Towards Holons-based Architecture for Medical Systems

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ABSTRACT

The aim of this paper is to provide a holon-based architecture for medical systems with the objective of increasing the flexibility, the agility, and the adaptability of the systems. Inherently, medical systems are safety-critical, thus their design requires a specific approach regarding solving the ever-rising problems and changes in the medical field. The proposed approach is inspired by holon-based manufacturing systems and is adequate for the construction of complex medical systems.

CCS CONCEPTS

• **Software and its engineering** → Software design engineering • **Social and professional topics** → Medical records, Health information exchanges

KEYWORDS

Holon-based architecture, medical holarchy, medical systems

ACM Reference format:

Gabriela Moise, Petre-Gabriel Moise and Petre-Sorin Moise. 2018. Towards Holons-based Architecture for Medical System. *In Proceedings of SEHS'18:IEEE/ACM International Workshop on Software Engineering in Healthcare Systems (SEHS'18). ACM, New York, NY, USA, 4 pages.* https://doi.org/https://doi.org/10.1145/3194696.3194702

1 INTRODUCTION

Contemporary society faces more and more profound and rapid changes, which should determine us to look for new ways of designing, coding, and implementing software applications. The dynamic aspect of society has an important influence on medical software applications, since they work with the personal data of people, and their results have an immediate and direct effect over the people's lives.

SEHS'18, May 27, 2018, Gothenburg, Sweden

ACM ISBN 978-1-4503-5734-0/18/05…$15.00
https://doi.org/10.1145/3194696.3194702

Medical systems are safety-critical systems, thus, creating the blueprint for the system requires a specific and domain-oriented methodology, which must take into account complexity of the medical field. Moreover, medical systems must be able to face a series of various challenges, e.g. global population growth, particularly from impoverished areas; the aggressive nature of pharmaceutical companies; the higher mobility of humans; the appearance of new diseases; population diversity; the increase of life expectancy at a global level coupled with the slower growth of a healthy life expectancy in certain regions of the world [1].

Medical systems must continuously adapt to new technologies, must guarantee privacy and protection of patients' data, and must allow the integration of different medical devices. Furthermore, they must be robust, reliable, and should offer "time" for their users (physicians, patients, healthcare practitioners, nurses, administrative personnel, and so forth) [2]. Also, it is necessary to ensure the interoperability with other systems in order to improve the quality and efficiency of the healthcare services. The medical system must flexible, being able to rapidly and correctly react to diverse changes and disturbances.

The functions of medical applications are complex and varied. They are provided by modules of medical software systems, whose integration requires thorough testing and validation. In [3], a new approach for testing the integration of the medical software's component is proposed, the one of examining the paths of execution of the modules and detecting the interaction errors through reusing representative unit test cases. Besides testing independently each component, testing the interactions between the system's components is necessary.

Electronic Health Records (EHR) or Electronic Medical Records (EMR) software applications must prove capable of helping medics in diagnosing, prescribing treatments, and monitoring patients [4]. The patients' data must be portable, and readily available to authorized personnel while maintaining the integrity and confidentiality of the data. At the same time, these applications should also represent a useful tool for patients, allowing them to make appointments, to check the results of analysis, to look up different effects, positive and negative, of the prescribed medication. The medical applications should also include the functions of a recommendation system: patients should be able to choose the doctor or the clinic based on the reviews delivered by the medical system.

Requirements for software are usually classified into three categories, the line between them being a little vague in reality: functional requirements, non-functional requirements, and domain requirements [5]. Functional requirements refer to the services which a system should possess, the reactions and the behaviour of the system in certain situations. Non-functional requirements specify the constraints imposed to services and functions of the system, while domain requirements reflect characteristics and constraints of a specific domain [5]. The last category is specialized, and often raises problems with regard to understanding and linking them with other system requirements [5]. Due to the expansive nature and complexity of the healthcare domain, the requirements of the medical system are varied, intricate, and numerous. Moreover, in medical systems, humans and technology must form a singular entity, from a certain perspective, in order to collaborate towards fulfilling the system's requirements.

