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Interoperability issues in EHR systems: Research directions

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1 Introduction

The primary goal of all healthcare systems is to provide the best healthcare experience to their clients, that is, patients. To provide high-quality, trustworthy healthcare, countries across the globe are working on converting the paper-based documentation to computer-based recordings (electronic health records (EHRs)). Electronic health records are the backbone of health information systems (HISs) and have revolutionized healthcare delivery. Various sources like hospitals, pharmacy, mobile devices, IoT, and social media all generate data that are useful for EHR construction.

Currently, EHRs are generated via data entry done by clinicians, doctors, nurses, etc., treating the patient, and hospitals, where the patient has taken the treatment, have full access to EHR. Patients do not have direct access to their EHR but will be provided part of the information in the form of lab reports and discharge summary. This restriction allows a hospital monopoly and is not in the best interest of the patient. Thus there is a need to create a framework that is patient centric where EHR of a particular patient and all health-related data pertaining to the patient, personal health record (PHR), is available to him and to those whom he wants to give access to. PHR can be enriched by including information on patient reports, laboratory results, and data from smartphones and other health monitoring wearable devices. Advantage of a PHR over traditional EHR is that it ensures storing of patient's medical records in a single place instead of storing

Data Analytics in Biomedical Engineering and Healthcare. https://doi.org/10.1016/B978-0-12-819314-3.00002-1

them at various hospitals. A complete and accurate summary of an individual's medical history across hospitals and different ailments can thus be generated from PHR. The availability of such consolidated data will help clinicians to provide better treatment by making informed decisions. To generate PHR the fundamental requirement is that EHRs need to be consolidated. There need to be mechanisms where the EHR generated by different sources can be understood and are interoperable.

In the healthcare domain, at any specified stage in time, one user operates in distinct role capacity. For example, a doctor may be a primary physician for one patient and serve as a specialist for another patient. The information in the EHR is confidential and needs to be made available after proper authentication as per authorization. The full power of EHR can only be leveraged in an interoperable environment. Communication, collaboration, and shared care should be established among health information systems to provide better healthcare.

Experts from different domains (like healthcare, information systems and security, computer science, public health, and public policy) have developed various structural and semantic standards to represent, share, and provide a consistent semantic representation for EHR. Interoperability helps in delivering communication and collaboration among healthcare systems and helps in improving the security, safety, and quality of healthcare.

In all distributed systems, interoperability is an essential characteristic and is the ability of computer systems or software to exchange and use information. ISO3 defines interoperability of electronic health record as "the ability of two or more applications being able to communicate effectively without compromising the content of transmitted EHR" [1]. EHR information needs to be shared among hospitals (within or outside sharing), clinicians, laboratories, insurance, etc., without affecting the privacy of the patient. This is challenging as currently it is found that different units/departments work according to different proprietary/open standards that are available like HL7, Fast Healthcare Interoperability Resources (FHIR), openEHR, and Continuity of Care Record (CCR). This results in various issues related to interoperability like naming disputes and resolving dependencies among access control. Syntactic and semantic validation is required to assess such characteristics. It is therefore essential to provide dynamic feedback to the scheme that will continue to run a specific algorithm needed to resolve any potential disputes. Interoperable issues of naming conflicts and resolving dependencies between distinct characteristics of distinct access control strategies also require an assessment of such traits to achieve two separate layers of syntactic and semantic validation.

Interoperability not only is applicable for EHR but also is used in many other areas. Web technology consists of a large variety of complex web-based information services. As web technology spreads, web-based information services are exploding in number. The web-based application allows a user to access web resources through a semantic layer with the function of incorporating multiple data resources in the same or similar domains. This is due to the distributed, heterogeneous, and open nature of these applications. Therefore a web-based application system requires a generic architecture by supporting semantic interoperability to incorporate web resource propagation.

