In the latter part of this chapter, there are sections about the roles of the cultural product ontology and Conceptual Recombination in a single-user CST as well as the importance of conceptual space for the generation of computational creativity. Lastly, this chapter defines the use of ET-creativity for the structures and features of cultural products in response to the key axiom of the cultural product ontology.

5.5.1 Propositions for the Formation of Conceptual Recombination

- **Proposition 3:** Conceptual Recombination requires the ontology it is working on to support its operations. That ontology should have properties that are in response to the components of Sloman's sub-conceptual system – constraints, temporal structures, simpler patterns with features, and soft constraints as discussed in 4.2.
- **Proposition 4:** Conceptual Recombination requires the task model concept of application ontology to describe its relation with the ontology.
- **Proposition 5:** Conceptual Recombination requires a balance between novelty and appropriateness to generate a creative design solution to a design problem.
- **Proposition 6:** Conceptual Recombination requires Boden's definition of a conceptual space (generative principles, distinct structures, dimensions, pathways, boundaries, and established styles of thinking) for its conceptual spaces to be searched to form a representational and creative system output.
- **Proposition 7:** The computational representation of Conceptual Recombination requires applications of Boden's ET-creativity to the ontological properties to help produce a representational and creative system output.

Chapter 6

The Operations of the Computational Representation of Conceptual Recombination

> "The fact that we are not conscious of how a creative idea manifests itself does not necessarily imply that a scientific explanation cannot exist" (Colton, de Mántaras and Stock, 2009, p. 14).

6.1 Overview

This chapter explains how Conceptual Recombination operates as a task model for the cultural product ontology. In 6.2 Conceptual Recombination is divided into two stages – deconstruction and reconstruction – to analyze and breakdown a user input, and to convert it into a system output through its three levels of prediction concerning cultural preferences, a system's conceptual space, and homeomorphism in topology as shown in Figure 6.1. The most important finding of this chapter is the utilization of the topology of the cultural product ontology that allows the objective measurement of productive aberration to take place – the second prerequisite of T-creativity in Wiggins's Creative System Framework. This chapter gives a detailed account of the computational representation of Conceptual Recombination that is a sub-conceptual design theory with ET-creativity.

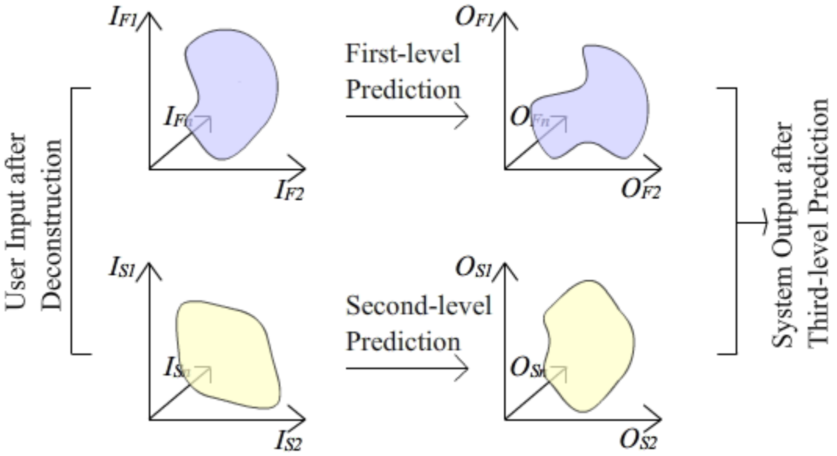

Figure 6.1: A new entity is derived from a user input according to homeomorphism. They share the same set of ontological properties, providing stable structures for the development of features. I_F stands for input feature, while O_F stands for output feature. Likewise, I_S is input structure; O_S is output structure. Readers can refer to 6.2 about the application of cultural preferences in the three levels of prediction of Conceptual Recombination and the role of the system's conceptual space during the prediction.

6.2 Conceptual Recombination as a Task Model for Cultural Product Ontology

As discussed in Chapter 2 Conceptual Recombination is akin to a functional reasoning approach. This is because Conceptual Recombination aims at helping cultural product creators to understand their ill-defined problems implied in their unfinished works, interpreting their problems into sets of functions, generating concepts for the required functions, and evaluating the concepts to form the solutions to their problems. This section refers to the idea of functional reasoning to explain the deconstruction and reconstruction stages of Conceptual Recombination in the context of a single-user CST that takes in a user unfinished cultural product and produces representational and creative system outputs as continuations to the user input.

6.2.1 The Deconstruction Stage

Since Conceptual Recombination is a creative method of a single-user CST that takes in a user’s unfinished creative work and produces representational and creative outputs as continuations to the user input, it first needs to read what the user input is about in order to produce the said outputs. In this way, it needs to read the user intentions implied in the user input. Generally speaking, user intentions in Conceptual Recombination are represented by the expected output structures and features in a system output. They are derived from the input features and input structures of a user input, and are further directed by the biases and rules of the cultural product ontology to form the expected output structures and features.

Referring to the cultural product ontology, a weak ontology, its two superclasses – structures and features – play an important role in forming a domain ontology developed from it. Furthermore, as discussed in Chapter 5, structures in a cultural product are stable and therefore predictable, while features are developed upon structures. As a result, if a part of a cultural product is known, it is possible to use it to predict another part of the creative work. For example, if an act of a narrative is known, its author can use it to predict another act based on certain events of it and the three-act structure. In this way, the user intentions represented by the structures and features of the first part can be used to predict the structures and features of the other part. Especially with the aid of biases, the structures and features of the first part are directed to form the structures and features of the other part in the reconstruction stage of Conceptual Recombination.

To identify input features and structures, Conceptual Recombination goes through a mechanism that belongs to the relevant domain ontology to deconstruct a user input in relation to the rules, structures, features, and biases of the cultural product ontology. Figure 6.2 illustrates the deconstruction stage of Conceptual Recombination. 8.3.1 and Table 8.5 further show an example of this deconstruction.

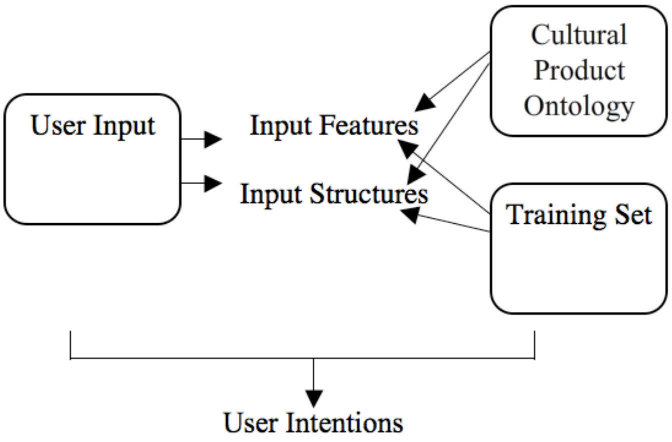

Figure 6.2: The deconstruction stage of Conceptual Recombination. It needs to work with a particular mechanism designed for a domain ontology to properly deconstruct a user input into input features and input structures to acquire the user intentions – expected output structures and features – to be implemented in the three levels of prediction of Conceptual Recombination. The training set contains the examples of the domain consisting of the relevant rules, structures, features, and biases – the ontological properties of the cultural product ontology.

The involved mechanism in the deconstruction stage takes two steps. Firstly, it checks the membership of the user input to ensure that it belongs to the domain of the CST (a key assumption in this study). Let I represent the user input and X the domain that I should belong to. $x \in X$ the domain information. The first step of the deconstruction stage can be further interpreted into a characteristic function:

$$1_I(x) = \begin{cases} 1 \; if \; x \in I \\ 0 \; if \; x \notin I \end{cases} \tag{1}$$

This function returns 1 if the user input contains the domain information in its elements. Or, it returns 0. Once this part of the mechanism can confirm that both the user input and CST are referring to the same domain, the mechanism further maps the user input to the CST's training set to identify the rules, structures, and features it has adopted and therefore its input structures and features:

$$f : I \rightarrow X \tag{2}$$

The input structures and features representing the user intentions will go through the reconstruction stage of Conceptual Recombination to form output structures and features. That is, the user intentions are to be realized in the first two levels of prediction in the reconstruction stage concerning the use of biases on the input features and the deployment of the prediction model for the input structures. Figure 6.3 shows an example of the first two levels of prediction of Conceptual Recombination to be detailed in 8.3.

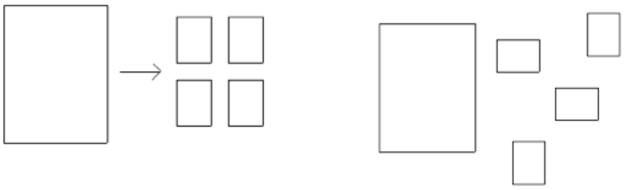

Figure 6.3: An example of the first two levels of prediction of Conceptual Recombination. The aim of this example is to produce an irregular 2D pattern based on a user input that is a symmetrical rectangle. The first two levels of prediction include a mechanism that divides the user input into smaller pieces and uses these pieces to form output features and structures. Readers can refer to 8.3.2 and 8.3.3 for details.

6.2.2 The Reconstruction Stage

In the reconstruction stage, Conceptual Recombination uses input features and structures to perform three levels of prediction to form a representational and creative output as a continuation to a user input. In the first-level prediction, it applies the biases of the cultural product ontology to the input features to predict output features. Referring to Figure 6.1, an example of biases is irregularity in a system output. Since biases are functions of rules, the input features do follow them to form output features. Let $P1$ be the first-level prediction. $P1$ applies biases (B) to input features (I_F) to form output features (O_F). Since I_F and O_F are strongly related through B, $P1$ can be interpreted as:

$$P1 = f: I_F \overset{B}{\rightarrow} O_F \tag{3}$$

In the second-level prediction, the input structures are used to predict the most probable output structures for the development of output features. It is due to the fact that structures of creative works are stable over time and therefore predictable, as discussed in 2.2. The input structures will first be mapped to the structures of cultural products in the training set of a single-user CST to identify those that have the similar structures. This research study assumes that the input structures are only a part of the user's completed work in the near future, and correspond to the parts of the training examples. A prediction model will further use these identified training examples to calculate the most probable output structures for the input structures with, for example, Bayes' rule. Let $P2$ be the second-level prediction. An example of $P2$ that predicts the most probable output structures (O_S) with the given input structures (I_S) is:

$$P2 = P(O_S \mid I_S) \tag{4}$$

An example of the first two levels of prediction is the relations between a verse and a chorus of a popular song. According to Ewer (2010), successful pop songs possess forward motion, increasing energy level, and tension-release principle. In his song analysis article about Lady Gaga's No.1 hit song "Paparazzi", he points out that the contrasting color of the key change (feature) from a minor key in the verse to a relative major key in the chorus effectively brightens the mood of the song, and the well-developed chord progression (structure) in the chorus helps make the hook line stand out when compared to the loosed harmonic structure in the verse. Key change, in tonal music, is not only a theory (rule) but also a cultural preference (bias) in many societies. If there is a training set about successful popular songs in a single-user CST for this research study, it is feasible for the CST to generate a well-developed chord progression for a chorus with the given loosed harmonic structure of a verse written by a user through, for example, Bayes' rule as discussed by Huron (2007) and Temperley (2007).

In the third-level prediction, output features and output structures come together to form an entity that is a continuation to the user's unfinished cultural product. Such an entity can be the second half of a complete cultural product with the user input as the first half as shown in Figure 6.4. These two individual parts can link to each other because of mereology and topology of the cultural product ontology. That is, the new entity is deducible from the user input. In topology, this is homeomorphism, a crucial part of it.

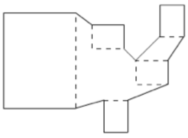

Figure 6.4: An example of the third-level prediction of Conceptual Recombination. The longest vertical dotted line divides the whole irregular shape into two parts. The right part is a system output acting as a continuation to the left part – a user input. Readers can refer to 8.3.4 for details.

Literally, homeomorphism allows the user input to deform into the system output while referring to the stable structures of the relevant cultural product and the changing features of it. That is, both the user input and system output share the same set of ontological properties, creating stability, even though they have different exteriors. This is in response to the key axiom of the cultural product ontology that requires a balance between the novelty (changing features) and appropriateness (stable structures) of a cultural product. In this way, the input structures may belong to part A of the cultural product, whilst the output structures belong to part B of it. Referring to the second-level prediction, the output structures are predictable with the given input structures. Moreover, the output features are formed in relation to the output structures and the biases derived from the input features. As a result, homeomorphism helps realize the user intentions (the expected output structures and features) implied in the user input with the aid of the first two levels of prediction.

In addition, due to homeomorphism, productive aberration, the second prerequisite of T-creativity in Wiggins's Creative System Framework (CSF), is guaranteed. That is, from the CST's perspective, the output structures are at least the parts of the system output that the user cannot resist. They are highly related to the input structures to support the development of the output features, and contain the successful output structures of the relevant domain represented by the training set. Referring to Figure 6.3, the output structures support irregularity, satisfying the need of the user though the initial system output as shown in Figure 6.4 might not yet be perfect to the user.

Technically, we can explain the relations between two parts of a cultural product (e.g. Figure 6.4) as follows:

i. These two parts have two topological spaces, G_{input} and G_{output}. They are used to define the connections between the two parts. Firstly, there are stable structures in the cultural product represented by the shared topological properties of the two topological spaces. That is, all the cultural products in the domain ontology of that cultural product share the same structures and so the topological properties. Secondly, there are changing features in the cultural product that allow the deformation of the first part into the second part, riding on the shared topological properties. These connections are also in response to the key axiom of cultural product ontology. Referring to the deconstruction stage, G_{input} assists in checking the membership of a user input by ensuring that the user input can be mapped to its topological properties.

ii. When there are topological spaces representing the two parts, and they are now represented by two numbers on a real number line, their contrary relations caused by the biases of the cultural product ontology can assign them to the quadrant I and II of a Cartesian coordinate plane that changes them into one negative number and one positive number lying on the x-axis. A zero is at the intersection between them. These two numbers not only form an open interval but also belong to other open intervals implying a continuous map and a continuous inverse. In this way, these two parts are homeomorphic. A topological property of the first part yields the corresponding topological property of the second part. Readers can refer to 8.3 and Figure 8.5 for an example.

iii. Furthermore, it is highly possible for these two parts to have bijection consisting of surjection and injection. This research study takes narrative as an example. The divorce of the main characters in a narrative is caused by the death of their son and the unemployment of the main actor. This is surjection, having an output feature caused by at least one input feature. When an output feature is caused by a single input feature such as the relation between an earthquake and a tsunami in a story, we have injection. Since bijection is very common in creative works, there is a very high chance for these two parts to have it as well.

iv. Lastly, if these two parts belong to an image full of pixels, and these pixels are represented by two numbers lying on the same x-axis as discussed earlier, for every open subset $A \subset$ the first part, the set $f^{-1}(A)$ is also open in the second part. In topology, this is continuous.

