8

Representation System for Quality Indicators by Ontology

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1. Introduction

We have not yet established a proper methodology to accurately evaluate the quality of medical services, although such a method is necessary for fair comparison between hospitals and/or improvement in the quality of medical services. The reason is that such a methodology needs a reasonable way to transform qualitative properties of medical services such as doctors' skill or patient satisfaction into quantitative properties that are measurable by data existing in medical databases, but, it has not yet been researched sufficiently. In general, it is not easy to fairly evaluate abstract things such as intelligence and performances by measuring quantitative aspects of them although we often have opportunities to evaluate such things. Moreover, even though we have quantitative properties denoting some useful properties, we need a proper method to accurately represent such quantitative properties in order to make users understand the definitions of the properties correctly.

In this chapter, we introduce a representation system of quality indicators. Quality indicators are barometers that indicate processes, results and/or other things of medical services numerically, in order to evaluate medical services. The representation system helps to define quality indicators and to calculate their values in a coherent manner that is based on the data in medical databases. The representation system primarily consists of three parts. The first one is an ontology to define concepts related to medical services. The second one is a set of graphs that express the targets of quality indicators. We call these graphs "objective graphs". The third one is a set of "quantifying concepts" that abstract the quantities of the subjects. The proposed system represents a quality indicator as a combination of an objective graph and a quantifying concept.

An objective graph can be interpreted as a set of instances of a concept. The set is defined by the properties described by the labels of the arrows in the graph. We also explain the interpretation of objective graphs for the sets in this paper.

The representation language provides the following advantages.

- The first advantage is that by representing a quality indicator with the representation system one can avoid the problem that occurs from a word in the quality indicator that

has multiple meanings. In fact, we use a lot of words, each of that has multiple meanings. For example, the word "the first visit" has the meaning that differs among hospitals. So, we need to clarify the meanings of the words that constitute quality indicators, and the representation language enables one to clarify the meaning of each word in a quality indicator.

- The second advantage is that the representation language enables one to transform qualitative expressions into quantitative ones based on reasonable rationales and processes. The reasonable rationales and processes are provided by the fundamental theory of quantifications of concepts.
- The final advantage is that, since a quality indicator expressed by the representation language has the accurate semantics, one can calculate the value of the quality indicator via given medical databases. In this chater, we show a way to calculate the value of a quality indicator that is expressed by our language.

We finally introduce several examples of quality indicators that show that the representation language provides accurate and easily understandable expressions to quality indicators.

This chapter is an extended version of (Takaki et al., 2012), which is obtaiend from it by adding more detailed explanations and examples to demonstrate the working of the proposed representation system of quality indicators.

The remainder of this chapter is organized as follows. Section 2 briefly explains our framework to define quality indicators and to calculate their values based on the data in medical databases. Section 3 explains an ontology called the “medical service ontology”. Sections 4 and 5 explain objective graphs and their interpretation based on a set theoretic interpretation of graphs. Section 6 explains quantifying concepts. Section 7 introduces an example of a quality indicator in the proposed representation system. Section 8 briefly explains a way to calculate the values of quality indicators based on the medical databases. Section 9 explains related works, and Section 10 concludes this chapter.

2. Framework for definition and calculation of quality indicators

We first show a whole image of the framework for definition and calculation of quality indicators.

From the user’s point of view, the framework consists of (I) a representation system of quality indicators, (II) medical databases in hospitals, and (III) mapping systems that connect a certain global data model with data models of real medical databases.

Figure 1 below indicates the relationship between the representation system, medical databases, mapping systems and stakeholders of the frameworks. Users of the framework, who intend to evaluate medical services of hospitals that are associated with the framework, first define quality indicators with the representation system. Quality indicators are described to be diagrams with nodes and arrows, which are concepts and properties defined in an ontology we call Medical Service Ontology (MSO). In order to define quality indicators with the representation system, knowledge engineers, medical staffs and system engineers of medical databases collaborate in developing MSO in advance. Concepts and properties in MSO are translated to a virtual data model called the Global Data Model (GDM), which is

translated to data models in medical databases in hospitals by the mapping system. In order to calculate values of quality indicators defined by the representation system, they are translated to query programs of tables (=data models) of medical databases through a certain interpretation and mappings in mapping systems. In many cases, the mapping systems are developed by system engineers who maintain the medical databases. By using the framework, users can define quality indicators and calculate the values of them without knowing structures of local medical databases.

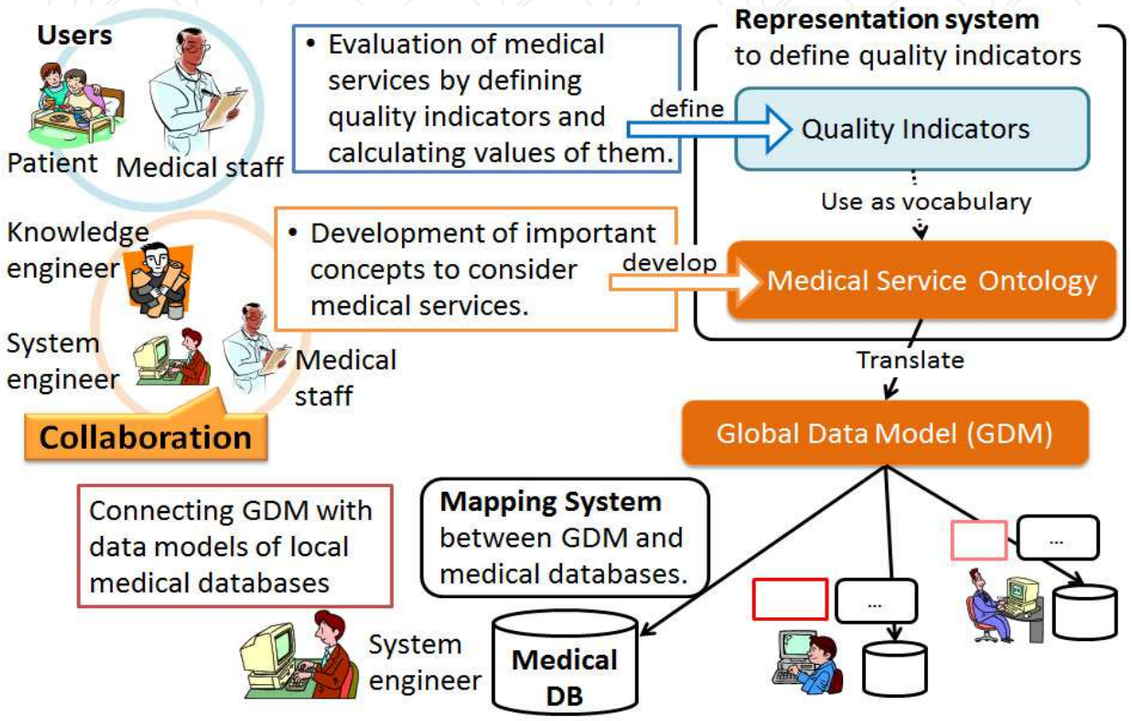

Fig. 1. Whole image of the framework for definition and calculation of quality indicators.

From a theoretical point of view, the framework consists of (i) the representation system, (ii) interpretations of components of the representation system, and (iii) several mappings that connect a database schema generated from MSO defined in the next section and other database schemas of given medical databases (see also Section 8). Also the representation system consists of (i) Medical Service Ontology, (ii) objective graphs, and (iii) quantifying concepts. Figure 2 below indicates how to define quality indicators and calculate values of them based on the representation system, the interpretations and the mappings.

