Framework Based on Relationship to Describe Non-Hierarchical, Boundaryless and Multi-Perspective Phenomena

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Abstract: Describing phenomena of interest as a system is valuable because system science methodologies are applicable for the analysis. This paper presents a model to describe and analyze phenomena which present (1) no definable boundaries, (2) multiple hierarchical levels, and (3) necessity of diverse viewpoints to understand the phenomena. The proposed framework, the hypernetwork model, is applied to describe the lifestyle disease and the music composition process. The hypernetwork model homogenizes boundaries, hierarchical levels, and different viewpoints to be treated as instances of relationship.

Key Words: system model, relationality modeling, hierarchy, boundary, viewpoints.

1. Introduction

This paper presents a hypernetwork model, a framework to describe phenomena as systems. Phenomena without definable boundaries or no clear hierarchical levels, or that require simultaneous descriptions based on multiple perspectives, can also be represented using the hypernetwork model.

System science focuses on the elucidation of elements that constitute the investigated phenomena and the interactions among the elements. The advance of measurement techniques provide data that result in increased number of detected elements and more detailed descriptions of the interactions among the elements. Furthermore, new measurement techniques provide new perspectives to understand the phenomena, and description based on a single perspective becomes insufficient to understand. For the deeper comprehension of the phenomena, a description that integrates descriptions based on different perspectives is required. The usefulness of a mere collection of descriptions based on different viewpoints is low compared to the integrated description of descriptions based on various viewpoints. Integrated representation allows the elucidation and analysis of the similarities and differences among distinct aspects to understand better the phenomena, which allows origination of new knowledge by assembling distinct viewpoints of the same fact.

For instance, in biological sciences, initially the data to study gene interactions at the genome scale were obtained by measurement of whole genome RNA expression levels [1],[2]. However, measurement of protein levels of the entire cell became possible, enabling the prediction of interactions among proteins based on the protein expression data, independent from the prediction based on RNA data.

Proteins and DNA are different kind of substances and belong to different sets of elements when describing an organism as a system, and they constitute different viewpoints. To better understand the biological system, an integrated representation containing both DNA level and protein level descriptions is desirable because separate descriptions of DNA level and protein level are incomplete representations of biological phenomena. In separate description, the properties that would appear only by the integration of both representations are absent, with no association between the two aspects that are elucidating different facets of the same entity, the living organism in this example. Furthermore, recent studies indicate that previously ignored non-coding DNA regions seem to have essential roles in regulating gene transcriptions [3]. Together with other new findings such as epigenetics, the concept of life’s “functional element” has changed. Therefore, biological phenomena should be represented as a collection of different perspectives (measured aspects) and diverse levels of structural hierarchy. The structural hierarchy denotes the hierarchy of structural aspects. For instance, organs are composed of tissues, and tissues composed of cells.

The present paper treats following aspects related to system representation models:

(1) No boundary. Although the boundary is a prerequisite in system science, the boundary of some phenomena is not easily recognizable or definable. Others apparently lack boundary. Even if the boundary can be directly defined, it is sometimes dynamic, not only the shape but also its existence. The boundary may also appear and vanish in a given scale, often in the time scale. It will be necessary to analyze the dynamism of the boundaries related to changes in elements’ dynamisms.

(2) No hierarchy. The proposed framework gives no special treatment to the hierarchical structure. Conventional system models place special emphasis on hierarchical relationship, partially due to the existence of the emergence. The hierarchical structure is closely related to the emergence, where the level of the observed phenomenon, the emergent phenomena, and the level of interacting elements constitute the hierarchical relationship. The former belongs to the upper hierarchical level, and the latter to the lower level. Although system science assumes that the elucidation of causal relationship between these two levels is possible, no theory has succeeded in clarifying the
emergence mechanism.