When the relations between the two parts of a cultural product are homeomorphic, continuous, and explainable with bijection, homeomorphism takes place. In Conceptual Recombination, this is the third-level prediction supported by the output features and output structures from the first two levels of prediction. Note that the system output hitherto is the initial output before the happening of T-creativity that requires productive aberration and a search beyond the single-user CST as stated in

Wiggins's CSF. In other words, the system output is not yet the finished work. There are further discussions on this matter in 6.3. Theoretically, Conceptual Recombination is a homeomorphism at the topological level:

$$f : G_{input} \rightarrow G_{output} \qquad (5)$$

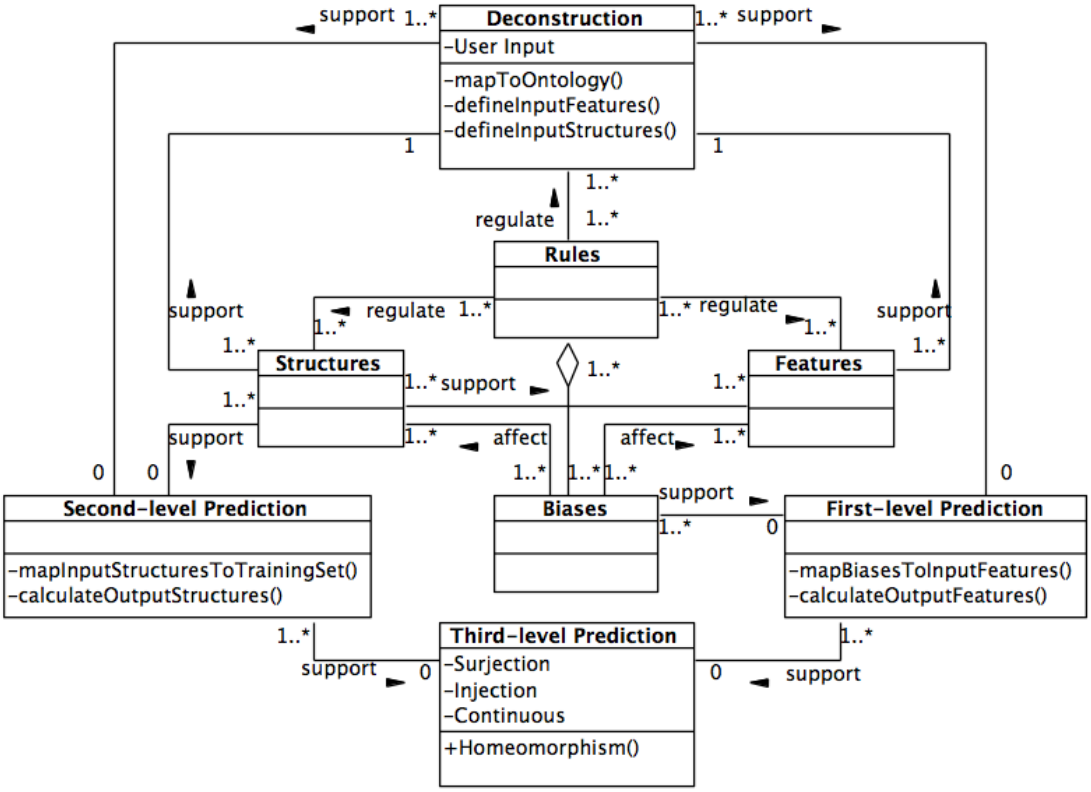

Figure 6.5: A UML class diagram depicting the relations between Conceptual Recombination and the cultural product ontology. The deconstruction stage and three levels of prediction are the four classes in the diagram responsible for the generation of system outputs. Note that mapToOntology() is equivalent to formula (1); defineInputFeatures() and defineInputStructures() correspond to formula (2); mapBiasesToInputFeatures() and calculateOutputFeatures() relate to formula (3); mapInputStructuresToTrainingSet() and caculateOutputStructures() link to formula (4); Third-level Prediction is formed in view of formula (5).

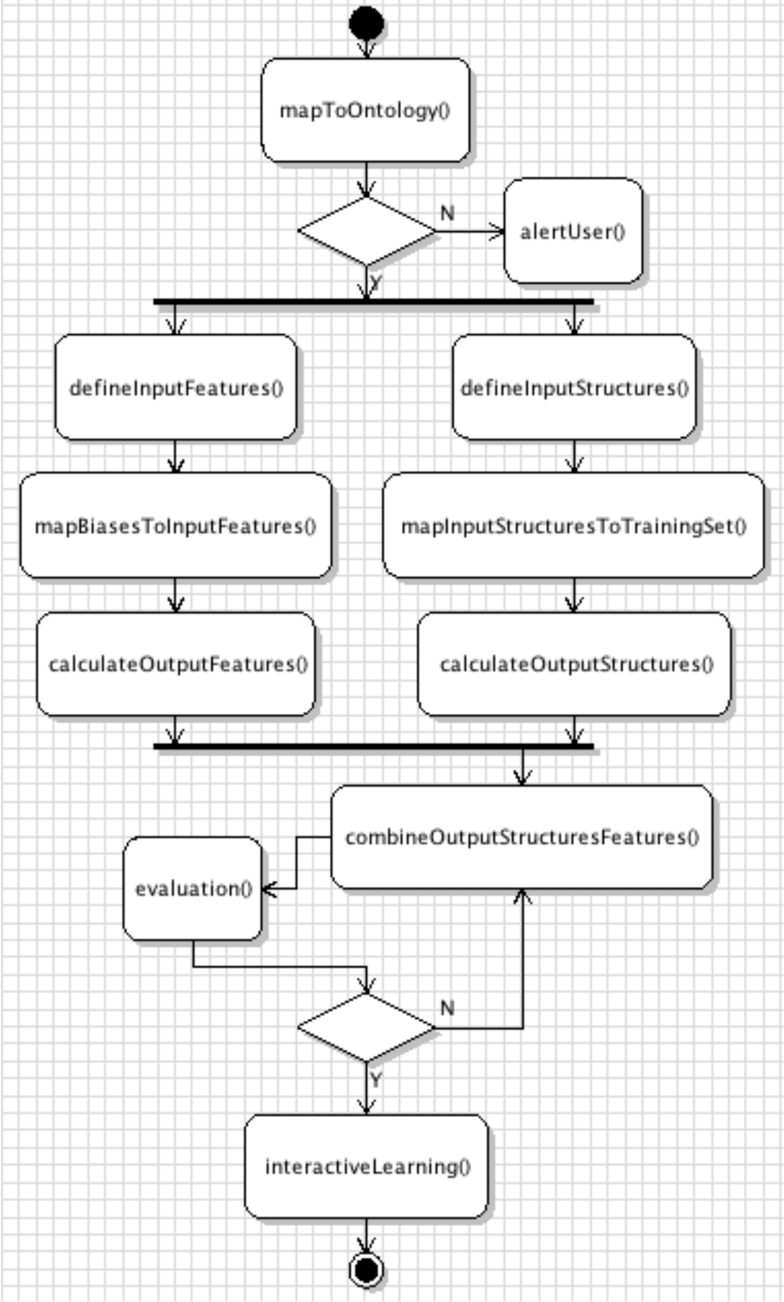

Figure 6.6: An activity diagram summarizing the three levels of prediction in Conceptual Recombination. The initial state represents a user input. interactiveLearning() is the interactive learning module as shown in Figure 6.7.

In fact, several scholars have already applied topology to describe creative works (Forth, McLean and Wiggins, 2008; Gärdenfors, 1995; Mazzalo, 2002). Yoshikawa (1981) specially highlights the importance of topology in design in his general design theory (GDT). Reich (1995) has a good summary of it in his critical review of GDT:

> "A *transformation* that conserves the continuity or convergence properties is useful in design because it allows creating different viewpoints of the desired functionality and the partial design description that may simplify or direct future design steps. In topology, such a transformation is called *homeomorphism*" (p. 7).

GDT states that a mapping between function space and attribute space is continuous. GDT does support the use of topology and homeomorphism in the design of cultural products. The third-level prediction in Conceptual Recombination is to further emphasize the importance of bijection. With the support of GDT, it is possible to claim that homeomorphism defines the relations between a user input and system output in Conceptual Recombination. These relations are further strengthened with the results of the first two levels of prediction, leading to the formation of a productive aberration to be detailed in 6.3.

6.3 ET-creativity in Conceptual Recombination

Can these three levels of prediction in a single-user CST produce a creative solution to a prediction problem (to predict a continuation) in a cultural product? This research study refers to Wiggins's CSF for an answer. Note that CSF is also the foundation for the computational model of Conceptual Recombination. There is a detailed discussion of it in Chapter 7. Here, this research study emphasizes how Conceptual Recombination fulfills two of its requirements for the occurrence of T-creativity regarding searching beyond a system's conceptual space and producing a productive aberration (an idea that is partly acceptable to a user) and therefore generates a creative solution to a prediction problem in a cultural product. Note that its last requirement – user self-awareness – is strictly dependent on the subjective evaluation of a user and is therefore immeasurable for an objective assessment of the availability of T-creativity in a single-user CST. Thus, it is excluded in this research study.

Firstly, with the three levels of prediction in place, a representational system output, consisting of the user intention and therefore representing the user, is guaranteed. This is mainly due to homeomorphism in topology. The system output and user input are interrelated to a certain extent. Referring to CSF, this is productive aberration meaning at least a part of the system output is considered as a quality output. This fulfills one of the prerequisites of T-creativity in CSF.

Moreover, a single-user CST is in fact an open system with a user acting as a part of it (Wegner, 1998). They do interact with each other when the CST is receiving a user input and the user is selecting and amending system outputs through the interactive learning module as shown in Figure 6.7. If we regard the training set of the CST as a conceptual space – C_{system}, and the user as another conceptual space – C_{user} (let's say we write down whatever the user has thought about his unfinished cultural product at that point of time and organize the information into a conceptual space according to 5.4.3), the interactive learning module of the CST facilitates a search that is beyond C_{system} and reaches C_{user} during its interactions with the user, fulfilling another prerequisite of T-creativity in CSF.

Since C_{system} and C_{user} belong to the same domain, it is possible to collectively name them as $C_{culture}$, which is a subset of the domain. When the two requirements for attaining T-creativity are met, the amended system output changes both the rules and traversal strategies in $C_{culture}$. These changes include the good concepts of the productive aberration yet exclude its bad concepts in $C_{culture}$ (Wiggins, 2003). Changes in rules or traversal strategies or both will transform $C_{culture}$ to different extents following T-creativity. Theoretically, we can say T-creativity happens in $C_{culture}$.

Note that C_{user} before T-creativity does not include the changes in the rules and traversal strategies. Or, there may be a lack of motivation for the user to use the CST to generate a system output. That is, the user already knew how to proceed with his unfinished cultural product. Furthermore, as discussed in Chapter 5, we have E-creativity on structures and T-creativity on features. E-creativity will only search for concepts in C_{system} to maintain the structures of a cultural product to support the development of output features. To a certain extent, C_{system} is similar to an inspiring set by Ritchie (2001), who claims that a creative program should have such a data set defined by a system designer to be the foundation of a search space, namely, $C_{culture}$ for the search of T-creativity.

In the case of having a new feature due to T-creativity, the output structures from the CST may not be able to support it. Under these circumstances, P-creativity happens until the user has given up on this new feature. If the user has decided to keep this new feature, there will be a new rule or rule change in the CST to allow its output structures to support it. If such a new rule or rule change is widely accepted in the society where the user resides, this will become H-creativity that is out of the scope of this dissertation that only focuses on P-creativity.

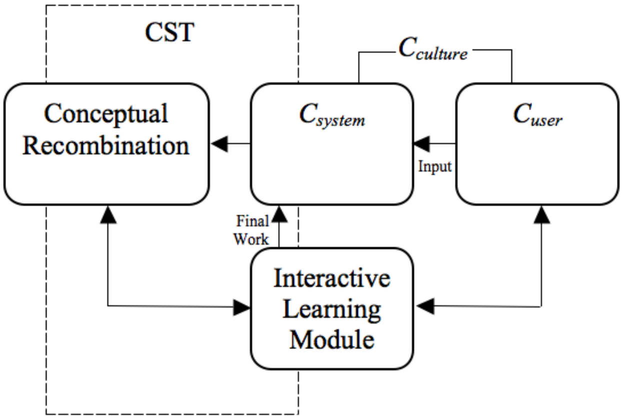

Figure 6.7: A simplified block diagram of the CST in concern. The dotted line represents the CST consisting of Conceptual Recombination, C_{system} (its training set), and an interactive learning module. C_{user} (a state of the user‘s thoughts on his unfinished cultural product) is originally not a part of the CST until it starts communicating with the interactive learning module. Those boxes with solid lines

are the components for the generation of T-creativity. When they work together, the interactive learning module of the CST facilitates a search that is beyond C_{system} and reaches C_{user} fulfilling a prerequisite of T-creativity. Furthermore, when there is a productive aberration after the reconstruction stage of Conceptual Recombination, both the rules and traversal strategies are changed in $C_{culture}$, a representation of C_{system} and C_{user}, fulfilling another prerequisite of T-creativity. Note that this research study does not discuss the components and operations of the interactive learning module. It simply assumes that the interactive learning module can display system outputs to a user, allow user revisions on the system outputs, alert Conceptual Recombination to generate another system output if the user dislikes the original system output, and pass the system output endorsed by the user to C_{system} to enrich it.

6.4 Conceptual Recombination as a Sub-conceptual Design Theory with ET-creativity

This research study assumes both the user input and CST belong to the same domain ontology developed from the cultural product ontology in a particular period of time, and there is a balance between novelty and appropriateness in the cultural product by Conceptual Recombination. Through the three different levels of prediction concerning cultural preferences, a system's conceptual space, and homeomorphism in topology, the CST generates a representational and creative system output as a continuation to the user input provided that the structures of the cultural product are limited by E-creativity. Then, there are features with T-creativity. Conceptual Recombination is built in accordance with the sub-conceptual system equipped with associative reasoning by Sloman (1996).

Mathematically, Conceptual Recombination is a homeomorphism, at the topological level, designed for the deformation of a user input into a system output acting as the user input's continuation, preserving the nature of its structures with E-creativity and subsequently freeing its combinations of features with T-creativity as shown in formula 5.

