HETEROGENEOUS KNOWLEDGE SHARING IN EHEALTH
MODELING, VALIDATION AND APPLICATION

Yang Guo

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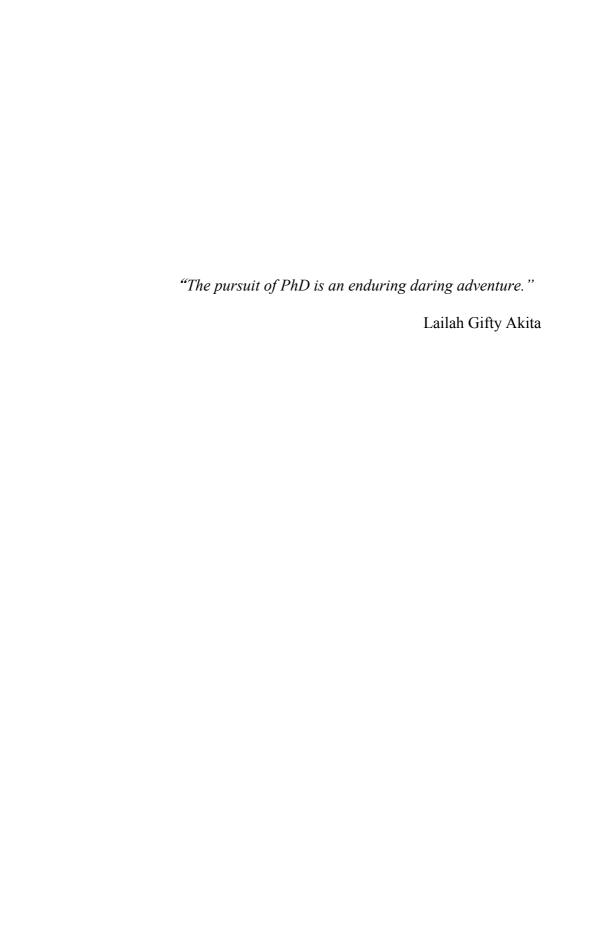Blekinge Institute of Technology
SWEDEN

"The pursuit of PhD is an enduring daring adventure."

Lailah Gifty Akita

Abstract

Knowledge sharing has become an important issue in the eHealth field for improving the quality of healthcare service. However, since eHealth subject is a multidisciplinary and cross-organizational area, knowledge sharing is a serious challenge when it comes to developing eHealth systems. Thus, this thesis studies the heterogeneous knowledge sharing in eHealth and proposes a knowledge sharing ontology. The study consists of three main parts: modeling, validation and application.

In the modeling part, knowledge sharing in eHealth is studied from two main aspects: the first aspect is the heterogeneous knowledge of different healthcare actors, and the second aspect is the interactivities among various healthcare actors. In this part, the contribution is to propose an Activity Theory based Ontology (ATO) model to highlight and represent these two aspects of eHealth knowledge sharing, which is helpful for designing efficient eHealth systems.

In the validation part, a questionnaire based survey is conducted to practically validate the feasibility of the proposed ATO model. The survey results are analyzed to explore the effectiveness of the proposed model for designing efficient knowledge sharing in eHealth. Further, a web based software prototype is constructed to validate the applicability of the ATO model for practical eHealth systems. In this part, the contribution is to explore and show how the proposed ATO model can be validated.

In the application part, the importance and usefulness of applying the proposed ATO model to solve two real problems are addressed. These two problems are healthcare decision making and appointment scheduling. There is a similar basic challenge in both these problems: a healthcare provider (e.g., a doctor) needs to provide optimal healthcare service (e.g., suitable medicine or fast treatment) to a healthcare receiver (e.g., a patient). Here, the optimization of the healthcare service needs to be achieved in accordance with eHealth knowledge which is distributed in the system and needs to be shared, such as the doctor's competence, the patient's health status, and priority control on patients' diseases. In this part, the contribution is to propose a smart system called eHealth Appointment Scheduling System (eHASS) based on ATO model.

This research work has been presented in eight conference and journal papers, which, along with an introductory chapter, are included in this compilation thesis.

Keywords: Knowledge sharing, eHealth, Activity Theory, Ontology, Decision making, Appointment scheduling

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List of papers

Included publications:

Paper I   Y.Guo, Y.Hu, J.Afzal, G.Bai, "Using P2P Technology to Achieve eHealth Interoperability", in 8th International Conference on Service Systems and Service Management (ICSSSM), pp.722-726, 2011.

Paper II   Y.Guo, G.Bai, "An IOT Architecture For Home-based Elderly Healthcare", in 2014 International Conference on Management and Engineering (CME 2014), pp.329-337, 2014.

Paper III   G.Bai, Y.Guo, "Activity Theory Ontology for Knowledge Sharing in eHealth", in International Forum on Information Technology and Applications (IFITA 2010), pp.39-43, 2010.

Paper IV   Y.Guo, G.Bai, "A General Architecture for Developing a Sustainable Elderly Care eHealth System", in International Journal of Information Technology and Business Management (JITBM), pp.095-101, Vol.027.No.1, 2014.

Paper V   Y.Guo, Y.Yao, G.Bai, "On Enhancement of Interactivity for Knowledge Sharing in eHealth", in 11th International Conferences on Communications (COMM), Bucharest, Romania, June, 2016.

Paper VI   Y.Guo, G.Bai, S.Eriksén, "Activity Theory based Ontology Model for efficient Knowledge Sharing in eHealth", in eHealth Telecommunication Systems and Networks (ETSN), Vol 6, pp.31-45, 2017.

Paper VII   Y.Guo, Y.Yao, G.Bai, "eHASS: A Smart Appointment Scheduling System for eHealth", in 12th Swedish National Computer Networking Workshop (SNCNW), Sweden, June, 2016.

Paper VIII   Y.Guo, Y.Yao, "On Performance of Prioritized Appointment Scheduling for Healthcare", in Journal of Service Science and Management, Vol 12, pp.589-604, 2019.

Related publications:

Paper IX   Y.Guo, G.Bai, Y.Hu, "Using Bayes network for prediction of Type-2 diabetes", ICITST-2012, pp. 471-475, 2012.

Paper X   Y.Guo, Y.Yao, G.Bai, "A new Software Framework for Heterogeneous Knowledge Sharing in Healthcare system", in Swedish Communication Technologies Workshop (Swe-CTW), Sundsvall, Sweden, June, 2016.

Contents

Introduction

1. Background

1.1. Healthcare Systems

In recent decades, with the advancement of medical knowledge and of new medical technologies, the average life of human beings has been prolonged. However, large numbers of chronic health problems exist worldwide, such as heart disease, cancer, stroke and diabetes [1]. These problems continuously afflict human societies. The attempt to overcome them remains a very challenging task and results in the need for sustainable development in the healthcare system. Healthcare refers to the requirements for the service of maintenance or improvement of health and can be accomplished through different approaches, such as effective diagnosis and treatment as well as improved measures for prevention of disease, illness, injury, and other physical and mental impairments in human beings [2]. There are different organizations or individuals (doctors, nurses, healthcare professionals etc.), hereafter called 'care providers (CPs)', which/who provide healthcare services for the different groups of people (patients, elderly etc.), hereafter called 'care receivers (CRs)'. Usually, healthcare services need to be delivered from the care providers to the care receivers.

Although care providers are usually the experts in offering healthcare when dealing with particular clinical conditions, the care receivers are the experts in living with those particular conditions. Further, it is important for care providers to better understand the effectiveness of healthcare as experienced on the patient side which can be achieved by the process of regularly gathering and analyzing the health status of care receivers. In this way, care providers can gain deep insights into how care receivers perceive their health problems, thus providing a knowledge base for improving the efficiency and quality of healthcare services.

Healthcare service provision is a sophisticated process, and it has the potential to become an information-intensive sector in the healthcare system. This situation raises the need for dealing with various types of information through electronic processes and communication. Such use of Information and

Communications Technology (ICT) for healthcare is known as eHealth, which is dating back to at least 1999 [3].

1.2. eHealth

Typically, eHealth is referred to as a system with different ICT applications that can support healthcare services. The underlying idea of eHealth is to practically conduct healthcare services by applying electronic processes and communication with different healthcare actors. A healthcare actor is defined as an individual person or organization that has an impact on or is affected by the eHealth system [4]. Examples of healthcare actors are healthcare organizations, doctors, nurses, patients and their family members. Both care providers and care receivers belong to healthcare actors.

In recent years, eHealth has played an important role in carrying out research and development on healthcare systems. The benefits from eHealth for human society include improving the quality of healthcare services, enhancing the interactivities among healthcare actors, expanding access to diagnostic services, increasing the efficiency of service delivery from care providers to patients, and reducing the cost of healthcare. eHealth systems can further provide a significant contribution to the economy by greatly profiting from new advances in ICT [5]. One of the promises of eHealth is to increase efficiency in healthcare, thereby decreasing costs. One possible way of decreasing costs would be by avoiding duplicative or unnecessary diagnostic or therapeutic interventions, through enhanced communication possibilities between healthcare establishments, and through patient involvement [53].

However, many current research issues concern challenges when it comes to the development of eHealth systems. For instance, designing an efficient eHealth system requires keeping up with the rapid advancement of ICT based technologies, such as mobile applications and various forms of sensor networks, often including wearable sensors. It is also important for healthcare professionals to periodically evaluate the quality and effect of eHealth system or eHealth systems in use on the delivery of healthcare services. Further, eHealth is

the transfer of health resources and healthcare by electronic means, and is enabled by communications technology through extensive information sharing and collaboration. Given the sensitive nature of medical information, and healthcare professionals' high degree of dependence on reliable records, issues of integrity, security, privacy, and confidentiality are of particular significance, and thus security must be clearly and effectively addressed by eHealth applications. Thus, one needs to ensure eHealth security in different tasks such as by protecting private information and conducting secure service-authorization processes [6].

1.3. Knowledge Sharing
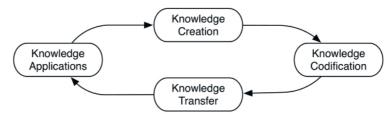
Knowledge sharing is an activity through which knowledge (i.e. information, skills, or expertise) is exchanged among people or members within and/or in different communities or organizations. Efficient knowledge sharing requires the ability to coordinate service delivery across the network. It must be possible to associate relevant medical information with patients regardless of which facility delivered the services. Knowledge sharing has become a very important resource when knowledge needed for conducted services is extended outside of the own organization. Sharing knowledge can realize potential gains and is critical to surviving and prospering in a competitive environment [15, 16]. Despite its importance, sharing knowledge is not easy to implement. Knowledge sharing is a fragile process due to the nature of knowledge (including multiple forms of knowledge such as explicit, tacit, private, collective, etc.) and people's diverse intentions. Moreover, knowledge is often considered as a valuable asset which is perceived as a source of power and reputation within a social setting. People may be reluctant to share this asset to avoid the risk of losing their power. Sharing knowledge brings some extra costs as well; one needs surplus resources (time, money etc.) and the means to share knowledge (IT infrastructure, meetings, etc). In eHealth field, people may not trust others. Some people are very sensitive to their privacy and do not want others to know their health status. Some people are also worried that sharing their knowledge will allow other people to be rewarded without giving credit or something in return, or result in the misuse of that knowledge [18].

There are significant challenges in collecting, organizing, and extracting value from data collected in the course of providing healthcare. How to transfer data to knowledge is a key to ensure needed information and knowledge from the data that are in healthcare system. Data is context relative raw facts/observations with no direct meaning, such as name, gender, birth date, address, phone number, temperature, and so forth. Attaching meaning to data transforms them into information. Knowledge, at the next level, implies contextualized information, which is information interpreted by the receiver and from the perspective of the receiver. Knowledge consists of data that are organized and processed to convey understanding, experience, accumulated learning and expertise as they apply to a current problem or activity. Knowledge can be the application of data and information to make a decision [7].

Knowledge sharing in eHealth has become crucial for healthcare, since the care providers are required to be researchable, creative in healthcare, and ready to make use of new medical knowledge opportunities that can be acquired through various organizational learning mechanisms [17]. In eHealth, health professionals usually need to employ information sources to support clinical activities and healthcare delivery rather than simply face-to-face interact with a patient [8]. One of the major impediments to efficient healthcare delivery is connected to the difficulty in sharing medical data and health knowledge among various healthcare actors.

In this thesis, knowledge sharing in eHealth is studied in relation to two important tasks. The first important task concerns how to transfer different types of medical data as knowledge. Here, the medical data are usually associated with different healthcare actors, such as the competence and expertise of a doctor, the age of a patient and the location of a hospital. The second important task is to manipulate the transferred knowledge with operations in terms of collection, exchange, analysis and application. These operations refer to different ways of sharing eHealth knowledge among various healthcare actors. To conduct the abovementioned tasks for eHealth knowledge sharing, one feasible approach is to follow

the knowledge management (KM) life cycle [7, 9]. In [7, 9], the knowledge management life cycle is used in eHealth to transfer the data as knowledge, and to organize the operations on knowledge in accordance with a group of prescribed paradigms, as shown in Fig. 1.

Source: Dalkir, K. (2011). Knowledge management in theory and practice. The MIT Press.
Fig.1. Knowledge management life cycle

- Knowledge creation refers to the processes of discovering, identifying and capturing the knowledge with reference to the given purposes.

- Knowledge codification refers to methods for storing, organizing, mapping and eventually visualizing the knowledge with regard to the particular user demands.

- Knowledge transfer includes the operations on the codified knowledge for further application purposes, such as distributing, exchanging and sharing the knowledge among different users.

- Knowledge applications indicate the activities of applying the acquired knowledge to solve particular problems.

The focus of this thesis work is knowledge sharing, which runs through the whole knowledge management life cycle [9].

1.4. Interactivities among Healthcare Actors

To share knowledge in eHealth, one important issue which must be considered is the interactivities among different healthcare actors. In this thesis, the interactivity among healthcare actors is defined as the operation through which the healthcare knowledge (i.e., information, skills, or expertise) is exchanged among different healthcare actors such as patients

and their friends, family members, a community or an organization.

Based on this definition, examples of such interactivity are as follows:

- Both care providers and care receivers have access to clinical information anywhere and at any time.

- The care provider (e.g., a doctor) and the care receiver (e.g., a patient) can both consult with each other.

- The care receiver (e.g., a patient or one or more of her/his family members who have been specifically authorized for this) has authorized access to the electronic health record (EHR) of the patient.

Without eHealth, traditional messages from care providers may be unintentionally disempowering for the improvement on the health status of care receivers [10]. In this situation, when care receivers seek knowledge or advice, only receiving information about health status in a perceived "authoritarian" form from care providers may become off-putting [11]. From the care receiver perspective, such traditional interactivities may further provoke negative feelings of fear, embarrassment and guilt, rather than empowerment [12]. Such a situation gives rise to the need for providing efficient mechanisms for interactivities with the help of eHealth.

In eHealth, dealing with interactivities among healthcare actors is a complicated process, as knowledge sharing in eHealth is usually achieved based on ICT services in terms of different forms of hardware and software. Therefore, the interactivities need to be prescribed with reference to a particular terminological representation, which can be recognized by hardware and software with reference to particular machine languages. Based on this, the interactivities among healthcare actors need to be classified into different categories in different scenarios.

1.5. Heterogeneous Aspects of eHealth Knowledge

To share knowledge in eHealth, another important issue must be considered is that the heterogeneous aspects of eHealth knowledge. In this thesis, the heterogeneous aspects of eHealth knowledge are expressed in terms of vertical and horizontal properties of the healthcare services, as shown in Fig.2. The detailed descriptions of these two properties are as follows.
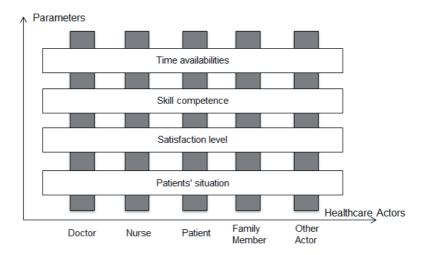
Fig. 2. Heterogeneous Aspects of eHealth Knowledge.

The vertical property means that the operation of delivering the healthcare service at the care provider side depends on several parameters. These parameters include the time availabilities of both care providers and receivers, the skill competence of the care providers, the types of patient diseases and the service delivery methods (e.g., face-to-face meetings and communications via phone or the Internet). For instance, although a doctor is highly competent to address a patient's particular disease, this doctor might not provide the health service due to unpredictable events, such as the patient being sick suddenly. Further, the quality of the health service experienced at the care receiver side builds upon various factors, such as the category of the disease, the patients' preferences, and their personal satisfaction level [13].

The horizontal property indicates the variety of healthcare actors that participate in the process of delivering the health service. Different groups of healthcare actors may be involved

in different healthcare scenarios, e.g., home-based healthcare and remote patient monitoring [14]. Accordingly, the interactivities among the involved healthcare actors need to be re-defined for different healthcare actors. For instance, if a patient stays at home and communicates with a nurse via phone, the interactivities between them may be related to an appointment request for a meeting with a doctor during a particular time slot.

2. PROBLEM DEFINITION AND RESEARCH QUESTIONS

Knowledge sharing among different healthcare organizations becomes significant when healthcare services are crossing outside one organization. In eHealth, there are usually different organizations or individuals providing similar or related services to the same group of people. These various services and applications in different organizations use different vocabularies, concepts, models, etc. and thus exacerbate the difficulty of sharing knowledge. For example, in Sweden the hospitals of county councils, municipalities and other social organizations all provide healthcare for elderly who have chronic health problems. They have to share their knowledge about the elderly in order to cooperate with each other, however this is done using their own disparate systems which are not able to communicate with each other. Therefore, it is crucial for eHealth systems designer to find a strategy to support sharing of knowledge among various healthcare actors.

Without technology that supports knowledge sharing both within and across organizational boundaries, it is difficult for healthcare actors to communicate and share knowledge effectively and consistently [19]. Traditional healthcare systems are mainly designed to support the treatment of acute diseases rather than chronic diseases. Thus most healthcare systems are targeted at healthcare providers, either to support the management of patients' healthcare records, control pharmaceutical prescriptions, or support diagnoses. In some healthcare systems, patients may access their healthcare records themselves, but cannot communicate with healthcare providers or other healthcare actors. However, chronic disease healthcare often needs efforts from multiple healthcare actors,

not only healthcare providers, but also healthcare receivers themselves and their family members or relatives. Therefore, knowledge sharing in eHealth has become a critical issue.

The aim of this thesis is to study the knowledge sharing problems in current healthcare and find an appropriate solution to overcome the problems. To achieve this goal, four research questions (RQs) are formalized below:

- *RQ1: What are the ICT solutions to create healthcare knowledge for further sharing purposes in eHealth?*

  To share knowledge in eHealth, eHealth knowledge must first be identified. RQ1 indicates the need for preliminary research work focusing on available ICT solutions for practically implementing knowledge sharing in eHealth. To conduct this task, Peer-to-Peer (P2P) and Internet of Things (IoT) technologies are suggested for creating the healthcare knowledge for further sharing purposes in eHealth. This is addressed in Paper I and II.

- *RQ2: How can the heterogeneous aspects of eHealth be represented and the interactivities among healthcare actors in eHealth be handled?*

  RQ2 is related to the process of designing efficient knowledge sharing in eHealth. Since eHealth is a multi-disciplinary and cross-organizational area, the lack of shared concepts, vocabulary plus a specification of its intended meaning (ontology) has been an obstacle to developing eHealth systems. To answer RQ2, we propose a knowledge sharing ontology on the basis of Activity Theory to represent the heterogeneous knowledge and interactivities among various healthcare actors, the so-called ATO model. The ATO model offers a feasible approach to interpret the associated heterogeneous healthcare knowledge and manage the interactivities among the healthcare actors. This is addressed in Paper III, IV and V.

- *RQ3: How can the feasibility and effectiveness of the proposed model for efficient knowledge sharing in eHealth be validated?*

In order to address RQ3, a questionnaire based survey is conducted to validate the feasibility and effectiveness of the proposed model. Further, a web based software prototype is constructed to validate the applicability of the ATO model for the practical eHealth system. This is addressed, together in Paper VI together with RQ2.

- *RQ4: How can the proposed model be used in practice to efficiently support the knowledge applications with the shared eHealth knowledge?*

To answer RQ4, healthcare decision making and appointment scheduling are selected to apply the proposed ATO model to solve real problems. The ATO model is integrated with the decision making process by providing different priorities to different types of patients. Such priorities can be prescribed in accordance with the heterogeneous knowledge shared through the interactivities among different healthcare actors, such as the historical results of a particular medical treatment on patients and the diagnostic experience of doctors and nurses. This is addressed in Paper VII and VIII.

3. RESEARCH METHODOLOGY

Research methodology (RM) is the systematic process for conducting study and research in a particular field. RM usually comprises a group of various methods and principles associated with theoretical analysis and quantitative or qualitative techniques [20].

In this thesis, we have used mixed research methodology containing both qualitative methods and quantitative methods. Table 1 lists different research methods used for answering research questions in this thesis.

Table 1 Research methods for addressing the research questions

Research Method	RQ1	RQ2	RQ3	RQ4
Literature Review	✕	✕	✕	✕
Interview	✕			
Survey			✕	
Prototyping	✕	✕	✕	
Simulation				✕

Literature study: A literature review provides a starting point for other researchers to know how much our research work has contributed to the solution of a particular problem and relevant literature [20]. A literature review also justifies the importance of a research topic and identifies gaps in both past and current research [21]. In this research, literature reviewing is used through the whole research process. For example, the literature study on the ontology model and Engström's activity theory model [35] led to the design of the eHealth knowledge sharing framework. Engström's triangle activity model [35, 36] provides a good ontology framework for knowledge sharing in eHealth.

Interview: Interviewing is a useful method for data collection, with a high response rate and closer judgment of people's experience, opinion, desire and feelings [20, 22]. We started with interviews of the healthcare providers and healthcare IT professionals to understand the current healthcare systems and knowledge sharing problems they are facing. We used a semi-structured interview with both open-ended and closed-ended questions. The interviewees were selected carefully on the assumption that they were aware of the importance and challenges of eHealth knowledge sharing, as well as of the government policies for eHealth.

Survey: Conduct a survey is another method that we used to collect data directly from potential users. The goal of a survey is usually to study the characterization of a population by sampling a group of individual units from a particular population [23]. The associated technique of collecting survey data is usually based on questionnaire construction and methods, which can improve the number and accuracy of responses to surveys. A questionnaire is a research instrument consisting of a series of questions (or other types of prompts)

for the purpose of gathering information from respondents. [22]. In this thesis, to validate the feasibility of the proposed ATO model, a questionnaire based survey was conducted during March and April 2016 at the Zhengzhou University Hospital in China. In this survey, four different sets of questions are distributed to representatives of four particular groups of healthcare actors, i.e., patients, doctors, nurses, and relatives of patients.

Prototype: Prototyping is the process of developing a system or a product by showing the feasibility of an idea. It is widely used in systems development and research [25]. Prototyping is an attractive method for complicated systems where there is no manual process or existing system to help determine the requirements, as well as no method for obtaining quick user feedback with regard to improvements [26]. As part of the research on which this thesis is based, we build a prototype to validate the applicability of the ATO model for practical eHealth systems-Web related techniques (e.g., HTML, Java/JavaScript, MySql) were used for the prototype development.

Simulation: Simulation attempts to carry over the essential structural elements of some real world phenomenon into a relatively well controlled environment [20, 24]. To validate the numerical analysis and results, an appointment scheduling simulator for eHealth has been developed to conduct the simulation validation. The simulator consists of two parts. The first part concerns the definition and configuration of a particular eHealth system, together with relevant parameters, such as the number of care providers and care receivers and the categories of the patients' diseases. The second part concerns simulating the dynamic behaviors of both care providers and care receivers, as well as their interactivities. The associated behaviors and interactivities can include the following: requesting an appointment, arranging a time slot for the appointment between a care provider and a care receiver and rejecting an appointment request due to the lack of time availability on the care provider sides. Furthermore, a discrete-event based simulation is adopted in the simulator.

4. RELATED WORK

For designing support for efficient knowledge sharing in eHealth, the main problem is the need for coordinating different healthcare actors and their associated healthcare knowledge. To accomplish such coordination is a complicated procedure that requires taking into account the KM life cyclic activities shown in Fig. 2. Based on this consideration, some related work is studied as follows:

4.1. Knowledge Creation

Knowledge creation is a preliminary task for knowledge sharing. In eHealth, the main responsibility of knowledge creation is to transfer the medical data of healthcare actors into knowledge, which can be further shared and acted upon among healthcare actors. Knowledge creation has two main tasks: data capture and data collection [27].

Data capture involves deploying suitable practical methods to capture the medical data (and other data relevant for healthcare provision) of different healthcare actors. The data capture methods are referred to as a group of tools in terms of hardware and software, based on the various types of data that can be collected from the healthcare actor side. Here, examples of tools for data capture include wearable sensors, medical devices, laboratory-based facilities, web-based appointment schedulers and mobile applications.

Data collection involves collecting the captured medical data from different healthcare actors and storing it in the data server, for example health cloud. To support data collection, one needs to design efficient networking topologies for data transmission via the Internet. Accordingly, two different categories of networking topologies are connected to this goal. The first category is associated with the networking process implemented for data collection using the aforementioned tools, such as a wearable network that connects all personal wearable sensors. The second category is related to the operation of information exchange over the Internet, e.g., a Peer-to-Peer (P2P) network.

