Automation of e-health systems through mobile devices and semantic technology

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Automation of e-health systems through mobile devices and semantic technology

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In the time where the digital world is moving to mobile devices, new opportunities are emerging for the e-health systems. We live in the time when data are stored in different databases and different ways. This imposed the use of ontologies to resolve interoperability issues. Ontologies can be used for automation of e-health system data flow, enabling automated responses in real time to patient data entered into the medical record from Physicians and hospitals, and by offering caregivers evidence-based, best-practice information about how to act in emergency or nonemergency situations. Mobile e-health semantic systems help Physicians tracking better the health of their patients, avoid mistakes and act faster in emergency situations. Semantic technology and database technology in combination with mobile devices together make a combined information system which will revolutionize the way how today's health institutions treat their patients.

Keywords

E-health, mobile computing, semantic technology, ontologies, system modelling

1. Introduction

We live in the new era of communication where each of us is equipped with at least one mobile device. This type of digital machines revolutionized our lives and our way of living, making our living easier. In this article we explain an e-health information system where mobile devices, web semantic and database technologies are combined to leverage health care services.

Health informatics, health care informatics or medical informatics is the intersection of information science, computer science, and health care. It deals with the resources, devices, and methods required optimizing the acquisition, storage, retrieval, and use of information in health and biomedicine. Health informatics tools include not only computers but also clinical guidelines, formal medical terminologies, and information and communication systems. It is applied to the areas of nursing, clinical care, dentistry, pharmacy, public health and (bio) medical research.

Among the advantages that e-health systems bring to health institutions one can count on following: better control, quality assurance, satisfaction for team members, clients and relatives[1], higher efficiency through optimized communication, competition in the public health sector, better service in nursing home care settings, etc.

[1] Relatives can be family members/care givers

2. Introducing a personal e-health system

Health care is information intensive field, rich on data, information and knowledge. These data are captured during clinical work and research processes but used by other processes as well. Clinical care of patients is shared among multiple provider enterprises (e.g. by mobile citizens) requiring information sharing.

Information needs to be aggregated per-patient to allow personalized healthcare and decision support and then across populations for public health analysis and medical research.

Healthcare is information multi type, complex and changing and therefore challenging to manage over time, with very high requirements for validity, privacy, safety and security.

In the basic introduction of electronic healthcare systems the term of e-Health was introduced, and became a standard in the whole world. E-health means the use of ICT to improve or enable health and healthcare. Internet as platform also became part of e-health. Since healthcare services are offered to be used through the internet, citizens have interaction with health professionals who look after their health needs. Nowadays e-health means not only the use of ICT technologies, but reengineering of health care processes, and consideration of the socio technical aspects of design and development of e-health systems.

A new era of e-health emerged with the last technological development trends in the mobile technologies.

More and more Smartphone's with different advanced functionalities are emerging in the market, while their use widely increased. In the same direction also application of mobile phones in every day activities has taken a very important role helping people to live easier and resolve problems more efficiently. Organizing the content of personal data in today's' Smartphone's achieved very high levels, qualitatively and quantitatively. The use of mobile devices had been evolved in a new direction especially after inventing the NFC technology from few mobile manufacturers. This technology allowed these devices to be used in different environments as ubiquitous computing devices. Some of the latest implementation of different systems using NFC and EPC technology in the past, showed as successful by adding intelligence to humans environments, like Roduner 5 from the Auto-ID lab in Switzerland, where scientist used RFID technology to track information about clothes and other similar products, Paik 6 used RFID to track medicaments, and the multinational project Bravo et all.8 , where NFC enabled mobile phones were used to track the Alzheimer's patient's daily life, etc. The later, also shows how one can use a combined system of NFC enabled devices and EPC technology, providing in such way services which overcome restrictions of both technologies when used separately.

Another perspective that will be implemented through this project is the use of Semantic Web achievements from the previous projects, like MobiSem and DBPedia, from Schandl and Zander 11, where they built an infrastructure that allows mobile devices to replicate RDF graphs for different objects, and make them available online. These semantic systems allow us to combine the RFID technologies of mobile devices and the mobile semantic systems to add value to the e-health systems. Using web semantics in this projects, allows us to built semantic applications that will allow doctors monitoring the health of their patients, to associate the data achieved from the process, with the data from best practices collected at the data base of best practices. Web semantics can be used to faster predict diseases, behavior changes of their patients, better associations with similar diagnosis in the past, and more effectively monitor patient's health conditions even when they are not in-house; this by replicating data collected from RFID enabled mobile devices in the system.

