Representation System of Quality Indicators towards Accurate Evaluation of Medical Services Based on Medical Databases

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***Abstract*—Quality indicators play an important role in quantitatively measuring the quality of medical services. In this paper, we introduce a representation system that helps define quality indicators and calculate their values in a coherent manner 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 quantification. The third one is a set of quantifying concepts that abstract quantities of the target concepts. The proposed representation system adequately divides the work for defining quality indicators and calculating their values from the data in medical databases, and, hence, it assists medical staffs and system engineers who manage medical databases to perform their own work and to collaborate on the evaluation and the comparison of medical services.**

Keywords - quality indicator, evaluation of medical service, ontology, medical database.

I. INTRODUCTION

A. Background

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 [1]. Quality indicators, which are quantitative criteria for the evaluation of medical services, have been attracting attention [2]. Many quality indicators already have been defined by standards organizations and projects such as IQIP [3], MHA [4], and OECD [5].

However, although many good quality indicators have been developed, the following issues remain for using quality indicators to fairly evaluate and compare medical services among hospitals.

Issue 1: 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.

Issue 2: 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.

B. Goal of this paper

In this paper, we introduce a representation system of quality indicators. The representation system helps to define quality indicators and 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, which we call "quantifier concepts". The proposed system represents a quality indicator as a combination of an objective graph and a quantifier concept.

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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.

C. *Significance of the proposed system*

One can define quality indicators by constructing objective graphs and selecting quantifier concepts. Objective graphs consist of concepts in the ontology of medical services. Therefore, medical staffs can define quality indicators in the representation system without knowledge of medical databases. The interpretation of objective graphs enables one to calculate the value of a quality indicator described in the representation system based on a series of virtual tables generated from the ontology of medical services. Thus, by establishing the mapping between the virtual tables and the corresponding tables of the database, the values of quality indicators in the representation system can be calculated by using the data in the database. As a result, medical staffs and system engineers who manage medical databases can perform their own work; the former can focus on defining quality indicators and the latter on establishing mappings.

By collaborating with medical staffs in other hospitals to develop the ontology of medical services and objective graphs, the gap between interpretations of quality indicators can be clarified, and, hence, the problems in the second issue (the use of words with different meanings) can be reduced.

Moreover, the quantifier concepts define adequate "rates", "averages", and so forth in templates, and so they provide a coherent way to abstract quantities from the target concepts and prevent defining unreasonable quality indicators.

D. *Organization of this paper*

The remainder of this paper is organized as follows. Section II briefly explains our framework to define quality indicators and to calculate their values based on the data in medical databases. Section III explains the representation system of quality indicators. Section IV briefly explains a way to calculate the values of quality indicators based on the medical databases. Section V concludes this paper.

II. Framework to Define Quality Indicators and Calcuate Their Values

The framework to define and calculate quality indicators consists of (i) a representation system to define quality indicators, (ii) medical databases (or medical data warehouses) that are used in hospitals, (iii) several mapping systems that connect a data model generated from the medical service ontology defined in the next section and the data models of given medical databases (see also Sec. IV), and (iv) an assistance tool that helps users (medical staffs) to construct quality indicators based on the representation system. By using the framework, medical staffs, system engineers and designers of concepts (or words) of medical services can perform their own work while collaborating on

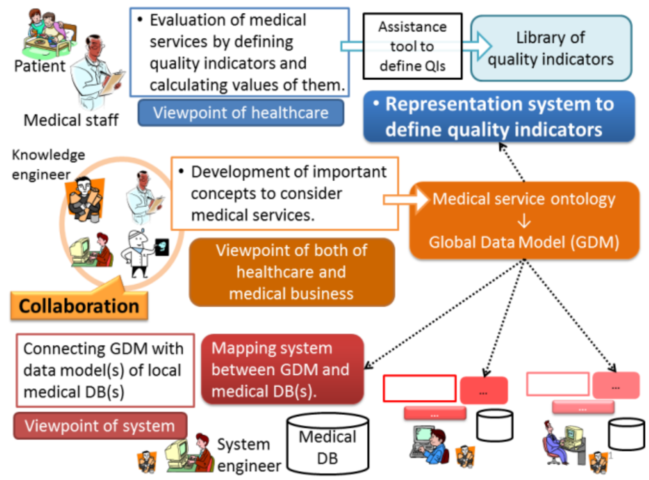

Figure 1. Framework to define and calculate qualitative indicators (QIs)

the evaluation and the comparison of medical services in the manner illustrated in Fig. 1.

