A System Description Model with Fuzzy Boundaries

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Abstract. Describing phenomena of interest as a system is valuable to analyze using system science methodologies. The boundary is considered as the necessary component of a system, through which the system interacts with its environment. Although system based analysis is applicable, not all phenomena seem to present boundaries. We discuss boundary description of two phenomena, namely the lifestyle disease and the music composition process. The hypernetwork model homogenizes boundaries and relationships, and boundaries can be treated as an instance of relationships.

1 Introduction

System science assumes that a given system has boundary that separates the system from its environment. This assumption further enables the inference that the boundary can be identified and extracted. This paper discusses phenomena that the concept of a well-defined boundary cannot be applied. We treat these phenomena because we are representing them as systems to analyze and understand their characteristics.

1.1 Boundary Definition

There are cases that the boundary of a system is a physical object or entity, and the boundary is clearly identified. For instance, a cell of a living organism has the cell membrane as the boundary between the cell and the environment. There are, however, cases that the boundary cannot be explicitly identified. For instance, when a person is treated in a social context, we understand that a boundary exists among individuals, between an individual and the society, among others. However, we cannot identify and point exactly these boundaries. The boundaries in these cases are describable, but ungraspable. Then these boundaries are not directly describable since they are subjective entities (not consisting of objects), but can only be described using the elements belonging to the both sides of the boundary. Therefore, we define two classes of boundaries:

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(i) Class-I: physical boundary
(ii) Class-II: conceptual boundary

Both types of boundaries actually exist. This paper discusses the boundary representation of both classes. Description of lifestyle diseases belongs to the class-I, and music composition process belongs to the class-II.

1.2 Boundary Description

Suppose we are modeling person-person interactions, and treating a person as a system (Fig. 1). In this case, the boundary between the system (person) and the environment is clear, as the body shape and the skin serve as the boundary of the system. Not only the physical substances but also abstract entities such as information is input to and output from the system, and the body contour is interpreted as the membrane that input and output "*matters*" pass through. When these "matters" pass from outer side of the membrane to the inner side, it is interpreted that these "matters" were input to the system. Similarly, when the direction is from the inside to the outer side of the membrane, it is the output of the system.

Now consider the modeling of interactions among individuals, for instance among two persons (Fig. 2). When modeling direct interactions between two people, the boundary is set in somewhere between the persons, such as the dotted line in Fig. 2(A). Another possible modeling is to include the environment (Fig. 2(B)), and to model the boundary as in the single person case (Fig. 1). The advantage of including the environment is that the boundary is modeled intuitively as in the single person case, but the direct interaction between persons is not modeled, as any exchange of "matters" between persons is intermediated

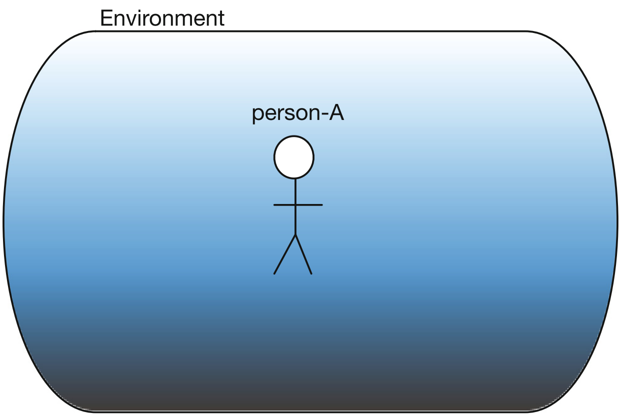

Fig. 1. A person surrounded by environment.