As Auto-ID Lab 1 experts consider, Mobile phones are the most popular personal devices worldwide, with roughly three billion units in operation as of 2006. Market researchers are anticipating that by 2012 20% of all sold phones will be NFC enabled. With 300 million NFC phones sold in 2012, mobile phones would become the largest infrastructure of RFID reader's world wide. On the other side, EPC tags will steadily become more available on logistical units and consumer products. The fact that more than a billion consumers might be equipped with NFC[2] enabled mobile phones by 2015 raises the question whether the compatibility of EPC item level tags to these devices would not offer significant benefits.

Important are the findings from Spanish researchers Bravo and all.4 and Swedberg 3, which identify the differences between NFC and EPC tags, whereas the later uses the RFID and EPC standards to identify patient needs as concerning medicament use and prescription tracking, etc. Encouraging are the achievements of Roduner and Langheinrich 5, and other similar projects implemented worldwide.[3]

Using above mentioned technologies in the context of e-health we can allow Hospitals and health institutions' to better monitor the health of their patients and also to avoid mistakes in the every day health processes. For, example by using NFC enabled smart phones we can allow patients' data about the medicament used to be tracked, and stored in a database at the Hospital, where his health is monitored. Doctors can track data about their patients, even if they are treated at their Homes.

Thus NFC and EPC technologies used to track medicaments can be used also to monitor patients' health and their behaviour even when they are outside the health institutions. As we mentioned before, these kinds of services belong to telenursing services, which as a part of telehealth have many points of contacts with other medical and non-medical applications, such as telediagnosis, teleconsultation, telemonitoring, etc.[4]

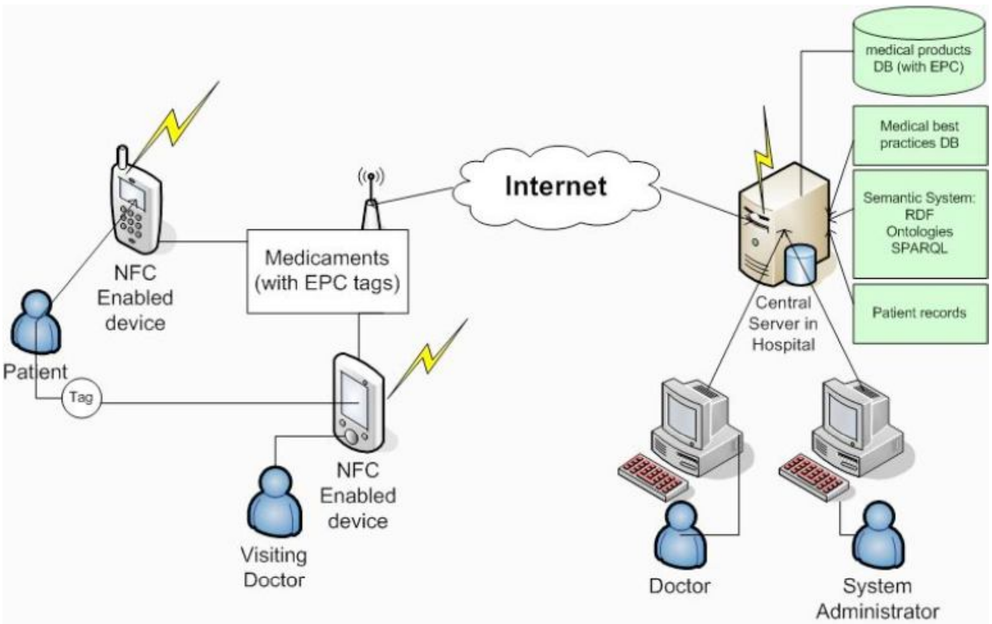

Figure 1 Simple view of e-Health system architecture

Another technology that can be used to advance the possibilities of the system is the Web semantics. This technology is one of the newest technologies developed nowadays.

The everyday work in hospitals consists of some kind of repeating health processes where we see semantic extended information can easily be captured automatically by a semantic management system. Tracking of information in its semantic context starts with the definition of the process aim and the planning of the realization. Typically this information is stored in file systems, project management systems or databases.

