The Development of Medical Ontology "HoPRO" (Hospital PRocess Ontology) and the Role of Ontologies in Multimethodological SAD Frameworks

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Abstract— **Recent advances in health informatics combined with system analysis methodologies can supply the techniques and tools to the development of more efficient Hospital Information Systems (HIS) that can be made to exchange data with each other and thus provide a more reliable patient oriented environment. In order to achieve this desired HIS interoperability, it is important to provide a clear understanding of the HIS ecosystem during the analysis and design phase that provides the infrastructure of this ecosystem and leads to the development of HIS, that will be capable of exchanging data within heterogeneous HIS modules. A great improvement towards this solution is to develop a hospital information business process ontology that will provide the infrastructure for a clear understanding of the HIS ecosystem and thus lead to the development of HI Systems that will be able to interpolate efficiently with each other. Ultimately, this creates a new way of thinking about how to approach any problem and identify the solution instituting a novel analysis and design framework in order to provide the ability to study the domain, address the issues that cause the problems and lead to more efficient informational systems and analysis and design methodologies. Such an ontology along with the systems analysis and novel design framework is developed and described here and its value is demonstrated through a case study.**

Keywords— **Ontology, Hospital Information Systems (HIS), Interoperability & System Analysis and Design (SAD)**

I. Introduction

Hardware and software developments in the field of health informatics (HI) have the potential to dramatically change the healthcare industry and provide the infrastructure and the ability of the industry to become more patient centered [1]. It has therefore attracted many studies focused on the development of the infrastructure and particularly, the electronic health record (EHR) and electronic patient record (EPR) systems where many other hospital systems are being based, like computerised physician order entry (CPOE) systems, in order to provide better, more accurate and efficient patient care [2]. Although the potential benefits have long been identified, the systems that have already been created have not yet fully achieved the anticipated results such as adverse drug events [3]. Many of these problematic issues that cause human mistakes that can lead to system errors could easily be addressed during the SAD phase of the HIS, prior to system build, in order to be documented and be resolved into the new developed systems. It is therefore obvious that these suggested steps need to be organised within a novel SAD framework that will have the ability to carefully address the above mentioned difficult cases. Such a multi methodology framework should be able to point out and study the social aspects of the care providers' teamwork and the care taking patient processes that are provided, together with their data needs, system interoperability and information quality and usability issues. The aim of this paper is to propose such a multimethodological SAD framework and implement it though a case study using a local hospital and to create a business process ontology that tries to capture the essence of this HI ecosystem.

II. Need for the Multimethodological Framework

Many approaches to problem-solving methodologies are focusing only on the initial problem definition and then follow with the objectives for the solution of the problem. Hard systems methodologies are based on purpose seeking, optimising and predict controlled choices approaches, treating the human factor in an emotionless and deterministic point of view [4]. However, there are many arduous situations in organisations that tend to depend on the human activity involved where the judgment of experts and their collaboration and the effectiveness of teamwork heavily affect the quality of patient treatment and therefore the focus on those activities become a critical element that must be addressed within SAD methods. Such problems where human perceptions and conflicts may lead to different problem definitions and thus unclear or fuzzy solutions require a different problem identification approach based on the human aspects of the system using the soft systems methodology (SSM) [5]. The analyst, usually someone external to the situation under study, must use a specific set of tools, ac-

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cording to the SAD methodology selected for the project, that provides a clear insight to the current problem, defining both the soft human aspects, concentrating on the role, concerns and perceptions of the people involved, as well as the hard aspects defining the processes that are used. However, SSM does not provide the tools to analyse in detail the processes and rules that govern such teamwork because it does not provide a methodology for a detailed focus on process analysis and data needs. On the other hand, hard SAD approaches tend to focus on the process details and tasks within a system but without a focus on the soft human factors of the system under study [4]. This exposes the need for the construction and use of a multimethodological framework, where SSM could be used during the initial stages of SAD as a front-end expressing the roles, perceptions and concerns of the people involved and then followed by a hard approach focusing on the analysis of the current processes and their data needs concluding with the design of the new system that will improve the current problematic situation. Such an approach is also suggested as an improvement to SAD by the Multiview methodology [6].

