Contextualized Access to Electronic Health Records
Application to Hospital Interoperability

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Keywords: Contextualized Access, Interoperability, EHR, Electronic Health Records.

Abstract: Everyday more hospitals develop their own Electronic Health Record (EHR) Systems to improve the accessibility to the information on it. There are some standards and proposals to homogenize the structure of these EHR, but they use to be so generic, that the final EHR structure has so many particularities that is different in each hospital. This situation has created a huge problem of interoperability, since Hospital Information Systems (HIS) are not capable of communicating nor understanding each other. At this point it seems very difficult that all the Hospital Information Systems change their EHR structures into a common one, to get this communication capability. Proposals to solve this issue require to create a common EHR or to translate all the existing EHR structures into a common one, and both cases seem to be unapproachable. This is why we propose a different approach based on the contextualized access to the information. The underlying idea is that the assistance acts, i.e. situations or *contexts*, where the information is acceded, as well as the data required for each, i.e *pertinent information*, is almost the same independently of the hospital where you are. Hence, it is not necessary to establish a correspondence between the EHRs, we only need to identify the context of the extern access and retrieve and send the information pertinent to it. In addition, our proposal also allows the adaptation to the needs of information of each medical doctor in each Hospital, as well as solves the problem of EHR fragmentation.

1 INTRODUCTION

Everyday more hospitals join to the digitalization of the medical records, which is giving room for a wide variety of proposals to structure the information into the Electronical Health Records (EHR). Some of them are specific for concrete medical specialities (Karahoca et al., 2010) or for the sanitary system of a given country (Stan et al., 2011). This variety of proposals has shown up the necessity of standardization, and this is where the standards HL7, Open EHR, SNOMED-CT, DICOM and the proposal of the European Committee for Standardization, the ISO 13606 regulation, come into play.

However these proposals are so generic, flexible and abstract, to allow the versatility of the information to be stored into the EHR, that the concrete implementations in each hospital end up being quite dissimilar. Is has made arise serious interoperability issues: on the one hand several venues of the same hospital can't access the EHR stored at the other; on the other hand there are no good connections between the part of the EHRs stored in the primary attention centers and the hospital EHR; and in addition, when a patient moves from one hospital (with its own EHR structure) to a different one (with a different EHR implementation) there is no way to access the from one of them the information generated in the other one, generating the EHR fragmentation problem.

Up to the moment the interoperability issue has been faced in the literature from different points of view:

- At the machine or communication protocol level, viewing the problem as the integration into an EHR structure the information produced from the different medical equipments and devices like PACs (Liu et al., 2011; Hu et al., 2011).
- From the security point of view, remarking the need of authentication methods and identity management when the different Hospital Information Systems (HIS) try to communicate (Campos et al., 2011).

Prados-Suárez B., Molina C., Prados De Reyes M. and Peña Yañez C..
Contextualized Access to Electronic Health Records - Application to Hospital Interoperability.
DOI: 10.5220/0004453602720279
In *Proceedings of the 15th International Conference on Enterprise Information Systems* (ICEIS-2013), pages 272-279
ISBN: 978-989-8565-59-4

- As the need of knowledge mobilization, to be able to access only the relevant parts of the EHR for the emergency situations where mobile devices are used (DePalo and Song, 2011).
- The problem of EHR fragmentation (Vergari et al., 2011) and the need of making the EHR more "person centric" by using cloud storage and computing (Van Gorp and Comuzzi, 2012) or integrated databases (de la Torre-Diez et al., 2013), but with the inconveniences of the personal data protection and database matching issues respectively.
- It is also essential to deal with the issue of the semantic understanding between different HIS, which has been approached in two different ways: as the construction of an Ontology to share the information (Arch-Int and Arch-int, 2011), or by means to the transformation of the OpenEHR archetypes into ISO EN 13606 and vice versa by combining Semantic Web and Model-driven Engineering technologies (Martinez-Costa et al., 2010). However, although these proposals allow logical and structured access to the information, they don't describe how to exploit the Ontology nor the Archetypes to get interoperability between systems, nor they avoid the uncomfortable selections steps and the successive screen-shots to reach the desired information (Miguel Prados de Reyes and Suárez, 2006).

