Towards Collaborative Typed Resources Manipulation in Health-Care Environments

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Abstract. Web service is a popular solution to integrate components when building a software system, or to allow communication between a system and third-party users, providing a flexible and reusable mechanism to access its functionalities. Due to differences in medical level and extremely uneven distribution of medical resources, medical information technology lacks unified planning and is not supported by digital health care system. Thus diagnosis resources of patients cannot be shared by each medical institution. Inspections usually repeat which not only increases the burden of hospitalizing and physical injuries, but also leads to the waste of medical resources. We propose a framework towards constructing and searching typed health resources in terms of data, information and knowledge through a hierarchy composing Data Graph, Information Graph and Knowledge Graph in order to improve performance in accessing and processing resources. We use cases to illustrate the mechanism of the framework.

Keywords: Knowledge graph · Collaborative adaptation
Typed resources

1 Introduction

Most collaborative work takes place in environments with abundant information [7]. Medical information management systems are characterized by a high degree of collaborative work, mobility, and information access from many devices or artifacts [8]. Sharing medical resources such as patients' information and medical

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technology is conductive to achieve the bidirectional referral, remote consultation and other medical services between different medical institutions so as to provide patients with better medical conditions and reduce medical costs. In order to improve quality of medical health care services, we propose a typed medical resources sharing approach towards temporal and spatial optimization with collaborative storage and computation adaptation based on Data Graph, Information Graph and Knowledge Graph. [4] extended the existing concept of Knowledge Graph into four aspects including Data Graph, Information Graph, Knowledge Graph and Wisdom Graph. In [9] the authors proposed to answer the Five Ws problems through constructing the architecture of Data Graph, Information Graph and Knowledge Graph. We propose to clarify the expression of existing Knowledge Graph corresponding to the progressive manner of typed resources including $Data_{DIK}$, $Information_{DIK}$ and $Knowledge_{DIK}$. We specify the architecture of Knowledge Graph as the combination of $DataGraph_{DIK}$, $InformationGraph_{DIK}$ and $KnowledgeGraph_{DIK}$. In Fig. 1 we describe a framework of collaborative medical resource sharing system. Collaborating health care workers may include doctors, CDC, health bureau and so on. Persons and institutes with different expertise and access rights cooperate in mutually influencing contexts, for instance, clinical studies.

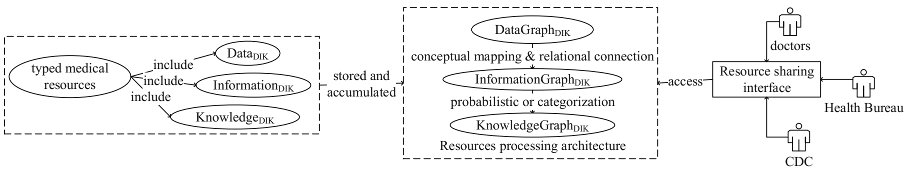

Fig. 1. A framework of collaborative medical resource sharing system

The rest of the paper is organized as follows. Section 2 introduces the construction of a collaborative medical information sharing service system. Section 3 elaborates the storage and computation adaptation towards sharing typed resources and Sect. 4 presents the results of our analytical and experimental evaluation of our proposed approach. Section 5 discusses the related work. And we summarize the conclusion of our work in Sect. 6.

2 Construction of Collaborative Medical Information Sharing Service System

Typed medical resources including $Data_{DIK}$, $Information_{DIK}$ and $Knowledge_{DIK}$ produced through medical activities are collected and accumulated into resource processing architecture. Definitions of typed resources and graphs are as follows.

Definition 1. *Typed resources. Typed resources including data, information and knowledge can be expressed as:*

$Resources_{DIK}: = <Data_{DIK}, Information_{DIK}, Knowledge_{DIK} >;$

D represents represent $Data_{DIK}$. *I represents* $Information_{DIK}$ *and K represents* $Knowledge_{DIK}$.