A quality indicator is represented to be a graph obtained by combining objective graphs and a quantifying concept. An objective graph is a graph that expresses a set of patients, events (in a hospital) or other things such as "a set of patients who had operations for stomach cancers" or "a set of operations on patients with stomach cancers". An objective graph is constructed based on vocabularies in MSO. On the other hand, a quantifying concept is a function from a concept or a set of instances of a concept that is expressed by an objective graph to a numerical value. For example, a quality indicator "average length of hospital stays of patients who had operations for stomach cancers" is represented by an objective

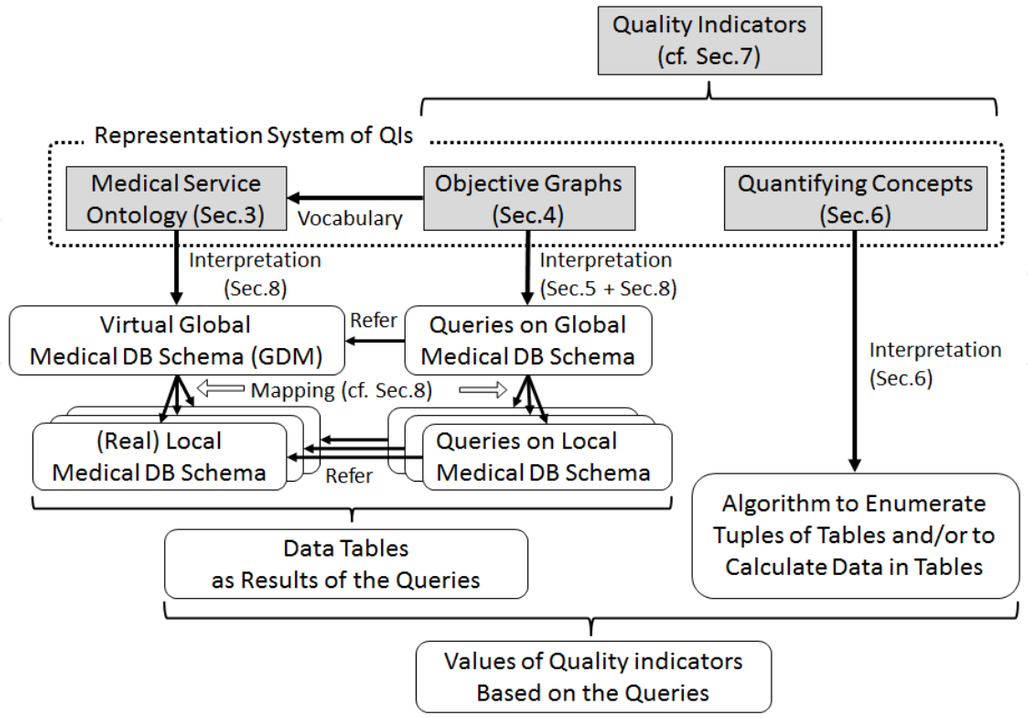

Fig. 2. Representation Language of Quality Indications and their values.

graph that expresses a set of hospital stays of patients who had operations for stomach cancers and a quantifying concept that calculate the average of length of the hospital stays for a given set of hospital stays.

In a coherent manner, concepts and properties in MSO are translated to tables or columns in them in GDM. Also an objective graph is translated to a query on GDM through a mathematical interpretation defined in Section 5. Moreover, by mappings between GDM and data models of local medical databases, tables and queries on GDM are translated to those in the local medical databases. On the other hand, a quantifying concept is translated to an algorithm to enumerate tuples of the tables that are obtained to be the results of the tables and queries above and/or to calculate data of them. Finally, the value of a quality indicator is calculated to be the result of the algorithm, queries and data above.

In this chapter, we focus on the representation system of quality indicators.

3. Medical service ontology

In the sections from now, we define the three main components of the representation system of quality indicators: medical service ontology (MSO), objective graphs, and quantifying concepts.

MSO is an ontology consisting of concepts related to medical services. In this section, we define the ontology by defining its concepts and properties[1]. The ontology has been

[1] In ontology engineering, concepts and properties in an ontology are often called classes and roles, respectively.

developed based on an ontology developing tool called the "Semantic Editor" (Hasida, 2011).

3.1 Concepts

We first define concepts in the medical service ontology. Concepts in MSO are used as vocabularies to describe quality indicators. Many quality indicators are described as the number, the rate or the average of (a) set(s) of patients or events in hospitals that are in a state. Moreover, many patients, events and states (of patients) can be characterized by them. Thus, concepts of stakeholders (especially, patients), events and states (of patients) are particularly important.

We introduce main concepts in MSO, as follows. Because of space limitations, we define some main concepts only. We describe a concept by the [name of a concept]. The concepts below are indicated by brackets.

1. Concepts of stakeholders:
   [patient], [medical staff]
2. Concepts of events
2.1. Concepts of events with terms:
   [hospital stay], [hospital visit]
   2.2. Concepts of events with no terms
      2.2.1. Concepts of scheduled events:
         [hospital admission], [hospital discharge],[diagnosis], [medical examination], [test], [operation], [prescription]
      2.2.2. Concepts of unscheduled events:
         [death], [bedsore], [falling]
3. Concepts of states:
   [state of age], [state of life or death], [state of disease]
4. Concepts of organizations:
   [department], [facility], [hospital]
5. Concepts of items:
   [medicine], [clinical instrument], [medical device]
6. Concepts of methods:
   [method], [cure], [method of examination]
7. Concepts of diseases:
   [disease]
8. Concept of time
   8.1. Concepts of time points:
      [date], [clock time]
   8.2. Concepts of terms:
      [number of years], [number of months],[number of weeks], [number of days]

A concept can be regarded as a set of instances of a given concept. Thus, we often identify the concept [patient] with the set of instances of that patient.

3.2 Properties

The ontology has two types of properties: the first type is an attribute of a concept, and the second type is a relation between two concepts. An attribute is a property that a concept own as an important part or feature. For example, name is one of typical attributes of a human, while parent and child relationship is one of typical relations on humans.

We often describe a property by the ⟨name of a property⟩.

3.2.1 Attributes of concepts

In medical service ontology, the concepts of actors, events and states are especially important. Thus, we here describe the attributes of actor concepts, state concepts and event concepts in Figures 3, 4 and 5, respectively.

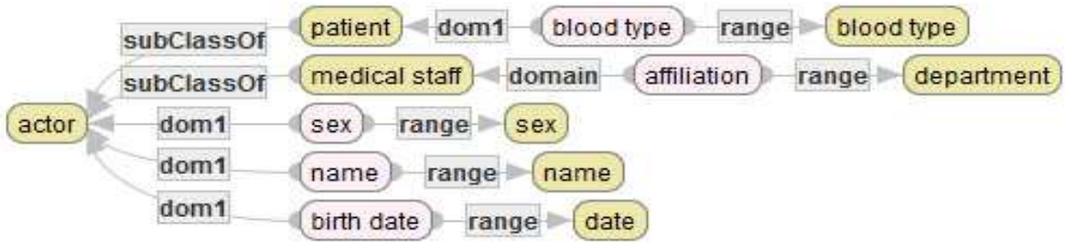

Fig. 3. Concepts and their attributes of actors (stakeholders).

In Figure 3, yellow rounded rectangles denote concepts, and pink rounded rectangles denote attributes. In general, pink rounded rectangles in diagrams on Semantic Editor denote properties.