Let I^D be a high dimensional user input with D representing its dimensions (rules form a dimension, for example). Conceptual Recombination converts I^D to I^d, with d representing the reduced dimensions, in accordance with the cultural product ontology to avoid the curse of dimensionality in computation and prepare for homeomorphism. Then, let O^D be a high dimensional system output, with D representing its dimensions, derived from Conceptual Recombination and endowed with ET-creativity. Formula 5 becomes:

$$\text{Conceptual Recombination} = f : I^D \rightarrow O^D \tag{6}$$

Note that though I^D and O^D might have the same dimensions, it is still possible to have T-creativity in O^D due to the fact that T-creativity only requires a transformation of one or more dimensions of a conceptual space. It does not require an addition or reduction of a dimension.

6.5 Summary

This chapter is the core of this research study. It develops every single step of Conceptual Recombination towards the formation of a sub-conceptual design theory with ET-creativity in a single-user CST environment. In 6.2 it explains the processing of Conceptual Recombination starting from the deconstruction stage deriving user intentions from a user input to the reconstruction stage leading to the first two levels of prediction regarding cultural preferences in the form of biases implied in output features and a system's conceptual space defining the scope for exploratory creativity to happen on output structures as well as the third-level prediction facilitating homeomorphism in topology to combine output features and structures to form system outputs as continuations to the user input. In 6.3 it provides objective measurements for the existence of the first two prerequisites of T-creativity in Wiggins's CSF concerning the search of concepts that happens beyond a system's conceptual space with the aid of $C_{culture}$ and the generation of productive aberrations through homeomorphism in topology as described in the third-level prediction. In 6.4 Conceptual Recombination is in a formula with homeomorphism to convert a low dimensional input space to a low dimensional output space, and ET-creativity to have a representational and creative high dimensional final output. Referring to the definition of computational creativity by Newell et al. (1963), this chapter also demonstrates the intuition and usefulness of T-creativity through the reconstruction stage of Conceptual Recombination.

6.5.1 Propositions for the Formation of Conceptual Recombination

Proposition 8: When the computational representation of Conceptual Recombination is in operation, both its user input and single-user CST belong to the same domain.

Proposition 9: The computational representation of Conceptual Recombination deconstructs a user input and reconstructs it to form a representational and creative system output.

Proposition 10: In the deconstruction stage a design problem is interpreted as the user intentions represented by the expected output structures and features implied in the user input.

Proposition 11: There is a mechanism in the deconstruction stage that belongs to the relevant domain ontology to deconstruct the user input.

Proposition 12: The reconstruction stage refers to the user intentions to produce a representational system output.

Proposition 13: There are three levels of prediction in the reconstruction stage to predict output features, output structures, and combine them to form an initial system output.

Proposition 14: The first-level prediction applies biases to input features to form output features.

Proposition 15: The second-level prediction adopts a prediction model to predict output structures with the given input structures. Note that E-creativity applies to the search for the most probable output structures.

Proposition 16: The third-level prediction uses homeomorphism to deform the user input into a system output topologically with reference to the results of the first two levels of prediction. Productive aberration is formed in the system output.

Proposition 17: Through the interactive learning module of the single-user CST, the CST can search beyond itself and reach the user for new concepts, fulfilling another prerequisite of Wiggins's CSF, apart from productive aberration. As a result, T-creativity happens on output features derived from the computational representation of Conceptual Recombination.

Proposition 18: $C_{culture}$, consists of C_{system}, a system's conceptual space, and C_{user}, a user's conceptual space, is designed for the generation of T-creativity.

Proposition 19: E-creativity will only happen on C_{system}.

Chapter 7

Defining Computational Model for Conceptual Recombination

7.1 Overview

This chapter defines the computational model of Conceptual Recombination in view of Wiggins's Creative Systems Framework (CSF) (Wiggins, 2001, 2003, 2006a, 2006b) and Ritchie's interpretations of its search mechanisms (Ritchie, 2012). It pinpoints the problems of CSF in a single-user CST and concludes with a 7-tuple computational model for Conceptual Recombination.

7.2 Wiggins's Creative Systems Framework

Wiggins designed CSF based on Boden's theory of computational creativity to describe and reason about creative systems. It is well recognized and has been adopted in different studies. For example, Banerjee et al. (2011) use it to achieve ET-creativity when designing a floor plan with a creative system. Swartjes et al. (2007) also refer to CSF when designing their Virtual Storyteller to generate stories. CSF consists of seven components:

U: A universe of mutually non-identical concepts.

L: A language that describes everything in U.

R: The rules that define a multi-dimensional conceptual space in U.

[.]: An interpretation function that is a partial function from L yielding real numbers in [0, 1]. It can be used to interpret rules and therefore assist in acquiring concepts in U according to R of a conceptual space. Under these circumstances, a conceptual space, C, is defined as $[R]U$.

T: The traversal strategy in U that represents the creative behaviors of an agent. It also locates and develops concepts mostly on C. There are occasions that T may go beyond C to facilitate T-creativity. Note that in order to avoid confusion in this research study, T will be renamed as TS.

E: The evaluation rules in U that check the qualities of concepts.

$\langle\langle .,.,. \rangle\rangle$: A function interpreted in L and designed for R, T, and E. It operates on an ordered subset of U to produce another ordered subset in U acting as a set of new quality concepts and system outputs. For example:

$C_{out} = \langle\langle R, T, E \rangle\rangle C_{in}$, where C_{out} and C_{in} carry concepts to be considered in order for further development under T. In this way, "the input and output of the function are successive states of a kind of agenda" (Wiggins, 2006a, p. 452).

When these seven components $\langle U, L, R, [.], T, E, \langle\langle .,.,. \rangle\rangle \rangle$ work together, E-creativity may happen due to an exploratory search in a structured conceptual space, resulting in a novel and unexpected idea. To trigger T-creativity, a single-user CST must be able to search beyond its conceptual space, produce perfect or productive aberration, and facilitate user self-awareness.

7.3 The 7-tuple Computational Model for Conceptual Recombination

If we regard the 7-tuple CSF as a Turing machine (Turing, 1936), it should produce results that are very different from those of a single-user CST due to its lack of human-computer interactions. That is, there is no user input and user evaluation in Turing machine that is a closed system. The 7-tuple CSF can also be a closed system since Wiggins never rules out this possibility. In this way, CSF is insufficient to explain an open system. To compensate this insufficiency, this research study adds four more components into it. They are H a human user, I a user input, M a user model, and W an interactive learning module of a single-user CST. It further refers to Ritchie's notions as discussed in 7.4 and revises the 7-tuple CSF into another 7-tuple $\langle N, H, I, M, Q, W, Q^{meta} \rangle$ for the computational model of Conceptual Recombination:

N: A single-user CST's conceptual space – C_{system}.

H: A user, alternatively named as C_{user}, is part of a transformational search as shown in Figure 6.7, capable of offering concepts that are not available in C_{system}.

I: A user input.

M: A user model consisting of user inputs.

Q: Exploratory search.

W: An interactive learning module of a single-user CST as shown in Figure

6.7.

Q^{meta}: Transformational search.

7.4 Ritchie's Search Mechanisms of ET-creativity

Ritchie (2012) finds CSF insufficient to explain how the exploratory and transformational searches (ET-searches) can happen and therefore carries out a study to re-interpret them. He first simplifies CSF into a quintuple and removes *L* and *U* since CSF should focus on its internal operation rather than its representation of the universe, and *U*, to a certain extent, behaves like a constant in all cases. In addition, he applies his findings about typicality and quality (Ritchie, 2006) to the 5-tuple CSF. He lets *N* represent the norms of a conceptual space and *V* represent values of concepts. That is, *N* represents the rules and finally the form of a conceptual space while *V* is about the quality of an artifact defined by certain quality concepts. *N* and *V* go beyond the original CSF to highlight the importance of membership of concepts. Furthermore, Ritchie regards a conceptual space as a fuzzy set as it is about the degrees of our acceptability ranged from 0 to 1. The "acceptability" may refer to the number of wheels of a car that we are expecting, for example. We may expect a taxi to have 4 wheels and a double-decker bus to have 6 wheels. Identifying a concept for a conceptual space of an exploratory creative system is similar to mapping a concept to a fuzzy set regarding the degrees of our acceptability. In formula 1 *N*, consisting of the rules of a conceptual space, belongs to a subset of a universe (*P*) holding the degrees of our acceptability for different concepts.

$$N \in [0, 1]^P \qquad (1)$$

In order to identify a conceptual space, we first define our degrees of acceptability for the concepts in a universe. Then, we group all these eligible concepts together to form *P* and dissect it to form different conceptual spaces according to different rules. According to Ritchie, *N* is also a conceptual space of an exploratory creative system as shown in formula 2.

$$N \cong [R]U \tag{2}$$

Assume that a quality threshold $\alpha \in [0, 1]$ is defined for concepts $X \subseteq P$ to spot which concepts can be parts of N. We have:

$$N_{\alpha}(X) = \{c \in X \mid N(c) > \alpha\} \tag{3}$$

In formula 3 *X* can be a conceptual space and *c* represents concepts that can be parts of *N*. In other words, if a concept of *X* can pass through a particular quality threshold, it will also become a concept of *N*. *N*(*c*) is a function to find out which concepts can pass through the quality threshold. By the same token, we have *V* to define quality of an artifact (a value mapping about a high degree of asymmetry, for example). It also belongs to a subset of a universe consisting of the degrees of our acceptability as shown in formula 4. We can also have α to define the quality threshold of *V*. *c* in this case represents all the possible concepts for the creation of an artifact. It may also come from a conceptual space named *X*. A concept of *c* must pass through a specific quality threshold to be a concept for an artifact as shown in formula 5.

$$V \in [0, 1]^{P} \tag{4}$$

$$V_{\alpha}(X) = \{c \in X \mid V(c) > \alpha\} \tag{5}$$

According to Ritchie, *V* is congruent to [*E*] an interpretation function that interprets the evaluation rules in *U*, checking the qualities of concepts for an artifact.

$$V \cong [E] \tag{6}$$

Ritchie defines the search mechanism for exploring a conceptual space as a mapping from $[0, 1]^{P}$ x $[0, 1]^{P}$ (i.e. *N* x *V* referring to the combinations of the norms of a conceptual space and the values of its concepts with *P* as a fuzzy subset of the universe possessing certain degrees of acceptability for different concepts) to a set of mappings from tuples(P) to tuples(P) because quality artifacts require quality concepts (tuples(P)) to form different parts of them. In other words, $[0, 1]^P$ x $[0, 1]^P$ represents our specification for a specific artifact. Ritchie interprets CSF's exploratory search mechanism as:

$$Q(N, V) \cong \langle\langle R, T, E\rangle\rangle \tag{7}$$

N represents a specific domain. V defines which concepts of it are qualified to produce a particular artifact. An exploratory search identifies these concepts (tuples of P) in N. Let $B \subset P$. B is a set of concepts to act as a starting point for an exploratory search on N in m steps:

$$\bigcup_{n=0}^{m} elements\ (Q(N, V)^n(B)) \tag{8}$$

In the respect of transformational search for T-creativity, Ritchie regards such a meta-level search as an exploration in a set of exploratory creative systems (ECS). He describes such a conceptual space as a set of triples $ECS(P)$ consisting of (N, V, Q). In a transformational search N and V become N^{meta} and V^{meta} respectively, possessing certain degrees of our acceptability for certain concepts.

$$N^{meta} \in [0, 1]^{ECS(P)} \tag{9}$$

$$V^{meta} \in [0, 1]^{ECS(P)} \tag{10}$$

Q^{meta} will map from $[0, 1]^{ECS(P)}$ x $[0, 1]^{ECS(P)}$ to a set of mappings from tuples($ECS(P)$) to tuples($ECS(P)$).

7.5 The ET-searches in the Computational Model of Conceptual Recombination

As discussed in Chapter 6, E-creativity happens in C_{system}, whilst T-creativity appears in $C_{culture}$ consisting of C_{system} and C_{user}. This research study revises Ritchie's formulae for the ET-searches in the computational model of Conceptual Recombination, forming a new set of formulae.

$$C_{culture} = (C_{user} \cup C_{system}) \tag{11}$$

$$C_{system} = N \text{ in } (1) \tag{12}$$

C_{system} acts as N consisting of the rules of a conceptual space that belongs to a sector of a universe full of degrees of acceptability for different concepts.

$$C_{system\ \alpha}(X) = \{c \in X \mid C_{system}(c) > \alpha\} \tag{13}$$

X can be a conceptual space with concepts c. α, a quality threshold, is defined by rules in a domain ontology regarding a type of cultural products that may also apply to X. Any concepts in c passing through α will become concepts of C_{system}.

$$V = \text{quality concepts relating to the structures, features, and biases of a type of cultural products} \tag{14}$$

In formula 15 α is defined by E_{user} (user evaluations) acquired through W the interactive learning module of a single-user CST. This happens when there is a user evaluating a system output after the reconstruction stage of Conceptual Recombination inclusive of the structures with E-creativity through the interactive learning module. In this way, E becomes E_{user}.

$$V_{\alpha}(X) = \{c \in X \mid V(c) > \alpha\} \tag{15}$$

$$Q(C_{system}, V) \cong \langle\langle R, TS_{user}, E_{user} \rangle\rangle \tag{16}$$

In Conceptual Recombination a single-user CST generates E-creativity in structures according to the derived user intention from the deconstruction stage. The derived user intention guides the reconstruction stage providing a traversal strategy. In this way, TS becomes TS_{user} that is obtained through M the user model that stores the information from the deconstruction stage, as shown in formula 16.

As discussed in Chapter 5 we have E-creativity on the structures of a cultural product to maintain certain level of typicality. Indeed, this is also in response to the typical structure preserving design of KBS (van Heijst et. al., 1997). Here, this research study lets structures in I, a user input, be I_S. $I_S \subseteq C_{system}$ since structures of cultural products are stable over time and C_{system} should be rich enough to cover Is. Searching on I_S can be considered as searching on C_{system}. An exploratory search starting on I_S or strictly speaking C_{system} in m steps is:

$$\bigcup_{n=0}^{m} elements\ (Q(C_{system}, V)^n(I_S)) \tag{17}$$

This exploratory search starts on the structures of the user input that are also parts of C_{system} to find out which structures are new and unexpected to the user. The exploratory search happens in the 2nd level of prediction of the reconstruction stage.

