

PhD Theses and other Dissertations about *openEHR* Archetypes

- **Towards Interoperable and Knowledge-Based Electronic Health Records Using Archetype Methodology** ([PDF¹](#))

- **Rong Chen**

- PhD thesis (som för avläggande av filosofie doktorsexamen vid Linköpings universitet och tekniska högskola kommer att offentligt försvaras i Eken, Campus US ingång 65, Linköping, torsdagen 5 november 2009, kl. 9.00)

- *Abstract:* The use of Electronic Health Records (EHR) is wide spread in healthcare today. EHRs are not only used to support daily care but also used to support important secondary uses, e.g. clinical research, quality assurance and education. Although considered advantageous compared to paper-based records, EHRs still have a long way to go in realizing its full potential as an integral part of a safe, effective and efficient health care system.

Making EHRs interoperable is a prerequisite to support increasingly distributed and diverse healthcare. Bringing up-to-date knowledge into EHRs for decision support is a critical step to foster evidence based care. EHR data from different sources need to be analyzed in research in order to find new evidence for improvement of the current practice. Knowledge in the form of guidelines needs to be disseminated and applied in practice through continuous education. This cyclic flow of information and knowledge between care, research and education must be facilitated in order to achieve a safer and more efficient healthcare. An interoperable EHR framework can facilitate the sharing of information and knowledge between not only human users but also participating software systems. This is the aim of this thesis, which is built upon the research in the field of semantic interoperability, in particular the pioneering work by the openEHR Foundation.

The journey of this thesis started with a template-based supplementary EHR system - Julius, which allows clinicians to define and share record structures for care and research. The formalism behind Julius is comparable to the openEHR archetype formalism but less expressive and without the backing of international standards. This finding led to an open source implementation of the openEHR design, which in turn initiated the validation and further improvements of the archetype formalism. The software components made the archetype formalism more accessible to academic and commercial projects around the world.

The investigation of the convertibility between a legacy EHR content model and the archetype model showed that the archetype format is more expressive and thus can be used to preserve legacy EHR content definitions. A general strategy for migration from legacy EHRs to archetype-based EHRs was formulated. A novel way of representing clinical practice guidelines using archetype formalism was proposed and tested on a lymphoma chemotherapy guideline. The implication of this study is improved interoperability between guidelines and EHRs that could facilitate both clinical decision support and guideline-compliance checking. Maintainability of guidelines could be increased through reuse of EHR content models as building blocks of guidelines. In the last part of the research, a way of expressing fully structured care plans using openEHR and CONTSys has been explored based on the requirements for elderly home care. A sharable and semantically well-defined care plan could contribute to the coordination of shared care.

The key contribution of the thesis can be summarized as the validation and further improvement of the openEHR archetype formalism through software implementation and the explorations on clinical guidelines, shared care plans and legacy EHR content models in relation to archetype-based EHR framework.

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- 1. • **Introducing an openEHR-Based Electronic Health Record System in a Hospital** ([PDF²](#))

- **Murat Gök**

- Masters Thesis submitted to Department of Medical Informatics, University of Göttingen, Germany, May 2008

- *Abstract:* this thesis reports a case study of an *openEHR* system at the Emergency Department, Austin Health, Melbourne, and arose from the collaboration with Austin Health, the Austin Centre for Applied Clinical Informatics (ACACI), the Nursing Informatics Group, the Biomedical Engineering Department, the Emergency Department, the Central Queensland University Health Informatics Research Group, Ocean Informatics, and the Department of Medical Informatics (University of Göttingen).

The aim of this thesis is to provide a roadmap for the introduction of an electronic health record system based on the openEHR (<http://www.openehr.org>) approach for a health service within a public hospital in Australia. The idea of electronic health records (EHRs) was born approximately 40 years ago [GL96] and consequently several concepts were developed. One of these approaches is the "Good European Health Record" (GEHR) project on which the openEHR Foundation builds.

Over time the openEHR approach has matured, however, there is still a lack of knowledge on how to introduce an openEHR-based system (implementation and migration strategies). To tackle this problem, the thesis gives an overview of the openEHR approach by presenting the history, architecture, and relations to other standards in electronic health care. The patient flow in an emergency department (ED) of a public hospital (Austin Health) is then analysed in regards to the information produced and documented. This thesis investigates how the data items in the ED can be gathered and mapped to openEHR archetypes, thus formally representing the clinical knowledge. The reusable archetypes cover more than 70% of all archetypes needed in the ED. This figure may vary for other departments. It also points at the development of openEHR templates (a combination of archetypes) through utilising mind maps. Using an example of a ventilation system, data can be migrated from proprietary systems and transferred to an openEHR-based data storage. An explanation is given for an openEHR architecture based EHR system, providing the foundation for the implementation of an openEHRbased prototype. The thesis shows how an openEHR architecture based EHR system can be introduced in practical terms and how this could lead to interoperability within a department.

