Paradigm Shifts in Health Informatics

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Abstract: There are many reasons to reflect upon the importance of paradigms in healthcare, their explicit use in health system restructuring and the possibility to anticipate the health field evolution with paradigms. For instance, it is known that an improving or restructuring strategy is needed to adapt health systems to major changes in the way of thinking or doing that occurred in the recent years in the health sector and the society. Such changes are often characterized as paradigm shifts where a paradigm is intended as a reference model of fundamental value widely accepted in a particular sector of activity. The paper claims that an explicit use of paradigms can speed up the restructuring process in healthcare. Some paradigms recently transferred from business modelling and engineering to healthcare could be more helpful if explicitly used in health system restructuring. Two recent paradigms in software engineering that will be found particularly useful to health informatics are also introduced.

1 INTRODUCTION

It's a fact that in many countries, in the presence of considerable demographic changes, national health systems have achieved over many years high cost levels that potentially continue to rise. These costs are not accompanied by corresponding effectiveness and efficiency in provided services. Moreover, the services offered are characterized by on the whole modest levels of quality, especially in the perception of citizens who are the main contributors to the system. In such a situation any business should settle upon a restructuring of its organization and processes that involves redeployment of functions, assets, and risks between associated organizations, but also conversion of business processes.

In fact, the governments of these countries are pursuing a restructuring strategy of national health systems to adapt them to new needs and epoch-making changes that occurred in the recent years in the society and the world. Such major changes in the way of thinking about something or do something are often described as a *paradigm shift*.

A *paradigm* is a reference model of fundamental value widely accepted in a particular area that could be a current of thought or a sector of manufacturing activity. A paradigm emphasizes relationships between some fundamental concepts that shape the thinking in that area. It is derived from a specific way of thinking, communicating and viewing the world, based on a specific system of values which leads to a specific representation of the world. A paradigm is thus an expression of a comprehensive belief system or world view that guides research and practice in a field. It works at the subconscious level and moves tacit knowledge by a series of implicit or explicit assumptions that synthesize a set of experiences, beliefs and values, and influence how an individual perceives an area of the real world or reacts to this perception. At the same time, a paradigm may be used as a benchmark to assess methods or conceptual tools that are related to the paradigm goal or idea.

The aspect we are interested with in this paper is how to use paradigms for transferring knowledge across domains. Let consider the following example.

When restructuring occurs for health systems a local health organization or a regional health system can be viewed as a small or, respectively, large industrial company and restructuring measures in the health sector can be the same or very similar to the measures that typically take place in companies with the purpose of making them more profitable, or better organized for their current needs. But one wonders: the knowledge gained in engineering companies may be transferred in health as paradigms

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to improve, innovate, or even re-engineer the healthcare system and its subsystems?

To answer this question a review was carried out of various paradigms that were invoked in the last years as panacea for many problems in healthcare activities. An analysis of their motivation in healthcare as well as of their possible origin in similar paradigms of other activity sectors was carried out. First, brief presentations of emerging paradigms in healthcare are given in the next section. Paradigms from other human activity sectors that were transferred to health are presented in the followings sections of the paper.

This paper regains an idea from (Serbanati, 1992) in accordance with which the explicit use of paradigms in modelling and designing software systems can significantly improve the quality of both the development process and the final product. A similar idea we find in the use of design patterns and architectural styles in software engineering, observing that in the case of paradigms the initial model is more general and highly abstract.

Advances in information technology (IT) brought the seeds for a new sector in healthcare: "e-health" based on an IT-supported care practice. Thus it is natural that many paradigms in e-health are echoes of paradigms in systems and software engineering that we use to restructure businesses and for software development. Their presentation could help us to understand how we can use them to restructure health systems in the view of challenges currently facing health care delivery systems.

Because a paradigm moves much specific knowledge that synthesizes experiences, beliefs and values, we claim that any paradigm transfer from engineering to healthcare represents an enrichment of the knowledge in the health domain and provides it with new approaches to its problems.

Generally speaking, transfer of paradigms from a domain to another involves organization, creation and distribution of knowledge, and ensures its availability for future users. The new paradigms are related not only with theories and "common sense", but mainly with the current trends in healthcare. The transfer may affect either the way of interpreting phenomena in health or the models and patterns accepted by the medical academic and scientific community to analyze these phenomena.