(3) No isolated viewpoint or perspective. The system model of a given phenomenon extracts only one perspective of the target phenomenon. Conventionally, when multiple models focusing on different aspects are generated from the same phenomenon, they are treated separately, offering no integrated view of multiple perspectives. This paper assumes the following two points: (i) the representation based on a single viewpoint is insufficient to understand thoroughly the phenomena; and (ii) simply providing multiple models describing different aspects is equally incomplete if the representation of each viewpoint is independent from the others, with no connections to other representations. The proposed model, the hypernetwork model, enables better understanding by the integrated description generated by interrelating representations of different viewpoints based on elucidated relationships. As a conceptual explanation, imagine the events involving activities of multiple persons, for instance historical events. In order to understand an event related to a conflict such as a battle or a negotiation between nations, viewpoints from all participants, at least those with the key role, should be elucidated. If a viewpoint from only one participant or a single side is described, the understanding will be not only incomplete but also biased. Moreover, the integration of descriptions from the viewpoints of all participants to the event corresponds to the integration of descriptions based on different viewpoints. A related problem is the analysis of human organizations such as companies, where agent-based simulations have been used [4].

The system description consists basically of elements and relationships among elements. Conventional representation models used for system description are mathematically equivalent to graphs [5]. However, conventional models present following defects: (1) unable to represent N-ary relationships or relationships among more than two nodes; (2) unable to represent relationships among relationships; (3) unable to specify relationships or assign attributes. The proposed model, the hypernetwork model, solves these issues. For instance, suppose a representation of movie co-stars (Fig. 1). The actors are related to movies, then the elements representing actors and movies are stored in the ocean. To visualize actor co-starring relationships, the actors are related to movies, then the elements representing actors have the concept role, and the elements representing the movies have the relationship role. This representation focuses on actors, and how the actors are associated with each other. It is also useful, on the other hand, to focus on movies in order to investigate how movies are related. The dual representation that interchanges the concept and attribute is also possible. In the movie costar representation, the details of a movie are also useful, such as the production year, producer, director, and revenue. These would be the attributes of a movie. Furthermore, associating the movies based on the production company, for instance, may be required. To represent this, it is necessary to relate movies. However, movies already specify the relationships among actors, and to associate movies, it is necessary to include a production company as the relationship among movies. Representing attributes of movies and relationships among movies are impossible to be represented simultaneously with movie costar representation in conventional models.

Some of these aspects related to living organisms and decision making sequences have been investigated [6]–[11], but no implementation details of the model were presented. This paper presents the proposed model and its theoretical basis.

2. Investigated Phenomena

The proposed model, the hypernetwork model, was elaborated in parallel to the description and the analysis of two phenomena from the system science viewpoint: the lifestyle disease and the music composition process. This section describes the two phenomena from the standpoint of the three aspects described above, which are hierarchy, boundary, and viewpoints. 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, and to generate an integrated view of multiple perspectives.

2.1 Lifestyle Disease

Since the feeding process is closely related to lifestyle diseases, particularly diabetes mellitus, a comprehensive description of the feeding process is valuable to define research questions related to lifestyle disease. The feeding process refers to all functions, processes, and control mechanisms regarding food intake, energy absorption, and feeding behavior [12]–[18]. It serves to better understand the phenomena, to detect ambiguities and missing relationships among available facts, and to clarify the perimeter of known facts, i.e., the boundary between the known and unknown.

Feeding process and lifestyle disease mechanism are interrelated phenomena, and they involve multiple description levels of elements. Multiple viewpoints exist and should be incorporated into the representation, from gene and small molecule level to individual person and family level. Genes, proteins, and molecules constitute the lowest description level, and the group of people the highest description level. An example of the description of person level is the "transmission" of obesity, as the obesity seems to be contagious, and "transmission" depends on the network shape of personal relationships [19]. Cells, organs, and persons, which belong to intermediate levels, are also described. Besides the processes based on molecular

![Fig. 1 Representation of movie costar relationships. Nodes represent actors, and links the movies. (A) is a representation using conventional model. (B) is an illustration to indicate that relationships among relationships cannot be represented with conventional models. The production "*w*" links movies with the same production company [p] and [q] (movies [p] and [s]). Dotted lines are used because it cannot be represented.](image-url)
biology, the phenomena related to oriental medicine, the meridian treatment, are also described and integrated to the descriptions based on molecular biology. Figure 2 is an illustration of meridians, where the black dots represent meridian points. The spots shown in Fig. 2 represent the knowledge of meridians which originates from ancient China and was introduced to Japan in the sixth century AD. However, the physical existence of the meridian network has not been confirmed yet. In the description of meridians, 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. The question is whether the boundary is necessary in the description, and it suggests that the boundary is not a requirement for the analysis.