4.2. Activity Theory

The historical roots of Activity Theory go back to the eighteenth- and nineteenth-century classical German philosophy of Kant and Hegel [28]. The concept of activity was elaborated further by Marx and Engels, though the most significant work was done by the Russian psychologists Vygotsky, Leontjew and Luria who used a cultural-historical perspective [28, 29]. At that time, Activity Theory was used when analyzing learning processes. In recent years, Activity Theory has evolved dramatically, foremost by the work of Engeström [35] and the ideas of Activity Theory are being used in different fields of research e.g., human-computer interaction [29], information systems design [37,38] and developmental work research [36].
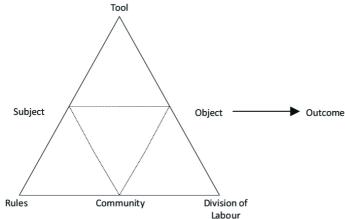
Fig. 3. Engström's activity theory model
Source: Engestrom, Y. (1987). Learning by Expanding: An Activity Theoretical Approach to Developmental Research. Helsinki, Finland

Fig. 3 shows Engström's activity theory model, the model illustrates the complex relations between the various elements in an activity. In Activity Theory, the unit of analysis is the activity that provides a minimal meaningful context for individual actions. Because context is included in the unit of analysis, the object of our research is always essentially collective even if our main interest is in individual actions. An individual can and usually does participate in several activities simultaneously. This implies that each activity has a unique goal, which is used to separate different activities from one another. An activity is carried out by a subject, the subject is

an individual or a group of individuals. The subject uses tools to manipulate and transform an object, which leads to an outcome. The object could also be called the motivation for the activity and could be a material thing or not material at all, such as a plan or idea, as long as it can be manipulated and transformed. A tool can be anything used in the transformation process, including both material tools and tools for thinking. The subject exists in a community, those who share the same object. The community has set different rules for the subject to follow. Rules cover both explicit and implicit norms and conventions, and social relations within a community. Division of labor is the organization of the community. Division of labor refers to the explicit and implicit organization of a community as related to the transformation process of the object into the outcome [29].

In this thesis, Activity Theory provides a high level and rich ontology for the development of eHealth system, which can encompass multi-disciplinary and cross-organizational healthcare knowledge. Activity Theory is a fundamental theoretical framework throughout the whole thesis, which is addressed in Paper III, IV, V, VI and VII.

4.3. Healthcare Ontology

In computer and information science, the term ontology is connected to a set of entities that coexist in a particular domain. It is also a semantics approach to address the types and structures of properties, events, processes and relations among these entities [30]. The goal of applying ontology in eHealth is to establish common semantics for addressing the concept of healthcare services. Corresponding entities in healthcare ontology consist of not only the healthcare actors but also the knowledge and efforts involved in designing the eHealth system. During the past decade, healthcare ontology has been widely investigated and developed. For instance, one standardization effort of Health Level Seven (HL7) was based on developing the Service-Oriented Architecture (SOA) based healthcare ontology. The goal of this effort was to bridge standard ontologies in associated domains, such as enterprise architecture, clinical care, and biomedicine [32]. Based on the work performed by HL7, the authors of [31] reported on the analysis of SOA based healthcare ontology by using a well-

founded ontological approach called the Unified Foundational Ontology for Service (UFO-S) [33]. The purpose of this work is to provide an ontological foundation to the SOA based healthcare ontology suggested by HL7. In [34], the authors studied the problem of representing the healthcare ontology from different perspectives associated with various healthcare actors and using different terminologies.

This thesis was motivated by the need to create a high level ontology for knowledge sharing in eHealth systems. Since eHealth is a multi-disciplinary and cross-organizational area, to have shared concepts, vocabulary plus a specification of its intended meaning, has been an obstacle to developing eHealth systems. In our thesis, we have proposed a knowledge sharing ontology based on activity theory to help designing eHealth system. The proposed ontology based on Activity Theory is called the ATO model, which is illustrated in Paper III, IV, V and validated in Paper III and VI.

4.4. Healthcare Decision Making

In eHealth, healthcare decision making is an important knowledge application based on knowledge sharing, and has been widely reported in previous literatures [39–43]. Healthcare decision making is a process applied for handling various decisions required by different healthcare actors. A decision is a series of steps, starting with information output and analysis and culminating in resolution, namely a selection from several available alternatives[54]. In eHealth, the action is the provision of possible treatments, medical tests, and clinical strategies. Therefore, making a decision is equivalent to the process of determining a suitable action from several alternative ones.

A healthcare decision is usually made across time and space and with regard to the multiple properties of the involved participants. To perform selections among alternatives, the decision maker needs to consider different types of healthcare knowledge, such as taking into account the preferences of patients, knowing the professionals' skill competence, and managing the limitations of resources in terms of hardware, software, people, time availabilities, and other factors jointly.

It is difficult to make an adequate decision in an eHealth system because the need of a healthcare decision is demanded at different system levels from different perspectives and in relation to a multitude of shared knowledge from different sources.

For example, a high-level decision making process may be associated with a budget holder, who needs to decide on suitable investments in the development of medical products [40]. Although the new technologies can enable the support of complex and high-quality healthcare services in the future, they have to be inspected with evidence based studies and early assessment tests. The test results are then useful for estimating the effects of medical products on the eHealth system at hand and for finding the corresponding bottlenecks and weaknesses.

A micro-level decision making may be connected to a patient, who needs to decide whether or not to receive the treatment suggested by the health professionals [41]. One common source leading to patient's dissatisfaction is not feeling properly informed about the offered treatment solution. Therefore, shared decision making is widely suggested in recent studies conducted on healthcare decision making [42, 43]. The key idea is to provide patient-centered communication between patients and health professionals by respecting the patients' preferences. It is also noted that not all patients desire to play an active role in the treatment selection [41]. Instead, some patients only want to be informed by clinicians in case their preferences are assumed to be absolutely necessary to take into account in order for the proposed treatment to have a successful outcome.

4.5. Appointment Scheduling

In eHealth, appointment scheduling (AS) is another important knowledge application based on knowledge sharing [44–49]. The main goal of using AS is to cope with the healthcare requests to care providers. Such accesses are usually demanded of care clinics throughout the entire healthcare procedure, such as arranging a meeting between a doctor and a patient or preparing for surgery in a hospital. Traditional AS systems are usually established in accordance with a particular

goal: to solve the problem of how to efficiently utilize limited resources, such as health professionals, laboratories, and medical devices. In recent years, the areas of patient experience and appointment management have met and developed jointly [44]. Indeed, providing alternative options to patients has become an outstanding characteristic when designing an efficient AS system. Such options can be built upon the patient preferences regarding where, how and when to receive medical treatments [46-48]. Hence, patients are provided with more flexibility when they are involved in the scheduling process. However, one needs to carefully construct the level of flexibility offered to patients by suitably estimating or predicting the operational consequence. For example, allowing patients to independently select times for appointments may lead to work overloaded for care providers. This problem accordingly results in the need to restrict the use of patient-centric based options, which are preliminarily prescribed in the AS system.

To support the above-addressed restrictions, most existing solutions are particularly interested in timely-access to healthcare services. Timely-access is an important characteristic to identify the quality of medical outcomes and to determine patient satisfaction [49]. Because many patients may need short-term based appointments for healthcare assistance, the care clinics usually operate the timely-access on a time-slotted basis. In other words, the available time period for providing health services is usually divided into multiple time slots. Hence, the healthcare requests of patients can be allocated within identical appointment slots. If more time is needed by a particular patient, multiple slots can be arranged. Therefore, the problem of restricting the patients' options is reduced to mapping the appointment slots and the patients' time preferences.

However, note that AS participants (e.g., patients, health professionals) usually need to address realistic situations that can vary over time. With this perception, mapping appointment supply and demand becomes a more complicated procedure. For example, a patient has booked an appointment with a doctor at a particular time moment. This appointment may be interrupted due to cancellation by the patient, lack of

time availability on the doctor's side, or a traffic jam that occurs while the patient is traveling to meet the doctor. Subsequently, the effectiveness of the AS system also lies in the actual activities of the AS participants. Connecting to this fact, knowledge sharing can be employed to bridge the information exchange among healthcare actors, thus enabling numerical analysis of the obtained information. At that point, the AS system can learn from the analysis results with the aim of proactively alleviating the effects of the participants' actual activities on the scheduling performance.

4.6. Mathematical Tools

In this thesis, two problems are considered to study the practical design and application of knowledge sharing in eHealth: healthcare decision making and appointment scheduling. Accordingly, two different mathematical tools (i.e., fuzzy-logic and queueing modeling) are used to provide suitable solutions to these two problems, along with the corresponding numerical analysis.

- Fuzzy-logic based hybrid decision maker: In this thesis, a new healthcare decision making strategy is suggested. This strategy builds upon the mathematic tool fuzzy-logic, which is widely used in the healthcare system [50, 51]. Fuzzy-logic is considered because of its capability of dealing with various parameters for decision making purposes. The suggested strategy is focused on setting up a uniform decision criterion. This decision criterion is able to help the decision maker in integrating different parameter values together into a single value. As such, the complexity of multiple-constraint based decision making problem can be reduced.

- Queueing modeling approach: In this thesis, the queueing theory based modeling approach [52] is adopted to perform a numerical analysis and performance evaluation on healthcare appointment scheduling. In queueing theory, a model is constructed with reference to different statistical information on the considered goals. For healthcare appointment scheduling, the statistical information can be related to the average time a patient spends visiting a doctor, the average number of patients

concurrently staying in a hospital, and the average time spent by a doctor performing an operation. This information can be obtained through different practical methods, such as doing data analysis on medical records. The queueing model then builds upon the prescribed rules, such as the definition of time availabilities of doctors and priority scheduling for certain patient diseases. Accordingly, the performance metrics need to be designed in accordance with the particular evaluation purposes. For instance, the probability of blocking appointment requests from patients can reveal the robustness of the scheduling system, while the average time period spent by a patient in the hospital can be defined as the total time spent waiting in the hospital and visiting the doctor. Such a performance metric can indicate the efficiency of the scheduling system.

5. CONTRIBUTION

5.1. Knowledge Sharing Framework

With the increasing information collected from various healthcare actors, it is essential to have sufficient support for the provision of information exchange and knowledge sharing among the healthcare actors for the different applications used in eHealth. Connected to this issue, one major problem is to address the heterogeneous healthcare knowledge available in eHealth efficiently. To solve this problem, this thesis proposes a knowledge sharing framework based on knowledge management life cycle to support knowledge sharing in eHealth. The goal of this framework is to bridge the relationship between the knowledge sharing and its applications, which can be implemented and deployed in the eHealth field.

Fig. 4 shows the proposed knowledge sharing framework based on KM life cycle. In Fig. 4, the bottom layer is connected to the four cyclic activities in knowledge management, while the top layer depicts the relationships between the knowledge sharing and its applications in the eHealth system, along with the connections between them and the different cyclic activities in knowledge management. More details of this knowledge sharing framework will be described in section 5.2 connected with the published papers.
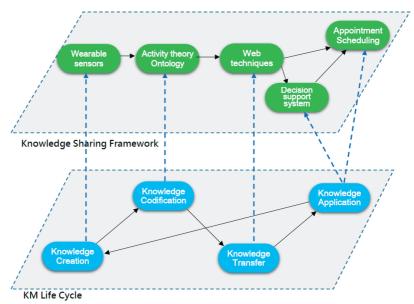
Fig. 4. Knowledge sharing framework in eHealth.

5.2. Paper Relationships and Answers to RQs

The main results of this research are described in 8 included academic papers, 7 of them are published and the last one has been submitted. The papers are listed as follows:

- Paper I. Y.Guo, Y.Hu, J.Afzal, G.Bai, "Using P2P Technology to Achieve eHealth Interoperability", in 8th International Conference on Service Systems and Service Management (ICSSSM), pp.722-726, 2011

- Paper II. Y.Guo, G.Bai, "An IoT Architecture For Home-based Elderly Healthcare", in 2014 International Conference on Management and Engineering (CME 2014)，pp.329-337, 2014

- Paper III. G. Bai, Y.Guo, "Activity Theory Ontology for Knowledge Sharing in eHealth", in International Forum on Information Technology and Applications (IFITA 2010), pp.39-43, 2010

- Paper IV. Y.Guo, G.Bai, "A General Architecture for Developing a Sustainable Elderly Care eHealth System", in International Journal of Information Technology and Business Management (JITBM), pp.095-101, Vol.027.No.1, 2014

- Paper V. Y.Guo, Y.Yao and G.Bai, "On Enhancement of Interactivity for Knowledge Sharing in eHealth", in 11th International Conferences on Communications (COMM), Bucharest, Romania, June, 2016.

- Paper VI. Y.Guo, G.Bai, S.Eriksén, "Activity Theory based Ontology Model for efficient Knowledge Sharing in eHealth", in E-Health Telecommunication Systems and Networks, 6, 31-45.

- Paper VII. Y.Guo, Y.Yao and G.Bai, "eHASS: A Smart Appointment Scheduling System for eHealth", in 12th Swedish National Computer Networking Workshop (SNCNW), Sweden, June, 2016.

- Paper VIII. Y.Guo, Y.Yao, "On Performance of Prioritized Appointment Scheduling for Healthcare", in Journal of Service Science and Management, Vol 12, pp.589-604, 2019.

Based on the proposed knowledge sharing framework, the main structure of the thesis in relation to the papers and RQs is shown in Fig.5.
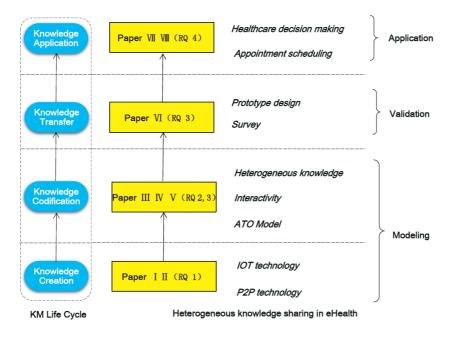

Fig. 5. Thesis Structure

In Fig.5, the contributions in this thesis can be summarized as follows:

In the knowledge creation part, the contribution is to explore how to support the identification and collection of eHealth knowledge through P2P and IoT technologies. P2P technology can support and enhance interoperability among healthcare organizations; with IoT technology, eHealth knowledge can be shared among the involved healthcare actors at home, in the community and also in the hospital, as well as across all these locations. Paper I and II have addressed these issues, which answered RQ1.

In the knowledge codification part, knowledge sharing in eHealth is scientifically represented with a special focus on two important aspects of knowledge sharing in the healthcare area that are often overlooked or downplayed in eHealth systems design and development-The first aspect is the heterogeneous knowledge of different healthcare actors, and the second aspect is the interactivities among various healthcare actors. The contribution is to propose a knowledge sharing ontology on the basis of Activity Theory, which highlights interactions as the very source of knowledge creation and the necessary basis for knowledge sharing and thus supports the construction of more efficient eHealth systems. This has been addressed in paper III, IV and V, which answered RQ2.

In the knowledge transfer part, the contribution is to explore and show how the proposed ATO model can be validated. This is done by building a prototype based on the proposed ATO model. After that, a questionnaire based survey is conducted to practically validate the feasibility of the proposed ATO model. This has been addressed in paper VI, which answered RQ3.

In the knowledge application part, healthcare decision making and appointment scheduling problems integrated with the ATO model have been studied. The contribution is to suggest a smart system called eHealth Appointment Scheduling System (eHASS). eHASS takes into account both heterogeneity aspects and interoperability requirements of eHealth systems, and is capable of jointly considering various appointment characterizations and decision making algorithms

for conducting appointment scheduling. Also, the performance of the system has been validated by using the Markov chains based modeling approach.This has been done in paper VII and VIII, which answered RQ4.

5.3. Paper Specification

All the included papers are written with the aim of to addressing and answering one or several of the four research questions. Specifically, in Paper I, we have interviewed healthcare system administrators and nurses in Blekinge County to gain a better understanding of the contexts of eHealth knowledge sharing issues. Then the interoperability problem between different healthcare systems has been discussed. Based on the interview results and literature study, we defined two layers of interoperability in eHealth. After that, peer-to-peer (P2P) technology was explored as a way to address and if possible solve the identified eHealth interoperability problems. In this thesis, P2P technology is seen as a way to support the creation of eHealth knowledge for sharing, thus this research partly answered RQ1.

In Paper II, the problem of providing effective and appropriate healthcare to elderly who are living at home has been studied. We explore Internet of things (IoT) technology as a way to achieve connectivity with care receivers and care providers. Based on IoT, we have proposed a four-level model including personal-family-community-hospital to provide sustainable healthcare services to elderly. In this four-level model, with IoT, elderly at home can share healthcare knowledge with family members at work, nurses in the community and doctors in the hospital. In this thesis, IoT technology is another way to support the creation of eHealth knowledge for sharing, thus this partly answered RQ1.

In Paper III, we have identified that lack of a shared ontology has been an obstacle to developing efficient support for knowledge creation and knowledge sharing in eHealth systems. We believe that Activity Theory can provide a high level and rich ontology for the developers of eHealth systems to encompass the multidisciplinary and cross-organizational knowledge that needs to be created and shared in healthcare

contexts. Thus, we proposed a knowledge sharing ontology on the basis of Activity Theory. We validate our approach in the end by demonstrating our project IMIS (Integrated Mobile Information System for Healthcare) that uses activity theory as ontological architecture for the construction of eHealth systems. This paper partly answered RQ2 and RQ3.

In Paper IV, based on the ATO model proposed in Paper III, we suggested architecture for developing eHealth system. The architecture has properties such as sustainability, generalizability, and expandability. We demonstrate the properties of the architecture through an ongoing research project. We conclude that this architecture can be widely used to integrate various small scale applications of eHealth systems and to resolve some current design problems such as interoperability and support for efficient knowledge sharing. This paper partly answered RQ2.

In Paper V, we have extended the ATO model proposed in Paper III. In this paper, the ATO model can scientifically represent various health actors in the eHealth system and enhance the interactivities among these healthcare actors for efficient knowledge sharing purposes. We also develop a prototype software system based on the suggested ontology model. The survey results collected from the system users show the feasibility of the developed software system. This paper partly answered RQ2 and RQ3.

In Paper VI, to validate the feasibility of the ATO model proposed in Paper III, three typical use cases are further studied. Then a questionnaire based survey is carried out and the corresponding survey results are reported, together with the detailed discussions. This paper partly answered RQ3.

In Paper VII, based on the proposed ATO model for designing and developing eHealth systems, the appointment scheduling is explored as an important task for the delivery of healthcare service among different healthcare actors. The key procedure is to support decision making on the selection of suitable appointments between the care providers and the care receivers. The appointment decision is a sophisticated problem in terms of how to efficiently deal with various parameters of involved healthcare actors. To solve this problem, we suggest

a smart system called eHealth Appointment Scheduling System (eHASS). eHASS takes into account both heterogeneity aspects and interoperability requirements of eHealth systems. As such, eHASS is capable of combining and making use of various appointment characterizations and decision making algorithms for conducting appointment scheduling. This paper partly answered RQ4.

In Paper VIII, we consider the healthcare system with the heterogeneous CRs in terms of urgent and routine CRs. Our suggested model assumes that the system gives the service priority to the urgent CRs by allowing them to interrupt the ongoing routine appointments. An appointment handoff scheme is suggested for the interrupted routine appointments, and thus the routine CRs can attempt to re-establish the appointment scheduling with other available CPs. With these considerations, we study the scheduling performance of the system by using the Markov chains based modeling approach. The numerical analysis is reported and the simulation experiment is conducted to validate the numerical results. This paper partly answered RQ4.

6. CONCLUSION

The research presented in this thesis is mainly in the field of eHealth, with emphases on knowledge sharing and on two specific application areas, i.e., healthcare decision making and appointment scheduling. To address the importance of knowledge sharing in eHealth, the heterogeneous aspect of eHealth systems is addressed in terms of various healthcare actors and different interactivities among them, along with the interpretability problem when formalizing the knowledge collected from healthcare actors.

The activity theory based ontology model is proposed to represent this heterogeneous aspect in eHealth knowledge sharing. With this model, a knowledge sharing framework is advanced to bridge the gap in knowledge sharing in eHealth and the corresponding applications. The knowledge sharing framework conceptually builds upon the knowledge management life cycle. Based on this framework, two applications, i.e., healthcare decision making and appointment

scheduling are further investigated. In particular, the mathematic tool fuzzy-logic is adopted to deal with healthcare decision making, while the queueing modeling approach is built to analyze the performance of appointment scheduling in the presence of urgent patients issues.

Finally, a web based prototype is developed with the aim of practically applying the activity theory based ontology in eHealth. By deploying this prototype in a hospital, this thesis also reports a survey based evaluation on its use by both care providers and care receivers.

7. FUTURE WORK

In this thesis, knowledge sharing in eHealth has been studied, the future work can be considered in three parts. They are as follows.

The first part regards the intelligent end-user applications that can be integrated with the ATO model, e.g., a wearable sensor, a smart-phone based application. This end-user application is responsible for dealing with efficient information collection from healthcare actors. Designing such software needs to consider problems such as information redundancy, data accuracy, and system robustness as well as safety, security, integrity and privacy issues.

The second part is related to the prototype implementation of healthcare appointment scheduling with different patient categories, such as urgent care. Such a prototype should be deployed in a hospital for further performance evaluation purposes. The evaluation results can be used to validate the corresponding numerical analysis, which is reported in this thesis.

The third part regards investigation of the cloud based architecture that is used for implementing knowledge sharing in eHealth. This architecture should be able to provide both online and offline based knowledge sharing. Furthermore, the feasibility of architecture implementation also needs to be investigated and studied. In addition, we aim to address the security and privacy control mechanisms of the cloud based platform.

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Papers

Paper I -
Using P2P Technology to Achieve eHealth Interoperability

Y.Guo, Y.Hu, J.Afzal and G.Bai

Abstract

eHealth is an emerging area that boosts up with advancement in Information and Communication Technology (ICT). Due to variety of eHealth solutions developed by different IT firms with no unified standards, interoperability issue has raised. In this paper, a case study in Blekinge County healthcare organizations has been conducted for understanding the contexts of eHealth interoperability issues. Then a peer-to-peer (P2P) model based on JXTA platform is implemented to solve the identified eHealth interoperability problems. According to the test result of the prototype, the suggested syntactic level interoperability among healthcare organizations has been achieved.

1. INTRODUCTION

With the rapid development in technology, world is undergoing a digital revolution in the area of Information and Communication Technologies (ICT) [1]. ICT tools are used to find, study, analyze, exchange and present information faster and more accurate. ICT has become the driving force for service organizations and citizens to access, adapt, apply and produce information interoperable [2]. One of the ICT applications in healthcare sectors is healthcare practice supported by electronic processes and communication, so-called eHealth [3]. eHealth is an emerging field that covers medical informatics, public health and business that related to deliver health services and information by using ICT. eHealth makes it possible, for example, for the care providers to have fast and easy access to patient information and connect patient to care providers for home treatment, appointment and seeking of help in case emergency. It breaks the barriers among health service providers from different organizations, so they can work more closely together. ICT can also help care receivers/citizens to have better control and self-management of their own health anywhere world around. Many eHealth technologies such as Electronic Transfer of Prescription (ETP), Computerized Patient Record (CPR), Electronic Health Record (EHR) and Telemedicine are widely used and they have delivered tangible benefits [4].

In Europe, efforts have been made to develop Electronic Health Record (EHR) to support the professionals to work with complex health care, and to provide accounts to simplify managing clinical work [5]. However, a major problem is interoperability among different healthcare organizations. According to the report of US Medical Management Association and Healthcare Information and Management System Society, only 31% of doctors and 19% of hospitals are using Electronic Health Records (EHRs) because system and equipment are not interoperable [6].

In Sweden, responsibility for providing health care is decentralized to the county councils and municipal governments in some cases. In line with Swedish policy, every county council must provide residents health care at a high

level, and work toward promoting good health for the entire population. Municipalities in Sweden are in charge of care for elderly people in the home or in special accommodation. Municipalities also for provide support and services for people released from hospital care as well as for school health care. In order to improve access to health care, Sweden is actively involved in cooperation across the EU. This includes collaborating on specialized care, improving patient safety and enhancing patient influence. In the other hand, the challenges of accessibility, quality, efficiency and funding are confronted in Sweden as well as other EU countries [7].

In Blekinge County Sweden, there are two main hospitals and several healthcare centers using electronic health record (EHR) in their respective systems. Hospitals use SYStem Cross while municipality healthcare centers use MAGNA CURA. These two systems are built in different technology platform. The two hospitals are interoperable with each other but they are not interoperable with municipality healthcare centers. Since these healthcare organizations are decentralized (no one is obliged to share data with others), the exchange of patient information is a problem though it is very needed from citizens (patients) perspective [8].

2. eHEALTH INTEROPERABILITY

General Systems Theory is a response to the failure of mechanistic thinking in the attempt to explain social and biological phenomena in the 50s, e.g., traffic systems, environmental disasters, nuclear threat, drug abuse, AIDS, politic and war, etc. General systems theory is a theory of theories, a law of laws. Kenneth Boulding [13] gave a good description of it:

2.1. What is eHealth Interoperability?

Healthcare interoperability is highly required among different systems in order to exchange of patient data [9]. Making systems and components interoperable will not be only a matter of speeding up information retrieval, processing and delivery among healthcare givers and hence resulting in an efficient care, it will also make the information accessible for

research purpose, diagnoses, treatment and prevention of new disease [10].

According to Brown and Reynolds [11], interoperability on a specific task is said to exist between two applications. It means that one application can receive data from the other and perform the desired task in an appropriate and adequate manner without the need of any extra operator involvement. This definition identifies two layers of interoperability [9].

2.1.1. Syntactic Interoperability
Syntactic interoperability is an application level interoperability that allowing multiple applications with different implementation languages, execution platforms and interfaces to communicate and cooperate for data exchange. Syntactic interoperability only refers to the exchange of data.

2.1.2. Semantic Interoperability
Semantic interoperability means that document is interpretable and the content is understandable by the receiver side. Semantic interoperability helps integrate data from different sources through semantic mediation. Semantic mediation is smart data discovery and integration system using knowledge based query system, which allows integrating disparate data resources.

2.2. Challenges in eHealth Interoperability

To achieve interoperability in eHealth area, some challenges should be faced [9].