The concept [actor] has three attribute ⟨sex⟩, ⟨name⟩ and ⟨birth date⟩. The sub classes [patient] and [medical staff] of [actor] have all attributes of [actor] and special attributes ⟨blood type⟩ and ⟨affiliation⟩, respectively. Though these concepts above have other attributes, we omit them since we do not use them in this paper.

The arrow "domain" from the attribute ⟨affiliation⟩ to [medical staff] denotes that the concept that has ⟨affiliation⟩ as an attribute is [medical staff], while the arrow "dom1" from the attribute ⟨sex⟩ to [actor] denotes that the concept having ⟨sex⟩ as an attribute is [actor] and that each actor has a single sex. On the other hand, the arrow "range" from the attribute ⟨blood type⟩ to the concept [blood type] denotes that the type of values of the attribute ⟨blood type⟩ is the concept [blood type]. On the other hand, the arrow "subClassOf" from the class [patient] to the concept [actor] denotes that [patient] is a sub class (a sub concept) of [actor].

The concept [state] in Figure 4 have five attributes ⟨subject (of a state)⟩, ⟨starting event⟩, ⟨terminating event⟩, ⟨starting time point⟩ and ⟨terminating time point⟩. ⟨starting event⟩ denotes a trigger of a state if the state has such a trigger, while ⟨terminating event⟩ denotes a trigger to stop a state. The arrow "dom01" from the attribute ⟨starting event⟩ to [state] denotes that [state] has ⟨starting event⟩ as an attribute and that each state has a single starting event or does not have any starting event.

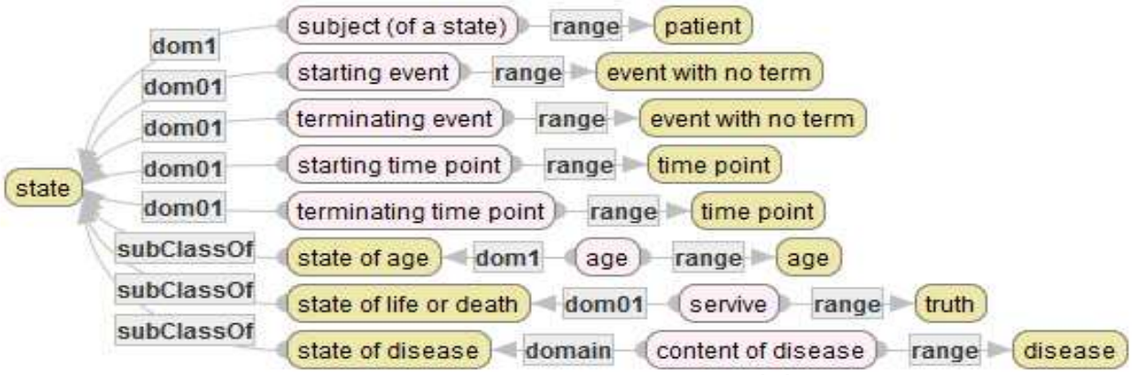

Fig. 4. Concepts and their attributes of patients' states.

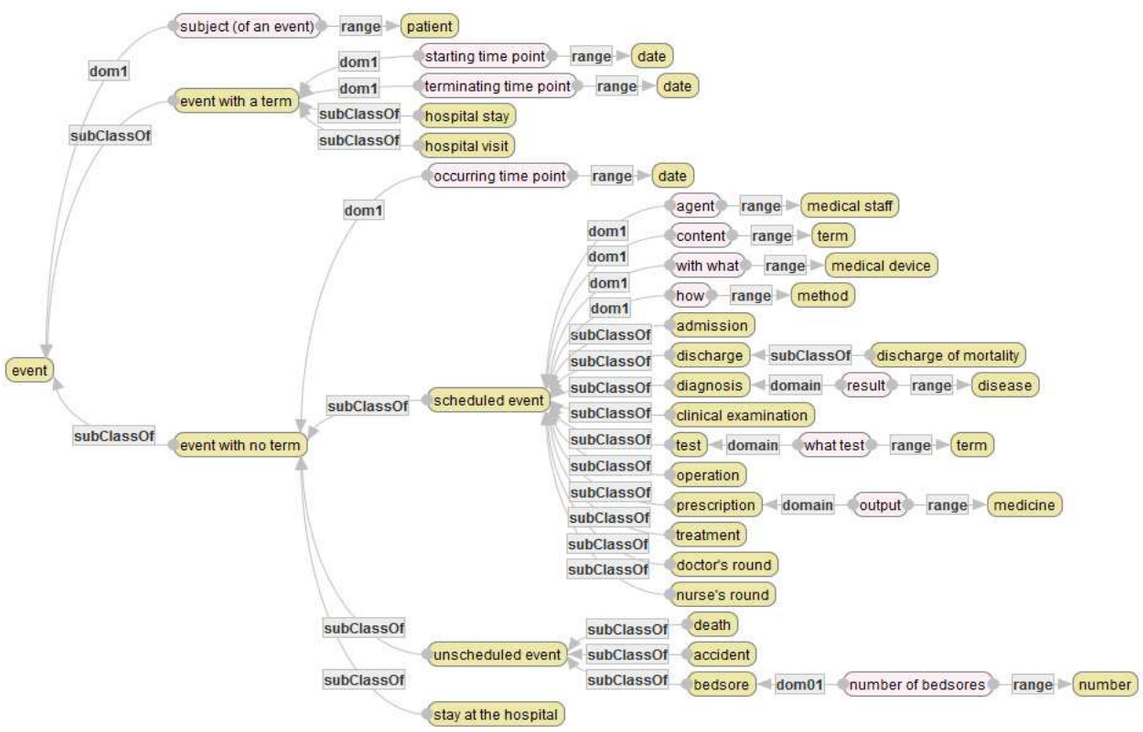

Fig. 5. Concepts and their attributes of events for patients.

3.2.2 Relations between concepts

We define the primary relations between concepts.

1. Relations of patients and events: The relations are defined between the [patient] and all event concepts. For example, the following relation denotes the relations between patients and their hospital stays.

$$\langle \text{subject (of an event)} \rangle \subseteq [\text{patient}] \times [\text{hospital stay}].$$

Note that these relations share the same name "subject (of an event)". We omit the explanation of the relations between patients and other events.

2. **Relations of patients and states**: The relations are defined between the [patient] and all state concepts. For example, the following relation denotes the relationship between patients and their states of diseases.

⟨subject (of a state)⟩⊆ [patient]×[state of disease].

Note that these relations also share the same name "subject (of an state)" and that all concepts of states have the attributes of starting time points and terminating time points. We omit the explanation of the relations between patients and other states.

3. **Relations of time ordering**: The relations are defined between the concepts of events and the states. For example, the following relations denote the relationships between operations.

⟨more than <p> before⟩ ⊆ [operation]×[operation],
⟨less than <p> befor⟩ ⊆ [operation]×[operation],
⟨less than <p> after⟩ ⊆ [operation]×[operation] and
⟨more than <p> after⟩ ⊆ [operation]×[operation].

Here, "<p>" denotes a parameter. For example, the relation ⟨before more than <2 weeks>⟩ consists of a pair <op_1, op_2> if op_1 and op_2 are performed and if op_1 is performed more than two weeks before op_2.

4. **Belonging relations of events**: The relations are defined between concepts of events with no term and events with terms. For example, the following relation denotes the relations between operations and hospital stays that have operations.

⟨belonging⟩ ⊆ [operation]×[hospital stay].

The relation contains a pair (op, sty) of an event of an operation op and that of a hospital stay sty if op is performed in the duration of sty.