The descriptions based on molecular biology and meridian, two unrelated phenomena, are being integrated to generate a complete picture of the lifestyle disease. The problem of defining the boundary also arises in integrated representation. The boundaries used in descriptions based on molecular biology are unsuitable for integrated description because of the incorporation of meridian.

2.2 Music Composition Process

The whole process of music composition is being analyzed, from the blank music sheet to the final work. The composition is treated as a sequence of decision makings [8] and analyzed using the systems science approach.

Musical pieces are described in music sheets, which contain every aspects of the musical pieces, such as the composer’s intentions, and what and how to be performed. It lacks, however, the historical aspects of the musical pieces, or how the musical piece was created. For the instrument players, the creation process is perhaps the most valuable information because the background information can be obtained. Details on the music composition process enable deeper understandings of musical pieces and offer new perspectives to interpret musical pieces, consequently providing new context to understand musical pieces. Furthermore, it is useful to clarify the influence of individual musical theories on the creative process.

Much work on music analysis exists, including the description model of music structure. The generative theory of tonal music (GTTM) [20] is a representative conventional study. However, conventional studies treat only the final version of musical pieces, commonly generating hierarchical structure from music scores, where the entire musical piece positioned on the top of the hierarchy, notes at the bottom level, and chords and phrases belonging to intermediate levels.

The description of the music composition processes is completely different from the music scores that represent only the final version of music pieces. The entire creation process is included, and the creation history is more valuable than static hierarchical structures generated by conventional methods. The detailed description of the composition process is useful for both musical instrument players and composers. For instrument players, the acquisition of background and underlying philosophy is invaluable because the deeper understanding of the musical piece is crucial for interpretation that results in better expressiveness. And for composers, it enables to clarify their own composition process to improve the quality of the composed musical pieces, besides the benefit of reorganizing their ideas.

In this study, decision makings extracted from the composition history connected based on relationships represent the musical pieces. Besides the extracted decisions, musical elements annotated on music sheets that constitute the composed music, such as music notes, are also described. There are decisions that involve a small number of musical elements, for instance, a single note, and others that affect the entire music. The granularity of described decisions corresponds to the description level in lifestyle diseases.

The same musical piece can be analyzed using different music theories, which helps the musical instrument players to understand better the musical pieces. It is analogous to analyze musical pieces from multiple perspectives, where the analysis based on each theory corresponds to a viewpoint. For example, the scale (modal) theory and the tonal theory can be used, which are completely distinct theories. Even if the musical piece was composed employing only the tonal theory, the scale theory can be used for the analysis, giving useful insights about the musical piece. Because no musical piece is completely tonal or atonal or follows strictly one musical theory, aspects related to other musical theories are present. The influences of multiple theories are stronger in contemporary musical pieces.

Two types of boundaries exist in the descriptions of composition process: (1) boundaries of described decisions, and (2) boundaries of musical elements in music sheets affected by decisions during the composition (Fig. 3).

3. Hypernetwork Model

This section provides details of the hypernetwork model. The hypernetwork model follows basic definitions of semantic networks [21], where a node is connected to other nodes (1) to specify the nodes or (2) when nodes are related by some relationship. Its theoretical basis is the extended theory derived from the hypergraph theory [22]; thus, the representation capa-
bility of the hypernetwork model is higher than a model based on the hypergraph theory, although no such model seems to exist. Conventional representation models, such as semantic network [21] and ER-model [23], are equivalent to graphs [5]. Since the hypergraph theory is the extended theory derived from the graph theory, the hypernetwork model presents representation capability higher than conventional representation models. The hypernetwork model is able to represent N-ary relationships, dual of a representation, relationships among relationships, and integrated multiple perspectives, which are unable to be represented using conventional models.