2 PARADIGM-ORIENTED MODELING AND DESIGN

It is worthy to note that paradigms usually emphasize only few aspects of the reality of reference: those concerning our interest for a limited understanding of existing situations in the real world or those that are sufficient for us to initiate the design of new artefacts.

Our claim is that a paradigm may guide research and practice in different areas of human endeavour. It can be used as a structuring schema in both teaching and model-driven design processes.

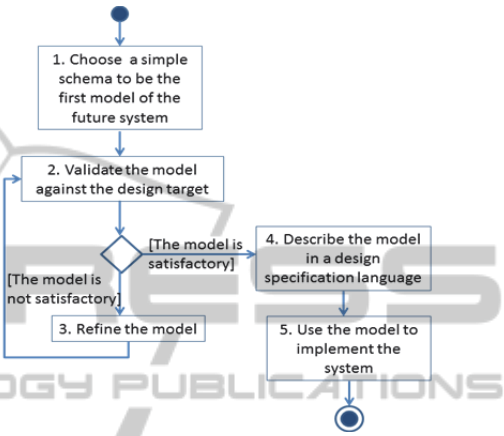

Figure 1: The paradigm-based design process.

According to (Serbanati, 1992) a paradigm-based design process goes through 5 steps (Figure 1):

1. An appropriate initial schema is identified/chosen. The schema is an intuitive, summarized structure, a kind of primary, very simple model that features the main elements of the system to be designed. Such an initial schema has a very general, often fuzzy specification and requires our intuition for its full understanding. It may be a paradigm or a meta-model with a paradigmatic function that originates from our basic knowledge of the reality where the system to be modeled will evolve, and experience in approaching this reality. In the following steps models of the target system will be iteratively built from this initial schema.
2. Models are continually validated against the target during the system construction. The cycle ends when a model that satisfactorily represents the target's properties and behavior is obtained.
3. The current model is refined, by bringing new ideas, practice or technology elements, in order to match the validation criteria.
4. Once validated, the model is described in a suitable design specification language.
5. The final model is used for the system's detailed design and implementation.

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3 PARADIGMS IN HEALTH

A *business model* is an abstract model that summarizes the way we observe and understand things and events that belong to the reality of the business we want to study or engineer. It describes the logic of how an individual, group or organization creates and disseminates economic, social or other forms of value. A business model may also express a meaningful view of an existing business or a future one and building the model is an integral part of the enterprise's strategy. Consequently, any business change should be model-based. This is why to restructure health systems as business organizations a model-based approach is needed. To transfer know-how from the corporate business restructuring to the restructuring of organizations and activities in the healthcare system some paradigms of business modelling can be usefully transferred, eventually with some changes of connotation, in healthcare.

Business models can be defined and conceptualized according to various paradigms that often appear us like some very synthetic models or meta-models. Examples can be the REA model initially coined for accounting (McCarthy, 1982) and successively extended to enterprise information systems (Geerts, 2000), and Zachman's framework (Zachman, 2008).

Let consider two paradigms the authors used to model various health-related environments.

Figure 2 shows a schema for modelling the business in software companies that was proposed in (Serbanati, 1992). It is an example of high-level meta-model acting as paradigm. It emphasizes the main components of business processes and their relationships, while other business aspects such as business functions or organization are ignored.

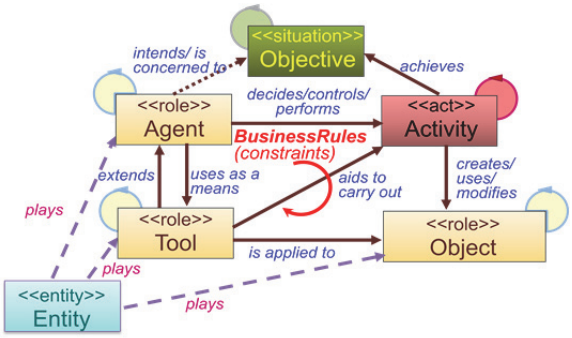

Figure 2: A business meta-model (Serbanati, 1992).