Only a few proposals are capable of facing some (not all) of these problems at once, and they are mainly based of the use of frameworks that work as intermediaries between HIS, working in two stages as Halevy suggests in (Halevy, 2011). His proposal is to first translate all possible clinical terminologies and definitions of all the EHR to communicate into a common format that will be used as local EHR. Then, in the second stage, the interoperability system will semantically organize the information to ensure that its meaning stays true in whatever environment the record is used. This is a theoretical proposal similar to the previous one of Sunil Kumar (Sunil Kumar et al., 2010), consisting on the creation of their own EHR structure, and the translation of every EHR of the HIS to communicate into their EHR proposal. Once done it, they have developed a healthcare information exchange software based on a proposed adaptable standard. This way they create a complete EHR of patient which is interoperable in healthcare systems according to their information exchange standard. Nevertheless these proposals have two main drawbacks: the need to translate each EHR of each different HIS into the local or proprietary one, and the above mentioned problem of the limited agreement on the standards to be used in the second communication stage.

In addition, none of the existing proposals face the problem as a whole, considering simultaneously all of the above mentioned implications and supplying an integrated solution, which doesn't require the change or translation of different EHR structures. This is precisely our aim here. In (Prados-Suárez et al., 2012; Prados-Suarez et al., 2012) we proposed to improve the accessibility of the information based on the identification of the *context* of the access and the information *pertinent* to it, that we have developed in collaboration with the University Hospital San Cecilio from Granada. Here we extend this proposal to solve the problem of the interoperability.

In section 2 we summarize the characteristics of the system that we take as example and reference, so it can be seen that it is common to the majority of the HIS, and hence our proposal is easily applicable. Then, in section 3, we show our proposal to access the information based on the *contextualization* of the situation from which it is required, and how to determinate the *pertinent* information for each context. In section 4 we propose how to exploit this contextualized access to solve the interoperability problem. Finally, in section 5, we summarize our conclusions.

2 BACKGROUND AND SYSTEM DESCRIPTION

Next we briefly describe the ISO 13606 standard and the main characteristics of the HIS that we have taken as reference.

2.1 CEN/ISO ISO 13606

The ISO 13606 (ISO-13606, 2008) proposes a dual model. The first one is the *reference model* and establishes a basic structure for the data using an object-oriented paradigm defining the main classes with the characteristics to store for each one. The second model sets the *Archetypes* as a way to define the clinical concepts or sets of clinical information items, managed by the systems and with a concrete clinical meaning (from the pregnancy protocol to the biochemistry information or HDL-cholesterol item inside an analysis).

2.2 EHR Information System

The HIS of the San Cecilio Hospital stores around 800.000 EHR, containing more than 50 millions documents, and it is having a fast increase in size due to the inclusion of new types of documents from two sources: old documents that still have not been digitalized (scanned images, MRI, etc.) and new documents generated from newly acquired devices and equipments like PACs.

This HIS gives service, not only to the Hospital itself, but also to several venues disperse in the city of Granada, including primary attention centers.

In Figure 1 we show the structure of the system.

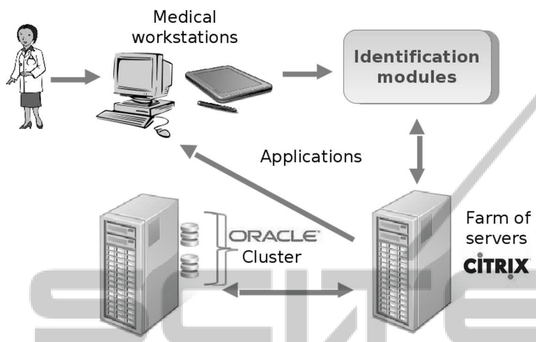

Figure 1: Structure of the system.