The hypernetwork model consists of two configurations (Fig. 4 top and bottom). Basically, the model is a set of isolated elements, where an element encompasses a set of rules to activate the element under a given viewpoint. The uniqueness of the proposed model is the intrinsic incorporation of multiple facet into the model, enabling multiple definitions of how to visualize the subset of elements. This is a “library” of elements to describe phenomena, and since this is just a collection, it does not have much value. The configuration of elements provides representations that humans can understand, where connections among elements are provided. In the basic representation of the lifestyle disease, for instance, a node represents any substance or phenomena or concept, and a link connects two or more substances or phenomena or concepts based on a given relationship. Although conventional models can only connect two nodes due to theoretical restrictions of the graph theory that they are based upon, the link of the hypernetwork can connect any number of nodes, including one node, a singleton. The generated representation is then converted to bipartite representation, where links that represents relationships also become nodes, and links of a new type are inserted to connect the nodes and nodes converted from links (Fig. 4 top).

The uniqueness of the hypernetwork model is the existence of three types of description elements, which are (A) concept, (B) relation, and (C) attribute. The concept element serves to represent substances or phenomena or concepts, and the relation element to describe relationships among them. The third element type, the attribute element, serves to specify the details and properties of concept elements and relation elements.

The dual representation of a viewpoint represented by the hypernetwork model is a representation using the same elements and connections among the elements, but with interchanged roles of elements. For instance, all elements with their role as the concept in representation A will have their role as the relation in representation B, and all relation elements in representation A will be concept elements in representation B. Such a switch to reciprocal perspective is useful to analyze the “representation” from the “opposite” direction.

The hypernetwork model allows integration and simultaneous description of 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 comparison among different viewpoints to analyze the system.

3.1 Rulesets of Elements

The system description of a phenomenon based on a given viewpoint consists of a subset of elements from the set of elements

\[ V = \{v_1, v_2, \ldots, v_N\}, \]

where \( v_i, i = 1, \ldots, N \), is an element, and \( N \) is the number of elements in the ocean (bottom of Fig. 4). This collection is denoted as an ocean of elements. Elements in the ocean can be generated, modified and deleted. Basically, all elements are employed to describe some aspect of the phenomena.

Each element in the ocean (bottom of Fig. 4) contains a set of rules (Fig. 5). A rule with no destination link is also possible (Fig. 6).

An element \( v_i \) is implemented as a collection of rulesets (Fig. 5), together with a unique identifier “elem-ID” assigned to the element:

\[ v_i = \{r_{i1}, r_{i2}, \ldots, r_{iM}\}, \]

where \( r_{ij} \) is the \( j \)-th ruleset of the element \( v_i \) (Fig. 5). The number of rulesets is arbitrary \( (M > 0) \).

A ruleset consists of the ruleset identifier “rule-ID”, the role of the element when the ruleset is activated, and the list of elements connected from the current element (Fig. 7). The role is specified as the concept, relation or attribute. The role of an

![Fig. 4](image1.png) The ocean and an example of hypernetwork representation. White nodes denote concept or attribute elements, and filled nodes represent relation elements, which define relationships among connected elements. For instance, the relation element “v1" is a relationship between elements “v1" and “v8". P1 and P2 denote the viewpoints.

![Fig. 5](image2.png) Multiple rulesets in an element. “elem-ID” denotes the ID of the element, and “rule-ID” the ID of the ruleset.
element is only one under a given viewpoint, and no simultaneous assignment of multiple roles is allowed under the same viewpoint. Each link ("link #1", "link #2", ...) specifies the connected element ("dest_elem-ID") from the current element and the ruleset ("dest_rule-ID") to activate in the destination element. Table 1 indicates possible connection combinations among the three element types. Two connections are prohibited: between a concept element and a concept element, and between a relation element and a relation element, due to constraints imposed from their role in hypergraph.