According to this paradigm any business model should specify the business main activities and entities that support these activities. The entities play some well-defined, proactive or passive roles in business: agent, object or resource, and tool. Activities are transformations that get outputs from some inputs in order to meet a pre-defined objective. They are carried out by agents who act upon business objects with the aid of tools, as extensions of human capabilities, to produce outcomes consisting of business objects, too. For each component in the meta-model (Serbanati, 1992) proposes a paradigm that can be used by the analyst to approach entities in the real world she/he wishes to model: the *multifaceted object* for (business) objects, the *processor* for agents and tools, and the *process* for activities. Such a paradigm may be used as initial model in a model-driven process as Figure 1 shows.

The meta-model in Figure 2 was successfully applied for modelling important healthcare activities as business processes: medical care in (Grifoni, 1995); (Grifoni, 1996) and (Luzi, 1997), home recovery in (Luzi, 1996), and clinical trials in (Fazi, 2004) and (Serbanati, 2005).

HL7 (Health Level Seven) is a standardization organization involved in development of standards of healthcare informatics interoperability (http://www.hl7.org, n.d.). HL7 version 3 introduces HL7 Development Framework (HDF), an object-oriented development methodology for continuously evolving message specifications that assure semantic interoperability between healthcare applications.

The cornerstone of the HDF methodology is the Reference Information Model (RMI), a UML class diagram that specifies the healthcare concepts which must be documented and/or communicated as messages within a specific clinical or administrative context, and their semantic and syntactic connections.

From the RIM HDF first derives domain-specific information models that are then transformed through a series of rule-based refinement processes to yield a static model of the information content of messages to be exchanged by the healthcare applications belonging to the domain.

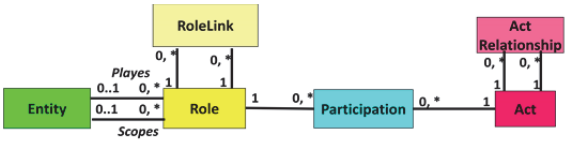

Figure 3: The RIM HL7 V3 meta-model.

Any clinical and administrative concept in RIM is derived from one of six core classes that compose the HL7 meta-model (Figure 3). This meta-model

forms a kind of high-level, abstract grammar for making statements about the delivery of medical care.

In the meta-model *Act* represents actions and events that make up health services. *Entity* represents physical things or beings. *Role* is a model of socially expected behaviour of an entity. *RoleLink* represents relationships between two individual roles played by entities. *ActRelationship* represents the ability of two acts of relating with each other. *Participation* instances indicate contexts for an act in terms such as: who performed it, for whom it was done, where it was done, etc.

It has become evident in recent years that HDF encompasses not only HL7 standard message specifications but may include standards resulting from analysis of new electronic health record architectures and requirements. (Serbanati, 2011) introduces an extension of the HDF scope for designing a virtual healthcare record in the Lumir system. Lumir is a software platform that enables semantic interoperability in collaboration of caregivers who assist the same patient.

The Lumir experience convinced us that the RIM meta-model might be widely used to model any business. We consider it a true paradigm that helps us not only for specification of messages between healthcare applications but also for modelling any business system in any other sector of activity that involves entities playing roles and participating in acts. By transferring the HL7 approach to business systems we can model any business as a framework where some real-world entities exist and some intentional actions (called acts) are performed.

Many paradigms are arising in healthcare to respond to huge challenges and mark epochal changes in the domain. They are focused on cost control as "pay for performance", the quality of services as "personalized medicine", “medical home” and "evidence-based medicine", or the citizens’ perception of the quality and efficiency of the health system as "patient care-centric” and "patient empowerment" paradigms.

All these paradigms require radical changes of mentality and extensive revisions of health organizations. Our claim is that the explicit use of paradigms in healthcare can substantially change the landscape of health, provided that a "cultural" evolution to happen and that they penetrate the doctors’ mindset and medical practice. A major shift in attitude will take place when care providers will realize that the critical element in work the ability to exchange ideas, information and knowledge in a collaborative environment and recognize the value in empowering their patients to collaborate.

4 PARADIGMS IN E-HEALTH

The carrier of many recent changes in healthcare are the advances in IT, particularly in computer networks, technological solutions for managing and sharing the patient’s clinical history, and web technologies. IT has made possible the development of some new paradigms in health informatics.