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

III. Representation Sytem of Quality Indicators

In this section, we define the three main components of the representation system of quality indicators: an ontology of medical services, objective graphs, and an ontology of quantifier concepts.

A. *Ontology of medical services*

The ontology of medical services is an ontology consisting of concepts related to medical services. Here, we define the ontology by defining its concepts and properties. (In ontology engineering, concepts are called classes, and properties in an ontology are often called roles or slots.) The ontology, which we define as follows, was developed based on an ontology developing tool called the "Semantic Editor" [6].

1) Conceptss

We first define concepts in the medical service ontology. 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*]

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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.

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.

a) Attributes of concepts

In medical service ontology, the concepts of actors, events and states have their own attributes. As an example, we describe the attributes of state concepts in Fig. 2 and the attributes of event concepts in Fig. 6 on the last page of this paper, where yellow rounded rectangles denote concepts, and pink rounded rectangles denote attributes.

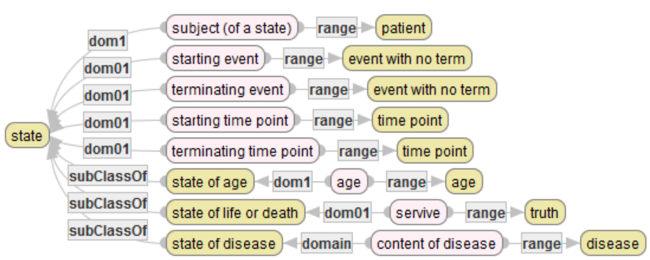


Figure 2. Concepts of states

b) Relations between concepts

We define the primary relations between concepts. We describe a relation by ⟨*name of a relation*⟩. Relations are denoted in the angled brackets.

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.

⟨*subject (of an event)*⟩ ⊆ [*patient*]×[*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.

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 a 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.

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*> *before*⟩ ⊆ [*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 <*op1*, *op2*> if *op1* and *op2* are performed and if *op1* is performed more than two weeks before *op2*.

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*.

B. 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 labeled directed graph with a root node.

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,…, n, and,
L($\mathbb{G}$)(f_i):=A_i for i =1,…, n, and
(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≥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 $\{n(i,j)\}_{0\le i\le n, 0\le j\le n}$ and,

(e) for each i with $0\le i\le n$ and j with $0\le j\le n$, 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) $E(\mathbb{G}):=\{f^1,\ldots, f^n\}\cup(\cup_{0\le i\le n, 0\le j\le n}\{f^{i,j}_1,\ldots, f^{i,j}_{n(i,j)}\})$, 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) $L(\mathbb{G})(*_i):=\mathbb{G}_i$ $(i = 0,\ldots, n)$,
$L(\mathbb{G})(f^i):=R^i$ $(i = 0,\ldots, n)$,
$L(\mathbb{G})(f^{j,i}_k):= R^{i,j}_k$ $(i, j = 0,\ldots, n$ and $k = 1,\ldots, n(i, j))$, and

(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 $\mathbb{G}$.

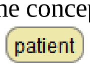
2) Example of an objective graph

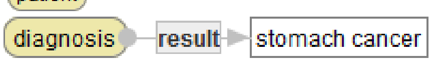
We give an example of an objective graph. For example, let us consider the quality indicator "5-year stomach cancer survival rate". The definition of the quality indicator is the ratio of the number of 5-year surviving patients to all stomach cancer patients, where a "stomach cancer patient" is a patient 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 express the set of 5-year surviving patients in Fig.3. We first construct three objective graphs $\mathbb{G}_0$, $\mathbb{G}_1$, and $\mathbb{G}_2$, as follows.

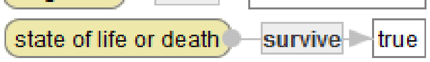
(1) $\mathbb{G}_0 = (\{*\}, *, \varnothing$ (the empty set), L_0, [*patient*]), where $L_0(*)$=[*patient*].