### 3.2 Representation of a Viewpoint

A viewpoint of phenomena is represented by the activating ("firing") sequence pattern defined by the rulesets of activated elements in the ocean. Usually a subset of elements in the ocean is activated, and these elements define the viewpoint. When a starting element or a set of elements is selected, the relevant elements that are described in rulesets are subsequently activated. Then a facet is defined as a set of elements $F = \{w_1, w_2, \ldots, w_P\}$, where $F \subseteq V$ and set of fired rules $R = \{r_1, r_2, \ldots, r_P\}$, where $r_1$ denotes the activated ruleset in the element $w_1$, $r_2$ in the element $w_2$, and so on. Then a viewpoint $P$ is represented as a set of pairs of the element and activated ruleset:

$$P = \{(w_1, r_1), (w_2, r_2), \ldots, (w_P, r_P)\}. \quad (3)$$

The number of elements connected from an element is defined by the fired ruleset. The role (concept, attribute or relation) of an element is also designated by the fired ruleset.

When an element is selected with the ruleset to fire, destination elements described in the activated ruleset is subsequently activated, i.e., the activation "signal" is propagated over the elements in the ocean, and the activation process stops when the signal reaches the elements without activated ruleset. The number of starting elements can be multiple, but conflict may occur if an element receives signals to activate different rulesets.

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**Table 1: Connectivity among concept element, relation element, and attribute element.** "○" indicates allowed connections between element pairs.

| Concept | Relation | Attribute |
|---------|----------|-----------|
| ×       | ○        | ○         |
| ○       | ×        | ○         |
| ○       | ○        | ×         |

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Instead of “firing” all possible elements until no more elements are activated following the rulesets, another representation is to enumerate predefined set of elements only.

Since the role of an element and connections among elements is viewpoint dependent, the set of elements in the ocean $V$ is simply a set of isolated elements without any connection among them. Elements are connected once the viewpoint is selected and connections appear between the elements used to represent the viewpoint. In other words, the viewpoint determines the role of elements and connections among them. Distinct viewpoints usually consist of different sets of elements, but when they are identical, connections among elements are different as different rulesets are activated.

Suppose a simple case where no attribute elements exist, then a viewpoint is a subset of the elements whose connections are defined by the relation elements (filled nodes in Fig. 4). The collection of the elements with relation elements constitute an interpretation of a system under certain viewpoint. The relation elements in Fig. 4 are also elements that belong to $V$. The function of the element is viewpoint dependent. Multiple viewpoints $P_1, P_2, \ldots, P_M$ ($M > 0$) exist for $V$. In Fig. 4, two viewpoints $P_1$ and $P_2$ exist, and the elements $v_1$ and $v_3$ appear in both $P_1$ and $P_2$. However, different roles are assigned, as the role of $v_3$ is the relation in $P_1$ and the relation in $P_2$. Similarly, the role of $v_3$ is the relation in $P_1$ and the concept in $P_2$.

Details of concepts and relationships can be specified by attaching attribute elements or by relating to other concept elements through relation elements. Simultaneous use of the two descriptions is also possible. The attribute element exists to specify any of three element types. Concept and relation elements may function as attribute elements of other elements under different viewpoints.

Then a viewpoint is defined as a set of elements $V$ and the rulesets activated in $V$, where $V$ is a subset of elements $V$ in the ocean, $S_V \subseteq V$. Figure 8 illustrates the representations of
different viewpoints of Fig. 1.

As Fig. 9 illustrates, the connection between elements can be whether directed or nondirected. Some relationships among elements should be directional, for instance the hierarchical relationship, where the upper and lower levels should be specified. The cause-result relationship is another example, where the direction is from the cause to the result, and the opposite direction is meaningless and not possible. On the other hand, the description of similarity between two elements, for instance, requires no direction of the connections. In the proposed framework, bidirection is treated as identical to nondirection, and the link is described in the rulesets of both elements. For instance, to represent the connection of Fig. 9 (B), the link to the element B is described in a ruleset of the element A, and the link to the element A is described in the ruleset of the element B. The IDs of rulesets specified in links of the elements A and B should match the ID of the activated ruleset. A ruleset without a link is possible, meaning that the element is not further connected (element B in Fig. 9 (A)).

