A System Description Model to Integrate Multiple Facets with Quantitative Relationships Among Elements

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Abstract. We propose a framework of system description model to represent directly the details of relationships among elements, for the quantitative analysis of individual relationships and the whole described system. The proposed model also enables analyses of dynamic aspects of the system integrating the specifications of relationships described in the system. Multiple types of relationships can coexist in the same representation.

Keywords: Description model · Quantitative relationship
Multiple viewpoints

1 Introduction

This paper presents a modeling framework to describe directly the interactions and relationships among entities, and focuses on quantification of relationships. This paper also presents a global system property using the quantitative definitions of relationships.

The basic description of systems treated in this paper consists of a set of entities and relationships among them, and these are represented as a network, where nodes denote entities and links denote relationships. For example, Fig. 1 consists of five nodes A, B, C, D, E and relationships exist between nodes connected with links. This is a basic representation, and conventional models such as the semantic network [1] and ER-model [2] are essentially the same. As discussed later, it based on the graph theory [3] and presents limited capability of representation. On the other hand, our model is based on the hypernetwork model [4] which presents higher model-ling performance than conventional models.

Conventionally, system model-ling focused mainly on the entities, and relationships had secondary treatments. It might be related with our cognitive system. We sense less difficulty when describing a phenomena with its elements

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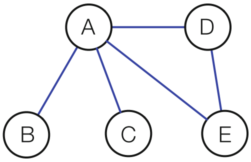

Fig. 1. A simple network representation. Links connect related nodes.

and how they are related. However, we usually focus on the elements, and less attention is paid to the relationships or extracting only the relationships for the analysis is rare. Interactions have been represented indirectly using the descriptions of elements that act as interacting elements. However, indirect modeling is insufficient when analyzing the interactions and relationships themselves. Relationships can be fully analyzed if they are directly represented, and direct representation should generate insights directly related with interactions themselves.

A general framework for the description of relationships is presented, together with the discussions on the quantification of relationships of some phenomena.

2 Quantification of Relationships

If the quantitative aspects of relationships can be represented, it would be more valuable than qualitative descriptions, because it enables predictions of phenomena in interest focusing on the relevant relationships. The measure and aspects of interactions and relationships depend on the phenomena and objective of description and analysis. However, it is possible to build basic framework that enables the descriptions of relationships.

This paper also focuses on the framework to incorporate quantitative aspects of relationships.

Conventionally, relationships are represented with following types. (1) Binary, where the relationship exists or not. (2) Qualitative, where relationships are described using natural language or types of predetermined categories. An example of the first type is the friendship relationship among people, and two persons are connected if they are friends, and isolated otherwise. There are only two quantitative possibilities, whether two persons are friends or not, and no quantitative measures such as the "degree of friendshipness" or "friendshipness amount" are used. Regarding the second type representation, inter-personal relationships can be represented using categories such as family, relatives, friends and acquaintances. Similarly to the type 1 representation, no quantitative degree of individual category is described, such as the degree of acquaintance relationship. An example of natural language description is the description of conversation among people, where the guessed context and meanings of utterances are used to annotate [5]. Another example of natural description is the analysis of human behavior and communications, mainly targeting non-linguistic aspects, such as gestures and body movements. In these cases, body movements are described using methods similar to the conversation analysis.

In the context of this paper, Shannon's entropy [6] is a successful case of quantification of relationships or interactions. Although it is denoted as communication theory, accurately it is transmission theory, because no meaning is quantified. Furthermore, the theory is sometimes misapplied to phenomena uncovered by the theory. However, it is a useful theory, as can be used to design the capacity of transmission lines and to design encoding and decoding algorithms.

Once the quantification of relationship is available, clearer definition of the entire system is possible. Conventionally, the existence of hierarchical structure is assumed in systems. For instance, a bee colony consists of bees, where each bee has assigned role such as queen, worker, foraging and nursing. And the bee colony treated as a system assumes the bees and interaction among bees constitute the "bee colony system". Although bees are modeled, interactions among bees are simply represented as transmitted symbols. However, we assume the bee colony society is the result of interactions or relationships among bees, and the relationships are the key factors that enable the existence of the bee colony. In other words, modeling of relationships is more important than that of elements, which are bees in this example. Figure 2 illustrates this structure. Conventional representation models do not allow such structure because links connect only the nodes, and no links are connected by links.

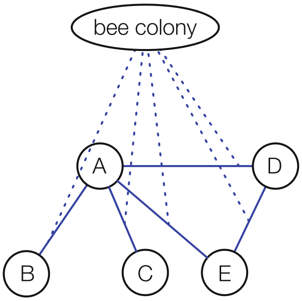

Fig. 2. Nodes A … E represent bees, and links represent relationships among bees.

