Initial development of a health-care software architecture model based on the autonomic computing paradigm

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***Abstract*—When a patient requires health-care attention, several hospital departments are involved, but there are some issues to solve to offer excellent services to the patients. The main problem is the resultant complexity as consequence of health-care systems integration, and the identified challenges are: (1) efficient administration, considering all the involved hospital systems; (2) the management of a large amount of information; (3) transforming the clinical and medical information to knowledge; (4) development of new medical and clinical knowledge-based applications, which will offer new patient benefits. This work is centered in the challenges (3) and (4); however, the former would be addressed much as required. To face these challenges, it is proposed an architectural model to represent generic solutions, using the autonomic computing paradigm. In order to test the model, a case study is under consideration for a mexican hospital. In this work it is presented the first project advances: the state of the art realization and the initial model proposal.**

***Index Terms*—Health-Care Information Systems, Autonomic Computing, Software Architecture.**

I. Introduction

The information systems used in health-care, direct or indirectly, support the patient diagnostic and treatment in the different hospital departments. These systems would be classified in three levels [1]: (1) stand alone systems, (2) integrated systems by other system (system of systems) and (3) regional systems which integrates systems from different hospitals in the region (mega system). In this work we are considering an Health-Care Information System (HCIS) as described in (2).

When a patient needs health attention, several services are frequently required. In this matter, the interoperability between legacy systems of the related departments is fundamental to provide an efficient patient service. But the information integration from different sources would be hard [2] [3].

In the mexican scenario, it is common to find isolated information stored in several information systems in the hospital departments. Therefore, the information is shared manually and the patient services show several deficiencies [4].

The systems produce and manage information that represents implicit knowledge [5]. Therefore, the hospital systems integration, as HCIS, produces a lot of knowledge which would be managed to offer better and new services, and benefits to patients. In this sense, the HCIS evolution and development should be projected into the future to face the new patient services [6], or the health-care medical models evolution, like *Evidence-Based Medicine* or *Patient-centered Medical Home* [4]. Also, it requires a great effort to promote cultural changes in the new systems operation [2] [3].

In the hospitals there are legacy information systems in their departments and their evolution has added complexity. Normally, these systems are hard to understand, to maintenance and to extend [5] [7] [8]. Also, the frequent technological changes have promoted the design of huge computer and information systems, working in distributed and heterogeneous environments and fast evolution [9] [10] [11]. The results are huge systems with very high complexity, which have imposed new challenges as: (1) efficient administration, considering all the involved hospital systems; (2) the management of a large amount of information; (3) transforming the clinical and medical information to knowledge; (4) development of new medical and knowledge based clinical applications, which will offer new patient benefits.

Several efforts have been reported to face the challenges. However, those systems are limited to particular problems, centered only to integration, and few of them report the use of autonomic computing.

In this work it is proposed a generic model, to face the challenges (3) and (4), considering that the former would be addressed much as required. The model will be based in a software architecture, will include medical/clinical knowledge management and will consider evolution mechanisms using the autonomic computing paradigm [12] [13]. It has been considered a case study to apply the model in a mexican hospital in some medical/clinical context.

II. Related works

There are some efforts to apply the autonomic computing paradigm to HCIS:

Knowledge management to make-decision support: in [14], it is proposed a system to handle the patient Electronic Medical Record (EMR) information, using autonomic computing to support decision-making in the patient medical diagnosis and treatment. The reported functionalities are *self-search* of patient information, *self-configuration* to present the information; *self-detection* of medical images and signals; (4) data *self-conversion* from the EMR to formats used in the system. In [15], it is presented a perspective about how the autonomic computing would face the human errors in the health-care of patients, in a Intensive Care Unit (ICU), to avoid propagation on secondary or tertiary diseases when a patient is admitted with a primary disease.

Autonomic computing in operational activities: in [16] is proposed an information system in an emergency department related to resources *self-management*. The goal is to optimize automatically the department's resources in use to preserve its operational objectives and the quality of services. In [17], it is mentioned a autonomic system to monitor the patient Blood Pressure (BP) through a mobile devices; the device controls the BP record process and allows patient to choose between look over recorded PA or send it to remote server to be stored. But along the work, the authors do not explain how the autonomic computing is used.

The autonomic computing paradigm has had few application in health-care field, according with the found out literature, and the reported works are different to our proposal: to develop an autonomic architecture model whose instances may extend the HCIS functionality managing the knowledge through autonomic computing.