This system, as legally demanded, stores each access to the EHR and the data acceded, including the staff member acceding and the assistance situation (called *"controlled assistance situation"*) in which the access occurs. In case of modification, it also stores the modified data. From now on, we will call this access data base as *Retrospective Access Data Base (RADB)*. The number of records stored in the RADB is in the order of hundreds of millions. Our proposal is based on the analysis of the registers of this RADB since, it allows us to know which information has been acceded and the related context.

2.2.1 Electronic Health Records Structure

As given by the ISO13606 *Reference Model* the EHR structure is organized according to an Ontology with a class *structure* with the classes *Folder*, *Section*, *Entry*, *Cluster* and *Element*.

The EHR gathers all the documents of any type generated in each assistance act of a patient, following the structure shown in Figure 2). In (Prados-Suárez et al., 2008), can be found the properties used to characterize each *document* in the EHR, which are organized according to assistance episodes and classified considering 1500 different documents classes in the system.

Items inside the documents can be grouped into *data groups*: small logical units related under a clinical point of view. Each data group has its own specific properties, but also inherits the general properties of the document where it is contained. The "special" data group with the EHR's and patient's identification, common to all the documents is discarded from the processes explained later.

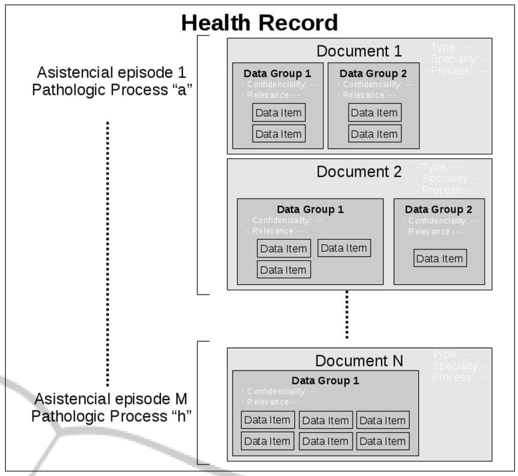

Figure 2: Logical Organization of the EHRs.

3 CONTEXT-BASED ACCESS TO EHRS

In this section we briefly show the context-based mechanism of access, but in (Prados-Suárez et al., 2012; Prados-Suarez et al., 2012) can be found a more detailed explanation of this system.

Definition 3.1. *We call* Context *to a situation in the doctor-patient relationship inside an assistance act, requiring an access to the information previously stored in the EHR.*

We set three criteria according to which it is objectively reasonable to identify the set of contexts: *pathological process*, *medical specialty* and *kind of assistance*.

To automatically detect the situation or context where a medical doctor accesses an EHR we consider the following variables: type of medical staff (specialty and position), type of the medical workstation (type of terminal, medical unit associated and physical location) and type of the present and last patient's appointments.

To identify the data groups for each context we introduce the concept of *pertinence*:

Definition 3.2. *We define the* pertinence *of a concrete data group for a given context as its relevance: the more needed or interesting the data group is for the context, the higher its pertinence to the context is.*

This pertinence is calculated considering a the following factors:

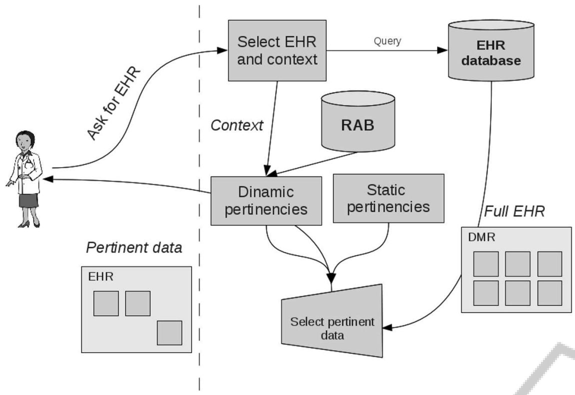

Figure 3: Scheme of the contextualized query process.