(2) $\mathbb{G}_1 = (\{*_0, *_1\}, *_1, \{f_1{:}*_0\rightarrow *_1\}, L_1,$ [*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) $\mathbb{G}_2 = (\{*_0, *_1\}, *_1, \{f_1{:}*_0\rightarrow *_1\}, L_2,$ [*state of life or death*]), where $L_2(*_0)$ = [*state of life or death*], $L_2(*_1)$ = ⟨⟨*true*⟩⟩, $L_2(f_1)$ = ⟨*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) $\mathbb{G}_0$= 

(2) $\mathbb{G}_1$= 

(3) $\mathbb{G}_2$= 

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

(i) $N(\mathbb{G}) = \{*_0, *_1, *_2\}$,

(ii) $R(\mathbb{G}) =*_0$,

(iii) $E(\mathbb{G}) = \{f^1{:}*_1\rightarrow *_0, f^2{:}*_2\rightarrow *_0, f^{21}{:}*_2\rightarrow *_1\}$,

(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>⟩, and

(v) $C(\mathbb{G}) = C(\mathbb{G}_0)$ = [*patient*].

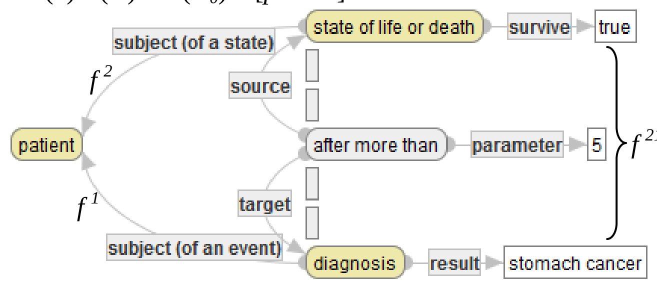


Figure 3. 5-year surviving patients with stomach cancer (objective graph $\mathbb{G}$)

3) Segments of an objective graph

In the following subsection (Sec. II.*C*), we 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 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 $N(G^*)\cup E(G^*)$), and

(v) $C(\mathbb{G}^*)= C(\mathbb{G})$.

Here, 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 <u>restriction</u> of f to Y.

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 $*_i \in N(\mathbb{G}^*)\backslash\{*_0\}$, the main edge from $*_i$ to $*_0$ in $E(\mathbb{G})$ is contained in $E(\mathbb{G}^*)$. Note that, for sets X, Y with $Y\subseteq X$, $X\backslash Y$ denotes the set $\{x\in X|\ x\notin Y\}$.

(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) Example of a segment of an objective graph

For the objective graph $\mathbb{G}$ in Fig. 3, the objective graph $\mathbb{G}$* in Fig. 4 is a segment of $\mathbb{G}$, which expresses the set of stomach cancer patients.

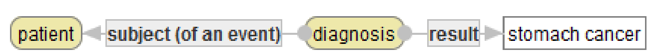


Figure 4. A segment $\mathbb{G}$* of $\mathbb{G}$

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C. Values of objective graphs

1) Definition of values 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,

$[[\mathbb{G}]]:=\{c\in C \mid f_1(c.A_1)=a_1 \wedge \ldots \wedge f_n(c.A_n)=a_n\}$, where $c.A_i$ is the value of the attribute Ai on c and the symbol $\wedge$ denotes the logical connective symbol of "and."

Case 2. Let $\mathbb{G}$ be an objective graph defined in Case 2 of the definition of objective graphs. Then,

$$[[\mathbb{G}]]:=\{x_0\in[[\mathbb{G}_0]] \mid \exists x_1\in[[\mathbb{G}_1]],\ldots,\exists x_n\in[[\mathbb{G}_n]] (\wedge_{i=1,\ldots,n} R^i(x_i, x_0))\wedge(\wedge_{i,j=0,\ldots,n} (\wedge_{k=1,\ldots,n(i,j)} R^{i,j}_k(x_i, x_j)))\}.$$

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 $\mathbb{G}$.