A smart grid is an electricity supply network that monitors and responds to local changes in the use of electricity using digital communication technologies. Smart grid vision requires both syntax interoperability to allow exchange information physically and semantic interoperability to understand and interpret the meaning of the changes. Semantic technology in a smart grid system can be used to make decisions. The issue of a unified global ontology in a smart grid scenario is yet to be achieved [2].

In the healthcare scenario, there is a higher requirement for semantic interoperability as the system is managed by nontechnologists, and most notes are written in natural language where terms are from the medical domain. The existing EHR solutions are complying to different standards, and it is challenging to consolidate and derive meaning from these data. To do an intelligent summarization for semantic interoperability, the use of artificial intelligence is needed and is very challenging. This chapter explores types of interoperability in distributed systems in Section 2, and Section 3 lists the specific to healthcare. Section 4 talks about the benefits of semantic interoperability, and Section 5 enumerates the challenges to achieve the same. Section 6 lists some use cases for interoperability, and Section 7 concludes the chapter.

2 Types of interoperability

In general, there are three different types of interoperability—syntactic, semantic, and organizational interoperability. Syntactic interoperability is when two or more devices use popular information formats (such as XML and SQL) and communication protocols to communicate with each other. Semantic interoperability is the ability to interpret meaningfully and accurately exchange data automatically to generate meaningful outputs as specified by both systems. The common technique used to achieve semantic interoperability is to refer to a common reference model for information exchange. Organizational interoperability includes social, political, and legal entities working together for a common interest and/or exchange of information.

Reference frameworks are useful to relate different types of interoperability and to compare concepts, principles, methods, standards, models, and tools in a certain domain of concern [3]. Some of the reference models are the LISI reference model, ATHENA interoperability framework (AIF), healthcare information and management systems society (HIMSS), European interoperability framework, etc.

The Levels of Information Systems Interoperability (LISI) Reference Model provides the common vocabulary and structure required to discuss interoperability between IT systems. It illustrates five levels of interoperability as shown in Table 1 [3].

The AIF offers a composite structure and related reference architecture to capture research elements and solutions to interoperability problems. The AIF provides a related methodological structure to describe the interoperability strategy from the choice to assess cooperation to the maintenance of the solution and the reference rules for adopting the reference architecture [4]. The framework is divided into three parts: conceptual integration, application integration, and technical integration. Conceptual integration (organizational interoperability) focuses on concepts, metamodels, languages, and model relationships. The framework defines a reference model for interoperability that provides a basis for various systemizing aspects of interoperability. Application integration (semantic interoperability) focuses on methodologies,

Table 1 Five levels of interoperability defined in LISI.

Level	Interoperability
Level 0	Isolated systems (manual extraction and integration of data)
Level 1	Connected interoperability in a peer-to-peer environment
Level 2	Functional interoperability in a distributed environment
Level 3	Domain-based interoperability in an integrated environment
Level 4	Enterprise-based interoperability in a universal environment

Reused from F.B. Vernadat, Technical, semantic and organizational issues of enterprise interoperability and networking, IFAC Proc. Vol. 42 (4) (2009) 728–733.

standards, and domain models. The framework describes methods that provide guidelines, principles, and patterns that can be used to solve problems of interoperability. Technical integration (technical interoperability) focuses on software development and execution environments. The framework defines a technical architecture that includes development tools and execution platforms for integrating processes, services, and information [3].

The European Interoperability Framework is a standard framework that describes three fundamental levels of interoperability, namely, technical, semantic, and organizational interoperability, as shown in Fig. 1 [3].