Today, it is a fact that to assess the quality and effectiveness of their services, healthcare systems are relying on information systems. Progress in IT has opened the door to the restructuring of the health sector, stimulating the emergence of new paradigms, some of them acquired from IT itself.

The evolution that IT pursued in health initiated from the needs of system innovation essentially focused on goals of "efficiency" and only later it joined the responsibility of re-construction of the relationships between caregivers and with their patients. The result was e-health, a new, not only technological, but also scientific field in the intersection of medical informatics, public health and business. It is the key field that facilitated transfer of paradigms from systems and software engineering to healthcare. (Eysenbach, 2001)

“*Interconnecting health*” is a central paradigm in e-health. It focuses on approaches, challenges, and solutions affecting the ability to connect health organizations and systems, and the role of IT as an enabler in achieving this connectivity. Collaboration between all stakeholders is a key element to creating new health systems, more efficient in easily conversion of knowledge on the health of citizens in therapies that benefit the health. The growth in importance of *electronic health records* in the last two decades marked a technological but also "cultural" shift:

1. EMR (Electronic Medical Record), a computerized medical record created and used in an organization that delivers care, such as a hospital or physician's office.
2. EHR (Electronic Health Record), an evolving concept defined as a systematic collection of digital information about individual patients’ health thanks to all contributions of information that GPs, hospitals, and laboratories caring them supply with. (Contenti, 2010)
3. PHR (Personal Health Record), an electronic health record that grants patients access through the web to a wide range of health information sources,

best medical practices and health knowledge and where health data related to the care is entered by the patient himself/herself.

4. VHR (Virtual Health Record) is a Web 2.0 evolution of the EHR concept with a more emphasized vocation towards collaboration, coordination and integration. (Contenti, 2010) and (Serbanati, 2011) introduce VHR as an internet resource that provides healthcare applications with a comprehensive and authoritative representation of the current health state, medical history and ongoing treatments of any subscribing citizen. This information is stored in a longitudinal, distributed repository and highly structured according to various criteria: clinical contacts, episodes of care, health issues, care providers, medical equipment, organizations, individual and territorial jurisdictions. VHR provides more than a comprehensive, uniform, and consistent data source: with its proactive behaviour it is a trusted partner for the caregivers who jointly support integrated and patient-centric care processes in a Regional Health Information Organization (RHIO). VHR can support the care workflow and evidence-based decisions, quality management, and reporting.

We observe that the evolution "Interconnecting health" was a continuous broadening of the horizon of interoperability in health from EMR to RHIO, that is an extension to an ever larger community of the opportunity to share and communicate information using collaboration of healthcare applications running on heterogeneous platforms.

5 NEW PARADIGMS IN HEALTH INFORMATICS

Current advances in systems and software engineering give us a glimpse of the next generation of information systems supporting healthcare. While current efforts in e-health are focused on the development of information systems based on service-oriented architectures, in the near future a shift will be towards integration of healthcare information systems (HISs) in *multi agent systems* (MAS). In the long run when more and more heterogeneous health applications will be highly integrated in national and regional HISs a new paradigm, the *digital health ecosystem* (DHE), could be used to model them. A DHE consists of virtual entities, information and knowledge sources, and applications that adapt to local needs will be created.

An intelligent agent is a software component with autonomous behaviour similar to human agents. It has the following characteristics: autonomy, sociality, pro-activity, mobility, and reactivity.

Agent-based health applications require a population of agents knowing health ontologies and working together in an MAS to solve problems on behalf of patients, organizations, professionals, or even of the agents themselves. The MAS paradigm could be used to model, design and implement software platforms that integrate software applications in healthcare systems. Such an approach has many advantages over a traditional approach.

An agent-based paradigm is a more natural way to represent many situations that often occur in medical settings, such as: absence of a comprehensive control system, limited or insufficient resources for a care provider to solve a given problem, and geographical distribution of the needed information and knowledge. On the other hand, in health systems we can identify many recurrent features common to MASs: delegation of responsibility, re-allocation of tasks, need to consider a large variety of user concerns and problems, planning the collaborative work , think and work in open spaces, etc. Moreover:

1. Agents related to each other can be easily put together in an organized community to efficiently coordinate and perform operations of recovery, analysis and integration of information originating from geographically distributed sources.
2. Interoperability of legacy systems in health systems are facilitated by the MAS approach.
3. A network of interconnected agents better model distribution of computing resources and capacity in the existing health system.