Definition 2. *Graphs. We propose to specify the existing concept of Knowledge Graph in three layers. Graphs can be expressed as:*

$Graph_{DIK}: = <(DataGraph_{DIK}), (InformationGraph_{DIK}), (Knowledge Graph_{DIK})>.$

With the extensive application of information technology, medical information systems are rapidly deployed and put into use in various medical institutions. Medical information systems integrate scattered medical resources and implement the centralized storage of medical resources to achieve the sharing of resources. Development of a service system can be divided into stages of data sharing, information transfer, and knowledge creation [10]. In the development of a medical information sharing service system, following situations will cause deficient design efficiency:

- Extra $Data_{DIK}$, $Information_{DIK}$ and $Knowledge_{DIK}$ which is not contained in original artifacts is introduced in resulting artifacts.
- Improper control of $Data_{DIK}$, $Information_{DIK}$ and $Knowledge_{DIK}$ flow.
- Redundant $Data_{DIK}$, $Information_{DIK}$ and $Knowledge_{DIK}$ that is produced and collected through performing activities repeatedly.

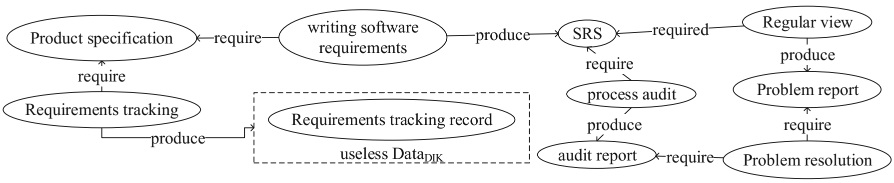

Fig. 2. Activities generating useless $Data_{DIK}$

2.1 Processing of Useless $Resources_{DIK}$

Useless $Data_{DIK}$, $Information_{DIK}$ and $Knowledge_{DIK}$ are modelled as resources that are generated during the participants' activities but are not useful for subsequent activities. Figure 2 shows the existence of useless $Data_{DIK}$ marked by a dashed box. The out degree of $Data_{DIK}$ "Requirements tracking record" is 0 which means that no activity requires the $Data_{DIK}$. The introduction of useless $Data_{DIK}$, $Information_{DIK}$ and $Knowledge_{DIK}$ requires additional human effort and improves the temporal complexity. We describe solution about useless $Data_{DIK}$, $Information_{DIK}$ and $Knowledge_{DIK}$ in Algorithm 1.

Algorithm 1. Remedying useless Resources$_{DIK}$

Input: All activities *act* of software development
Output: software development activities after deleting useless Resources$_{DIK}$
If Resources$_{DIK}$ produced by act_i is not required act_j
Deleting act_i;

2.2 Remedying Improper Data$_{DIK}$, Information$_{DIK}$ and Knowledge$_{DIK}$ Flow Control

Development activities of a service system should be performed according to a necessary execution sequence in order to improve the temporal efficiency and reduce costs of development. In actual development process, results of sequential implementation and parallel implementation of some activities are equivalent, but costs of parallel implementation are much lower. In Fig. 3 there is an execution dependency relationship between activity "regular inspection" and activity "track and solve problems". Activity "regular inspection" must be performed in advance because the execution of activity "track and solve problems" requires the Information$_{DIK}$ produced by activity "regular inspection". But implementation of activity "write test plan" does not depend on activity "write design specification". Thus these two activities can be executed in parallel. We elaborate method to remedy deficient Information$_{DIK}$ flow control in Algorithm 2.

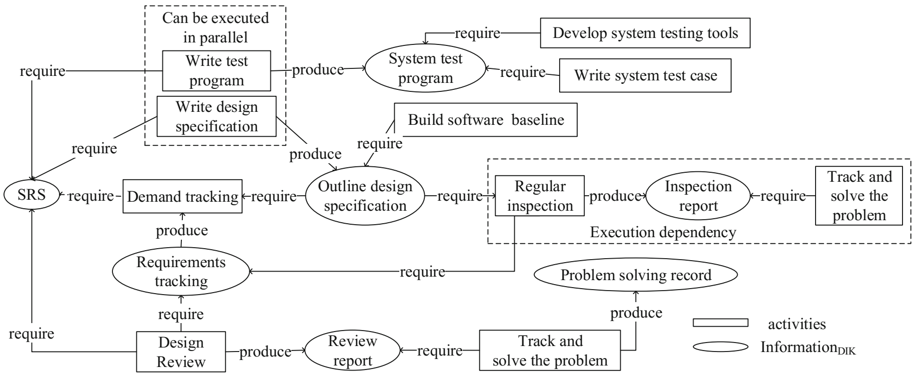

Fig. 3. A framework of collaborative medical resource sharing system

Algorithm 2. Remedying deficient flow control of Information$_{DIK}$

Input: An improper execution order of activities
Output: An adjusted execution order of activities
1. Find a topological order of activities that is deficient;
2. Adjust pre-order activities to be effective;
3. Computing a new topological order of deficient activities after remedying pre-order deficiencies;
4. Repeat Step 2.

