Adaptive Requirement-Driven Architecture for Integrated Healthcare Systems

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***Abstract*—In order to improve the quality of healthcare services, large-scale medical information systems should be integrated with adaptability in response to the changing medical environment. In this paper, we propose a requirement-driven architecture for healthcare information systems that will be able to respond to new requirements. The system operates through the mapping mechanism between these layers and thus can organize functions dynamically adapting to user's requirement. Furthermore, we introduce the organizational semiotics methods to capture and analyze user's requirement through ontology chart and norms. Based on these results, the structure of user's requirement pattern (URP) is established as the driving factor of our system. Finally, we propose an integration framework for data sharing amongst different hospital organizations and also present the HL7 based virtual database to realize the data integration. Our research makes a contribution to the design and implementation of the architecture of healthcare systems which can adapt to the changing medical environment.**

***Index Terms*—healthcare systems, adaptive, requirements modeling, organizational semiotics, requirements patterns, data integration**

I. INTRODUCTION

With the development of hospital digitalization, the improvement of medical treatment level depends more and more on the efficient management and usage of various kinds of medical information systems. However, current medical information systems are separated from each other and lacking of information sharing and interoperability, which construct barriers for maximal usage of medical resources. Therefore an integrated large-scale healthcare system which is composed by many interoperable subsystems is needed to adapt to the evolving medical area.

To construct the integrated healthcare system, the key problem is to adopt advanced information systems architecture in order to deal with the changing medical environment. Based on the definition by the Institute of Electrical and Electronics Engineers, IEEE 610.12 (1995), architecture refers to the structure of the units, their relationship, the principles and guidance guiding their design and evolution in a defined domain. IEEE Std 1471 (2000) defines the Information Systems Architecture (ISA) as "the fundamental organization of a system embodied in its components, their relationships to each other and to the environment and the principles guiding its design and evolution" [1].

As it can be seen that information architecture is the overall description of the components and their relationship in the information system; it is the integration of the business logic, information process logic and technical solutions, which is the top model of the information system structure.

In this paper, we propose an adaptive healthcare systems architecture in which the complex healthcare system will be divided into five layers together with information sharing mechanism and knowledge backbone. This architecture is driven by user's requirements patterns (URP), and can dynamically identify, organize and adjust system's functions adapting to the changing requirements and environment thus satisfies users' demands intelligently. Furthermore, we will focus on the requirements layer in which the requirements are modeled using semiotic methods and the framework of user's requirements patterns (URP) is proposed based on the results of semantic analysis and norm analysis.

II. RELATED WORK

In fact, the act of Clinger-Cohen passed by American congress in 1996 clearly states that the government lacks the overall framework of harmonizing and managing the

This work is supported by the National Natural Science Foundation of China under Grant 70740003 and The Beijing Natural Science Foundation Program-the mobile healthcare services platform under Grant 4092048

doi:10.4304/jcp.5.2.186-193

construction, usage and maintenance of information system. This act is based on the belief that the enterprise's architecture can lead to the improvement of information provision for decision-making and it also compels all the federal government departments to develop and maintain their own information technology architecture.

According to the requirements of Clinger-Cohen act, the committees were established by CIOs of governments in 1999 and the evaluation standards and practice guidelines were published and named as Federal Enterprise Architecture Framework (FEAF) which provide a reference model for federal and other government organizations, and the document is updated every year [2, 3]. The Department of Health and Human Services (HHS) as defined in this framework is a core decision support tool which integrates enterprise's information, planning and management functions (including strategy planning, human resources, operation continuity, safety, investment, business process reengineering, information management and facilities). HHS enterprise architecture not only can be used to guide information technology investment, but also ensures the consistency in strategy and operations in information technology investment and HHS planning [1].

The National Institute of Health (NIH) proposed a framework for healthcare information systems architecture which depicts the enterprise technology environment of NIH. This framework is composed of three different systems architectures which are business architecture, information architecture and technology architecture, as shown in Fig.1 [5].