2.2.1. Interfacing
Since interoperability among healthcare organizations is needed for exchanging information, the first problem is the interfacing problem. Interfacing is the boundary or layer at which interaction between two systems occur.

2.2.2. Integration
Combining several diverse applications into a relation for collaboration as a single entity refer to integration. This requires implementation of different standards and communication platforms.

2.2.3. Accessibility

Accessibility means that who has the right to access for patient information and at which level. There should be certain levels of accessibility like a patient can only view his record while doctor or nurse can have access to view and update his record after treatment. To cope with this challenge, a proper authentication mechanism need to be applied and certain level of accessibility should be defined.

2.2.4. Security and Privacy

Personal information should be kept private, and even may not be shared with any authority without the consensus of patient. For information security and privacy, healthcare provider should follow HIPAA (Health Insurance Portability and Accountability Act) rules, authentication procedure by allowing only authorized users also should be done.

In this paper, we focus on solving syntactic interoperability among different healthcare organizations. The semantic interoperability needs high level of standard and ontology among healthcare organizations, and will not be discussed within this paper.

3. A CASE STUDY IN BLEKINGE COUNTY

To deep investigating the eHealth interoperability issues, we conducted a case study in Blekinge County, Sweden through interview.

3.1. Purpose of Interview

The purpose of interviews is to gain knowledge about the work of existing systems and problems during communication. The main investigating topic of interview is interoperability among different healthcare centers in Blekinge County.

3.2. Interview Planning

For interview, we searched for contacts of the relevant personals, then sent to them brief emails about the objective of interview and requested for appointment. Three interviews were conducted based on the availability and suitability of interviewees. Two of the interviews in Ronneby from Ulf Danielsson (IT-Adminstrator, Ronneby Muncipility) and Anne

Maire (Senior Nurse, Vidablick Ronneby). The 3rd interview was conducted from Jakobson (Deputy System Administrator, LANDSTINGET Karlskrona). All interviews were conducted in decent manner with full cooperation of interviewees.

3.3. Interview Design

We formulated a semi-structured interview including 30 open-ended questions in the beginning, and reduced them to 12 later on. The reason for this reduction was that some of those questions were already answered through literature or during the interviews form pervious research. Questions were designed in a way to help author for overseeing the vision of the professional about their working experience in the relevant domain. They were asked both in formal and informal mode. The whole session was mainly focused on the interoperability problem and challenges during the communication of systems.

3.4. Interview Analysis

The main objective of this interview is to study interoperability problem between SYStem Cross and MAGNA CURA, solutions to overcome this problem and discuss our proposed design. The same questions were asked to all the three interviewees in order to know different opinions about the same topic.

According to the response, health care centers in Blekinge use MAGNA CURA for healthcare management of elderly and handicapped citizen. These systems are interoperable to communicate and collaborate with each other. However, they are unable to communicate directly to SYStem Cross. There is a need for communication and collaboration between SYStem Cross and MAGNA CURA, when an elderly or handicapped patient is referred to hospitals for medical checkup or emergency. So the main purpose of communication is to exchange patient treatment summary and read some new health relevant information.

4. WHY PEER-TO-PEER

4.1. What is P2P and JXTA?

Peer-to-Peer is a class of applications that takes advantage of resources – storage, cycles, content, human presence – available at the edges of the Internet [12]. To say it in a more clear way, P2P is a way to take advantage of previously unused resources.

According to Shirky, a problem can be solved by P2P, it must have two characters [13]:

● It treats variable connectivity and temporary network addresses as the norm.

● It gives the nodes at the edges of the network significant autonomy.

Peer-to-Peer communication can be achieved by using JXTA technology, "An open source Java based network programming and computing platform for modern distributed computing, especially for P2P networking". It designed by 'SUN Microsystems' to solve the current problems of distributed computing like interoperability, ubiquity and portability and so on. Peers in JXTA set up virtual or Ad-hoc network where each peer in the network cooperate and use resources directly behind firewall or network address translations (NATs) and even on different network [14][15]. JXTA is also a platform independent like TCP/IP and can use features of TCP/IP. JXTA does not rely on a single transport protocol as TCP/IP, but use the features provides by transport protocols. JXTA define six kinds of basic protocols such as Peer Discovery Protocol (PDP), Peer Resolver Protocol (PRP), Peer Information Protocol (PIP) and so on.

4.2. Why P2P?

P2P has some advantages that make it a powerful tool:

● Content and resources can be shared from both the center and the edge of the network. In client/server networking, content and resources are typically shared from only the center of the network.

- A network of peers is easily scaled and more reliable than a single server. A single server is subject to a single point of failure or can be a bottleneck in times of high network utilization.

- A network of peers can share its processor, consolidating computing resources for distributed computing tasks, rather than relying on a single computer, such as a supercomputer.

- Shared resources of peer computers can be directly accessed. Rather than sharing a file stored on a central server, a peer can share the file directly from its local storage.

In this paper, we propose Atomistic P2P model for our health scenario because health is a critical issue to avoid the evolvement for central authority. Fig.1 shows Atomistic P2P model.
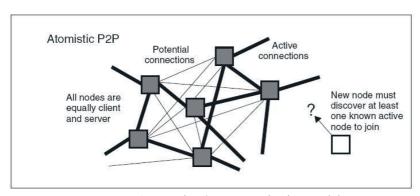
Fig. 1. Automatic P2P communication model

5. VALIDATION FOR THE PROPOSED SOLUTION-PROTOTYPE DESIGN

In our study, we design a prototype for achieving interoperability between different healthcare systems in Blekinge County. Based on the results of literature review and informal discussions, we find that JXTA may be a suitable development platform for P2P communication. JXTA is a P2P-based collaborative approach to deal with sharing services. It is used for the different P2P systems to solve interoperability

problems. JXTA is independent on operating system, network transmission technology and programming languages. It can be used in cross-platform. After the development, we test the domo with different patient data to validate our qualitative study.

5.1. Basic Framework

In order to clarify the scope of the prototype implementation, we design a basic framework of the whole P2P workgroup communication model shown as Fig.2.
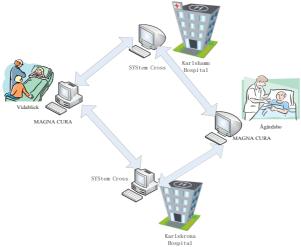
Fig. 2. Basic framework of the P2P model

In this model, every healthcare center is defined as a peer. Every system is connected to the Internet. The following list the minimal basic operations.

- Share their own database to the P2P platform in every fixed time, in our case, share their database to jxta.org.

- When one system needs to find some information of their patients, they send the request. And then if the other system has the information, they will receive the detail soon.

5.2. Scenario for the Prototype Design

For the prototype design, we assume these situations:

- When the nurse at Ronneby Vidablick needs to do some medicine physical therapy, she may need some medicine information of the senior citizens from Karlskrona Hospital. So she inputs the personal number of the citizen in the third P2P communication program as a request, and then she can receive the information from the hospital's database.

- When the doctor in Karlskrona Hospital needs the physical therapy information from Ronneby Vidablick, he does the same processes to get the patient data from Vidablick's database.

Fig.3 describes the scenario of the two different systems which share the patient information.
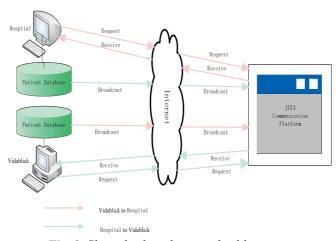
Fig. 3. Share database between healthcare centers

5.3. Healthcare Systems Simulation

We simulated the two mentioned healthcare systems 'MAGNA CURA' and 'SYStem Cross' to validate the proposed P2P solution. The interface of 'MAGNA CURA' and 'SYStem Cross' are shown in Fig.4 and Fig.5.
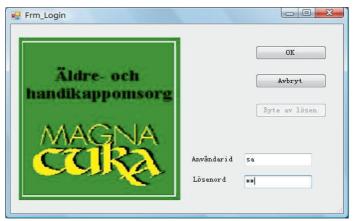
Fig. 4. Healthcare system -MAGNA CURA
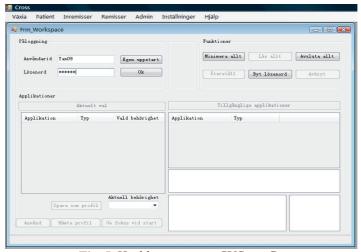
Fig. 5. Healthcare system-SYStem Cross

5.4. JXTA Platform Development

According to "JXTA JXSE Programmers Guide 2.5" [16], we build our JATX communication platform as following steps.

1. Build up JXTA data exchange architecture which is called Pipe advertisement based on XML.

2. Build JXTA group, in this case it is automatically built in Peer Group Net.

3. Set up JXTA data sending mechanism. First, we get the basic information from the database, then the Adv/ send

message is created in the JXTA based data architecture. In the end, broadcast the created Adv/ send message.

4. Set up JXTA data receive mechanism. In the beginning of this step, query data is got, then query is sent and waiting for response. At last, Resolution is done if the query message is received.

5.5. P2P Communication Implementation

In the beginning of the communication, each system broadcasts their database in the third party system. In our case, all data in our peer group is sent to JXTA.org. Fig.6 shows sending data from SYStem Cross.

Fig. 6. Sending data from SYStem Cross

When the nurse who uses MAGNA CURA wants some medicine information from the SYStem Cross side, he/she just inputs the personal number of the elderly citizen. After some minutes, the information of that citizen is shown on the screen. As the same to the doctor of SYStem Cross, he/she inputs the personal number of the patient, the therapy records from the Vidablick is also received. Fig.7 shows receiving data in MAGNA CURA side.
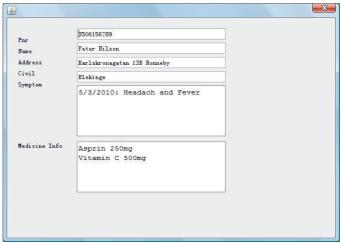
Fig. 7. Receiving data in MAGNA CURA side

In the equivalent situation, if healthcare providers in SYStem Cross need to access the data stored in MAGNA CURA side, in our proposed P2P model, it can be accessed easily in the same way. That's so called Peer-to-Peer.

6. CONCLUSION AND FUTURE WORK

The main goal of the study is to cover current interoperability gaps through proposed solution via P2P communication. We also studied many solutions that provide P2P communication but these are either proprietary or they do not provide eHelath information security. JXTA is the most important technology which is newly developed with a set of XML support and open source protocols. This study finds that it can be used to avoid these concerns. A P2P based prototype was developed with the use of JXTA technology. We tested prototype by making a group of 3 peers, and then patients' information from other peer was successfully received. In this way, we are able to achieve eHealth interoperability in Blekinge healthcare organizations at syntactic level.

However, validation of our proposed solution should be done through the real data and a survey on the targeted population for approval is needed. For the future work, we would like researchers to perform quantitative study by conducting experiments through real data in Blekinge healthcare organizations. Also, the more challenging task is semantic

interoperability since eHealth is a much more complex area that needs a lot of efforts.

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Paper II -
An IOT Architecture For Home-based Elderly Healthcare

Y.Guo, G.Bai

Abstract

The problem of providing effective and appropriate healthcare to elderly and disable people home has been increasingly talked around. Information and communication technology (ICT) is believed to enable home healthcare management to mitigate some problems. This paper is to contribute IoT (Internet of things) architecture to achieve connectivity with the patient, sensors and everything around it. A four-level model including 'personal-family-community-hospital' is constructed in order to provide complete and intelligent health management services to elderly home, which provides sustainable healthcare service for elderly people. This new solution makes both the elderly life easier and the healthcare process more effective.

1. INTRODUCTION

Information and communication technology (ICT) should be able to improve the quality of elderly life and healthcare. However, the progress is very limited comparing to other ICT related application areas, such as business, education, entertainment, etc. There are some identified barriers based on some studies in the field of healthcare.

1) Lack of health information sharing system [1]. Currently, medical information system used by most domestic hospitals is confined within the hospital alone. The medical data information is not shared with the outside the hospital, especially not with elderly home. The consequences of this non-sharable health information are resulting in waste of medical resources, low efficiency of health services, and high cost of health management.

2) Lack of sustainable monitoring and preventive management of health indicators [2]. As a common expression from ancient China saying that "Superior doctors cure diseases before symptom, medium doctors cure diseases during symptoms, and inferior doctors cure diseases after symptoms, the current healthcare management is mainly on treatment of patient after the symptoms of diseases. The lack of preventive and monitoring management process may result in problem to predict many chronic diseases and to achieve sustained treatment effect.

3) The existing healthcare system cannot integrate the multiple needs of healthcare [3]. The current health care system is mostly 'disease oriented', that is, the healthcare system targeting for individual disease paroxysm, instead of the health of the patient. A consequence is that patient's related information (health records or patient journals for example) is sliced according to kinds of diseases and the treatment locations. The multiple needs due to multi-diseases of elderly, especially chronic diseases cannot be integrated by today's system.

4) ICT technologies for intelligent health management are difficult to use [4]. Medical dedicated sensor terminal may be

developed of high precision, but inconvenient and complex to use, and even requiring professional operations. Radio Frequency Identification (RFID)-based small sensing devices could be easy to move and easy to operate, however, they have problems with measurement reliability, transmission reliability, lack of remote monitoring and diagnosis. Other problems, such as reliability, security, instantaneity and technical infrastructure are still not reached a widely accepted status.

5) Problem of security and privacy [5]. How to ensure that personal data is not damaged, leaked, abused, etc. have become major barriers when private home is connecting with many types of sensors, and with multiple networks. When people realize that their every move is detected in by some sensors and can be transmitted to others, the problem of trust is also a crucial factor for acceptance of this kind of technology.

This paper focuses on the system structure of intelligent health management under the IoT environment, which consists of five parts: The first part has introduced the background and analysis the problems existed in intelligent healthcare management field. The second part described IoT technology and related theoretical issues, and detailed describe features of IoT in healthcare. Based on IoT technology, the third part proposed a four-level health management model. The fourth part specified the division of labor and functions at all levels. In the end of the paper, we conduct a discussion of the designed architecture, and provide a point of departure for future research.

2. INTERNET OF THINGS AND HEALTHCARE

The Internet of Things (IoT) is a technological phenomenon originating from innovative developments and concepts in information and communication technology associated with: Ubiquitous communication, Pervasive computing and ambient intelligence [6]. Ubiquitous Communication means the general ability of objects to communicate (anywhere and anytime); Pervasive Computing means the enhancement of objects with processing power (the environment around us becomes the computer); Ambient Intelligence means the capability of objects to register changes in the physical environment and thus actively interact in a process. Typically, objects fulfilling

these requirements are called smart objects [7]. Hence, the IoT is defined as the ability of smart objects to communicate among each other and building networks of things, the Internet of Things. It is expected that the IoT change the web from being a virtual online space to a system that is embedded in the real physical world. Typical characteristics of the IoT are as follow:

a) It creates new independent networks that operate with their own infrastructures

b) It will be implemented with new services and

c) It will apply new and different modes of communication between people and things and things themselves, including Machine-to-Machine (M2M) communication [8].

The key players in enabling the IoT are smart objects, which are characterized by four technological attributes, identification, location, sensing and connectivity. The major enabling technologies for smart objects are Radio Frequency Identification (RFID), Global Positioning system (GPS), developments in sensor networks, Micro Electro-mechanical Systems (MEMS) and further developments in wireless connectivity. The main goals in realizing the IoT will be to provide relevant information in the right format, when and where it is needed and hence to bridge the gap between the web and the real world. Additionally, the IoT will be a key part of the future Internet, which will be made up of the Internet of Services and the Internet of Things [9].

Based on characteristics of health care filed, healthcare IoT can be viewed from following three aspects [10]:

a) "Things" is physical objects, that is, doctors, patients, and medical device etc.

b) "Of" can be explained as Connecting, it is information exchange. The networking standard defined objects are perceivable, can be interactive, can be controlled.

c) "Internet" is the process. The concept of IoT in healthcare must be based on standardized medical procedures. The concept of IoT must be elevated to a process.

The world population is rapidly ageing: the number of people aged 60 and over as a proportion of the global population will double from 11% in 2006 to 22% by 2050. By then, there will be more old people than children in the population for the first time in human history [11]. Internet of Things type of applications can improve the living conditions of these older people and allow them to stay longer independent and residential. This poses, however, various challenges related to privacy, respect for liberty, dignity and autonomy.

Applications that appear already on a large scale are monitoring systems such as sensors in exit doors that give warnings about undesired "movements", or devices that make it possible to localize elderly. These new applications mark the need for solutions that protect senior citizens from ethical and privacy risks because of misuse and abuse of these IoT applications. IoT is supposed to being capable of providing all characteristics necessary for an ambient assisted environment [12]. With respect to the fields of needs for elderly, it is possible to accomplish all fields through the IoT. The monitoring of chronic illnesses (health), on-demand provision with fresh food (safety), alarming systems (security), reminder services (peace of mind) and enabling people-to-people communication for instance with relatives (social contact) without recognizing the technology behind it.

3. FOUR-LEVEL INTELLIGENT HEALTHCARE MANAGEMENT MODEL BASED ON IOT

In the traditional model of healthcare services, the patients are hospital-centered, while the service of doctors and nurses shall be based on information system software in the hospital [13]. Therefore, "difficulty and costliness" has troubled the patient for a long time. Under the internet of things model, IOT-based intelligent healthcare management system focuses on the patients and the medical resources including doctors, nurses and medicines target at the patients. This greatly improves the medical quality, service quality and operation level of medical

organizations. Meanwhile, it also improves operation efficiency, reduces costs, and increases transparency between healthcare providers and receivers.

The traditional hospital-centered healthcare management model enables the residents to automatically deliver at home the vital signs data collected to the doctors through a home videophone. Service platform medical resource mainly provides general practitioners for remote advisory services, and offers residents with nearby services and community family physicians for chronic disease management. In addition, it also supplies the residents with registration service by appointment. Service platform integrates into family health services, intelligence community services and living consulting services to create "a key intelligence community life" model.

However, as such model belongs to integrated community services, health management is just one kind of such services. Meanwhile, as vital signs monitoring, collection and data support of chronic disease management can only be conducted at homes of residents, such model has some limitations. Health Management focuses on managing health service of whole life. The so-called health service of whole life refers to a kind of health management concept, which monitors on the real-time basis and dynamically counts health parameters according to vital signs parameters of a person in different life periods, timely analyzes and calculates the changed parameters, timely intervenes the parameter variations harmful to the health. It is a ubiquitous health management model at any time.

Combing with the traditional health management model, the individual-Family-Community-Hospital four levels health management system model is proposed to provide a certain reference for intelligent healthy management. This model is based on personal mobile health and is designed for healthy management of health service of whole life.

4. SPECIFICATION OF THE IOT HEALTHCARE MANAGEMENT MODEL

In the four-level healthcare management model, functions vary from each level. Health data needs to be shared through community platform to achieve real-time sharing of health records with family physicians. The model at community level highlights gathering, analysis and feedback of health data collected, timely feeds back abnormal physiological data collected, notifies family or individual and makes appointments with family physicians for on-site service, etc. The model at hospital level integrates personal data and real-time data reporting cases provided by the Community Service Center and links with HIS system to achieve remote medical service, real-name registration for appointments and other medical services.

4.1. Personal Healthcare Model

Personal mobile health refers to a kind of means to monitor and record human health by using mobile network technology. The mobile health includes three concepts, namely, intelligent terminal, health data management and related matching resources. The above forms a harmonious system. Both simple digital medical philosophy and internet of things-based medical architecture focus on mobile medical field. There are four main points for mobile health: First, collection of physical body data. Second, auxiliary programs related to health and fitness. Thirdly, provide medical advices without a large number of treatment means and data. Finally, provide follow-up services after hospitalization, including disease investigation and remote detection.

Implementation of health service of whole life depends on completion of personal movement. Under the medical internet of things environment, the patients are focuses of health management. Thus, it is necessary to ensure that the patients can collect, process, transmit and analyze healthy data anywhere and anytime under non-fixed healthy testing environment other than hospitals, communities and families. Therefore, personal mobile health management is the core to achieve the healthy concept management of health service of whole life. As shown in the Fig. 1:
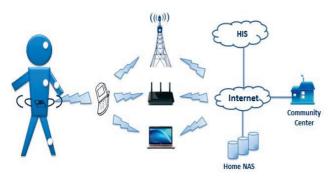
Fig.1. Schematic diagram of personal health model

4.2. Family Healthcare Model

Development of sensors and internet of things technology makes medical testing equipment smaller and more powerful. Regular health monitoring can be completed at home. By using existing Internet environment, family members health data will be sent on the real-time basis to healthy data centers and analyzed via cloud computing. Finally, healthy management of health service of whole life is achieved after community health services, remote medical services and other services system are combined.

For patients, this means more and more convenient medical treatment, fewer and fewer outpatient visits and lower and lower medical costs. However, in order to make use at home, home health care equipment must be simple and safe for operation, allow the wrong use, and be able to distinguish the correct results with the results from the wrong order.

Such design experiences, especially some devices, are useful for execution of the new generation of home medical fitness equipment. When this technology is jointly used with high-performance instruments, instrument grade sensors and data collection devices, the final product can be built into the medical grade system and be easily placed at home. Of precision semiconductor products, reliable high-performance sensors, amplifiers and data converters, can be used to extract precise signals and converts them into digital; embedded processors can be used to analyze the collected signal on a complex basis. See Fig. 2 for family health management model:
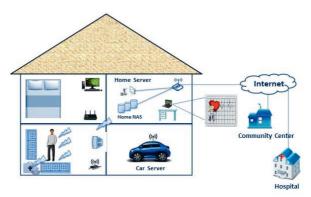
Fig. 2. Family health management model

4.3. Community Health Service Model

Community Health Service is a very complex system with a large amount of information required for processing. It is a feature of health care information processing information technology industry and requires a high degree of information sharing integration. A new architecture and pattern is created by using the characteristics of cloud computing. The service platform is composed of three levels: 1) service management. Its primary task is to enable computer system and regional networking to process health information in the cloud platform. 2) Regional application. It must be changed as a virtual application to run on the platform, rather than to run on each computer. 3) Virtual resource. The so-called virtual resource is the server, storage, and networking. It shall be made as a backstage, in a bid to provide more virtual resources to different people. Therefore, cloud computing can be decomposed into a number of different applications, such as public cloud, private cloud , community cloud and so on.

IoT-based community health management is based on personal electronic health records, internet of things and cloud computing technology. It is designed to create a health management platform between resident and community service centers and hospitals and telemedicine. The platform uses remote life signs monitoring, sensitive disease indicators monitoring, remote health management, health housekeeper video communications, telephone communication platform etc., to manage files related to the family member's health indicators and provide "health service of whole life health

management " for family members with chronic diseases. In addition, it can be also used to identify potential health risks, prevent and treat simultaneously such risks to protect the health of residents. Under the community health service platform where the dynamic detection is featured, hospitals emphasize treatment, and communities focus on underlying service. Family and mobile management is based on different situations where people are situated. This platform is committed to enhance and improve the residents' medical experience, optimize the use of medical resources. In addition, being people-centered, it is designed to meet healthcare demand of people at different levels. It takes health management as the starting point, to achieve "prevention first, prevention and treatment combined" and "minor illness in the community, serious illness in the hospital, rehabilitation at home". By doing this, it can effectively use medical resources, improve service levels, alleviate the "difficult and expensive treatment" problems, while alleviating the enormous pressure on medical institutions.

4.4. IT Model of Hospital Health Management

4.4.1. It Management

Health care industry is an industry where the mistakes are not allowed to be made. Its service quality is directly related to the health. As a special commodity for life-saving, the medicine is closely related to the user's life. In the medical industry, the radio frequency identification technology can be utilized to track and detect patients, drugs, medical devices, and medical wastes, etc. Correct and effective patient identification is used to reduce medical malpractice and improve the medical management. Each patient hospitalized will wear a RFID wristband. The wristband stores the patient-related information, including personal information, drug allergies, and other important information. For more detailed information, go to corresponding database via can be electronic code on the electronic tag.

In the current HIS in the hospitals, there have been records about basic information of each registered patients. However, such information does not always go along with a patient. The medical staff can only log in a computer terminal to check the

accurate information of the patient. With a simple RFID smart wristband, the medical staff can know accurate information of every patient anywhere and anytime via the handheld terminal reader.

4.4.2. To Improve the Efficiency of Patient Visits

ID card of the patient is solely bound with RFID medical card. There are three ways for registration: scanning on the card reader, self-help, or manual registration, confirmation of remote registration information on the terminals. Doctors' consultation process is based on the hospital's existing HIS, LIS and other systems. Via system expansion, the followings can be provided: consultation content is stored in the data sharing platform through health center; patients can check treatment information via information releasing platform at any time, or authorize the health center to monitor their health indicators; upon comparison with past medical cases, the information can be automatically fed back to hospitals for timely patient follow-up. This can maximize treatment efficiency and avoid the cases where the patients have to line up for five hours in the hospital while it only takes 5 minutes to complete the process of seeing doctor.

4.4.3. Positioning of Patients

By using specially designed wristbands, the patient' personal data is stored in the wristband, which is put on for 24 hours to effectively fast position and monitor the patient at any time. Monitoring the life state of a patient can be achieved by inserting various sensors and small sensors into RFID wristbands. When reading the information of the patient, the medical staff can also timely obtain real-time information about physiological state of the patient, which can release from all kinds of complicated routine examinations and save valuable time for timely treatment.

4.4.4. Medical Equipment and Waste Tracking

During treatment, medicines and equipment required for patients can be identified and monitored via the patients' RFID tags. This will eliminate misdiagnosis due to wrong medicine prescribed and used to implement all quality records throughout the entire treatment process. Disposal of medical

waste should be monitored to prevent the reuse of disposable devices and environmental pollution due to medical waste.