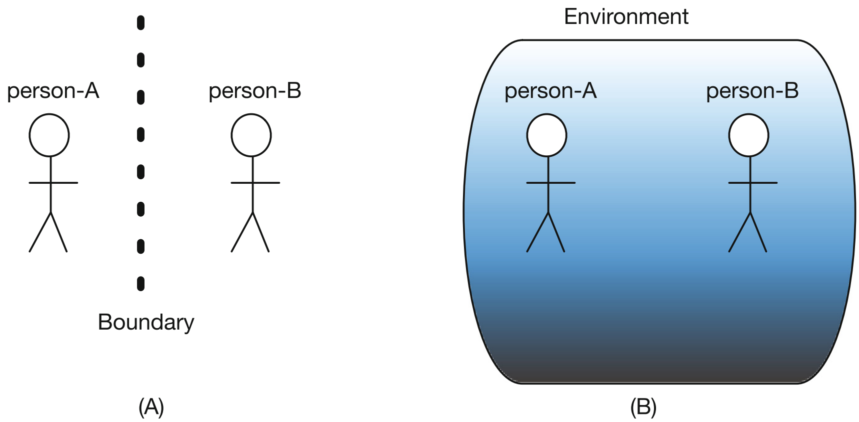

Fig. 2. Boundary between two persons. (A) The boundary exists between person-A and person-B. (B) Extension of the illustration of one person case, where both persons are surrounded by an environment.

by the environment, introducing inaccuracy into the model. The boundary in Fig. 2(A) is conceptual and imaginative, differing from the boundary between a person and environment (Fig. 1). In Fig. 2(B)), it is also possible to interpret the entire environment as the boundary between persons. The difference from Fig. 1 emerges, as the body shape would no longer function as the boundary in Fig. 2(B).

Now consider the modeling of interactions among groups of people, for instance among families (Fig. 3). Clearly, there are interactions among groups of people, which is different from interactions among individuals. In interactions among groups, the unit of interaction is the group of people, therefore there is a boundary that distinguishes a group of people from other groups. However, differing from the case of individual person's interactions where the body shape of each person could be interpreted as the boundary, it is difficult to find similar physical entity that represents the boundary of the group of people. Suppose the interaction between two families. A family is a set of people with consanguineous or legal relationship. We recognize the members of a family, and looking at the family members makes us recognize them as a single family. However, the concept of the family is virtual, and there is no physical entity that encompasses the family members, or something analogous to body shape that helps us identify as a single family.

But when treating interactions among families, where the representation unit is family, we interprete two families as distinct entities although the boundary between them cannot be described. Analogous to person-person interaction case, the interactions are executed through the boundary between two families, although it is a conceptual boundary.

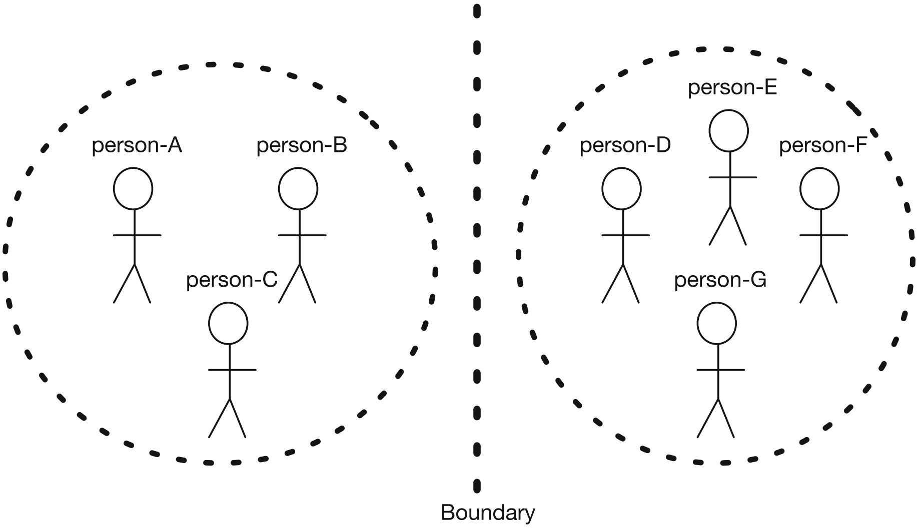

Fig. 3. Boundary between two group of people, one consisting of three persons, and the other of four persons. Dotted circles denote the groups. The location of the dotted line denoting the boundary is arbitrary.