Generally, the research of information systems architecture is conducted from two aspects [6]. One is from the aspect of software application systems which propose the service guided architecture solving the interoperation between heterogeneous systems, such as the service-oriented architecture (SOA) and enterprise service architecture (ESA). The other is from the aspect of management which consider roles and critical success factors in organizations and guide to organize the systems and integrate the components, such as Zachman architecture [1], the Department of Defense Architecture Framework (DoDAF) [7, 8], the Open Group Architecture Framework (TOGAF) [9], as well as FEAF,

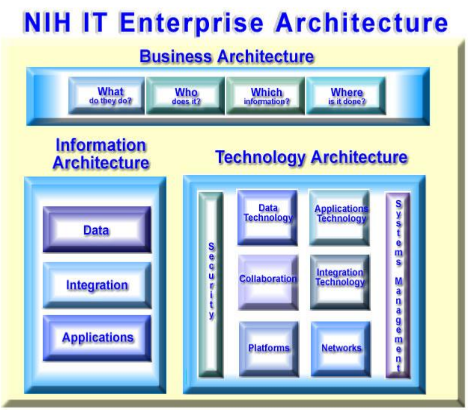

Figure 1. The architecture of NIH

HHS and NIH as we discussed above.

The architecture from software aspect has the advantages of guiding the development of application systems directly with good operability and reliability. However, an information system is not only a software system and there are also social, organizational and human factors. The software aspect can hardly cover these factors. In addition, the software architecture is generally formed within a particular domain in a particular style. Although recently there is a great deal of research in the adaptability of software architecture, most of the architectures depend on the particular computing environment and realization technology, so there exists limitations in adaptability, reliability, safety, expansibility, usability and reusability. Taking the SOA as an example it mainly attempts to address the flexibility and adaptability, but it does not deal with the business level therefore it cannot expand and integrate the business according to the requirements. Although ESA has been improved up to the business level, it can neither identify user's requirements automatically nor operate adaptively. It can only provide the flexibility on the mechanical level. The market and the application should provide something common and advanced in industry, such as requirement reorganization, service model, supporting configuration and expansion which cannot be realized only through SOA and ESA. This situation can be improved by formally clarifying user's requirement, business services and the adaptive mapping mechanisms between them so that the architecture will be more flexible both at the business level and technical level.

The information architecture from the management aspect has the advantage of considering the needed information from multiple perspectives and levels which cover the intention and desires from different stakeholders. However, the architecture derived is too conceptual and always lacks of methodological guidance for the modeling and implementing so that cannot ensure the mapping between the business model and the technological model; although the linkage between business, information and communication technology is important in systems architecture [10].

The complicated and changing requirements and environment are the main challenges in the current information systems. Although the definitions of information systems emphasize that the architecture should consider the relationship between the systems and environment to guide the systems design for evolution, the existing information systems lack the mechanism for adaptation and evolution .Therefore they have weak adaptability to user's requirement and environment and hard to meet the need for revolution and development in the complicated and changing environment.

These problems pose difficulties for designing architectures of adaptive healthcare information systems to satisfy changing requirement. The NIH (National Institute of Health) IT Enterprise Architecture was proposed to cover the business architecture, information architecture and technology architecture; the IHE (Integrating the Healthcare Enterprise) project [11]was presented to integrate various information systems in the hospital environment through standardizing the implementation of DICOM and HL7. However, they can hardly adapt to the changing medical requirements and environment due to the lack of adapting and evolving mechanism.

To solve these problems, we propose the requirement driven architecture for adaptive healthcare system which integrated the advantages of architecture from both software aspect and management aspect. The system not only covers the social and management factors but also considers relationships among requirements, business and technology by modeling and analyzing user's requirements, domain services, business processes, functions, data and mapping mechanism. Our architecture is adaptive and evolvable which can dynamically identify, organize and adjust system's functions according to the changes of user's requirement and environment.

III. THE REQUIRMENT DRIVEN ARCHITECTURE OF HEALTHCARE SYSTEM

A. The Framework

The healthcare information system is a complex and dynamic system with the hierarchy structure which are composed of relatively simple and similar elements from lower levels to upper levels. Therefore the system will have better reusability, expansibility, adaptively and self-evolving ability as long as the mapping mechanism among different layers is built. As shown in Fig.2, we establish the healthcare system consisting of five layers, information sharing and safety mechanisms, and ontological knowledge.