Most current hospital systems are mainly designed based on the human activities and assessments and on the knowledge and skills of the clinician experts that are involved in decision making. Unquestionably, the study of these activities must form the basis of the initial stages of the SAD processes. Furthermore, a multimethodological SAD approach is fundamental to embed SSM as a front end and expose the challenging soft aspects of the providing system followed by a hard approach that will focus in the analysis of the system processes and their data requirements. Such an approach could be based on the PIECES framework, an abstraction of the Zachman framework that provides the directions to be followed in order to comprehend the analysis and the design of HI systems [7].

III. Effectiveness multimethodological frameworks

The effectiveness and the quality of patient treatment depend heavily upon collaboration and teamwork of the clinicians involved and is evident that the focus of the analysis should be directed on the mechanisms that manage this framework of collaboration. Initially SSM must be used to expose the problems of the current situation focusing on the role of the clinicians that are involved in the teamwork. Using SAD methods such as the Rich Picture methodology, a drawing of the current situation can be created followed by the analysis and the investigation of the personal actions focusing on the individual point of views of the people involved in the case under study, such as their worries and concerns about their role and involvement in the patient care. For example, the study needs to try and identify incidents that can cause strain to doctors that prescribe treatments for patients and occasionally can lead to mistakes.

This study can provide a valuable understanding in the analysis and identification of teamwork problems within the healthcare environment. First the teamwork problems need to be identified and recorded properly and then implement them along with their resolutions resulting into a new redesigned system. Conceptual modeling within traditional SAD methodologies is focused only on the development of models for a specific application in mind, however, the complex contemporary environment within which information systems (IS) operate require a high level of IS interoperability and adaptability that current models fail to capture. In order to improve future HIS is important to understand well that environment under study during the modelling phases of SAD for HIS projects. This analysis requires a study of a general agreement of all environmental concepts, terminology, data structures, processes and task practices. A potential solution is the use of ontologies ensuring the interoperability, data and information quality and adaptability of any HI proposed solutions. Ontologies can be used as a basis for the enhancement of analysis of such contemporary and ill-structured HIS with complex interoperability data needs [8].

Although the idea of using ontologies is still being improved with more research and development, it has already created a new way of thinking about the role that ontologies could play within the context of SAD. Guarino [9] introduced the concept of “ontology driven” IS, arguing that when ontologies are used during development time (defined as computational ontologies) the semantic content that they contain could form the basis for the creation of more efficient IT components (application programs, db's and user interfaces). The development of computational ontologies could be directed by a set of activities and techniques as described by recent researches such as Methontology [10]. In a study of conceptual schemas, Olive [11] argues that the part of the conceptual schema that represents domain knowledge, which is independent of the existence of the particular IS application, closely corresponds with the domain ontology and forms the basis for the functional specifications of the IS. Several studies attempt to provide methods and techniques to produce the functional specifications schema (logical schema) based on the domain and task ontology [12][13]. However, sometimes, computational ontologies that target specific domains do not correspond with the users’ view of reality and thus they cannot be used as a basis for the production of logical schemas. These on-

tologies need to be adjusted to include local conditions which should then be reflected onto conceptual schemas. Therefore, the focus of the computational ontology should be on the explanation of the domain and information integration and then the conceptual schemas should focus on linking the general ontological categories with particular observations regarding the system under study. Consequently, in order to benefit from the use of computational ontologies, a SAD framework of methods and techniques should be introduced to contextualise the use of computational ontologies and conceptual schemas and lead the development of more effective HI systems. The reason of lack of convincing results is that little research has been directed on the foundation of such a framework and the development of novel methods and techniques that will use computational ontologies to reflect teamwork problems. The main thrust of this paper is to propose a multimethodological framework (OntoDrive) and introduce these methods and techniques.

IV. The Proposed SAD Framework (OntoDrive)

A multimethodological SAD framework is needed in order to be able to address the above mentioned problematic methodological cases. This can be accomplished when domain specific knowledge and data structures are collected into the computational ontology ensuring the interoperability of systems and the quality of information within that domain. This computational ontology could also represent the guidelines that direct the efficient teamwork within the domain providing the basis for task standardisation. Such computational ontologies could then be used for the development of conceptual and logical schemas and information system components within specific projects.