- The regulations about each clinical process: P^R_{Dc}.
- The opinion of the concrete doctor: P^C_{Dc}.
- The data groups with a great and especial importance for a given patient: P^P_{Dc}.
- The aging of the information (loose of validity as the time passes) or *time pertinence*: $P_T(D)$.
- The access patterns or *restrospective pertinence*, obtained according to the accesses stored in the RADB database: $P^C_R(X)$

Next definition aggregates this information:

Definition 3.3. *Let* X *be a* group of data *in a document* D*, and* C *a* context*, we define the* global pertinence of X to C *as*

$$P^C_G(X) = (P^R_{Dc}(X) \oplus P^C_{Dc}(X) \oplus P^P_{Dc}(X) \oplus P^C_R(X)) \otimes P_T(D) \quad (1)$$

All the pertinences are in $[0,1]$ and we have chosen the *maximum* and the *minimum* as t-conorm and t-norm because of their simplicity, and therefore, efficient and fast calculation as well as they are quite extended.

This way a data group is relevant if the number of accesses to it is high in comparison to the total number of accesses allowing, the update of the pertinence according to the decreasing relevance due to the aging of the access and to automatically adapt to new accesses patterns and future needs.

An scheme of the access process in shown in Figure 3. With this scheme we never loose the access to the whole EHR, but we get the information in it according its relevance for the present act. More information about the interface once logged, the process to get a concrete data item and a comparison with the context based access can be found in (Prados-Suárez et al., 2012; Prados-Suarez et al., 2012).

The update of the system is performed on each access by the update of the *retrospective pertinence* when the access is logged in the RADB. A scheme summarizing of the process is shown in Figure 4.

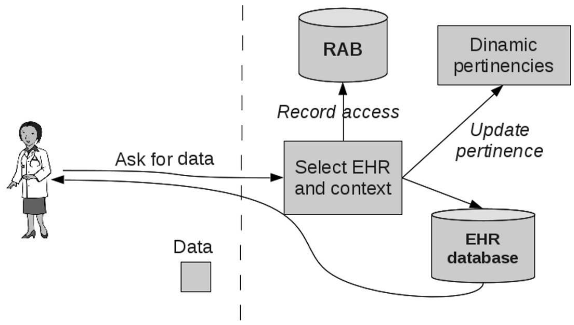

Figure 4: Scheme for pertinence's update process.

4 CONTEXT-BASED INTEROPERABILITY

As previously seen proposals made so far lies in focusing their attention in the interoperability between system structures, forgetting the real users of the system. We change the approach and face it in a more practical way, giving more importance to the users and to satisfy their needs of information.

In a real situation, the medical staff does not need to access the complete EHR of the patient but only the portion of it related to the act in process. In other words, in every hospital what a medical doctor needs is the portion of information *pertinent* to the *context* he/she is involved in. In addition, the contexts in most of the hospitals are almost the same due to the medical praxis is very similar in most of the institutions.

Considering these two premises, the main idea is to apply the context-based access to the communication between systems such that given two hospital H1 and H2 with a context-based interface (Figure 5):

- A staff member inside a given context in H1 needs information from H2.
- H1 sends to H2 the identification of the context.
- H2 retrieves the information defined as pertinent for that context, stores the record of the access performed and returns it as response to H1.
- H1 shows the received blocks of information to the staff member in the usual interface of H1.
- If the information required is not in the received block the communication process is repeated till the desired data items are retrieved.

Based on the two premises above, in most of the cases the information needed will be found in the first blocks. Let us remark that each user works with the