4. Representation of objects of quality indicators

In this subsection, we define a graph that represents a target of quantification based on the medical service ontology defined in the previous subsection. We call such a graph an "objective graph". An objective graph is defined as a finite and labelled directed graph with a root node. A node in an objective graph is labelled by an instance of a concept or a value of an attribute of a concept in MSO, while an edge in an objective graph is labelled by an instance of a property in MSO.

4.1 Definition of objective graphs

An objective graph $\mathbb{G}$ consists of the five components (N($\mathbb{G}$), R($\mathbb{G}$), E($\mathbb{G}$), L($\mathbb{G}$), C ($\mathbb{G}$)), where

i. N($\mathbb{G}$) is a set of nodes,
ii. R($\mathbb{G}$) is a root node,
iii. E($\mathbb{G}$) is a set of edges,
iv. L($\mathbb{G}$) is a label function on N($\mathbb{G}$)∪E($\mathbb{G}$), and
v. C($\mathbb{G}$) is a concept.

We define these components by induction on the structure of the node labels, as follows.

Case 1. Assume that the following data are given:

a. concept C,
b. attributes $A_1,\ldots, A_n$ of C, and
c. values $a_1,\ldots, a_n$ of $A_1,\ldots, A_n$, respectively.

Then, we define an objective graph $\mathbb{G}$, as follows.

i. $N(\mathbb{G}):=\{*_0, \ldots, *_n\}$,
ii. $R(\mathbb{G}):=*_0$,
iii. $E(\mathbb{G}):=\{f_1,\ldots,f_n\}$, where each f_i is an edge from $*_0$ to $*_i$.
iv. $L(\mathbb{G})(*_0):=C$,
$L(\mathbb{G})(*_i):=a_i$ for $i=1,\ldots, n$, and,
$L(\mathbb{G})(f_i):=A_i$ for $i=1,\ldots, n$,
v. $C(\mathbb{G}):=C$.

Note that if n=0, then $N(\mathbb{G})$ is the singleton set $\{*_0\}$ and $E(\mathbb{G})$ is the empty set.

Case 2. Assume that the following data are given:

a. an integer n with $n\geqq 1$,
b. a set of objective graphs $\{\mathbb{G}_0, \ldots, \mathbb{G}_n\}$,
c. a set of relations $\{R_1,\ldots, R_n\}$, where each R_i is a relation between $C(\mathbb{G}_i)$ and $C(\mathbb{G}_0)$,
d. a set of integers $\{n(i,j)\}_{0\leqq i\leqq n,\ 0\leqq j\leqq n}$ and,
e. for each i with $0\leqq i\leqq n$ and j with $0\leqq j\leqq n$, the set of relations is $\{R^{i,j}{}_1,\ldots, R^{i,j}{}_{n(i,j)}\}$, where each $R^{i,j}{}_k$ is a relation between $C(\mathbb{G}_i)$ and $C(\mathbb{G}_j)$. (Note: if $n(i,j)=0$, the set $\{R^{i,j}{}_1,\ldots, R^{i,j}{}_{n(i,j)}\}$ is the empty set).

Then, we define an objective graph $\mathbb{G}$, as follows.

i. $N(\mathbb{G}):= \{*_0, \ldots, *_n\}$,
ii. $R(\mathbb{G}):= *_0$,
iii. $E(\mathbb{G}):=\{f_1,\ldots, f_n\}\cup(\cup_{0\leqq i\leqq n,\ 0\leqq j\leqq n}\{f^{i,j}{}_1,\ldots, f^{i,j}{}_{n(i,j)}\})$, where each f_i is an edge from $*_i$ to $*_0$ and each $f^{i,j}{}_k$ is an edge from $*_i$ to $*_j$.
iv. $L(\mathbb{G})(*_i):=\mathbb{G}_i$ $(i=0,\ldots, n)$,
$L(\mathbb{G})(f_i):=R_i$ $(i=0,\ldots, n)$ and,
$L(\mathbb{G})(f^{j,i}{}_k):= R^{i,j}{}_k$ $(i,j=0,\ldots, n$ and $k=1,\ldots, n(i, j))$.
v. $C(\mathbb{G}):= C(\mathbb{G}_0)$.

Each f_i is called a main edge of $\mathbb{G}$ and each $f^{i,j}{}_k$ is called an optional edge of $\mathbb{G}$.

4.2 Example of an objective graph

We give an example of an objective graph. For example, let us consider the quality indicator "5-year stomach cancer survival rate". The definition of the quality indicator is the ratio of the number of 5-year surviving patients to all stomach cancer patients, where a "stomach cancer patient" is a patient who had a diagnosis whose result was stomach cancer, and a "5-year surviving patient" is a patient who had a diagnosis whose result was stomach cancer but who is alive 5 years after that medical examination. Thus, we will first express the set of 5-year surviving patients in Figure 6. To this end, we construct three objective graphs $\mathbb{G}0$, $\mathbb{G}1$, and $\mathbb{G}2$, as follows.

(1) $\mathbb{G}_0$ = ({*}, *, $\emptyset$ (the empty set), L_0, [patient]), where $L_0(*)$=[patient].

(2) $\mathbb{G}_1$ = ({$*_0$, $*_1$}, $*_1$, {f_1:$*_0$→$*_1$}, L_1, [diagnosis]), where $L_1(*_0)$ = [diagnosis], $L_1(*_1)$ = ⟪stomach cancer⟫, $L_1(f_1)$ = ⟨result⟩ and [diagnosis] denotes an event concept, ⟪stomach cancer⟫ denotes an instance of the concept of diseases, and ⟨result⟩ denotes an attribute of the concept [diagnosis]. Note that the range of ⟨result⟩ is the concept of diseases.

(3) $\mathbb{G}2$ = ({$*_0$, $*_1$}, $*_1$, {f_1:$*_0$→$*_1$}, L_2, [state of life or death]), where $L_2(*_0)$ = [state of life or death], $L_2(*_1)$ = ⟪true⟫, L2(f1) = ⟨survive⟩, [state of life or death] denotes the viability status of a patient, ⟪stomach cancer⟫ denotes an instance of the concept of diseases, and ⟨result⟩ denotes an attribute of the concept [diagnosis]. Note that the range of ⟨result⟩ is the concept of diseases.

(1) $\mathbb{G}_0$= patient

(2) $\mathbb{G}_1$= diagnosis → result → stomach cancer

(3) $\mathbb{G}_2$= state of life or death → servive → truth

We next construct an objective graph of "5-year surviving stomach cancer patients" G, as follows.

(i) N($\mathbb{G}$) = {$*_0$, $*_1$, $*_2$},
(ii) R($\mathbb{G}$) =$*_0$,
(iii) E($\mathbb{G}$) = {f^1:$*_1$→$*_0$, f^2:$*_2$→$*_0$, f^{21}:$*_2$→$*_1$},
(iv) L($\mathbb{G}$)($*_i$) = $\mathbb{G}_i$ (i=0, 1, 2),
L($\mathbb{G}$)(f^1) = ⟨subject (of the event) ⟩ ,
L($\mathbb{G}$)(f^2) = ⟨subject (of the state) ⟩,
L($\mathbb{G}$)(f^{21}) = ⟨after more than <5 years>⟩,
(v) C($\mathbb{G}$) = C($\mathbb{G}_0$) = [patient].