2.3 Processing of Redundant Data$_{DIK}$, Information$_{DIK}$ and Knowledge$_{DIK}$

Deficient design process of a service system comes from the situation that some development activities are not planned efficiently and the resulting product is not as effective as expected. Redundant Data$_{DIK}$, Information$_{DIK}$ and Knowledge$_{DIK}$ will cost more time and waste more storage space and redundant Data$_{DIK}$, Information$_{DIK}$ and Knowledge$_{DIK}$ will lead to inconsistency in the service system development. A redundancy occurs when a design artifact (perhaps partial) is represented multiple times, possibly in varying views. Redundancies can occur either in design or resource representation. We describe the processing approach to redundant Information$_{DIK}$ in Algorithm 3. We reserve the earliest activity that is the most feasible to produce a piece of Information$_{DIK}$ and minimize the occurrence of other repeated production to 1.

Algorithm 3. Remedying Information$_{DIK}$ redundancy

```
Require: Collection of activities A and Information_DIK I
Ensure: activity ∈ A, info_DIK ∈ I
  For : each activity ∈ A, info_DIK ∈ I Do
    if occurrence(activity, info_DIK): Amount(info_DIK)
  +=1;
      For info_DIK ∈ I∧ amount(info_DIK) ≥ 1 Do
        Adjust A, ensure amount (info_DIK) = 1
      End For
    End For
```

3 Collaborative Adaptation Towards Typed Resources Sharing

To enhance resources sharing between multi medical institutes and avoid repeated medical examination of patients, we propose a collaborative adaptation approach to reduce medical burden. We make the assumption that typed medical resources have been well organized on the hierarchy of DataGraph$_{DIK}$, InformationGraph$_{DIK}$ and KnowledgeGraph$_{DIK}$. We propose to measure searching efficiency according to computations related to transferring cost of resource types and scale of resources in order to determine which graph should be traversed preferentially. We define sharing medical resources and resources that have been organized on Graph$_{DIK}$ as follows:

Definition 3. *Sharing medical resources. Sharing medical resources are defined as a tuple SMR = <STY, SSC>, where STY is the type set of sharing resources represented by a triad* $< sty_D, sty_I, sty_K >$ *and SSC is the scale of different kinds of sharing resources represented by a triad* $< ssc_D, ssc_I, ssc_K >$ *where each scc denotes the scale of resource in the form of sty.*

Definition 4. *Resources on Graph*$_{DIK}$*. We define Resources on Graph*$_{DIK}$ *as a tuple RoG = <GTY, GSC>, where GTY is the type set of resources* *on* $Graph_{DIK}$ *represented by a triad* $< gty_D, gty_I, gty_K >$ *and GSC is the scale of different kinds of resources on* $Graph_{DIK}$ *represented by a triad* $< gsc_D, gsc_I, gsc_K >$ *where each gsc denotes the scale of resources in the form of gty.*

3.1 Calculation of Resource Type Transferring Cost

We assign values from Resources_{DIK} to each element in the type set STY of SMR to form combination case $\text{STY}' = \{sty'_D, sty'_I, sty'_K\}$ where sty'_D, sty'_I and sty'_K belong to $\{\text{Data}_{DIK}, \text{Information}_{DIK}, \text{Knowledge}_{DIK}\}$. The atomic type conversion cost of resources in SMR, denoted as *SCost*, is shown in Table 1. Transferring cost of all resources from SMR to STY′, denoted as $CostTF_1$, can be calculated according to Eq. 1:

$$CostTF_1 = \sum_{D,I,K} SCost * ssc_i, i \in \{D, I, K\} \tag{1}$$

Table 1. Atomic type conversion cost of resource in SMR

	Data_{DIK}	Information_{DIK}	Knowledge_{DIK}
Data_{DIK}	$SCost_{D-D}$	$SCost_{D-I}$	$SCost_{D-K}$
Information_{DIK}	$SCost_{I-D}$	$SCost_{I-I}$	$SCost_{I-K}$
Knowledge_{DIK}	$SCost_{K-D}$	$SCost_{K-I}$	$SCost_{K-K}$