[2] www.nfc-forum.org
[3] More information at: http://www.rfidjournal.com/pharmaceutical
[4] http://en.wikipedia.org/wiki/Telenursing (accessed 28.05.2010)

During this initial stage of the project the basic ontology is already founded, including all persons that are assigned to tasks based on their skills, experiences and responsibilities.

According to Gruber 10, Ontologies are designed for the purpose of enabling knowledge sharing and reuse. In that context, an ontology is a specification used for making ontological commitments. For pragmatic reasons, we choose to write an ontology as a set of definitions of formal vocabulary. Practically, an ontological commitment is an agreement to use a vocabulary (i.e., ask queries and make assertions) in a way that is consistent (but not complete) with respect to the theory specified by an ontology. We build agents that commit to ontologies. We design ontologies so we can share knowledge with and among these agents.

In our case ontologies can be built based on clinical data, medical products prescriptions, medicine best practices, etc.

3. Resolving Interoperability issues in e-health systems

One of the key problems in e-Health (health informatics), is the lack of interoperability among different e-Health systems, and can be investigated in different categories in the e-Health domain, such as the interoperability of the messages exchanged between healthcare applications, interoperability of Electronic Healthcare Records (EHRs), interoperability of patient identifiers, coding systems, clinical best practices, and health care business processes.

All these categories can be investigated in two major layers: Syntactic interoperability layer, which involves the ability of two or more systems to exchange information, and Semantic interoperability layer, that refers to the ability for information shared by systems to be understood at the level of formally defined domain concepts.

Clinical research and practice understands, treats, and prevents human diseases. Data, information, and knowledge muss be extracted, collected, developed, processed, and applied in these activities. Representations of these data, information and knowledge are based on observations, examinations, care records and other kinds or recorded empirical data. A shared understanding is needed. In place are unambiguous communications of complex and detailed concepts, leaving the user free to make explicit their own conceptualisation. Conceptualisation on the other hand means querying: across institutional and geographical boundaries, or longitudinally in patient record, simultaneously in many and varying data and information sources for one patient, across cohorts of patients or studies. The meaning, must formally relate to the semantic definition of the information.

3.1. Semantic integration and Ontologies

3.1.1. User Data and their Semantic integration

User data is either stored directly in the application systems, where they are needed, or they are stored in centralized user management directories. Also, the data storage itself can be carried out differently, for example: relational databases, or simple text files. To ensure efficient identity management, as a condition that allows effective access control, the existing user data will be synchronised. This can be summarized under the concept of user integration. The integration of these heterogeneous data can be performed at different levels, on a syntactic or semantic level. The syntax or syntactic structure of the data is defined in 13 as *"relationships, deriving directly from the array of characters."* You will put a formal grammar underlying the constructions allowed and exclude forbidden states. In the area of LDAP-based user directories, this is achieved through the LDAP information model, in particular by the strict definition of schemas. The concept builds on the syntax, semantics, and includes further term relationships that result from an interpretation of rule. This means that a syntactically correct set of characters, words and phrases specific meaning is attached. The commonly used approach to integration in the user data management takes place on a syntactic level. This means that the data structure is analyzed in each data source and a sink, and further based on mapping one defines rules. These are then hard-coded into computer-aided synchronization application.

In order to achieve semantic integration of user data, a common view of the underlying data is required. Although, for different representations of user data in different data storage technologies, for various data structures in different business contexts, a large syntactic heterogeneity pre-exists, one can determine a semantic Homogeneity, by reduction of the data to user's i.e. digital identities, on the substantive (content) level.

Relevant to this work, we will introduce the Identity data for the users, which will give us understanding about the Semantic structure of the given Data. To formalize the Semantic over these data one uses Ontologies.

3.1.2. Ontologies for Semantic Modelling

According to Gruber 25 and Ontology can be defined as following: "An ontology is a formal and explicit specification of a shared conceptualization."

By the term of conceptualization we understand an abstract model of a certain world section, which identifies the relevant elements for this section. Under a formal specification, the description will be understood by means of a notation, whose semantics is defined. Such a notation is called a formal language whereas the aim is the formalized and precise description in a self-consistent and closed model.

Another definition is that of the W3C which states:

"OWL can be used to explicitly represent the meaning of terms in vocabularies and the relationships between those terms. This representation of terms and their interrelationships is called an ontology."

