Ontologies, Knowledge Representation, Artificial Intelligence – Hype or Prerequisites for Interoperability?

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Abstract— **Nowadays, eHealth and pHealth solutions have to meet advanced interoperability challenges. Enabling pervasive computing and even autonomic computing, pHealth system architectures cover many domains, scientifically managed by specialized disciplines using their specific ontologies. Therefore, semantic interoperability has to advance from a communication protocol to an ontology coordination challenge, bringing knowledge representation and artificial intelligence on the table.**

Keywords— **Semantic interoperability, Ontology, pHealth, Generic Component Model**

I. INTRODUCTION

Traditionally, interoperability has been considered from a technology perspective. Finalizing the European Interoperability Framework [1], the European Commission is however looking for the following interoperability aspects: Organizational Interoperability; Legal Interoperability; Semantic Interoperability; Technical Interoperability. From the politicians' and administrators' viewpoint, such classification might be understandable, not saying that this approach is scientifically correct. In this paper, we will go for a more systematic and formal approach.

Interoperability happens when two or more actors such as persons, organizations, devices, systems, applications, components, or single objects communicate and collaborate – or interact – to achieve a common goal. Therefore, interoperability requirements define matter and quality of interactions as well as environmental conditions needed to achieve the business objectives. The definition of those objectives, the reflection of needs, and the assessment of environmental conditions are objectively depending on the considered domain, but subjectively depending on cultural background, knowledge, skills, but also additional constraints (social, political, organizational, legal, etc.).

This paper is one in a series of contributions on interoperability and HL7's role therein. In [2], HL7 has been formally compared with architectural approaches to interoperability. After redefining its mission and scope from healthcare communication to interoperability standards, HL7 has started to step by step meeting the challenges connected to comprehensive interoperability. This is a long and demanding endeavor as demonstrated by SDOs which have far more advanced on this matter. Therefore, we are not surprised that we have not arrived yet. In [3], intermediate status and role of HDF and SAEAF have been investigated. Nevertheless, we might venture to ask the following questions: Are the essential basic principles followed? Is the strategy right and ready? How can we harmonize and speed up the process? The paper tries to answer some of the most burning questions.

II. THE ROLE OF THE INFORMATION CYCLE IN THE INTEROPERABILITY'S CONTEXT

For meeting the objectives of interaction processes, the entire information cycle is composed by the following steps that must be interactively performed with iterations: (i) observation of status and interrelationships of the objects involved resulting in data, (ii) the appropriate and correct interpretation (semantics) of those data, (iii) the performing of the correct action. Those different aspects of information connected to events or data lead to the different definitions of information: the focus on the observation (data) lead to the definition of the statistical aspect of information provided by Shannon, the focus on interpretation of data using knowledge lead to Brillouin's definition of the semantic aspect of information, and the focus of properly using information to achieve the business goals resulted in Wiener's description of the pragmatic aspect of information [4]. Knowledge and skills for populating those different informational aspects are commonly different as well.

Conclusion: For meeting the interoperability challenge, the information cycle has to be completed. Without finally taking the right action, there is no interoperability.

III. CO-EXISTENCE OF INTEROPERABILITY LEVELS

Interoperability between two actors is frequently not performed directly, but supported and mediated by other actors forming an interoperability chain. The different actions or services within this interoperability chain can be tightly coupled or loosely coupled. This circumstance defines whether sharing the knowledge about the entire process or just the input/output from/to the neighbors in the chain is required. Another related prerequisite concerns the a-priori availability of competence (knowledge) and capability (performance) for collaboration, thereby running the aforementioned information cycle. If this availability is not given, the related knowledge has to be communicated and/or the capability has to be provided. So, different interoperability levels can be defined as shown in Tab. 1 and used as follows.

Table 1. Interoperability levels

Interoperability Level	Instances
Technical interoperability	Technical plug&play, signal- & protocol compatibility
Structural interoperability	Simple EDI, envelopes
Syntactic interoperability	Messages, clinical documents, agreed vocabulary
Semantic interoperability	Advanced messaging, common information models and terminology
Organizations/Service interoperability	Common business process

The interoperability level required depends on the health service paradigm which is changing from organization-centered through process controlled to personalized care. Because policies, business processes, terminologies and ontologies and even technological decisions essential for semantic interoperability can be more or less statically predefined and also enforced in organization-centered care settings, lower interoperability levels of the communication and cooperation protocols (structural interoperability within one domain and syntactic interoperability between different domains covered by one organization) are sufficient to enable semantic interoperability between all principals involved in patient’s care. In process-controlled scenarios, the aforementioned conditions for enabling and ruling communication and cooperation must be disease-specifically negotiated and agreed prior to putting such processes in place. This requires that the semantic interoperability level is being realized by exchanging the related information prior to, or connected with, the process. As personalized care services are individually defined by health status, environmental and contextual conditions, expectations and wishes of the subject of care, the care environment has to be designed and implemented autonomously, sharing and integrating services. For guaranteeing that the shared information is being understood, it has to be described using shared ontologies. The paper aims at broader scope of interoperability consideration.

