GIRLS, a Gateway for Interoperability of electronic health Record in Low-cost System

* Interoperability beetween FHIR and OpenEHR Standards

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***Abstract*—Clinical information about patients should be consistent, complete and available to health professionals, ensuring quality care. This information is recorded on paper or on electronically-stored in a digital format. A few years ago, both Brazilian government and private healthcare providers invested in Information and Communication Technology to replace paper medical record with Electronic Medical Record (EMR). Nowadays, EMRs are evolving into Electronic Health Record (EHR), which allows for interoperability between different systems. While brazilian public health system recommends the OpenEHR standard as an information model for EHR, private providers in Brazil have adopted the HL7 FHIR standard. This article proposes the GIRLS, a low-cost gateway for EHR interoperability that uses both standards. As proof of concept, a chikungunya OpenEHR archetype and an equivalent FHIR feature have been implemented. This archetype is available to the Clinical Knowledge Manager (CKM), the largest online repository of archetypes on the Web.**

***Index Terms*—Archetypes, EHR, OpenRHR, HL7 FHIR**

I. Introduction

Brazilian healthcare is provided by the Unified Health System (Sistema Único de Saúde, SUS in Portuguese) and private supplementary healthcare providers. SUS is one of the largest and most complex public healthcare providing systems in the world with approximately 150 million beneficiaries (about 75% of Brazils population), covering everything from simple procedures through Basic Assistance to organ transplant in high complexity hospitals, guaranteeing full, universal and free access to healthcare services for the entire country. While private healthcare providers assist in average 50 million people, a population that do not lose their right to assistance by SUS should they need to [9].

Both public and private healthcare providers need, in addition to an efficient physical and human infrastructure, full access to the patients clinical information and history in order to guarantee the quality of their services. This information must be consistent, safe and complete so that healthcare professionals can make adequate decisions throughout the treatment process [7].

Throughout SUSs process of consolidation and private healthcare plans implantation there were many investments in Information and Communication Technologies for Health (ICT) and many Health Information Systems (HIS) have been developed for processing, storing and transmitting electronic data regarding Brazilian citizens health information. Among those HIS, we have the Electronic Medical Record (EMR), which stores patients clinical and administrative information in a health care unit, guaranteeing its security and availability [8]. EMRs are proprietary systems, which means each health care unit, either public or private, has their own solution, built with different technologies and information models, with its own architecture and sets of business rules, as well as diversified clinical terminologies [13]. This complicates the interoperability among HIS, bringing along issues such as: clinical history fragmentation among different HIS, unavailability of relevant patient data in new health care units (or units that patient didnt visit previously), medical error due to lack of the patients complete medical history, clinical information redundancy scattered across multiple EMRs, omission of test results (which forces the patients to redo procedures) and a larger consumption of time and resources. All of these issues compromise the quality of patient care and information management for decision-making by healthcare professionals and managers [10].

With the advance of ICTs, EMRs have evolved, originating the concept of Electronic Health Record (EHR). EHRs are medical history repositories that process, store and transmit the data electronically in a safe and efficient way [7]. This solution has the advantage of sharing and reusing clinical data to make them available anywhere and whenever necessary, facilitating decision-making for healthcare professionals during patient treatment, avoiding rework and reducing time and cost with exams and procedures that have been previously performed, guaranteeing efficiency and optimization of the healthcare process [5].

