Cross-cutting concerns: Improving an Intelligent System for Decision Making in Healthcare

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***Abstract* – This paper proposes a better way to represent the architecture of LARIISA, an intelligent system for decision making in healthcare. The proposed representation weaves health and computational domains in a multidimensional architecture, which facilitates the visualization of specialized applications added to the LARIISA framework. New concepts as Big Data, Internet of Things and Linked Data are also introduced to the proposed architecture. Acquiring new data from different sources to the LARIISA database, and making use of it, will permit a more efficient decision-making process for the system.**

Keywords - context-aware; governance; architecture; decision-making; health

I. Introduction

In healthcare practice, the key tasks are collecting and recording patient's health data, patient's context information, getting a diagnosis, treating the disease and prescribing drugs for treatment of the patient. Health managers need to make important decisions when performing these tasks, with regard to the diagnosis, investigations to be done, optimum treatment and long-term care according to the outcomes of the disease.

Even though modern information technology offers some solutions as different systems for some of the above healthcare aspects, usually they are not integrated to form a reasonably complete decision making system in healthcare governance. Since the healthcare decisions are made concerning all the relevant aspects, it would be productive to have such system. This paper presents how health information and computational techniques can be integrated to form a better system for clinical practice in healthcare. In our research work, we have built a cube representation including cross-cutting concerns to demonstrate the applicability of those techniques.

As a proof of concept, we also describe on this paper (section V) two systems that are sponsored by Brazil's Ministry of Health and are being developed, at this moment, in a Brazilian Research and Development Institution.

The organization of this paper is presented as follows: Section 2 describes the LARIISA framework. Section 3 introduces an overview about system architecture. Section 4 presents the proposed representation for the system, and finally section 5 concludes this paper and discusses future work.

II. LARIISA

LARIISA Framework takes into account local and global health context information models for governance decision making. LARIISA defines the basic architecture for building context-aware applications and supporting decision-making in the health care area. LARIISA was specified taking into account specific requirements of five governance domains: Knowledge Management, Systemic Normative, Clinical and Epidemiological, Administrative and Shared Management [1]. Therefore, the architecture proposed in this paper provides a new approach over those five domains, proposing four main domains as it is shown on figure 1.

Out of the five original health governance domains proposed in [1], we kept only four of them, as we considered "knowledge management" to be a crosscutting functionality, transversal to the other four domains. Figure 1 shows the health governance domains proposed.

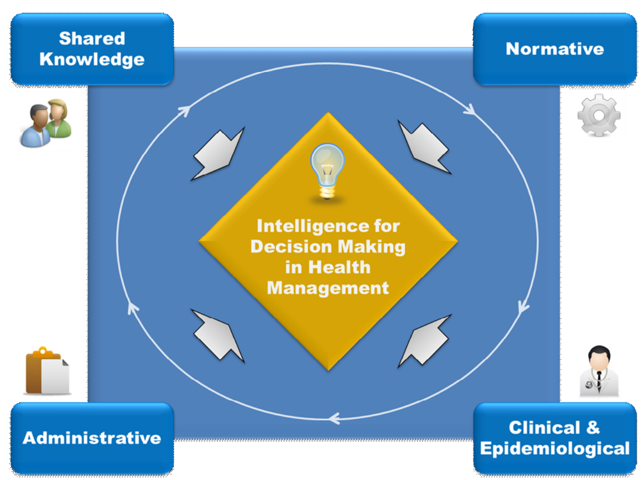

Fig. 1. Four health governance domains

Figure 1 represents the health module on the cube representation proposed on this paper. Further it will be added to the cube (figure 4).

LARIISA framework works with real-time information and comprises inference systems based on ontology models. Figure 2 presents the LARIISA core architecture. This architecture will be further used as part of the new proposed architecture. For a better understanding, LARIISA's components are described as follow:

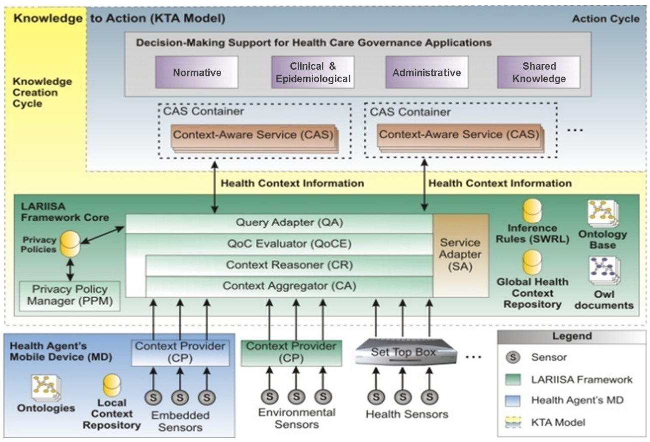

Fig. 2. Ontology and context-aware architecture

- **Context Provider (CP):** it is in charge of gathering raw healthcare context data from the environment, mobile sensors (e.g., health agent's mobile device), and family homes (i.e., by using Set Top Box), which will be sent to the context aggregator (CA) layer;
- **Context Aggregator (CA):** it is in charge of receiving health context information from various context providers, running context aggregation operations in order to have useful high-level context represented by the Local Health Context Ontology;
- **Context Reasoner (CR):** it runs inference/derivation processes on health context information described by Local Health Context instances in order to obtain semantic high-level context information and to generate Global Health Context information;
- **QoC Evaluator (QoCE):** it evaluates the Quality of Context (QoC) information [2], generating QoC indicators assigned with each context concept that will be used for improving health care governance decisions;
- **Service Adapter (SA):** it is the main layer of LARIISA. It is in charge of identifying health context information relevant to the three following cycles: i) knowledge creation process; ii) health care governance decision-making process; and iii) health care actions;
- **Context-aware Service (CAS):** it uses Local and Global Context information obtained from the Service Adapter for adapting their functionalities. Context-aware services will compose health care governance decision-making applications designed according to the Action Cycle of KTA model;
- **CAS Container (CasC):** it represents a group of CAS. A governance decision-making application is composed by one or more CasC;
- **Query Adapter (QA):** it handles context queries from context-aware services and entities of knowledge cycle, extracting relevant context information from the Context Global health Repository.

Figure 2 represents the computational module on the cube representation proposed on this paper. Further it will be added to the cube (figure 4).

LARIISA is centered on the concept of health context information. Based on Dey's definition of context [3], we consider health context as any information that can be used to characterize the situation of an entity in a health system. LARIISA is able to perceive the status of emergency epidemiological and adapt itself in real time to a risk situation.

III. System Architecture

On this paper we will propose a new informal architecture for LARIISA framework, based on a cross concept vision. This architecture draws from the ISO/IEC/IEEE 42010 formal standard for software architecture description [15]. One of the problems found when thinking about systems architecture is that this terminology has been poorly borrowed from other disciplines (such as civil architecture or naval architecture) and is widely used inconsistently in a variety of situations [4]. For instance, the term architecture is used to refer to the internal structure of microprocessors, the internal machine structure, the organization of data networks, the structure of software programs, and many others.

When we try to understand a computer system, we are interested in what their individual parts actually do, how they work together, and how they interact with the world around them - in other words, this is architecture. A good definition of architecture that is widely accepted in the community, comes from work done by the Software Architecture Group Software Engineering Institute (SEI) at Carnegie Mellon in Pittsburgh: "The architecture of a software system are the system structures , which comprise software elements, the externally visible properties of these elements, and the relationships between them".

Architecture for a software system can be very complex. The architect's role is to describe this complexity for people who need to understand the architecture. The architect does this through a description of the architecture [5].

An architecture description (AD) is a "set of products documenting an architecture in a way that people can understand and demonstrate that the architecture reached their needs" [6].

An architecture description needs to present the essence of an architecture and its details at the same time - in other words, it should provide an overview that summarizes the entire system, but must also decompose it in sufficient details so that it can be validated and the described system can be built.

While it is true that every system has an architecture, it is unfortunately not true that every system has an AD. Even if an architecture is documented, it can be documented in parts, or the document may be outdated or unused. Efforts to formalize languages to describe systems architecture have been made over time. Collectively, these languages are called architecture description languages (ADLs) [4].

IV. LARIISA NEXT GENERATION

The architecture proposed in [7] was adjusted for a new integration-based architecture (figure 3). The adjustments presented in layers were intended to bring the concept to a computer model dividing the layers within the computational logic, the scheduling of the stages applications, similar to the layer architecture TCP/IP network.