III. Research objectives

The main research objective is to define an autonomic architecture model to health-care information systems which supports: (1) the consistent information management in all the hospital departments, (2) the information integration to favor the medical take-decisions in the hospital departments that require it, and (3) the event prediction in medical and clinical activities in the hospital departments.

IV. Methodology

The proposed methodology consists of four stages: (1) state of the art realization (2) model development, (3) case study, and (4) model refinement. These stages are described in the next paragraphs:

1) **State of the art realization.** This stage is defined to review the advance, challenges and problems in the HCIS development. A Systematic Mapping Study (SMS) methodology [18] would be applied to obtain response to defined research questions.
2) **Model development.** This stage includes several steps and tasks to develop the model.
    a) Defining the model scope: in this step several tasks are included to analyze the relevant HCIS features, to review architectural styles and their elements, and to specify the necessary autonomic elements.
    b) Reviewing the design methods and tools: the tasks, in this step, include to analyze and select the methods, techniques, and tools, required to develop the model; to analyze and select the reported methods to develop autonomic components; to search and select technical standards to develop HCIS, including the software architectures standards for critical systems.
    c) Designing autonomic architectural model design: this step includes tasks to design the model, using all the selected resources, and to test the model, applying the selected methods and techniques.
3) **Case study**: this stage defines a set of activities related to a hospital problem and the tasks defined include to choose a context to identify a problem as case study; to analyze all the possible scenarios in the problem solution according with the selected context; to define the model application environment and estimate the problem solution scope; to generate a model instance and apply it; to document and analyze the results.
4) **Model refinement:** according with the case study results, a plan should be defined to adjust the model.

V. Results

Following the methodology, several results have been obtained: (1) state of the art realization, (2) the model scope definition and (3) the case study outline.

A. State of the art

1) Methodology: The Systematic Mapping Study (SMS) methodology [18] has been used to realize the state of the art, looking for a wide coverage of primary studies about HCIS: software and system architectures, knowledge management, technical standards, challenges and problems, and the application of autonomic computing paradigm. The methodology concrete steps were adapted from [18] and [19]: (1) to establish a motivation to apply a SMS, (2) To define the research questions according with the scope of HCIS interest themes, (3) primary studies automatic search, (4) primary studies selection, (5) criteria definition to classify and analyze primary studies, (6) primary studies analysis, and (7) results summary.

2) Results: in the next paragraphs, some results are presented, trying to offer a quick view about how SMS was applied.

a) Research Questions (RQs): The RQs considered to this project are the following:

- RQ_1 What are the non-functional requirements considered in the HCISs?
- RQ_2 How are the software architectures used in the HCISs development?
- RQ_3 Do the HCISs implement some kind of medical knowledge management?
- RQ_4 What are the standards related to the HCISs implementation?
- RQ_5 What are the challenges and problems that HCISs have to face?
- RQ_6 Are there HCISs whose implementation includes autonomic computing?

b) Automatic search and primary studies selection: the automatic search requires to define search engines, according with the required information, and Search Expressions (SEs) composed from the RQs. Since the information required includes concepts, technical and medical, the following search engines were chosen: ACM digital library, IEEE Xplore, EI-Compendex, Science Direct, Scopus, and Springer Link. Also, for each RQ, a SE was defined, using the proposed techniques of [18] and [19]. However, each search expression had to be refined to reach the best results. Also, each SE had to be adapted according with specific search engine syntax. Applying the SE in each search engine gives a total of 1197 primary studies.

To select the primary studies it was necessary to establish inclusion and exclusion criteria to decide if each primary study is accepted or rejected. Applying the inclusion and exclusion criteria gives a total of 276 primary studies.

c) Primary studies analysis: The information from the primary studios was analyzed according with a set of relevant properties, finding answers to the RQs and aligning the information to project objectives. High level objectives were recorded like: clinical information access in appropriate format [20] [21] [22] [23]; Suitable coupling between the participant hospital information systems in regional applications [22]; medical knowledge management [24] to support making medical decisions [25], [24], from the processing of large data sets for particular pathologies [25]; efficient access to information [20] [21] and excellent performance in data processing [25]; Recovery and data integration for seamless exchange in heterogeneous environments [20] [21] [23] [26]; consistent information management in hospital departments [23].