A single-user CST will further use the exploratory search result to assist in the generation of T-creativity that only happens on features. In formula 18 $C_{culture}$, consisting of the rules of a conceptual space inclusive of C_{system} and C_{user}, belongs to a sector of a domain, P, regarding a type of cultural products. P is always full of degrees of acceptability for different concepts. $C_{culture}(P)$ owns the concepts that can be parts of $C_{culture}$.

$$C_{culture} \in [0, 1]^{Cculture(P)} \tag{18}$$

In fact, $C_{culture}$ is also similar to $ECS(P)$ comprising a set of exploratory creative systems for a meta-level search. That is, we can assume C_{user} is an exploratory creative system. In this way, C_{system} and C_{user} (and therefore $C_{culture}$) forms a set of exploratory creative systems for a meta-level search. Whenever there is a transformational search by a single-user CST running Conceptual Recombination, $C_{culture}$, a substitute for N^{meta}, will be involved.

$$V^{meta} \in [0, 1]^{Cculture(P)} \tag{19}$$

V^{meta} describes the quality of an artifact at a meta-level. Its quality concepts are about the ontological properties – structures, features, and biases – of a type of cultural products. V^{meta} also belongs to $C_{culture}(P)$ consisting of the concepts that can be parts of $C_{culture}$.

$$Q^{meta}\,(C_{culture}, V^{meta})(I_F) \tag{20}$$

$C_{culture}$ and V^{meta} are used for a transformational search. I_F is a set of features of a user input acting as the starting point for the search.

$$\bigcup_{n=1}^{m} elements\,(Q^{meta}\,(C_{culture}, V^{meta})^{n}(W)) \tag{21}$$

Since Wiggins's CSF requires a search beyond an existing conceptual space for the generation of T-creativity, a transformational search triggered by a single-user CST will quickly move from I_F to W, the interactive learning module of the CST, to access the concepts in C_{user}. Therefore, n starts at 1 but not 0. 0 is the first search initiated by I_F.

7.6 Summary

This chapter provides detailed information about the 7-tuple computational model of Conceptual Recombination when it is deployed in a single-user CST. It is based on Wiggins's CSF and Ritchie's interpretations of its search mechanisms as stated in 7.2 and 7.4 respectively. Most importantly, it clearly defines the search mechanisms of ET-creativity for Conceptual Recombination as discussed in 7.5.

7.6.1 Propositions for the Formation of Conceptual Recombination

Proposition 20: The computational model of Conceptual Recombination is an open system that can manage human-computer interactions.

Proposition 21: The computational model of Conceptual Recombination should support ET-searches to produce a representational and creative system output.

Chapter 8

Evaluations

8.1 Overview

Referring to the methodology of this research study stated in Chapter 3, there are three cases to demonstrate the operations of Conceptual Recombination in which a representational and creative design solution is derived from an incomplete cultural product. This is especially in response to the concepts of functional reasoning as discussed in Chapter 2 and prescriptive model in Chapter 3. When it is applied to cultural product creation, it is about how to help cultural product creators to understand their ill-defined design problems implied in their unfinished cultural products that hinder them, interpret their problems into sets of functions, generate concepts for the required functions, and evaluate the concepts to form solutions to their problems.

The first case study in 8.3 is about using a single-user CST to produce a 2-dimensional (2D) asymmetrical shape with a given user input that is a 2D symmetrical shape to demonstrate the full operations of Conceptual Recombination and its contribution to cultural product creation. The second case study regarding a door pattern design in 8.4 is to further illustrate the application of Conceptual Recombination to the design of a specific cultural product. The third case study in 8.5 is about generating a chorus for a given verse of a Chinese pop song to mainly explain those parts in Conceptual Recombination that require a knowledge engineer to specify.

Furthermore, this chapter also summarizes the previous chapters and lays down the guiding principles for building a single-user CST equipped with Conceptual Recombination in 8.2. This section corresponds to all the propositions for the formation of Conceptual Recombination.

8.2 The Guiding Principles of Conceptual Recombination

The guiding principles below are designed for the development of a single-user CST equipped with Conceptual Recombination:

Table 8.1: The Necessary Conditions for the Guiding Principles of Conceptual Recombination

	Items	Descriptions
1	Domain Ontology (Proposition 1, 2, 3, 4)	There is a training set for Conceptual Recombination consisting of rules, structures, features, and biases corresponding to the ontological properties of the relevant domain ontology developed from cultural product ontology. The training set supplies vital information for the operations of Conceptual Recombination regarding a specific type of cultural products.
2	$C_{culture}$, C_{system}, and C_{user} (Proposition 6, 7, 17, 18, 19, 21)	Both the single-user CST in concern (C_{system}) and its user (C_{user}) belong to the same domain. They form two subspaces. A user input is a part of C_{user}. $C_{culture}$, including C_{system} and C_{user}, is a subset of the domain ontology. Its existence is for the CST to search beyond its C_{system} reasonably and reach the rest of C_{user} excluding the part about the user input to fulfill a prerequisite of T-creativity. $C_{culture}$ and C_{system} will

		only expand when there is a new rule or rule change due to T-creativity. C_{user} will also expand in this way in addition to learning from C_{system} through the interactive learning module of the CST. Note that all expansions due to a new rule or rule change require H-creativity to sustain. P-creativity may not gain any social recognition, and is therefore ephemeral. However, H-creativity is not discussed in this dissertation. Readers can refer to Chapter 9 for more information about H-creativity in the discussion of ET-creativity life cycle.
3	The Key Axiom of Cultural Product Ontology (Proposition 5, 7, 15)	The ET-creativity in Conceptual Recombination operates according to the key axiom of cultural product ontology. That is, there is a balance between novelty and appropriateness in a cultural product. E-creativity runs on the structures of the cultural product to produce appropriateness, while T-creativity runs on the features to generate novelty in accordance with Wiggins's CSF and to be evaluated by the user (P-creativity).
4	G_{input} and G_{output} (Proposition 8, 9, 16)	In order to apply homeomorphism to Conceptual Recombination, this research study assumes that both the user input and system output are two metric spaces that can be further interpreted into two topological spaces – G_{input} and G_{output} – that belong to a complete cultural product. That is, the metric

		spaces first represent the ontological properties of a domain through its grouping of data. Then, if there are topological spaces in the domain ontology, it is possible for the metric spaces to represent the topological spaces up to a certain extent. Strictly speaking, G_{input} is a subset of C_{user}, while G_{output} is a subset of C_{system}. Since these two topological spaces are from the same cultural product, they share the same set of topological properties, contributing to the appropriateness required in this research study. They describe all the cultural products in the domain ontology before the happening of T-creativity that may bring in a new rule or rule change, leading to their expansions.

Table 8.2: The Guiding Principles of Conceptual Recombination		
1	Computational Model (Proposition 20 & 21)	$\langle N, H, I, M, Q, W, Q^{meta} \rangle$ This 7-tuple computational model runs on an open system similar to the single-user CST in this research study to take in a user input and produce representational and creative system outputs through the below deconstruction and reconstruction stages. Readers can refer to 7.3 for a detailed discussion of the computational model.
2	Deconstruction (Proposition 10 & 11)	$1_I(x) = \begin{cases} 1 \; if \; x \in I \\ 0 \; if \; x \notin I \end{cases}$ $f : I \rightarrow X$

		As stated in 6.2.1 these two formulae ensure that a user input does belong to the same domain of the single-user CST that has received the user input and further identify the features and structures of the user input to predict the user intentions implied in the user input. This also involves a function to convert the high dimensional user input into G_{input} with fewer dimensions to efficiently identify the input features and structures to avoid the curse of dimensionality. Based on the identified input features and structures, there is a mechanism in the deconstruction stage to identify the best biases representing the user intentions to be realized in the reconstruction stage, becoming output features and structures. These best biases are also in response to the missions of the single-user CST. Referring to Figure 6.5 these two formulae provide information for mapToOntology(), defineInputFeatures(), and defineInputStructures().
3	Reconstruction (Proposition 12, 13, 14, 15, 16, 17)	First-level Prediction ($P1$): $P1 = f: I_F \overset{B}{\rightarrow} O_F$ $P1$ applies the biases of the domain ontology to the input features of the user input to predict output features. This is similar to deforming G_{input} into G_{output} while preserving their ontological properties as discussed in the second-level prediction in 6.2.2. Referring to Figure 6.5 $P1$ is equivalent to mapBiasesToInputFeatures() and calculateOutputFeatures(). However, it is the responsibility of a knowledge engineer to define calculateOutputFeatures() in a single-user CST equipped

with Conceptual Recombination for the generation of system outputs regarding a specific type of cultural products.

Second-level Prediction ($P2$):

$P2 = P(O_S \mid I_S)$

$P2$ can be a Bayesian model. It predicts the most probable output structures for the development of output features with the given input structures of the user input. Referring to Figure 6.5 $P2$ is equivalent to mapInputStructuresToTrainingSet() and calculateOutputStructures(). Note that the search of O_S is an exploratory search leading to E-creativity as discussed in 6.3 and 7.5:

$$\bigcup_{n=0}^{m} \mathit{elements}\,(Q(C_{system}, V)^{n}(I_S))$$

Third-level Prediction ($P3$):

$P3 = f : G_{input} \rightarrow G_{output}$

After $P1$ and $P2$, $P3$ further combines output features and output structures together to form a complete system output according to the rules and biases of the domain ontology. This also involves a function that converts G_{output} into a high dimensional system output (since this study focuses on Conceptual Recombination at a sub-conceptual level, the details about how G_{output} becomes a high dimensional system output is excluded). In this way, the user must regard parts of the concepts in this initial system output as appropriate. This is because both the system output and user input share the same set of topological properties, and are therefore highly related to

		each other as discussed in the second-level prediction in 6.2.2. As a result, productive aberration happens, fulfilling another prerequisite of T-creativity. Furthermore, it is the responsibility of a knowledge engineer to define the mechanism that combines output features and output structures together. Note that there is T-creativity on output features through the transformational search after *P*3 with the aid of the interactive learning module of the CST after the initial system output: $\bigcup_{n=1}^{m} elements\ (Q^{meta}(C_{system}, V^{meta})^{n}(W))$

8.3 A Case Study on a Pattern Maker with Conceptual Recombination

In this section this research study demonstrates the potential of Conceptual Recombination with a simple case study about producing a 2D asymmetrical shape by a single-user CST in response to a user input that is a 2D symmetrical rectangular shape. The background of this case study is that a 2D pattern designer who is involved in an artist project regarding the recent trend of a specific culture that has a preference of combining symmetry and asymmetry together wants to speed up his task and have more inspirations. He decides to use a pattern maker in the form of a single-user CST that can take in his initial 2D symmetrical shape and produce a 2D asymmetrical shape inclusive of his input. Such a CST adopts Conceptual Recombination as the creative method to produce representational and creative outputs. It is also equipped with an interactive learning module, a user model, and an evaluation method applicable to all system outputs. Figure 8.1 shows a subset of the 2D shape ontology in this case study presumably developed by a knowledge engineer in relation to the said culture, working with Conceptual Recombination to produce asymmetrical outputs with a given symmetrical user input. It also summarizes the various discussions in this case study regarding the operations of the computational representation of Conceptual Recombination.

In fact, this case study shows that the operations of the computational representation of Conceptual Recombination in a single-user CST are, to a certain extent, similar to automated or assisted conceptual design with reference to stored design knowledge. An example of automated or assisted conceptual design is the computational design tool for concept generation with component taxonomy (Kurtoglu et al., 2009a; Kurtoglu et al., 2009b). The main difference between the computational representation of Conceptual Recombination and automated or assisted conceptual design is the openness of the former that allows information not available in the stored design knowledge in the forms of user input and new rules to enter the CST and contribute to the formation of system outputs with ET-creativity.

Figure 8.1 shows a subset of the 2D shape ontology developed from cultural product ontology working with the computational representation of Conceptual Recombination to produce asymmetrical outputs with a symmetrical user input. Note that the two classes about the first two levels of prediction form the mechanism 1 stated in Table 8.3 whilst the class Third-level Prediction forms the mechanism 2. In addition, outputDelivery() in Third-level Prediction sends asymmetrical outputs to the interactive learning module of the CST to help facilitate T-creativity in output features. Readers can further refer to 8.3.4.1 for details.

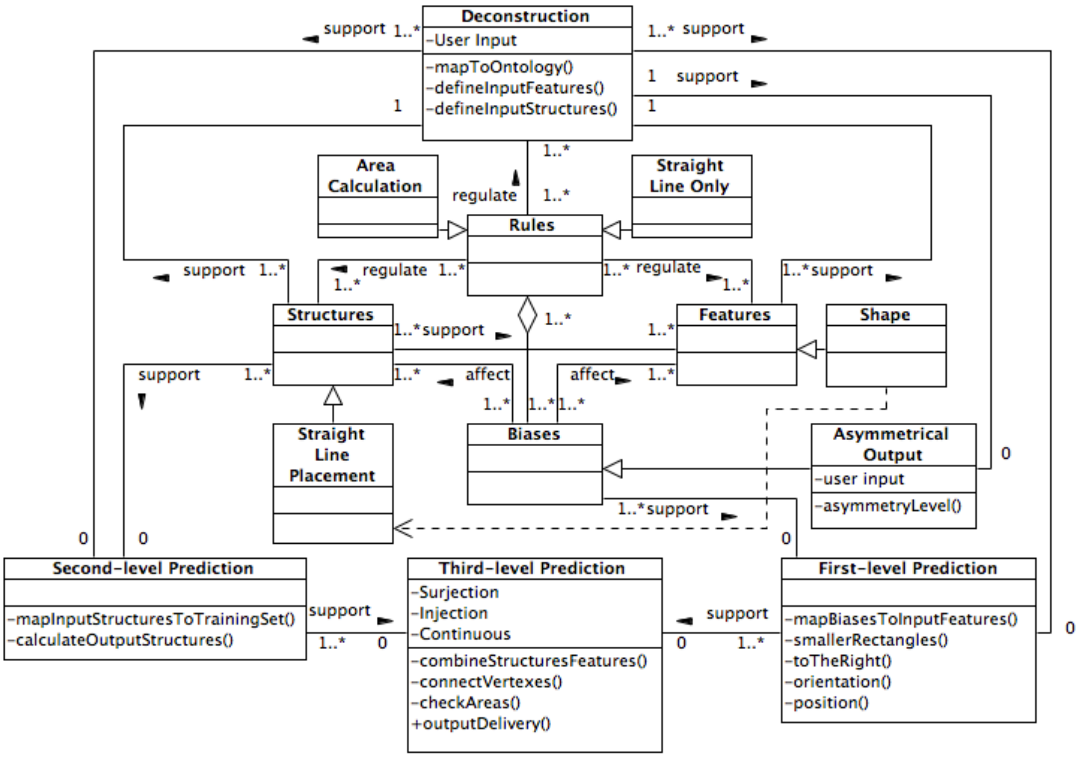

Figure 8.1: A subset of the 2D shape ontology developed from the cultural product ontology. The related classes include “Area Calculation,” “Straight Line Only,” “Straight Line Placement,” “Shape,” and “Asymmetrical Output.”