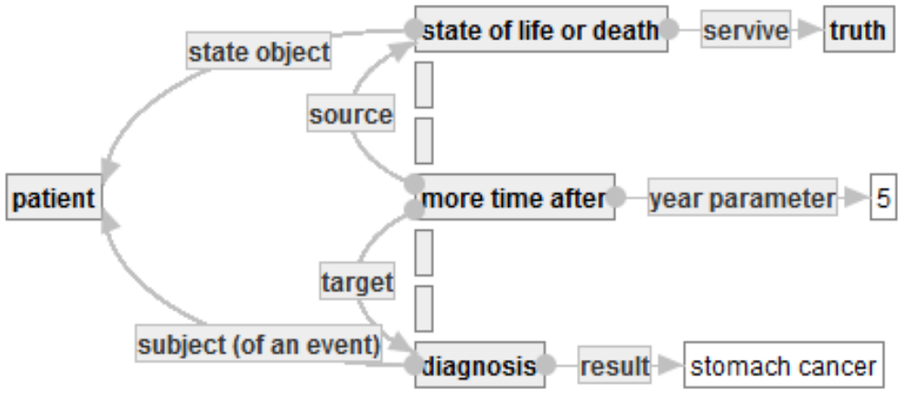

Fig. 6. Objective graph $\mathbb{G}$ describing 5-year surviving patients with stomach cancers

4.3 Segments of an objective graph

In the later section (Section 5), we will interpret an objective graph $\mathbb{G}$ as a set that is obtained from C($\mathbb{G}$) by adding the conditions defined by L($\mathbb{G}$). We define an objective graph $\mathbb{G}$*, which is called a segment of $\mathbb{G}$ and which can be interpreted as a super set of the interpretation of a given objective graph $\mathbb{G}$, as follows.

Case 1. If $\mathbb{G}$ is an objective graph defined in Case 1 of the definition of objective graphs, then graph $\mathbb{G}^*$ defined in the following properties is a segment of $\mathbb{G}$.

(i) $N(\mathbb{G}^*) \subseteq N(\mathbb{G})$,
(ii) $R(\mathbb{G}^*) = R(\mathbb{G})$,
(iii) $E(\mathbb{G}^*) \subseteq E(\mathbb{G})$,
(iv) $L(\mathbb{G}^*) = L(\mathbb{G})|_{N(\mathbb{G}^*)\cup E(\mathbb{G}^*)}$ (the restriction of $L(\mathbb{G})$ to $N(\mathbb{G}^*)\cup E(\mathbb{G}^*)$), [2]
(v) $C(\mathbb{G}^*) = C(\mathbb{G})$.

Case 2. Let $\mathbb{G}$ be an objective graph defined in Case 2 of the definition of objective graphs. Then, graph $\mathbb{G}^*$ defined in the following properties is a segment of $\mathbb{G}$.

(i) $N(\mathbb{G}^*) \subseteq N(\mathbb{G})$,
(ii) $R(\mathbb{G}^*) = R(\mathbb{G})$,
(iii) $E(\mathbb{G}^*) \subseteq E(\mathbb{G})$, where, for all $*_i \in N(\mathbb{G}^*)\setminus\{*_0\}$[3], the main edge from $*_i$ to $*_0$ in $E(\mathbb{G})$ is contained in $E(\mathbb{G}^*)$.
(iv) $L(\mathbb{G})(*_i) := \mathbb{G}^*_i$ for all $*_i \in N(\mathbb{G}^*)$, where $\mathbb{G}^*_i$ is a segment of $\mathbb{G}_i$,
$L(\mathbb{G})(f^i) := R^i$ for all $f^i \in E(\mathbb{G}^*)$ and
$L(\mathbb{G})(f^{j,i_k}) := R^{i,j_k}$ for all $f^{j,i_k} \in E(\mathbb{G}^*)$.
(v) $C(\mathbb{G}^*) = C(\mathbb{G})$.

4.4 Example of a segment of an objective graph

For the objective graph $\mathbb{G}$ in Fig. 6, the objective graph $\mathbb{G}^*$ in Fig. 7 is a segment of $\mathbb{G}$, which expresses the set of stomach cancer patients.

Fig. 7. A segment $\mathbb{G}^*$ of $\mathbb{G}$.

5. Interpretation of objective graphs

An objective graph $\mathbb{G}$ can be regarded to be a concept denoted by $C(\mathbb{G})$ and modified by other concepts and properties that are denoted by $L(\mathbb{G})$. If each concept is identified with the set of instances of the concept, an objective graph can be identified with a subset of the set denoted by $C(\mathbb{G})$ that is obtained from $C(\mathbb{G})$ by restricting it by sets and functions denoted by $L(\mathbb{G})$. To make the identification clear, we here define an interpretation of an objective graph, as follows.

5.1 Definition of the interpretations of objective graphs

For an objective graph $\mathbb{G}$, we define a set $[[\mathbb{G}]]$, as follows.

Case 1. Let $\mathbb{G}$ be an objective graph defined in Case 1 of the definition of objective graphs. Then, $[[\mathbb{G}]] := \{c \in C \mid c.A_1 = a_1 \wedge \ldots \wedge c.A_n = a_n\}$,[4] where $c.A_i$ is the value of the attribute A_i on c.

[2] For sets X and Y with $Y \subseteq X$ and for a function f on X, $f|_Y$ denotes the function of Y that is defined by $f|_Y(y) := f(y)$ for all $y \in Y$. We often refer to $f|_Y$ as the restriction of f to Y.
[3] For sets X, Y with $Y \subseteq X$, $X\setminus Y$ denotes the set $\{x \in X \mid x \notin Y\}$.

Case 2. Let $\mathbb{G}$ be an objective graph defined in Case 2 of the definition of objective graphs. Then, $[[\mathbb{G}]] := \{x_0 \in [[\mathbb{G}_0]] \mid \exists x_1 \in [[\mathbb{G}_1]], \ldots, \exists x_n \in [[\mathbb{G}_n]]$

$$(\bigwedge_{i=1,\ldots,n} R^i(x_i, x_0)) \wedge (\bigwedge_{i,j=0,\ldots,n} (\bigwedge_{k=1,\ldots,n(i,j)} R^{i,j}{}_k (x_i, x_j)))\}.$$

Lemma. For an objective graph $\mathbb{G}$ and a segment $\mathbb{G}^*$ of $\mathbb{G}$, $[[\mathbb{G}]] \subseteq [[\mathbb{G}^*]]$.

Proof. One can easily show the lemma above by induction on the structure of $\mathbb{G}$.

5.2 Example of the interpretation of an objective graph

In this subsection, we show a small example of the interpretation of an objective graph.

We first consider a concept of scheduled events denoted by [diagnosis] (cf. the definition of medical service ontology and Figure 5). Then, the concept has seven attributes (see the parenthetic names of columns of the table in Figure 5). Thus, one can obtain (the list of columns of) Table 1 corresponding to [diagnosis], whose attributes correspond to those of [diagnosis]. Let $\mathcal{T}_1$ be data (a set of tuples) in Table 1 and assume that there is no tuple in $\mathcal{T}_1$ whose value of the attribute "disease" is "stomach cancer" besides the tuples with id 1, 2, 3 and 5.

Id	Patient (subject (of an event))	Date (occurring time point)	Staff (agent)	Term (content)	Device (with what)	Method (how)	Set of Diseases (result)
E_1	P_1	03-11-2011	D_1	-	-	-	{stomach cancer}
E_2	P_2	03-15-2011	D_1	-	-	-	{stomach cancer}
E_3	P_3	04-06-2011	D_2	-	-	-	{stomach cancer}
E_4	P_4	05-08-2011	D_2	-	-	-	{gastric ulcer}
E_5	P_2	06-09-2011	D_2	-	-	-	{stomach cancer}
E_6	P_5	07-06-2011	D_1	-	-	-	{gastric varices, duodenal ulcer}
…	…	…	…	…	…	…	…

Table 1. The table generated from the concept of scheduled events [diagnosis] with tuples $\mathcal{T}_1$.