All of the aforementioned facts come together in order to prove a paradigm based on holons is better suited for medical systems than other traditional paradigms. Through using simple rules and holons' hierarchies, complex systems can be developed with the necessary attributes of medical systems: open, dynamic, flexible, interoperable, reliable, distributed structure, human, software and hardware integrating, cooperation and collaborative.

Unlike other medical holarchies focusing mainly on diagnosis, we are designing and implementing a holarchy encompassing all aspects of a medical organization, starting from administrative issues to the actual medical procedures. The aim of our research is constructing a medical holarchy, which will be the backbone of a hospital's or clinic's software. The starting point for our research work is the ten lessons for developing healthcare software presented in [6], which can be summarized in an user-friendly, highly flexible, easily updatable software, which has reached a balance point between privacy and usability, while also incorporating specialized characteristics necessary for certain tasks.

Through this paper, we present our work in progress regarding the holons-based development of a medical system. The objective of this approach is obtaining a flexible and reactive medical system.

2 RELATED WORKS ON HOLONIC APPROACHES FOR MEDICAL SYSTEMS

The term *holon* was proposed by Arthur Koestler in [7] from the Greek *holos* (whole) and the suffix *on*, which suggests a particle or part, in order to explain the evolution and organization of social and biological systems. These systems evolve by forming stable intermediate holons [7]. *A holarchy of holons is a hierarchy of self-regulating holons which function (a) as autonomous wholes in supra-ordination to their parts, (b) as dependent parts in sub-ordination to controls on higher levels, (c) in co-ordination with their local environment* [7]. A holarchy is a recursive structure of holons, which means that a holon can be a holarchy and can act as an autonomous and cooperative entity in the holarchy it belongs to. Furthermore, holons can be a part of multiple holarchies at the same time; they can create and shift in a dynamic manner in the holarchies [8].

At the beginning of the 1990's a new holons-based paradigm for manufacturing systems was proposed, called Holonic Manufacturing System (HMS) [9, 10]. Soon after this, specialists from different countries formed the HMS Consortium and developed the concepts of holons and holarchy in relation to manufacturing systems. In their opinion, holons are autonomous and cooperative units, which contain physical components (machines, hardware, controllers, etc.) and also information processing components (software application, databases, knowledge bases, etc.) [11]. A group of holons cooperating towards achieving an objective form a holarchy. The HMS is seen as a big holarchy, comprised of other holarchies and holons [11, 12]. The main attributes of the holons of a HMS are: autonomy, cooperation and openness. A detailed review of Holonic Manufacturing Systems can be found in [12].

There are few approaches based on holons for medical systems, and, more than that, the entire medical system of a clinic or hospital is mostly never seen as a whole and, also, as a part of another system, for example a national or global system.

In [13], a medical holarchy is defined as a system of collaborative medical entities (patients, physicians, medical devices, etc.) that work together to provide a needed medical service for the benefit of the patient. The components of Holonic Enterprise (HE) are defined on three levels [13]:

1. *Inter-Enterprise Level*: Hospitals, Pharmacies, Medical Clinics/Laboratories,
2. *Intra-Enterprise Level*: Sections/Units/ Departments of the enterprise level entities,
3. *Resource Level*: Machines for medical tests, information processing resources (medical files, computers, databases, decision support systems), physicians, technical medical personnel, medical assistants, etc.

In [14], a layers-organized medical diagnosis system is proposed (Holonic Medical Diagnosis System – HMDS), drawing concepts from both the HMS and the MAS (Multi Agent system). HMDS presents three types of agents: Disease Representative Agents (DRA) for representing a specific disease, Diagnosis Specialist Agent (DSA) for modeling the information in a specific medical field, and Mediator Agent for facilitating the communication between the system and the external environment and the collaboration between agent's holarchies.

Exploiting the synergetic triad Soft Computing – Internet – Multi Agent Systems, in [15] it is described a medical holarchy for progression monitoring of glaucoma patients. Soft computing techniques are used for developing the diagnosis and prediction engines.