The assumptions for this case study are as follows:

Table 8.3: The Assumptions for this Case Study

Domain ontology	There is a 2D shape ontology developed from cultural product ontology regarding all kinds of 2D symmetrical and asymmetrical shapes. It also has rules, structures, features, and biases. A subset of it is called C_{system} for the CST in this case study as shown in Table 8.4.
Creative method	Conceptual Recombination is adopted as the creative method for the CST in this case study. It is now the task model for 2D shape ontology represented by the C_{system}. It has certain mechanisms about forming different 2D shapes that are not available in the discussions in Chapter 6 when it is the task model for cultural

	product ontology (a weak ontology). In other words, the complexity of Conceptual Recombination may vary due to a different domain ontology developed from cultural product ontology. In this case study, there are two such mechanisms. Mechanism 1: This mechanism is to produce output features and output structures contributing to a very high degree of asymmetry in a system output. Its different parts are further discussed in the first two levels of prediction of the Conceptual Recombination in this case study. Mechanism 2: This mechanism is to combine output features, output structures, and the user input together to form a new asymmetrical shape. It happens in the third-level prediction of the Conceptual Recombination.
Conceptual space	C_{system} and C_{user}: This research study assumes that there are only straight lines in the user input (a part of the C_{user}) and C_{system}. However, curves are still available in the remaining parts of the C_{user} and 2D shape ontology. $C_{culture}$: It is a representation of the C_{user} and C_{system} at the third-level prediction of the Conceptual Recombination. It is used for the generation of T-creativity.
Computational creativity	The Conceptual Recombination in this case study applies ET-creativity to the structures and features of the $C_{culture}$ respectively.
User input	A symmetrical rectangle for a simple and illustrative case study.

This simple but interesting example is pertinent to many creative works listed in Table 2.1. For example, both architecture and clothing fashion requires 2D design in complex shapes consisting of symmetry and asymmetry in their production processes. Narrative, on the other hand, always involves settings that can be easily imagined by readers as pictures made of many different symmetrical and asymmetrical objects. The subtle relation between words and images can probably explain why it is possible to convert a storyboard into a script. Also, music has melodic contours forming incomplete shapes on a score. If an incomplete melody is converted into different melodic contours for the said CST, and system outputs also appear in the form of melodic contours significantly different from the user input, the newly formed melodic contours may inspire the user who is having a creative block.

Table 8.4: The Rules, Structures, Features, and Biases of the C_{system}

Rules	The formulae for calculating areas of triangle and quadrilaterals (rectangle, square, rhombus, parallelogram, trapezoid, kite, chevron, bow-tie). Use straight lines to form shapes.
Structures	The placement of straight lines to form a shape. For example, four straight lines should form four right angles and connect at their ends to form a rectangle.
Features	The different descriptions for the different 2D shapes such as rectangle, chevron, symmetrical, and asymmetrical.
Biases (cultural preferences)	Apply asymmetry to the generation of a system output inclusive of the user input. This research study assumes that the level of asymmetry in a system output is proportional to the level of symmetry in the user input.

Referring to Chapter 5, the rules of the C_{system} are the generative principles, ensuring the appearance of a closed area with straight lines for the developments of the structures and features. The structures are hidden and require our analyses to find out the placements of the straight lines that form a shape. The features supported by the structures reaffirm the shape of a user input for the development of output features. In addition, the biases are the established styles of thinking of the relevant culture regarding the level of asymmetry in a system output. In fact, the biases are the functions of the rules as discussed in 5.2.1, affecting the formation of output structures and output features.

8.3.1 The Deconstruction Stage

The Conceptual Recombination performs its deconstruction stage in accordance with the formulae in Table 8.2 as follows:

Table 8.5: The Deconstruction Stage

User Input: A Symmetrical Rectangle

	Actions	Methods	Outcomes
1	Identify input features – the shape of the user input.	Check against the rules, structures, and features of the C_{system}.	Rectangle.
2	Identify input structures – the construction of the straight lines.	Check against the structures of the C_{system} to define the input structures.	There are four straight lines connected end to end to form four right angles.
3	Define user intention (a very simple user traversal strategy/TS_{user}).	Since the user input is a rectangle with a high degree of symmetry, the system output should possess a high degree of asymmetry. The user intention is relevant to the cultural preferences (biases).	

8.3.2 The First-level Prediction

In the first-level prediction, the Conceptual Recombination maps the biases of the C_{system} to the input features to form output features as stated in the formula in Table 8.2. In this case study, both the user intention and biases require an asymmetrical system output inclusive of the user input. The details of the first-level prediction are as follows:

Table 8.6: The First-level Prediction

Input: A Rectangular Shape

Actions	Methods	Outcomes
Apply bias (asymmetry) to the input features to form output features.	Break the rectangle into certain number of smaller equal sized rectangles in view of its area. This is a part of mechanism 1.	Four smaller equal sized rectangles as shown in Figure 8.2.
	Move the four smaller rectangles to the right hand side of the user input; randomize their orientations and position them accordingly. All these contribute to mechanism 1.	Figure 8.3 shows the orientations and positions of the four smaller rectangles with the support of the second-level prediction to be discussed in 8.3.3.

Note that the first-level prediction is designed in response to the concept of homeomorphism in topology that allows stretching and twisting of the user input. However, before a stretched asymmetrical user input is shown to the user, the Conceptual Recombination needs a specific mechanism to perform stretching or twisting. For simplicity's sake, this research study only demonstrates some simple steps in Table 8.6 as the parts of mechanism 1.

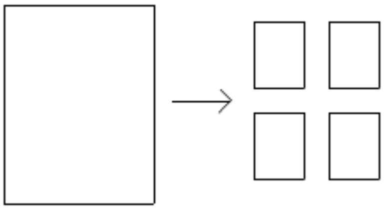

Figure 8.2: Breaking the user input into four smaller rectangles at the first-level prediction.

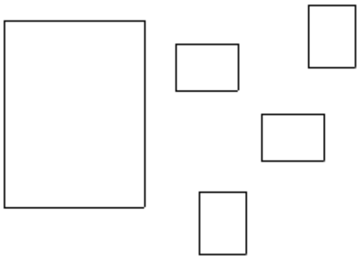

Figure 8.3: Positioning the four smaller rectangles to form output features further supported by output structures. This figure shows the most probable output structures out of the identified structures in C_{system} with the given input structures. The output structures support the orientations and positions of those four smaller rectangles for the formation of an asymmetrical shape – feature.

8.3.3 The Second-level Prediction

In the second-level prediction, the Conceptual Recombination maps the structures of the asymmetrical shapes in the C_{system} to the input structures to find out which of them contains the similar structures. In other words, those identified asymmetrical shapes own a rectangle like the user input. The Conceptual Recombination further identifies the most probable output structures out of these identified structures with the given input structures for the development of the output features. Note that the second-level prediction also involves the application of E-creativity on the output structures.

Table 8.7: The Second-level Prediction

Input: The Four Straight Lines Connected End to End to Form Four Right Angles

Actions	Methods	Outcomes
Map the structures of the asymmetrical shapes in the C_{system} to the input structures to derive output structures.	If we assume the user input is simply a half of the overall 2D shape in the system output, the Conceptual Recombination will search for the asymmetrical shapes in the C_{system} that also contain the similar rectangle as their halves. This is a part of mechanism 1.	Assume there are *k* asymmetrical shapes in the C_{system} that fit into this case study.
	Use a prediction model to run Bayes' rule, for example, to derive the most probable output structures out of the identified structures with the given input structures. This is another part of mechanism 1.	Figure 8.3 shows the most probable output structures with the output features together.

8.3.3.1 Applying E-creativity to the Output Structures

To explore the C_{system} (the system's conceptual space) for new and unexpected output structures, the Conceptual Recombination requires mechanism 1 to compare the user input with the identified asymmetrical shape in the C_{system} to ensure a very high degree of asymmetry in the final output is available. This exploratory search of asymmetry will continue until an appropriate asymmetrical shape is identified. Since the user input is symmetrical, any asymmetrical final output inclusive of the user input should be new to the user. If there is a very high degree of asymmetry in the final output, it should be a surprise to the user. However, the exploratory search will not change or add any rule or structure to the C_{system}. Referring to formula 17 in Chapter 7:

$$\bigcup_{n=0}^{m} elements\ (Q(C_{system}, V)^{n}(I_S))$$

the C_{system} already has structures that are qualified for the second-level prediction before the CST takes in the user input. This is based on the assumption that the C_{system} and its user belong to the same domain. V contains structures that are qualified for the processing of the prediction model to derive the most probable output structures. An exploratory search triggered by the input structures (I_S) will go for m times until the most probable output structures are defined. In this case study, the exploratory search will only stop when there is an asymmetrical shape in the C_{system} that can provide a very high level of dissimilarity between itself and the user input.

In addition, the application of E-creativity on the output structures is in response to the key axiom of the cultural product ontology as stated in Chapter 5. It stresses the importance of the balance between novelty and appropriateness in a cultural product. E-creativity does preserve the nature of the structures in the C_{system}

by not changing or adding any rule or structure, maintaining the appropriateness of the output structures for the given input structures.

8.3.4 The Third-level Prediction

In the third-level prediction, the Conceptual Recombination adopts mechanism 2 to use straight lines to connect some of the vertexes of the four smaller rectangles and the user input to form a complete asymmetrical shape. A requirement of mechanism 2 is that the new asymmetrical shape on the right hand side should have a similar area of the user input. This greatly affects how the CST chooses vertexes to form the new asymmetrical shape. Most importantly, the third-level prediction reflects the happening of homeomorphism in topology of cultural product ontology in the formation of the system output as stated in the formula in Table 8.2. The details of it are as follows:

Table 8.8: The Third-level Prediction

Input: As Shown in Figure 8.3

	Actions	Methods	Outcomes
1	Combine output features and output structures.	With the derived output structures, the Conceptual Recombination assigns the output features to the output structures as detailed in Figure 8.3.	Figure 8.3
2	Connect the four smaller rectangles and the user input together.	The four rectangles are the seeds for the formation of the final output. The Conceptual Recombination uses	Figure 8.4

		straight lines to connect some of the vertexes of them and the user input to form a complete asymmetrical shape in which both the new asymmetrical shape on the right hand side and user input share a similar area.	

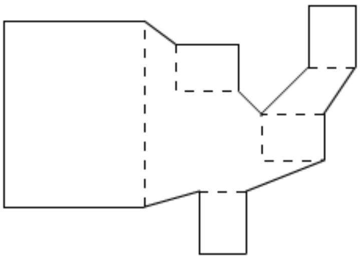

Figure 8.4: Connecting the four smaller rectangles and user input with straight lines at the third-level prediction. The dashed lines represent the sides of the rectangles not shown in the system output.

8.3.4.1 Applying T-creativity to the Output Features

In this case study, when the user is interacting with the CST through its interactive learning module, he can change those straight lines connecting the vertexes of the four smaller rectangles and his bigger rectangle into curves as shown in Figure 8.5. Since curve does not exist in the C_{system} and user input, such a new concept from the C_{user} triggers a transformation of the $C_{culture}$ consisting of the C_{system} and C_{user} to include such a new rule. That is, when there is a transformational search, the remaining parts of the C_{user} will be explored to acquire a concept that is totally different from those available in the C_{system} and user input. In this case, it is the curve concept. Note that this research study does not discuss how the user model (M) in the

CST can learn the curve concept for future productions in this case study. Readers can assume that the CST has a way to update itself regularly. According to formula 21 in Chapter 7:

$$\bigcup_{n=1}^{m} elements\ (Q^{meta}\ (C_{culture},\ V^{meta})^{n}(W))$$

a transformational search happens in the $C_{culture}$ through the interactive learning module (W) for m times until the curve concept is found. Note that the curve concept affects the area (including rules and structures) of the final asymmetrical shape, its appearance (features), and the perception of the culture (the bias regarding the use of curves) towards it.

To have productive aberration, this research study needs to prove the existence of homeomorphism in the third-level prediction. Firstly, it assumes that the user input and the new asymmetrical continuation on the right hand side are the two halves of the final output. This may imply that they have the similar areas. It further assumes that the user input is 12 cm^2 and the new continuation is 14 cm^2. Since one of them is symmetrical and the other is asymmetrical, there is a contrary relation between them. If we put them onto a Cartesian coordinate plane, it is possible to put the user input in quadrant II and the new continuation in quadrant I as shown in Figure 8.5.

After taking out cm^2, we have 12 and 14. If these two numbers lie on the x-axis and stay in quadrant I and II respectively, we have -12 and +14. A zero is at the intersection between the two parts. On a real number line, -12 and +14 form an open interval. Meanwhile, they also belong to other open intervals. For example, 14 is in the open interval (11, 20). When both the user input and new continuation are represented by two numbers on a real number line, they do imply the happenings of a continuous map and continuous inverse in topology. In this way, their relations can be interpreted as homeomorphic. That is, if they are two topological spaces belong to the same cultural product, a topological property of the user input yields the corresponding topological property of the new continuation. For instance, the rectangular shape at the bottom of the overall asymmetrical shape labeled as ℓ in Figure 8.5 is in fact one of the four smaller rectangles derived from the user input. In topology, this is injection.

Furthermore, the part labeled as h in Figure 8.5 is formed by two smaller rectangles derived from the user input. In topology, this is surjection. If we deduct the areas of the four smaller rectangles as shown in Figure 8.2 from the user input, and divide its remaining parts into many curved shapes, it is possible to map these shapes to the new curved shapes of the new continuation according to surjection. Thus, bijection does happen in the Conceptual Recombination for this case study.

Lastly, if the system output is represented by pixels, and the pixels of the two parts are also represented by numbers sitting on a real number line as discussed above, for every open subset $A \subset$ new continuation, the set $f^{-1}(A)$ is also open in the user input. In topology, this is continuous. When the two parts are homeomorphic, continuous, and explainable with bijection, the new continuation is deducible from the user input through homeomorphism.

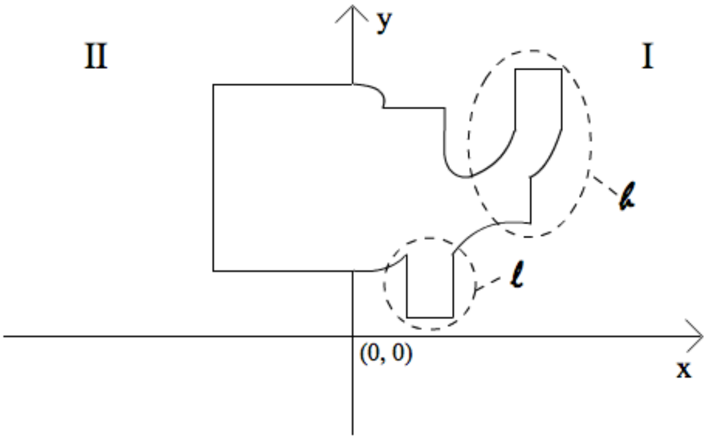

Figure 8.5: After applying T-creativity to the output features, some straight lines in Figure 8.4 have become curves. This figure also shows surjection and injection in topology labeled as 𝓱 and 𝓵 respectively in the quadrant I of the Cartesian coordinate plane when compared to the respective smaller rectangle(s) derived from the user input as shown in Figure 8.2.