We can see from Fig.2 that the whole system is directly driven by requirements of users such as patients, physicians, hospitals, government and the third-party institutions. The satisfaction of user's requirement is the direct aim of healthcare information system as well as the main basis for its function and performance ,thus this requirement-driven architecture can make the healthcare system directly respond to user's various and evolving requirement. Based on the problem-solution pattern of information services, the healthcare system provides services in a layered form including requirement layer, service layer, process layer, function layer and data layer in which the patterns in different layers are related by the one-to-many dependency.

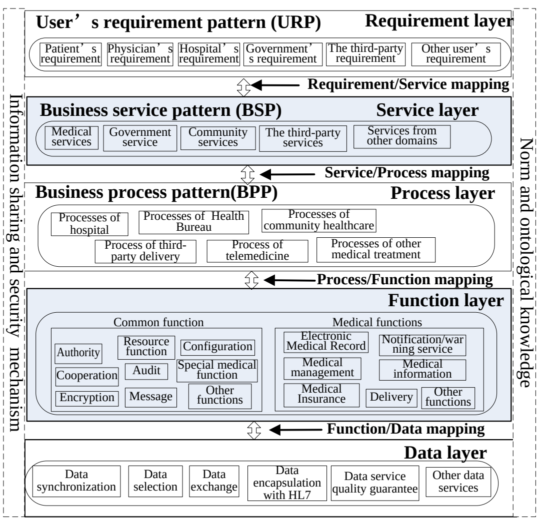

Figure 2. The framework for requirement driven architecture of healthcare system

The requirement layer identifies, analyzes and models user's possible requirements. Furthermore it summarizes and standardizes frequent cases of requirement as a series of User's Requirement Pattern (URP).

The service layer interacts with requirement layer and provides services in certain domains to satisfy user's requirement pattern. Each domain ,for example medical domain and government domain ,has its particular business services pattern(BSP) .User's requirement pattern from requirement layer may be satisfied by several various business services pattern(BSP).

The process layer interacts with service layer and includes medical, government, third-party delivery and other related process. Business process patterns (BPP) are obtained by classifying and standardizing possible processes. Business service pattern from service layer may be satisfied by several different business process patterns.

The function layer and data layer are organized by the Service Oriented Architecture (SOA) in which each function is a web service and the data layer provides necessary data to achieve these functions. In our healthcare system, the functions are encapsulated in the form of web services which can be invoked conveniently by process layer for the probable combination according to user's requirement. Furthermore the medical data exchange standard HL7 (Health Level Seven) and DICOM (Digital Imaging and Communication in Medicine) are adopt to achieve medical data sharing among different systems.

Additionally, the healthcare system can modify norms and ontological knowledge according to the changes of society, organization and environment, which give system more flexibility and adaptively. The information sharing mechanism supports interoperation and data sharing meanwhile the security mechanism ensure the safe operation of the whole system.

B. The implementation of the requirment driven healthcare system

The implementation for the requirement driven architecture of healthcare system is shown in Fig.3

We adopt the four-layer B/S structure to implement our system and they are browser, Web server, application server and database server. Especially there are particular applications in the application server for requirement layer, service layer and process layer respectively. These applications includes conversion engine (generating patterns through formalized description and classification), pattern search engine (matching the patterns), integrated inference engine (generating new patterns through case based inference and norm based inference) and mapping/invocation engine (the mapping and invocation for the patterns/functions).The patterns, cases ,norms and ontology knowledge needed by each layer are layered ,classified and stored in the corresponding database in database server. For example the user's requirement pattern base for the applications in requirement layer, user's requirement case base, user's requirement ontology base as well as social ,organizational and operational norm base. The management of patterns, cases, ontology and norms is conducted by the corresponding pattern management system, case management system, ontology management system and norms management system in the application server. The business process layer invokes the web services in the function integration platform by UDDI registry center. The execution of this application system platform needs to visit the corresponding data center in the data layer. The platform management system, mail service system and single sign-on system in the