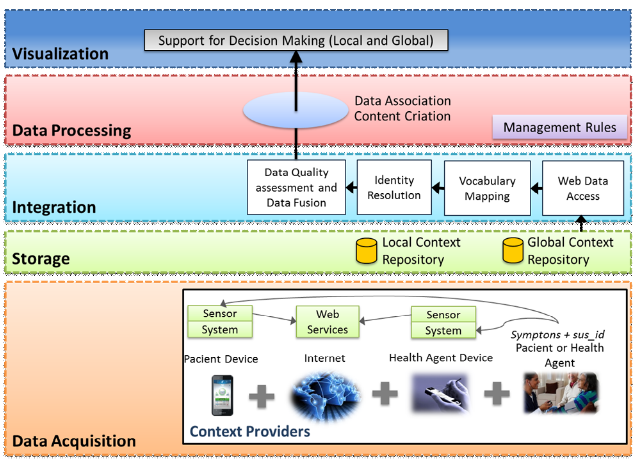

Fig. 3. Integration architecture

The global and local context databases were relocated to the layer storage. An integration layer was added to the architecture (figure 3) so the LARIISA framework will be able to integrate data stored in external databases, improving its inferences and consequently its decision-making process.

One of the most important layers of this architecture is the integration layer, which contains four major modules for integrating present data on internal/external databases in information aggregation process for making inferences and decisions. The following will describe the modules present in this layer:

- **Data Access:** This module consults data available on the Web. The module only consults important data for the decision making process of LARIISA. To perform this access and integrate the collected data with the framework, it is necessary to apply standardized rules as defined by the RDF[1].
- **Vocabulary Mapping:** This module translates the Web data that are represented using different vocabularies terms within a single target vocabulary. For this step we use SPARQL query languages. The expressiveness of this language allows the module to negotiate with all requirements when translating Linked Data from the Web into a target representation.
- **Identity Resolution:** This module implements a discovery framework to find different Uniform Resource Identifiers (URIs) that are used within different data sources to identify the same real-world entity. To each set of duplicates which were identified by the discovery framework, Linked Data Integration Framework (LDIF) replaces all aliases with a unique URI within the target output data.
- **Data Quality Assessment and Data Fusion:** This module consists of two separate steps. First, the Data Quality Assessment module assigns each Named Graph within the processed data one or several quality scores based on user-configurable quality assessment policies. These policies combine an assessment function with the definition of the quality-related meta-information which should be used in the assessment process. Then the Data Fusion module takes the quality scores as input and resolves data conflicts based on the assessment scores. The applied fusion functions can be configured on property level.

Figure 3 represents the functional module on the cube representation proposed on this paper. It will be added to the cube (figure 4) presented below.

We added all concepts researched above in a single cube representation that permits us to develop new concepts using all data and information from a health or computational point of view. By doing that, as presented in figure 4, we started a new vision of the system and new specialized applications can be developed to the LARIISA framework from now on.

[1] http://www.w3.org/RDF/

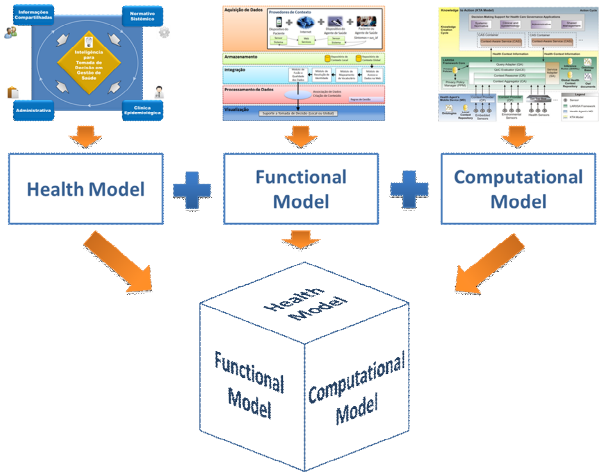

Fig. 4. Cube representation

In order to group the main technologies currently applied to LARIISA, it was developed a "cube" so we can visually draw attention to the three main concerns which guided the project. In other words, and using the ISO/IEC/IEEE 42010 architecture description standard jargon, each side of the cube is just a *view* adhering to one of the three *viewpoints* used when conceiving the system. Important to note that the cube analogy emphasizes the fact that fields on a particular side of the cube should be regarded independently of fields present on the other sides and any implementation effort should take this in account (for instance, when implementing LARIISA's knowledge management component for the normative or regulatory domain).

The right side specifies the technologies proposed in LARIISA project (context-aware services, inference rules, knowledge representation and knowledge management).

The upper side shows the four governance domains, which, according to Andrade [14], are instrumental for decision making in the health sector. They are disparate areas and require specialists in each area.