From the high level objectives it was found non-functional requirements and restrictions: *portability* [20] [21] [25], *usability* [20] [24], *adaptability* [20] [21] [25] [22], *availability* [20], *performance* [22] [25], *security* [22] [25] [20] [21], *reliability* [25] [22], *interoperability* [23] [20] [21] [26] [21], *using standards in hospital information systems* [23].

The software architectures information, from primary studies, is related to give response to non-functional requirements and the used information technology. For example, *portability* is solved in distinct ways: using J2EE technology [20], loose coupling component design in cloud environment [21], information processing using agents from a repository of agents, which stores different versions for different execution platforms [25].

Implemented knowledge management using different mechanisms. Semantic management through *archetypes* [21], semantic links an ontologies to clinical knowledge integration [26], and ontologies to represent represent behavioral models related to specific hospital department [24].

The standards reported in primary studies have been considered in 2 ways: HCIS development and software development. In the first, HL-7 standard is used to implement syntactic interoperability mechanisms [20] [21] [23] [27] and, in the second way, software system standards are reported [27] for software-intensive (ANSI/IEEE 1471-2000)[1] and open distributed processing (ISO/IEC 10746-2:2009)[2].

B. Initial model

An initial model has been proposed (see Figure 1) considering that the mexican hospitals have legacy systems operating daily since several years ago, and several elements obtained in the state of the art realization.

1) Considerations:

a) Information integration: to ensure that medical/clinical information from legacy systems, the information is integrated in a consistent and appropriate format to be used as relevant knowledge.

b) Legacy systems operation: to keep the service levels of legacy systems in terms of performance, communication, availability, user concurrency, etc., through loose coupling mechanisms between them.

c) Business policies: to keep business policies of legacy systems established by the hospital.

2) Functional and non-functional requirements: the functional requirements to be considered in the initial model have been established as to provide mechanisms for subsystems integration; to transfer information to the hospital departments where it would be required; to give information to the users according with their requirements; to add loose coupling interface mechanisms to legacy systems; to define persistence mechanisms for knowledge; to define autonomic mechanisms from the management of acquired knowledge. The non-functional requirements have been already considered as interoperability, performance, security, availability and reliability, considering that it will appear new of them that have to be considered in the model.

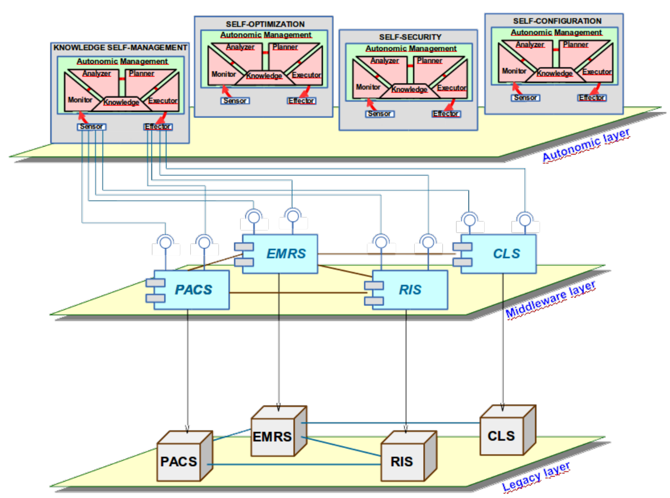

Fig. 1. Three layer initial model of a health-care software architecture based on the autonomic computing paradigm.

[1]http://standards.ieee.org/findstds/standard/1471-2000.html.

[2]http://www.iso.org/iso/isocatalogue/catalogueics/cataloguedetailics.htm?ics1=35-n&ics2=080n&ics3=n&csnumber=55723

3) The model: the initial model is shown in the Figure 1, and it consists of three layers structure: (1) legacy layer, (2) middle-ware layer and (3) autonomic layer. The legacy layer contains the hospital legacy systems, the middle-ware layer is a interface layer that connects the legacy systems with autonomic layer to monitor and to execute some process in the legacy systems, and the autonomic layer is defined to analyze the monitored information from legacy systems and planning actions to them, considering previous knowledge stored.

VI. Conclusions

In this paper has been proposed the initial development of a software architecture model based on the autonomic computing paradigm, which intention is to face the current challenges in HCIS. The formal process to realize the state of the art has permitted to define required mechanisms, functional and non-functional requirements, business perspective, standards, business policies, as elements to be considered in the model development. Also, these elements have also been very useful to outline an initial model, which will be detailed in the following stages of the project.

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