The later is at mostly used from the researchers, while is valued as more complete, since it answers most of the questions discussed, like Guirano and All at 27.

With RDF, any kind of statements can be asserted using arbitrary identifiers (URIs) for resources and predicates. Thus, one requires knowledge about the meaning of these identifiers (often referred to as vocabulary) in order to allow for meaningful interpretation of the data.

Ontologies are designed towards this problem, with Ontology Web Language (OWL) being the most prominent example of an ontology description language.

Ontologies can be edited using mark-up languages based on XML, which facilitates their utilization in different semantic platforms to annotate research resources. These languages define tags to represent the different elements of the ontology (like: <owl:Class>, <owl:ObjectProperty>, <rdfs:subClassOf>, etc.).

3.1.3. Challenges in Ontology design

Ontologies help to separate the importance of data (semantics) of its representation. The semantics is extracted from existing data sources, and can be changed independently of the storage form.

This has several advantages: First, an ontology provides a uniform nomenclature for the domain. This implicitly contributed to the achievement of a semantic clarity, since all Entities of an ontology, have a unique name and a semantically well defined meaning. This makes it possible, that identical syntactical elements (for example, elements of the same name), not semantically equal, be erroneously considered synonymous.

Furthermore, the use of ontologies allows a more flexible integration, since the fixed wiring in terms of mapping rules between two synchronization endpoints, is given in favour of an externalized, semantic mapping. Ontologies also enable the implementation of consistency checking. To implement the ontologies one can use the OWL.

The first obstacle in the integration of e-health user data imposes the heterogeneity of data sources. This issue was already discussed previously in 3.1.1. According to Kashyap and Sheth 14, heterogeneity differs as follows: first, in structural and syntactic heterogeneity, known as schematic heterogeneity, on the other hand, semantic heterogeneity, which is called as Data-heterogeneity.

Structural heterogeneity implies that different schemas (structures) are used for data storage, where in contrast, semantic heterogeneity in information content and thus distinguishes the meaning of a date.

In order to enable semantic integration of data of any kind, the (semantics) meaning of the cross-system exchanged data must be established. Although, already, in service-oriented architectures, a variety of different application systems are used, which can be very heterogeneous in terms of their professional domain, however, the area of this Article viewed by this user data is semantically very homogeneous. The semantics can therefore be well mapped by ontologies.1516

According to Wache 17 for the use of ontologies there are few approaches: the introduction of a single ontology approach, the use of multiple ontology approach and hybrid approaches.

The use of a common ontology provides a common vocabulary available, which will be used for description. All data sources are set in relation to this common ontology.

This approach is useful when dealing with data sources of the same domain and have a similar perspective on this domain.

When using multiple ontologies, each data source will be described individually and independently. However, this complexity is shifted to a "Connection ontology", which brings the respective ontologies into alignment. Hybrid approaches work with local ontologies; however, try to use a global ontology in the sense of a shared vocabulary or glossary. This global ontology, for the (human) developers in the creation of local ontologies, will present a guideline. In the context of this work we use a Single Ontology Approach.

There is a fundamental, common understanding of digital identities 18, but the representation and storage in the various application systems is handled differently. The problems to be solved here are varied, including name collisions of attributes. The simplest case of a name conflict, the use of different attribute names in different systems for the same attribute, such as givenName = 'Besim' and firstName = 'Besim'. This relationship can be expressed by the explicit definition of synonym relationships in the expressed ontology. Another challenge presents the different data granularity. An example of this are single-attributes firstName and lastName in a data source, while in other data sources a commonName is stored as a combination of two attributes. This fact can be represented using ontologies.

3.1.4. Ontology Development

To implement Ontology we are going to start using the approaches given from 23 which provide a starting point.

Important elements, which we use, for Person identification: commonName, address, credentials, title, email and telephone, the main classes beside this are: MedicalTest, ExerciseTest, Device, Location, Disease, Medication, InformationEntity, Alert, Activity, etc. This list is not completed, but is a start point toward ontology creation. Next we divide the elements in Datatype Properties, and complex elements. The complex elements will be defined as Classes and designed through OWL hierarchy. Examples of complex elements are commonName, address and credentials. Additionaly, we define object Properties for these classes, for example: In the Person Ontology from 13 classes commonName, and cn are characterised as semantically equivalent (owl:equivalentClass). Also classes with diversities like userPassword, from the LDAP object schema, and password from HR-XML are specified with (owl: disjointWith). Attributes of all classes are to be defined through the OWL construct owl:DatatypeProperty.