A system for differential diagnosis is described in [16]. Using machine learning techniques for diagnosis, a holonic-Q-learning algorithm is introduced to support the functionality and the dynamics of the holonic system.

However, the studies presented in [13-16] focus only on diagnosing diseases or monitoring patients, whereas the holonic paradigm proves most advantageous when used in highly complex systems.

3 HMedA - A HOLONIC ARCHITECTURE FOR MEDICAL SYSTEMS

In the architecture proposed in this paper, the medical system is seen in its entirety and as a part of a national system, which is part of a continental system (see Fig. 1). The system's clients include: patients, physicians, medical personnel, other clinical users, and other external systems. In this context, in order to provide services to the medical system's clients, we define a *medical holarchy as a recursive structure of holons, representing medical or non-medical entities and processes* (related to patients, physicians, medical devices, treatments, financial resources, administrative or maintenance-related situations, etc.).

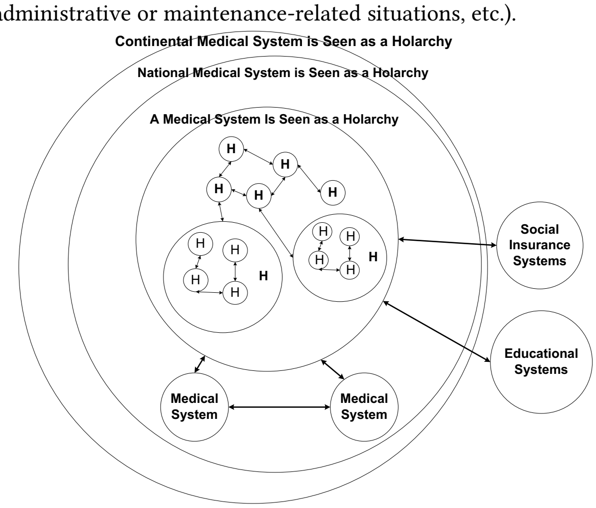

Figure 1: General View of Medical Systems' Interactions.

The *HMedA architecture* (Holonic Medical Architecture) uses concepts of the ADACOR architecture [17] and it's comprised of the following classes of holons:

1. service holons;
2. resource holons;
3. medical specialty holons;
4. supervisor holons.

These classes of holons are determined by the roles the holons have in the holarchy (Fig. 2).

Supervisor holons (*SupH*) coordinate the holons' activities in a holarchy. Supervisor holons know to which category a holon is part of, what the holon's role is and, more than that, it facilitates the interactions between holons and their integration in the holarchy. The supervisor holons are also responsible for the global optimization of the entire holarchy and for the system's control.

Service holons (*SerH*) are responsible for the management, planning, execution and delivery of services in the system: data security services, diagnosis and personalized treatment services, assistance services for physicians/patients/nurses, medical or financial decision services, quality standards inspection services, services for collaborating with other systems, etc.

Resource holons (*ResH*) represent the primary resources of the system, such as patients' data, medical devices, the clinic's data, infrastructure, etc. and their management.

Medical speciality holons (*MedSpecH*) are special holons dedicated to particular fields in medicine (urology, cardiology, opthalmology, etc). This category of holons deals with configuring the service and resource holons for the medical branch they refer to. This type of holon was proposed because of the sheer complexity and diversity of specialties in the medical domain.

In order to assure cooperation with other systems, a medical system contains a *specialized ontology* for representing and organizing the medical terminology. The ontology is necessary for a clear understanding of the medical concepts for all systems.

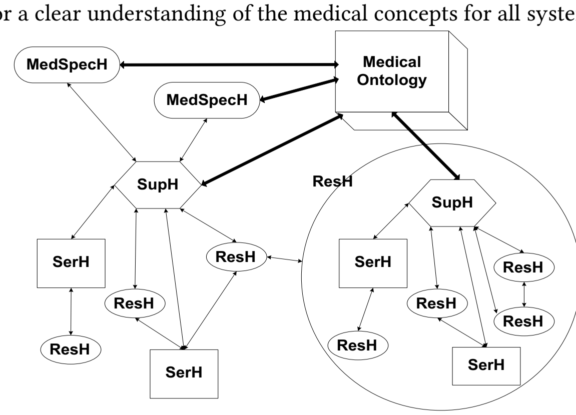

Figure 2: HMedA Architecture.