There are challengers in addressing interoperability between systems. The most adequate solution is through a consensual standard, be it adopted by the market - a *de facto* standard - or by the government -a *de jure* standard [5]. In Brazil, there is an effort in applying interoperability standards in HIS, such as the publication of the Ordinance 2.073/2011 by the Ministry of Health. This ruling defines twelve interoperability standards for HIS, among which OpenEHR [12]. OpenEHR is based on archetypes or metadata models that represent clinical information, as it is for blood pressure today. In order to define a clinical register (e.g., discharge report), we need a set of archetypes that compose a template [1]. The archetypes and templates constitute a knowledge model, which is stored in a shared online database called CKM (Clinical Knowledge Manager). One practical application of OpenEHR and the other standards contained in ordinance 2.073 is the construction of Minimal Data Content (MDC) by the Ministry of Health, which is a public system that collects medical assistance data from every health care unit in the country [11]. Another example of OpenEHR use is MARCIA (Brazilian Portuguese acronym for Management of Applied Clinical Registry), which was born from an academic work (MSc Thesis) and proposes an epidemiologic EHR by using OpenEHR archetypes defined in CKM. MARCIA registers and manages medical data while aiding medical professionals during basic attention in be treatment and prevention against Chikungunya [3].

Another interoperability standard used in the construction of EHR, especially in private care providers, is HL7 Fast Healthcare Interoperability Resources (FHIR), that is a combination of the best features found in HL7 2.x (version 2), HL7 3.x (version 3) and Clinical Document Architecture (CDA). [12].

This research proposes an evolution of another work based on the OpenEHR standard into an equivalent proposition using the FHIR standard, proposing an architecture in layers of interoperability, FHIR-oriented, capable of promoting data exchange between different standards. This architecture comprises an API that connects different systems through endpoints, a broker server that maps the data from different standards into the FHIR standard and manages the microservices for data access and exchange.

II. Theoretical Framework

A. OpenEHR

The OpenEHR standard is characterised by a set of free tools and specifications that enable the development of modular clinical records. This standard is maintained by the OpenEHR Foundation, which proposes the development of EHRs capable of keeping up with the dynamism and complexity of the medical field, enabling the development of open, flexible and independent interoperable systems [2]. This standard's objective is to represent clinical knowledge in a structured, uniform and organized manner through the construction of objects called archetypes (metadata standards), which represent clinical data from various origins, e.g., heart frequency [4]. When building an EHR with OpenEHR, there is a separation of responsibilities, as illustrated in "Fig. 1", such as:

- **Healthcare professionals:** responsible for defining models that describe consensual concepts and creating templates to be used in health care units. The template is a set of archetypes that represents a clinical record, for example a discharge report;
- **Information Technology professionals:** responsible for developing software that comprehends these models and adjust to their definition, guaranteeing version control for the information and efficient data management [6].

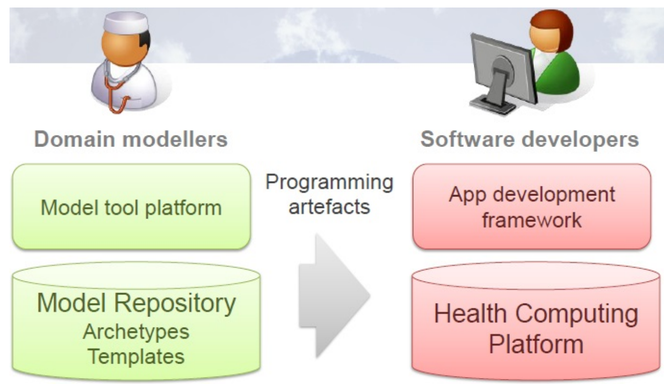

Fig. 1. Dual model of OpenEHR standard. Source OpenEHR(2017).

B. FHIR

FHIR (Fast Healthcare Interoperability Resources) is the newest standard released by HL7 (Health Level Seven) foundation, which is a non-profit organization focused on developing a set of international patterns for the sharing, integration and exchange of clinical and administrative data between software applications used by healthcare professionals. FHIR is flexible, easily implementable and employs web services such as XML, HTTP, REST, OAuth, JSON, among others [14].

FHIR uses an Application Programming Interface (API) with a RESTFul architecture, which facilitates data exchange, for example, between mobile applications and medical equipment, and the sharing of files that are based on EHRs [15].

FHIR supports four interoperability paradigms: documents, services, messages and RESTFul web services, as shown in "Fig. 2". Unlike other standards that support these paradigms separately and require an interface to communicate between them, FHIR has the same content in all four paradigms [17].