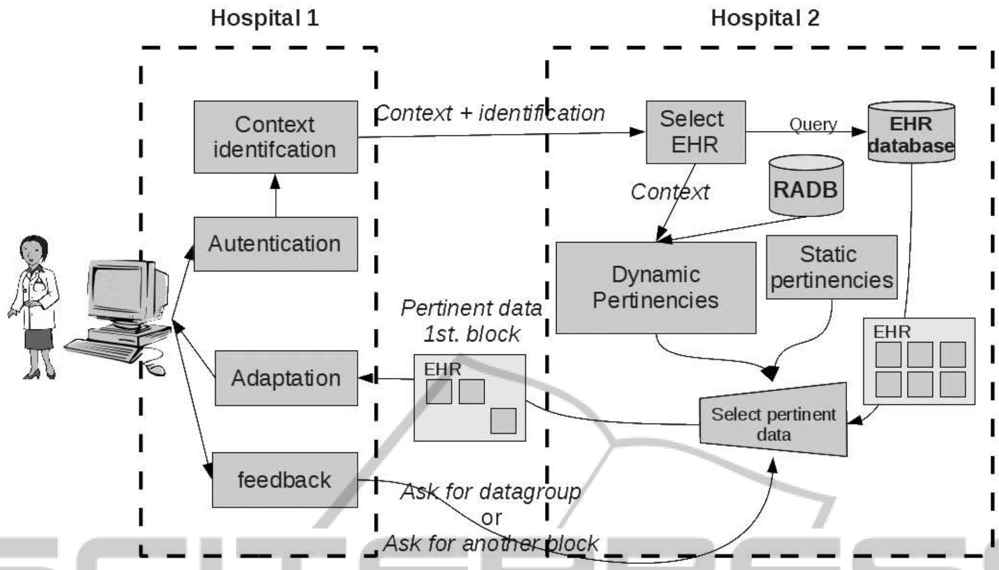

Figure 5: Scheme for an extern access.

usual interface of his/her hospital. Since the communication is made at the level of archetypes it is only necessary that both systems support the archetype language and that the user interfaces are context-based.

Even if H1 doesn't have a context-based interface, H1 could send the information that H2 needs to identify the context and H2 would perform the context identification and return the information in any of the standard formats for medical documents, like DICOM for images and PDF or XML for textual information.

4.1 Archetype-based Contexts

As mentioned above, the CEN/ISO 13606 only defines a general structure for EHR system interfaces but not for the internal structure of the system. It is figured out to establish the interoperability at the level of archetypes because otherwise it would be necessary to perform the translation of data and structures between systems. Our proposal here is to define the contexts as archetypes in such a way that the communication between institutions will be reduced to send the identification of the context and get the information pertinent to it in the archetype language.

4.1.1 Context Definition

To define the contexts as archetypes we need that their definition is made as standard as possible. In addition, the resulting set of contexts must be complete enough to consider the widest set of possible contexts so all usual access situations from hospital and institutions are taken into account. Here we propose to define the contexts based on the three criteria indicated above but filling them with standard sources instead of personalizing them for a concrete hospital. Then the set of contexts will be obtained from:

- Pathological Process. Each HIS must register all the diseases defined by the World Health Organization (WHO) in the ICD, International Statistical Classification of Diseases and Related Health Problems, even though they are unusual. Hence a context for each will be created. The same process can also be performed with the ICF (International Classification of Functioning, Disability and Health) and ICHI (International Classification of Health Interventions).
- Medical Specialty. There are several standards and correspondences between medical specialities in different countries, that can be used to create the contexts. This is the case of the regulation of the European Union related to the medical specialities that are automatically recognized in all the EU plus Norway, Iceland and Liechtenstein or the American or Australian listings.
- Kind of Assistance. This source has more variety since it is more related to the internal work-flow of the sanitary systems, but there are also some attempts of standardization like the one in the Clinical Care Classification (CCC) System or ICF.

In the ICD, ICF and ICHI the WHO has coded the information (each disease, intervention, etc. has an unique code), so it isn't necessary to establish a correspondence. Only in the case of the contexts defined by medical speciality may be necessary to create a table that stores the correspondences between different sanitary systems. But, as can be seen, this is a very simple and small table that, in addition, the system can automatically complete with the use.

With it the spectrum of contexts covered is wide enough to ensure a fluent communication and interoperability in most of the usual cases, and only very special and rare situations might not be covered. However, even in these cases the access could be performed, it will only require the more queries till the desired information is found.