Healthcare Information and Management Systems Society (HIMSS) classifies interoperability as foundational, syntactic, semantic, and organizational. Foundational interoperability defines the building blocks of information exchange between different systems by establishing the connection requirements required for one system or application to share and receive information from another system. Structural interoperability specifies the structure or format of data exchange. The syntax of the data exchange is defined by structural interoperability. It ensures that data exchanges can be interpreted at the level of the data field between information systems. Semantic interoperability is the ability of two or more systems to understand, exchange, and

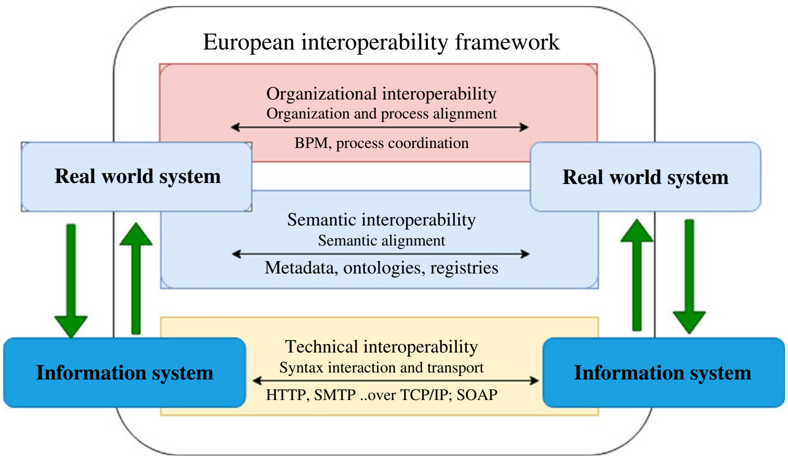

Fig. 1 European interoperability framework Redrawn from F.B. Vernadat, Technical, semantic and organizational issues of enterprise interoperability and networking. IFAC Proc. Vol. 42 (4) (2009) 728–733.

use information. Semantic interoperability makes use of the structuring of the data exchange and the codification of the data, including standards, publicly available vocabulary so that the receiving information management systems can understand the data. Organizational interoperability contains the technical components, policy, social, and organizational elements. These elements promote the secure, seamless, and timely communication and use of information within and between organizations and individuals [5].

3 Interoperability in healthcare

According to HIMSS, interoperability is the ability of different information systems, devices, or applications to connect, in a coordinated manner, within and across organizational barriers to access, exchange, and cooperatively utilize data among stakeholders, with the goal of optimizing the health of individuals and populations [5]. Healthcare systems demand interoperability among medical experts, clinicians, systems, and workflow. Domain-specific interoperability standards are needed and have to support cross-domain use. Communication and collaboration among healthcare systems and their components require the following [6]:

- openness
- scalability
- flexibility
- portability
- distribution at internet level
- standard conformance
- service-oriented semantic interoperability
- appropriate security and privacy services

For achieving the aforementioned characteristic HIS components, their relationship and functionalities should meet the following criteria:

- distributed architecture;
- component orientation (flexibility and scalability);
- model-driven and service-oriented design;
- separation of platform-independent and platform-specific modeling and separation of logical and technological views (portability);
- specification of reference and domain models at metalevel (semantic interoperability);
- interoperability at service level (concepts, contexts, and knowledge);

- common terminologies and ontology;
- semantic interoperability;
- security, safety, and privacy services;
- deep learning and neural networks (algorithms) [7].

Semantic interoperability must be incorporated with the health information system to get secure and high-quality healthcare. Semantic interoperability helps in sharing information between different stakeholders in the healthcare system. It helps in creating a common vocabulary that creates a way for accurate and reliable communication among computers. This communication between systems depends on the ability of different HIT systems to map different terms to shared semantics, or meaning. Semantic interoperability is viewed as critical for several healthcare initiatives like quality improvement programs, population health management, and data warehousing. Critical security issues of interoperability are whom to share, how much to share, and how to share such that no unauthorized access can be made to any data. Security can be ensured by using technologies like blockchain architectures to develop secured interoperable EHR systems [8, 9].

Semantic interoperability allows healthcare organizations to move from legacy systems. Heterogeneous HISs in healthcare environments use openEHR archetypes to represent the information contained in clinical EHR extracts and support the interoperability [10]. Table 2 compares the existing healthcare interoperability standards.