The paradigms presented in "Fig. 2" are:

Fig. 2. The interoperability Paradigms of HL7 FHIR.

- **FHIR Messages:** messages are exchanged based on a set of FHIR resources, which conjointly represent messages similar to the ones in HL7 v2 and v3.
- **RESTful FHIR:** the RESTFul API serves as an interface for the resources between the FHIR application or client and the FHIR server.
- **FHIR Documents:** the document-based exchange involves a typically larger package of FHIR resources. Together, they would represent a C-CDA HL7 document [18].
- **FHIR Services:** services can be conceived as a simple way of building messages. Services will likely be used for support and decision-making purposes [17].

*1) **FHIR infrastructure**:* HL7 and the US United States President's Council of Advisors on Science and Technology (PCAST) established an agreement in 2011 for the determination of a basic data exchange block, that is, only the most significant data must be sent in the information structure [19]. FHIR was designed on top of this concept, using small exchange blocks with context metadata and an efficiently defined structure. FHIR has two main infrastructure components:

- **Resources** the data elements related to the medical assistance context (e.g., Patient, Observation, Device, Allergy or Intolerance, Medication) are called resources. The 150 types of FHIR resources encompass every area of medical attention and care. FHIR resources physical infrastructures comply to either JSON or XML formats and are manipulated via API, like HAPI FHIR. These resources will be externally exposed as Web services [20].
- **API** - A set of well-defined interfaces to interoperate applications. Messages are expressed as XML, JSON. These formats are distributed via web services as RESTFul, allowing us to match various contexts, such as the sharing of electronic clinical records. The RESTFul API describes the resources as a set of operations (such as interactions), in which their instances are monitored as collections by their types [21].

III. Related Works

- **MARCIA (Applied Clinical Record Management):** This work proposes a methodology for the development of interoperable and flexible systems, using the EHRServer framework of the OpenEHR standard. As a case study, this methodology has been applied in Aracati/CE since March / 2017, in the context of the Chikungunya disease. The methodology is supported by a system that implements a set of OpenEHR archetypes representing the clinical treatment of Chikungunya. The archetypes and the MARCIA Templates were made available to the Clinical Knowledge Manager (CKM), the largest online repository of archetypes on the Web [3]. The GIRLS proposed in this paper is an evolution in the MARCIA including of the FHIR standard, used in data exchange with any other system.
- **SMART on FHIR** is a set of open specifications to integrate apps with Electronic Health Records, portals, Health Information Exchanges, and other Health IT systems. With SMART on FHIR an application can be launched from an EHR system. This means an application is being launched inside another application, staying away from things like external links [18]. SMART on FHIR is an EHR integration platform, excluding OpenEHR, unlike GIRLS proposed in this paper.
- **National Health Service (NHS)** in England uses FHIR APIs for data exchange. They are called CareConnect Open APIS, developed by NHS Digital and INTEROpen. They support exchanging data kept in different medical care environments during care-giving by using FHIR resources defined nationally. A generic CareConnect record contains metadata (patient, location), written declarations about the care provided (diagnosis, medications, procedures, patient allergies) and codified entries (medication, diagnosis, procedures) [22]. In short, it is an FHIR-oriented API that allows the integration of various national systems, excluding OpenEHR, unlike the purpose of this paper.

IV. ARCHITECTURE STANDARDS FOR FHIR

FHIR resources and services can help with the specification of heterogeneous platforms, allowing for flexible architectures that assure exchange between systems. Structurally, FHIR does not limit system architecture. Developers have the freedom to build solutions using different approaches in their architectures, two of which stand out as semantic interoperability solutions:

- **FHIR Broker:** systems with different data formats ("Fig. 3"), including proprietary data formats, are converted into FHIR format so that health organizations can mutually exchange data with suppliers, educators and Health Information Exchange (HIE) networks, integrate laboratory requests, vaccination registries, compulsory notifications for public health agencies. The data is not necessarily stored in these systems, as they are usually designed to transport data [23].