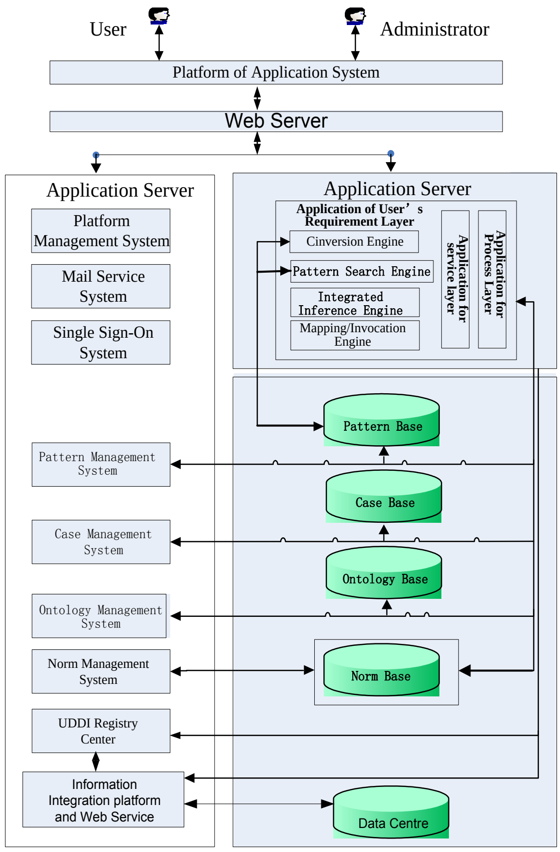

Figure 3. The implementation for the requirement driven architecture healthcare system

application server will provide the system maintenance for platform, e-mail service and user's identity check.

C. The adaptive mapping mechanism

The searching and mapping mechanism between neighboring layers assisted by norm based reasoning, case based reasoning and necessary human coordinating are the operation way of our system.

As we can see from Fig.2, the basic information unit in every layer is pattern. A user's requirement pattern is the collection of characters of a whole requirement. A business service pattern is the collection of characters of a whole service in certain business domain other layers are similar. There are one-to-many relationships from upper layer to lower layer. That is to say, a URP matches one or several BSPs and a BSP matches one or several BPPs.

The granular size of the patterns in this framework become larger and larger form bottom level to top level .The granularity of patterns and the mapping mechanism are the basis of system's adaptability to changing requirement and environment, since various permutation and combination of small-sized elements from lower layer can satisfy the changes of large-sized elements from upper layer[12].

IV. Requirement Modeling Using Organizational Semiotic Methods

The requirement layer, which is responsible for capturing and analyzing user's requirement, is the most important layer for the requirement driven healthcare system. Since user's requirement is the driven factor for our system, only the accurate and comprehensive representation of it can ensure the successful operation of healthcare information system.

The methods of requirement analyzing and modeling in the traditional domain of requirement engineering only focus on the function and data aspects which describe user's functional and non-functional requirements. However, the traditional methods can barely provide the explicit descriptions of user's requirements from the aspect of social business domain. This will lead to the incomplete modeling of user's requirements, especially for the potential requirements. These potential requirements exist widely in actual business which often manifest as some of system's tasks for user's social goals but hardly being represented clearly.

Another problem is the understanding of user's requirements. Generally we build the vocabulary for consistency but this method will cause problems that the same term may has different meanings in different occasions or different terms may describe the same meaning. These problems will lead to semantic loss in understanding user's requirements.

To solve these problems and represent user's requirement accurately and comprehensively, we adopt organizational semiotics as the theoretical foundations for requirements modeling. Semantic analysis and norm analysis from MEASUR (Methods for Eliciting, Analyzing and Specifying User's Requirements) are introduced to model user's requirements [13].

A. Semantic Analysis

The Semantic Analysis Method assists the users or problem owners in eliciting and representing their requirements in a formal and precise model [13]. Using semantic analysis, the required system functions are specified in an ontology chart, which describes a view of responsible agents in the focal business domain and their behavior or action patterns named affordances. The ontology chart describes the patterns of behavior of human actors and IT systems, and defines the relationships of concepts and terms that correspond to the patterns of behavior. (In a way this model is similar to 'ontology' for a problem domain, as used in the AI community).