5. DISCUSSIONS AND CONCLUSIONS

IoT is building a dynamic network of world's objects, which is connected by the internet and sometimes designated as the network of networks. Focusing on the health management objective of "health service of whole life," this paper presents four-level intelligent health management system model of individual-family-community-hospital based on IoT technology. Meanwhile, it designs in detail the requirements on health management, features and functions of individual, family, community and hospital models, plans hardware and software, network architecture and security design requirements in the system model to be more in line with features of the IoT intelligent health management. In the future work we will mainly work on implementing a prototype of the approach and evaluated by different methods. Some artificial intelligent techniques for diagnosis can also be used in this framework to make people home healthcare easier and more effective.

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Paper III -
Activity Theory Ontology for
Knowledge Sharing in eHealth

G. Bai, Y.Guo

Abstract

Knowledge sharing has become an imperative and challenging issue in the eHealth field for improving total quality of services. However, since the eHealth subject is a multi-disciplinary and cross-organizational area, to have shared concepts, vocabulary plus a specification of its intended meaning, namely an ontology, has been an obstacle to develop eHealth system. We will in this paper propose a knowledge sharing ontology on the basis of Activity Theory. We believe that Activity Theory can provide high level and rich ontology for the developers of eHealth system to encompass the multi-disciplinary and cross-organizational knowledge. We validate our approach in the end by demonstrating our project IMIS (Integrated Mobile Information System for Healthcare) that uses the activity theory as ontological architecture for the construction of the whole system.

1. INTRODUCTION

Knowledge sharing has become a very important resource when knowledge needed for conducted services is extended outside of its own organization. In the eHealth sector, sharing knowledge can realize potential gains and is critical to surviving and prospering in a competitive environment [1]. Knowledge sharing in the eHealth sector has become crucial for patient treatment, since the practitioners are required to be research-oriented, creative in healthcare, and ready to take new medical knowledge opportunities that can be acquired through various organizational learning mechanisms[2]. Despite its importance, sharing knowledge is not easy to implement. Knowledge sharing is a fragile process due to the nature of knowledge (explicit, tacit, private, collective, etc.) and people's diverse intentions. Moreover, knowledge is often considered as a valuable asset which is perceived as a source of power and reputation within a social setting. People may be reluctant to share this asset to avoid the risk of losing their power. Sharing knowledge brings some extra costs as well; one needs surplus resources (time, money etc.) and the means to share knowledge (IT infrastructure, meetings etc). Several reasons can be cited but the most limiting factor has been the poor connectivity between a company and its customers and also among the customers themselves [3].

A most important problem in eHealth is that there are usually different organizations or individuals, hereafter called 'care providers', providing similar or related services to the same group of people, hereafter called care receivers. These various services and applications in different organizations use different vocabulary, concepts, models, etc. and lead to the difficulty of sharing knowledge and problem of interoperability. For example, in Sweden the hospitals of county councils, municipalities and other social organizations all provide healthcare for elderly who have chronic problem. They have to share their knowledge about the elderly in order to cooperate with each other, however using their own disparate systems which are not able to communicate with each other. Therefore, it is very crucial for eHealth systems designer to find a strategy to deal with the diversities in the healthcare information system development. A shared

ontology may be a necessity to start with this strategy. Ontology, from technological aspect, is "an explicit machine-readable specification of a shared conceptualization" [4]. Ontology is "a specific artefact designed with the purpose of expressing the intended meaning of a shared vocabulary", "a shared vocabulary plus a specification of its intended meaning" or "a specification of a conceptualization". Ontology may be utilized to promote knowledge sharing within organizations or inter-organizations.

In this paper, we will briefly define the ontology problem existing in the current knowledge sharing activities in eHealth. Then we introduce the activity theory to provide a basic conceptual network as an ontological architecture for eHealth system design. Finally, we demonstrate our approach by our IMIS project to validate our approach.

2. KNOWLEDGE SHARING IN EHEALTH

2.1. Knowledge in eHealth

Knowledge is the whole body of data and information that people bring to bear to practical use in action, in order to carry out tasks and to create new information. Electronic Health Record (EHR) is the most discussed knowledge in eHealth. According to Iakovidis[5], clinical information contains medical record of patient which is stored in digital format. This clinical information objective is to provide chain of care and learning for research purposes. Moreover this information is stored in structured and unstructured documents in a variety of formats. EHR can store different types of information for a patient like different lab reports, images, treatments, and patient identification number [6]. Many countries are trying to provide solution to their health care services. In this regard some standardized organizational and technological infrastructure is used to provide basic factors for introducing EHR [7]. According to Jian-Cheng Dong etc. [8], The EHR is an electronic history record produced directly in personal health-related activity and worth keeping for future reference to health care management and clinical decision-making. There have been many efforts in building and designing the content and structure of the electronic health record. Moreover

this emergence of EHR brings new challenges in the field of medical informatics.

2.2. Sharing Knowledge in eHealth

Knowledge sharing is an activity through which knowledge (i.e. information, skills, or expertise) is exchanged among people, friends, or members of a family, a community or an organization [9].

Organizations have recognized that knowledge constitutes a valuable intangible asset for creating and sustaining competitive advantages [1]. Knowledge sharing activities are generally supported by technology, such as knowledge management systems. However, technology constitutes only one of the many factors that affect the sharing of knowledge in organizations, such as organizational culture, trust, and incentives.

To be specific, some issues of knowledge sharing between different healthcare providers are:

- To have access to distributed clinical information at any place with any time.

- To have access to different information communicating tools (ICT) based services.

- Doctor and patient both can consult with each other.

- Patient can access his/her electronic health record.

There are many standards to address clinical knowledge among healthcare organizations. The main objective of these standards is the exchange of clinical record by defining some structures and markup. Studies about these standards are focusing on the structure and the content, functionality of the requested retrieval of the record, complementarities of different standards and how they influence in the market relevance [10]. In the absence of standardized and sharable clinical information we can have lots of problems in different aspects [11]. Many countries are trying to develop and utilize health care information for providing different services. So it

is even important to build up a high and global level model for knowledge sharing among nations, since people are now traveling more and more crossing the border and they need healthcare services no matter where they are.

Different standards in the local level will exist since the varieties of the specific services are impossible to be unified and standardized. The eHealth system must allow the local level flexibility and able to encompass the varieties. Meanwhile the eHealth system must provide a sharable platform to allow different standards to communicate each other and able to share knowledge. This requires a high level and recursive model and ontology to guide designers constructing the eHealth system. We have found that activity theory can provide such a solution, and we propose it as an ontological architecture for constructing eHealth systems.

3. INTRODUCTION OF ACTIVITY THEORY

The cultural-historical theory of activity, also known as Activity Theory (AT), is a framework of knowledge that seeks to explain the unity and inseparability of subjective mind and the objective human practice [12]. The origins of the theory can be found in the work of the Russian developmental psychologist Lev Vygotsky[13], Aleksei Nikolaevich Leontev[14], and especially further expanded by Engeström[15]. In Activity Theory, activity is the basic unit that preserves the essential quality behind any human practices. Engeström developed a triangle model based on previous work by Vygotsky and Leontev to recapitulate and visualize the components and relationships that compose an activity (Fig. 1). A philosophical discussion about the model and relationship can be found from [15], and will not be discussed here. We just take up some points that contribute to the purpose of constructing ontology for eHealth system.
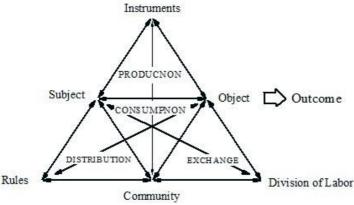
Fig.1. Engström's model of activity system

An activity is always conducted by some goal-oriented actors, a subject, directed towards an object or outcome that is being transformed. According to the theory a basic feature of human activity is the use of artefacts/instrument as mediation. Much of human interaction with the world is mediated through various artefacts/instrument. This triple relationship is represented in the top part of the triangle (Subject – Instruments – Object – Outcome). The subject and object are related to and members of a community that is shown in the bottom part of the triangle. The Division of Labour between the Object and the Community is to specify responsibility of the Object's all needs. The Rules are to legitimize the actions of the subject actors involved in the activity [16].

Activity Theory has become a focal point of interest recently among developers of Information Systems (IS) [16,17]. In this paper we are using Activity Theory as a framework to develop knowledge sharing ontology for Healthcare System.

We specialize the work activity of a doctor (Subject) working at a healthcare center for elderly (Object). The outcome of the activity is to cure the elderly from their health problems and illnesses. The instruments include such tools as EHR, X-rays, laboratory, and medical devices - as well as partially internalized diagnostic knowledge and treatment-related concepts and methods. The community consists of the staff of the clinic, other collaborating clinics and hospitals, municipality's home nurses. The division of labor determines the tasks and decision-making of the physician, the nurse, the

nurse's aide, and other employee categories. Finally, the rules regulate the legislate actions taken by the doctor, use of time, the measurement of outcomes, and the criteria for rewards, etc.

If we take the point of view of another subject in the community, for instance a nurse in the same elderly healthcare activity, the model will keep the same, however, only the contents will be different. Also, if we take the elderly as the subject of the activity system, their object will be the healthcare providers, which include doctors, nurses and other staff in healthcare center. Yet, they share the same architecture/model. This property of the model that is applicable in different levels and for multiple actors is a recursive property. Recursive property of a model can be used for constructing a system for multiple users in different organization levels which is exactly the case for eHealth system.

4. IMIS: KNOWLEDGE SHARING PLATFORM BASED ON THE ACTIVITY THEORY MODEL

We believe that the above activity model composes the most important ontology and related knowledge for various human social activities in general and healthcare activity in specific. In the following, we demonstrate how to use the ontology in constructing a knowledge based healthcare system to validate our approach.

The project 'Integrated Mobile Information System for Diabetic Homecare (IMIS)' is a project financed by VINNOVA (The Swedish Governmental Agency for Innovation Systems) from 2001-2001 and 2003-2006. IMIS is to integrate both healthcare providers (such as hospital care, primary care, home care, and school care) and healthcare receivers (especially chronic, diabetic, and elderly care) into a web based and mobile platform in order to increase healthcare interoperability, integrity, mobility for both sides.
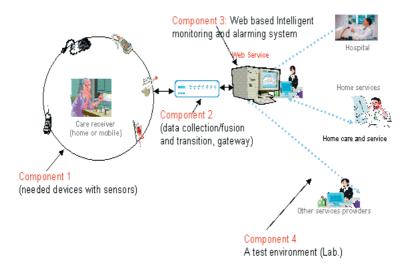
Fig. 2. The architecture of IMIS – integrated platform for both care providers and receivers

The proposed architecture is shown in the Fig. 2. The focus for the IMIS is the construction of component 3: a web based intelligent monitoring and alarming system based on ontology of the activity theory model.

4.1. System for Both Care Providers and Receivers

Very common for today a system is either developed for users as care providers (hospitals system, homecare system) or users as care receivers (patient self-management) separately. However, according to our suggested activity model, the two are inseparable to each other in conducting healthcare activity. Therefore our designed system integrates the two independent parts (subject vs. object) into one system, and makes the subject-object relationship as a mutual and reciprocal one another.

Through registration (Fig. 3), the users (either care providers or care receivers) define their specific role in the activity, such as doctor, nurse, home assistant, relative, parent to a child who has diabetes, or elderly. Accordingly there will be a certification management to validate the specific role the user's input. After successful registration and validation, the role of the user will be the key to decide which information is relevant, and what user interface should be used, etc.
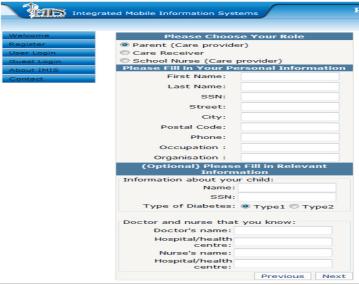
Fig. 3. User's Role Registration (e.g. shows as a parent's role)

4.2. Subject Login & Auto-recognition of Role's System

When a user is successfully registered and verified his/her role in the system, the user can get into his/her role system by name and password. The system will automatically direct the user to the role's system accordingly. Fig. 4 shows the user Christian Persson as a school nurse logs in.

Fig. 4. Login as predefined role – Christian is a school nurse

It is always team work in conducting an activity. One member must know well about his/her team members in order to share information and responsibility about the targeted object. In this case, Christian needs relevant contact information about all other members (Fig. 5). Especially, in a shift work to take

intensive care about an elderly, knowing former and successor's work situation and keep tracking some happenings are vital to patients/clients life.
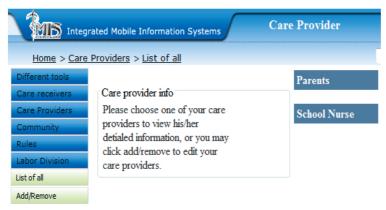
Fig. 5. Christian's team info. as a collective subject

4.3. Various Tools for Conducting Healthcare Activity

Tool is one of the most important artifacts mediating the relations or contradictions [18] between a subject and object, in this case, care providers vs. receivers. The usefulness and fitness of the tools in relation to the tasks and the users are vital to success. The tools must be subject/users oriented according to the different role in the healthcare activity. In our example in Fig. 6, the school nurse Christian could have tools such as message board/e-mail, booking calendar, diary of his care receivers, various tools for diet, and many more can be added when he feels needed. There will be different tools available for different roles and individuals dependent on the login key.

Fig. 6. Various tools for Christian's nursing work

4.4. Knowing the Object

 Knowledge about the targeted object, in this example, the care receivers, is certainly a necessity for achieving some expected outcome/goals. The knowledge can be for example, health journal, diets, relatives, daily practice, and history that is relevant to health (Fig. 7).
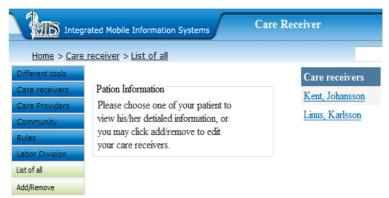
Fig. 7. Knowing the object/care receivers

4.5. Connecting the Social Network as Community

All individuals will share some interests and knowledge with some other people who create an autopoietic (self -creation) network, namely a community. This is especially helpful for parents to exchange experience and obtain knowledge when their child first time gets diabetes. This community is also very helpful for elderly to feel connected with society and friends, to avoid the loneliness and repression. Fig. 8 shows a network/community for a parent.

Fig. 8. Community – a social network sharing the same interest

4.6. Shared Responsibility – Labor Division △.

A contradiction in all modern societies is that on the one hand the more and more specified labor divisions and on the other hand the complexity of different health services that requires a systemic and integrated approach in order to meet the multiple needs. Knowledge about who is responsible to what, i.e. the labor divisions, is thus crucial. Whenever a need of the care receivers is not served, there will be a responsible division to take action or new measures to meet the need. For example, in Sweden elderly care is normally shared by county council/hospital and the municipalities/home services. A clear labor division between the two organizations is not always possible especially when an elderly home has sudden heart failure after some chronic diseases. The transferring process of the elderly must be well specified and also co-operated. Under some critical situation, some overlap must exist in order to secure human life.

The labor division is an important knowledge in our system, and very dynamic co-constructed through a laboring process. We will not give the screenshot of this part since most contents are context specific.

4.7. Complying with Social Regulations △

Health services are extremely sensitive related to various regulations, laws, and protocols, since it is life critical system. eHealth is relatively new kind of service and information about care receivers is the fundamental resource to implement e-services, such as digital receipt, remote consultancy, remote monitoring. All the services are based on personal information and identity. To whom and what information should be accessible is often regulated by various laws and regulations, for example, the law of personal number (identity) in Sweden. When a service provider is providing with a service to a receiver, he or she must know what is allowed and not allowed according to different regulations, including costs/services regulations, need assessments regulations, etc.

The knowledge about different regulations and laws is very crucial and yet very difficult to remember all. Then it is very important that the IMIS can provide this knowledge as

reference to all care providers for conducting service activity. Again, we will not present the screenshot here for the sake of clarity.

4.8. Evolutionary Development with Embedded Feedback Learning Mechanism

eHealth system is a very complex and dynamic system, and cannot be designed as one shot business. Therefore an evolutionary development must be adopted in order to take care of dynamic needs, new technologies, and new tools. We have created an embedded feedback learning mechanism to support this evolutionary development [19]. Under each functional page of IMIS, there is a feedback box that the users can open and write directly their suggestions to the designers. Since the suggestions are always linked to the current page where the users are oriented, it is very direct for the designers understanding the suggestions. Fig. 9 shows an example how Christian suggests the designer to add a new function text field as 'door code'. Since recently many elderly homes have installed new digital lock, and the IMIS has not predicted this need. After the designer received this suggestion, it takes minutes to implement this desired, yet not able to know before, function for Christian.

Fig. 9. Embedded feedback learning mechanism

5. DISCUSSION

This paper basically explores an ontology framework for knowledge sharing based on the Activity Theory. The purpose of this paper is to provide the eHealth system designer a platform that can be used to integrate and share knowledge among all actors involved in the healthcare activity. Concepts and principles from Activity Theory as ontology for knowledge sharing are in an abstract level, and will not replace the local levels of different organizations and even not the levels discussed in agent technology. We find out through our studies that Activity Theorists are consistent with Agent Technology researchers in the abstract level. However, how to technically design and implement each knowledge component in our knowledge sharing ontology is left for our future research, which will be based on this approach. Conclusion

We believe that an agent approach can improve the collaboration problem in the diabetic healthcare. A holistic analysis on the diabetic healthcare provides a three level view. On the collaboration level, the accessibility and interoperability problems are analyzed. The MAS coordination techniques are used to solve the accessibility problem. And the agent communication using predefined ontology can improve the interoperability problem.

ACKNOWLEDGMENT

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Paper IV -
A General Architecture for Developing a Sustainable Elderly Care eHealth System

Y.Guo, G.Bai

Abstract

Based on some identified problems and challenges to the current healthcare system, this paper proposes architecture for developing eHealth system to meet the challenges of knowledge sharing. The architecture is based on a solid theoretical model of human activity, and it has properties such as sustainability, generality, and expandability. We demonstrate the properties of the architecture through an ongoing research project. We concluded that this architecture can be widely used to integrate various small scale applications of eHealth systems and to resolve some current design problems such as interoperability and knowledge sharing.

1. INTRODUCTION

There is a well-known fact that the proportion of people aged 65-and-older is increasing quickly. The prediction of World Health Organization (WHO) shows that the ratio of elderly is from 7.6 percent of total population in year 2010 to 16.2 percent in 2050 (Fig. 1). Meanwhile, more and more elderly are living with chronic conditions that need long term and ongoing healthcare, preferably in their home [1]. This trend will continue more dramatically among fast developing countries, especially in China. China is the country that is called getting aged before getting rich. Though the current chronic disease prevalence is notably lower in China than in western countries, the numbers are rapidly increasing, with an estimated 80 percent of total deaths and 70 percent of disability attributed to chronic diseases in 2005[2].
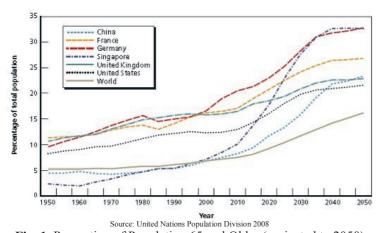
Source: United Nations Population Division 2008
Fig. 1. Proportion of Population 65 and Older (projected to 2050)

Elderly are the largest consumer of healthcare. Generally speaking, elderly consumes three times healthcare resources as much as than other groups [3]. From economic dimension, the healthcare sectors are under great pressure of limited financial resources and man power resources, lack of qualified doctors, nurses, and home healthcare staffs. This is more serious for countries that aging populations are quickly increased before social welfare system well developed and established.

Against this background, there is a growing concern about sustainability of the current healthcare delivery system. The

current healthcare delivery system is historically based on the traditional needs to deal with mainly short and episodic treatment, like infection treatment by hospitalization. When elderly care moves across home and different care organizations, a big problem to the current healthcare system is little continuity, lack of interoperability, and knowledge sharing among those care-providers. After seeing the doctor, patients are discharged from hospital, and the hospital normally doesn't communicate with home health providers. There is no one within the care providers to ensure care in the home is appropriate and meshes well with the broader plan of care for that individual. Patients are likely to "ping-pong back and forth between providers" and no provider takes responsibility for how care is coordinated [4].

Technological advances, especially Information & communication technologies (ICT) related biomedical technologies have pushed the frontier of healthcare into the home settings [5]. Tools as integrated of monitoring with therapeutic systems, educational content in the Internet, and data sharing between healthcare sectors are all driving the healthcare frontier towards home settings. The ICT thus provides the healthcare branch with a new possibility to meet the challenges, namely eHealth.

2. WHY EHEALTH

New challenges and possibilities mentioned above have caused the healthcare organizations try to transform current paradigm of healthcare system which is based upon a 'provider driven' model into a 'patient-centric' system. With the development of ICT, healthcare practice supported by electronic processes and communication, so called eHealth, can be a potential solution to this transformation [6]. EHealth can empower patients to self-manage their health to a great extent and help shift care from high cost of institutional and hospital settings to patients home [7].This shift would be consistent with fundamental culture changes with respect to that elderly wish to live in their home as long as possible, and as independent and active as possible. The benefits of eHealth can be summarized as the following three points [8]:

2.1. Information Sharing

By using ICT, the diagnosis and treatment information can be shared instantly between patients and those who may be concerned, like the doctors, nurses, care providers, and the patients' families, etc. During the whole treatment process, the information concerning the patients' symptoms, the treatment solutions applied, and the effectiveness of such solutions, etc, can be shared instantly among different medical establishments, thus the efficiency in making up new workable treatment solution will be greatly improved. Meanwhile, the instant communication technology can also help doctors from different locations to discuss the treatment plans online, and then give instructions to the patients, doctors, or those who may happen to be around the patients for operation. Lastly, with the network set up, patients can share their experience and treatment solutions online with those who may be suffering from similar symptoms. With such practice applied, the efficiency in sickness treatment can be highly improved.

2.2. Effective Healthcare

During the whole treatment process, the patients may be transferred to different care providers for treatment of different purposes. The role for different healthcare professional may differ dramatically. Without a clear definition for the role players and a good management for the activities involved during the whole treatment process, the patients may miss the best time for medical treatment.

EHealth system can provide with a clear role allocation and activity workflow concerning different treatments and coordinating different parties. Elderly can better understand their process during the whole treatment. With knowledge of the process, the patients will be more willingly to make an active participation, and hence to increase the effectiveness of healthcare.

2.3. Patient Oriented

In the past, due to the lack of knowledge about their symptoms and the effectives of the various medical treatment solutions, patients were rendered in an inactive role. Most decisions are made by the doctors or healthcare professionals. With the

information shared in the eHealth system, patients are now getting more ideas about how to manage their health. The opinions proposed by the patients will be coordinated with that from the healthcare professionals. Thus a solution will be worked out with a more focus on the patients' needs and their personal demands.

Different from traditional healthcare systems, eHealth provides continuous healthcare both in hospital and at home. In next chapter a spectrum of eHealth solution for elderly will be introduced.

3. A SPECTRUM OF EHEALTH SOLUTION FOR ELDERLY

EHealth, telemedicine, health informatics in many cases are interchangeable synonyms [9], and in this paper, we use eHealth as a general term to cove this broad area. EHealth is defined as the use of information and communication technology, such as computer, Internet, mobile devices, to improve or to enable health care services [10]. It spans a broad spectrum from mobility support, diagnostic and therapeutic tools, and self-management related to knowledge consulting. From technology used and interactive properties, the author specifies eHealth into three levels when it is applied to elderly healthcare.

First Level or stand-alone: Devices are single purpose (e.g. blood-pressure meter, blood-glucose monitor) without connection to Internet (possibly connected to a home computer). The devices are well accepted by users, but with limited impact to the healthcare sectors (passive therapeutic and self-management functions).

Second level or one-way connected system: Devices are connected to computer and internet, but only sending data from patients to some third party database servers or to professional healthcare providers (e.g. alarm system, telemonitoring system). Patients can get advices and education materials from some internet server, but without interactivity and personal oriented services.

Third level or interactive connected system: devices are connected via internet or wireless to personalized services with therapeutic decision support. The system should have intelligent, proactive, and preventive functions with trusted feedback and juridical responsibility of the healthcare providers. It is this systemic solution that can change the healthcare paradigm from today's provider oriented delivery system to patient centric healthcare system.
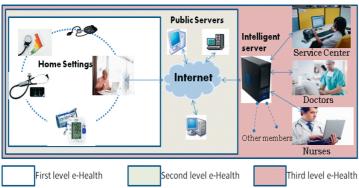

Fig. 2. The three-level of eHealth system

The three-level of eHealth system is demonstrated by Fig 2. The first level system is quite matured in the market and mostly is covered by social insurance or willing to be paid by privates. The second level of eHealth system is mostly mentioned in the literatures or industries. It is not yet well accepted, not matured in the markets, and not covered by social insurance. The third level of eHealth system is the future system, and needs a systemic implementation and paradigm change. Only through this kind of systemic solution can we achieve a fundamental improvement to the current healthcare system.

One good example of the third level of eHealth system is demonstrated by a project so called 'Telecare services' in Taipei city [11]. The system provides 328.000 people over 65 with remote care, mobile applications, and location-based services. The system enables patients to keep track of their own vital signs (blood pressure, blood glucose, pulse rate, etc.); it also allows the Telecare Call Center to monitor the health of subscribers, taking necessary steps when detecting abnormal readings (Fig 3).
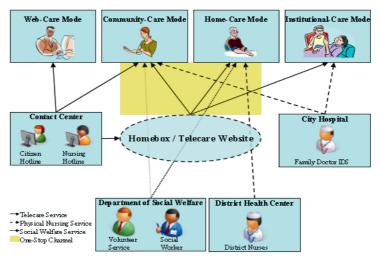
Fig. 3. Telecare service systemic architecture

The implementation of 'telecare service' system has adopted a systemic approach by involvement of actors from all social-economic-technological departments, such as Department of Health, Department of Social Welfare, Department of Information Technology, Legal Affairs Commission, Taipei City Hospital, and 12 district health centers. Without this multi-involvement by actors from all relevant departments, it will be not possible to implement the eHealth system. The author deeply believes that one key factor of success for the complete eHealth solution is to apply systemic methodologies, process, architecture, and involvement of stakeholders in developing the system. In this paper, the authors propose architecture for the third level eHealth system design based on an Activity System model, which is stem from cultural-historical development psychology. A systemic architecture based on an Activity Theory model will be introduced in the next chapter.