8.3.5 Implications

This research study provides a simple example to demonstrate the operations and capability of the computational representation of Conceptual Recombination in this case study. It shows one of the possible interpretations of the user input through the said pattern maker in the form of a single-user CST equipped with the said Conceptual Recombination. It also shows how the Conceptual Recombination fulfills the first two prerequisites of T-creativity in CSF (the criteria to interpret the case study results). When we can accept the fact that a creative work can transform through homeomorphism, many possibilities can happen. For example, apart from those shapes discussed in the case study, the four smaller rectangles can also be stretched or shrunk into other shapes such as a square or parallelogram. The most famous example of such a transformation is the one about stretching a donut (torus) into a teacup as shown in Figure 8.6.

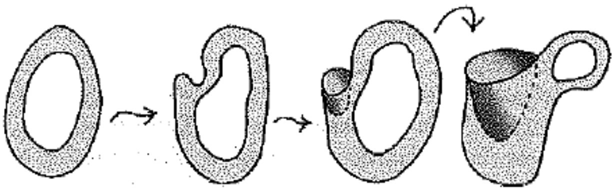

Figure 8.6: The transformation of a donut (torus) into a teacup through topology (Crilly, 2007, p.92). Both objects have a hole. The teacup's hole takes the form of a handle.

Another important aspect of this case study is about how the computational representation of Conceptual Recombination executes cultural preferences for a cultural product. This is first handled by the respective domain ontology through its ontological property – biases. This property is implemented in the first-level prediction of the Conceptual Recombination affecting the manifestation of output features. Furthermore, the participation of a user leading to T-creativity in output features provides another implementation of the cultural preferences provided by the user. Also, the different mechanisms of the Conceptual Recombination designed for the respective domain ontology reveal certain cultural preferences regarding how a cultural product is formed.

8.4 A Case Study on a Door Pattern Design with Conceptual Recombination

The pattern maker example in 8.3 can be applied to door panel design. Figure 8.7 shows two door panel designs that also contain rectangles and other shapes. This research study takes the left one as an example. Assume that a door panel designer has come up with two rectangles to be placed at the bottom of a door as shown in Figure 8.8 but does not have any idea about how to complete the whole door panel design that is supposed to be irregular. The door panel designer tries to get help from a single-user CST equipped with Conceptual Recombination to generate an irregular door panel design inclusive of his rectangles. Herein, the assumptions (except the mechanism for the creative method) and 2D shape ontology of the pattern maker example as stated in Table 8.3 and 8.4 respectively are adopted since the user inputs and intentions of these two cases are almost the same. Note that the system output and user input might not share the same area in this door panel design example.

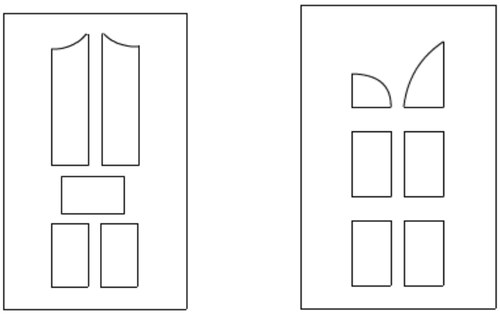

Figure 8.7: Two door panel designs with rectangles and other shapes.

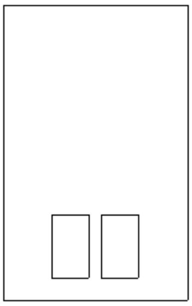

Figure 8.8: An initial door panel design with only two rectangles residing at the bottom of a door.

In the deconstruction stage of Conceptual Recombination, the structures and features of the two rectangles are identified. Readers can refer to Table 8.5 for details. The user intention is also about having a high degree of asymmetry in the final door panel design.

In the reconstruction stage, the first-level prediction designed by a knowledge engineer firstly duplicates the user input twice then puts them above the user input and positions them as shown in Figure 8.9. Note that the distributions of the output features and output structures are limited by the average size of doors that is about 2040*820mm. Figure 8.9 also shows the output structures of the system output from the second-level prediction supporting the output features.

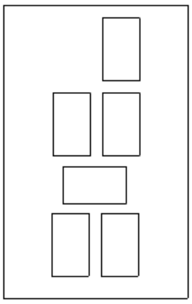

Figure 8.9: A system output inclusive of the user input at the bottom of the door.

In the second-level prediction the user input is mapped to the testing samples in the single-user CST to identify the potential structures for the system output. There is an exploratory search on these potential structures to locate the most probable output structures with a high degree of asymmetry, which is also the quality threshold of the exploratory search leading to productive aberration.

In the third level prediction the system output is placed onto a rectangle representing a door as shown in Figure 8.9. This system output is sent to the interactive learning module of the single-user CST for user revision. At this stage, transformational creativity can happen. The door panel designer might find the system output too conservative and not able to cover the empty space at the upper left of the door. As a result, the designer has lengthened the upper left rectangle and combined the two upper right rectangles as shown in Figure 8.10. He has further curved the top parts of the two new upper rectangles as shown in Figure 8.11. Since there is no rule about using curves to form a shape in the single-user CST as stated in the 2D shape ontology, the designer's curve concept has transformed a dimension – the rules – of the single-user CST's conceptual space, leading to T-creativity especially when the interactive learning module has already facilitated a search of concepts beyond the single-user CST's conceptual space and there is productive aberration due to the exploratory search in the second-level prediction.

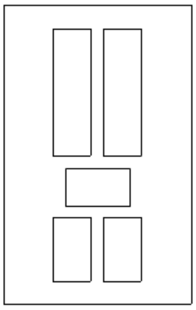

Figure 8.10: There are two new upper rectangles in the door panel design due to user amendment through the interactive learning module of the single-user CST.

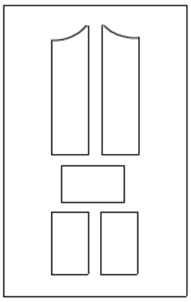

Figure 8.11: The system output with curves at the top parts of the two new upper rectangles, leading to T-creativity.

It is expected that this simple door panel design example can provide a realistic use of Conceptual Recombination in a computational environment.

8.5 A Case Study on Chinese Pop Song with Conceptual Recombination

In this section this research study further demonstrates the potential of Conceptual Recombination with a Chinese pop songwriting case study regarding the construction of a chorus melody in view of a given verse written by a songwriter. This is in response to the common situation that a songwriter may encounter a creative block or the point of frustration (Sapp, 1992) during his creative process as discussed in Chapter 1 and does not know how to compose a chorus. However, this case study shows only the key parts in the operations of the computational representation of Conceptual Recombination that require a knowledge engineer to specify in such a real-life scenario, but not a massive amount of musical information about composing or algorithmic composition that may hinder readers without musical background to comprehend. Readers can further refer to the respective literature cited in this case study for more information about the musical aspects in this case study.

On the other hand, this research study assumes that there is a single-user CST equipped with Conceptual Recombination that allows a songwriter to input his verse and expect a representational and creative chorus from the CST. Similar to the previous case study about producing 2D asymmetrical shape, such a CST has an interactive learning module, a user model, and an evaluation method for all its outputs.

The assumptions for this case study are as follows:

Table 8.9: The Assumptions for this Case Study	
Domain ontology	There is a Chinese pop song ontology developed from cultural product ontology regarding all kinds of Chinese pop songs. It also has rules, structures, features, and biases. A subset of it is called C_{system} for the CST in this case study. Please refer to Table 8.10 for details about the C_{system}.
Creative method	Conceptual Recombination is again adopted as the creative method for the CST in this case study. It is now the task model for the Chinese pop song ontology represented by the C_{system}. It has certain mechanisms about defining verse type and chorus type (see Table 8.12 and 8.13 for examples), predicting a chorus type with a Bayesian model, and constructing a chorus melody: Mechanism 1: This mechanism is to define a verse type for a user input that is also a verse. It refers to the verse types in the C_{system}. In fact, this research study defines verse types and chorus types according to Schenkerian analysis (Chan, 2004), a functional analysis of harmonic progression, and ITPRA Theory

	of Expectation (Huron, 2007), a hidden Markov model about the conditional probabilities in tonal music (Please refer to 8.5.1.1 for details about them). Mechanism 1 is similar to identifying user intentions in the deconstruction stage of Conceptual Recombination. Mechanism 2: This mechanism is to use a Bayesian model to predict a chorus type with the given verse type (see formula 1). It refers to Temperley's Bayesian model of key finding (Temperley, 2007) to form the model. Mechanism 2 is similar to the second-level prediction of Conceptual Recombination. Mechanism 3: This mechanism is to use the rules and biases of the C_{system} to construct a chorus melody in relation to the most probable chorus type derived from mechanism 2. Mechanism 3 acts similar to the first and third-level predictions of Conceptual Recombination.
Conceptual space	C_{system} and C_{user}: This research study assumes that both the C_{system} and C_{user} are referring to the Chinese pop song ontology. They share the same set of ontological properties. $C_{culture}$: It is a representation of both the C_{user} and C_{system}. It is used for the generation of T-creativity.
Computational creativity	The Conceptual Recombination in this case study also generates ET-creativity in the structures and features of the Chinese pop songs respectively.
User input	A given verse consisting of a melody, chords, and other basic information such as tempo from a songwriter.

Table 8.10: The Rules, Structures, Features, and Biases of the C_{system}

Rules	Tonal music theory
Structures	The harmonic structures and rhythmic structures of tonal music theory.
Features	Melodic contours as discussed in tonal music theory.
Biases (cultural preferences)	This research study defines biases as two sets of cultural preferences concerning the relations between a verse and a chorus and the construction of a chorus melody. They are further discussed in Table 8.14 and 8.19. Note that this research study refers to Lerdahl and Jackendoff (1983), Chai and Vercoe (2001), Temperley (2001), Hamanaka et al. (2006), Huron (2007), Shave (2008), Ewer (2010) to form these two tables.

$$P(\text{chorus type} \mid \text{verse type}) \propto P(\text{verse type} \mid \text{chorus type})P(\text{chorus type}) \quad (1)$$

8.5.1 The Operations of Conceptual Recombination

In this subsection this research study explains the steps involved in the Conceptual Recombination that convert a verse (user input) into G_{input} to derive user intentions in the form of input structures and features, deform G_{input} into G_{output} to produce productive aberration, and further facilitate T-creativity through the interactive learning module of the CST.

8.5.1.1 The Deconstruction Stage

With the given verse from the songwriter, the first task of the Conceptual Recombination is to identify what kind of verse it is. This is because according to ITPRA Theory of Expectation (Huron, 2007), there are conditional probabilities in the different parts of a piece of tonal music and so do the relations between a verse and a chorus. In short, ITPRA stands for Imagination, Tension, Prediction, Reaction, and Appraisal. It represents different types of responses to different human expectations in tonal music. It adopts hidden Markov model to prove that conditional probabilities do exist in tonal music.

Furthermore, this research study refers to Schenkerian analysis (Chan, 2004) to define the different parts in a verse and a chorus so that when a verse type is known, it is possible to predict a chorus type for it. In fact, Schenkerian analysis, a functional analysis of harmonic progression, is also named as SPEAC – Statement, Preparation, Extension, Antecedent, and Consequent. SPEAC attempts to use the characteristics of tonal music to explain the function and character of a group of pitches. Table 8.11 gives a summary of the different roles of SPEAC:

Table 8.11: SPEAC – Schenkerian Analysis

Statement	It is typically the beginning of a musical passage.
Preparation	It is a dependent identifier preceding a statement or other identifiers, by which meanings are modified.
Extension	It only happens after a statement, antecedent, or consequent.
Antecedent	It conveys an implication and requires a consequent to follow.
Consequent	It appears in response to an antecedent.

Table 8.12: An Example of a Verse Type

1c	An opening statement with an anacrusis.
2a	A transition to phrase III.
3a	A repetition of phrase I.
4a	A preparation to a chorus with a traditional chord progression.

Table 8.13: An Example of a Chorus Type	
1c	A hook line with an anacrusis.
2d	A transition to phrase III with an ornamental chord and a triplet.
3d	A hook line with variations in chords to create a climax.
4a	An end similar to phrase II with a traditional chord progression.

Table 8.12 and 8.13 imply that there are different options for different phrases in a verse or chorus. When they have been identified and grouped together into a verse type or chorus type such as the one in Table 8.12 named as 1c2a3a4a, this research study further uses them to check against the C_{system} to define the user intentions in the form of input structures and input features. The user intentions are important that once the verse type is found to be identical to or very similar to a verse type in the C_{system}, it is possible to predict what kinds of melodic features, harmonic structures, rhythmic structures, etc. should happen in the chorus according to ITPRA Theory of Expectation. Thus, in this case study, a verse type is an important aspect representing the user intentions implied in a given verse. The other aspects are the input features appear in the form of values designed for the bias functions as shown in Table 8.14 and the harmonic information, for example, in the input structures that appear as a chord progression such as:

I-III/VII-VI-III/V-IV-I/III-II-V-I-III/VII-VI-III/V-IV-V-I

Referring to the guiding principles stated in Table 8.2, G_{input} consists of a verse type, a set of input features, and a set of input structures describing all the complex relations between the rules, structures, features, and biases of the Chinese pop song ontology. By the same token, G_{output} is a chorus type with output features and structures deducible from G_{input}.

8.5.1.2 The Reconstruction Stage

In the first-level prediction, the identified input features are mapped to the different bias functions shown in Table 8.14 to define the values of the biases in the output features. For example, if there is no melodic pattern in the given verse ($MP_V = 0$), there should be a melodic pattern in the chorus ($MP_C = 1$). As a result, the Conceptual Recombination returns a set of values for the biases in the output features in the first-level prediction.