Fig.4 shows an example of ontology chart, ellipses represent 'agents' who can act by themselves and can take responsibilities. They may act according to the 'affordances' (represented as rectangles) to which they are linked. Affordance is a collection of patterns of behavior which define an object or a potential action available to members of a society and will be formally specified by norms. The 'role' (represented as half circles) is always defined with respect to the role carrier on its left and the concept determining the responsibility on its right. An agent may have several roles. The concept at the left of a line is an antecedent of that at the right; the former provides the necessary context for the latter. For example, a person and hospital (both agents) are jointly antecedents for the concept employed. This means the existence of a person and hospital is necessary for an employment. This structure can help to describe user's context and potential requirement by finding antecedents of some concepts. A person employed by the hospital has a role name, "physician", which then entitles the person to conduct medical care for a patient. Note that a person can also be employed by government and the third-party organization, but the connotations of these "employed" may differ from each other. Employees of third-party organization conduct delivery service governed by contract, as indicated by a dotted line with an "@" sign.

The semantic analysis can be carried out according to the domain of requirement, such as medical care, government support, community healthcare or other subjects. One can divide an entire problem into several domains if the problem is large and difficult to represent in one model. The ontology chart in Fig. 4 defines the roles and responsibilities, particularly distinguishing different meanings of the "employed" and "contract" from different perspectives respectively. Take the affordance "contract" for example, there are contract between government and hospital, and contract between hospital and the third-party organization. But their meanings and effects are different and are distinguished by the relationships among the involved concepts described in the ontology chart, which to some extent avoid the problem of semantic loss.

In this way, we build the requirement model not only from the perspective of system's user but also from the perspective of social actor, which covers the wide range of factors such as society, organization ,technology and other factors .This can help to obtain stakeholders' objectives and thus describes requirements in business domain more comprehensively and accurately.

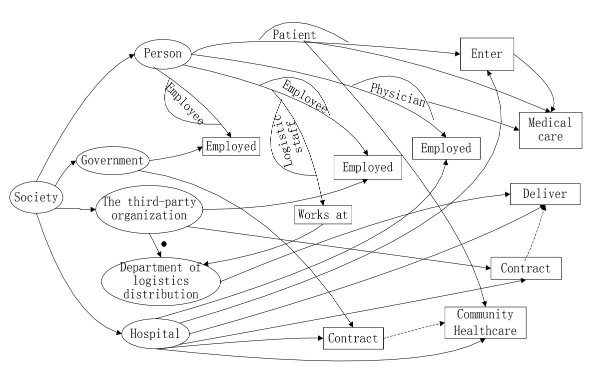

Figure 4.An ontology chart of business requirements

B. Norm analysis

Norm analysis enables us to elicit and represent business rules that have an effect on the system. Norm analysis recognizes various types of rules in a broad sense, which may be either embedded in the system or in the operation processes as follows [14] :(1) Straightforward rules that can be specified explicitly as conditions and constraints for system operations;(2) Rules defining responsibilities and authorities;(3) Rules for reasoning and decision-making specified by possible conditions and resulting consequences;(4) Ethical values, socially acceptable practices and business standards.

Using this method, norms, which determine whether and when a certain activity takes place and also determine the invocation of services of in service layer for satisfying certain requirement, can be specified to identify the controlling relationships with certain system actions.

The norm analysis is based on the ontology chart in which the patterns of behavior entailed in an affordance can be formally specified by norms. Each affordance has a lifetime marked by a start and a finish controlled by a set of norms.

A norm specification covers the following elements: **Whenever**<condition>**If**<state>**Then**<actor>**Is**<deontic operator>**To do**<action>**Consequence**<Post-condition>

"State" together with "condition" represent the precondition for certain action of an affordance. "deontic operator" is derived from deontic logic and can be one of the following: "obliged", "permitted" and "prohibited" which prescribe what people must, may, and must not do. "Action" here is derived from affordance which refers to some patterns of behavior;"consequence" is the post-condition after successful execution of the norm which represent user's objective to execute this action.