The teamwork dynamics could be reflected by the use of a four-step process based on SSM. To do this human perception, worries and concerns regarding that teamwork will have to be identified. This four-step process is as follows: (See Diagram in Figure 1)

Step 1 - Expose Teamwork Dynamics
Step 2 - Define the Teamwork Purposeful Activities
Step 3 - Define Corrective Actions
Step 4 - Embed Actions into the Computational Ontology

V. His and Ontological Systems Analysis

An ontology is "a collected set of all processes and logical axioms of a domain area that captures the intended

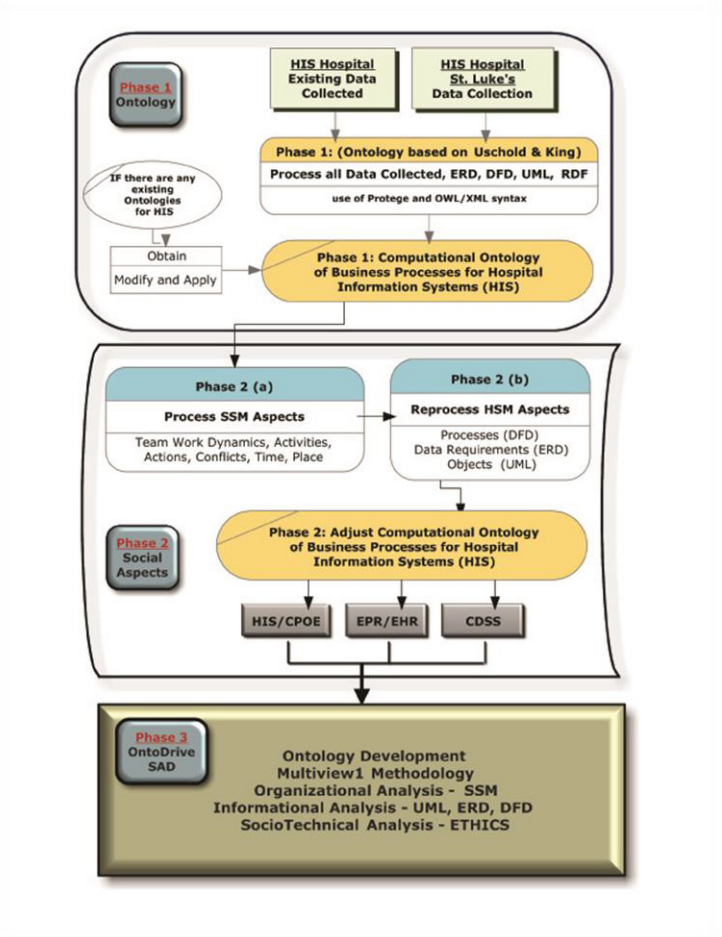

Fig. 1 The multimethodological framework.

meaning of a dictionary used in this domain" [14]. Ontologies describe and document a domain in order to provide the common understanding of an environment that is used by people and systems at the same time [15]. In the complex field of health care, the design and implementation of ontologies main focus is on the creation of medicine and diseases terminologies (domain ontologies) and not in the area of describing the business processes of these institutions (top-level ontologies). The "HoPRO" ontology fills in this gap by providing a higher level description of hospital process environment that is needed to be homogenized before someone moves to the much needed and necessary domain HIS ontologies. Scientifically, ontologies belong to the domain of knowledge management and their use has the potential to improve the understanding of the hospital information systems, during the analysis phase where analysts seize a clear understanding of the current complex HIS

ecosystem and then develop systems that will be able to accomplish the tasks for which they were designed.

For the purpose of this research many methodologies and techniques were investigated in order to be used to develop the hospital ontology [9][10][11]. The sequence of steps used to create the "HoPRO" ontology is summarised as:

A. Capture the knowledge of the domain in study
B. Conceptualization of data requirements
C. Formalization of knowledge acquired
D. Encoding and Implementation of the ontology
E. Review, Evaluate and Release
F. Documentation and Maintenance