The class Person will be connected with the class Address which is subclass of the class Location, through the hasAddress (owl:objectProperty). The class address is ein Supper class for further classes like postalAddress or street. The Class postalAddress is connected with the commonName through object property hasCN. Connection that represent equivalent classes are defined through owl:equivalentClass, or owl:equivalentProperty, and represent an equality. Also non-equality will be defined, like for example classes: userPassword and password, which have been defined explicitly as not equal (owl:disjointWith), similarly we declare as disjoint the classes MedicalTest and the ExcerciseTest, while both of the tests are different from the nature so they can not have any relation or similarity in between.

Further we depicted this Person e-health system Ontology designed in Protégé:

Figure 2 Example of Personal e-health Ontology, part of it in RDF/OWL format

3.1.5. Ontologies are flexible to expand

As mentioned from 13, the person ontology presented a framework that is extensible, which logic can be used also within the e-health ontology developed above. Therefore they muss be newly integrated through the synchronisation with all participating data resources. For this, the ontologies designed previously should be extended. If the semantics of the added data source has been already described by ontology, it can be used as a starting point for expansion. If not, this must be remedied. On this basis, the semantic connection with the primer ontology is performed. If the amount of the attributes to be added is low, this can be done manually. There are also possibilities, to add attributes in automated or semi-automated way 29. In the event that two semantically different attributes from different data sources carry the same name, is taken into account the concept of namespaces, where the name of each data source can serve as a namespace.

One of the opportunities that Ontologies provide is the resolution of different interoperability issues during the use of different information resources, data banks, etc. One of the advantages that ontologies provide is their easiness to merge, which is lot easier than the integration of different databases, as we can see from the results of 3231, and others.

The Figure 3 Example shows how two ontologies can be merged:

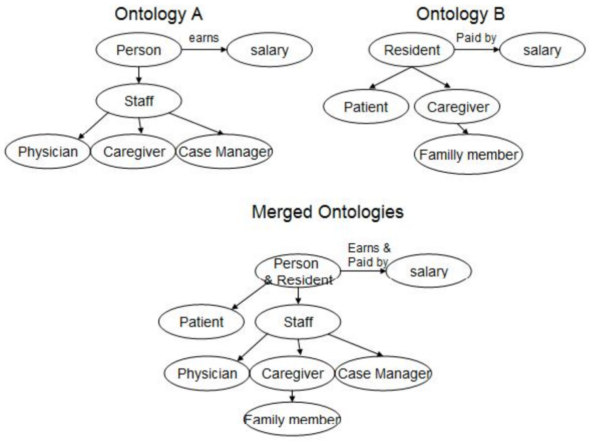

Figure 3 Merging of Ontologies

3.2. Toward automation of e-health systems

Beside Ontologies, in the Semantic Web is also used the RDF and SPARQL language.

RDF provides the foundation for publishing and linking user data, in other words: "RDF is a language for representing information about resources in the World Wide Web"[5].

RDF is particularly intended for representing metadata about Web resources, such as the title, author, and modification date of a Web page, copyright and licensing information about a Web document, or the availability schedule for some shared resource like for example: an activity in a location. However, by generalizing the concept of a "Web resource", RDF can also be used to represent information about things that can be identified on the Web, even when they cannot be directly retrieved on the Web. Examples include information about items available from on-line shopping facilities (e.g., information about specifications, prices, and availability), or the description of a Web user's preferences for information delivery.

RDF is intended for situations in which this information needs to be processed by applications, rather than being only displayed to people. RDF provides a common framework for expressing this information so it can be exchanged between applications without loss of meaning. Since it is a common framework, application designers can leverage the availability of common RDF parsers and processing tools. The ability to exchange information between different applications means that the information may be made available to applications other than those for which it was originally created.

RDF is based on the idea of identifying things using Web identifiers (called Uniform Resource Identifiers, or URIs), and describing resources in terms of simple properties and property values. This enables RDF to represent simple statements about resources as a graph of nodes and arcs representing the resources, and their properties and values.