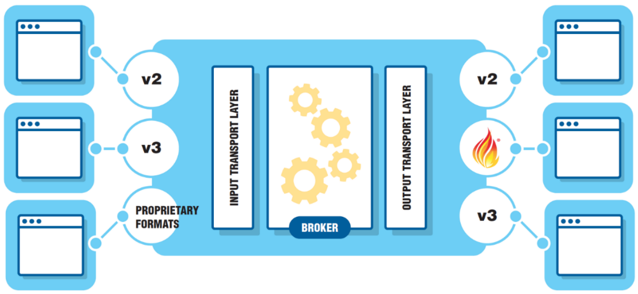

Fig. 3. FHIR Broker: converts different data formats into FHIR format.

- **FHIR as an integration Hub ("Fig. 4"):** integrates various formats by using the FHIR data format as a native exchange format for mapping data from other formats into FHIR. This architecture makes the design process for applications simpler, as the responsibility of mapping proprietary formats into FHIR belongs to the BROKERs supplier [23].

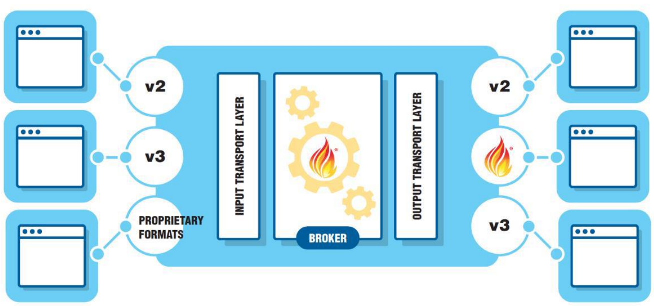

Fig. 4. FHIR as an Integration Hub.

In Brazil, where the healthcare unified system (SUS) proposes an OpenEHR standard, while private health insurance companies adopt the FHIR standard, the problem is no longer the syntactic or functional interoperability that define how the data must be written. What we aim for is the interoperability between systems that employ different data standards, in other words, the semantic interoperability that allows for different systems to consume data with different standards, namely FHIR and OpenEHR. This would enable the implementation of a platform that operates as an integration Hub, an N:1:N interoperability model where the components communicate with each other through a data bus or server and all communication is brokered, allowing these distinct environments to integrate their systems and exchange data through public or private networks.

V. GIRLS INTEGRATION HUB

The Figure 5 shows the architecture of the GIRLS integration hub, proposed in this work. It is based in the FHIR approach mentioned in the "Fig. 4".

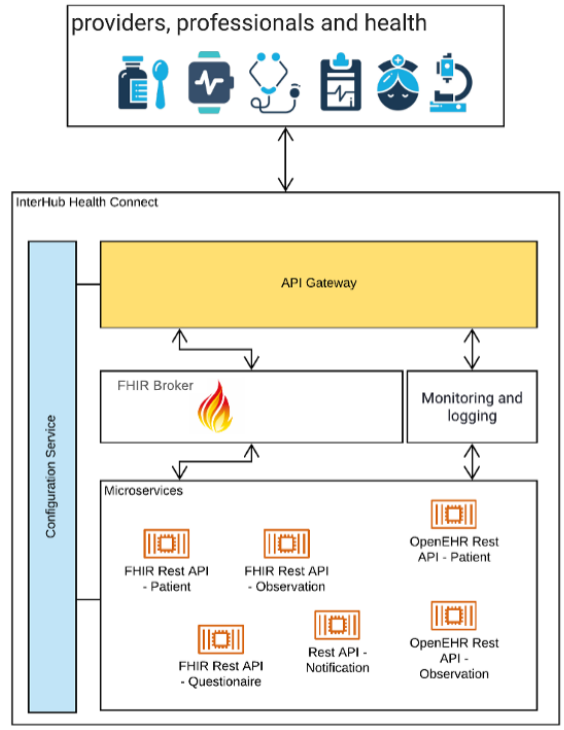

Fig. 5. Interoperability Hub GIRLS.