One of the major faults with the standards is that they are domain dependent and they are not built to include information of various formats from wearable devices. Moreover, what is achieved in the standards is primarily a way to attain syntactic interoperability, whereas a greater need is for semantic interoperability.

4 Use case of semantic interoperability in healthcare

A typical use case depicting the need for semantic interoperability is listed in the succeeding text. Patient A will undertake treatment in Hospital A for some medical condition and may need to move to Hospital B for some other issue. In the course of his life as he visits different hospitals, he manages to create a lot of data in the form of electronic health records scattered across various hospitals, as shown in Fig. 2. The summary of the treatment may be given to the patient at the time of discharge. But this is only a piece

Table 2 Comparison of existing interoperable standards in healthcare.

Properties	HL7	CCR	EN/ISO 13606	openEHR	IHE
Unified process modeling	Yes	No	No	No	No
Business modeling	Yes	No	No	No	Partial
Service-oriented process	Partial	No	No	No	Partial
Reference information model	Yes	No	Yes	Yes	Yes
Metamodel	Partial	No	No	No	No
Concept representation	Yes	Partial	Yes	Yes	No
Domain independent	No	No	No	No	No
Ontology driven	No	No	Yes	Yes	No
Vocabulary	Yes	No	No	No	No
Reference to terminology	Yes	Yes	Yes	Yes	Yes
Communication security	No	Yes	No	No	Yes
Inclusion of medical devices	Yes	No	Feasible	No	Feasible
Implemented	Yes	Yes	No	Partial	Yes
Commercial product	Yes	Yes	No	No	Yes

of limited information when compared with other details like nurse's notes and doctor's notes that might be captured during the stay.

If the EHRs are semantically interoperable, then data from different health providers can be consolidated automatically. This can be used by an intelligent clinical decision support system (CDSS) for intelligent summarization and giving alerts. When patients visit specialists, the system can check to see if there are any interdependencies with other treatments he has undertaken and give appropriate warning. If, in his medical history, there is an indicator of strong reaction to some drugs, this can be extracted and informed, thus ensuring better healthcare experience.

Another use case is the generation of a patient-centric, patient-mediated EHR system. EHRs of the patient from different sources can be consolidated and stored in the form of PHR. The patient can provide access to this information to those who need to know. In case of emergency, this information will be quickly accessible and will be useful to make informed decisions by caregivers. Currently, EHR software providers are using different standards that make the concept of interoperability challenges.

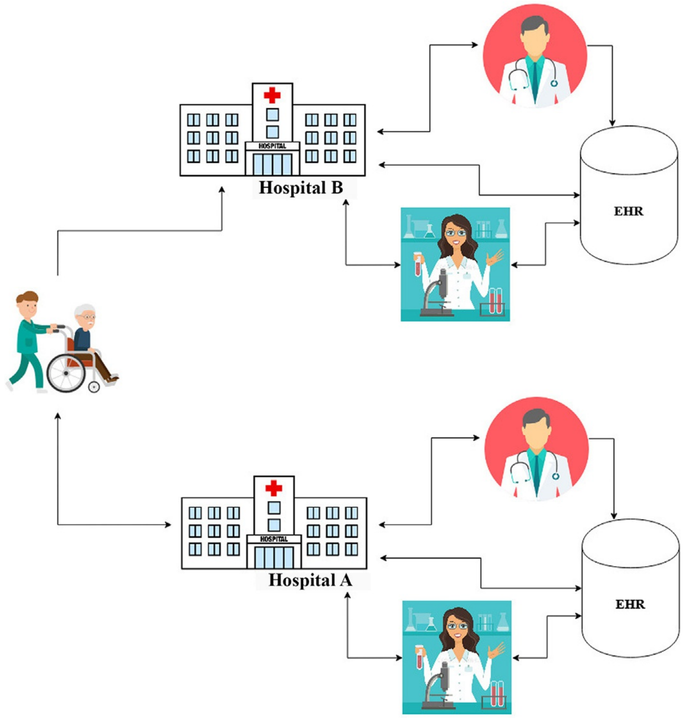

Fig. 2 Scenario where same patient visit multiple hospitals.