D. Quantifier concepts

A quantifier 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 quantifier concepts into three types. In the following, we explain each type of quantifier concept. We describe a quantifier concept by $\langle\langle$*name of a quantifier concept*$\rangle\rangle$. Note that we often identify a concept with a set and that all sets are considered to be finite.

a) 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 quantifier concept $\langle\langle$*cardinality*$\rangle\rangle$ 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 $\sum_{s\in S} f(s.A_1,\ldots, s.A_n)$ 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 quantifier concept $\langle\langle$*total attribute number*$\rangle\rangle$ 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: $C_1\times\ldots\times C_n\rightarrow\mathbb{R}$, where $C_i := \{s.A_i \mid s\in[[\mathbb{G}]]\}$.

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

b) 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 $A_1,\ldots, A_n$ 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 quantifier concept $\langle\langle$*cardinality rate*$\rangle\rangle$ 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 quantifier concept $\langle\langle$*total attribute number rate*$\rangle\rangle$ 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 $A_1,\ldots, A_n$ of $C(\mathbb{G})$, and
4. f: $C_1\times\ldots\times C_n\rightarrow\mathbb{R}$, where $C_i := \{s.A_i \mid s\in[[\mathbb{G}]]\}$.

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

c) Average

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

E. Examples of quality indicators in the representation system

A quality indicator can be represented as a combination of an objective graph and a quantifier concept. In this subsection, we describe one of the typical quality indicators "stomach cancer 5-year survival rate" with objective graphs and a quantifier 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 Fig. 3 and Fig. 4, respectively. Thus, one can describe the quality indicator by using $\mathbb{G}$, $\mathbb{G}^*$, and the quantifier concept $\langle\langle$*cardinality rate*$\rangle\rangle$ as the graph in Fig. 5 on the next page.

IV. 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 [7] from the medical service ontology in Sec. III.A by translating the main 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 main 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.

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By the interpretation of Sec. III.C, 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 [8], since the condition of $[[\mathbb{G}]]$ is defined as a formula in first-order logic on the concepts and properties, and all properties are simple so 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**.

V. CONCLUSIONS

It is important to describe quality indicators that have no ambiguity of interpretation and to calculate their values accurately in a coherent way. In this paper, we introduce a representation system of quality indicators, which consists of (i) an ontology of medical services, (ii) objective graphs to represent the subjects of quantification and interpretation of objective graphs as sets, and (iii) quantifier concepts. We also briefly explain the whole image of our framework to define quality indicators and to calculate their values and a way to calculate the values of quality indicators based on the medical databases. The proposed representation system plays a central role in the framework and assists the specialization of jobs of the medical staffs, who evaluate their medical services, and the system engineers, who develop or manage medical databases, and the collaboration between them.

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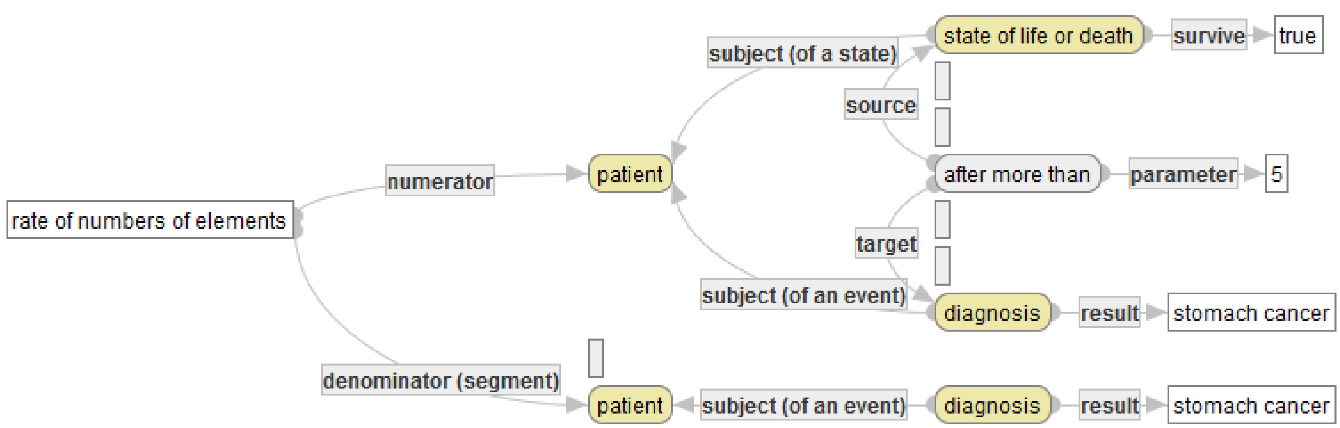