4. WHY ACTIVITY THEORY MODEL AND HOW IT WORKS

Many studies pointed out a lack of consolidated theoretical approaches for identifying sustainable platform and vital components for developing eHealth system [12]. Without a general and shared architecture for developing eHealth system, many efforts can lead to a short and fragmented project, and difficult to evolve to a systemic and sustainable eHealth

solution. However, due to the multiplicity of actors, different purposes, and varieties of the specific services, it is impossible to unify and standardize all elements within the same architecture. EHealth system architecture must allow the local level flexibility and able to encompass the varieties. Meanwhile the eHealth system architecture must provide a sharable platform to allow the multiplicity of actors to communicate each other and able to share knowledge. This requires a high level and recursive architecture to guide designers constructing the eHealth system. Let's say that we want to build up a building for sustainable/lasting multi-functional use. It is important for the architects to first identify the necessary and shared functional building blocks and their relationship for different types of purposes (such as windows, doors, roofs, floors, etc.). We have found that activity theory can provide with such architecture for the design of eHealth systems

The concept 'Activity' has a very general meaning that covers human being's most important 'thing' we are all socially involved in. We are doing various activities in work, education, family, and healthcare. We may not feel mentally healthy and normal if we are deprived from the rights of conducting various activities (human right). Activity Theory (AT), also called cultural-historical development theory of activity is a framework of knowledge that seeks to explain the unity and inseparability of subjective mind and the objective human practice [13]. The origins of the theory can be found in the work of the Russian developmental psychologist Lev Vygotsky[14], Aleksei Nikolaevich Leontev[15], and especially further expanded by Engeström[16]. In Activity Theory, activity is the basic unit that preserves the essential quality behind any human practices. Engeström developed a triangle model based on previous work of Vygotsky and Leontev to recapitulate and visualize the components and relationships that compose an activity (Fig. 4).
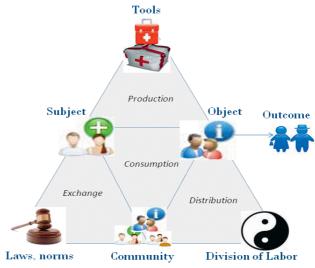
Fig. 4. Engström's model of activity system

According to the model, an activity is always conducted by one or several goal-oriented actors, a subject, who is directed towards or acting on an object in order to produce an outcome. According to the theory a basic feature of human activity is the use of artefacts/instruments as mediation. All human activities are mediated by various artefacts/instrument. This triple relationship is represented in the top part of the triangle (Subject –Tools – Object – Outcome). For example, we study the healthcare providers' activity. The subject/actor of conducting the healthcare activities (e.g. diagnosis, advices, monitoring) are people who provide with healthcare to the targeted patients that are accordingly defined as an object of the healthcare activity. Outcome will be the actor's goal for performing the activities, for example, patient becomes healthy or the targeted disease cured (the two goals are not the same. Even the latter is commonly accepted, it is however not patient oriented, instead it is disease oriented). It is vitally important to understand the crucial role of artefacts/tools in an activity. The artefacts/tools include both physical and non-physical types, such as computer, internet, software, data, information, models, theories etc. A successful activity must use right tools in the context of the users (subject) and targeted object or task. Another important characteristic of the activity model is its subject-object mutuality, i.e., depending on the focus of activity the subject and object can be exchangeable. In the above example of healthcare activity, if we focus on the

patient activity how they manage their own health to contact the doctor, then the subject will be the patient, and object the doctor. This interchangeable and mutually interdependent subject-object within neighbouring activities is the key to design a shared architecture for different roles of actors. In our case, the care providers activities and care receivers activities are neighbouring activities, and therefore they can share the same architecture of the system instead to build separately a healthcare providers system and then a receivers system which in turn creates problem for interoperability and knowledge sharing.

The subject and object are always part of and members of a community which includes also other actors who share the same object and contribute to the outcome of the targeted activity. This important recognition of social settings is shown in the bottom part of the triangle. In the elderly healthcare activity, the members of community for a doctor (as subject of the activity system) to take care of an elderly (object) could include other doctors, other elderly, district nurses, home nurses, relatives to the elderly and neighbours etc. They all contribute to different parts of the outcome – healthy elderly. However, comparing to the top part of the triangle which is visually observable (you can see an actor is using a tool producing an outcome), the bottom part of community is not visually observable, or it is to be recognised and to be constructed. It is like an ice berg, and what we see is the top, but much bigger and also important part is under the surface.

To work cooperatively among members of community, there need two more important mediating components, one is the division of labour, and another is the rules related regulations including laws, culture, tradition, norms, work routines, and contracts. The Division of Labour is to specify responsibility how to take care of different needs of the objects. For example an elderly will need both medical care (responsibility of hospitals) and home care (responsibility of municipality services). When some needs of elderly are not met, the labour division should clearly identify the responsible actors and allocate the needs to the actors. If the needs should be met cooperatively among different labour divisions, then the joint responsibility must be seamlessly connected with each other.

For example, an elderly after dispatched from hospitalisation will need continuous home healthcare. The handover process must be a joint responsibility for the hospital and the municipality that is responsible for the home healthcare. Information Technology (IT) can play an important role to link the actors towards a holistic process oriented to the elderly. For example, a project called 'IT supported seamless healthcare' conducted in Sweden has focused on the handover process. A digital protocol is shared by different actors and followed after each step during the whole process of the elderly care [17].

The Rules are to legitimize the actions of the actors involved in the activity, including security policy; standard for payment and services; time distribution; and need assessment and specifications, etc. It plays an important mediating role for all members in the community to share and understand the 'play rules'. This part can be also ontology for the design of eHealth system when we need to represent shared knowledge cross the border of actors.

5. A VERIFICATION OF THE MODEL- IMIS PROJECT

The triangle structure of an activity described by Engeström (1987) has been used in many cases as an analytical model to clarify a context or to analyze a problem. In a project 'Integrated Mobile Information System for Healthcare (IMIS)' we apply the model as an externalising tool to design the architecture of the eHealth system. It serves as an ontological 'microcosm', a model of database, to abstract some fundamental components and relationships in real activity of the healthcare work. This architecture is shown in Fig 5.
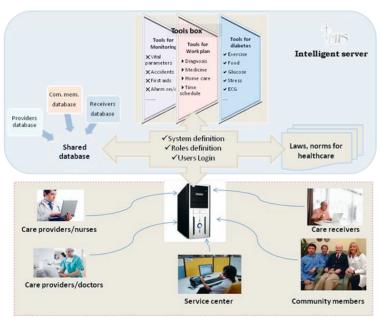
Fig. 5. IMIS Architecture

Very common an eHealth system is either developed for care providers (hospitals system, homecare system) or for care receivers (patient self management) separately. This separation leads often problem of interoperability and knowledge sharing. According to the activity model, we know that the two (care providers and care receivers) are inseparable to each other in conducting healthcare activity. In our approach, the IMIS integrates the two independent parts (subject vs. object) into one system, and makes the subject-object relationship as a mutual and reciprocal one another.

To start using the IMIS, the users (either care providers or care receivers) will need first to register their role in using the system, such as elderly, doctor, nurse, home assistant, relative, or other members of the community. After verification of their role, the system will specify related sub-systems, data, interface, namely his/her 'role system' to the specific users.

After the user specified his/her 'role system', next important step is to find the right tool to do the activity in focus. Tool is one of the most important components of activity in conducting an activity. The usefulness and fitness of the tools in relation to the tasks and the users are vital to success. The

tools must be users (subject) oriented according to the different role in the healthcare activity. In our IMIS system, we have designed different tools boxes for different roles and individuals according to the 'role system'.

Knowing the targeted object is a necessity for conducting an activity and to achieve some expected outcome/goals. All information about the object relevant to the activity can be organized into an 'object database'. As we said in the above, the subject and object are reciprocal in our system. Therefore the object database and subject database are also reciprocal.

Care providers, care receivers, and other people who in one way or another contribute to the outcome of healthcare activity, are organized together as a community. Through the shared database in Fig 5, the member, either care providers or care receivers, can get access to other members of the community and to share knowledge and to cooperate in the healthcare activity. This community is also very helpful for elderly to feel connected with society and friends as peer, to avoid the loneliness and repression.

Services today are very specified and located to various labor divisions. For example, elderly care in Sweden is normally provided by county council/hospital and the municipalities/home services. A clear labor division between the two organizations has to be defined especially when an elderly suddenly has heart failure in home and need to be transferred cross the border of home care of municipality to hospital care of county council. Sharing knowledge among those labor divisions is crucial when a need of the care receivers has to be provided jointly by several labor divisions. This important component is firstly identified through 'role system', and then shared database about cooperation among labor divisions.

EHealth is a life critical system and it is strictly regulated by various laws, culture, norms, etc. New kinds of services enabled by new technologies, such as IT enabled digital receipt, remote consultancy, remote monitoring often require new regulations. Many regulations, including costs/services regulations, need assessments regulations, privacy and integrity regulations, etc. are very crucial and yet very difficult

to remember all. Therefore it is very important for any eHealth to provide with references to different kinds of laws and regulations. In Fig 5, the IMIS architecture includes this reference as a database named 'laws, norms for healthcare'.

6. USER CASES- INTEGRATED EHEALTH SYSTEM

To demonstrate how the different components specified in the architecture work together to provide a holistic and integrated solution to elderly home, we take four interconnected use cases to demonstrate some representative scenarios in the followings. The colored text indicates the use of identified components in the architecture.

Use case 1: Elderly home input measured body parameters (glucose, blood pressure, heart pulse rate) into IMIS system.
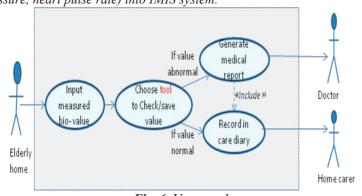
Fig. 6. Use case 1

When a elderly home measured his/her body parameters, such as glucose, blood pressure, heart pulse rate etc. and inputs into the IMIS system, some tools will be used from the IMIS tool box to save and check up the value if it is normal or not based on pre-settings or tracks. If the value is abnormal, the IMIS will generate an analysis report about the situation (relationship and tendency analysis) to the responsible doctor(s). Also, a summary or reference will be sent to the home care for diary of daily care. There can be many tools designed in the tool box according to the needs of the pair (subject – object), and many cases the tools can be already made by some third partners. It is very important that the IMIS

system can integrate those tools flexibly (plug in) according to the requests of users.

Use case 2: Doctor receives signals from elderly and requests diagnose and action.
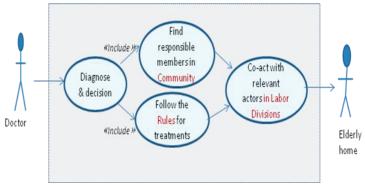
Fig. 7. Use case 2

When a doctor received a signal from elderly home and an analysis report from IMIS which indicates a need for a new diagnose and decision, the doctor will have to first conduct some basic diagnosis and make decision for the actions. Then s/he will have to identify other relevant members (other doctors, nurses, elderly children, home care etc.) within her/his community and to follow the basic rules and routines (social, moral, ethical, operational, etc.) to carry out the needed actions. The actions will involve mostly other labor divisions and therefore s/he has to co-act with relevant actors according to the responsible areas (labor division). To co-act with relevant actors according to labor division is an important step to make a systematic treatment for elderly as person, instead as disease.

Use case 3: Elderly home has an accident and alarms sent out to IMIS system.
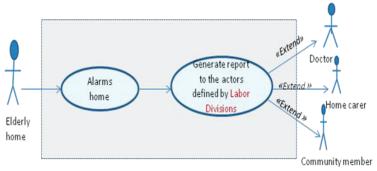
Fig. 8. Use case 3

When an accident triggered out an alarm, the IMIS system will first identify the type of alarm, such as emergency of a fall, heart failure, home alarm. Based on the type of alarm, the IMIS system will find the responsible division of labor to report the situation. For example, if the alarm is from heart failure, then the report will be sent to SOS emergency, doctor, and ambulance; if the alarm is sent by the home alarm then the report will be sent to police department, or neighbors.

Use case 4: Elderly home needs community care (being connected)

Fig. 9. Use case 4

Elderly at home can feel themselves isolated and lonely if no community is connected to them. Also elderly people could have problem to move around performing daily tasks like shopping, cleaning, etc. When they need such community care, the IMIS system could provide the right person to contact with from his/her community.

7. DISCUSSIONS AND CONCLUSIONS

In this paper, we have demonstrated that different user groups, either as elderly at home, various care providers, or members of a community, can share the same architecture. While the contents can be accordingly conFig.d after different users' needs, the elements and their relationships in the architecture will be kept the same. This recursive property of architecture can be used for constructing a system for multiple users in multiple levels of an organization, such as health care organizations. Since different users and organizations share the same architecture, the interoperability and knowledge sharing can be simply achieved. This recursive property is also important for system sustainability since it can be evolved to

integrate and update new applications, new user groups, and new type of services.

We have developed a prototype to verify our approach. By using user cases we showed how the architecture can be designed and used by different user groups. However, we have not implemented the system into real use, and validation to the feasibility of proposed architecture will be proceeded in the future projects.

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Paper V -
On Enhancement of Interactivity for Knowledge Sharing in eHealth

Y.Guo, Y.Yao and G.Bai

Abstract

Today, knowledge sharing rises as an important issue that challenges for the eHealth management system. It becomes one of the most demanding applications with references to the dynamic interactivities among different health actors and the complex data structures involved in this application. In this paper, we suggest an activity theory based ontology model to scientifically represent various health actors in the eHealth system. The goal of the suggest model is to enhance the interactivities among these health actors for the efficient knowledge sharing purposes. We also develop a prototype software system based on the suggested ontology model. The survey results collected from the system users show the feasibility of the developed software system.

1. INTRODUCTION

The proportion of elderly people (aged 65 or over) in the european countries is predicted to rise from 16.4% in 2004 to 29.9% in 2050 [1]. This prediction shows a critical problem that more elderly in the future may suffer from chronic diseases such as diabetes. To alleviate this problem, a promising solution is to strain the personal healthcare services to assist in self-care using the eHealth system. This can be done by two main service-oriented operations, i.e., data collection and data processing. The data collection is usually accompanied through advancing novel technologies for patients (e.g., elderly people), for instance, the wearable and mobile systems [2]. However, the data processing is a very challenging issue in the form of how to coordinate the involved health actors for the self-care assistant purpose. Therefore, one needs to design and develop an efficient management system to exchange and update the information acquired at the individual health actor side. The corresponding process conducted in eHealth is knowledge sharing.

So far, there are many studies done on knowledge sharing in the eHealth area. For instance, the authors of [3] report a multi-viewpoint based model to represent the heterogeneous health actors by using ontology. In [4], the authors report on the problem of distributed knowledge sharing among patients and physicians. They also suggest a multi-agent based method to overcome this problem. Clearly, the focus of these studies is laid on the representation of different health actors. The corresponding solution approach for knowledge sharing is mainly operated on two traditional heath actors. They are the care provides (e.g., healthcare center, doctors, nurses) and the care receivers (e.g., elderly people). Given the increasing demand for self-care on chronic health problems, the care receivers may require the external assistant from other health actors like, e.g., family members, neighbors, social care agencies, third party organizations. This situation gives rise to the need of the long-term financial sustainability of the personal healthcare services. Subsequently, the ultimate motivation comes down to the development of solution approach to enhance the interactivities among different health actors. The goal is to support knowledge sharing among the

aforementioned various health actors, and thus improving the quality and efficiency of the assistant in self-care. To the best of our knowledge, there are few studies done so far along with this research line.

In this paper, we study the interactivities among different health actors in a particular eHealth system. We suggest a new model to deal with these interactivities for the efficient knowledge sharing purposes. This model is based on the activity theory and an ontological model. Based on this model, we also develop a prototype software system called Activity Information System. The rest of paper is as follows. Section 2 describes the main health actors existing in eHealth. Section 3 represents the activity theory ontology and its advantage for representing the interactivities among various health actors. Section 4 describes our developed prototype software system, and reports the survey results on the deployment of this system. Finally, the paper is concluded in Section 5.

2. SYSTEM MODEL AND INTERACTIVITIES

We consider a particular eHealth system, which is advanced to provide the personal healthcare services to elderly people. In this system, six different health actors are taken into consideration. They are described below:

- Database for care receivers: it stores the personal information about the care receivers for the self-care assistant purposes. Examples of such information are the age, the suffered chronic diseases, and the relatives (i.e., family members). Further, the information about the associated care providers is also required to be recorded in this database.

- Database for care providers: similarly, this database needs to record the personal information about the care providers. Examples of such information are the time scheduling of care providers, the competence of care providers, and the information about the assigned care receivers.

- Instruments: they are referred to as the items used for personal healthcare services, for instance, a laboratory, the

electronic health record, the X-rays and the relevant diagnostic knowledge. These items need to be integrated into a single base, which provides the uniform Application Programming Interfaces (APIs) to different categories of users such as healthcare providers and receivers.

- Community network: it is connected to different social elements like, e.g., healthcare providers, healthcare receivers, family relatives, healthcare centers, shopping centers, banks, TAXI, family members.

- Laws/rules: they are used by different people to know the relevant information about the particular social laws, contracts and decisions.

- Labor division: it provides the prescribed social contact information for dealing with personal healthcare, together with the suitable methods to solve the particular conflict problem among different people.

In the following, an activity theory based ontology model is suggested to represent these health actors, together with the descriptions of interactivities among them.

3. INTERACTIVITIES IN EHEALTH

In the previous work [5], we report on the feasibility of using the activity theory to represent the health actors in the eHealth system. In this section, we extend our studies done in [5]. Specifically, we adopt the activity theory to further investigate the interactivities among various health actors existent in the above considered eHealth system.

3.1. Activity Theory Ontology for Knowledge Sharing in eHealth

The activity theory is a conceptual framework with the responsibility of representing the abstract knowledge existing in mind. By activity, it means the basic unit that preserves the essential quality behind any human practice. The key idea of this theory is to explain the inseparability of subjective and the objective from the human practice point of view [6]. The activity theory is initially coined by the authors of [7] and [8].

In [9], the authors further develop the activity theory by suggesting a triangle model. This model is used to recapitulate and visualize the components and relationships among them.

In accordance with the triangle model advanced in [9], we suggest an activity theory based ontology model to represent the health actors described in Section II, as shown in Fig. 1. The main advantage of this model is referred to as the flexibility and extendibility of representing various health actors for conducting knowledge sharing in the eHealth system. The detailed description about the suggest model is as follows.

In Fig. 1, there are three key activity units, i.e., care provider, care receiver and tool box. First, the care provider and the care receiver are defined to be the activity subject and activity object, respectively. The work activity of the care provider is then referred to as the assistant in the self-care requested by a particular care receiver. The outcome of this work activity is connected to the process of dealing with the particular health problem suffered by the particular care receiver. To accomplish such process, one needs the particular instruments such as laboratory, medical devices (e.g., electronic health record, X-rays), relevant diagnostic knowledge, and the suitable psychological treatment methods. Further, all these instruments are provided by the tool box.
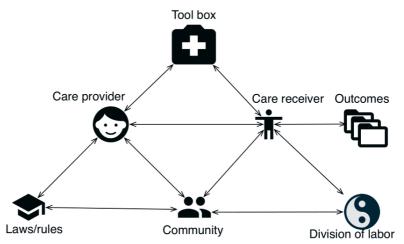

Fig. 1. Activity theory ontology model for knowledge sharing in eHealth

The functions of the above-described three key activity units are further extended by connecting them to another three

activity units. The first unit is related to the community network, which is connected to both the care providers and receivers. This is because that different social contacts belonging to this community may need collaborate with care providers to give more efficient healthcare service to care receivers. The second unit is the division of labor, which is responsible for doing decision-making on the particular tasks in the eHealth system. Examples of tasks are assigning the competent physician for the patient, allocating the nurse to the patient, and arranging meetings between care providers and care receivers. Due to the limited resource on the care provider side, the division of labor is designed to connect to the community unit. The third unit is the associated with the prescribed rules, which give the particular constraints to different subjects and objects in the community.

3.2. Interactivities among Different Health Actors

By using the suggested activity theory based ontology model, the eHealth system is capable to efficiently deal with various healthcare services. Accordingly, three typical cases are shown in Fig. 2. The detailed descriptions are as follows.

3.2.1. Case 1: A Patient Communicates with a Nurse:
- (1): a patient stays at home and feels bad, and thus reporting the health status to a nurse, who is responsible for assisting this patient.

- (2): the nurse checks the health status reported by the patient. Depending on the particular condition of the health status, the nurse may give different feedbacks to the patient.

- (3): if the situation is not serious, the nurse may directly give the corresponding suggestion to the patient. If the situation is serious, the nurse immediately reports the patient's health status to a doctor who is responsible for taking care of the patient.
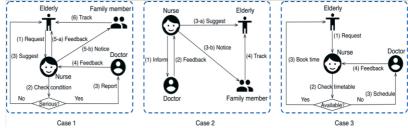
Fig. 2. Three cases regarding personal healthcare using the activity theory based ontology model.

- (4): the doctor makes a further investigation on the reported health status. The doctor also makes a prescription for the patient, and sends the prescription to the nurse.

- (5): the nurse provides the received prescription to the patient. Meanwhile, the nurse also sends the notice to the patient's family member.

- (6): the patient's family member could help the nurse to keep tracking the health status of the patient.

3.2.2. Case 2: A Family Member Takes Care of a Patient:
- (1): a nurse checks the health status of a patient, which is reported by a patient's family member. The nurse observes that the patient's health status is not good, and thus informing a doctor who is responsible for taking care of the patient.

- (2, 3, 4): they are same to the steps (4, 5, 6) described in case 1.

3.2.3. Case 3: A Patient Makes an Appointment to Meet a Doctor:
- (1): the patient sends an appointment request to a particular nurse who is responsible for assisting this patient.

- (2): the nurse checks the time availabilities of the corresponding doctor, and sends the suggested time slots to the doctor.

- (3): based on the received information about the suggested time slots and the appointment request, the doctor

arranges a particular time slot to meet the patient. This particular time slot is then sent to the nurse.

- (4): once the nurse receives the arranged time slot for meeting from the doctor, the nurse informs this time slot to the patient and prepares for the meeting between the doctor and the patient.

4. A PROTOTYPE SOFTWARE SYSTEM FOR KNOWLEDGE SHARING IN EHEALTH

Based on the suggested activity theory ontology, a prototype software system is developed to deal with the interactivities for knowledge sharing in eHealth. This software system is called Activity Information System (AIS).

4.1. System Design and Software Development

Differing from the traditional healthcare systems, the AIS is designed to support different categories of healthcare activities (e.g., primary care, intensive care, home care, elderly care, disabled care, etc.). It allows different users to record, to track, and to share knowledge in eHealth like, e.g., the competence of a doctor, the time scheduling of a nurse, the chronic diseases of a patient.

An important goal of using the AIS is that the assistant in self-care services can be provided either by public/private healthcare organization or individual person (e.g., a doctor, a nurse, the patients' relatives). To achieve this goal, one demands for a uniform platform to share different information about the individual care actors. With regarding to the diversity of care actors, this platform needs to be simple for use, and to be independent from devices and operating system. In our work, the development of such platform is therefore accomplished through the web technologies like, e.g., HTML, Java/JavaScripts, MySql.
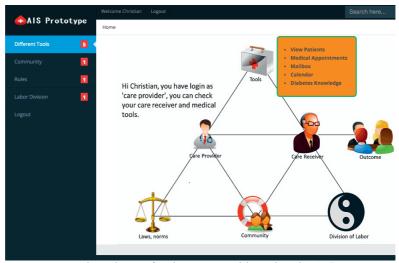
Fig. 3. Example webpage for the care provider using the AIS prototype

For a particular AIS user, once the user is successfully registered in the system, he/she is assigned with a role like, e.g., a care provider, a care receiver. Then, the AIS system shows the particular webpage content in accordance with the user's role. For example, Fig. 3 shows that the user takes the role as a doctor. Moreover, different roles may share the same activity theory ontology in terms of the same information and responsibility about the targeted activity units.

4.2. System Deployment

By the end of 2015, the developed prototype is practically deployed in the Zhengzhou University Hospital for the experimental test purposes. The reason for the selection of the city Zhengzhou is that, the average age of elderly people in Zhengzhou is above the one in other major cities in China. During the test, the deployed system is available for the use by both the healthcare providers (e.g., the doctors working in the hospital) and the healthcare receivers (e.g., the elderly people staying at home), as shown in Fig. 4. Examples of their interactivities are booking an appointment with a doctor, reporting outcomes by either nurses or by doctors, checking results either by patients or by the patients' relatives.

Fig. 4. Deployment of the AIS prototype in Zhengzhou University Hospital

4.3. Survey Evaluation and Discussions

To study the feasibility and usability of the suggested system (i.e., AIS), the survey based system evaluation is conducted. The evaluation procedure consists of two parts. The first part is regarding the questionnaire distribution to the AIS users. Specifically, two different groups of questionnaire are distributed to the healthcare providers and the healthcare receivers, respectively. The second part is to collect and analyze the questionnaire results.

Specifically, for the healthcare providers, there are 60 people participating in the survey with the given questionnaires. These participants are the doctors, nurses and the patient relatives. Similarly, the questionnaires for health receivers is distributed to 100 patients, and 86 of them are elderly people. Eventually, 55 results are received from the health providers, while 87 results are received from the health receivers. In other words, the response rates to the survey are around 92% and 87% for the care providers and receivers, respectively. The discussions about these results are described below.