4. Discussions

4.1 Hierarchical Relationships

A hierarchical relationship is one of the basic concepts in system science, as many phenomena are closely related to hierarchical relationships. For instance, emergence is a phenomenon that results from interactions among elements belonging to the hierarchical level below the observed level.

Two concepts of hierarchy are used in this paper, differing on the aspect to extract hierarchical relationships: structure and phenomena. Two elements A and B are defined to have a hierarchical relationship when the element A constitutes the element B, defining the structural aspect of the hierarchy. The aspect related to phenomena is derived from the structural aspect, defined as the phenomena induced by elements of adjacent hierarchical levels of structure. Two phenomena $P_1$ and $P_2$ are defined to have hierarchical relationship when a set of elements $E_1$ causes phenomenon $P_1$ and a set of elements $E_2$ causes phenomenon $P_2$, where the sets $E_1$ and $E_2$ have hierarchical relationship.

This paper assumes the existence of the structural aspect of the hierarchy, but not the second type of the hierarchy, the aspect related to phenomena. The existence of structural hierarchical relationships does not imply the hierarchical relationships among phenomena resulting from elements of adjacent hierarchical levels. In other words, there is no hierarchical relationship between the phenomena $P_1$ caused by a set of elements $E_1$ and the phenomena $P_2$ caused by a set of elements $E_2$, where the sets $E_1$ and $E_2$ have hierarchical relationship.

For instance, a musical piece is composed of phrases, and phrases of chords, and chords of notes, so there are at least four structural hierarchical levels. A chord is a combination of multiple notes, which listeners recognize as a combination of multiple sounds. The combination of notes and chords that constitute the entire musical piece induces emotional state change. Although the notes, chords, phrases, and the musical piece constitute hierarchical structure, this paper assumes the phenomena associated with them are unrelated and independent, namely the sound recognition for notes and chords, and the invoked emotion for the entire musical piece.

Another example is the feeding mechanism of living organisms, closely related to the input, output, and consumption of energy. The basic energy balancing mechanism of living organisms functions at the molecular level, consisting of the current energy level detection and signal generation to modify the energy level. Figure 10 illustrates more detailed molecular level mechanism. However, the feeding mechanism of humans presents additional mechanism involving the cerebral cortex, a functional unit of the brain different from the central nervous system (CNS), responsible for decision makings that functions in parallel with the basic energy balancing mechanism. Humans are able to override this mechanism, by eating even on a full stomach or not eating when hungry. The decision makings involved in feeding are driven by principles fundamentally different from the mechanism of Fig. 10. In a more ordinary situation, when a person feels hungry, she chooses what to eat depending on the time (a meal or snack), location (at home, at work, outside) and situation. She may go to a restaurant alone or accompanied by family, friends or acquaintances. The choice of the restaurant involves the food type (Japanese, Italian, French, ... ) and subsequent choice of the food, which can be a la carte or a single plate. Furthermore, the similarity and closeness among people in feeding situations are strong factors, and generate groups of people consisting of similar body mass index (BMI) [19], indicating that the spread of obesity is influenced by person-to-person contact manner.

![Fig. 10 Molecular level relationship network of energy balance. CNS represents the set of insulin and leptin receptor neurons and the neurons that emit energy intake signals to organs. Compiled from [16],[18].](image)

This paper assumes the existence of hierarchical relationships among structural elements, for instance between genes, cells, and organisms in lifestyle diseases, and between notes, chords, and musical pieces of music. Differing from conventional studies, however, phenomena of different hierarchical levels are treated as different viewpoints, and this paper assumes that phenomena of different structural hierarchical levels are governed by independent principles, and negates the presence of hierarchical relationship among phenomena. In the case of lifestyle diseases, (i) control mechanism of energy intake at the molecular level and (ii) decision mechanism to eat or not and to select a food type at the organism level, are assumed to be independent phenomena. Similarly, in the case of musical pieces, (i) pitch (frequency) recognition mechanism evoked by a single note or a chord and (ii) mechanism to generate feelings when listening to a passage or the whole musical piece, are also considered as distinct phenomena.

Whether the emergence phenomena can be reduced to the principles of the lower hierarchical level was discussed in [24],
but no framework model was proposed.