Conclusion: System properties and environmental conditions define the interoperability level needed. The solution should be restricted to that interoperability level.

IV. The need for an open systems approach

To manage collaborative multi-disciplinary systems like health service providers and consumers, we have to abstract from the real systems diversity just focusing on the business objectives. The focus of interest defines the considered characteristics (components, processes, etc.) as well as the abstract system's boundaries to the environment. By that way, components can be externalized if their function can be sufficiently summarized as environmental effect. On the other hand, influential components can be internalized. The system design results in a simplified model of reality – the system architecture – describing structure function as well as internal and external interrelationships of the system's components relevant for the business objectives. Here, we have to have in mind that the business objective in eHealth is first of all defined by the specialties involved such as medicine, biomedical engineering, biology, genomics, legal affairs, administration, etc., and just supported by information and communication technology (ICT). More details about this traditional approach of system theory and system engineering in the papers context can be found in [5].

Conclusion: For managing multi-disciplinary environments, a system-theoretical or cybernetic approach to model real-world systems within a clearly defined architecture framework is inevitable.

V. The generic component model

The generic system description or architecture framework used has been developed in the early nineties in an architecture-centric standards development environment: the Object Management Group (OMG). The resulting Generic Component Model (GCM) [4, 6, 7] has been developed using system engineering, control theory, cybernetics and their application on technical as well as living systems, the approach describes any kind of system beyond ICT ones.

The GCM (Fig. 1) defines three dimensions comprehensively characterizing any system: the architectural components perspective describing composition/decomposition including concepts and interrelationships representation; the domain perspective separating system’s aspects described by domain ontologies; the view on the system describing development process. For connecting the different instances

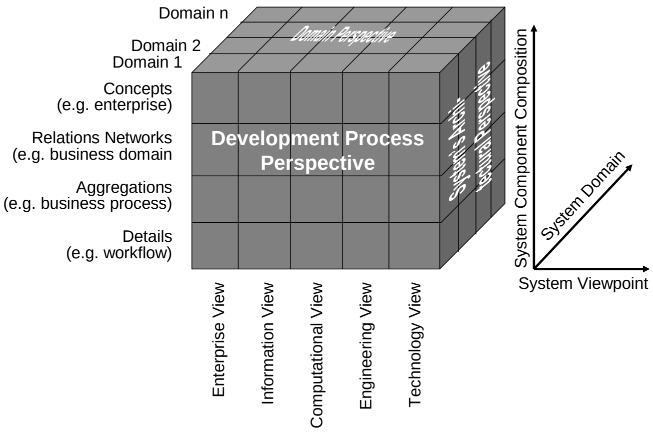

Figure 1. The Generic Component Model

within and between the aforementioned dimensions, reference models or meta-models are needed, including the driving ontologies and terminologies used for representing concepts as well as mapping between different domain languages.

Informationally, the abstract model of the GCM approach forms a three-dimensional type representation, which corresponds to the improved Barendregt's Lambda Cube consisting of a set of Pure Type Systems (PTSs), additionally refined through parameters, constraints, context, etc. [8]. By that way deploying universal logic, the three dimensions' construction rules are created [9, 10], representing knowledge or more generally ontologies of a multi-domain, multidisciplinary pHealth system.

Conclusion: The GCM supports analysis and design of multi-disciplinary real-world systems. Being based on a formal type theory for expressing any representation style, the GCM manages the systems architecture for multiple, interconnected domains as well as the ICT development process. Representing any system, the GCM also allows for managing language systems and ontologies. As HL7's HDF as well as SAEAF are rather immature approaches in comparison to existing standards such as ISO 10746 [11] or IEEE 1471 [12], they can be easily and comprehensively represented by the GCM as well.

VI. Domains in the pHealth Context – The Ontology Challenge

pHealth, i.e. health service delivery independent of time and location, depends on the implementation of three technological paradigms: mobile computing, pervasive computing and autonomic computing.

Mobile computing enables the permanent accessibility of the principals involved in the care process, providing e.g. teleconsultation services. Pervasive computing allows for remote and pervasive services provided by any type of principal, thereby directly integrating the subject of care in the communication and cooperation network using sensors, actors, body area networks [13], home networks, etc. Autonomic computing enables self-organizing, adaptive system design and implementation based on specific ontologies. Together, ubiquitous care delivery is installed. For more details, see e.g. [4].

Pervasive computing connects different domains such as medicine, informatics, biomedical engineering, bioinformatics, genomics, but also legal affairs and administration. For defining semantic interoperability and even more for autonomic computing solutions, the formal description of the system considering every domain's aspect is inevitable.