4.1.2 Context Identification

The local system at H1, prior to ask for the data, identifies the context of the access. The system sends it to the extern hospital H2 when asking for the EHR using an standard language for medical data like HL7. The system at H2 looks for that context on its database. If H2 finds the context, then looks for the pertinent data groups and sends them back to H1. If the context is not found, the H2 system uses the specialty of the medical staff member at H1 to send back a list of contexts related to that specialty. The medical staff member at H1 selects then the more appropriated context and H1's system sends the choice to H2's system. Then the list of pertinent data groups is created and sent back to H1. If the person at H1 selects one of these data groups to see it, then H2 system makes a correspondence between the required context and the one selected from the list so in future accesses the system can identify it, and send back the pertinent information without this previous negotiation.

At this point let us remind that once acceded any context it is always possible to access the whole history if necessary, so entering through a wrong context only would mean that it will be necessary more mouse clicks to reach the desired information.

4.1.3 Context Adaptation: Extern Pertinence

At this point arise questions like:

- How to obtain information that is pertinent in the context of the hospital querying, but is not for the same context of the other hospital.
- How the content of the context can reflect the changes in the needs of information.

The response in all the cases is the same as in the local system. To adapt the system to the peculiarities of the accesses from each hospital or institution, we introduce an *extern pertinence* This pertinence will be learnt with the consecutive accesses in the same way as explained above for the local system. To calculate this pertinence the acceded data groups are stored in a table like the RADB. Then, when a new access is performed, this new pertinence (P_E) is introduced in the calculation of the global pertinence as follows:

$$P_G^C(X) = \big(P_{Dc}^R(X) \oplus P_{Dc}^C(X) \oplus P_{Dc}^P(X) \oplus P_R^C(X) \oplus P_E(X)\big) \otimes P_T(D)$$

Hence, as seen in figure 6, in the case of extern accesses both the local *dynamic pertinence* and the *extern pertinence* are considered. Tanking into account only the *extern pertinence* would make the system unable to adapt to new needs in the case of few accesses, due to the lack of information to update the pertinence. On the other hand, considering only the local *dynamic pertinence* the system would never adapt to the needs of the extern hospitals requirements, since the extern accesses would never have enough weight regarding the local number of accesses.

The first time the EHR is acceded for the extern hospital, the P_E is 0 for all the data groups and contexts, so the local information determinate the pertinent information. This access updates the extern pertinence and is stored for future accesses (increasing the P_E for some data groups). If the interaction continues the system will be adapted to the extern hospital needs. This is specially useful, as an example, when patients are derived from the primary attention to hospitals with medical specialties, or when a hospital frequently send patients to a special unit in another hospital (i.e. emergency or maternity centers).

Regarding implementation issues, the system only requires to store the pertinence of the acceded data groups in a table similar to the dynamic pertinence one, adding the identification of the extern hospital.

4.2 Final Remarks

In this section we indicate the requirements to implement this proposal, as well as how the problems mentioned in the introduction are tackled.

4.2.1 System Requirements

First of all it must be noted that in most of the countries laws obligate to store the information about the medical staff accesses to the information in the EHR. In other words, all the hospitals must have a database similar to the above mentioned RADB. To implement this proposal in addition to this RADB are only necessary:

- A context-based user interface.
- Support for an archetype based language or for any other standard of communication like HL7.
- A table to store the correspondences between contexts of different institutions.
- A table to store the extern pertinence.