Query languages go hand-in-hand with databases. If the Semantic Web is viewed as a global database, then it is easy to understand why one would need a query language for that data. In this sense SPARQL is the query language for the Semantic Web.

"Query", in the Semantic Web context means technologies and protocols that can programmatically retrieve information from the Web of Data.

[5] According to W3C

The paper of Schandl 9 25 and Zander 11 explains more closely the possibilities of web semantics. Among the projects that mostly contributed in the aspect of automation of mobile information systems we can mention MobiSem[6] and SemDav 9.

The technology developed within these projects can be adapted to e-health systems, which will bring higher level of automation for this kind of systems. Within Mobisem there is also a ranking engine implemented, which based on heuristics selects the most important triples from the triple store i.e. selecting RDF graphs by relevance.

The automation concepts means that the systems based on mobile devices enforced with strong servers at the health institutions that support e-health system processes, can match, compare and store different information collected from context providers and data providers, which further through data mining (similar findings as of 34) can drive to alerts or predictions about the health of patients i.e. for example if the caregiver in a given time has measured a blood pressure of the patient with some value, this value is saved in the e-health system. The central e-health system server will compare these data with the database of medical best practices, and if the value provided from the caregiver about the blood pressure of the patient is higher than the allowed limit, the system will generate an alert which will be send to the Physician which is in charge for this Patient or the Case Manager, and they will take immediate action to give some prescription to this patient. Similar systems are already implemented in practice but remain in the test phase.

3.2.1. Ontologies as Software artefacts

Ontologies as Software artefacts in Ubiquitous Computing Applications can be used at run time for: Ontology-driven applications and Ontology-aware applications (Guraino 1998).

Ontologies as software artefacts at development time: includes the ontologies used as artefacts in software development and maintenance, or in other complementary activities of the development: support activities, project management, knowledge reuse, etc.

Ontology driven applications: when ontologies are part of the system software architecture, as an additional component, cooperating with the rest of the system at run time to attain the software objective.

Ontology aware applications: Are used by the software during run time for a specific purpose, as an information resource, normally remote, upon which the software operates, carrying out, for example, specific queries.

Ontology aware Applications Example (Ontology as database substitute): Mapping relational databases into ontologies, using a mapping processor for generating the ontology and for the execution of queries on the ontology. This refers to facilitate the transformation of the applications that use a relational database to allow semantic access to the content available in the database, 36.

Ontologies at Development Time Example: GAS Ontology: Conceptualises the Gadgetware Architectural Style (GAS), which supports the composition of ubiquitous computing applications from everyday physical objects enhanced with sensing, acting, processing and communication abilities (Christopoulou et al., 2004).

Ontology driven Applications Example: GAIA Pervasive Computing Environment: A smart spaces framework, using an ontology server to get the interoperability among different entities, the semantic discovery and matchmaking in ubiquitous computing systems (Ranganathan, 2003).

[6] More information about Mobisem at www.mobisem.org

4. Conclusions and further research

Since most of the implemented e-health systems are in their beginning phase, is difficult to predict how these system will further develop, but for sure the phase of implementation and practical use of this kind of systems will lead to new findings, identified bottlenecks, better solutions and more satisfied clients. At the other hand, the complexity of the technology implemented will be higher and higher, which will lead to new research efforts toward more integrated solutions.

We explained that e-health systems, especially personal health systems are in the right way, and achieved a level of automation and acceptance from patients and their caregivers. Health care institutions are realising savings thanks to the reduced overload of their staff, and also reduced costs for health services.

Further efforts should be done in the aspect of web semantic applications which for the moment are highly complex and are hanging from the further development of many other frameworks used within these projects[7].

Ontologies used in the actual systems are very well developed, but, they are in the process of development. Ontologies are very flexible instrument that can change and adapt according to the systems. Further research need to be done in the direction of impact analysis based on use cases, ontology driven information systems, enterprise architecture approach of ontologies, and use of ontologies as database substitute[8].

The further development of the mobile technologies and mobile semantic solutions should be carried out in the direction of faster response time of mobile applications, increased capacity and further development of web semantic frameworks in use.

Another issue which leaks behind to the e-health systems is the issue of security of exchanged and stored user data, which remains at the very beginning phase, whereas institutions stated very height security requirements, which leads to very scarce implementation of different pilot projects in practice.

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