As we can see that the norms are fundamentally different from the causal–effect relationship, which normally states that if the conditions are met, certain events will happen or actions will be taken. The conditions and consequences in these logical expressions are always bound, with no room for human discretion. Therefore, the norms reflect better how people behave in a business context, and are more suitable for modeling user's requirements in actual business domain.

In this way we can describe the changes of user's requirement according to the evolving situation by the norms embedded in the affordances. Furthermore, the model which fully considers the changing factors can help to provide alternative solutions in service layer and process layer by identifying, organizing and adjusting systems functions dynamically.

V. REQUIREMENT PATTERN MODELING

User's requirement pattern (URP) is essential for the operation of our system. URPs are summarized and standardized from cases of former requirements and are the basis for the efficient and accurate selection of appropriate services in service layer. URPs are the main elements in requirement layer which match with user's requirements and guide the operation of the whole healthcare system. The concept of user's requirement pattern (URP) in our system is similar with the concept of pattern in software engineering, since both of them are the standard summarization of frequent cases. However URP is differentiated from the latter one in that URP is concrete and can be implemented for system operation [15]. Since URPs are the results of analyzing user's requirement using requirement model, its structure is also based on the requirement model we build above through ontology chart and norms.

We identify social actors as users according to the 'Agent' items in ontology chart with their definition of 'Role', antecedent and successor. We represent them in the form of XML based specification in which '*' means none or more; '+' means one or more; others without these symbols means that there is only one.

<User>
<Role>*
<Antecedent >*
<Successor>*

Objectives are the aims that users want the system to achieve and can be divided into business objective and information technology objective. The business objective can be obtained from post-conditions of norms embedded in affordances. IT objectives indicate the technical performance, reliability and environmental factors under which the business objectives are delivered.

<Objectives>
    <Business objectives>+
    <IT objectives >+

Assignments are the tasks required to achieve certain objectives and correspond to the affordances in ontology chart. They are the driven factors for service layer and we need only focus on assignment's content, antecedent and successor. The antecedents and successors of an assignment construct its operational context. Each assignment has several norms control its start and finish as well as the possible changes in future. Additionally the assignments can be organized to achieve certain objectives according to the post-condition of the norms.

<Assignment>
    <Content>
    <Antecedent >+
<Successor>*
<Norms>+
    <Condition>
    <State>
    <Actor>
    <Deotic operator>
    <Action>
    <Post-condition>

Finally, by putting together various information of user's requirement captured from semantic analysis and norm analysis, we define a URP frame in the form of the following XML based specification:

<URP ID>
<URP Name>
<URP Domain>
<User>*
<Objectives>
<Assignment>+
<Related URP>*
    <URP ID>
    <URP Name>

As we can see that a URP is the collection of characters for a whole user requirement. Based on the operation mechanism of our system, the requirement layer identifies requirements and then the lower layers provide and organize services, processes and functions dynamically according to URPs. This will make the healthcare system more adaptable in the changing medical environment.

VI. DATA INTEGRATION

To construct the adaptive and integrated healthcare system, we have to solve the problem of integration to ensure their interoperability since the systems and data from different organizations are heterogeneous .

A. *The Integration Framework for Data Sharing Among Different Hospital Organizations*

The hospital data integration is based on the technical results of IHE (Integrating the Healthcare Enterprise) which are based on the standards of HL7 and DICOM3.

IHE aims at establish a set of standard processes ,which are realized by DICOM, HL7 and other message systems, in order to integrate different systems. The Cross-Enterprise Document Sharing (XDS) is proposed in IHE in order to solve the problem of regional medical information sharing.

HL7 is the medical system integration standard based on messages and mainly used for data integration. Fig. 5 illustrates an integration framework for data sharing among different organizations [16].

B. *The HL7 based virtual database*

The main source of data in actual hospital institutions for integration is relational database [17].Comparing with ontology approach to solve the semantic heterogeneity, the XML based data integration of hospital information systems provides a unified interface of data manipulation for practical application to deal with structural heterogeneity. XML schema serves as the global data model and XQuery is the unified transformation language for operation of data source. The integration result is in the unified form of XML which can be shared by application programs and systems [18]. As Fig.6 shows, together with ontology for semantic integration, the XML based virtual database of hospital information system is composed of four parts: query processor, integration service manager, semantic part and structural part.