Major hospital information systems are separate component based, however integrated information systems that manage and support the needs of hospital operations, such as patient data, medical data, administrative data, financial data, legal data, etc [20]. Usually the different HIS components are designed and implemented by different software developers without explicitly focusing on the interoperability of the different HIS components, resulting into practical problems of interfacing and transferring data to each other. There were many approaches and technologies that are used to solve similar problems, such as Sun's Enterprise JavaBeans (**EJB**), the OMG's Common Object Request Broker Architecture (***CORBA***), and Microsoft's Distributed Component Object Model (***DCOM***) and more recently Health Level Seven (***HL7***) protocols [17]. Each of these standards defines the interface of its components making its services available to others as to resolve interoperability issues. Such approaches are undoubtedly useful, however still produce many problems and don't solve all the operational errors of the different HIS components [22]. It is thus very important to introduce an SAD framework that will enable analysts and developers to better understand this environment and then introduce components that will be able to efficiently work with each other. The aim of this paper is to present the development of an HIS ontology that will be able to be used as basis by SAD frameworks and provide an example based on a case study to demonstrate its use. This computational ontology should cover all health care providing processes and not describe only domain specific conditions e.g. the physician order entry process within specific healthcare domain [16].

VI. The "HoPRO" Ontology

To create the top-level computational ontology described below the St. Luke's hospital in Thessaloniki, Greece was used as a case study. St. Luke's has many custom developed software systems and is using numerous software solutions in order to communicate and transfer patient data from one department to another. However, many times during the transferring of the data or the re-entry of all or some of the patient information, double entry mistakes or improper assignments occur due to interoperability issues. From the research completed at the given hospital the "HoPRO" business process ontology was created based on benchmarked systems analysis methods and models and the data that was gathered and described were conceptualized as ERD, DFD and UML [16]. All this collected knowledge base was then transformed into an OWL ontology called "HoPRO". The "HoPRO" ontology has been implemented using Protégé 4.2 [21]. During 2013-2014, there were many repeated personal visits to the chosen case study of St. Luke's hospital and all essential concepts of their day to day functions were collected along with any possible interactions between them, either through observations, along with the cooperation of the IS people and the medical staff of the hospital or from existing documentation describing the obeying rules and laws of the hospital. This paper is compiling collectively this entire newly acquired knowledge of the HIS domain with all the relevant entities and their relations.

There are four different modelling paradigms, used to obtain much needed domain knowledge of a specific area:

- Entity-Relationship-Diagrams (ERD) - Data
- Data-Flow-Diagram (DFD) - Processes
- Unified-Modeling-Language (UML) - Classes
- Ontology (OWL) - Domain

Based on the data and processes collected, a complete ERD was created in order to have a conceptual model of all of the hospital information. In similar method the DFD describing the hospital business processes was created. From the ERD and DFD, it was easy to extract the UML, in order to obtain the initial knowledge of the domain of our case study St. Luke's Hospital in Thessaloniki. Finally, the UML was used to transform all the acquired knowledge base into the RDF/OWL HIS Ontology "HoPRO" (**Ho**spital **PR**ocess **O**ntology).

"HoPRO" includes the following:

- The entire HIS IT landscape (e.g. hardware, operating systems, applications) in the form of an ontology
- Each existing atomic and composite process inside an HIS organization described semantically
- HIS Domain knowledge (e.g. technical constraints, business rules), stored it in the form of axioms
- Queries expressed in SPARQL query language

High level ontologies start with the entity "thing" followed by the major entities and concepts of the domain in study as classes. In our case study, the root classes are the business processes of the hospital.

The root classes of "HoPRO" displayed in Figure 2.