The GIRLS Integration Hub proposed in this work uses microservice technology. The microservice architecture standard is increasingly used in software solutions that operate on the cloud and need to withstand an increasing demand in requests for data insertion and access. Implementing monolithic applications to satisfy a scenario where interoperability is the main challenge is not the best option when considering scalability, volume of data and, most of all, the integration of a network of systems with distinct purposes. Therefore, the implementation of a Hub capable of integrating the multiple systems that exist in the public and private health sectors allows that, despite the distinct data formats, medical professionals and healthcare centres can consume the information in a smooth and transparent manner. Structurally, this architecture contemplates Richardson Maturity Model, reaching the four levels of implementation of a RESTFul API, HATEOAS (Hypertext As The Engine Of Application State). The architecture is composed by several layers of autonomous services that complement each other:

- **API Gateway:** Provides the endpoints for the data exchange between the many systems in the public and private networks and manages the microservices;
- **Configuration Service:** This layer makes the communication and management of microservices easier and more

transparent. Considering the quality of communications and configuration between services, the implementation of a configuration service becomes necessary. This resource is fundamental to manage dozens of microservices simultaneously;
- **FHIR Broke:** Processes the data from proprietary systems and systems whose standards differ from FHIR. All the standard mapping is done by the FHIR Broker;
- **Monitoring and logging:** when a microservice architecture is employed, we face some challenges such as monitoring and logging. As there will be many services, which may be implemented in different languages, we need solutions capable of monitoring and logging the dataflow of the various services. As a solution, we propose the use of Zipkin, a distributed tracking system commonly used with microservice architectures.

VI. IMPLEMENTED PROTOTYPES

A. GIRLS HAPI FHIR PROTOTYPE

Hapi FHIR is an open-source library for FHIR specification in Java. In this section, we present a case study using the HAPI FHIR server to test a set of resources, correlating them with the archetypes for Chikungunya previously presented in the related works session [3].

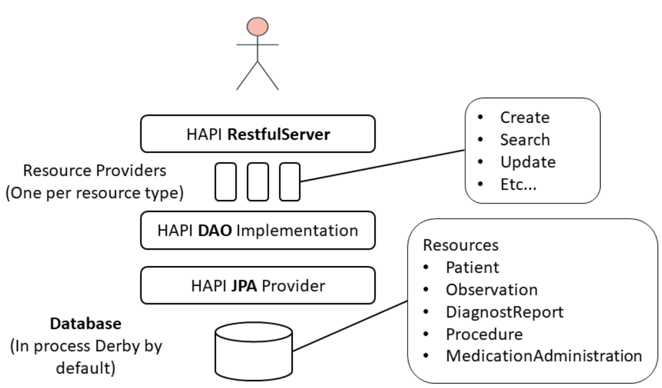

Fig. 6. HAPI FHIR Architecture (source: adapted from the HAPI FHIR library, 2019).

As shown in ”Fig. 6”, this servers architecture behaves as follows:

- On the first stage of creating an FHIR RESTFul server, we define one or more resource providers. A resource provider is a class that can offer exactly one type or resource to be served. For example, in this scenario the server will supply the resources Patient, Observation, Procedure, Diagnosis Report (bundle) and Medication Administration, so we needed to develop 5 different providers. Each resource provider implements a Search method that contains a full set of search parameters defined in the specification of the FHIR for the resource at hand. These resources extent from a superclass that implements all the methods belonging to the FHIR, such as Create, Read, Update and Delete (CRUD).
- Resource providers dont implement any logic for searches and updates. They simply receive every HTTP request and transmit them to the Data Access Objects (DAOs).
- The HAPIs DAOs implement all the databases business rules related to resource storage, indexing and recovery using the underlying JPA API.
- The HAPI JPA Server uses the JPA library implemented by Hibernate. The server does not use any specific Hibernate resource, therefore the library must work for other providers as well.
- The RESTFul server uses the Derby integrated database, although it can be configured to communicate with any other Hibernate-supported database. In this case, during its installation and configuration, the application was set up to access the MySQL Server database. The Postman API allows us to send and request data in a JSON representation via HTTP actions.