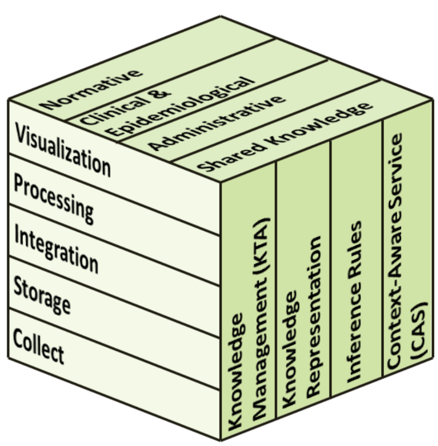

Fig. 5. Cross concepts (cube representation)

The left side lists the five implementation aspects of computer systems (i.e., collecting, storaging, integrating, processing and visualizing data). The integration layer is given in two ways: integration with national and international standards recommended by the Brazil Ministry of Health (SNOMED, cIAP2, openEHR, LOINC, etc.) [8] and integration to DATASUS systems (SISAB, CNS, SISRCS, ESUS AB, etc) [9].

The proposed cube representation (figure 5) enables new applications to be integrated with LARIISA with more granularities. It means that the architecture proposed in figure 2 was a macro view of each module, but the relationship between each component of the system did not have much visibility – as opposed to this new proposed cube representation.

By adding all concepts on the cube representation, we started developing a new informal architecture (figure 6) that represents the main elements of the intelligent system for decision-making in healthcare governance. Modules shown in figure 6 are explained next:

- **Cross-cutting concerns:** As described in sections II and IV of this paper, functional, computational and health concepts that guide LARIISA were integrated into a multidimensional representation (cube), which now permits us to correlate all of the information and mechanisms from health and computational areas. Therefore we can decompose each transversal element into micro cubes (figure 7).
- **Privacy Module:** This module ensures the confidentiality of patient's health information. There are specific regulations in health area all over the world regulating access, storage and provisioning of health information. One of these regulations is HIPAA[2] (Health Insurance Portability and Accountability Act).
- **Data Acquisition Module:** On this module are managed all aspects and standards related to the collectors of context aware information collected by context providers and health sensors. Some of the components of this module: Set-top-box, Digital TVs, medical sensors installed in hospitals or patient's houses and sensors embedded in mobile devices (smartphones, watches, etc.).

[2] http://www.hhs.gov/ocr/privacy/

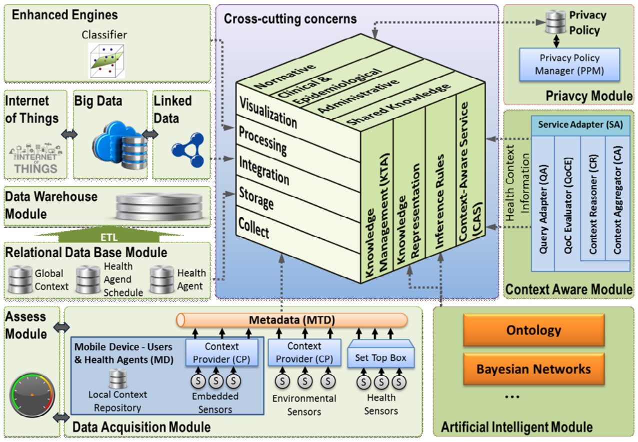

Fig. 6. Enhanced Architecture

- **Assess Module:** This module of the architecture, connected directly to the Data Acquisition module, provides standardization mechanisms for the context providers and health sensors of the system. For instance, one sensor that collects vital signs, even if it is embedded in a device or installed in a patient's home or public place (e.g. health center or hospital), it must be precise in its vital signs measurements.

- **Artificial Intelligence Module:** On this module are specified and implemented the LARIISA intelligence mechanisms to participate on the decision-making process. Studies have been deepened in the use of context aware applications, ontologies and Bayesian networks.

- **Context Aware Module:** This module consists of the components shown in section II of this work and this is one of the main framework of the mechanisms whose function is to make the contextual information so that they can be used by the system.

- **Relational Database Module:** This module has the relational databases that store data collected by manifolds and related persistent data to registered health workers, their specialties and their work schedules. This information is treated by the ETL component and then stored in a data warehouse that will be described hereinafter.

- **Data Warehouse Module:** This module is responsible for receiving the module above data (relational databases) through a process of ETL (Extract, Transform and Load). From this module will be generated reports with intelligent health information to assist in decision-making processes by health managers.

- **Linked Data:** This module architecture works in the integration layer of the functional model and aims to ensure standardization in the search for information in external databases to LARIISA and its relation to the information in the storage layer also the functional model presented architecture.