- ***Semantic Mapping Of Clinical Model Data To Biomedical Terminologies To Facilitate Interoperability*** ([PDF³](#))

- **Rahil Qamar**

Submitted to the University of Manchester for the degree of Doctor of Philosophy in the Faculty of Engineering and Physical Sciences, Mar 2008
Supervisor: Prof Alan Rector

- *Abstract:* The thesis presents and evaluates, the Model Standardisation using Terminology Systems (MoST) methodology, for integrating the clinical content in data models and terminology models. The MoST system developed for the purpose, aims to find semantically equivalent SNOMED terminology codes to map to archetype data model fragments. The two key stages of MoST include, (i) term finding, and (ii) data mapping. While the term finding procedure is completely automated, the data mapping procedure is assisted by clinical experts. The research recognises the significance of human intervention in ensuring the quality of the terminology codes being mapped to the data model fragments. Ensuring the quality of the mappings, helps maintain accuracy and unambiguity of coded data. The evaluation of the MoST system shows the importance of incorporating linguistic and semantic procedures, in addition to lexical lookups, to increase the chances of finding semantic matches. A significant contribution of the thesis is the description of the issues with current Archetype and SNOMED models with regards to the information needed to achieve effective model integration

2. http://www.openehr.org/publications/archetypes/goek-masters-thesis_2008.pdf

3. <http://www.openehr.org/publications/archetypes/RQamar-PhD-Thesis-Mar2008.pdf>

at content level. These issues were highlighted by the qualitative analysis of the evaluation. The issues point to semantic gaps in both the data and terminology models, which inhibit automated systems, such as MoST, from making intelligent inferences on the semantic appropriateness of the content. Suggestions for resolving these issues are detailed, where appropriate. A final contribution of the thesis is the set of guidelines that are suggested to the two modeling (Archetype and SNOMED) communities, to improve the quality of their model content. The hypothesis is that an increase in the content compatibility of the two models will increase the likelihood of the overall integration of the models, to achieve interoperability

- **Archetype based Domain Modelling for Health Information Systems** (PDF⁴)

- **Koray Atala#**

- Submitted to Department of Information Systems, Middle East Technical University (METU), July 2007

- Supervisor: Prof. Dr. Semih Bilgen

- **Abstract:** A major problem to be solved in health informatics is high quality, structured and timely data collection. Standard terminologies and uniform domain conceptual models are important steps to alleviate this problem which are also proposed to enable interoperability among systems. With the aim of contributing to the solution of this problem, this study proposes novel features for the Archetypes and multi-level modeling technique in health information and knowledge modeling. The study consists of the development of a research prototype for endoscopic data management, and based on that experience, the extension of Minimal Standard Terminology in Digestive Endoscopy (MST). A major contribution of the study consists of significant extensions to the modeling formalism. The proposed modeling approach may be used in the design and development of health information systems based on archetypes for structured data collection, validation and dynamic user interface creation. The thesis work is aimed to make considerable contribution to the emerging Electronic Health Records (EHR) standards and specifications.

Papers Specifically about openEHR/CEN Archetypes

User Interface

- **Generic screen representations for future-proof systems, is it possible? There is more to a GUI than meets the eye** (PDF⁵)

- **Helma van der Linden**(a,#), **Tony Austin**(b), **Jan Talmon**(a)

- (a) School for Public Health and Primary Care: Caphri, Maastricht University, Maastricht, The Netherlands

- (b) CHIME, University College London, United Kingdom

- # Corresponding author at: Medical Informatics, Maastricht, University, POBOX 616, 6200 MD Maastricht, The Netherlands.

- E-mail address: h.vanderlinden@mi.unimaas.nl

- pp213–226 Computer methods and programs in biomedicine 95 (2009)

- **Abstract:**

- **Background:** Future-proof EHR systems must be capable of interpreting information structures for medical concepts that were not available at the build-time of the system. The two-model approach of CEN 13606/openEHR using archetypes achieves this by separating generic clinical knowledge from domain-related knowledge. The presentation of this information can either itself be generic, or require design time awareness of the domain knowledge being employed.

- **Objective:** To develop a Graphical User Interface (GUI) that would be capable of displaying

4. http://www.openehr.org/publications/archetypes/KorayAtala%20THESIS_Final.pdf
previously unstructured clinical data structures in a meaningful way.