Let $\mathbb{G}_1$ be the objective graph in Section 4.2. Then, if the concept [diagnosis] is identified with $\mathcal{T}_1$, the interpretation of $\mathbb{G}_1$ based on $\mathcal{T}_1$ is $\{ c \in \mathcal{T}_1 \mid c.\langle \text{result} \rangle \ni \langle\!\langle \text{stomach cancer} \rangle\!\rangle \}$, which is equivalent to $\{\text{tuple}^1{}_1, \text{tuple}^1{}_2, \text{tuple}^1{}_3, \text{tuple}^1{}_5\}$. Here, each $\text{tuple}^1{}_i$ denotes the tuple in $\mathcal{T}_1$ whose id is E_i. That is,

$$[[\mathbb{G}_1]] = \{ c \in \mathcal{T}_1 \mid c.\langle \text{result} \rangle \ni \langle\!\langle \text{stomach cancer} \rangle\!\rangle \} = \{\text{tuple}^1{}_1, \text{tuple}^1{}_2, \text{tuple}^1{}_3, \text{tuple}^1{}_{5,\ldots}\}.$$

Moreover, let $\mathbb{G}^*$ be the objective graph in Figure 7. Then, $\mathbb{G}^* = \{\{*_0, *_1\}, *_0, \{f^1\}, L, [\text{patient}]\}$, where L is the function satisfying the following properties.

(i) $L(*_0) = \mathbb{G}_0$ in Section 4.2,
(ii) $L(*_1) = \mathbb{G}_1$ in Section 4.2, and
(iii) $L(f^1) = \langle$subject (of a state)$\rangle$ ($\subseteq$ [patient]×[diagnosis]) (cf. Section 3.2.2).

[4] The symbol $\wedge$ denotes the logical connective symbol of "and."

Moreover, consider Table 2 corresponding to [patient], which is defined in Figure 3 and which has attributes ⟨result⟩ and ⟨blood type⟩, and let $\mathcal{T}_1$ be the set of tuples in Table 2.

Id	Name (name)	Sex (sex)	Blood type (blood type)
P_1	Alice Johnson	female	A
P_2	Richard Miller	male	O
P_3	Robert Williams	male	AB
P_4	William Brown	male	B
P_5	Susan Wilson	female	O
…	…	…	…

Table 2. The table generated from the concept of a stakeholder [patient] with tuples $\mathcal{T}_2$.

Thus, the interpretation of $\mathbb{G}^*$ based on $\mathcal{T}_2$ is $\{ c \in \mathcal{T}_2 \mid \exists x_1 \in [[\mathbb{G}_1]]\ \langle \text{subject (of a state)} \rangle (c, x_1) \}$, which is equivalent to $\{\text{tuple}^2_1, \text{tuple}^2_2, \text{tuple}^2_3\}$. Here, each tuple^2_i denotes the tuple in $\mathcal{T}_2$ whose id is P_i. That is,

$$[[\mathbb{G}^*]] = \{ c \in \mathcal{T}_2 \mid \exists x_1 \in [[\mathbb{G}_1]]\ \langle \text{subject (of a state)} \rangle (c, x_1) \} = \{\text{tuple}^2_1, \text{tuple}^2_2, \text{tuple}^2_3\}.$$

6. Quantifying concepts

A quantifying concept plays a role in a function that has an objective graph and optional parameters as input data and that outputs a numerical value. In general, one can classify quantifying concepts into three types. In the following, we explain each type of quantifying concept. We describe a quantifying concept by ⋘name of a quantifying concept⋙. Note that we often identify a concept with a set and that all sets are considered to be finite.

6.1 Total numbers

For a finite set S, the summation of numbers obtained from elements of S is called the total number of S. For example, if each element is assigned to 1 as the existence of the element, then the total number is the same as the cardinality of S. The quantifying concept ⋘cardinality⋙ is regarded as a function that has an objective graph $\mathbb{G}$ as input data and that outputs the cardinality of $[[\mathbb{G}]]$.

For a concept S, attributes $A_1,\ldots, A_n$ of S, and the real-valued function f on the set of values of instances of S with respect to $A_1,\ldots, A_n$, the summation $\Sigma_{s \in S} f(s.A_1,\ldots, s.A_n)$ is called the total attribute number of S with respect to $A_1,\ldots, A_n$ and f, where $s.A_i$ denotes the value of an instance s with respect to A_i, is an attribute quantifier function.

The quantifying concept ⋘total attribute number⋙ is regarded as a function that has the following data as input data:

1. an objective graph $\mathbb{G}$,
2. attributes $A_1,\ldots, A_n$ of $C(\mathbb{G})$, and
3. f: $C_1 \times \ldots \times C_n \to R$, where $C_i := \{s.A_i \mid s \in [[\mathbb{G}]]\}$.

⋘total attribute number⋙ outputs the total attribute number of $[[\mathbb{G}]]$ with respect to $A_1,\ldots, A_n$ and f.

6.2 Rate

For a finite set S and a subset S* of S, the rate of the total number of S* among the total numbers of S obtained in the same way as that to calculate the total number of S* is called a rate of S* among S. In particular, the rate of the cardinality of S* among that of S is called the cardinality rate of S* among S. Moreover, the rate of the total attribute number of S* with respect to $A_1,..., A_n$ and f among that of S with respect to the same attributes and the same attribute quantifier function is called the total attribute number rate.

The quantifying concept ≪cardinality rate≫ is regarded as a function that has the following data as input data:

1. An objective graph $\mathbb{G}$, and
2. A segment $\mathbb{G}^*$ of $\mathbb{G}$.

In contrast, the quantifying concept ≪total attribute number rate≫ is regarded as a function that has the following data as input data:

1. An objective graph $\mathbb{G}$,
2. A segment $\mathbb{G}^*$ of $\mathbb{G}$,
3. Attributes $A_1,..., A_n$ of $C(\mathbb{G})$, and
4. f: $C_1 \times ... \times C_n \rightarrow R$,, where $C_i := \{s.A_i \mid s \in [[\mathbb{G}]]\}$.

≪total attribute number rate≫ outputs the rate of the total attribute number of $[[\mathbb{G}]]$ with respect to $A_1,..., A_n$ and f among that of $[[\mathbb{G}^*]]$ with respect to the same attributes and the same attribute quantifier function.

6.3 Average

For concept S, attributes $A_1,..., A_n$ of S, and attribute quantifier function f, the ratio of the total attribute number of S with respect to $A_1,..., A_n$ and f and the cardinality of S is called the average of the value of S with respect to $A_1,..., A_n$ of f. The quantifying concept ≪average≫ is regarded as a function that has the same input data as that of ≪total attribute number≫ and that outputs the average of the value of S with respect to $A_1,..., A_n$ of f.