3 Quantitative Relationships

As discussed above, a problem of conventional studies is that relationships are indirectly represented through modeling of relevant elements that are associated through relationships of interest. For instance, when studying human-robot communications, message generation mechanism and interpretation mechanism are incorporated into the model that represents either human or robots. However, the "message" itself that relates and defines the interaction between humans and robots are merely treated as a combination of symbols, and no model of the message itself is created. It implies that the analysis of interaction would be incomplete. Evidently, it is necessary to include the entities that interact into the analyses of interactions, besides the interactions themselves. However, conventional studies focused on the entities, and less emphasis was given to the interaction.

A model that enables description of interactions and relationships is the prerequisite for quantification of relationships, which permit the construction of theory. This paper assumes quantitative aspects should exist in such theory. In other words, purely qualitative description is insufficient to establish a theory. Because of this, we assume conventional descriptions of interactions are unsuited.

3.1 Logistics

A phenomena suitable to describe details and quantitative aspects of relationships is logistics. When represented as a network, logistics is described by representing places (ports, airports) as nodes and transportation lines as links that connect two locations with direct means of transportation. Transportation can be air or maritime or land, and their quantitative aspects such as cargo specifications, movement velocity, value and volume flow are associated to the link. Furthermore, multiple vessels may be traveling simultaneously between two places. The model correspondence is clearer for container based shipping [7], which is the mainstream maritime shipping method. A ship carries hundreds to thousands of containers, where all containers should be assumed to be carrying no identical goods. Then the detailed descriptions of containers are necessary, such as the container type, goods list, shipment origin and destination. The unit of low can be the total of goods in volume or value or quantity of all containers in a ship, the number of containers, or the ship, constituting a hierarchical relationship.

Even for inter-personal relationships, the thickness of the link or relationship is relevant for the analysis and visualization.

For instance, suppose the description among logistic companies, where the freight companies, which owns the ships used to carry cargo, and intermediary companies (brokers), which receive freight orders from customers and find adequate freight companies for their purpose, are represented. Sometimes there are high volume freight orders, and intermediary companies should find a vacancy of cargo space in ships. Similarly, there may be a limited availability of cargo space in a ship, and multiple intermediary companies are looking for that space. The thickness or closeness among persons in charge of the freight companies one intermediary companies will be decisive to obtain the extra cargo space in ships. Therefore, the representation should enable quantitative description of relationships.

3.2 Production Conveyor

Production line in industries, for instance automobile factory, is another phenomena that quantitative relationship representation is required for the analysis. Operators' sites are represented as nodes, and the site representations are connected to represent the flow between adjacent operator sites. The conveyor speed, quantity of materials and parts traveling between adjacent points.

3.3 Music Composition Process

Mainly two types of relationships are quantified in the analysis of the music composition process: (i) Between the composer and the musical piece, (ii) between decision makings and the musical piece. The former relationship is subtle and more abstract. We have been representing musical pieces as sequences of decision makings executed by the composer during the composition process. In our study, decision makings represent the intentions of composers, thus the composer and the musical piece are related by the decisions executed to create the musical piece.

Basically, a decision is represented as a structure of concepts that describes the decision. This is rather qualitative representation. Currently decisions are quantified in two modes. The first procedure is the quantification of individual decision. Quantified feature involves the passage in the musical piece affected by the decision. Thus the number of notes, quantitative difference before and after applying the decision, and the number of involved concepts in the decision, are used as quantitative measure of decisions. The second procedure, which measures a set of decisions, treats the decisions as a flow from the composer to the musical piece. This concept of the flow is also used in the quantification of relationships of other phenomena, for instance the biological network at the molecular level discussed in the next subsection.

Since representations of decisions are assigned with timestamp when the decision was executed, it is possible to trace the temporal density of decisions. Combined with the quantitative description of individual decisions, we can visualize the music composition process as the flow pattern of decisions related to the creations, modifications and deletions of notes in the musical score. This is different from simply dividing the total number of decisions generated to create the musical piece by the total time duration consumed to compose the musical piece. The difference relies on the quantification of individual decisions. Then it is possible to visualize the music composition process as the temporal flow pattern of decisions executed during composition. Musical pieces can be classified according to the composition patterns. Without quantitative relationship description, no such classification is possible.

3.4 Gene and Protein Interaction Networks

The interactions among genes and proteins constitute the biological network at the molecular level. Proteins constitute both nodes and relationships depending on their function. If a protein is an enzyme, it is a relationship among substances that are catalyzed by the enzyme. On the other hand, proteins acting as substrates and products of reactions serve as the nodes of networks.