5. <http://www.ncbi.nlm.nih.gov/pubmed/19387989>
Methods: Through “reasoning by analogy” we defined an approach for the representation and

implementation of “presentational knowledge”. A proof-of-concept implementation was built to validate its implementability and to test for unanticipated issues.

Results: A two-model approach to specifying and generating a screen representation for archetype-based information, inspired by the two-model approach of archetypes, was developed. There is a separation between software-related display knowledge and domain-related display knowledge and the toolkit is designed with the reuse of components in mind.

Conclusions: The approach leads to a flexible GUI that can adapt not only to information structures that had not been predefined within the receiving system, but also to novel ways of displaying the information. We also found that, ideally, the openEHR Archetype Definition Language should receive minor adjustments to allow for generic binding.

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Querying

- ***EHR Query Language (EQL) – a query language for archetype-based health records.*** (PDF⁶)
 - **Chunlan Ma (a), Heath Frankel (a), Thomas Beale (a), Sam Heard (a)**
(a) Ocean Informatics
 - pp 397-401 Proceedings of MedInfo 2007, K. Kuhn et al. (Eds), IOS publishing, 2007.
 - *Abstract:* OpenEHR specifications have been developed to standardise the representation of an international electronic health record (EHR). The language used for querying EHR data is not as yet part of the specification. To fill in this gap, Ocean Informatics has developed a query language currently known as EHR Query Language (EQL), a declarative language supporting queries on EHR data. EQL is neutral to EHR systems, programming languages and system environments and depends only on the openEHR archetype model and semantics. Thus, in principle, EQL can be used in any archetype-based computational context. In the EHR context described here, particular queries mention concepts from the openEHR EHR Reference Model (RM). EQL can be used as a common query language for disparate archetype-based applications. The use of a common RM, archetypes, and a companion query language, such as EQL, semantic interoperability of EHR information is much closer. This paper introduces the EQL syntax and provides example clinical queries to illustrate the syntax. Finally, current implementations and future directions are outlined.

Archetypes, Semantic Integration and Ontology

- ***Archetype-based semantic mediation: Incremental provisioning of data services*** (PDF⁷)
 - **Jesus Bisbal, Gerhard Engelbrecht, and Alejandro Frangi**
CISTIB - Universitat Pompeu Fabra, and CIBER-BBN, Barcelona, Spain
{name}.{surname}@upf.edu
 - 23RD IEEE International Symposium on Computer-Based Medical Systems
(<http://www.cbms2010.curtin.edu.au/>).
 - *Abstract:*
Modern organizations need to exploit the information stored in heterogeneous and interrelated data sources, but often have no means to integrate them in a principled fashion. This general database research challenge is particularly relevant in distributed e-Science. Specifically, biomedical research generates a vast amount of heterogeneous data, which exceeds the current technological capacity to exploit it efficiently. Typically, service-oriented architectures are used in this context to define a unified view over all sources to be integrated. This unified schema needs to be mapped onto the underlying data sources, often including also semantic annotations. This approach suffers from high complexity and setup costs. In this paper we propose a novel application of semantic and mediation technologies, which leads to an incremental and on-demand definition of data mediation services. The so-called archetypes provide the context

6. http://www.openehr.org/publications/archetypes/MedInfo_2007_EQL_MA.pdf

7. <http://www.dtic.upf.edu/~jbisbal/publications/Bisbal-455-CBMS2010.pdf>

and semantics needed to setup such services, which significantly simplify their definition.

- **Combining OpenEHR archetype definitions with SWRL rules – a translation approach.** ([Springer link⁹](#))

- **Lezcano, L., Sicilia, M.A. and Serrano-Balazote, P.**

- In Proceedings of the First World Summit on the Knowledge Society (WSKS'08), Springer Lecture Notes in Artificial Intelligence, 52880, pp. 80-89.

- *Abstract:*

The interoperability of electronic healthcare information systems is critical for a more effective healthcare management. Several specifications and standards have been created for facilitating such interoperability at different levels. Among them, the OpenEHR initiative emphasizes the sharing of flexible specifications of healthcare information pieces in the form of archetypes. However, the OpenEHR ADL language does not provide support for rules and inference which are important pieces of clinical knowledge. This paper reports on an approach to convert ADL definitions to OWL and then attach rules to the semantic version of the archetypes. This allows for an automated means to reuse knowledge expressed in the form of rules which is also flexible and follows the same philosophy of sharing archetypes.