On one hand, the number of healthcare providers showing the interest in AIS is around 80%. The majority responds related to the interest are referred to as the convenience of using AIS to deal with the task scheduling. For instance, i) doctors arrange appointments to meet patients, ii) nurses prepare the patients' outcomes for both doctors and the patients' families,

iii) the family members of a patient periodically track the health status of this patient. However, two important problems are also addressed in the survey results. The first problem is that it is difficult for the healthcare providers to assist the emergent healthcare by using current AIS. The second problem is that some doctors prefer a face-to-face meeting with the particular patients who have serious illness, in order to alleviate their psychological pressures.

On the other hand, around 85% of patients think that AIS is helpful for them to do self-care. However, only 50% of patients are sure about that they can get benefits from AIS. The reason for this result is that most patients are elderly people, and they are not familiar with web technologies. This motivates us to do further development on AIS by making the simple client running on smartphones.

5. CONCLUSION

The problem of coping with interactivity among different health actors for knowledge sharing in eHealth is considered. The activity theory based ontology model is suggested for representing the health actors in eHealth. Three typical interactivities among these health actors are presented. A prototype software system Activity Information System (AIS) is developed to enhance the interactivities in the eHealth area. The system is practically deployed for evaluation purposes. The survey based evaluation is conducted, and the results show the feasibility and usability of the developed system. The future work is to do the further performance evaluation on the AIS, and integrate the machine-to-machine techniques such as the connected smart home into the AIS.

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Paper VI -
Activity Theory Based Ontology Model for Efficient Knowledge Sharing in eHealth

Y.Guo, G.Bai and S. Eriksén

Abstract

Knowledge sharing has become an important issue that challenges the efficient healthcare delivery in eHealth system. It also rises as one of the most demanding applications with reference to dynamic interactivities among various healthcare actors (e.g. doctors, nurses, patients, relatives of patients). In this paper, we suggest an activity theory based ontology model to represent various healthcare actors. The goal of the suggested model is to enhance interactivities among these healthcare actors for conducting more efficient knowledge sharing, which helps to design eHealth system. To validate the feasibility of suggested ontology model, three typical use cases are further studied. A questionnaire-based survey is carried out and the corresponding survey results are reported, together with the detailed discussions.

1. INTRODUCTION

Over the recent decades, eHealth has played an important role in carrying out healthcare delivery and development on healthcare system. eHealth is referred to as the system with different applications of information and communications technology (ICT) that can support healthcare services [1]. The benefits from eHealth for society are many, such as improving the quality of healthcare services, expanding access to diagnostic services, increasing the efficiency of service delivery, reducing the cost of healthcare, contributing to the economies [2]. The underlying idea of eHealth is to practically conduct the healthcare services by applying electronic processes and communication into different healthcare actors. Here, healthcare actors are the individual persons or organizations that have impacts on or are effected by eHealth systems. Both healthcare providers and healthcare receivers are healthcare actors.

Knowledge sharing has become a very important resource when knowledge needed for conducted services is extended outside of its own organization [3]. By eHealth, the diagnosis and treatment knowledge need to be shared between pa-tients and those who may be concerned, like the healthcare providers. Meanwhile, with the healthcare network set up, healthcare receivers can share their experience and treatment solutions online with those who may be suffering from similar symptoms. With such practice applied, the efficiency in healthcare can be highly improved. In eHealth, sharing knowledge can realize potential gains and is critical to surviving and prospering in a competitive environment [4]. Knowledge sharing in eHealth has become crucial since health practitioners are required to be research-oriented, creative in healthcare, and ready to take new medical knowledge opportunities that can be acquired through various organizational learning mechanisms [5].

A very important problem in eHealth is that the various services and applica-tions in different organizations use different vocabulary, concepts, models and so on, which leads to the problem of interoperability and the difficulty of sharing knowledge. To deal with this problem, it is very crucial for

eHealth system de-signers to find a strategy to deal with the diversities in healthcare knowledge sys-tem development. A shared ontology may be a necessity to start with this strategy. Ontology, from technological aspect, is "an explicit machine-readable specification of a shared conceptualization" [6]. It is also a semantics approach to address the kinds and structures of objects, properties, events, processes and relations among these entities [7]. The goal of applying the ontology in eHealth is to establish a common semantics for addressing the concept of healthcare services. Corresponding entities in the healthcare ontology consist of not only the healthcare actors but also the knowledge and efforts involved in designing the eHealth system. Ontology may be utilized to promote knowledge sharing within organizations or inter-organizations.

During the past decade, the healthcare ontology has been widely investigated and developed. For instance, one standardization effort of Health Level Seven (HL7) is laid on developing the Service-Oriented Architecture (SOA) based healthcare ontology. The goal of this effort is to bridge standard ontologies in the domains like enterprise architecture, clinical care, and biomedicine [8]. Based on the work done by HL7, the authors of [3] report on the analysis of SOA based healthcare ontology by using a well-founded ontological approach called Unified Foundational Ontology for Service (UFO-S) [9]. The purpose of this work is to provide an ontological foundation to the SOA based healthcare ontology suggest-ed by HL7. In [10], the authors study on the problem of representing the healthcare ontology from different perspectives associated with various healthcare actors and with using different terminologies. This work is motivated by a fact that it is difficult to creating a single universal ontology for the eHealth system.

So far, there are a large amount of studies done on knowledge sharing in the eHealth area. For instance, the authors of [11] report a multi-viewpoint based model to represent the heterogeneous health actors by using ontology. In [12], the authors report on the problem of distributed knowledge sharing among patients and physicians. They also suggest a multi-agent based method to overcome this problem. Clearly, the focus of these studies is laid on the representation of differ-

ent health actors. The corresponding solution approach for knowledge sharing is mainly operated on two traditional heath actors. They are the care provides (e.g., doctors, nurses) and the care receivers (e.g., patients). Given the increasing demand for self-care on personal health problems, the care receivers may require the external assistant from other health actors like, e.g., family members, neighbors, social care agencies, third party organizations. This situation gives rise to the need of the long term financial sustainability on coordinating various healthcare actors. The motivation comes down to the development of solution approach to enhance the interactivities among different health actors. The goal is to support more general knowledge sharing among the aforementioned various health actors, and thus improving the quality and efficiency of the assistant in self-care. To the best of our knowledge, there are few studies done so far along with this research line.

2. MTHODOLOGY

To meet the requirement on the above-mentioned goal, in this paper we put the interest in investigating the interactivities among different healthcare actors in eHealth system.

- Firstly, the fundamental concepts related to healthcare ontology and activity theory are presented, together with the report on the related work.

- Secondly, based on activity theory we have proposed a new ontology model to represent dynamic interactivities of different healthcare actors, which are involved in the considered use cases to conduct knowledge sharing.

- Thirdly, to validate the feasibility of applying the suggested model in the considered use cases, a questionnaire based survey is carried out. Four different sets of questions are therefore distributed to four particular healthcare actors, i.e., patients, doctors, nurses, and relatives of patients.

- Finally, the corresponding survey results are reported. The detailed discussions are also presented to further analyze

how the suggested model can practically enhance the interactivity of knowledge sharing in the considered use cases.

3. ACTIVITY THEORY BASED ONTOLOGY MODEL

Based on the above discussion, an intelligent agent should be equipped with a knowledge component, which makes it operate on a knowledge model level. However, the indulgent use of individual knowledge models/components lead to conflicts when different agents cooperate. Two kinds of conflicts should be separately treated: (1) different agent may have different knowledge on the same problem; (2) different agents have different ontologies about the same knowledge pieces.

The first kind of conflicts results from the human personality. Because of the personality, different designers give agent different perspectives, from which agents perceive the environments and make decisions. The differences among those knowledge bases should be considered as complementary rather than conflicts. Weinberg stated "two different perspectives (or models) that reveal truths of a system are neither entirely independent nor entirely compatible. Two different kinds of knowledge on the same problem situation may give their solutions from different angles [11]. All roads lead to Rome. The relationship between two such kinds of knowledge models should be cooperative rather than competitive.

The second kind of conflicts lie on the ontology level, which means that two agents use different concepts to refer to the same objects, or the same concept to refer to different objects. An agent's ontology consists of the specification of a conceptualization, which includes the terms used to name objects, functions, and relations in the agent's world[12]. This can be resolved in two ways: first, in the beginning of a particular MAS design, all the agents are equipped with the same ontology. However, this assumes the neglect the self-learning capability of agent. Self-learning leads the agents to update their ontologies into multi-finality from the same initial

state, which comes back to our original problem. The first solution is also not preferable because it is impossible for all the MASs all over the world to agree on a common ontology. The second solution is based on the agent's learning capability. The agents are able to learn from others to complement and update their own ontologies. This learning capability is discussed in the following sub-section.

3.1. Activity Theory in eHealth

The cultural-historical theory of activity, also known as Activity Theory (AT), is a framework of knowledge that seeks to explain the unity and inseparability of subjective mind and the objective human practice [13]. The origins of the theory can be found in the work of the Russian developmental psychologist Lev Vygotsky [14], Aleksei Nikolaevich Leontev [15], and especially further expanded by Engeström [16]. In Activity Theory, activity is the basic unit that preserves the essential quality behind any human practices. Engeström developed a triangle model based on previous work by Vygotsky and Leontev to recapitulate and visualize the components and relationships that compose an activity (Fig. 1). A philosophical discussion about the model and relationship can be found in the study of [16], and will not be discussed here. We just take up the points which will contribute to the purpose of constructing ontology for eHealth system.
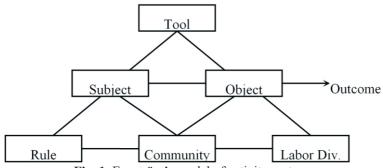

Fig. 1. Engström's model of activity system.

An activity is always conducted by some goal-oriented actors, a subject, directed towards an object or outcome that is being transformed. According to the theory a basic feature of human activity is the use of artefacts/instrument as mediation. Much of human interaction with the world is mediated through

various artefacts/instrument. This triple relationship is represented in the top part of the triangle (Subject–Tool–Object–Outcome). The subject and object are related to and members of a community that is shown in the bottom part of the triangle. The Division of Labour between the Object and the Community is to specify the responsibility of the Object's all needs. The Rules are to legitimize the actions of the subject actors involved in the activity [17].

We specialize the work activity of a doctor (Subject) working at a healthcare centre for patients (Object). The outcome of the activity is to cure the patients from their health problems and illnesses. The instruments include such tools as EHR, X-rays, laboratory, and medical devices - as well as partially internalized diagnostic knowledge and treatment-related concepts and methods. A community is commonly considered a social unit (a group of people) who have something in common, such as norms, values, identity, and often a sense of place that is situated in a given geographical area (e.g. a village, town, or neighborhood). In healthcare area, the community consists of the staff of the clinic, other collaborating clinics and hospitals, municipality's home nurses. The division of labor determines the tasks and decision-making of the physician, the nurse, the nurse's aide, and other employee categories. Finally, the rules regulate the legislate actions taken by the doctor, use of time, the measurement of outcomes, the criteria for rewards and so on.

If we take the point of view of another subject in the community, for instance a nurse in the same healthcare activity, the model will keep the same, however, only the contents will be different. Also, if we take the patient as the subject of the activity system, their object will be the healthcare providers, which include doctors, nurses and other staff in healthcare center. Still, they share the same architecture/model. This property of the model that is applicable in different levels and for multiple actors is a recursive property. Recursive property of a model can be used for constructing a system for multiple users in different organization levels which is exactly the case for eHealth system.

3.2. System Description

Based on the above-addressed activity theory and healthcare ontology, we consider a particular eHealth system, which is to provide personal healthcare services to elderly people. In this system, six different healthcare entities (i.e., healthcare actors and healthcare elements) are taken into consideration. They are described below:

- Information about care receivers: it is related to the personal information about the care receivers for the self-care assistant purposes. Examples of such information are the age, the suffered chronic diseases, and the relatives (i.e., family members). All these information will be recorded in this database of care receivers. Further, the information about the associated care providers is also required to be recorded in this database.

- Information about care providers: similarly, it is related to the personal information about the care providers. Examples of such information are the time scheduling of care providers, the competence of care providers, and the information about the assigned care receivers. All these information will be recorded in this database of care providers.

- Instruments: they are referred to as the artefacts used for personal healthcare services, for instance, a laboratory, the electronic health record, the X-rays and the relevant diagnostic knowledge. These items need to be integrated into a single base, which provides the uniform Application Programming Interfaces (APIs) to different categories of users such as healthcare providers and receivers.

- Community network: it is the social context which includes all actors involved in the activity system. The community network is connected to different social actors and elements like, e.g., patients' relatives, family members, healthcare centers, shopping centers, banks, TAXI etc.

- Laws/rules: they are conventions, guidelines and rules regulating activities in the system. They are used by

different actors to know the relevant information about the particular social laws, contracts, and decisions.

- Labour division: it is the social hierarchical structure of activity, the division of activities among actors in the system. Labour division provides the prescribed social contact information for dealing with personal healthcare, together with the suitable methods to solve the particular conflict problem among different healthcare actors.

3.3. Ontology Model Description

In accordance with the triangle model advanced in [16], we suggest a new model to represent the above-described system. This model is based on both activity theory and healthcare ontology, and thus so-called Activity Theory based Ontology (ATO) model. The main advantage of this model is referred to as the flexibility and extendibility of investigating the interactivities among different healthcare actors. The goal of using this model is to enhance the efficiency of conducting knowledge sharing in more general eHealth system. The detailed description about the suggested model is as follows.

In Fig. 2, among six activity units, there are three key ones, i.e., care provider, care receiver and tool box. First, the care provider and the care receiver are defined to be the activity subject and activity object, respectively. The work activity of the care provider is then referred to as the assistant in the self-care requested by a particular care receiver. The outcome of this work activity is connected to the process of dealing with the particular health problem suffered by the particular care receiver. To accomplish such process, one needs the particular instruments or so-called tool box such as laboratory, medical devices (e.g., electronic health record, X-rays), relevant diagnostic knowledge, and the suitable psychological treatment methods. Further, all these instruments are provided by the tool box.
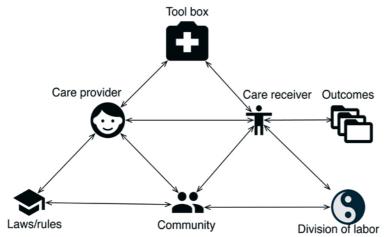
Fig. 2. Activity theory ontology model for knowledge sharing in eHealth.

The above-described three key activity units are further extended by connecting them to another three activity units. The first unit is related to the community network, which is connected to both the care providers and receivers. This is because that different social contacts belonging to this community may need collaborate with care providers to give more efficient healthcare service to care receivers. The second unit is the division of labor, which is responsible for doing decision-making on the particular tasks in the eHealth system. Examples of tasks are assigning the competent physician for the patient, allocating the nurse to the patient, and arranging meetings between care providers and care receivers. Due to the limited resource on the care provider side, the division of labor is designed to connect to the community unit. The third unit is the associated with the prescribed rules, which give the particular constraints to different actors who involved in the activity like, e.g. the legislate actions taken by care providers, the outcome evaluations, the reward criteria for physicians.

4. MODEL VALIDATION

4.1. Use Cases

To validate the feasibility and effectiveness of the suggested model, one needs to apply it to the practical healthcare system. To do this, we have conducted the preliminary observation on the typical use cases existing in the real healthcare sys-tem. The observation was done at the Zhengzhou University

Hospital, which is located in the city of Zhengzhou in China. The reason for selecting this hospital is that, the population of elderly people in the city of Zhengzhou is larger than the other major cities in China. Such situation leads to various interactivities among various healthcare actors during healthcare service delivery process.

The observation results show that there are three typical use cases: i) a patient at home communicates with a nurse; ii) a family member takes care of a patient; iii) a patient makes an appointment to meet a doctor. We then apply the suggested ATO model to these three use cases. Accordingly, the newly formalized representation of interactivities among different healthcare entities (i.e., actors and elements) are illustrated Fig.s 3-5, together with the brief descriptions.
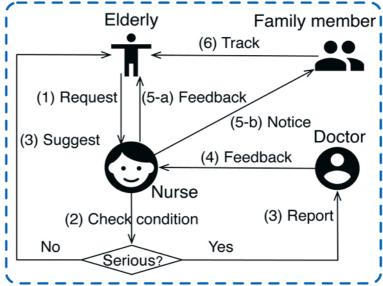
Fig. 3. Activity theory ontology model for case 1.

Use case 1: a patient communicates with a nurse

Number (1), (2), etc. are according to the numbers in Fig. 3.

(1): A particular patient stays at home and feels bad. As such, this patient re-ports the health status to a nurse, who is responsible for assisting this patient.

(2): The nurse checks the information about the health status reported by the patient. Depending on the particular condition

of the health status, the nurse may give different feedbacks to the patient.

(3): If the situation is not serious, the nurse may directly give the corresponding suggestion to the patient. If the situation is serious, the nurse immediately reports the patient's health status to a doctor who is responsible for taking care of the patient.

(4): The doctor makes a further investigation on the reported health status. The doctor also makes a prescription for the patient, and sends the prescription to the nurse.

(5): The nurse provides the received prescription to the patient. Meanwhile, the nurse also sends the notice to the patient's family member.

(6): The patient's family member could help the nurse to keep tracking the health status of the patient.
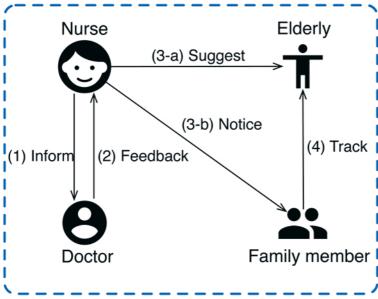

Fig. 4. Activity theory ontology model for case 2.

Use case 2: a family member takes care of a patient

Number (1), (2), etc. are according to the numbers in Fig. 4.

(1): A nurse checks the health status of a patient, which is reported by a patient's family member. The nurse observes that the patient's health status is not good, and thus informing a doctor who is responsible for taking care of the patient.

(2, 3, 4): They are same to the steps (4, 5, 6) described in case 1.
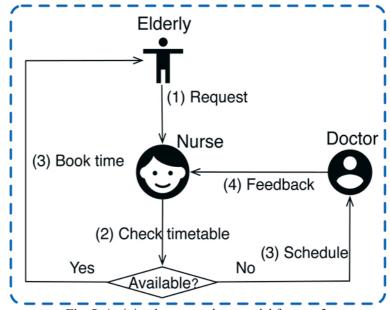
Fig. 5. Activity theory ontology model for case 3.

Use case 3: a patient makes an appointment to meet a doctor

Number (1), (2), etc. are according to the numbers in Fig. 5.

(1): A particular patient sends an appointment request to a particular nurse who is responsible for assisting this particular patient.

(2): The nurse checks the time availabilities of the corresponding doctor, and sends the suggested time slots to this doctor.

(3): Based on the received information about the time slots suggested by the nurse and the appointment requested by the patient, the doctor arranges a particular time slot to meet the patient. The information about this particular time slot is then sent to the nurse.

(4): Once the nurse receives the arranged time slot for meeting from the doctor, the nurse informs this time slot to the patient and prepares for the meeting between the doctor and the patient.

4.2. Questionnaire Based Survey

The above described three use cases show the potential possibility of applying the ATO model in eHealth system. However, the implementation feasibility of this model and the assumed effectiveness of dealing with healthcare service still need to be preliminary validated in accordance with the practical demands from different healthcare actors. To do this, the questionnaire based survey is conducted.

The survey was carried out between 2016 March and April at the Zhengzhou University Hospital (the same hospital we mentioned before). The survey goals mainly include four categories of healthcare actors represented in the ATO model. They are the healthcare providers (e.g., the doctors and nurse working in the hospital), the healthcare receivers (e.g., the elderly people staying at home), the community (e.g., the patients' relatives or family members) and the tool box (e.g., laboratory in the hospital). Examples of the considered interactivities among them are booking a meeting appointment with a nurse and/or a doctor, conducting the examination on the healthcare status of patients, reporting outcomes by either nurses or by doctors, checking results by either patients or by their relatives.

Further, four sets of questions are distributed to four groups of participants, respectively. They are accordingly referred to as Group of patients, Group of doc-tors, Group of nurses, and Group of patients' relatives. For the simplicity purpose, the four groups of participants are labeled as G-p, G-d, G-n and G-r in the following presentation.

The focus of the questionnaire based survey is to enhance interactivities among these health actors for conducting more efficient knowledge sharing, which is helping design eHealth system. The suggested ATO model and the considered use cases indicate that designing efficient knowledge sharing in eHealth system is a sophisticated procedure due to

heterogeneous healthcare actors and their interactivities involved in healthcare service delivery. To alleviate the complexity of this procedure, a feasible solution approach is to redefine the responsibilities of those healthcare actors with reference to their particular roles of assisting the particular interactivities. The main goal of this approach is to help healthcare providers (e.g., doctors and nurses) to have the better understanding of the real need from patients from both medical treatment and psychology perspectives. As such, they can improve the efficiency of carrying out the corresponding interactivities with patients and other healthcare actors (e.g., the relatives of patients), and thus delivering better healthcare services to patients.

Subsequently, the above-mentioned four sets of questions need to be well formalized with the aim at identifying and developing the necessary responsibilities for various healthcare actors. Along with this line, 12 key questions are reported in Fig.s 6-9, together with corresponding survey results.

4.3. Result and Analysis

For group G-p, there are 40 patients participating in the survey with the given questionnaires. The questionnaires for groups G-d and G-n are distributed to 25 doctors and 35 nurses, respectively. Similarly, the questionnaires for group G-r are distributed to 40 people. They are the relatives of the patients in group G-p. Eventually, 35 results are received from the group G-p. While, 23 and 32 results are received from groups G-d and G-n, respectively. Further, 33 results are received from group G-r. In other words, the response rates to the survey are about 87.5%, 92.0%, 91.4% and 82.5% for the patients, doctors, nurses and relatives, respectively. The survey results for all the above-listed questions are reported in Fig.s 6-9. The discussions about these results are described below.
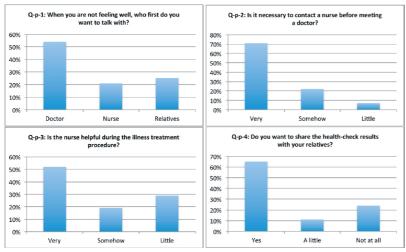
Fig. 6. Survey results for group G-p questions.
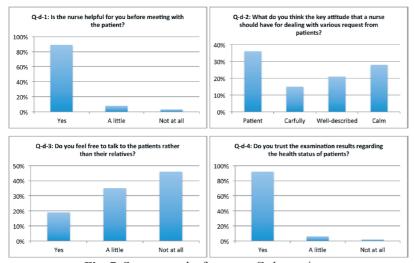
Fig. 7. Survey results for group G-d questions.

In Fig. 6, the answers to question Q-p-1 show that the individual patient usually wants to discuss with the doctor about their potential illness when he/she does not feel well. However, the doctor may be not available for the direct contact demanded by the patient due to the constrained time scheduling. In this case, the nurse becomes an important role who can take the responsibility of dealing with various requests from patients. Based on the preliminary evaluation on the health status of patients, if the meeting between the doctor and the nurse is needed, the nurse can further arrange such a meeting according to the time availabilities of both doctor and

patient. Such preliminary evaluation is highly necessary by both the doctor and the patient, as shown by the answers to questions Q-p-2 and Q-d-1 in Fig. 6 and Fig. 7. As shown by the answers to question Q-d-3 in Fig. 7, the patient also thinks that the nurse is also helpful during the illness treatment procedure.

Fig. 8. Survey results for group G-n questions

Fig. 9. Survey results for group G-r questions.

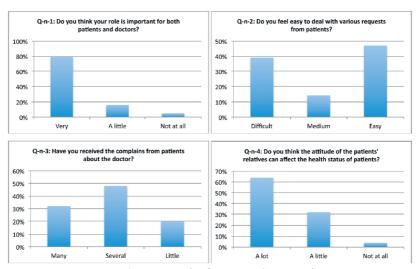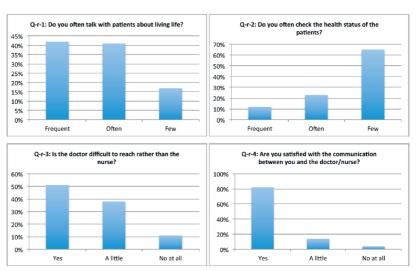As shown by the answers to Q-n-1 in Fig. 8, most of nurses agree with that their responsibility of bridge communication gap between doctors and patient is very important to the healthcare delivery service. The biggest problem faced by the

nurse is connected to the need of coping with various requests demanded by patients, including the expected complains about the doctor, as shown by the answers to questions Q-n-2 and Q-n-3 in Fig. 8. To alleviate this problem, the doctors suggest that the nurses should have several important attitudes to patients, such as being patient and maintaining calm, as shown by answers to question Q-d-2 in Fig. 7.

In Fig. 9, the answers to questions Q-d-1 and Q-d-2 show that, although the patient's relatives are care about the health status of the patients, they may lack time to provide the professional healthcare to the patient. This also indicates that the patients prefer to talk with the healthcare professions (i.e., the doctor) about their health status, as shown by answers to question Q-p-1 in Fig. 6. However, the answers to question Q-p-4 show that the patients want to share the information about their health status to their relatives, as they definitely want to get the help from the relatives. Further, the relatives of patients also agree with that the nurse is easier to communicate rather than doctor, as shown by the answers to question Q-r-3.