7. Examples of quality indicators in the representation system

A quality indicator is a barometer to evaluate a medical service. We regard it as a combination of an objective graph and a quantifying concept. In this subsection, we describe one of the typical quality indicators "stomach cancer 5-year survival rate" with objective graphs and a quantifying concept. This indicator is defined to be the rate of the number of patients diagnosed with stomach cancer surviving 5 years after diagnosis among the number of patients diagnosed with stomach cancer. Thus, the numerator and the denominator of the indicator can be described to be objective graphs $\mathbb{G}$ and $\mathbb{G}^*$ in Figure 6 and Figure 7, respectively. Thus, one can describe the quality indicator by using $\mathbb{G}$, $\mathbb{G}^*$, and the quantifying concept ≪cardinality rate≫ as the graph in Figure 8 on the next page.

We will show another example of a quality indicator "the average length of the hospital stays for stomach cancers". The following figure denotes a set of hospital stays for stomach cancer treatments that have stomach cancer operations by laparotomies.

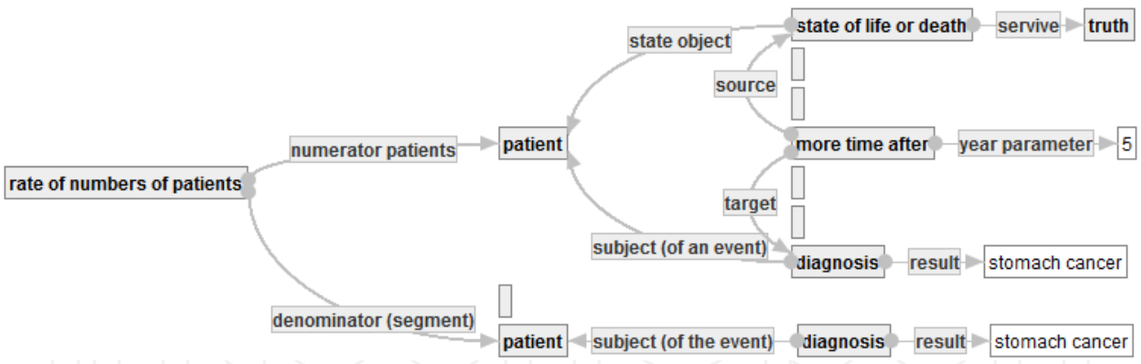

Fig. 8. Quality indicator "Stomach cancer 5-year survival rate".

Fig. 9. Objective graph describing Hospital stays for stomach cancers.

To be more precise, Figure 9 denotes the set of hospital stays that have admissions with purposes treatments of stomach cancers and operations for stomach cancers by laparotomies. By using the objective graph above, the quantifying concept ⋘average⋙ (cf. Section 6.3) and a function that assigns to two dates the number of days between the two dates, one can obtain the quality indicator "the average length of the hospital stays for stomach cancers", as follows.

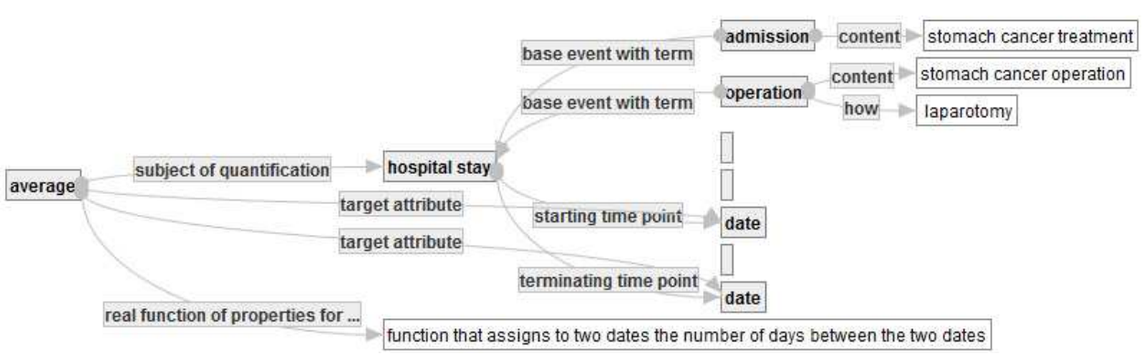

Fig. 10. Quality indicator "The average length of the hospital stays for stomach cancers"

In Figure 10, the objective graph in Figure 9 is the first input data of ⋘average⋙, two attributes ⟨starting time point⟩ and ⟨terminating time point⟩ of the concept [hospital stay] are assigned as second input data of ⋘average⋙, and the function that assigns to two dates the number of days between the two dates is the third input data of ⋘average⋙ (see Section 6.3).

8. Calculation of values of quality indicators based on medical databases

In this section, we briefly explain how to calculate the values of quality indicators described in the representation system by using medical databases. One can obtain an entity-relationship model (Chen, 1976) from the medical service ontology in Section 3 by translating concepts to entities and the properties between them to the relationship between entities obtained from the given concepts. Moreover, by translating the attributes of a concept to those of the entity translated from the concept, one can obtain a relational data model, which we call the global data model (GDM) of medical service ontology. In this paper, we often call an entity in GDM by a "table" and an attribute of an entity by a "column" of a table.

For example, a concept [diagnosis] of a scheduled event that is described in Figure 5 is translated to an entity in GDM, that is, it is translated to (a list of columns of) a table, as follows.

Diagnosis (diagnosis)	Patient (subject (of an event))	Date (occurring time point)	Staff (agent)	Term (content)	Device (with what)	Method (how)
E_1	P_1	03-11-2011	D_1	-	-	-
E_2	P_2	03-15-2011	D_1	-	-	-
E_3	P_3	04-06-2011	D_2	-	-	-
E_4	P_4	05-08-2011	D_2	-	-	-
E_5	P_2	06-09-2011	D_2	-	-	-
E_6	P_5	07-06-2011	D_1	-	-	-
…	…	…	…	…	…	…

Table 3. Modification of the table 1.

Here, the parenthetic name of a column of the table above denotes the concept or one of its attributes. The columns of this table are obtained from the concept [diagnosis] and its attributes whose values (instances) are uniquely determined by an instance of [diagnosis], and the column "Diagnosis" is the primary column (the primary key) of the table. The list of columns of Table 3 is obtained from the list of all columns of Table 1 in Section 5.2 by removing the column generated from the attribute ⟨result⟩, which may have multiple values of a single diagnosis (an instance of [diagnosis]). Each attribute of a concept that may have multiple values of a single instance of the concept is translated to (a list of columns of) a table whose primary key is the attribute. For example, the attribute ⟨result⟩ is translated to the list of columns in the following table.

Result (result)	Diagnosis (diagnosis)	Diseases (the range of result)
Rs_1	E_1	stomach cancer
Rs_2	E_2	stomach cancer
Rs_3	E_3	stomach cancer
Rs_4	E_4	gastric ulcer
Rs_5	E_5	stomach cancer
Rs_6	E_6	gastric varices
Rs_7	E_6	duodenal ulcer
…	…	…

Table 4. The table generated from the attribute of the concept scheduled events [diagnosis].

As another example of a table, we describe the list of columns of a table generated from the concept [sate of life or death] in Figure 4, as follows.

State of life or death (state of life or death)	Patient (subject (of a state))	Event (starting event)	Event (terminating event)	Starting time point (starting time point)	Terminating time point (terminating time point)	Truth value (service)

Table 5. The list of columns generated from the concept of states [state of life or death] and its attributes.

The data of tables in GDM generated from the medical service ontology is obtained from data in (real) medical databases. The data of each table is obtained by one of two ways: the first way is to define mapping functions between the table and those in medical databases; the second is to define the way to calculate data from other tables in GDM plus medical databases. For example, in many cases, data of Table 3 and Table 4 is obtained by a mapping function between the tables and those in medial databases and such a mapping function can be simply defined, since most of data models in medical databases have similar tables to them. On the other hand, many medical databases should not have any table similar to Table 5. Instead of defining a mapping function between such a table and some tables in medical databases directly, one had better consider a way to calculate data from other tables in GDM (and medical databases). For example, one can obtain data of important columns of Table 5 from the table generated from the concept [death] of unscheduled event in Figure 5, as follows.