- **Expressing Clinical Data Sets with openEHR Archetypes: A Solid Basis for Ubiquitous Computing.** ([IJMI link¹⁰](#))

- **Garde S, Hovenga E, Buck J, Knaup P**

- *International Journal of Medical Informatics.* 76 (S3): S334-S341.

- *Abstract:*

Purpose: The purpose of this paper is to analyse the feasibility and usefulness of expressing clinical data sets (CDSs) as *openEHR* archetypes. For this, we present an approach to transform CDS into archetypes, and outline typical problems with CDS and analyse whether some of these problems can be overcome by the use of archetypes.

Methods: Literature review and analysis of a selection of existing Australian, German, other European and international CDSs; transfer of a CDS for Paediatric Oncology into *openEHR* archetypes; implementation of CDSs in application systems.

Results: To explore the feasibility of expressing CDS as archetypes an approach to transform existing CDSs into archetypes is presented in this paper. In case of the Paediatric Oncology CDS (which consists of 260 data items) this led to the definition of 48 *openEHR* archetypes. To analyse the usefulness of expressing CDS as archetypes, we identified nine problems with CDS that currently remain unsolved without a common model underpinning the CDS. Typical problems include incompatible basic data types and overlapping and incompatible definitions of clinical content. A solution to most of these problems based on *openEHR* archetypes is motivated. With regard to integrity constraints, further research is required.

Conclusions: While *openEHR* cannot overcome all barriers to Ubiquitous Computing, it can provide the common basis for ubiquitous presence of meaningful and computer-processable knowledge and information, which we believe is a basic requirement for Ubiquitous Computing. Expressing CDSs as *openEHR* archetypes is feasible and advantageous as it fosters semantic interoperability, supports ubiquitous computing, and helps to develop archetypes that are arguably of better quality than the original CDS.

- **Semantic Issues in Integrating Data from Different Models to Achieve Data Interoperability** ([PDF¹¹](#))

- **Rahil Qamar (a), Alan Rector (a)**

(a) Medical Informatics Group, University of Manchester, Manchester, U.K.

9. <http://www.springerlink.com/content/k706u20xg1176042/>

10. pp 674-678 Proceedings of MedInfo 2007, K. Kuhn et al. (Eds), IOS publishing, 2007.

11. *Abstract:* Matching clinical data to codes in controlled terminologies is the first step towards http://www.openehr.org/publications/archetypes/Medinfo_2007_QamarRector.pdf

achieving standardisation of data for safe and accurate data interoperability. The MoST automated system was used to generate a list of candidate SNOMED CT code mappings. The paper discusses the semantic issues which arose when generating lexical and semantic matches of terms from the archetype model to relevant SNOMED codes. It also discusses some of the solutions that were developed to address the issues. The aim of the paper is to highlight the need to be flexible when integrating data from two separate models. However, the paper also stresses that the context and semantics of the data in either model should be taken into consideration at all times to increase the chances of true positives and reduce the occurrence of false negatives.

- **Framework for Clinical Data Standardization Based on Archetypes** (PDF¹²)
 - **Jose A. Maldonado (a), David Moner (a), Diego Tomás (a), Carlos Ángulo (a), Montserrat Robles (a), Jesualdo T. Fernández (b)**
 a Biomedical Informatics Group, ITACA Institute, Technical University of Valencia, Spain
 b Departamento de Informática y Sistemas, University of Murcia, Spain
 - pp 454-458 Proceedings of MedInfo 2007, K. Kuhn et al. (Eds), IOS Press, 2007
 - *Abstract:* Standardization of data is a prerequisite to achieve semantic interoperability in any domain. This is even more important in the healthcare sector where the need for exchanging health related data among professional and institutions is not an exception but the rule. Currently, there are several international organizations working on the definition of electronic health record architectures, some of them based on a dual-model approach. We present both an archetype modeling framework and LinkEHR-ED, an archetype editor and mapping tool for transforming existing electronic healthcare data which do not conform to a particular electronic healthcare record architecture into compliant electronic health records extracts. In particular, archetypes in LinkEHR-ED are formal representations of clinical concepts built on a particular reference model but enriched with mapping information to data sources which define how to extract and transform existing data in order to generate standardized XML documents.
- **Exploiting ebXML registry semantic constructs for handling archetype metadata in healthcare informatics.** (PDF¹³)
 - **Dogac, A., Laleci, G.B., Kabak, Y., Unal, S., Beale, T., Heard, S., Elkin, P.L., Najmi, F., Mattocks, C., Weber, D. and Kernberg, M. (2006).**
 - Int. J. Metadata, Semantics and Ontologies, Vol. 1, No. 1, pp.21–36.
- **Archetype-Based Semantic Integration and Standardization of Clinical Data.**
 - **Moner, D. Maldonado, J.A. Bosca, D. Fernandez, J.T. Angulo, C. Crespo, P. Vivancos, P.J. Robles, M.**
 - In: **Engineering in Medicine and Biology Society, 2006. EMBS '06. 28th Annual International Conference of the IEEE**¹⁴. Aug. 2006. pp 5141-5144.
- **Integration of Tools for Binding Archetypes to SNOMED CT.** (PDF¹⁵)
 - **Erik Sundvall, Rahil Qamar, Mikael Nyström, Mattias Forss, Håkan Petersson, Hans Åhlfeldt, Alan Rector.**
 - Semantic Mining Conference 2006.