2 Methods

The representation model to describe the boundaries is the hypernetwork model, an extended model derived from graph theory [6,7], but with more representation capabilities. The hypernetwork model allows multiple viewpoints to comprehend the target phenomena. Representation is viewpoint dependent, and representations are generated from the same set of elements. Its advantage is the freedom of the representation viewpoint to analyze the system.

The system description of a given viewpoint is realized by a set of elements of the system and relationships among them. Relationships are N-ary, and are also represented as an element of the system. Elements can be generated, modified and deleted.

Mathematically, the elements that constitute a system is a set

$$V = \{v_1, v_2, \ldots, v_N\} \tag{1}$$

where N is the number of elements.

Then a viewpoint is a subset of the elements whose relationships are defined by the relationship nodes (colored nodes in Fig. 4). The collection of the elements with relationship nodes constitute an interpretation of a system under certain viewpoint. The relationship nodes in Fig. 4 is colored for illustration purpose, but these nodes are also elements. The function of an element is viewpoint dependent.

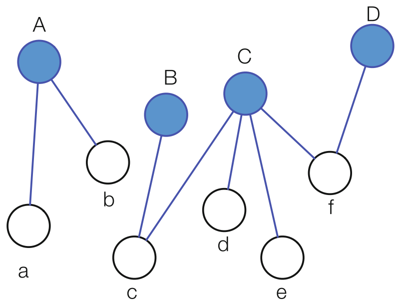

Fig. 4. An example of hypernetwork representation. White nodes at the bottom (nodes a $\cdots$ f) denote nodes functioning as elements, and filled nodes (nodes A $\cdots$ D) represent nodes defining the relationships among connected element nodes. For instance, the relationship node "A" is a relationship between nodes "a" and "b".

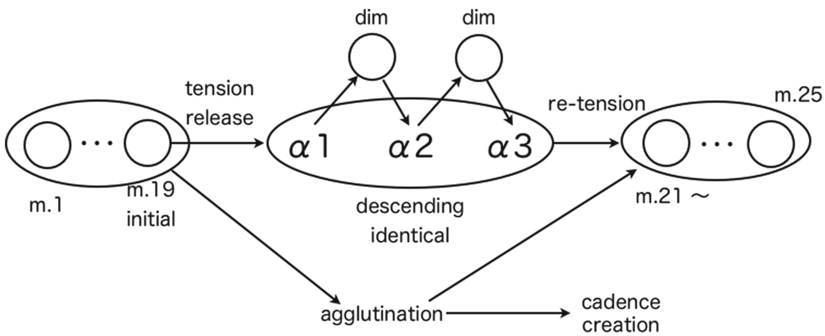

Fig. 5. An example of hypernetwork representation of a decision during music composition.

A viewpoint P is defined as

$$P = E \times R, \text{ where } E \subseteq V,\ R \subseteq V,\ E \cap R = \emptyset \tag{2}$$

Thus the set of elements E and the set of relationships R are non-overlapping subsets of V.

Multiple viewpoints $P_1, P_2, \ldots P_M$ exist for V. The details of an element and a relationship can be specified by connecting other elements as attribute nodes. Let $A \subseteq V$ denote the set of attribute nodes. An attribute may specify multiple nodes, and element and relationship nodes function as attribute nodes of other nodes. Figure 5 is a representation of a decision in music composition process.

2.1 Describing Boundaries

The description of the boundary depends on the boundary type whether it is conceptual or not. In the case of person-person interaction, the boundary is

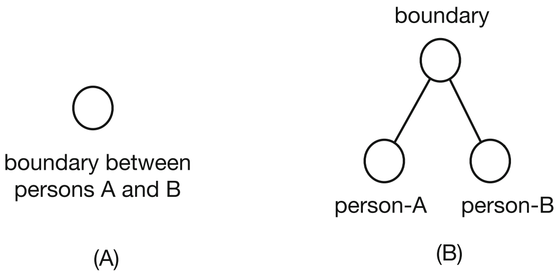

Fig. 6. Two representations of the boundary between persons A and B of Fig. 2.