Another scenario is the requirement of different stakeholders having access to the data. Healthcare providers/administration/insurance all have different uses of these data. EHR is confidential information as far as the patient is concerned. So, semantic understanding of data can help in determining how data can be shared among different stakeholders in the best interest of the patient.

5 Benefits of semantic interoperability

The primary goal of the healthcare system is to provide better healthcare and safety to patients. Semantic interoperability allows the healthcare system to work together and helps to provide better patient care and effective healthcare delivery. In addition to the improvement of patient care, semantic interoperability offers the following benefits:

- Meaningful analysis: Semantic interoperability allows generating useful analytics about doctors' or clinicians' processes. It helps in identifying excesses of resources and thereby allows planning releases for clinicians for other critical work to boost productivity. The analytics will enable administrators for streamlining work balance and keeping track of staff schedules.
- Clinical process reengineering: Semantic interoperability enables clinical procedures to be reengineered to make it more efficient. When systems are fully interoperable, administrators can recognize excursions from account, when and how a clinician or physician behaves in an outside protocol.
- Resources utilization: Semantic interoperability analyzes and optimizes the use of resources.
- Clinical quality monitoring: Semantic interoperability helps in efficient monitoring of clinical processes and thereby provides better patient care. Semantic interoperability analytics help administrators to detect and avoid issues before they become problems.
- Solving issues in legacy systems: In the case of legacy systems, semantic interoperability allows legacy systems to operate in maintenance mode.

6 Challenges in semantic interoperability

Healthcare will move to a new dimension if semantic interoperability between EHR can be achieved, and the same can be used to derive intelligence. It can be given as an input to the clinical decision support system (CDSS), workflow management, and evidence-based healthcare. Some of the issues that need to be addressed to achieve semantic interoperability to share EHR among different stakeholders are as follows [1, 3]:

- Partial mapping of multiple sources: Combining the attributes identified in different systems leads to semantic differences, which lead to partial data mapping. This is due to inconsistent and nonformalized information structuring.
- Need for user intervention: It is challenging to identify common meaning and use of conflicting terms in a health information system without user intervention.
- Setting standards and guidelines: There is a need to construct a set of principles that ensure that updated rules are syntactically and (or) semantically correct, it is important to examine and define policy conflicts.

- Addressing contextual constraints: Currently, there are many vocabulary lists that are built, but identifying the right interpretation of similar concepts with different meanings remains a challenge.
- Existence of semantic difference in attributes: The existence of semantic difference in attributes and many times the meaning has to be inferred utilizing reasoning rules that form the foundation for the valid identification of similarities between them.
- Platforms for semantic interoperability: There is a need to leverage information retrieval techniques, neural networks, and artificial intelligence to assess the similarity of different elements in the profile.
- Medical terminologies: A bigger challenge is the correct understanding and interpretation of medical terminology.

Literature review done on the existing works revealed that there is a scope of much work in the limitations listed earlier. The findings of the literature survey are summarized in Table 3.

7 Research directions

Use of IoT devices like a wireless sensor and smartphone helps to achieve patient-centric health records (PHR). Semantic interoperability plays a crucial role in achieving patient-centric care. EHR, wireless devices, and information from healthcare environments need to be consolidated to create advanced CDSS. This CDSS must make real-time decisions on incoming EHR from personal health record (PHR) and historical EHR. The decision made must be based on clinical practice guidelines (CPG), validated by a domain expert. Advanced techniques like artificial intelligence, big data analytics, data mining, and cloud computing need to be used to improve decisions. Security and privacy of patients' EHR, network devices (wired and wireless) is another direction to improve healthcare.