At the end of this process, it was possible to manipulate patient clinical data through the Postman tool. FHIR can easily manipulate and exchange data in comparison with OpenEHR. This case study will be used in the interoperability architecture proposed in the following section.

B. GIRLS GATEWAY PROTOTYPE

We implemented a Gateway prototype on Spring Cloud and used Eureka Server for the management and discovery of microservices, acting on the service configuration layer, as we can see in ”Fig. 7”.

Initially, the implemented services accept requests with FHIR and OpenEHR standards. In this context, the FHIR API uses HAPI FHIR as an implementation library, as shown in ”Fig. 7”. The following URIs can be used for service access and usage: http://server-ip:8888/service-fhir/api to consume the FHIR resources and http://server-ip:8888/service-openehr/api to consume the OpenEHR Template services.

The Message Broker implemented with Apache Kafka for the communication between microservices is structured over the FHIR architecture, so that every service will be internally communicating with the same language and the data in the requests issued by every service will be converted to each system’s specific standard upon delivery.

VII. RESULTS

Initially, we proposed a case study to select a set of resources. Subsequently, the FHIR HAPI API was configured and installed. For testing purposes, we used the Postman tool to send and receive HTTP requests, as we can see in ”Fig. 8”. A POST request was executed for each selected FHIR resource. After manipulating the datasets that composed each resource, the API allowed for the visualization of each resource according to their type, as shown in ”Fig. 8”. That way, we can observe the flexibility and easy manipulation of the standardization of the syntactic interoperability, code reuse, high availability of easily computable resources, profiles and extensions.

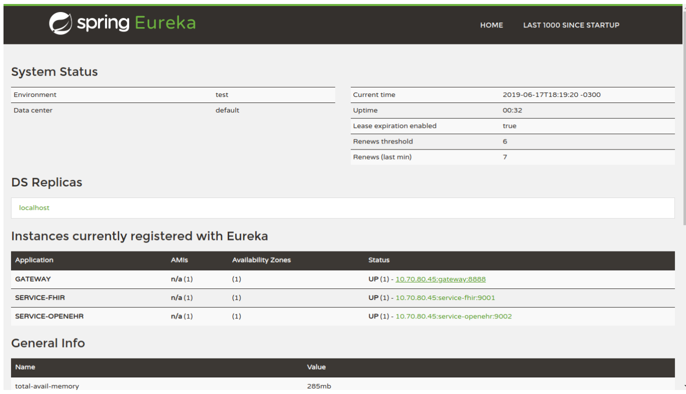

Fig. 7. Running GIRLS Prototype.

Fig. 8. HAPI-FHIR Library.

VIII. Conclusion

Interoperability in HIS is still a big challenge for the health informatics universe. There are substantial advances in the area and researches bring us to the conclusion that the way to achieve that is through the development of consensus standards embraced by the market and governments alike, aggregating the APIs that use web protocols and services.

In the EHR context, the two widely used standards for semantic interoperability are FHIR and OpenEHR. Thus, one challenge is allowing OpenEHR and FHIR systems to communicate. With this respect, this work proposes a viable solution for data exchange between those systems. However, there is an impedance mismatch to evercome, since, conceptually, OpenEHR-patterned archetypes are more complete than FHIR resources, considering that OpenEHR archetypes are able to fully represent medical knowledge by allowing healthcare professionals to define their own software models. On the other hand, FHIR standard, while imposing a predefined model, is much less disruptive to existing vendors, due to its adherence to RESTful design principles, which are ubiquitous in modern software development. Nevertheless, semantic interoperability among HIS using different standards - in particular, OpenEHR and FHIR - is still a big challenge.

Finally, it is worth highlighting the importance of GIRLS to provide interoperability in a scenario where the user would move from Europe (OpenEHR) to the US (FHIR), or vice versa.

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