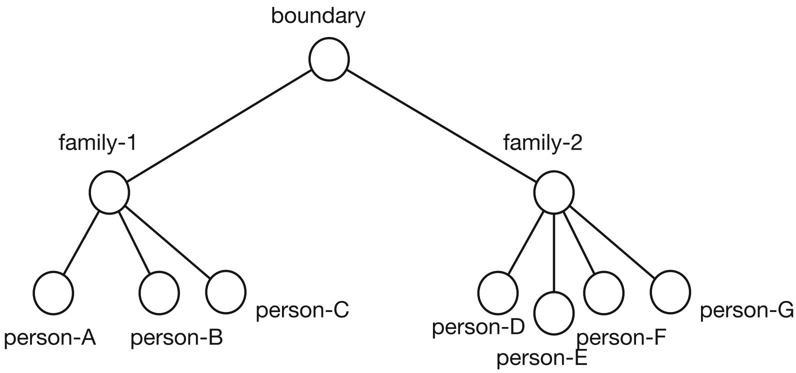

Fig. 7. Representation of the boundary between two groups of people illustrated in Fig. 3.

physical, so the boundary can directly be described using entities that constitute the boundary. Another possible description of the boundary is the external space that surrounds the persons (Fig. 6). On the other hand, the same description is unapplicable for family interactions, because the shape of the boundary cannot be defined.

Since the boundary between families is conceptual, one representation of the boundary is to describe using the descriptions of families that the boundary separates. More specifically, we describe each family using corresponding family members, and then use the family descriptions to represent the boundary between them. The description of the boundary is indirect in this representation scheme, and requires two steps. The step is defined as the number of intermediated links from the node representing the entity to the elements used in description. The step in hypernetwork model corresponds to the node level. Figure 7 illustrates the representation of the boundary between families. This is because the family is a concept and no physical entity exists.

2.2 Boundary as a Relationship

Comparison of Fig. 5 with Figs. 6 and 7 reveals similarity of the representation. The boundary can be interpreted as the relationship among elements. A relationship among entities is based on the similarities and differences of properties of the entities. This similarity enables two formulations: (1) boundary is a relationship among elements that the boundary separates; and (2) relationship is a border among elements that the relationship associates.

The hypernetwork model dissolves the difference between the relationship and the boundary. It enables the understanding that the gap is a kind of relationship. If the boundary is conceptual, it is analogous to conventional relationships, and details can added to specify the boundary. Similarly, if the boundary is physical, as in the case of person-person boundary, the specifications function identically. A relationship is represented with a node in hypernetwork model, and specifications are described using attribute nodes attached directly to the relationship node. The representation of a boundary is the same, and attribute nodes can be attached for detailed description.

Then the hypernetwork homogenizes the boundary and the relationship. More specifically, the boundary is treated as a kind of relationship. When representing physical boundaries, for instance in person-person case (Fig. 2) and cell membranes of living organisms, it means that the relationship, which is usually a concept and non-physical, has corresponding physical "matter". Many relationships are conceptual or hypothetical, such as friendship, but they are also represented with a node. In hypernetwork representation, there is no explicit distinction between representations of conceptual and physical boundaries. As previously explained in this paper, the hypernetwork model is able to represent duals. In dual representation, the boundary becomes the entity, and the elements represented as entities are treated as relationships.

Representing the boundary between two entities is simple compared to more entities. A node represents the boundary, and it connects the nodes representing the two entities (Fig. 8). Multiple possibilities or representation arise for boundaries among more than two entities. The boundary among N entities can be treated as a single boundary (Fig. 9(A)), or the boundary can be split and treated as a set of boundaries between pair of entities (Fig. 9(B)). For boundaries among $N > 2$ entities, both interpretations are possible, and both representations can

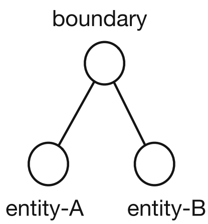

Fig. 8. Boundary representation between two entities.