Commonly, domains are defined as groupings of common characteristics such as methodologies, business objectives, etc. Representing one dimension of a component-based system model, domains can be aggregated to super-domains or separated into sub-domains. From a methodology viewpoint, internal medicine, microbiology, radiology and nuclear medicine belong to different domains, while the business objective of diagnosis integrates all of them. As any characteristic has to be described, ontologies are a natural way of grouping components to a domain from a knowledge representation perspective. Such strategy can best be exemplified at personalized health. Beside medicine, sensors, actors and other biomedical devices monitoring the patient (or better the citizen before becoming a patient), genomics individually tailoring diagnosis and therapy, legal affairs such as legislation, regulations, especially security and privacy issues, and finally social and ethical aspects have to be implemented in an ICT environment. All aforementioned domains are represented by domain experts using their specific terminologies based on the domains' ontologies. The description of health status and health-related processes can be differently reflected depending on knowledge, skills, context, etc. As a result, the concept space or domain described by medical doctors is different from those expressed by patients normally being laymen.

According to the architectural perspective of the GCM, systems components and their interrelationships domain-specifically described through the domains concepts and relations (component aggregation rules or logics) are represented by business case specific application ontologies derived from the domain's ontology. The integration of the different domains included is controlled by meta-ontologies (upper level ontologies) and modeled in an ICT environment using IT-specific ontologies.

Conclusion: The integration of different domains as well as adaptive and intelligent behavior of ubiquitous and personalized health services require ontology management and coordination as well as autonomic computing based on artificial intelligence (AI) approaches. Interoperability of pHealth solutions is described by a system of interrelated ontologies.

VII. Principles and Strategies to be Followed for HL7 Interoperability

- Analysis, design, and specification of health system interoperability solutions must start with the business domain, but not with the ICT domain as the field of HL7. The HL7 Service Functional Models as well as the Domain Analysis Models are a very late but important step into the right direction. The formalized model must be derived from reality, but not vice versa, thereby causing problem with the evolutionary, information model centric HL7 approach including the RIM foundations.
- The multi-disciplinary approach advanced interoperability standards for eHealth/pHealth solutions are faced with must be based on a system-theoretical methodology. The ICT development is the last and least part.
- Design and integration of collaborating systems must be based on an architecture framework. The GCM combines system-theoretical and traditional architectural approaches, by that way enabling the management of different disciplines and their representation. It also applies for ontology systems, therefore enabling ontology coordination. Being interrelated, real systems and their ontological representation have to follow the same architectural framework. Architecture models like SAEAF just represent some aspects as they violate the aforementioned basic principles. Weaknesses are, e.g., the reverse process with the information view as root, the impossibility to reflect the concepts by an accepted ontology framework and the missing reuse of existing approaches for a-priori harmonization.
- Growing complexity of systems requires higher levels of abstraction and expressivity of the ontology representation. However, complexity of systems and abstraction level of their ontological representation should be kept as low as possible. Otherwise, computability challenge and degrees of freedom cause serious problems.
- Reusing existing approaches, specifications and developments from other domains and regions would essentially shorten the development cycle of HL7 products and avoid inconsistencies as well as painful harmonization processes.
- Certification of specifications and solutions is an essential prerequisite for workable interoperability.

VIII. Discussion

Semantic interoperability deals with the challenge of common understanding and use of shared information to meet common business objectives. As the different disciplines involved in pHealth manage their specific knowledge representations based on their evolution and environmental constraints, the mutual understanding of domain-specific, to the partner foreign concepts, relations and joint use is unlikely. So, interoperability is not a technical challenge as traditionally managed in standardization and system implementation.

Engineering and bridging the different ontologies of a pHealth solution formally and openly integrates the different disciplines involved in personalized care settings, thereby allowing stakeholders of using their domain-specific languages, "translating" semantically between them, and thereby providing comprehensive interoperability amongst them.

This aspect of a formal architectural approach is especially important for the empowerment of patients (or citizens in general) as a characteristic of personal health [14]. Only if the subject of care is enabled to reflect his/her concerns, wishes, expectations, etc., as well as to perceive the recommendations, regulations and procedures defined by care professionals properly, he/she can manage the care process safely and responsibly. For that purpose, education on the one hand and intelligent support as presented here on the other hand has to be provided.

IX. Conclusions

Traditionally, semantic interoperability between different principals has been considered and standardized from a technology perspective. eHealth and pHealth solutions are characterized by the integration of different disciplines representing different domains based on different ontologies, policies, etc. Therefore, semantic interoperability has to advance from a communication protocol to an ontology bridging challenge. In that context, eHealth and pHealth solutions have to be based on a formally modeled architecture comprehensively meeting the GCM architecture framework and the underlying principles the paper addressed.

Acknowledgment

The authors are indebted to their colleagues from ISO, CEN, HL7, and IHTSDO for kind collaboration.

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