8 Conclusion

Heterogeneous healthcare data are being generated from various sources like hospitals, laboratories, doctor prescription, nurse's notes, and wearable devices. This information is valuable for the construction of EHR. EHRs from various sources need to be interoperable so as to leverage the maximum benefit and provide the best care for the patients. Existing software are not designed with interoperability in mind. Many of the software do not follow any standard, and those that follow use different standards like

Table 3 Current works in semantic interoperability and its limitations.

Paper referred	Interoperability standards	Achieving semantic interoperability	Methodology	Purpose	Advantages	Limitations
[11]	HL7	Nil	Rational unified process, SOA, model-driven architecture (MDA), ISO 10746, generic component mod	Develop a framework for semantically interoperable HIS	Generic component model, not restricted to single standards	HL7 specifications have been partially reused
[6]	HL7 Version 3	HL7RIM	Model-driven, SOA	Highly dedicated and distributed healthcare facilities must interact and collaborate in a semantically interoperable manner to fulfill the challenge of high-quality and effective care	Model-driven, service-oriented design	Difference in generic and domain-specific knowledge concepts
[12]	HL7 and FHIR	Ontology and medical standards	OWL2 ontology	To provide monitoring of T1D patients	Distributed, semantically intelligent, cloud and mobile technologies	Uncertain nature of medical Data not handled

[10]	openEHR	Archetype and ontology	openEHR and agent-based technology	Developing e-health applications and reusing legacy systems	Use of agent-based system and archetype	Questionnaire used in assessment is not entirely subjective, as each participant can respond to it in a specific manner. Health professionals grouped and their vast expertise, findings have been generalized
[13]	HL7	Ontology	Nil	Semantic interoperability requires different levels of inter- and intraorganizational integration and is challenging	Nil	Nil
[14]	Nil	SNOMED-CT, ontology	Service-oriented architecture(SOA)	Reuse of CDSS by encapsulating in web service	Reuse of CDSS	Political, legal, organizational, and technical challenges
[15]	openEHR ISO EN 13606	Ontology, archetype	Model-driven architecture	Semantic interoperability of two EHR standards: openEHR and ISO EN 13606	Different interpretations for different purposes	Only two standards compared
[16]	Integrating the Healthcare Enterprise (IHE)	HL7 CDA	Nil	Secure P2P agent coordination framework	To enable secure interactions among communities	Nil

Continued

Table 3 Current works in semantic interoperability and its limitations—cont'd

Paper referred	Interoperability standards	Achieving semantic interoperability	Methodology	Purpose	Advantages	Limitations
[17]	HL7	HL7, ontology	Generic component model	Introduces the fundamental paradigms, specifications, architectural reference models, concepts, and formalization principles and processes for the development of comprehensive service-oriented personalized eHealth	PHR, pHealth	Key demand for personal health is to bridge disciplines including ontology
[18]	HL7	HL7 RIM, UML, SNOMED C T	Local information models	Build a digital electronic health record in the cardiology and dental medicine	Structured data entry over free-type data entry	Concept-related issues and their mapping of global classification schemes require close collaboration with physicians
[19]	HL7, CCR, openEHR, IHE, and EN/ISO 13606	Nil	Nil	Analysis and evaluation of EHR approaches using various standards	Nil	Nil
[20]	HL7 CDA, CEN 13606, and openEHR	Ontology	Unified fuzzy ontology	Framework for distributed EHR based on fuzzy ontology	Fuzzy ontology	Nil

HL7 and FIHR. Thus, to improve the healthcare system and provide better quality care, there is a need to provide syntactic and semantic interoperability among EHR. Semantic interoperability enables healthcare systems to work together and achieve better patient outcomes and effective healthcare. By achieving semantic interoperability and with artificial intelligence, big data analytics and data mining real-time decisions for better care can be made. The rich information that can be consolidated from the EHRs combined with artificial intelligence techniques can revolutionize modern healthcare delivery.

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