Table 8.14: The Biases in Chinese Pop Songs

Bias Functions	Descriptions
Melodic Pattern – the probability of having identical phrases in a verse or chorus: MP ($0 \leq MP \leq 1$)	• If a verse has 0 for its *MP*, the following chorus should have 1 to create contrast. • If a verse has 1, the following chorus should also have 1 with other patterns to create contrast. • If the *MP* of a verse is between 0 and 1, for example 0.75, the following chorus should have approximately 1 – 0.75 = 0.25 to create contrast.
Note Duration – the probability of having a specific note duration that has the highest frequency in a verse or chorus: ND_d ($0 < ND_d < 1$) d (duration) = {2, 3, 4, 6, 8, 12, 16}	If an 8th note has the highest frequency of 0.64 in a verse, the following chorus should have approximately 1 – 0.64 = 0.36 for its 8th notes.
Specific Note Duration – this applies to any ND_d that is 0.5 or above:	• If a verse has 0 for its *SND*, the following chorus should have a *SND* that happens frequently to create contrast.

$SND_d = \{0, 1\}$ $d = \{2, 3, 4, 6, 8, 12, 16\}$	• If a verse has 1 for its *SND*, the following chorus should possess another value for *SND* to create contrast. For example, if there are lots of 8th notes in a verse, the following chorus should have 16th notes as the majority. • A chorus should always have 1 for *SND* to create contrast.
Specific Note Choice – the probability of having a specific note choice that has the highest frequency in a verse or chorus: SNC_p ($0 \leq SNC_p \leq 1$) p (pitch) = {0…11}	• If the *SNC* of a verse is below 0.4, the following chorus should have a *SNC* that happens frequently to create contrast. • If the *SNC* of a verse is 0.4 or above, the following chorus should not have any *SNC*.
Starting Position $SP_b = \{0, 1\}$ b (beats) = {1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5}	The starting positions of the different phrases in a chorus should be different from those in its preceding verse.

In the second-level prediction, this research study adopts a Bayesian model to predict the most probable chorus type with the given verse type. This is with reference to Temperley's Bayesian model of key finding (Temperley, 2007). Before using formula 1 to perform any calculations, it is important to define the different probabilities of the different phrases in a verse type and a chorus type in view of the training examples in the C_{system}. Table 8.15 and 8.16 show the probabilities of those phrases in Table 8.12 and 8.13:

Table 8.15: A Verse Type with Probabilities

Phrases	Descriptions	Probabilities
1c	An opening statement with an anacrusis.	0.1
2a	A transition to phrase III.	0.2
3a	A repetition of phrase I.	0.2
4a	A preparation to a chorus with a traditional chord progression.	0.2

Table 8.16: A Chorus Type with Probabilities

Phrases	Descriptions	Probabilities
1c	A hook line with an anacrusis.	0.5
2d	A transition to phrase III with an ornamental chord and a triplet.	0.3
3d	A hook line with variations in chords to create a climax.	0.7
4a	An end similar to phrase II with a traditional chord progression.	0.7

Referring to formula 1:

$$P(\text{chorus type}) = \prod_{seg} C \tag{2}$$

where C is a chorus segment (phrase) probability and seg is a chorus segment.

$P(\text{chorus type}) = 0.5 \times 0.3 \times 0.7 \times 0.7 = 0.0735$ for the chorus type in Table 8.16.

Table 8.17: Calculating the Probability of a Verse Type with the Given Chorus Type

$P(\text{verse type} \mid \text{chorus type}) = P(\text{verse type} \cap \text{chorus type})/P(\text{chorus type})$

Referring to General Multiplication Rule, it is possible to convert the calculations into a probability table:

	Chorus Type				
Verse Type	A	B	C	D	Total
A	0.025	0.150	0.050	0.075	0.3
B	0.050	0.075	0.000	0.075	0.2
C	0.125	0.050	0.025	0.200	0.4
D	0.000	0.025	0.025	0.050	0.1
	0.2	0.3	0.1	0.4	1.00

Table 8.18: Calculating the Probability of a Chorus Type with the Given Verse Type

Suppose the given verse type is 1c2a3a4a or simply verse type B.

An example of $P(\text{chorus type}) = 0.0735$

To find out the most probable chorus type with the given verse type, we need to identify the chorus type that generates the maximum probability. This research study uses different chorus types for the calculations. For example, verse type B and chorus type B:

$P(\text{verse type B} \mid \text{chorus type B}) = 0.075$

$P(\text{chorus B} \mid \text{verse B}) = 0.075\text{x}0.0735 = 0.0055125$

Note that the Conceptual Recombination also performs an exploratory search to identify the most probable chorus type with the given verse type in its C_{system}. This greatly affects the kinds of harmonic and rhythmic structures available in the chorus type.

In the third-level prediction, the Conceptual Recombination follows the biases in Table 8.19 and tonal music theory to construct a chorus melody in accordance with the results from the first two levels of prediction. For example, the first note in the chorus should not be the last note in the verse unless it is an anacrusis as discussed in the Finite Automata for Note Choices in the table.

Table 8.19: The Biases for the Construction of a Chorus Melody

Biases:	Affected Areas in a Chorus:
	Whole Chorus
Tempo (*TP*) $d_{max} = \begin{cases} 8 \; if \; TP \geq 120 \\ 32 \; if \; TP < 120 \end{cases}$	Tempo affects note durations. Up-tempo songs should avoid 16th and 32nd notes to have an easy melody. In the contrary, slow tempo songs should put in more 16th notes to create melodic movements.
Singing Range	Singing range affects note choices and the appearance of a melodic contour.
Chord Note	Use chord notes to construct a chorus melody.
Common Note	Always adopt common notes that happen in two or more consecutive chords to build a chorus melody.
Gestalt Principle of Proximity (Temperley, 2001)	It states that closer elements are grouped together in preference to those that are further apart. This affects note choices for passing notes and other ornamental notes happening between chord notes.
Scale	Not to let any note become the fourth consecutive note in any scale.
Interval	Limit note choices to maintain comfortable melodic intervals for singing.
No-three (*N3*)	Not to repeat any phrase twice. Exceptional case occurs when

	new chord notes are introduced or certain chord notes are altered to enrich the original chord sequence.			
No-four (*N4*)	Not to repeat any note for the third time. *N4* overrides *N3*.			
N3 & *N4*	When *N3* and *N4* happen together, reduction of note(s) takes place.			
Inner Contrast (optional)	The third phrase of a chorus should provide inner contrast in terms of rhythmic patterns and note choices when compared to the other phrases in the chorus.			
Melodic Contour	If a melodic contour is up for more than 3 beats, it should go down for the next note so that the singer can take a rest and hit another high note later on.			
	Phrase I	Phrase II	Phrase III	Phrase IV
	Always move in a different direction when compared to the ending melodic contour in the preceding verse.	Go down for the coming climax.	Go up for the climax and emotional outbreaks.	Go down to end the chorus and get ready for the next verse.
Finite Automata for Note Choices	The first note is not the last note of the verse except	-	Having the highest notes in the chorus.	Refer to the common ending phrases in the

	being an anacrusis. Start with a popular note after a verse.			C_{system} while adopting *N3*.
Rest	If phrase I lasts more than one bar, the singer should rest for at least half a beat at the end of the phrase.	A little rest at the end of phrase II to prepare for the climax in phrase III.	Put in a little rest before a high long note.	-
Rhythmic Pattern	Refer to *MP*, ND_d, SND_d, SP_b, d_{max}, and the Rest rule to construct a rhythmic pattern.	A little variation of phrase I.	Construct a new pattern to have varieties and internal contrasts.	Refer to phrase II, *N3*, and the common ending phrases in the C_{system} to construct phrase IV.

8.5.1.3 T-creativity in Output Features

After the three levels of prediction, there is an initial system output that may take the form of a phrase in the chorus or a complete chorus. Due to homeomorphism, a productive aberration is guaranteed as discussed in Chapter 6. The songwriter can further revise the phrase or the complete chorus from the CST through the interactive learning module to fulfill another prerequisite of T-creativity. For example, the songwriter may find the anacrusis in phrase I of the chorus redundant, or a note in phrase IV too long. This allows the CST to search beyond its C_{system} and reach C_{user} for new concepts.

8.5.2 Implications

Compared to the case study in 8.3, this case study provides details about the parts in the operations of Conceptual Recombination that require a knowledge engineer to specify. Furthermore, this research study purposely selects pop music as the topic for this case study due to the fact that tonal music is by far the only art form that can be explained by a solid theory, though a commonly agreed creative method of writing a particular type of successful pop songs is not yet available, leading to the rise of Conceptual Recombination. This is in sharp contrast to the pattern maker case study in which the rules are borrowed from mathematics and not yet formalized for the ontology.

8.6 Summary

This chapter uses three cases to demonstrate the operations of the computational representation of Conceptual Recombination and explain how cultural product creation may happen to assist cultural product creators in completing their partial works creatively.

Chapter 9

Conclusions

9.1 Discussion

This research study aims at borrowing the essence of conceptual design theories to develop a design theory for cultural product creation. It purposely explores the nature of cultural products and identifies any relevant conceptual design theories that can properly describe the design processes of cultural products.

As shown in Chapter 8, the formation process of a complete cultural product that is based on an incomplete one is akin to the concepts of homeomorphism. This is in response to the key axiom of the cultural product ontology – changing features riding on stable structures. Homeomorphism to a certain extent reflects the creative processes of different cultural products. This gives a scientific prescriptive account of the rather mysterious creative processes of cultural products.

On the other hand, this research study finds out that there is not yet a commonly agreed creative method for all cultural products though they do share the same set of ontological properties. However, it is possible to apply functional reasoning of conceptual design to describe their creative processes in view of prescriptive model and their commonalities. Under these circumstances, it further investigates the practices of engineering design and concludes that a series of observations about the creative processes of different cultural products can be translated into a creative method that acts as a task model for them at an ontological level. This research study coins this creative method as Conceptual Recombination.

Furthermore, this research study locates Conceptual Recombination at a sub-conceptual level (domain level) with reference to Sloman's two systems of reasoning, whilst conceptual design theories stay at a conceptual level. Such a sub-conceptual design theory is a brand new design research area emphasizing associative reasoning for designing, providing a much more specific scope for the operations of the concepts of conceptual design theories.

In addition, the computational representation of Conceptual Recombination defines a creative method for those single-user CSTs that take in user unfinished cultural products and produce representational and creative system outputs as continuations to the user inputs. By now, this is the only available method in doing so. Also, it offers a demonstration about the application of Conceptual Recombination as well as the generation of ET-creativity in system outputs.

Hatchuel et al. (2012) claim that design is "a type of rationality that cannot be reduced to standard learning or problem-solving … It keeps the logic of intention but accepts the undecidability of its target; it aims at exploring the unknown, and it is adapted to the exploitation of the emergent." By the same token, Conceptual Recombination does not regard design as a simple solvable problem. Instead, its computational form combines traditional artificial intelligence study targeting problem solving with computational creativity research targeting artifact creation to handle design in the form of cultural products that can be described with the four ontological properties, namely, rules, structures, features, and biases of the cultural product ontology. Conceptual Recombination explores the unknown that may become a continuation to a given incomplete user's cultural product through its three levels of prediction concerning cultural preferences, a system's conceptual space, and homeomorphism in topology as well as ET-creativity and associative reasoning.

It clearly explains how a single-user CST can deconstruct and reconstruct a user input into an unusual or, to some users, an exceptional system output.

Moreover, Conceptual Recombination provides an objective evaluation of the first two prerequisites of T-creativity in Wiggins's CSF regarding searching beyond a system's conceptual space and producing productive aberration. This not only makes explicit the operations of CSF but also provides a reliable mechanism for other CSTs to generate ET-creativity. From the perspective of creativity management, Conceptual Recombination constrains the combinations of the ontological properties of a domain ontology developed from cultural product ontology to generate useful and creative system outputs. Although this dissertation does not emphasize on the evaluation methods of computational creativity, an objective evaluation of the first two prerequisites of T-creativity in CSF should deserve a highlight in this chapter to reveal its contribution to computational creativity.

In addition, this dissertation applies ET-creativity to the structures and features of a cultural product respectively. This innovative use of Boden's theory is also in response to the key axiom of the cultural product ontology. Such an application of ET-creativity puts Boden's theory to practical use.

As for the learning in a single-user CST equipped with Conceptual Recombination, there is case-based reasoning that allows a rule change or new rule originally not available in $C_{culture}$ consisting of C_{system} and C_{user} to be learned. Referring to the four steps of case-based reasoning regarding i) case retrieval, ii) information reuse, iii) information revision, and iv) information retention, the single-user CST firstly retrieves testing samples (cases) to perform deconstruction. Then, it reuses the information of the deconstruction to execute the three levels of prediction of the reconstruction. The user can revise its system outputs through its interactive learning module in which any rule change or new rule due to T-creativity in the features of the system outputs are identified and sent to C_{system}.

Lastly, the biases in Conceptual Recombination define what kind of system outputs to happen. These biases are formed according to the user intentions defined by the deconstruction stage. In other words, the user input implies what biases to be applied. Conceptual Recombination can apply the biases to both input features and structures simultaneously to derive output features and structures. These biases act like the traversal strategy to guide Conceptual Recombination to form its outputs. Referring to homeomorphism, the biases define the deformation of the user input into a system output. In this way, the applications of biases are monotonic – a potential topic to be explored in the future.

9.2 Limitation

The success of Conceptual Recombination partly relies on its working relations with the relevant domain ontology, especially the two classes, namely, structures and features. This requires the respective knowledge engineer to carefully define them by analyzing the related cultural products. Another critical successful factor of Conceptual Recombination is about its reconstruction stage embracing the concepts of homeomorphism as regards the key axiom of cultural products. Though the three levels of prediction of the reconstruction stage have been explicitly defined, they still require the respective knowledge engineer to define the involved mechanisms as demonstrated in 8.3. These mechanisms can be about how to use the domain rules to embed features into structures and how to define a new rule or rule change when a new feature after T-creativity is not compatible with the existing structures.

In fact, Conceptual Recombination, as an instance of a sub-conceptual design theory, is distant from a symbolic level in which a designer may find it handy to use. To translate Conceptual Recombination into symbolic rules, the respective knowledge engineer needs to carefully define the related domain ontology as well as the deconstruction and reconstruction processes. All these will take up a substantial amount of time. This research study assumes that the cultural product ontology and the current findings about cultural product creations through Conceptual Recombination can greatly speed up the translation processes of Conceptual Recombination into different symbolic rules regarding different types of cultural products for different knowledge engineers.

In addition, the ET-searches at a symbolic level may encounter certain technical issues regarding time, resources, the control over the number of possible outcomes, and so on. This research study acknowledges these problems. However, they are by now out of the scope of this dissertation.

Under these circumstances, there are two major limitations in this research study that deter a more comprehensive evaluation of Conceptual Recombination to be carried out. Firstly, there is not yet a fully developed domain ontology developed from the creative work ontology to support the operations of Conceptual Recombination. Secondly, since this research study demonstrates the practicality of Conceptual Recombination through several small-scale case studies, there is not yet an exhaustive list of the involved mechanisms in the reconstruction of Conceptual Recombination.