4.4. Disscussion

In this paper, to improve knowledge sharing efficiency in eHealth, we proposed ATO model to enhance the interactivities among different healthcare actors. The above considered use cases and corresponding survey results show the feasibility and effectiveness of the suggested model. Specifically, for a particular interactivity in eHealth, the proposed model can be used to redefine the particular responsibilities of healthcare actors, who are involved in conducting the particular interactivity. Such redefined responsibilities can then contain the information about how to efficiently accomplish the corresponding interactivities among different healthcare actors. Meanwhile, the efficiency of knowledge sharing among these healthcare actors is improved with reference to the efficient accomplishment of the related healthcare service delivery. Regarding the aforementioned need of redefining the responsibilities of healthcare actors, the discussions are as follows.

The above-reported survey results show that knowledge sharing in eHealth system is a sophisticated procedure due to heterogeneous healthcare actors and their interactivities involved in healthcare service delivery. To alleviate the complexity of this procedure, one needs to redefine the responsibilities of those healthcare actors with reference to their assistant in accomplishing the associated interactivities.

For instance, an important interactivity in the healthcare system is regarding the examination on the illness of patients. The involved healthcare actors are like, e.g., the patient, the nurse, the doctor, the patient's relative and the laboratory (including e.g., medical devices). Due to the need of dealing with multiple patients, the doctor usually needs the information about the preliminary evaluation on the health status of individual patient. Based on evaluation results, the doctor then decides on whether or not carrying out examination by using the laboratory. In this case, the nurse becomes very important to take the role of doing such preliminary evaluation patients with reference to the historical information about the health status of patients. As show in Fig. 6, such new role of the nurse is also required by patients as they prefer to first talk to the nurse about their health status rather than the doctor. This is because a particular doctor is likely difficult to reach by patients as the constraint on the doctor's time scheduling, as show in Fig. 9.

Another important interactivity is connected to delivering the examination re-port from the doctor to the patient. In this interactivity, the involved healthcare actors should be referred to as not only the patient, the nurse and the doctor, but also the patient's relatives. From Fig. 8, we observe that the patient's relatives can bridge the communication gap between the doctor and the patient. Specifically, the doctor is usually expert in the profession skills like, e.g., illness examination, medical treatment, summarizing examination results. However, the Fig. 6 shows that when the examination results are delivered to the patient, more social communication is demanded by the patient. This is because the direct result report from the doctor to the patient may significantly affect the patient's emotion, and thus leading to the unexpected mental injury to the patient. In this case, the patient's relatives

can accordingly provide the necessary psychological support to the patient.

The survey results also show other interesting interactivities, such as the time scheduling for both the doctor and the patient to do illness examination, coping with various requests and complains from patients, the social activities among patients. By using our suggested ATO model, all of these interactivities can be represented in an efficient way, based on which the responsibilities of the involved healthcare actors are redefined and the knowledge sharing among them is hence enhanced.

5. CONCLUSION

In this paper, we studied the problem of coping with interactivity among different health actors for knowledge sharing in eHealth. The activity theory based ontology model is suggested for representing the interactivities among different health actors in the eHealth system. Based on three typical use cases, a questionnaire based survey is conducted. The goal is to validate the suggested model with reference to the practical requirements demanded by the real healthcare system. The results show the feasibility of the suggested model and the effectiveness of applying it to the considered use cases. The future work is to implement a prototype software system, based on which, the suggested model can be practically integrated and be used for improving the efficiency of knowledge sharing in eHealth.

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Paper VII - eHASS: A Smart Appointment Scheduling System for eHealth

Y.Guo, Y.Yao and G.Bai

Abstract

In the eHealth system, the appointment scheduling is an important task for the delivery of healthcare service among different healthcare actors. The key procedure is to do the decision making on the selection of suitable appointments between the care providers and the care receivers. The appointment decision is a sophisticated problem in terms of how to efficiently deal with various parameters of involved healthcare actors. To solve this problem, we suggest a smart system called eHealth Appointment Scheduling System (eHASS). eHASS takes into account both heterogeneity aspects and interoperability requirements of eHealth system. As such, eHASS is capable of jointly considering various appointment characterizations and decision making algorithms for conducting appointment scheduling. The paper reports the eHASS architecture as well as the related work-in-progress.

1. INTRODUCTION

The eHealth is a promising solution approach advanced as the growing prominence of chronic diseases and financial challenges in healthcare spending [1]. It is bringing to the efficient delivery of healthcare service in accordance with people's needs and expectations. The development on eHealth also leads to the substantial provision of innovative technologies from both industry and academia, such as the wearable and mobile systems [2]. Among others, an important task in eHealth refers to as the appointment scheduling, which is demanded by different healthcare actors. The corresponding procedure is connected to a decision making problem by jointly considering various parameters associated with the involved healthcare actors. This problem is further complicated with the need of employing different candidate decision making algorithms.

Many studies on appointment scheduling have been reported in recent literature. For instance, in [3], the authors suggest an appointment scheduling solution by considering the patient-provider mutual preference. This solution is used to reduce the schedule fragmentation, and thus yielding higher appointment acceptance rate and clinic time utilization rate. In [4], the authors suggest a load balancing strategy for aid scheduling in eHealth. The goal is to optimize the Quality of Service (QoS) of healthcare delivery. In [5], the authors consider the appointment scheduling problem for patients visiting a given place. A queueing theory model is further built up and the corresponding numerical analysis is reported.

To our best knowledge, less focus however has been laid on the heterogeneity aspects and the interoperability requirement existent in eHealth. In our work, the heterogeneity is expressed in terms of vertical and horizontal properties of appointment scheduling system. The vertical property means the joint consideration of different kinds of healthcare actors such as the Care Provider (CP) and the Care Receiver (CR). The horizontal property refers to different characterization parameters associated with appointment availability, which are like, e.g., the time availabilities of CPs, the skill competence of CPs, the disease status of CRs, the cancellation probability

of appointments. The heterogeneity aspects further lead to different decision making algorithms for doing appointment scheduling between CPs and CRs. Subsequently, the appointment decision maker requires an interoperability framework across various characterization parameters and different algorithms.

In this paper, a new system called eHealth Scheduling Support System (eHASS) is suggested to schedule the suitable appointment for CPs and CRs. To solve the above addressed requirement problem, eHASS adopts a new parameter Fuzzy Appointment Availability (FAA) defined from fuzzy-logic point of view. The goal of using FAA is to map different types of characterization parameter to an uniform type with respect to FAA. Further, an overlay decision maker is built up, and it is used to jointly consider different decision making algorithms.

The rest of paper is organized as follows. Section 2 describes the architecture of eHASS. Section 3 discusses the setting up of an overlay decision maker in eHASS. The related work in progress is presented in Section 4. Finally, we conclude the paper in Section 5.

2. APPOINTMENT SCHEDULING SYSTEM

2.1. Element Classification

Compared with the other eHealth management systems, eHASS is a novel system with the efficient provision of healthcare assistant. The key idea is to do decision making on scheduling the suitable appointments between CPs and CRs, the so-called appointment scheduling. The corresponding decision making process jointly considers different elements, which are involved in the healthcare assistant. By *element*, we mean the individual entity in the eHealth area, which can be like, e.g., a patient, a nurse, a time slot for meeting, a laboratory, a decision making algorithm.

Further, we classify various elements into four categories, i.e., active unit, information base, interactivity chain, and algorithm factory. They are described as follow.

2.1.1. Active Unit

It includes different healthcare actors like, e.g., CP, CR, tools, community network. Specifically, both CPs and CRs are essential elements in eHealth. They can communicate with each other by using a face-to-face or a remote based manner, for instance, a meeting with a doctor or a telephone call from a nurse. Tools are referred to as the items used for healthcare assistant, for instance, a laboratory, transport systems, the electronic health record, the X-rays and the relevant diagnostic knowledge. Community network is regarding the social elements like, e.g., family relatives, healthcare centers, shopping centres, banks.

2.1.2. Information Base

It has two different parts, which are the information content and information collection. The information content is about the characterizations of healthcare actors. Examples of such information are the chronic diseases suffered by the CR, the electronic health record for the CR, the competence of the CP, the time availabilities of the CP, and the availabilities of the laboratory. The information collection is referred to as the ways of collecting different information. It can be done through solutions like using wearable systems and information exchange among healthcare actors.

2.1.3. Interactivity Chain

It is related to the interactions and communications among different healthcare actors. Examples of interactivities are booking an appointment with a doctor, reporting outcomes by either nurses or by doctors, checking results either by patients or by the patients' relatives.

2.1.4. Algorithm Factory

It has various candidate decision making algorithms, which can be used to do healthcare decision. Different algorithms may have different characteristic features and respective decision criteria. For instance, a key characteristic feature related to fuzzy-logic is given by the *fuzzy membership degree*. Furthermore, a particular decision criterion may have a prescribed method to decide on the most suitable appointment for a patient.

2.2. Two-layer Representation

To conduct the appointment scheduling, the eHASS needs to deal with two important tasks. The first task is to process the information about the relevant healthcare actors and their characterizations, the so-called *information processing*. The second task is to select one or more decision making algorithms, and thus scheduling the appropriate appointments between the CPs and CRs, the so-called *overlay decision making*. Subsequently, we suggest a two-layer based representation for eHASS, as shown in Fig. 1. In the Fig., the lower and upper layers are connected to the first and the second tasks, respectively.

2.2.1. Activity Theory Ontology Model

The lower layer contains various healthcare actors and their interactivities, which can be represented in accordance with an activity theory ontology model. Such model is suggested and described in our previous work [6]. Here, the activity means the basic unit that preserves the essential quality of the focuses from the human practice point of view [7]. The underlying idea of activity theory is to explain the inseparability of subjects and objectss. The main advantage of using the aforementioned model is related to the flexibility and extendibility of representing various healthcare actors for conducting knowledge sharing in eHealth.
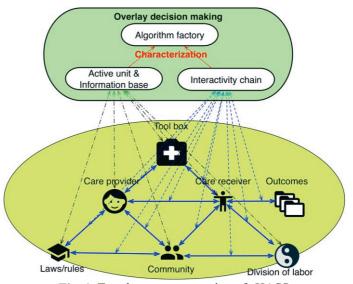

Fig. 1. Two-layer representation of eHASS

2.2.2. Overlay Decision Making

The upper layer is referred to as the function called overlay decision making. On this layer, both active unit and information base are connected to the healthcare actors on the lower layer, where the interactivity chain is connected to various interactivities among these healthcare actors. Regarding the algorithm factory, it is connected to other three categories of elements for doing decision making on appointment scheduling.

2.3. Scientific Functionalities of eHASS

Based on the above-addressed two-layer representation, we suggest three scientific functionalities for eHASS. They are described as follows.

2.3.1. Overlay Decision Maker

So far, most of decision making algorithms (e.g., fuzzy-logic, game theory) have so far been independently used for different research problems. Because there may exist different metrics (e.g., the doctor's time availabilities, the patient's diseases) for doing appointment scheduling for eHealth, this raises the need of jointly considering different decision making algorithm with aiming at managing them to work together.

2.3.2. Queueing Modeling

The particular appointment decision strategy may affect the overall performance of the whole appointment scheduling system. Investigation of related performance characteristics is usually based upon theoretical analysis or simulation experiment. In eHASS, we use the queueing modeling to carry out theoretical analysis.

2.3.3. Appointment Scheduling Simulator

To validate the theoretical study on the appointment scheduling performance, we develop a simulator to conduct simulation based experiments. The simulator consists of two parts. The first part is to configure the simulation parameters and scenarios, for instance, the numbers of CPs and CRs, the appointment duration. The second part is to simulate the dynamic behaviors of both CPs and CRs, and to deal with the interactivities among them. The interactivities can be like, e.g.,

the appointment request from CRs, the arrangement of appointment time slot.

2.4. eHASS Structure

We show the eHASS structure in Fig. 2. In the Fig., the components in the area of grey color compose the eHASS. The detailed description is as follows:
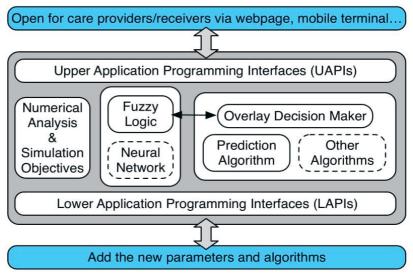
Fig. 2. Abstract structure of eHASS.

2.4.1. UAPIs
They indicate that eHASS is open for upper users (e.g., CPs, CRs) by using tools like web techniques and mobile terminals.

2.4.2. LAPIs
They imply that new parameters or new decision making algorithms can be added into eHASS.

2.4.3. The Arrows Inside the eHASS
They show the internal functions of eHASS. The fuzzy-logic/neural-network module is responsible for processing all input appointment characterizations with respect to the uniform decision criterion. Then, the overlay decision maker uses the processed information to do suitable appointment scheduling based on candidate decision making algorithms, e.g., Markov chains base prediction, graphic theory.

Clearly, the key module of eHASS is the overlay decision maker, and it is presented below.

3. FUZZY-LOGIC BASED DECISION MAKING

Because the appointment between the CP and the CR can be scheduled with respect to different parameters, the scheduling procedure becomes a multiple-constraint based decision making problem. To solve this problem, a three-dimension model is used to represent the appointment characterizations, and an overlay decision maker is constructed by using fuzzy-logic.

3.1. Appointment Characterization

We consider an eHealth system with M CPs, which are denoted by a set $\{p_m | m = 1, 2, ..., M\}$. For the simplicity purposes, the CRs are assumed to have the same priority to obtain the healthcare assistant from CPs. While, the appointment availability of CP is assumed to be characterized by a set of independent parameters $\{e_n | n = 1, 2, ..., N\}$. Examples of these parameters are the CP's time availability, the CP's skill competence, the CP's familiarity on the patient's diseases, the patient's time preference. We let $a_{e_n}^m(t)$ denote the observed parameter value of e_n for the CP p_m at time t, where $n \in \{1, 2, ..., N\}$ and $m \in \{1, 2, ..., M\}$. Then, the characterizations of appointment availability of all CPs at time t can be represented by a matrix:

$$\mathbf{A}(t) = \begin{bmatrix} a_{e_1}^1(t) & a_{e_2}^1(t) & \cdots & a_{e_N}^1(t) \\ \vdots & \vdots & \ddots & \vdots \\ a_{e_1}^m(t) & a_{e_2}^m(t) & \cdots & a_{e_N}^m(t) \\ \vdots & \vdots & \ddots & \vdots \\ a_{e_1}^m(t) & a_{e_2}^m(t) & \cdots & a_{e_N}^m(t) \end{bmatrix} \tag{1}$$

Further, the time period used for the appointment scheduling between CPs and CRs is denoted by $(t, t + K\delta]$. This time period is identically divided into K slots, and these slots are labelled as $\{t_k | k = 1, 2, ..., K\}$. During each time slots, every CP is assumed to be either available for or be occupied by an appointment. We then obtain a set of appointment characterization matrixes at discrete time points $\{t_1, t_2, ..., t_K\}$, which is expressed as $\{\mathbf{A}(t_0), \mathbf{A}(t_1), ..., \mathbf{A}(t_H)\}$.

Subsequently, the characterizations of appointment availability for M CPs in the time interval $(t, t + K\delta]$ can be represented by a three-dimension model. The three dimensions are referred to as three domains, namely, time, care provider and parameter.

3.2. Uniform Decision Criterion

Due to the parameter diversity of the above-formulated appointment characterization, the overlay decision maker needs to set up a uniform decision criterion. To do this, a new parameter called FAA is introduced. The goal of using FAA is to map different types of parameter values to a uniform type, i.e., fuzzy membership degree.

FAA is a fuzzy-logic based parameter, and it is used to represent different levels of appointment availability between CPs and CRs. For simplicity, in this paper we adopt three typical levels, which are formalized as three fuzzy sets *"high-level"*, *"medium-level"* and *"low-level"* appointment availabilities, respectively. With regard to parameter e_n, these three fuzzy sets are denoted by α_{e_n}, β_{e_n} and γ_{e_n}, respectively. Further, let σ_{e_n} denote the set of all possible values of parameter e_n. For the CP p_m at time t, we have $a_{e_n}^m(t) \in \sigma_{e_n}$.

According to the fuzzy set theory, a function denoted by g_{e_n} is introduced to act as the characteristic function of the fuzzy set σ_{e_n}. Specifically, g_{e_n} is generalized to a *fuzzy membership function*, based on which the value range of $g_{e_n}\left(a_{e_n}^m(t)\right)$ is given by a unit interval $[0.0, 1.0]$. Subsequently, the fuzzy membership degrees of $a_{e_n}^m(t)$ to three fuzzy sets of FAA are denoted $g_{e_n}^\alpha\left(a_{e_n}^m(t)\right)$, $g_{e_n}^\beta\left(a_{e_n}^m(t)\right)$ and $g_{e_n}^\gamma\left(a_{e_n}^m(t)\right)$.

Let $\pi_\times$, π_+, and π_- denote the importance weights of three fuzzy sets α_{e_n}, β_{e_n} and γ_{e_n}, respectively, on decision making for appointment scheduling. Then, the FAA-based characterization of appointment availability for the CP p_m under the parameter at time t is given by

$$\xi_{e_n}^m(t) = g_{e_n}^\alpha(a_{e_n}^m(t))\pi_\times + g_{e_n}^\beta(a_{e_n}^m(t))\pi_+ + g_{e_n}^\gamma(a_{e_n}^m(t))\pi_- \quad (2)$$

Moreover, let the set $\{w_n | n = 1, 2, ..., N\}$ denote the importance weights of N parameters on on decision making for appointment scheduling. Based on this equation, the numerical appointment availability of CP p_m at time t is computed as

$$\eta_m(t) = \xi_{e_1}^m(t)w_1 + \xi_{e_2}^m(t)w_2 + \ldots + \xi_{e_n}^m(t)w_n + \xi_{e_N}^m(t)w_N \quad (3)$$

Subsequently, the most suitable CP for the appointment at time t is associated with the largest value of $\eta_m(t)$, and it is obtained as follows:

$$\eta^*(t) = argmax\{\eta_1(t), \eta_2(t), \ldots, \eta_M(t)\} \quad (4)$$

3.3. Group Decision Making

In the above subsection, we assume that the importance weights of all FAA-based decision factors can be prescribed. However, in some particular cases, we may not pre-assign a FAA-based decision factor with an adequate weight value. In these cases, we need another algorithm called *group decision* to do decision making on appointment scheduling.

The group decision is proposed by Blin [8], and it is also based on fuzzy-logic. The key idea of group decision making is to define a set of group orders, as well as using graphic theory. The group orders are associated with the comparison results of different parameters with regarding to their importance on doing decision making. The graphic theory is used to plot a set of directed graphs by using the obtained group orders. Due to the space limit, the procedure of carrying out group decision making is not presented in this paper, while the detailed description is reported in the previous work [9].

4. LATEST RESULSTS

We developed a prototype system called Activity Information System (AIS) with using the eHASS to do appointment scheduling. The corresponding development was accomplished through the web technologies like, e.g., HTML, Java/JavaScripts, MySql. For the experimental test purposes, we also deployed the prototype in the Zhengzhou University Hospital, China, by the end of 2015 (Fig. 3). Due to time

limits, we first conducted a survey based system evaluation. Specifically, there were 60 CPs in terms of doctors, nurses and the family members participating in the survey, as well as 100 CRs. Eventually, the response rates to the survey were around 92% and 87% for CPs and CRs, respectively. The discussions about these results are described below.

On one hand, around 80% of CPs and around 85% of CRs show the interest in the developed system. An important problems is addressed in the survey results of CPs. That is, it is difficult for CPs to assist the emergent healthcare by using current system. On the other hand, only 50% of CRs are sure about that they can get benefits from AIS. The reason for this result is that most CRs are elderly people, and they are not familiar with web technologies. This motivates us to do further development on AIS by making the simple client running on smartphones.

Fig. 3. Practical deployment and test of developed prototype.

5. CONCLUSION

The complexity of doing appointment scheduling in eHealth is considered. A new system called eHealth Appointment Scheduling System (eHASS) is suggested for appointment scheduling. eHASS is designed to jointly take into account various parameters and decision making algorithms to determine the suitable appointments between the care providers and the care receivers. To do this, the elements of eHealth system are classified in four sets: active unit, information base, interactivity chain, and algorithm factory.

Based on this classification, the functionalities and structure of eHASS are presented. Further, the setting up of an important eHASS module, i.e., overlay decision making, is discussed in details. Our latest work results related to the development of eHASS are also presented. Future work is to investigate and improve the system performance of eHASS.

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Paper VIII -
On Performance of Prioritized Appointment Scheduling for Healthcare

Y.Guo and Y.Yao

Abstract

Designing the appointment scheduling is a challenging task for the development of healthcare system. The efficient solution approach can provide high-quality healthcare service between care providers (CP)s and care receivers (CR)s. In this paper, we consider the healthcare system with the heterogeneous CRs in terms of urgent and routine CRs. Our suggested model assumes that the system gives the service priority to the urgent CRs by allowing them to interrupt the ongoing routine appointments. An appointment handoff scheme is suggested for the interrupted routine appointments, and thus the routine CRs can attempt to re-establish the appointment scheduling with other available CPs. With these considerations, we study the scheduling performance of the system by using the Markov chains based modeling approach. The numerical analysis is reported and the simulation experiment is conducted to validate the numerical results.

1. INTRODUCTION

Today's demand for healthcare is dramatically increasing as the factor of the aging population and expectations growing during the past few years [1] [2]. This raises the need to develop the substantial healthcare services with innovative technologies from both industry and academia [3] [4]. A major technical challenge refers to the requirement for the provision of high-quality healthcare services delivered from the Care Provider (CP) like, e.g., a nurse, a doctor, to the Care Receiver (CR) such as a patient [5]. One important research focus associated with this challenge is laid on the problem called appointment scheduling [6] [7]. This is because the suitable solution to the appointment scheduling can enhance the efficiency of healthcare delivery, and thus improving the quality of healthcare services.

Designing the efficient appointment scheduling is a complicated process due to the crucial responsibility of dealing with the limited resources (e.g., in terms of hardware, people, time availabilities) for the concurrent timely-access by multiple users (i.e., CRs). Connected to this process, the interactivities between CPs and CRs need to be modeling, and needs to be measured and optimized. This can be performed by using different methods such as analytical approaches, simulation experiments and practical measurements on the healthcare system [8] [9] [10]. Most of previous studies done along with this research line mainly consider the statistical characterizations of timely-access activities of CRs. The corresponding examples are the average waiting time of CRs for the new appointment and the average service time of CPs dealing with the secluded appointment.

Apart from the above-addressed statistical characterizations, another important factor affecting the performance of appointment scheduling is related to the heterogeneous aspect of the healthcare system. In our work, such heterogeneous aspect is expressed in the form of the diversity of CRs, which inherently exists in the healthcare system. A typical example is that the CRs consist of both routine and urgent patients. The urgent patients are usually given a higher priority over the routine ones to have the appointments. Under this situation,

the scheduled appointments for routine CRs may be interrupted. As a result, the appointment scheduling performance of routine CRs may degrade.

In this paper, the motivation comes down to the numerical analysis on the prioritized appointment scheduling for the healthcare system. To do this, a Discrete Time Markov Chain (DTMC) based queueing model is built up to theoretically represents the appointment scheduling in the presence of both routine and urgent CRs. Moreover, a new scheme called appointment handoff is suggested for routine CRs to deal with their interruption by urgent CRs. To evaluate the performance of the suggested scheme, we use metrics in terms of the probabilities of blocking and terminating the appointments of urgent CRs, the appointment-completion throughput and the average service time.

The rest of the paper is as follows: Section 2 presents the background related to the appointment scheduling and the urgent patient modeling, together with our contribution. Section 3 describes the system model used in our study. A DTMC based queueing model is built up in Section 4. The numerical and simulation results for performance evaluation are discussed in Section 5. Finally, the paper is concluded in Section 6.

2. RELATED WORK

A large number of studies on appointment scheduling have been reported in recent literature. For instance, the authors of [11] suggest an appointment scheduling solution by considering the patient-provider mutual preference. This solution is used to reduce the schedule fragmentation, and thus yielding a higher appointment acceptance rate and clinic time utilization rate. In [12], the authors suggest a load balancing strategy for aid scheduling in eHealth. The goal is to optimize the Quality of Service (QoS) of healthcare delivery. In [13], the authors suggest a metaheuristic approach to solve the appointment scheduling problem. This approach is developed based on the Greedy algorithm and Tabu search mechanism.

Further, the particular interest associated with the healthcare appointment scheduling is placed on the system performance

evaluation. To do this, two typical methodologies are widely used in many studies. They are the numerical analysis and the simulation or practical implementation based experiments.

The work done on numerical analysis of the performance of carrying out appointment scheduling is as follows. In [14], the authors consider the appointment scheduling problem for patients visiting a given place. A queueing theory model is further built up and the corresponding numerical analysis is reported. In [15], the authors report on a mathematical model to study the queue dynamics of blood collection system. The goal is to use the simulation-optimization based approach to improve the performance of the blood donor's appointment scheduling. In [16], the paper considers the problem of how to optimize the number of patient appointment. To solve the problem, the authors develop a stochastic mathematical overbooking model. The goal is to maximize the expected total profits for diverse healthcare environments. In [9], the authors consider the no-show behaviour of patients, who have successfully booked the appointments. Based on the single server M/D/1/K queueing approach, they develop a social welfare function that makes the tradeoff between patients reward and cost. As such, the numerical analysis is conducted to study the impact of no-show rate on the outcome of social welfare.

Regarding the simulation or experimental based performance evaluation, the corresponding studies are reported below. In [17], the authors develop a new appointment scheduling system. This system takes into account both patients and providers preferences. The simulation-based performance evaluation is conducted to show the effectiveness of the developed system. The main advantage of such solution is to provide patients with more flexibility when they are involved in the scheduling process. Similar studies can be found in [18] [19]. In [8] and [20], the optimization on patients' waiting time in healthcare services especially with appointment scheduling is studied. The simulation-based experiments are conducted to find the suitable solution. In [21], the paper reports the problem of surgery appointment scheduling with the limited resources in terms of operating rooms and surgery durations. The authors address that such problem is presumably NP-hard.