Basically, phenomena of molecules are chemical reactions of diverse types. Therefore, the direct quantitative representation is the reaction velocity and related aspects, which quantifies the relationships among specific substances. Analogous to the case of music composition process, we also define a measure of the entire molecular network, which is the global network characteristic. This global property extracts the integrated reaction pattern of substances that constitute the network of interest. We have shown that biologically plausible gene regulatory networks have different global patterns from randomly generated networks [8]. It implies that the global reaction pattern captures the reaction pattern characteristics, computed using the quantitative values of individual reactions.

4 Model

Two kinds of descriptions are treated in this paper. First is the description of individual relationships, and the second is the description of the global characteristic of the network.

Details of individual relationships are described using the hypernetwork model [4]. Similar descriptions are impossible with other conventional models. Figure 3 is a representation example using the hypernetwork model. Both qualitative and quantitative aspects can be described to specify relationships.

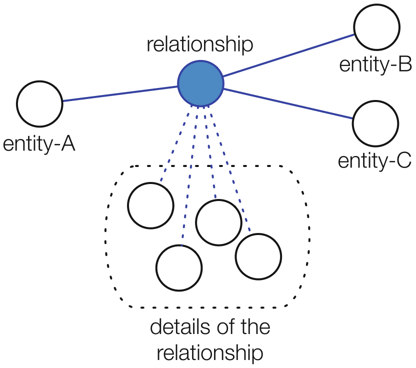

Fig. 3. A general illustration of a relationship among entities (entities A, B and C). Elements inside the dotted box are descriptions of the relationship element.

The second type of description, the global quantitative description, require the representation of individual relationships for computation. Basically, the global network property measures how the "activation signal" flows over the network, passing through modification specified in relationships denoted in the network. The "element" that flows over the network is not of single kind, and multiple types are possible for the same network that represents a given phenomena. In other words, diverse types of "elements" flow. Temporal aspects of the flow, such as the signal that triggers the flow from an element and the frequency of the trigger, can be described for each element of the network.

Figure 4 is an example of a network, where links are directional, indicating the direction of flow of "elements". The link between entities $v6$ and $v7$ are bidirectional, which means two links of opposite directions exist between them.

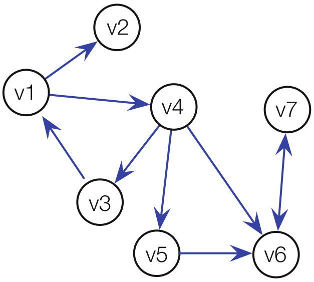

Fig. 4. An example of network with directional links that indicate the flow directions.

Figure 5 is the detail of the flow of relationship between two entities A and B. In this case, the relationship, with the description of its details attached, constitute the flow unit of relationships among the elements.

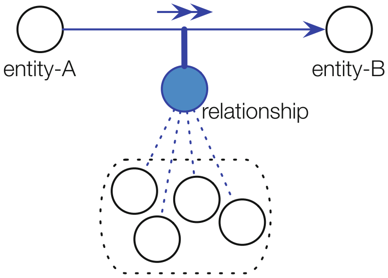

Fig. 5. Basic relationship flow between two entities. "relationship" flows from the entity-A to the entity-B, as the arrow indicates. Elements inside the dotted box denote the description of the relationship element.

There are numerous indexes that measure network properties [9]. Those measures are applicable to the hypernetwork model with appropriate modifications. The basic unit of the proposed model is defined by the description of relationships, which subsequently defines the unit of flow on the links. Because conventional models used in network science are reduced to graph theory [3]. Thus details of relationships cannot be represented, and the detailed flow analysis is not possible using conventional models.

Another difference of the proposed model is the existence of diverse types of relationships and "elements" that flow through links. Furthermore, these elements are sometimes converted to different elements through relationships and entities (Fig. 6).

In this case, a relationship (relationship-Z) can be described as the relationship between the relationship-1 and relationship-2 to specify the conversion from the relationship-1 to relationship-2. Therefore, quantification of a network

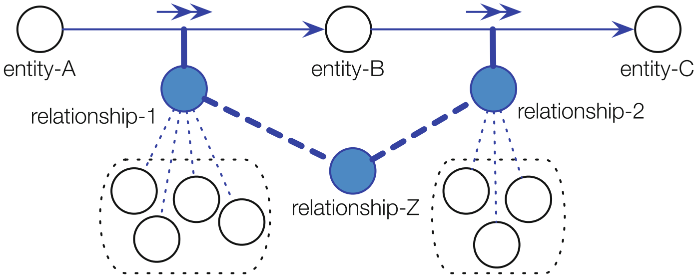

Fig. 6. Sequence of relationship flow.

requires the detailed description of individual relationships or interactions. The description of relationships among relationships is not possible with conventional models.

