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Review of Semantically Interoperable Electronic Health Records for Ubiquitous Healthcare

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In order to provide more effective and personalized healthcare services to patients and healthcare professionals, intelligent active knowledge management and reasoning systems with semantic interoperability are needed. Technological developments have changed ubiquitous healthcare making it more semantically interoperable and individual patient-based; however, there are also limitations to these methodologies. Based upon an extensive review of international literature, this paper describes two technological approaches to semantically interoperable electronic health records for ubiquitous healthcare data management: the ontology-based model and the information, or openEHR archetype model, and the link to standard terminologies such as SNOMED-CT.

Keywords: Ubiquitous Healthcare, Electronic Health Record, Ontology, OpenEHR Archetype, SNOMED-CT

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I. Introduction

Ubiquitous technology allows services to be accessed anytime and anywhere [1]. Ubiquitous computing, following the vision of Weiser [2], aims to embed small computer devices into every day objects augmenting them with new functionality, building an environment full of distributed computers. Healthcare seems to be an ideal field for the application of ubiquitous computing [3]. Scenarios for major applications include homecare monitoring [4-6] and assistance for health professionals [7-9]. In the ubiquitous healthcare environment, health data are transferred to a remote healthcare server by a wearable system or mobile computer. Collected health data can then be managed and analyzed in the server computer to generate case-specific advice. Despite the fact that ubiquitous healthcare computing generates massive amounts of data, healthcare enterprises are knowledge poor because this data is rarely transformed into strategic decision-support resources. An intelligent active knowledge system for health data management is necessary to support clinical decisions by health professionals.

Dual model architecture [10] is gaining relevance for the development of an electronic health records system for ubiquitous healthcare. This architecture, which takes into account the dynamic nature of the healthcare environment, is based on two modeling levels: information and knowledge. The information level is provided by the reference model and the knowledge level by the archetype model. Dual modeling follows two main rules. The first is the separation of concepts into two levels, one defining the reference model and another, formed by formal models of domain concepts, defining different clinical concepts. The second rule is that computing systems are based on the reference model, and valid healthcare records extracts are instances of the reference model. This methodology is currently used by the major standards for representing electronic health records – openEHR, CEN, and Health Level Seven (HL7) . Based on dual model architecture, two major technological approaches for semantic interoperability are the ontology-based and the archetype models. The ontology-based modelof clinical information is designed to make health information systems properly interoperable and safely computable. The openEHR archetype model is an open standard specification that describes the management, storage, retrieval, and exchange of health data from electronic health records [11].

We review here these two technological approaches for semantically interoperable electronic health records to construct an intelligent active knowledge system for ubiquitous healthcare data management.

II. Ontology-based Models of Clinical Information

Over the past decades, ontologies have become key components of information systems [12,13] and have found various applications includingnatural language processing [14], software engineering [15], and knowledge management in the semantic web [16] and healthcare [17]. Ontology engineering and management in healthcare have a long tradition, starting with controlled vocabularies with restricted lists of terms such as catalogs, unstructured glossaries, and structured arrangements of words. Nowadays, a variety of ontology system representations have been introduced.

1. Previous Models

Various attempts have been made to construct ontology-based models of clinical information. Weed's "problem-oriented medical record (POMR)" methodology [18] formally linked a model of process of care to the information gathered during that care. Einstein's "hypothetico-deductive" model of clinical reasoning [19] mainly accounted for the cognitive aspects of clinical care during diagnosis. The Danish "general electronic patient journal (G-EPJ)" [20] included a conceptual model of the iterative problem-solving process and categories of information, implementing both process and information based on rational problem-solving, but proved too rigid in clinical practice. Various clinical modeling efforts from the RICHE project [21] to the present HL7 version 3 standard [22] have based their models on an "act management" paradigm, in which all aspects of healthcare are represented as "acts", enabling "everything that is done" to be recorded.

2. Protégé

Currently, the most widely-used ontology editor is Protégé. Protégé is an open source ontology development and knowledge acquisition environment developed by Stanford Medical Informatics [23]. As a JAVA tool, it provides an extensible architecture for the creation of customized knowledge-based tools and assists users in the construction of large electronic knowledge bases. Protégé provides two main ways of modeling ontologies: 1) Protégé-Frames editor and 2) Protégé-OWL editor. In Protégé-Frames, the knowledge model is compatible with the open knowledge base connectivity protocol (OKBC) [24]. All entities are frames and instances represent objects in the domain of interest. Classes are either named collections of instances or abstract conceptual entities in the domain. Protégé supports the construction of domain ontology, the design of knowledge-acquisition forms, and entering domain knowledge. It provides a platform which can be extended with graphical widgets for tables, diagrams, and animation components to access other knowledge-based system embedded applications.