To tackle the computational complexity, the authors suggest a set of algorithms together with simulation experiments. In [22], the authors report on the development of a web-technology based solution for doctors to handle the appointment scheduling with patients Similarly, the authors of [23] and [24] report on an intelligent appointment scheduling system, which can be deployed in hospital with using the Near Field Communication (NFC).

Moreover, the variety of CRs existent in the healthcare system is also widely investigated. In [25], the authors suggest a Markov Decision Process (MDP) based model to schedule six different types of patients. The goal of this model is to maximize the average revenue of accepting outpatients and minimize the average overtime penalty. In [26], the authors suggest a simulation model for doing appointment scheduling between CPs and CRs. They consider two types of patients (i.e., the new and existing patients) for further simulation-based study. The goal of this simulation model is to find the best balance between new and existing patients with respect to their arriving time and average service-completion time. In [27], the authors consider the problem of scheduling patients to visit a cancer infusion room with limited resources in terms of chairs and nurses. The authors further suggest the acuity-based rules to schedule two different types of patients, i.e., the high-acuity and low-acuity based patients. In [28], the authors consider the problem regarding the outpatient appointment schedule problem with routine and urgent patients. The authors develop a numerical solution approach under the assumption of deterministic service time together with the no-show behaviour of patients.

The work reported above has laid the ground to investigate the effect of heterogeneous aspect of CRs (e.g., patients) on the appointment scheduling in the healthcare system. However, to the best of our knowledge, there are few studies done so far on dealing with the interactions among different types of CRs, together with the corresponding feedback activities. In this paper, our main contribution is to suggest an appointment handoff scheme for the CRs to deal with the appointment interruption. We also build up a DTMC based queueing model for the numerical analysis purposes. We also carry out the

simulation based performance evaluation. Both numerical and simulation results show the feasibility of the suggested scheme.

<div align="center">Table 1. Parameter Notations</div>

Parameter Notations	Definition
M	Number of CPs in the system.
(i, j)	A pair of values indicating a system state that i ongoing routine appointments and j ongoing urgent appointments.
S	System state space.
$\pi_{i,j}$	Steady-state probability of Markov state (i, j).
λ_1	Mean request rate of appointments by urgent CRs.
λ_2	Mean request rate of appointments by routine CRs.
μ_1	Mean service-completion rate of ongoing urgent appointments for a single CP.
μ_2	Mean service-completion rate of ongoing routine appointments for a single CP.
λ_j^*	Mean rate of allocating CPs to the appointment requests by urgent CRs, depending on the value j.
μ_j^*	Mean rate of completing the appointments by urgent CRs, depending on the value j.
$\lambda_{i,j}^{\dagger}$	Mean rate of allocating CPs to the appointment requests by routine CRs, depending on the values of i and j
$\mu_{i,j}^{\dagger}$	Mean rate of completing the appointments by routine CRs, depending on the values of i and j.

3. SYSTEM MODEL

A particular eHealth system is considered in our study. Different parameters are used in the system modeling as indicated in Table 1. The detailed descriptions are as follows.

3.1. Care Provider Model

In the system, there are M CPs, which are denoted by p_1, p_2, ..., p_m, ..., p_M respectively. These CPs provide the candidate appointments to CRs during the prescribed time period. As shown in Fig. 1, this time period is assumed to consist of multiple identical time slots. These time slots are denoted by a set with infinite elements, i.e., $T = \{t_k | k = 0, 1, 2, ...\}$. Each time slot has a uniform value δ, which can be equal to, like, e.g., 20 minutes, 1 hour. Further, two neighboring time slots

may not be continuous along the time domain, for instance, t_k=[10:00 *AM*, 11:00 *AM*] and t_{k+1} = [2:00 *PM*, 3:00 *PM*].

Fig. 1. Appointment scheduling schemes.

During each time slot, each CP is assumed to be able to only deal with a single appointment with a single CR. Let two states *free* and *busy* denote the appointment status of a particular CP. Here, the state *free* refers to the event that there is no booked appointment and the particular CP is available for a new appointment demanded by a CR. Similarly, the state *busy* refers to the event that there exists an appointment booked for the particular CP and a CR.

3.2. Care Receiver Model

We assume that there are two different types of CRs existing in the system. They are called *urgent* CRs and *routine* CRs, respectively. Both urgent and routine CRs need the appointments with CPs.

The arrivals of the appointment requested by CRs are assumed to independently follow the process with mean rates λ_1 and λ_2 for urgent and routine CRs, respectively. The time periods of the appointments between CPs and CRs are assumed to be exponentially distributed with average values $1/\mu_1$ and $1/\mu_2$ for urgent and routine CRs, respectively.

Further, the two pairs of values $\{1/\lambda_1 , 1/\mu_1\}$ and $\{1/\lambda_2 , 1/\mu_2\}$ are actually equivalent to the average time periods of the two states *free* and *busy* for urgent and routine CRs, respectively. Because the two states may cross one or more consecutive time slots, these values are the integer times of value δ.

3.3. Appointment Scheduling Model

To deal with the appointment requests of CRs, we suggest a group of schemes for CPs, as shown in Fig. 1. The goal of these schemes is to give the priority to the urgent CRs over the routine CRs for conducting the appointment scheduling. These schemes are prescribed in accordance with two key factors, i.e., the CR type and the current number of idle CPs being available for appointments. The detailed description is as follows.

For the urgent CRs, they can exclusively obtain the appointment service of CPs even when they already have the scheduled appointment with the routine CRs. Specifically, if a new appointment is requested by a particular urgent CR and at least one CP is idle, this CP is allocated to the newly requested appointment. If there is no idle CP and at least one CP is allocated to a routine CR, this CP is re-allocated to the appointment newly requested by the particular urgent CR. Otherwise, the newly requested appointment is blocked. For the simplicity purposes, the scheduled appointment between the particular urgent CR and the allocated CP is called *ongoing urgent appointment*. For a new appointment requested by a particular routine CR, if at least one CP is idle, this CP is allocated to the newly requested appointment. Simply put, the scheduled appointment between the particular routine CR and the allocated CP is called *ongoing routine appointment*. Because the appointment requests of urgent CRs have the higher priority than the ones of routine CRs, a particular routine CR may be interrupted due to an appointment newly requested by an urgent CR. In this situation, the ongoing routine appointment associated with this particular CR needs to be paused.

The interrupted routine CR can request another idle CP with available time slots, the so-called *appointment handoff*. If the

operation on appointment handoff is succeed, the interrupted routine CR can resume the paused routine appointment. Otherwise, the paused routine appointment is forced to be terminated.

4. QUEUEING MODELING

Based on the above model of the appointment scheduling in eHealth, a DTMC queueing model is built up, as shown in Fig. 2. This model has three characteristics: system state, state transition and steady-state probability [29, 30]. Let an integer pair (i, j) denote a system state when i ongoing routine appointments and j ongoing urgent appointments coexist in the system. The system state space is defined as $S = \{(i, j)\}$, where the values of i and j are constrained by $i \in [0, M], j \in [0, M]$ and $(i + nj) \in [0, M]$.
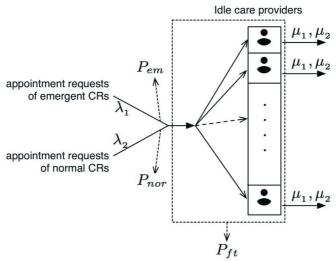
Fig. 2. Queueing model with P_{ur}, P_{ro} and P_{ft}
(P_{ur} is for blocking probability of urgent appointment requests, P_{ro} is for blocking probability of routine appointment requests and P_{ft} is for forced-termination probability of ongoing routine appointment.)

4.1. State Transition

The state transition of the system is triggered by several activities. These are the activity of urgent CRs, activity of routine CRs without the appointment interruption by urgent CRs, the feedback of routine CRs in response to the appointment interruption.

4.1.1. Urgent Care Receiver Activity

The urgent CRs have two different activities:

- A new appointment requested by the urgent CR is assigned with a CP.

- The urgent CR releases the appointment from the CP at the service completion.

The first activity indicates the arrival of PU calls into the system. Both the second and the third activities indicate PU calls leaving the system.

For j ongoing urgent CRs in the system, we let λ_j^* and μ_j^*, denote the arrival and the leaving rates of PU calls, respectively. The values of λ_j^* and μ_j^* depends on the four parameters j, λ_1, μ_1 and M. They are given by:

$$\lambda_j^* = \begin{cases} \lambda_1, & 0 \le j \le M \\ 0, & others \end{cases} \tag{1}$$

$$\mu_j^* = \begin{cases} j\mu_1, & 0 \le j \le M \\ 0, & others \end{cases} \tag{2}$$

4.1.2. Routine Care Receiver Activity without Interruption

Given that i ongoing routine CRs and j ongoing urgent CRs are in the system, a new appointment requested by a routine CR is treated in two different ways:

- For $(i + j) < M$, an idle CP is allocated to the routine CR with a scheduled appointment.

- For $(i + j) = M$, the appointment request is blocked.

Similar to the urgent CRs, we let $\lambda_{i,j}^\dagger$ denote the arrival rate of the appointment requests of the routine CRs. Let $\mu_{i,j}^\dagger$ denote the leaving rate of the routine CRs after completing the

appointment. The values of $\lambda^{\dagger}_{i,j}$ and $\mu^{\dagger}_{i,j}$ depends on the six parameters i, j, λ_2, μ_2 and M. They are computed by:

$$\lambda^{\dagger}_{i,j} = \begin{cases} \lambda_2, & 0 \leq i + j \leq M \\ 0, & others \end{cases} \tag{3}$$

$$\mu^{\dagger}_{i,j} = \begin{cases} i\mu_2, & 0 \leq i + j \leq M \\ 0, & others \end{cases} \tag{4}$$

4.1.3. Routine Care Receiver Feedback in Response to the Appointment Interruption

Given the system at state (i, j), where $(i, j) \in S$ and $j < M$, a new appointment requested by an urgent CR is assigned with a particular CP. Because of the higher priority for urgent CRs, the routine CR being scheduled with this particular CP is interrupted and the associated ongoing routine appointment is paused. To resume the paused appointment, the interrupted routine CR attempts the handoff to another idle CP. The success in such attempt depends on the numbers of ongoing urgent CRs and PU calls and connected SU calls in the system at state (i, j) as follows:

- If $(i + j) < M$, this means that the interrupted routine CR can find an idle CP for appointment scheduling. It is further assumed that a successful appointment handoff can be immediately accomplished by an interrupted routine CR. As a result, the system changes state from (i, j) to $(i, j + 1)$.

- If $(i + j) = M$, this indicates that the system becomes overloaded for re-allocating the CP to the interrupted routine CR. Therefore, the paused routine appointment is forced to be terminated. As a consequence, the system changes the state from (i, j) to $(i - 1, j + 1)$.

4.2. Steady-State Probability

The system state diagram is shown in Fig. 3, where $\theta_{i,j}$ equals one if $\{j \neq m, n(m - 1) + q < (i + nj) \leq (nm + q)\}$ and zero if others. $\varphi_{i,j}$ equals one if $\{i \neq 0, (i + nj) = (nm + q)\}$ and zero if others.
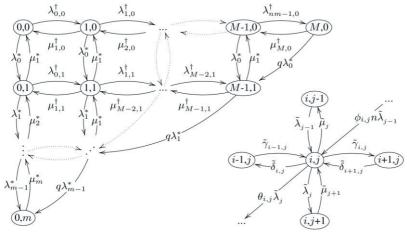
Fig. 3. State diagram of the modeled system for $0 < g < m$, $0 < q < n$, $0 < h < q$.

Let $\pi_{i,j}$ denote the steady-state probability of state (i, j). If $(i, j) \in S$, the value of $\pi_{i,j}$ is in the value range $(0.0, 1.0)$. Otherwise, $\pi_{i,j}$ is equal to zero. Further, the rate of transition flow into a state (i, j) must be equal to the rate of transition flow out of this state.

For the four particular states $(0, 0)$, $(M, 0)$ and $(0, M)$, we have equations 5-7. For the states satisfying $0 < i < M$ and $j = 0$, we have the equation 8. For the states satisfying $i = 0$ and $0 < j < M$, we have the equation 9. For the states satisfying $i + j = M$ and $0 < j < M$, we have the equation 10. For other particular states, we have the equation 11.

$$\pi_{0,0}(\lambda_{0,0}^{\dagger} + \lambda_0^*) = \pi_{1,0}\mu_{1,0}^{\dagger} + \pi_{0,1}\mu_1^* \tag{5}$$

$$\pi_{M,0}(\lambda_0^* + \mu_{M,0}^{\dagger}) = \pi_{M-1,0}\mu_{M-1,0}^{\dagger} \tag{6}$$

$$\pi_{0,M}\mu_M^* = \pi_{0,M-1}\lambda_{M-1}^* + \pi_{1,M-1}\lambda_{M-1}^* \tag{7}$$

$$\pi_{i,0}(\lambda_{i,0}^{\dagger} + \mu_{i,0}^{\dagger} + \lambda_0^*) = \pi_{i-1,0}\lambda_{i-1,0}^{\dagger} + \pi_{i+1,0}\mu_{i+1,0}^{\dagger}$$
$$0 < i < M, j = 0 \tag{8}$$

$$\pi_{0,j}(\lambda_{i,0}^{\dagger} + \lambda_j^* + \mu_j^*) = \pi_{1,j}\mu_{1,j}^{\dagger} + \pi_{0,j-1}\lambda_{j-1}^* + \pi_{0,j+1}\mu_{j+1}^*$$
$$i = 0, 0 < j < M \tag{9}$$

$$\pi_{i,j}(\lambda_j^* + \mu_j^* + \mu_{i,j}^{\dagger}) = \pi_{i-1,j}\lambda_{i-1,j}^{\dagger} + \pi_{i,j}\lambda_{j-1}^* + \pi_{i+1,j-1}\lambda_{j-1}^*$$
$$i + j = M, 0 < j < M \tag{10}$$

$$\pi_{i,j}(\lambda_{i,j}^{\dagger} + \mu_{i,j}^{\dagger} + \lambda_j^* + \mu_j^*) = \pi_{i-1,j}\lambda_{i-1,j}^{\dagger} + \pi_{i+1,j}\mu_{i+1,j}^{\dagger}$$
$$+ \pi_{i,j-1}\lambda_{j-1}^{\dagger} + \pi_{i,j+1}\mu_{j+1}^* \tag{11}$$

We sum up all steady-state probabilities in conjunction with $\sum_{\forall i,j}^{(i,j)\in S}[\pi_{i,j}] = 1$. By combining the above equations, we can construct a set of linear equations. By solving them, we can accordingly compute the steady-state probabilities of all states.

4.3. Performance Metrics

The following performance metrics are considered.

4.3.1. Blocking Probability of Urgent Appointment
Clearly, the event of blocking the appointment requested by an urgent CR occurs for $j = M$. In other words, all the CPs are allocated to the urgent CRs and there is no ongoing routine appointment. Let P_{ur} denote the blocking probability of urgent appointment requests, and it is given by.

$$P_{ur} = \pi_{0,M} \tag{12}$$

4.3.2. Blocking Probability of Routine Appointment
According to the appointment handoff model, the event of blocking the appointment requested by a routine CR occurs for $(i + j) = M$. Let P_{ro} denote the blocking probability of routine appointment requests, and it is computed by.

$$P_{ro} = \sum_{\forall i,j}^{(i,j)\in S}[\pi_{i,j} | (i+j) = M] \tag{13}$$

4.3.3. Forced-termination Probability of Routine Appointment
For the state (i, j), when a particular CP is allocated to an urgent CR with the new appointment request, the termination

of an ongoing routine appointment may occur for $i + j = M$ and $j < M$. This means the system has not enough CPs to accommodate the interrupted routine CR that has experienced the unsuccessful appointment handoff. Let P_{ft} denote the forced-termination probability of ongoing routine appointment. We then define P_{ft} as:

$$P_{ft} = \frac{Total\ forced-termination\ rate\ of\ ongoing\ routine\ appointments}{Actual\ average\ appointment\ request\ rate\ of\ routine\ CRs}$$

For the state $(i,\ j) \in S$ satisfying $i + j = M,$ the forced-termination rate at this state is equal to the product of urgent appointment request rate and the number of terminated routine CRs. Given that the PU occupies the band with arrival rate λ_j^*, the number of terminated SU calls is equal to one. Therefore, at state $(i,\ j)$ the forced-termination rate is equal to λ_j^*. As a result, the total forced-termination rate of ongoing calls is equals to:

$$\sum_{\forall i,j}^{(i,j)\in S} [\lambda_j^* \pi_{i,j} | (i+j) = M, j \neq M] \qquad (14)$$

Because the routine appointment requests are blocked with probability P_{ro}, the actual average appointment request rate of routine CRs into the system equals $[\lambda_2 (1 - P_{ro})]$. Subsequently, P_{ft} is given by:

$$P_{ft} = \frac{\sum_{\forall i,j}^{(i,j)\in S} [\lambda_j^* \pi_{i,j} | (i+j) = M]}{\lambda_2 (1 - P_{ro})} \qquad (15)$$

4.3.4. Appointment-completion Throughput

For a particular category of CRs, the associated appointment-completion throughput is defined as the average rate of ongoing appointments completing with CPs. Let R_{em} and R_{ro} denote the appointment-completion throughput of urgent and routine CRs, respectively. According to the description in section 3, each of appointments requested by different CRs faces four different cases (i.e., being scheduled, being blocked,

being forced-terminated, and completing the service). Then, R_{em} and R_{ro} are computed by:

$$R_{ur} = \lambda_1(1 - P_{ur}) \tag{16}$$

$$R_{ro} = \lambda_2(1 - P_{ro})(1 - P_{ft}) \tag{17}$$

4.3.5. Average Service Time

The service time of a particular CR means the time spent by the allocated CP for dealing with the appointment scheduled with this particular CR. Let T_{ur} and T_{ro} denote the average service time of an ongoing appointment for the urgent and routine CR, respectively. To compute them, we need to consider the average numbers of ongoing urgent and routine CRs in the system, which are denoted by N_{em} and N_{ro}, respectively. According to the expectation definition, they are given by:

$$N_{ur} = \sum_{\forall i,j}^{(i,j) \in S} [i\pi_{i,j}] \tag{18}$$

$$N_{ro} = \sum_{\forall i,j}^{(i,j) \in S} [j\pi_{i,j}] \tag{19}$$

Subsequently, T_{ur} and T_{ro} can be computed with respect to Little's Theorem [30]:

$$T_{ur} = \frac{N_{ur}}{\lambda_1(1 - P_{ur})} \tag{20}$$

$$T_{ro} = \frac{N_{ro}}{\lambda_2(1 - P_{ro})(1 - P_{ft})} \tag{21}$$

5. PERFORMANCE EVALUATION

This section reports on the performance evaluation of the modelled eHealth system for doing appointment scheduling.

5.1. Parameter Settings

To study the effects of the priority and handoff schemes on the appointment scheduling performance, both numerical analysis and simulation experiments are conducted.

Table 2. Parameter Settings

CPs	$M = 6$
Urgent CRs	$\lambda_1 \in \{4; 6; 8; 10; 12\}$ $\mu_1 = 5$
Routine CRs	$\lambda_2 = 6$ $\mu_2 = 6$

Numerical analysis is carried out based on the developed queueing model. The corresponding parameter settings are reported in Table II. Simulation experiments are carried out to demonstrate the validity of the numerical analysis. In our experiments, the simulator is developed in C/C++.

The results are shown in Fig.s 4(a), 4(b), 4(c), 4(d), 4(e) and 4(f). In all Fig.s, the marker '+' indicates the simulation result. From the Fig.s, we observe that the simulation results closely match the numerical results. The discussions of results are as follows.

5.2. Blocking Probability of Appointment Requests

In Figs. 4(a) and 4(b), we observe that blocking probabilities of both urgent and routine appointment requests (i.e., *Pur* and *Pro*) increase with the arrival rate of urgent appointment requests (i.e., λ_1). The reasons for this under two different types of CRs are different.

For the urgent CRs, they can exclusively occupy the idle time slots provided by CRs, which are the limited resource with a fixed max value, i.e., $M = 6$. Therefore, the more the appointment are requested by urgent CRs, the higher the possibility of experiencing the blocking event becomes. For the routine CRs, they are only allowed to opportunistically share the CRs for appointment scheduling, when these CRs are not allocated to the urgent CRs. In this situation, the system needs to deal with more urgent appointments. As a

consequence, the resource availability for routine CRs is decreased with λ_1 , and thus a larger amount of routine appointment requests are accordingly blocked.

5.3. Forced-termination Probability of Routine Appointments

As addressed in subsection 3.3, the forced-termination of an ongoing routine appointment occurs for the case of no available CPs for accomplishing the appointment handoff. As shown in Fig. 4(c), the forced-termination probability (i.e., P_{ft}) increases with λ_1 . This is because the more urgent CRs are requesting for resources (i.e., CPs), and thus leading to the more interruptions caused to the ongoing routine appointments. As such, the system capability of dealing with the appointment handoff for the interrupted routine appointments is decreased.

5.4. Appointment-completion Throughput

Figs. 4(d) and 4(e) show that the appointment-completion throughs (i.e., R_{ur} and R_{ro}) increases and decreases with λ_1 for the urgent and routine CRs, respectively. This is because when λ_1 increases, a larger amount of urgent appointments can be actually initiated in the system. As a result, the more urgent appointments can be accomplished. On the contrary, the amount of initiated routine appointments becomes smaller, while the fewer routine appointments can be accomplished.

5.5. Average Service Time

Fig. 4(f) shows that the average service times (i.e., R_{ur} and R_{ro}) maintain as constant values for the urgent and routine CRs. The reason behind this result is intuitive. For the urgent CRs, they can request the appointments from CPs by ignoring the existence of the routine appointments. Therefore, the corresponding scheduling service provided by the system can be modeled as M/M/m-lose system, where the average service time only depends on the service rate [29]. Similarly, although the scheduling service for the routine CRs is constrained under the exclusive occupancy by the urgent CRs, the corresponding service model can also be modeled as M/M/m-lose system.
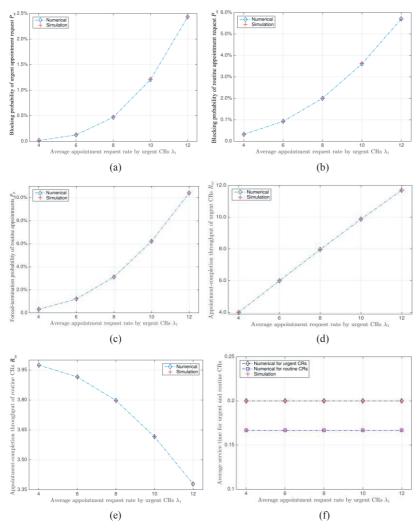
Fig. 4. Numerical and simulation results of
P_{ur}, P_{ro}, P_{ft}, R_{ur}, R_{ro}, T_{ur} and T_{ro}.

6. CONCLUSION

The appointment scheduling in the healthcare system was studied in our paper. Specifically, the heterogeneous aspect of Care Receivers (CR)s was considered in terms of urgent and routine users. The scenario of the concurrent appointment scheduling on these two different types of CRs were presented. The importance of giving the higher priority to the urgent CRs over the routine CRs was addressed as well. To provide such

priority, the interruption activity on the ongoing routine appointments due to the newly arrived urgent CRs was discussed. The appointment handoff mechanism was therefore suggested for the interrupted routine appointments.

To investigate the scheduling performance in the considered system, we used a Discrete Time Markov Chains (DTMC) based queueing model. We presented a numerical solution to this model. For performance evaluation, we derived seven different metrics. They are the blocking probabilities of urgent and routine appointments requests, the forced-termination probability of ongoing routine appointments, the appointment completion throughputs of urgent and routine CRs, the average service time of urgent and routine appointments. The numerical results were also validated by the simulation experiments.

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ABSTRACT

Knowledge sharing has become an important issue in the eHealth field for improving the quality of healthcare service. However, since eHealth subject is a multidisciplinary and cross-organizational area, knowledge sharing is a serious challenge when it comes to developing eHealth systems. Thus, this thesis studies the heterogeneous knowledge sharing in eHealth and proposes a knowledge sharing ontology. The study consists of three main parts: modeling, validation and application.

In the modeling part, knowledge sharing in eHealth is studied from two main aspects: the first aspect is the heterogeneous knowledge of different healthcare actors, and the second aspect is the inter-activities among various healthcare actors. In this part, the contribution is to propose an Activity Theory based Ontology (ATO) model to highlight and represent these two aspects of eHealth knowledge sharing, which is helpful for designing efficient eHealth systems.

In the validation part, a questionnaire based survey is conducted to practically validate the feasibility of the proposed ATO model. The survey results are analyzed to explore the effectiveness of the proposed model for designing efficient knowledge sharing in eHealth. Further, a web based software prototype is constructed to validate the applicability of the ATO model for practical eHealth systems. In this part, the contribution is to explore and show how the proposed ATO model can be validated.

In the application part, the importance and usefulness of applying the proposed ATO model to solve two real problems are addressed. These two problems are healthcare decision making and appointment scheduling. There is a similar basic challenge in both these problems: a healthcare provider (e.g., a doctor) needs to provide optimal healthcare service (e.g., suitable medicine or fast treatment) to a healthcare receiver (e.g., a patient). Here, the optimization of the healthcare service needs to be achieved in accordance with eHealth knowledge which is distributed in the system and needs to be shared, such as the doctor's competence, the patient's health status, and priority control on patients' diseases. In this part, the contribution is to propose a smart system called eHealth Appointment Scheduling System (eHASS) based on ATO model.

This research work has been presented in eight conference and journal papers, which, along with an introductory chapter, are included in this compilation thesis.