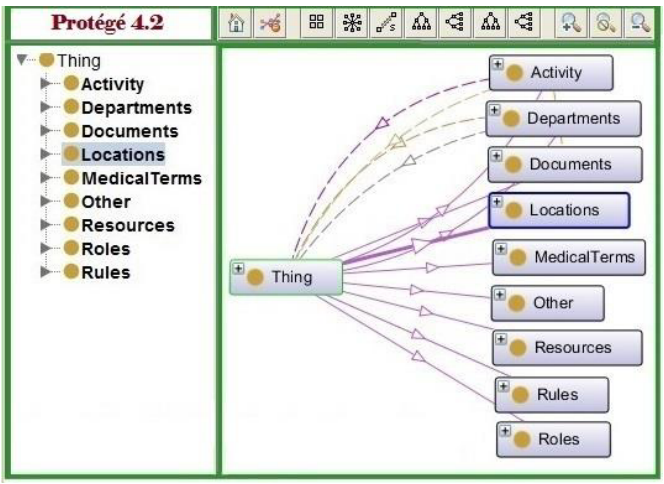

Fig. 2 The Root Classes of the "HoPRO" ontology

A. The "HoPRO" root classes

"Activity" has as subclasses all the main hospital business processes. "Departments" has all the medical departments from St. Luke's Hospital as subclasses. "Documents" has all possible medical and corporate reports. "Locations" has the locations of the hospital. "Medical Terms" has all the terminology of all the Hospital business also inheriting existing HI ontologies like UMLS, ICD-10 and SNOMED. "Other" was created as to include classes and events that do not follow normal business rules now and in future, currently there is only one subclass "MedicalWaste". "Resources" consists of all assets of St. Luke's hospital such as devices, material and the most important resource of a hospital, its people. Finally, we have the classes "Roles" and "Rules" which describe regulations for the personnel of the hospital.

B. The "HoPRO" *object and data properties*

Here, we continue with the difficult task of constructing the relationships and value restrictions between these classes. "Properties" scripted with *owl:Object/Data/Property* in ontologies are separated into "object" as allowed processes and "data" as allowed values; "Properties" is the ontological way to add reasoning between individuals by generating boundaries between two instances of the same or two different classes. For example, "canPrescribe" assigns people the right to prescribe. This segment is extremely important, making ontologies unique and powerful, since here is where the reasoning of a domain is being considered, making ontologies a fundamental design tool to avoid inappropriate transactions between the entities of a domain.

VII. Conclusions and Discussion

This paper introduced a SAD framework that attempted to address the issues that have been identified as concerns that cause problems in the development of systems and thus lead to inefficient HI systems that are not well accepted by the very demanding medical community and it can eventually create problems that occasionally can seriously harm patients. The interoperability problem of exchanging valuable patient data information across heterogeneous HI Systems is one of the major obstacles in the health care business that is causing problems of inefficient and inaccurate delivery of patient care [1]. The sensitive knowledge based domain of healthcare requires the use of complex multimethodological SAD approaches to enhance the understanding and grasp the requirements of the users providing the healthcare services in the domain of study.

A new way of thinking and approaching the problematic issues is described in order to take advantage of the potential benefits of ontologies in designing new health information systems that can drastically improve the efficiency and quality of the healthcare industry. Future HIS created based on conceptual models such as UML, RDF and OWL will be able to better integrate healthcare information systems of various healthcare organizations. A case study of a hospital in Thessaloniki, Greece, St. Luke's is introduced to demonstrate the use of this framework in practice. From data collected based of the case study at St. Luke's hospital [16] an ontology was developed that describes the complete HIS ecosystem in study; "HoPRO" is the descriptive logical model of all the hospital processes and all their relevant entities, along with their properties, interrelations, logical functions and axioms. Since the research problem is clearly

defined, the study now must be focused on providing methods and solutions that will resolve the problematic issues with the use of ontologies especially using the ontology "HoPRO" that was introduced in this paper.

The answer to the HIS interoperability problem is to create a thorough and precise 'Model of Healthcare Information' that will be based on a detailed top-level ontological framework. Ontologies can be used as cognitive maps for the analysis of a system in order to provide solutions to complex IS interoperability problems [18][19]. Future work will need to incorporate SSM issues into the four-step process methodology and the system analysis of our case study in order to reflect the teamwork dynamics of the major activities of the HIS domain and then extrapolate them into the computational ontology. So far, the ontology has been validated using the St. Luke's hospital's IT staff feedback and numerous evaluations of the annual data reports between the hospital and the ministry of health of Greece using HL7 or no interoperability platform at all, reporting the annual hospital transactions to the Greek government. Future work will need to test and validate "HoPRO" against specific problematic situations measuring the interoperability success rates of before and after implementing the ontology. These steps will amend the "HoPRO" ontology trying to enrich interoperability of future HIS.