Figure 5. Stomach cancer 5-year survival rate

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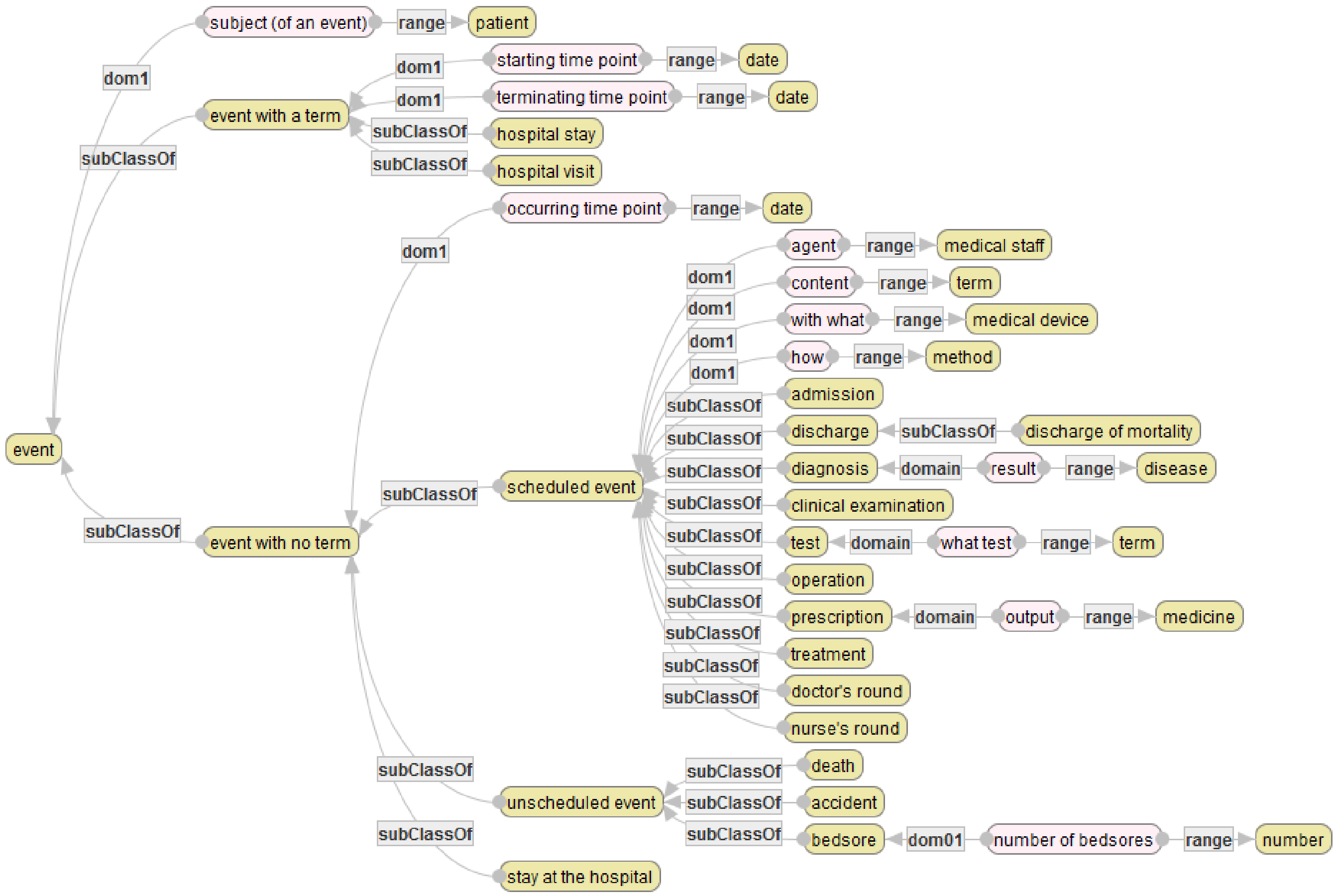

Figure 6. Concepts of events

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