Implementing this type of architecture is laborious; however, this careful planning is exactly the way in which a medical system should be approached. In the end, the effort will pay off, offering a system which can be described through the following attributes: flexibility, robustness, scalability, quick reaction to unexpected disturbances, modularity, decentralization, auto-configuration.

4 A CASE STUDY - SMALL-SIZED HOSPITAL

In order to implement the proposed architecture in a medical system, a specific methodology, called holonification, is required. Through it, the holons and their categories are identified [17, 18].

In the case of a medical holarchy, the following steps are proposed:

1. defining and prioritizing the systems objectives (the objectives are systems services provided to their clients);
2. identifying medical or non-medical entities and processes;
3. describing medical or non-medical entities and processes;
4. identifying holons and their duties;
5. establishing logical dependencies between holons.

To exemplify a medical holarchy, we consider a small-sized hospital and the main objective of providing accurate, timely and readily accessible patients' medical records. In Fig. 3, a part of the medical holarchy is shown.

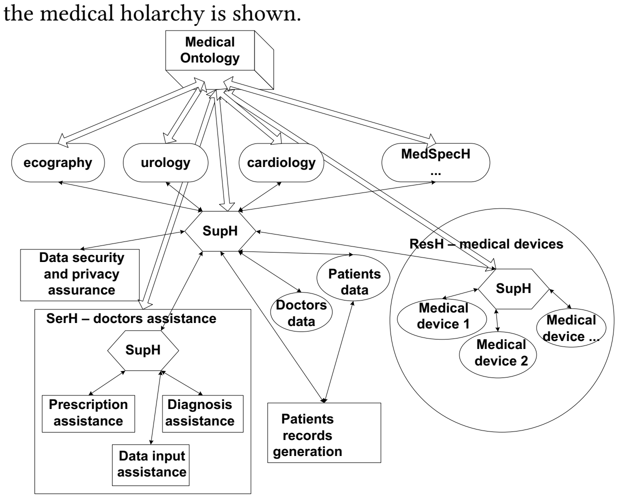

Figure 3: Part of a Medical Holarchy.

Given the following medical specialities of the hospital: ecography, urology, and cardiology; domain-dedicated holons are generated, which in turn configure service and resource holons for each field. For example, the *urology* holon offers support to the urinary tract's disease diagnosis system and configures the assistance module used by the urinary apparatus data input.

The inner holon *SupH* coordinates the activity of *HMedA* holons. In order to help physicians with diagnosis, prescribing treatment and data input, the *SerH - doctors assistance* holon is introduced. All medical devices are part of a resource holon, *ResH – medical devices,* and the patient's data are managed through the *Patients data* resource holon. Data security and privacy are provided by a dedicated service holon.

All holons are implemented through software, hardware, and medical infrastructure. Based on the holon's structure proposed in [19, 20], the holon consists of two parts: a functional component and a communication and cooperation component. The functional component has a goal-oriented structure and it is responsible for achieving the holon's goal. The communication and cooperation component deals with holons' interactions.

5 CONCLUSIONS

Developing good software in the medical field is a challenge in our modern society due to the direct effects it has on people. Moreover, the medical systems' complexity grows rapidly over time and, in the designing process, we have to take into consideration making them be scalable, adaptable, and flexible.

The holonic paradigm used in manufacturing systems is adequate for the informational systems of hospitals and clinics. The one of the most important characteristics of a holonic architecture-based system consists of that fact that even if one of the component changes, the functionality of the system is not affected. In this paper, we proposed a holon-based architecture for the informational system of a hospital. The implementation of this architecture will be done as an open-project, in which specialists from different fields will contribute. In our opinion, the holonic approach allows constructing medical systems having all the necessary attributes.

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