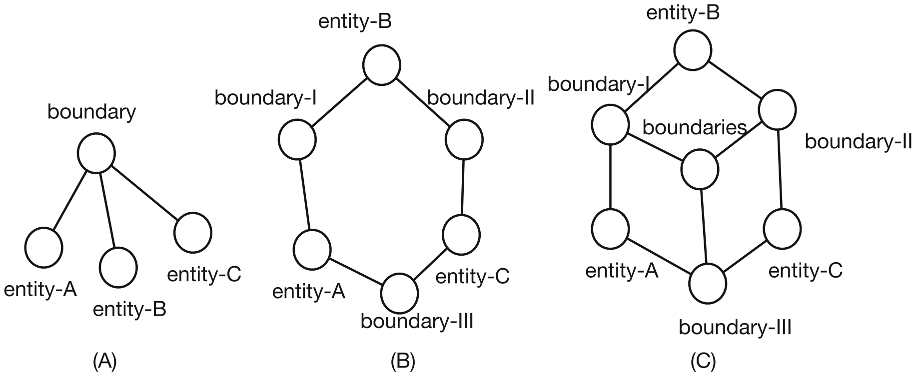

Fig. 9. Boundary representation between three entities. Three examples are shown.

coexist in hypernetwork model. A node representing all pairwise boundaries can be added (Fig. 9(C)).

Treating the boundary as an entity or a relationship depends on the viewpoint to treat the system. When visualizing the boundary as an entity, each boundary will be treated as distinct ones, and each will be identified with the specific label. For instance, the representation of Fig. 9(B) has three boundaries (I, II and III) and three "matters" (A, B and C). Suppose the three "matters" represents persons, and the boundaries denote the boundaries among persons. When treating the boundaries I, II and III as entities to analyze the nature of these boundaries, the persons A, B and C function as relationships or boundaries.

The advantage of the hypernetwork model is that it allows the representation of boundary as the relationship or the entity, and the "matter" as the relationship of the boundary, even if the interpretation of a viewpoint lacks immediate meaning.

3 Boundaries in Actual Phenomena

This section describes the application of the model to actual phenomena. The objective of describing as a system is to understand the phenomena by analyzing how the changes in properties of elements that constitute the system influence the phenomena. It is to observe the phenomena as a whole, the "*global behavior*", by modifying the behavior of individual elements that constitute the phenomena and relationships among elements.

The boundary of the system is one of global behaviors to analyze. Then the goal is defined as the analysis of how the boundary behaves due to changes in elements' behaviors.

3.1 Lifestyle Disease

We are currently describing the feeding process of human beings. The feeding process refers to all functions, processes and control mechanisms regarding intake of food, energy absorption and feeding behavior [8–14]. The feeding process influences a wide range of other phenomena, mainly those related with energy. One of the most important phenomena may be lifestyle diseases represented by diabetes meritus, in a sense that a huge number of people is affected. Other diseases are also related, for instance hyperorexia and anorexia, which are directly related with the control mechanism of feeding. Energy consumption is a fundamental function of organism behavior, thus the fact description of feeding behavior treats one of fundamental aspects of life.

We have been describing mechanisms of life style disease using the hypernetwork model. Multiple viewpoints are incorporated to the representation, from gene and small molecule level to individual person and family level. Feeding process and lifestyle disease mechanism are interrelated phenomena and they involve multiple description levels of elements.

Genes, proteins and molecules constitute the lowest description level, and a group of people the highest description level. Cells, organs and persons, which belong to intermediate levels, are also used for descriptions. Besides the processes based on molecular biology, we are also integrating process related to oriental medicine, the meridian treatment.

Boundaries are clearly defined in descriptions based on molecular biology of levels below single person. However, descriptions based on meridian present no corresponding physical "matters". Figure 10 is an illustration of meridian, where the black dots represent the meridian points. The body shape may function as the boundary, and its description can be incorporated to the representation.

On the other hand, when a part of meridian points is of interest, the body shape can no longer be used as the boundary, and the use of conceptual boundary is required. The shape of the boundary is undefined, and can be freely defined.