Archetypes and Governance

13. http://www.semantic.org/publications/archetypes/EMBS_dogac_et_al_2006.pdf
14. **Towards Semantic Interoperability for Electronic Health Records: Domain Knowledge Governance for open EHR Archetypes.** (PDF¹⁶)
<http://ieeexplore.ieee.org/xpl/RecentRef.jsp?punumber=4028925>
15. http://www.semantic.org/publications/archetypes/Garde_Sy_Kumar_P_Hovenga_L_S_Heard_S_2007.pdf
16. [http://methods.informatics-in-medicine.com/46\(3\)/EHR-343.html](http://methods.informatics-in-medicine.com/46(3)/EHR-343.html) (doi:10.1160/ME5001)..

- *Nursing Constraint Models for Electronic Health Records: a vision for domain knowledge governance.* (PDF¹⁷)
 - **Hovenga E, Garde S, Heard S (2005).**
 - Int J Med Inform . 74(11-12): pp886-898.

Archetypes in Use

- *Importing Clinical Data into Electronic Health Records - Lessons Learnt from the First Australian GEHR Trials.* (PDF¹⁸)
 - **Bird L, Goodchild A, Heard S.**
 - Proceedings HIC 2002 conference.
- *Experiences with a Two-Level Modelling Approach to Electronic Health Records.* (PDF¹⁹)
 - **L. Bird, A. Goodchild, Z. Tun.**
 - Journal of Research and Practice in Information Technology 35 (2003).

Principles

- *Templates and Archetypes: how do we know what we are talking about?* (PDF²⁰)
 - **S. Heard, T. Beale, G. Freriks, A. Rossi-Mori, O. Pishev.**
 - HL7 internal paper, 2003.
- *Archetypes: Constraint-based domain models for future-proof information systems.* (PDF²¹ 185kb, 17pp)
 - **Beale T.**
 - In: Eleventh OOPSLA Workshop on Behavioral Semantics: Serving the Customer (Seattle, Washington, USA, November 4, 2002). Edited by Kenneth Baclawski and Haim Kilov. Northeastern University, Boston, 2002, pp. 16-32.
- *Archetypes - An Interoperable Knowledge Methodology for Future-proof Information Systems.* (PDF²² 700 kb)
 - **Beale T.**
 - Published on the internet in 2000.

Papers and Theses mentioning archetypes

Knowledge Engineering & Use

- **Knowledge Mobilization: Architectures, Models and Applications** (PDF²³)

17. <http://dx.doi.org/10.1016/j.ijmedinf.2005.07.013>

18. http://www.openehr.org/publications/archetypes/HIC2002_bird_goodchild_heard.pdf

19. <http://www.isi.iad.cs.cmu.edu/JRPITVolumes/JRPIT35/JRPIT35.2.121.pdf>

20. http://www.openehr.org/publications/archetypes/templates_and_archetypes_heard_et_al.pdf

21. http://www.openehr.org/publications/archetypes/archetypes_beale_oopsla_2002.pdf

22. http://www.openehr.org/publications/archetypes/archetypes_beale_web_2000.pdf

23. <http://hera.ugr.es/tesisugr/17611404.pdf>

Papers about Related Subjects

Frame Logic (F-logic)

- *Logical Foundations of Object-Oriented and FrameBased Languages*. (See [here](#)²⁴ for link to [PDF](#)²⁵).
- **Kifer M, Lausen G, Wu J.**
- JACM May 1995.
- The Archetype cADL syntax and semantics are formally speaking a synthesis of F-logic queries with terminology (the node encoding).

24. <http://www.cs.sunysb.edu/%7Ekifer/dood/papers.html>

25. <ftp://ftp.cs.sunysb.edu/pub/TechReports/kifer/flogic.pdf>