If new HIS ecosystems are making use of such computational ontologies like "HoPRO" during the system analysis and design phase, then all derived HI Systems will have minimal interoperability issues of mistaken or mismatched information. Finally, all the findings from the above described multi-methodology steps will be interpolated into the novel multimethodological approach for system analysis and design methods called (OntoDrive). This will be accomplished by defining, describing and documenting the necessary steps of the new approach into the initial steps of the well-known and traditional systems of analysis and design methods. More details towards the development of the ontology "HoPRO" along with current advancements to this work can be found on the dedicated to this research website, www.ontodrive.com.

Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Kuhn K.A., Wurstl S.H.R., Bott O.J., Guise D.A., (2006), "Expanding the scope of health information systems: challenges and developments". *IMIA Yearbook of Medical Informatics, Meth. Inf. Med.* 45 (Suppl 1), S43–S52.
2. Bates D., Leape L., Cullen D., et al., (1998), "Effect of computerized physician order entry and a team intervention on prevention of serious medication errors". *Journal of American Medical Association, JAMA*, 280(15):1311– 6.
3. Ammenwerth E., Schnell-Inderst P., Machan C., Siebert U., (2008) "The Effect of Electronic Prescribing on Medication Errors and Adverse Drug Events: A Systematic Review". *Journal of American Medical Informatics Association, JAMIA*, 15(5):585-600
4. Ho K.K.J., Sculli D., (1994) "Organizational theory and soft systems methodology. Journal of Management Development", Vol. 13 No. 7, pp. 47-58.
5. Checkland P., Scholes J., (1990), "Soft Systems Methodology in Action", John Wiley & Sons Ltd..
6. Avison D., Wood-Harper A., et al., (1998), "A further exploration into information systems development: The evolution of Multiview2". *Journal of Information Technology and People,* 11:2, pp 124-139.
7. Whitten J., Bentley L., Dittman K., (2001) "Systems Analysis and Design Methods", 5th Edition, McGraw-Hill, Boston, Massachusetts.
8. Ramaprasad A., Papagari S., (2009), "Ontological Design". *Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology DESRIST09*.
9. Guarino N., (1998). "Formal ontology and information systems". *In:* N. Guarino, ed. *Formal Ontology in Information Systems*, Amsterdam, Netherlands: IOS Press, pp. 3-15.
10. Fernández M., Gómez A., Juristo N., (1997), "METHONTOLOGY: from ontological art towards ontological engineering.". *Workshop on Ontological Engineering:AAAI-97 Spring Symposium, Stanford, USA*
11. Olivé A., (2004), "On the Role of Conceptual Schemas in Information System Development". *Ada-Europe, LNCS* 3036.
12. El-Ghalayini H., (2006), "*Reverse Engineering Domain Ontologies To Conceptual Data Models"*. PhD thesis, University of the West of England, UK.
13. Conesa J., Palol X., Olivé, (2003), "A. Building Conceptual Schemas by Refining General Ontologies". In Marik, V, et al. *DEXA*, 693-702
14. Fensel D., "Ontologies: A Silver Bullet for Knowledge Management and Electronic Commerce",(2000)
15. Uschold M., King M., (1995) "Towards a Methodology for Building Ontologies", IJCAI'95 Workshop on Basic Ontological Issues in Knowledge Sharing, Montreal, Canada, pp. 6.16.10
16. Keramaris V., Danas K., (2014) "Development of Medical Ontology "HoPRO" (Hospital PRocess Ontology)". IOS Press ISSN: 0926-9630, ICIMTH '14, pp. 75-78
17. Smith B., Ceuster W., (2006) "HL7 RIM An Incoherent Standard"
18. Furkh Z., Radziah M., (2012) "Medical Ontology in the Dynamic Healthcare Environment, 3rd International Conference on Ambient Systems, Networks and Technologies"
19. Kishore R., Ramesh R., Sharman R., (2004) "Computational Ontologies and Information Systems: I. Foundations", *Communication of the AIS*
20. Velde R., Degoulet P., (2003) "Clinical IS Component-Based Approach", XVII, Springer, p. 296
21. Horridge M., (2011) "A Practical Guide To Building OWL Ontologies using Protégé 4"
22. Barry Smith and Werner Ceusters., (2006), "HL7 RIM: An Incoherent Standard" Studies in Health Technology and Informatics, vol. 124, 133–138

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