9.3 Future Work

In this section this research study first discusses the possible future work according to the order of the different chapters in this dissertation. Then, it further explores other valuable topics not yet mentioned in the chapters.

9.3.1 Conceptual Recombination as a Method Ontology

As discussed in Chapter 5 there is no commonly agreed creative method for cultural products. Therefore, the cultural product ontology, acting as a weak ontology, does not include a method ontology. This explains why Conceptual Recombination is acting as a task model for the cultural product ontology. However, the nature of Conceptual Recombination does contribute to the possibility of having such a method ontology. Although this research study only uses Conceptual Recombination to produce continuations to a user input, which is an unfinished cultural product, it does shed light on the importance of homeomorphism in topology as a critical ontological property for the possible method ontology. The availability of such a method ontology may be revolutionary to many academic domains including computer science, cognitive science, and arts. It allows them to look at their current researches from a brand new perspective and possibly provide them with a paradigm shift.

9.3.2 The Standardization of Conceptual Recombination for CSTs

As discussed in Chapter 1, there is a sub-problem in this dissertation regarding the lack of a reliable mechanism of generating ET-creativity in a sub-conceptual design theory in the form of a single-user CST that takes in a user's unfinished cultural product and produces representational and creative system outputs with computational creativity as continuations to the user input. With Conceptual Recombination as a solution to this problem, it is worthwhile to further investigate the standardization of it so that all similar CSTs can use it efficiently and effectively. In other words, this investigates the compatibility, interoperability, and repeatability of the computational representation of Conceptual Recombination.

9.3.3 ET-creativity Life Cycle

Throughout this research study, ET-creativity only happens in P-creativity but not H-creativity. This is due to the need of a better management of the scope of this dissertation. However, this research study does not ignore the importance of H-creativity and regards it as a future work. In this section, it introduces an ET-creativity life cycle that involves P- and H-creativity and concludes with three variations of Boden’s theory to support such a life cycle.

When a user is working on a cultural product with a single-user CST equipped with Conceptual Recombination, and there is transformational creativity in the output features of the work that he loves so much, he can order the CST to store the outputs for future reference. At this point, T-creativity in output features involves at least one new rule under P-creativity. This rule happens due to various reasons. It could be about a violation of an existing rule, an amendment of the current rules, or simply a brand new rule that has never happened before. The user can share his new cultural product inclusive of the system outputs with other people in the society he is living in. If they like it, his work will receive a social recognition forming H-creativity referring to the consent of the society about the quality of it. However, there is no clue about when H-creativity may happen. It may take place in a month or a century depending on the popularity of the work in the society. For example, 12-tone music is never popular, notwithstanding a history of more than ninety years. However, Facebook only takes a few years to make the world zealous about it. Whenever there is H-creativity, the new rule will become the new norm in a particular society, affecting people and the relevant CSTs working on the same type of cultural product. The evolving role of the new rule leading to H-creativity is summarized as follows:

i. A single-user CST generates system outputs as continuations to a user input. T-creativity (something that could not be synthesized previously) happens on the output features. Meanwhile, E-creativity (something that has not yet been synthesized) happens on the output structures and plays a supportive role to provide certain level of typicality for the development of the output features.

ii. The user is satisfied with the system output and orders the CST to store it including the new rule(s) for future reference. P-creativity happens.
iii. The user passes his new cultural product including the system output to a particular society. If there is a social recognition about the quality of it, the new rule(s) will stay in the society and become the new social norm(s). H-creativity happens.
iv. Thereafter, all the CSTs working on that type of cultural product will include the new rule(s) in their conceptual spaces affecting their future outputs.

To conclude, a new rule caused by T-creativity in an output feature evolves over a timeline starting from day 1 residing in a single-user CST's internal state to day N winning the affections of a user leading to P-creativity. If it can receive a social recognition, there will be H-creativity for it. If P- and H-creativity happened just a day apart, the new rule of yesterday was the new norm of today.

This research study summarizes the above analyzes with the three variations of Boden's theory as defined below:

Definition (*Short-term P-exploratory Creativity*). Short-term P-exploratory creativity is only available in the output structures of a single-user CST and P-creativity to reserve the typicality of a creative work. Its life span relies heavily on the sustainability of short-term P-transformational creativity to be defined below. It will become obsolete if a user or a society rejects the cultural product inclusive of the system outputs, or due to long-term H-transformational creativity as discussed below.

Definition (*Short-term P-transformational Creativity*). Short-term P-transformational creativity will only happen in output features co-created by a single-user CST and a user. It is under P-creativity, and will become obsolete along with short-term P-exploratory creativity if the user or the respective society rejects the cultural product inclusive of the system outputs, or due to long-term H-transformational creativity.

Definition (*Long-term H-transformational Creativity*). Long-term H-transformational creativity is a social recognition for a cultural product co-created by a single-user CST and a user. It comes with short-term P-exploratory creativity and short-term P-transformational creativity, and is under H-creativity. There is no guarantee for its formation. Once there is a successful case, its profound impact can last forever, affecting an ever-increasing number of societies. An example is the different periods in art history such as Baroque and Classicism. Each of them had a profound impact on almost the whole world.

9.3.4 Conceptual Recombination as a Design Method

Can we use Conceptual Recombination without the single-user CST? Is it possible to change it into a design method at a symbolic level?

If a designer's self-awareness of his design problem and design process can greatly assist him in getting a satisfactory design solution, Conceptual Recombination's deconstruction and reconstruction methods and creative model should be able to help this designer to arrive at the design solution. This may sound contradictory to the original design of Conceptual Recombination that does not discuss user self-awareness. However, it is possible to use a tailor-made worksheet for Conceptual Recombination to replace the single-user CST and to explain why it can facilitate user self-awareness:

Table 9.1: Conceptual Recombination in a Worksheet for Human Use Only

	Items:	Descriptions:
1	Domain Information	
	Rules	
	Structures	

	Features	
	Biases	
2	Design Problem	
	Expected Structures	
	Expected Features	
3	Design Process	
	First-level Prediction – identify / use biases to create expected features	
	Second-level Prediction – define expected structures to support expected features	
	Third-level Prediction – identify / use rules and biases to combine structures and features together	
4	Creative Model	
	E-creativity on Structures – identify extreme changes in structures that support the development of features	
	T-creativity on Features – identify rules for the development of features that can be violated to form a new rule or a rule change	

It is possible to interpret user intentions as what to be expected in a design problem, the operations of the three levels of prediction as a design process, and the generation of ET-creativity as a creative model. Through such a worksheet, the designer should have a better understanding about what he should produce to tackle the design problem, what components in a design solution should stay intact to give a sense of appropriateness to the users, what can be changed in the structures to give surprises, and what can be changed in the features to give a new look and feel to the users. All these help facilitate a designer's self-awareness of a design problem and the design process that follows it.

If Conceptual Recombination can be simply used by a designer without any assistance from a single-user CST, what is its relation with the existing design theories? Are they the same or significantly different from each other? Since Conceptual Recombination is a sub-conceptual design theory, can it offer anything to compensate for the current design theories? It is worthwhile to further explore its potential as a design method in order to find out how it can possibly contribute to the design community.

9.3.5 Conceptual Recombination in Ethnocomputing

Lastly, Conceptual Recombination brings out the importance of ethnocomputing, referring to the localizations of computational knowledge that allow different cultural groups to contribute to "the development of better universal understanding of different aspects of computing" (Tedre, Sutinen, Kähkönen and Kommers, 2006, p. 130). This aspect is reflected in the invention of the cultural product ontology in this dissertation. On the one hand, it is in response to the needs of a specific domain for associative reasoning in a sub-conceptual design theory; on the other hand, it is designed to act as a weak ontology for the developments of other domain ontologies regarding cultural products. As time goes by, the individual domain ontologies may generate new definitions of rules, structures, features, and biases. Their impacts may last forever in an ever-increasing number of societies, especially when there is long-term H-transformational creativity. As a result, they will contribute to the development of the even more robust cultural product ontology in the long run, and facilitate a better universal understanding of it or a better use of it enhancing its popularity. The relations between Conceptual Recombination and ethnocomputing should be further explored.

Appendix A

A.1 The Twenty-one Propositions for the Formation of Conceptual Recombination

- **Proposition 1:** Conceptual Recombination requires a smaller scope defined as a domain for associative reasoning.
- **Proposition 2:** Conceptual Recombination requires constraints, similarities and temporal structures, simpler patterns with features, and soft constraints of a sub-conceptual system in the domain.
- **Proposition 3:** Conceptual Recombination requires the ontology it is working on to support its operations. That ontology should have properties that are in response to the components of Sloman's sub-conceptual system – constraints, temporal structures, simpler patterns with features, and soft constraints.
- **Proposition 4:** Conceptual Recombination requires the task model concept of application ontology to describe its relation with the ontology.
- **Proposition 5:** Conceptual Recombination requires a balance between novelty and appropriateness to generate a creative design solution to a design problem.
- **Proposition 6:** Conceptual Recombination requires Boden's definition of a conceptual space (generative principles, distinct structures, dimensions, pathways, boundaries, and established styles of thinking) for its conceptual spaces to be searched to form a representational and creative system output.

- **Proposition 7:** The computational representation of Conceptual Recombination requires applications of Boden's ET-creativity to the ontological properties to help produce a representational and creative system output.
- **Proposition 8:** When the computational representation of Conceptual Recombination is in operation, both its user input and single-user CST belong to the same domain.
- **Proposition 9:** The computational representation of Conceptual Recombination deconstructs a user input and reconstructs it to form a representational and creative system output.
- **Proposition 10:** In the deconstruction stage a design problem is interpreted as the user intentions represented by the expected output structures and features implied in the user input.
- **Proposition 11:** There is a mechanism in the deconstruction stage that belongs to the relevant domain ontology to deconstruct the user input.
- **Proposition 12:** The reconstruction stage refers to the user intentions to produce a representational system output.
- **Proposition 13:** There are three levels of prediction in the reconstruction stage to predict output features, output structures, and combine them to form an initial system output.
- **Proposition 14:** The first-level prediction applies biases to input features to form output features.
- **Proposition 15:** The second-level prediction adopts a prediction model to predict output structures with the given input structures. Note that E-creativity applies to the search for the most probable output structures.
- **Proposition 16:** The third-level prediction uses homeomorphism to deform the user input into a system output topologically with reference to the results of the

first two levels of prediction. Productive aberration is formed in the system output.

- **Proposition 17:** Through the interactive learning module of the single-user CST, the CST can search beyond itself and reach the user for new concepts, fulfilling another prerequisite of Wiggins's CSF, apart from productive aberration. As a result, T-creativity happens on output features derived from the computational representation of Conceptual Recombination.
- **Proposition 18:** $C_{culture}$, consists of C_{system}, a system's conceptual space, and C_{user}, a user's conceptual space, is designed for the generation of T-creativity.
- **Proposition 19:** E-creativity will only happen on C_{system}.
- **Proposition 20:** The computational model of Conceptual Recombination is an open system that can manage human-computer interactions.
- **Proposition 21:** The computational model of Conceptual Recombination should support ET-searches to produce a representational and creative system output.

Appendix B

B.1 Glossary

This section is a glossary of the main terminology used in this dissertation. It is a quick reference for readers. Please refer to the respective sections for detailed explanations.

Axiom

An axiom is a rule that describes the relations between things in classes.

Computational Creativity

According to Colton, Mántaras, and Stock (2009), computational creativity is about building software that exhibits behavior that is regarded as creative in humans.

Conceptual Design

Referring to the well-known general design theory (Yoshikawa, 1981), conceptual design is a mapping from a function space (problem) to an attribute space (solution) under certain constraints.

Conceptual System

According to Sloman (1996), a conceptual system describes knowledge for a universe with cultural rules.

Conceptual Recombination

Conceptual Recombination is a sub-conceptual design theory for cultural product creation. In this dissertation, its computational representation acts as a task model for a cultural product ontology, and runs on a specific computational model of a single-user CST that takes in a user unfinished cultural product and produces representational and creative outputs as continuations to the user input. Mathematically, Conceptual Recombination is a homeomorphism at a topological level.

Conceptual Space

According to Boden (1995), a conceptual space is a particular set of generative principles of a domain with established styles of thinking and distinct structures. It has its own dimensions, pathways, and boundaries.

CST

According to Chen (1998), a creativity support tool (CST) is a computer system aiming at enhancing human creativity by assisting users in producing and organizing ideas.

Cultural Product

According to Hirsch (1972), a cultural product is a nonmaterial good for a mass public of consumers. It serves an aesthetic rather than a clearly utilitarian purpose.

Cultural Product Ontology

A cultural product ontology consists of two superclasses called structures and features with rules as axioms. It is culturally inclined with biases acting as functions of rules, and acts as a weak ontology that allows individual domain such as music, narrative, or architecture to have its own subclasses for further ontological developments.

E-creativity

Exploratory creativity in Boden’s theory of computational creativity explores the potential of a conceptual space to create new and unexpected ideas.

ET-creativity

ET-creativity is the short form of exploratory and transformational creativity in Boden’s theory.

H-creativity

Historical creativity (H-creativity) in Boden's theory requires recognitions of a society about the quality of a system output.

Long-term H-transformational Creativity

Long-term H-transformational creativity is a social recognition for a creative work co-created by a single-user CST and a user. Its profound impact can last forever, affecting an ever-increasing number of societies.

Ontology

According to Schreiber et al. (1995), an ontology is an explicit, partial specification of a conceptualization that is expressible as a meta-level viewpoint on a set of possible domain theories for the purpose of modular design, redesign and reuse of knowledge-intensive system components.

P-creativity

Personal creativity (P-creativity) in Boden's theory only requires judgments of an individual about the quality of a system output.

Short-term P-exploratory Creativity

Short-term P-exploratory creativity is only available in the output structures of a single-user CST and P-creativity to reserve the typicality of a creative work.

Short-term P-transformational Creativity

Short-term P-transformational creativity will only happen in output features co-created by a single-user CST and a user. It is under P-creativity, and will become obsolete along with short-term P-exploratory creativity if the user or the respective society rejects the creative work inclusive of the system outputs, or due to long-term H-transformational creativity.

Sub-conceptual Design Theory

A sub-conceptual design theory acts like a conceptual design theory with a creative model in a domain. It refers to Sloman's sub-conceptual system to perform associative reasoning.

Sub-conceptual System

According to Sloman (1996), a sub-conceptual system is about associative reasoning focusing on the simpler patterns with features, similarities and temporal structures, and soft constraints of a domain for predictions.

T-creativity

Transformational creativity in Boden's theory requires a transformation of one or more dimension(s) of a conceptual space to generate exceptional ideas.

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