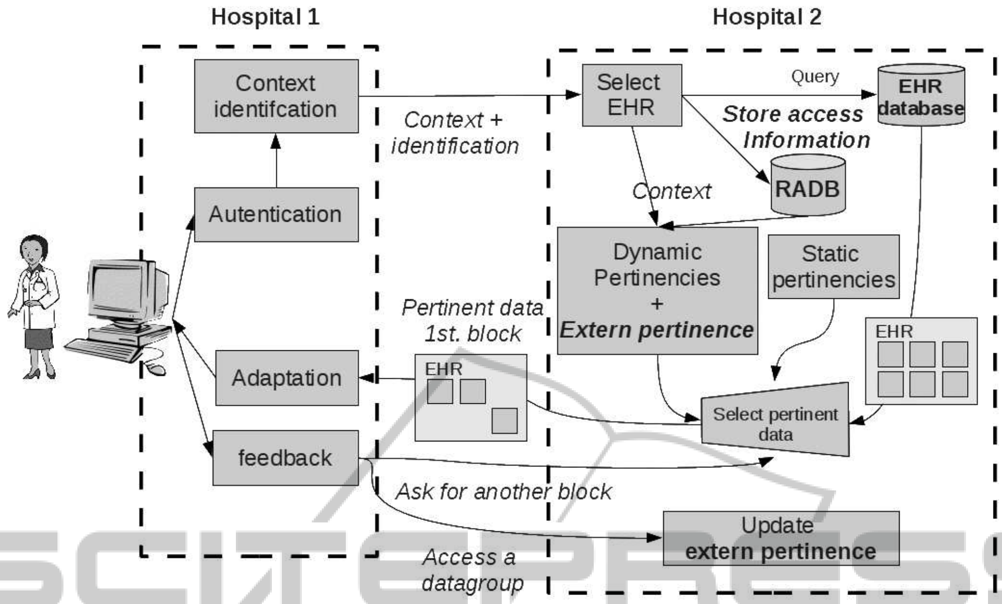

Figure 6: Scheme for an extern access with Extern pertinence and access record.

4.2.2 EHR Defragmentation

The fragmentation of the EHR for a given patient is also solved in the following way: When an extern hospital H1 attends a patient and access his/her EHR, this access is stored in the RADB of the hospital queried H2 as mentioned above. When that patient returns to his/her usual hospital H2, all the contexts related to the context from which the extern access was performed will reflect the extern access. If the medical doctor consider that extern act as relevant, they can make an extern consultation to H1 to retrieve the part of the EHR generated in that extern assistance act. Otherwise, this information will lose relevance with the time and stop being pertinent, but a record of it will remain stored in the EHR.

4.2.3 Communication between Systems

The solution to transfer the information depends on the systems that interact: if both systems support an archetype language, then the information can be sent using this language. In other cases, standard formats for medical documents can be used like DICOM for images and PDF or XML for textual information.

4.2.4 Security and Authentication

The problems of security and authentication are easily to solve in this proposal since each hospital and institution is responsible of authenticating the members its staff when they access the local system. The authentication problem then is transferred to the authentication between institutions, in such a way that when a hospital receives a query from another one they are sure of the identity of each other. This problem in fact is also solved since most of the institutions use digital certifies, and if not, any of the available mechanisms to this purpose can be used.

5 CONCLUSIONS

In this paper we have presented an approach to provide the HIS with interoperability capabilities by the use of a context-based interface. In addition our proposal improves the accessibility of the information , since the medical staff can reach the desired information easier and faster (in less steps), also the mobilization of the knowledge since specific contexts for the mobile devices can be created. Even more the system is able to adapt to the specific requirements of information of each staff member or patient in a hospital, as well as to the requirements performed from any other extern institution. Moreover it also adapts to the changes in the patterns of access over time and it all is done in an automatic an efficient way.

The problem of the EHR fragmentation is also solved trough a mechanism to register and localize all the disperse parts of it, regardless where it is or the format it is stored in, and avoiding the saturation of the medical doctors with too much information.

There are no problems of security, since the identification between institutions is done as usual, and every hospital is responsible of the staff identification.

Finally, this proposal is easy and not costly to implement, and doesn't require to modify the structure of the EHR of the hospitals to communicate nor perform the translations between these structures. In addition it is not dependent on the underlying technology, and it complies with the ISO 13606 standard but is also valid for any other protocol of communication solving the problem of the lack of agreement in the standard to use.

ACKNOWLEDGEMENTS

The research reported in this paper was partially supported by the Andalusian Government (Junta de Andalucía) under project P07-TIC03175 "Representación y Manipulación de Objetos Imperfectos en Problemas de Integración de Datos: Una Aplicación a los Almacenes de Objetos de Aprendizaje", by the Spanish Government (Science and Innovation Department) under project TIN2009-08296, and also by project UJA11/12/56. We would also like to thank their collaboration to the medical personnel that is participating in the development of the system.

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