Ontologies are important informatics resources for large multicentric clinical research projects providing semantic interoperability. While they offer a stable, language-independent vocabulary that helps standardize and explain the meaning of domain terms, the use of ontology editors such as Protégé is complex and therefore less suited for application to clinical practice.

III. OpenEHR Archetype Models

OpenEHR archetype models, commonly referred to as archetypes are clinical data models that conform to the openEHR Reference Model. The openEHR foundation, an international, on-line community whose aim is to promote and facilitate progress towards electronic healthcare records of high quality, to support the needs of patients and clinicians anywhere, is the originator. The openEHR's information model is the archetype, a re-usable formal model of a

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domain concept. Information models are templates for the acquisition of clinical data which provide semantic interoperability within the bounds of the given information model but not between different information models.

Archetypes are usually built by domain experts and are computable expressions of a domain content model of medical records, defining the particular configuration or desired composition of instances of clinical concepts. They constitute a tool for building clinical consensus in a consistent way. Expression is in the form of structured constraint statements, inherited from the reference model [25]. This model describes the health record itself, and is composed of packages, defining openEHR specification documents, and information models [25]. The EHR information model is organized in folders and compositions (Figure 1). Compositions are a broader concept than documents, but include documents. Examples of compositions are progress notes, or laboratory reports. The composition is the EHR's top level

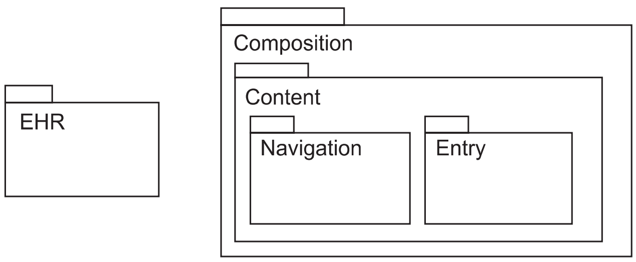

Figure 1. Package structure of openEHR information model. EHR, electronic health record.

data container. Folders can be used to classify compositions in a hierarchy. The package is the top level structure of the EHR and contains the entry and navigation packages.

In general, archetypes are defined for wide use; however, they can be specialized to include local particularities and in healthcare, an archetype can model concepts.

An archetype is divided into 3 main parts:

1) Descriptive = a unique identifier, machine-readable code describing the clinical concepts modeled by the archetype and various metadata,
2) Definition = the main part describing the architecture, content, or restrictions of the archetype, and
3) Ontology = defines the vocabulary and may contain language translations of code and meanings of codes used within the archetypes and tied to external vocabularies such as SNOMED or LOINC.

This structure constrains the cardinality and content of information model instances complying with the archetype. Codes representing the meanings of nodes and constraints on text or terms binding to terminologies such as SNOMED or LOINC are stated in the ontology section.

The formal language for expressing archetype is Archetype Definition Language (ADL) [26], a knowledge description language. ADL uses three other syntaxes to describe constraints on data which are instances of some information model–cADL (constraint from ADL), dADL (data definition from ADL), and a version of first-order predicate logic (FOPL). Archetypes are represented in Web Ontology Lan-