4.2 Boundary

The boundary is a prerequisite element of a system in system science, which defines the system and distinguishes from its environment. It is assumed that the boundary can be identified and extracted. However, the assumption of well defined boundary is not always applicable. The lifestyle disease and the music composition process, two phenomena discussed in the previous section, are examples where boundaries cannot be explicitly identified.

Two classes of boundaries are defined: (i) physical boundary, and (ii) conceptual boundary. Boundaries defined by the functionality discussed in [24] belong to the second type. The boundaries of the first class are simple cases of physical objects or entities, such as cell membrane that serves as the boundary between the cell of a living organism and its environment. In hypernetwork representation, there is no explicit distinction between representations of conceptual and physical boundaries.

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. Then these boundaries are not directly describable since they are conceptual, only describable using the elements belonging to the both sides of the boundary.

Consider the modeling of interactions among persons, where a person is treated as a system. The simplest case is the interaction between two persons, where the boundary between the person (system) and its environment is evident, as the body shape and the skin serve as the boundary of the system. The body contour is interpreted as the membrane that matters pass through, and the direction that matters pass through the membrane defines the input and output of the system. Matters denote not only the physical substances but also abstract entities such as information. Another possible description of the boundary is the external space that surrounds the persons.

On the other hand, modeling of interactions among groups of people, for instance families (Fig. 11), is more complicated, because multiple possibilities of the entities functioning as the unit of interactions exist. There is a conceptual boundary that separates a group of people from other groups. However, no physical entity serving as a boundary between groups of people exists, differing from person-person interactions where the skin or body shape is the boundary. Suppose the interaction between two families. A family is a set of people with consanguineous or legal relationship. 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. Families are interpreted as distinct entities to analyze interactions among families, and interactions are executed through the boundary between families (Fig. 11). However, the boundary between families is conceptual and no corresponding physical entity exists. Therefore the shape of the boundary is undefined.

Multiple descriptions of the boundary are possible, depending on the perspective. In the case of person-person interaction, the boundary is physical, so the boundary can directly be described using entities that constitute the boundary. 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, each family is described using corresponding family members, then the family descriptions are used to represent the boundary between them (Fig. 12). The description of the boundary is indirect in this representation scheme.

4.3 Multiple Viewpoints

For the comprehensive representation of the system, multiple representations based on different viewpoints should be present in the described model, together with the detailed relationships among the viewpoints. Different viewpoints are connected with relation elements to associate and integrate different facets or viewpoints. A relationship corresponds to a new viewpoint to associate the existing viewpoints. Then the existence of multiple relationships in representations implies multiple approaches to associate viewpoints. Details of relationships can be represented by the proposed framework, by adding attribute, concept or relation elements to describe the details.

The integration of multiple emergent phenomena, where each phenomenon results from the different hierarchical level of structure and the integration of multiple perspectives, results in similar descriptions. Thus the proposed model homogenizes the integration of emergent phenomena and the integration of different viewpoints. Then the term “viewpoint” denotes any set of elements extracted from the hypernetwork representation with any defined relationship among elements.

For instance, the description of biological phenomena, specifically lifestyle disease, and of decision makings, particularly music composition processes, indicates that “structural” elements constitute hierarchy, but not the phenomena derived from interaction among elements of lower hierarchical level. It implies that each phenomenon needs to be described independently from phenomena of other levels. For the integrated representation, the representations of individual phenomena should be associated, which is analogous to the integration of descriptions of multiple viewpoints.
4.4 Boundary as a Relationship

The hypernetwork homogenizes the boundary and the relationship. Figure 12 suggests that the boundary can be interpreted as the relationship among elements. This similarity enables two formulations: (1) the boundary is a relationship among elements that the boundary separates; and (2) the relationship is a boundary among elements that the relationship associates. More specifically, the boundary is treated as a kind of relationship. A relationship among entities is based on the similarities and differences of the properties of the entities. When representing physical boundaries, for instance the cell membrane 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 an element. A relationship is represented by a relation element in hypernetwork model, and the representation of a boundary is analogous.