Death (death)	Patient (subject (of an event))	Date (occurring time point)
F_1	P_2	11-10-2011
F_2	P_5	12-12-2011
…	…	…

Table 6. The table generated from the concept [death] and its attributes.

For example, one can obtain data of Table 5 from Table 6, as follows.

State of life or death (state of life or death)	Patient (subject (of a state))	Event (starting event)	Event (terminating event)	Starting time point (starting time point)	Terminating time point (terminating time point)	Truth value (service)
S_1	P_2	-	F_1	-	11-09-2011	True
S_2	P_2	F_1	-	11-10-2011	-	False
S_3	P_5	-	F_2	-	12-11-2011	True
S_4	P_5	F_2	-	12-12-2011	-	False
…	…	…	…	…	…	…

Table 7. Data generated from the data of Table 6.

By the interpretation of Section 5, one can perform a query on the GDM from a given objective graph $\mathbb{G}$ by translating the condition of $[[\mathbb{G}]]$ in a way based on relational calculus (Abiteboul et al, 1995), since the condition of $[[\mathbb{G}]]$ is defined as a formula in first-order logic on the concepts and properties, and all properties are so simple that one can translate them to queries on the GDM automatically. Therefore, for a given medical database MD, if one has a suitable mapping between the data model on the MD and the GDM, one can automatically calculate the value of quality indicators based on the data in the MD.

For example, we calculate the value of the quality indicator "stomach cancer 5-year survival rate" in Section 7 based on data in Tables 2, 3, 4 and 7. Let $\mathbb{G}$ be the objective graph of Figure 6 in Section 4.2, and let $\mathbb{G}^*$ be the objective graph in Figure 7. Thus, by the definition of the interpretation of objective graphs in Section 5, $[[\mathbb{G}]]$ and $[[\mathbb{G}^*]]$ can be considered to be sets of tuples in the table generated from the concept [patient], that is, Table 2 in Section 3.2. Moreover, they are calculated by using Tables 2, 3, 4 and 7, as follows.

```
[[𝔾]] = select * from Table-2 where
                Table-2.Patient=Table-3.Patient                 and
                Table-3.Diagnosis=Table-4.Diagnosis             and
                Table-4.Disease="stomach cancer"                and
                Not exists * from Table-7 where
                        Table-2.Patient=Table-7.Patient         and
                        Table-7.Truth-value="False"             and
                        Table-7.Starting-time-point < Table-3.Date + "5-years" (*)
```

= {$tuple^2_1$, $tuple^2_3$}, where each $tuple^2_i$ denotes the tuple in Table 2 (see 5.2).

```
[[𝔾*]] = select * from Table-2 where
                Table-2.Patient=Table-3.Patient                 and
                Table-3.Diagnosis=Table-4.Diagnosis             and
                Table-4.Disease="stomach cancer"
```

= {$tuple^2_1$, $tuple^2_2$, $tuple^2_3$}.

Thus, the value of "stomach cancer 5-year survival rate" is calculated to be 2/3.

Note that all condition expressions in the queries above besides (*) are directly translated from the definitions of $[[\mathbb{G}]]$ and $[[\mathbb{G}^*]]$. On the other hand, the condition expression (*) is obtained from the condition "the date of the state of life or dead with truth value true is

more than 5 years after the date of an event of diagnosis" in a coherent way, which is not difficult to establish.

9. Related works

It is important to fairly evaluate or compare the qualities of medical services that hospitals provide in order to improve the services. To this end, the qualities of medical services must be identified and adequate methods must be found to measure these qualities accurately (Donabedian, 1966). Quality indicators, which are quantitative criteria for the evaluation of medical services, have been attracting attention (Mainz, 2003). Many quality indicators already have been defined by standards organizations and projects such as IQIP (IQIP, 2011), MHA (Scheiderer, 1995), and OECD (Mattke et al, 2006).

However, as we mentioned in Section 1, although many good quality indicators have been developed, at least the following two issues remain for using quality indicators to fairly evaluate and compare medical services among hospitals.

The first issue is that, while many quality indicators (of medical services) are defined by terms in relation to medical care, many medical databases are developed from the aspect of accounting management. Moreover, many medical databases are developed in the vendors' or hospitals' own schema. Therefore, to calculate the values of quality indicators or to define them, it is often necessary for medical staffs to collaborate with system engineers who manage or developed the medical databases. However, the gaps in their knowledge and viewpoints often prevent them from collaborating to calculate the values of quality indicators and/or to define them accurately.

The second issue is that many words for medical services have meanings that differ according to the hospital or community of the medical staff. For example, at least in our country, the meaning of "new patients" or "inpatients" sometimes differs according to the medical staff in some hospitals, even though the hospitals may belong to the same hospital group. Such different interpretations of words also prevent medical staffs from coherently calculating accurate values of the quality indicators among multiple hospitals.

The proposed representation system of quality indicators helps to define quality indicators and calculate their values in a coherent manner that is based on the data in medical databases.

10. Conclusion

It is important to describe quality indicators that have no ambiguity of interpretation and to calculate their values accurately in a coherent way. To this end, we introduce a representation system of quality indicators, which consists of (i) an ontology of medical services, (ii) objective graphs to represent the objectives of quantification and an interpretation of objective graphs as sets, and (iii) quantifying concepts. We also briefly explain the whole image of our theoretical framework to define quality indicators and to calculate their values. Moreover, we explain a way to calculate the values of quality indicators based on the medical databases through an example of a quality indicator.

The proposed representation system plays a central role in the framework explained in Section 2, which enables medical staffs and patients, who desire to evaluate medical services, to define quality indicators and to calculate their values based on medical databases, without knowing the structure of the data models of them. Moreover, the representation system helps medical stuffs and system engineers, who develop or manage medical databases, collaborate in developing useful vocabularies to establish and standardize quality indicators.

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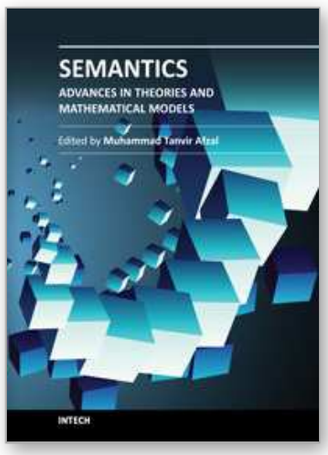

Semantics - Advances in Theories and Mathematical Models

Edited by Dr. Muhammad Tanvir Afzal

ISBN 978-953-51-0535-0
Hard cover, 284 pages
Publisher InTech
Published online 25, April, 2012
Published in print edition April, 2012

The current book is a nice blend of number of great ideas, theories, mathematical models, and practical systems in the domain of Semantics. The book has been divided into two volumes. The current one is the first volume which highlights the advances in theories and mathematical models in the domain of Semantics. This volume has been divided into four sections and ten chapters. The sections include: 1) Background, 2) Queries, Predicates, and Semantic Cache, 3) Algorithms and Logic Programming, and 4) Semantic Web and Interfaces. Authors across the World have contributed to debate on state-of-the-art systems, theories, mathematical models in the domain of Semantics. Subsequently, new theories, mathematical models, and systems have been proposed, developed, and evaluated.

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