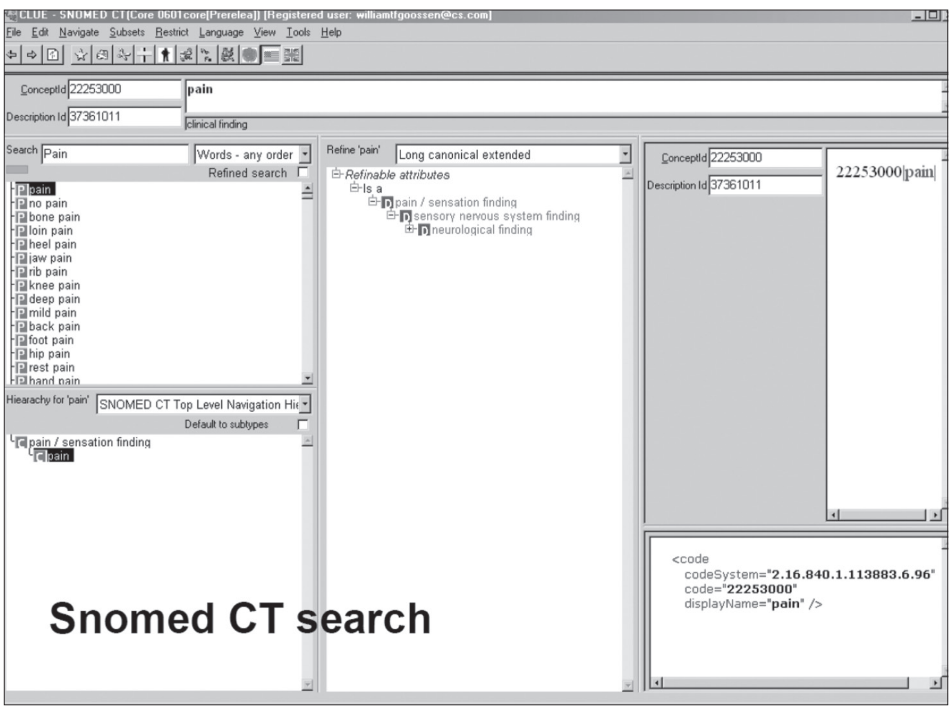

Figure 2. SNOMED CT search browser.

Table 1. Free and open source tools for implementation of data interchange standards

Data interchange standard	Tools
HL7	Mirth, HAPI, Perl HL7 Toolkit, Net_HL7, xHL7, etc
DICOM	DCMTK, GCDM, Dcm4che, DVT, etc
ISO/IEEE 11073	ICSgenerator, PDUvalidate, etc

HL7: Health Level Seven, HAPI: HL7 application programming interface, DICOM: digital imaging and communications in medicine, DCMTK: DICOM toolkit, GCDM: generated conceptual data model, Dcm4che: DICOM implementation in JAVA, DVT: DICOM validation tools, ISO: International Organization for Standardization, IEEE: Institute of Electrical and Electronics Engineers, ICS: Implementation Conformance Statements, PDUvalidate: protocol data unit validate.

guage (OWL) by mapping each ADL construct to its OWL counterpart.

The intended purpose of archetypes is to empower clinicians to define the content, semantics, and data-entry interfaces of systems independently from the information systems [27]. A feature of archetypes is the ability to separate internal model data from formal terminologies. The internal data are assigned local names which can later be bound or mapped to external terminology codes. This feature eliminatesthe need to make changes to the model whenever the terminology changes. In archetype models, the SNOMED CT terminology system is commonly used for mapping processes.

IV. SNOMED-CT Terminology

SNOMED-CT aims to be a comprehensive terminology that provides clinical content and expressivity for clinical documentation and reporting [28]. SNOMED has been developed using the description logic Ontylog [29] to allow formal representation of the meanings of concepts and their inter-relationship [30]. The SNOMED hierarchy is easy to compute, which was the primary reason for selecting the terminology for the research. SNOMED-CT has approximately 370,000 concepts and 1.5 million triples i.e. relationships of one concept with another in the terminology (Figure 2).

V. Data Interchange Standards

Besides medical records, various medical data measured from sensors and devices must be interchangeable in ubiquitous healthcare. The most common data exchange standards used in healthcare IT are HL7 for general health information, Digital Imaging and Communications in Medicine (DICOM) for medical images, and ISO/IEEE 11073 for medical devices. HL7 version 3 has evolved from a pure data interchangeable format to include a reference information model and a suite of other standards for capturing the conceptual structure of health information systems.

Both HL7 and DICOM are built on the “free open source” philosophy therefore, most of the enabling and editing tools are “free open source” software as well. There are also some free conformance test tools available for 11073. A list of the major “free open source” tools available for data interchange implementation is shown in Table 1.

Although not stated in the above sections, national and international standards developments, connectivity using HL7, and document exchange using HL7 CDA [31] are also contributing to the implementation of content-based ubiquitous healthcare systems.

VI. Conclusion

In the health informatics community, a considerable amount of progress has been made in the area of for semantic interoperable electronic health records for ubiquitous use of patient information and health knowledge management. These methodological developments, particularly the ontological approach and openEHR archetype, have changed ubiquitous healthcare allowing it to become more semantically interoperable and individual patient-based, These advances will allow healthcare professionals to manage complete electronic healthcare records of the patients regardless of which institution generates each clinical session.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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