- **Big Data:** Through this module the LARIISA will be able to query information stored in entities outside the framework. Through Linked Data module, which we talked about earlier, this module will provide the integration of essential information for decision making global context level.

- **Internet of Things:** Module inserted recently in LARIISA framework and it has been discussed within the Internet since 1999, but in recent years has gained more strength with the advent of microcomputers in various devices and the variety of possibilities with connectivity to the Internet.

- **Enhanced Engines:** This module, connected to the functional model processing layer, aims to increase the capacity of the framework on processing health information and then choosing the best artificial intelligent system for decision making process, based on a classifier [10].

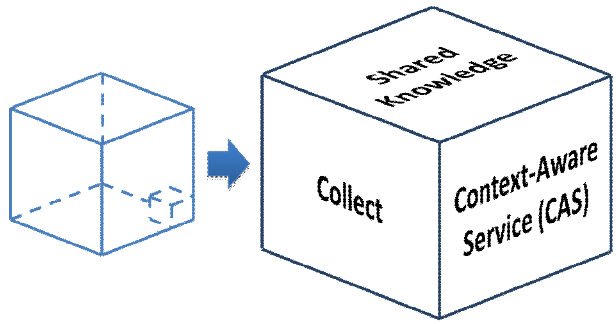

Fig. 7. Smaller part of the cube (specialist applications)

Exploring one of the cube layers displayed (figure 5), we note the mainstreaming of the cube layer and the possibility of unifying concepts. In this sense, we can see the four (4) areas of intelligence for health decision-making have a correlation with the Context Aware Service (CAS) layer belonging to the computational model side. Nevertheless, applications that address all four (4) domains can use the services provided by CAS layer. In addition, services provided by the functional model will also be available for each health domains (figure 1).

Compared with the micro cube shown in figure 7, we can mention as an example an application with Web sensors (collecting different health information from the Internet) as the plans of shared knowledge and collects and intelligent algorithms inferring from context awareness as the service plan sensitive to context.

Importantly, even with the granularity we arrived at micro cube of figure 7, it is necessary that application developers to LARIISA are concerned and attentive to integration of all micro cubes that form the cube shown in figure 5. That is, micro cubes runs have specialized, but are part of a cluster of micro-cubes interacting.

As an example, two micro cubes relating the concept of knowledge representation (e.g. ontology) in the computer model, the concept of clinical & epidemiology in the health model, and one of micro cubes relates the concept of integration in the functional model and the other relates the concept of storage in the functional model. Thus, it is evident that an application to solve the problem described above micro cube working in the storage layer of the functional model will address the ontology storage level, and the other micro cube working in the functional model integration layer will address the integration of domain ontologies present in external databases to LARIISA

V. Conclusion

The evolutionary process of LARIISA since its beginning in 2010, shows that research conducted brings innovation to it. This can be proven with two projects that were started in late 2014 - one sponsored by Finep[3] (*Financiadora de Estudos e Projetos*) and the other one by Funcap[4] (*Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico*). Both project were developed under all concepts presented on this paper.

With the inclusion of the concept of metadata in LARIISA framework and deepening of geolocation studies and their correlations [7], it was possible to move the platform to a standardized model of collecting and entering data into LARIISA databases. These components also enhanced the decision-making power of applications through contextual information.

GISSA architecture [11] was developed taking into account the architecture proposed in figure 3. With the growth of LARIISA project, it is possible to observe that the creation and evolution of scenarios and architectures favors the visualization of new applications that add functionality to the studied platform.

LARIISA [1] is an intelligent system for decision-making in a public health management environment. In [12] the authors propose a data integration platform for the LARIISA. The aim of this proposed platform is to enable the integration of a large variety of health information databases with different governance issues involved, enabling interoperability among these multiple sources of data. Making use of this platform, the framework on this paper will be able to correlate information stored in different databases of private or public companies. It would permit the system to find additional information of a specific patient (e.g. via SUS ID) to collect more health information related to a specific patient, thereafter taking a decision more accurately.

As future work, we will focus on improving Linked Data, Big Data and Internet of Things integration to the proposed architecture. We will also improve the enhanced engines module. Classifiers have already been studied as it can be read at [10].

[3] http://www.finep.gov.br/
[4] http://www.funcap.ce.gov.br/

The research presented on this paper has the purpose of joining Continua Health Alliance [13], a non-profit, open industry organization of healthcare and technology companies.

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