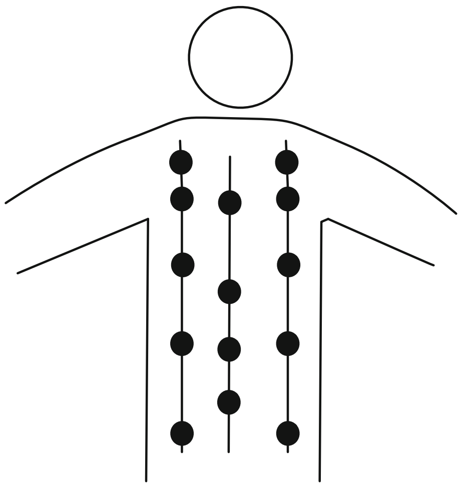

Fig. 10. A part of meridian in human body. A line denotes the grouping of meridian points represented by dots.

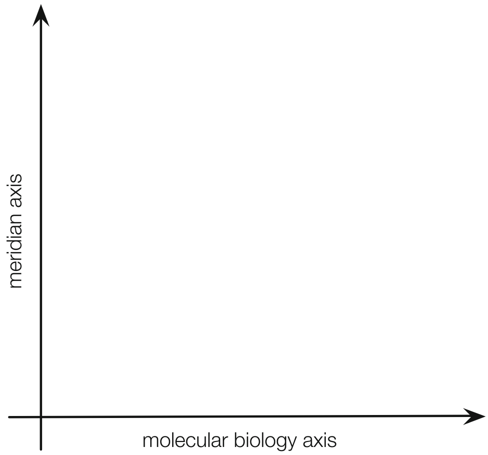

Fig. 11. Two perpendicular axes in lifestyle disease description.

The question is whether the boundary is necessary in this description, and our study suggests that the boundary is not a requirement for the analysis.

We are also conducting the integration of descriptions based on molecular biology and meridian. The problem of defining the boundary also arises in integrated representation. A possible visualization is the two dimensional space, each in perpendicular axes (Fig. 11). The boundaries used in descriptions based on molecular biology is unsuitable for integrated description because of the incorporation of meridian. Visualization of integrated model is necessary to analyze the influence of change in meridian to molecular biological phenomena and vice-versa.

3.2 Music Composition Process

We are analysing the music composition process of professional composers, treating the composition process as a sequence of decision makings. We focus on the creation process or composition process, from a blank music sheet to the final work. This is a "creation history" of musical piece, where the simultaneous employment of knowledge and imagination are essential [1].

Musical score is the de facto representation of musical pieces. Musical score encompasses every aspect of the musical piece, and it describes what to be performed, how to be performed, and composer's intentions. Many works on music analysis have been published, including the description model of music structure. For instance, Generative Theory of Tonal Music (GTTM) [2] is a model to describe the structure of musical pieces based on linguistic theory. Conventional works try to represent this type of knowledge as the static entity, usually treating as a structure of notes, chords and groups of these elements [2]. Typical structure is hierarchical, where the whole musical piece is positioned at the top of the hierarchy.

Music composition process presents following properties: (i) it is a creative process, and because of its artistic nature, sensitivity and emotion is strongly involved; (ii) there is a solid foundation of music theory, differing from other Arts fields such as paintings, sculptures and dances. Harmony of tonal music, for instance, involves mathematics of sound frequencies. The liberty and amount of sensitivity that is involved in music composition is higher than engineering process, industrial design and product design, for example, which have strong theoretical bases.

In the present work, a musical piece is represented by relationships among decisions. Such a creation history is more valuable than static structures generated by conventional methods. The disclosure of description of intermediate composition process is useful for both composers and players. For composers, it is valuable to overview and clarify his own composition process to improve the composed opus, besides the benefit to reorganize his ideas. For musical instrument players, the acquisition of background and underlying philosophy is invaluable, because deeper understanding of musical piece is fundamental and crucial for good execution.

In the description of the music composition process based on decision makings, the granularity of described decisions correspond to the description level in feeding process. There are decisions that involve a small number musical elements, for instance a single note, and others that affect the entire music. The former is fine granularity, and latter the coarse granularity. Then the boundary would be defined as the boundary of decision makings. The decision making is already conceptual, so its boundary is also necessarily conceptual.