In the case of "agentification" of a regional health system, all stakeholders (care providers, professionals, patients and their relatives) must be represented as agents in the system. We called "avatar" such an agent. It presents itself to other agents with the role of the stakeholder it represents.

An avatar is characterized by a stressed pro-activeness acting with own initiatives on behalf of an individual. Other virtual entities in the system may represent real organizations but also virtual, temporary, ad-hoc created organizations as teams of professionals involved in the patient's care process.

For instance, the avatar representing the patient should present itself as a manager of the patient's VHR and respond to queries regarding its content, interact with other agents to update the VHR, and interact with the patient to monitor her/his health state, notify her/him about relevant events and update its own information on the patient's concerns

and the context where the patient is currently found.

To "agentify" an HIS, additional agents are needed to provide services to avatars, interact with medical devices and other applications, supervise execution of care plans, play the role of mediators, or negotiate access permissions to a central authority that provides proper authentication and authorization management. (Vasilateanu, 2011)

A natural ecosystem is a biological community of interacting organisms plus their physical environment. Correspondingly, a health ecosystem can be defined as a network consisting of a multitude of health service suppliers and consumers, and healthcare organizations and institutions, all of them supported by HISs. Organisms of the health ecosystem are care suppliers and consumers and the environment is composed of their shared resources.

Digital business ecosystem is a self-organising digital infrastructure aimed at creating a digital environment for networked organisations that supports the cooperation, the knowledge sharing, the development of open and adaptive technologies and evolutionary business models. (Nachira, 2007), (www.digital-ecosystems.org/, n.d.).

(Serbanati et al., 2011) introduces the *digital health ecosystem* (DHE) as an IT infrastructure designed to support activities in the health ecosystem. Figure 4 shows the relationship between the health ecosystem and its DHE. The synergy of the two ecosystem is based on a continuous osmosis of information and knowledge flows between them: avatars gradually acquire digital representations of real world entities, clinical documents, and knowledge from the health ecosystem and deliver processed information in the real world.

DHE is composed of a hierarchically organized network of local digital ecosystems that mirror the organizations in the real world and preserve their identity and own knowledge.

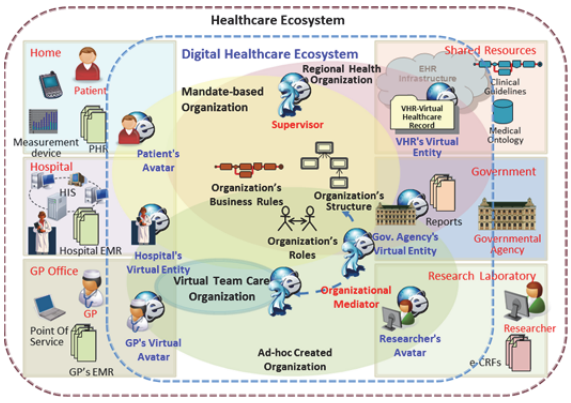

Figure 4: Health ecosystem and its digital ecosystem (Serbanati et al., 2011).

The DHE infrastructure becomes a resource in the health ecosystem, that manages virtual entities and avatars. It allows them to share digital resources and interact with each other on behalf of organizations and individuals in the real world. The infrastructure also implements self-generation mechanisms that enables DHE to include more functions of knowledge interpretation and to gain more high-level services, in other words to become more intelligent and provide more support for the health ecosystem.

5 CONCLUSIONS

This paper aims to open a discussion on the role of paradigms in our reasoning and proposes the use of innovative paradigm-based solutions in one or another field of activity. A paradigm better captures the nature of the differences between different approaches to solve a problem.

There are many reasons to reflect upon the importance of paradigms in healthcare, their explicit use in restructuring health systems and possibility to anticipate the health field evolution with paradigms. Explicit use of paradigm shifts shows how better control knowledge transfers between science fields. In particular, paradigm shifts in health informatics are good go-betweens in transferring knowledge to and from healthcare.

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