We assign values from Resources_{DIK} to each resource in the type set GTY of RoG to form combination case $\text{GTY}' = \{gty'_D, gty'_I, gty'_K\}$ where gty'_D, gty'_I and gty'_K belong to $\{\text{Data}_{DIK}, \text{Information}_{DIK}, \text{Knowledge}_{DIK}\}$. The atomic type conversion cost of elements in RoG, denoted as *GCost*, is shown in Table 2. Transferring cost of all resources from GTY' to RoG, denoted as $CostTF_2$, can be calculated according to Eq. 2:

$$CostTF_2 = \sum_{D,I,K} GCost * gsc_i, i \in D, I, K \tag{2}$$

Table 2. Atomic type conversion cost of resource in RoG

	Data_{DIK}	Information_{DIK}	Knowledge_{DIK}
Data_{DIK}	$GCost_{D-D}$	$GCost_{D-I}$	$GCost_{D-K}$
Information_{DIK}	$GCost_{I-D}$	$GCost_{I-I}$	$GCost_{I-K}$
Knowledge_{DIK}	$GCost_{K-D}$	$GCost_{K-I}$	$GCost_{K-K}$

3.2 Cost of Searching SMR in RoG

Sharing medical resources including Data_{DIK}, Information_{DIK}, and Knowledge_{DIK} are related to specific medical scene. The expansion of medical resources enable resource searching more inefficient which is called resource overload. In order to solve the problem we propose to adjust storage programs of sharing resources according to computation of searching cost. When resources are needed, health care workers can obtain resources through traversing Graph_{DIK} directly rather than perform related medical activities to produce required resources. Table 3 shows the atomic type conversion cost of resource. Searching cost, denoted as *SECost* can be calculated according to Eq. 3:

$$SECost = \sum_{D,I,K} (gsc + Cost * gsc') * ssc \tag{3}$$

where gsc' indicates the scale of medical resources that are found through traversing Graph_{DIK} of the different type with initial resources of SMR.

Table 3. Atomic type conversion cost of resource

	Data_{DIK}	Information_{DIK}	Knowledge_{DIK}
Data_{DIK}	$Cost_{D-D}$	$Cost_{D-I}$	$Cost_{D-K}$
Information_{DIK}	$Cost_{I-D}$	$Cost_{I-I}$	$Cost_{I-K}$
Knowledge_{DIK}	$Cost_{K-D}$	$Cost_{K-I}$	$Cost_{K-K}$

3.3 Calculation of Benefit Ratio

The expected investment such as responding time of health care workers that is denoted as $Inve_0$ and the maximum total cost that is denoted as $Total\_cost_0$ are pre-set. After computing $CostTF_1$, $CostTF_2$ and $SECost$, we calculate the total cost of each program, denoted as $Total\_Cost$, according to Eq. 4:

$$Total\_Cost = CostTF_1 + SECost + CostTF_2 \tag{4}$$

The corresponding investment that is denoted as *Inve* can be calculated according to Eq. 5 after computing the total cost of each resources searching program:

$$Inve = \mu * |Total\_Cost_0 - Total\_Cost| \tag{5}$$

where μ represents the required investment of reducing atomic $Total\_Cost$ that can be obtained through data training. And the ratio of investment and searching cost that is represented by $CostInv$ of each program can be calculated according to Eq. 6:

$$CostInv = \frac{Inve}{SECost} \tag{6}$$

Then we compare $CostInv$ and $Inve$ of each program with $CostInv_0$ and $Inve_0$ to determine whether the condition "$CostInv > CostInv_0 \& Inve < Inve_0$" is satisfied. When $CostInv$ is greater than $CostInv_0$, we make $CostInv_0$ equal to the current $CostInv$. If $CostInv$ is greater than $CostInv_0$, we perform the next step until the assignment towards STY and GTY are exhausted. We describe the specific process of investment driven searching sharing resources on resources of Graph$_{DIK}$ architecture composing DataGraph$_{DIK}$, InformationGraph$_{DIK}$ and KnowledgeGraph$_{DIK}$ in Algorithm 4.