1) The query processor manages the query request and control request respectively according to user's data request and return the results in the form of XML

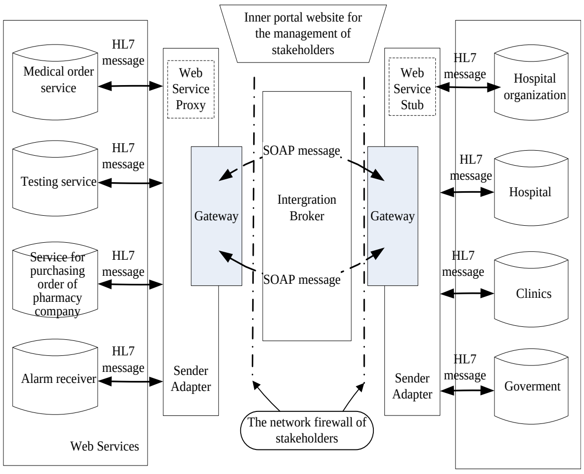

Figure 5. The integration framework for data sharing among different organizations

2) The integration service manager manages the metadata, local view and global view of the data source for integration by the definition of integration task and cooperates with global ontology and query processor.

3) The semantic part deal with the semantic heterogeneity by ontologies. This part gets the XML based source information from structural part and provides knowledge to integration service manager.

4) The structural part concerns the structural heterogeneity. The Wrapper is responsible for interacting with low-level data source, packaging heterogeneous data source and operating the relational database using standard SQL with the aim of realizing the transparency of data location and visiting.

The data integration provides the basis for middle service layer by sharing the information. However the shared data must be transported to medical information systems in a proper way.HL7 is suitable for the mass information exchange among hospitals, insurance company and super administrative departments. DICOM ,which simplifies the exchange of medical image and promote the development of tele-radiology system and picture archiving and communication system(PACS), make it for possible for the integration with other medical application systems such as HIS and RIS owing to its openness and interconnection

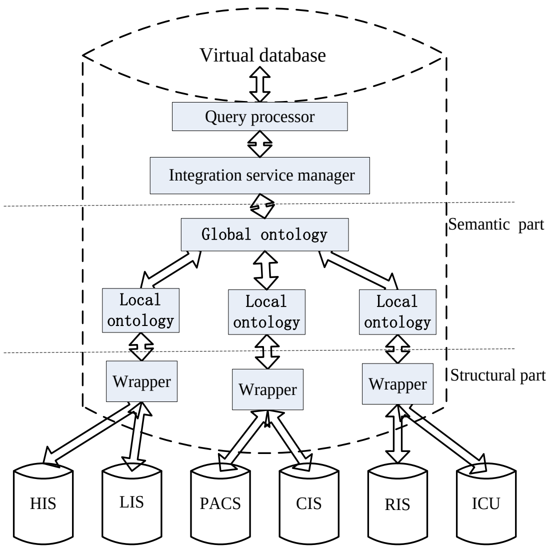

Figure 6. The structure of the XML based virtual database for hospital information systems

VII. Conclusion

Our system integrates both the social factor and the technical factor with the hierarchy structure and mapping mechanism. This architecture can dynamically identify and organize systems functions in order to satisfy user's requirement adaptively. Furthermore, the organizational semiotic methods provide explicit descriptions of user's requirements from the aspect of social business domain. This architecture of adaptive healthcare system is very suitable for the complex healthcare requirement which need the integration of distributed and heterogeneous medical services. Finally our integration framework for data sharing and the HL7 based virtual database, which solve the interoperability among heterogeneous systems, provides an implementation platform for this adaptive and integrated healthcare system.

Our future work includes semi-automatically constructing the ontological knowledge for the system. The analyzing and modeling of Business Service Pattern in service layer is also under investigation.

Acknowledgment

This work is supported by the National Natural Science Foundation of China under Grant 70740003 and The Beijing Natural Science Foundation Program-the mobile healthcare services platform under Grant 4092048.

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