Similar to the description of lifestyle disease, two aspects are represented in the description of the music composition process (Fig. 12): (1) decision elements

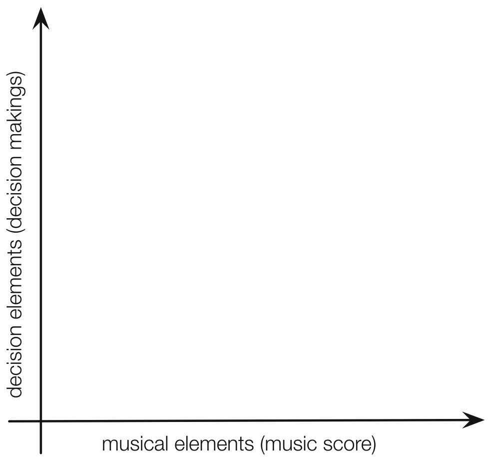

Fig. 12. Two perpendicular axes in music composition process description.

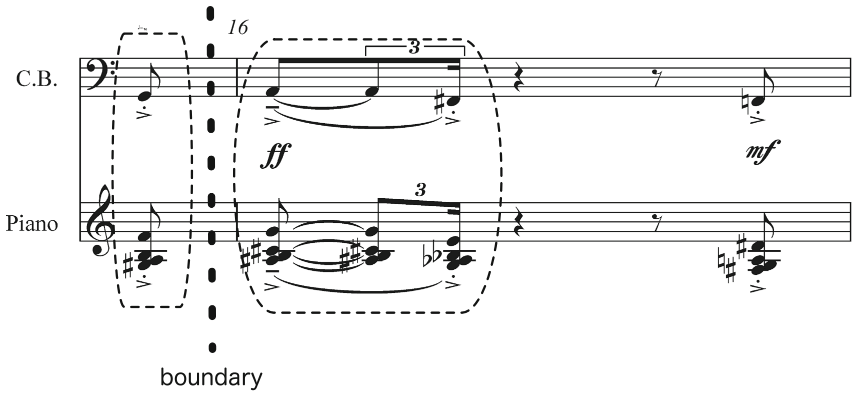

Fig. 13. An example of boundary between two adjacent music elements.

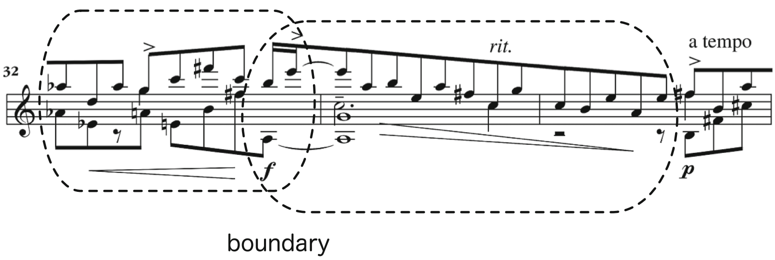

Fig. 14. An example of boundary between two overlapping music elements.

that describe decisions during composition; and (2) musical elements, such as music notes, that describe the composed music.

The boundary in representation of musical elements are intuitive because we can draw described regions on musical score. For adjacent and partially overlapped representations, the boundary is the intersection between the relevant elements. For instance, the boundary between adjacent elements can be traced as in Fig. 13. If an overlap exists, the overlap would be the boundary (Fig. 14). In both cases, the shape of elements and boundaries are conceptual.

4 Conclusions

This paper discussed the validity of boundaries in system representation of two phenomena, the lifestyle disease with feeding process and the music composition process. While the former belongs to the phenomena analyzed in classical system theory, the latter one is of different class. The conventional concept of the boundary, which functions to intermediate input and output from the system, does not apply to all system descriptions.

The hypernetwork model homogenizes boundaries and relationships, and boundaries are treated as kind of a relationship. This allows more boundless interpretations and analyses of the target phenomena.

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