Algorithm 4. Calculating $CostInv$ of each resource type combination program

```
Input: SMR, RoG, CostInv_0
Output: The maximum CostInv
    For: each sty Do
        Assign value from Resources_DIK;
        Compute CostTF_1;
        For: each gty Do
            Assign value from Resources_DIK;
            Compute CostTF_2;
            Compute SECost;
            Compute Total_Cost;
            If (CostInv > CostInv_0 & Inve < Inve_0)
                CostInv_0 = CostInv;
```

4 Case Study

We give an example to illustrate the rationality verify the feasibility of our proposed approach. Here we have listed eight cases of SMR and RoG assignment and the corresponding calculations of $CostTF_1$, $CostTF_2$ and $SECost$. For convenience, we assign values to parameters in the equations. But the actual value

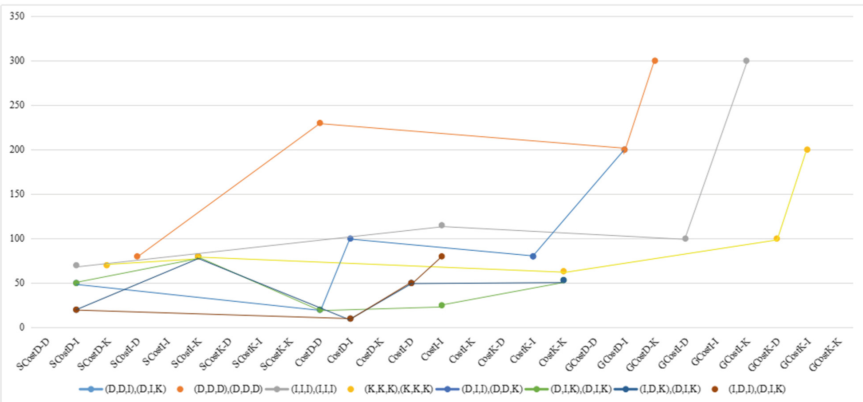

Fig. 4. Usage of indicators of $CostTF_1$, $SECost$ and $CostTF_2$

of each parameter should be obtained through data learning so as to compare the actual differences between results. Through comparing calculated results of $Total\_Cost$, we choose a program with the maximum $CostInv$ and the required investment should less than $Inve_0$. Figure 4 illustrates times of each indicator in $CostTF_1$, $SECost$ and $CostTF_2$ used in each program. In fact there are 27 * 27 programs because each element of SMR and RoG can be converted into one of the three types including Data_{DIK}, Information_{DIK} and Knowledge_{DIK}.

5 Related Work

The growth of Internet has been accompanied by the growth of Web services such as e-commerce and e-health [12]. In [6] the authors elaborated an infrastructure enabling archetype-based semantic interoperability of Web Service messages exchanged in the health care domain. [2] presented a medical knowledge service system for cross-organizational healthcare collaboration such that all medical professionals and staff at different healthcare organizations could capture, store, manage, integrate and share medical knowledge. Scientists have proposed numerous models for defining anything "as a service (aaS)", including discussions of products, processes, data and information management as a service [3]. In [11] the authors proposed a multi-agent web service framework based on service-oriented architecture for the optimization of medical data quality in the e-healthcare information system. In [1] the authors introduced a new service-centric framework for data sharing and manipulation. A Web service oriented and process-centric framework for supporting collaborative engineering services was introduced in [5].

6 Conclusion

Collaboration among healthcare organizations depends on coordination, communication and control among healthcare organizations and effective sharing of medical resources. Typed resources including Data_{DIK}, Information_{DIK} and Knowledge_{DIK} should be integrated, managed and shared using the Internet and information technology. In order to optimize medical resource allocation and provide more efficient services, we elaborate solution for remedying deficient development activities of a collaborative medical resources sharing platform. Different healthcare practitioners may desire to access patient information or other information at various points in a healthcare workflow. We propose a resource processing approach towards temporal and spatial optimization with collaborative storage and computation adaptation for sharing typed medical resources so as to improve the quality of health service. In the next stage, we will expand the scale of dataset to verify the feasibility of our work.

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