Representing the boundary between two entities is simpler than among three or more entities. An element represents the boundary, and it connects the elements representing the entities (Fig. 13). Multiple possibilities of representations are possible for boundaries among more than two entities. The boundary among $N$ entities can be treated as a single boundary (Fig. 14 (A)), or the boundary can be treated as a set of boundaries between pair of entities (Fig. 14 (B)). Both interpretations are possible, and both representations can coexist in the hypernetwork model. An element representing all pairwise boundaries can also be added (Fig. 14 (C)).

Treating the boundary as an entity or a relationship depends on the viewpoint to treat the system. To visualize the boundary as an entity, each boundary is treated as distinct ones and identified with unique labels. For instance, the representation of Fig. 14 (B) has three boundaries ($B_2, B_3,$ and $B_4$) and three entities ($E_1, E_2,$ and $E_3$). Suppose the three entities represent persons, and the boundaries denote the boundaries among persons. When treating the boundaries $B_2, B_3,$ and $B_4$ as entities to analyze the nature of these boundaries, the persons $E_1, E_2,$ and $E_3$ function as relationships or boundaries.

The ability of the hypernetwork model to represent duals enables the interchange of the role of concept and relation elements. In the dual representation, the boundary becomes the entity, and the elements represented as entities are treated as relationships among boundaries.

![Fig. 13 Boundary representation between two entities.](image1)

![Fig. 14 Boundary representation among three entities. Two examples are shown.](image2)

4.5 Reciprocity of Hierarchy, Boundary and Viewpoints

In the presented framework, the hypernetwork model, the viewpoint to capture the phenomena is closely associated with hierarchical levels and boundaries. The descriptions of (i) multiple hierarchical levels of structural aspects, (ii) multiple entities separated by boundaries, and (iii) multiple perspectives, result in similar representations in the hypernetwork model. These three aspects are equivalent, differing only in their interpretations.

In the case of hierarchical structures, phenomenon of each hierarchical level is treated as an independent phenomenon and interpreted as a distinct viewpoint of representation. The phenomena associated with hierarchical levels are also treated as viewpoints to understand the whole system by integrating the viewpoints of each hierarchical level.

Similarly, boundaries that relate distinct entities are equivalent to the relationships that connect different hierarchical levels. Then the relationship that connects distinct hierarchical levels and the relationship that represents the boundary between distinct entities are functionally similar, as the boundaries function as relationships among involved entities.

Then hierarchical levels, boundaries, and viewpoints are described identically, differing only on interpretations of their representations.

5. Conclusions

The framework presented in this paper, the hypernetwork model, assumes that the existences of the hierarchy and boundary are not requisites to describe and analyze phenomena of interest, and single viewpoint is insufficient to understand a phenomenon. The hypernetwork model homogenizes boundaries, hierarchies, and viewpoints, where boundaries, hierarchies, and viewpoints are treated as specific types of a relationship.

The hypernetwork model is being used to describe the lifestyle disease and the music composition process. The following advantages have been identified so far. The details will be presented elsewhere.

(i) In the description of the lifestyle disease, it was possible to detect missing links among different viewpoints, and to suggest possible connecting elements. A possible biological element between the molecular biology and meridian was identified by investigating the integrated representation of these two completely different viewpoints.

(ii) Similarly to the advantage (i), in the description of the music composition process, it was possible to visualize multiple connections among passages located in different regions of the music sheet. Furthermore, visualization of multiple viewpoints for the same passage resulted in a deeper understanding of the musical piece by instrument players, which is important for better performance. These were confirmed by survey answers from professional composers and professional musicians.

The presented framework enables the visualization of the whole picture of the target phenomena by allowing integration of descriptions based on multiple perspectives. Generation of new viewpoints is possible to understand the system by defining new relationships among the elements used in descriptions of existing viewpoints. The hypernetwork model allows detailed representations of relationships, and the homogenization of hierarchy, boundary, and viewpoints to treat them as special
types of relationships. These two points enable formulations of new research questions related to the described phenomena, by offering novel viewpoints to understand the phenomena and detection of missing links among viewpoints.

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