Our analyses on music composition processes and lifestyle diseases indicate that an important aspect to capture is the dynamic aspect of the phenomena, mainly temporal aspects but comprising time scale of diverse range, from milliseconds to hours in music composition process, and even larger range for the lifestyle diseases, from nanoseconds to years. The model should incorporate phenomena of these ranges. Furthermore, similar phenomena at different timescales result in distinct phenomena. For instance, the feeding process which comprises food ingestion, protein decomposition and energy conversion belong to the seconds to minutes scale phenomenon. However, the chemical reactions occurring during energy conversion is between nano seconds to milliseconds phenomenon. The descriptions of these two timescales are distinct, and correspond to two distinct facets or viewpoints of the feeding mechanism. In music composition processes, the decisions are of seconds to minutes timescale, while the modifications of musical pieces through decisions belong to hours to days timescale. These also correspond to two different facets.

Therefore, the ability to represent details of relationships is the prerequisite for the description of dynamic aspects, because the unit of the flowing "elements" and conversion of the elements should be specified. Due to this, conventional models cannot be used for the analysis of global characteristics related to the temporal flow pattern. The extended model of the hypernetwork model is capable for this purpose.

The flow pattern of the represented model of a phenomena is calculated using the flow rate of individual relationships.

The simplest definition of the flow pattern is described as a vector

$$F_k = (f_{1k}, f_{2k}, \ldots, f_{nk}) \tag{1}$$

where f_{ik}, $i = 1 \ldots n$ and $k = 1 \ldots m$, denotes the flow rate of relationship i under the viewpoint k. nn denotes the number of relationships under the viewpoint k, and m is the number of viewpoints.

The flow rate f_{ik} of a relationship and f_{jk} of another relationship, where $i \neq j$, may represent or not the flow of the same element. It depends on the viewpoint and on the details specified in the description of relationships i and j. Furthermore, the vector size of F_k is not fixed, and may vary for each viewpoint k. This is because the relationships among entities is not static, and vary for each viewpoint, including the existence and absence of the relationship among entities. For instance, two representations in Fig. 7 represent two facets (A) and (B) of the same entities A, B, C, D and E. Some relationships are identical in both facets, such as $A \rightarrow B$ and $A \rightarrow D$, but others differ in direction (A and C) and in existence. For instance, $B \rightarrow E$ and $C \rightarrow E$ exist in the viewpoint (B), but are absent in the viewpoint (A).

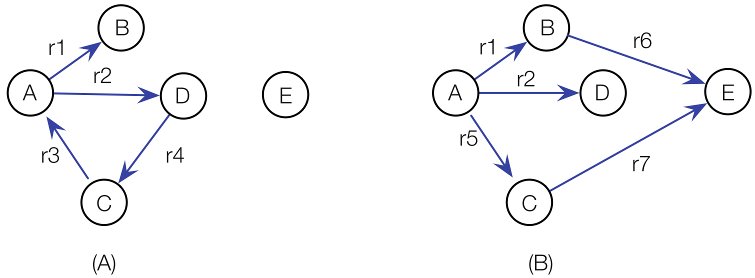

Fig. 7. Two facets of the descriptions with same entities.

The simple flow pattern of the facet 1 (Fig. 7(A)) is

$$F_1 = (f_{11}, f_{21}, f_{31}, f_{41}) \tag{2}$$

where f_{11} is the flow rate of the relationship r_1, and f_{21} is of the relationship r_2, and so on. And of the facet 2 (Fig. 7(B)) is

$$F_2 = (f_{12}, f_{22}, f_{52}, f_{62}, f_{72}) \tag{3}$$

where f_{12} is the flow rate of the relationship r_1, and f_{22} is of the relationship r_2, and so on.

The size of vectors F_1 and F_2 are different. While the relationship r_4 exists only in the facet (A), relationships r_6 and r_7 exist only in the facet (B). They are denoted as different flow rates: f_{41} from r_4, and f_{62} and f_{72} from r_6 and r_7.

5 Conclusions

The proposed framework focuses mainly on the dynamic aspects of the structure described as a system. Quantitative definition of a global network parameter that incorporates the flow and element type was presented. It assumes that multiple kinds of elements flow on links of the network, and their combination depends on the viewpoint that the observer treats the represented system. This paper also assumes that a phenomena of a system is mainly due to the combination of interaction among entities of the system, and not of the entities. Therefore, direct modeling of interactions are necessary, which are given little importance. Conventional studies focuses on modeling of entities, and not of interactions or relationships. In other words, interactions have main role on characterizing the phenomena emerging from the system. The quantitative model of the flow focuses on the relationships present in the system, and the global flow measurement reflects the individual relationships.

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