

# Visualization of Medical Data Based on EHR Standards

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## Keywords

Data visualization, ISO 13606, graphical user interface, archetype

## Summary

**Background:** To organize an efficient interaction between a doctor and an EHR the data has to be presented in the most convenient way. Medical data presentation methods and models must be flexible in order to cover the needs of the users with different backgrounds and requirements. Most visualization methods are doctor oriented, however, there are indications that the involvement of patients can optimize healthcare.

**Objectives:** The research aims at specifying the state of the art of medical data visualization. The paper analyzes a number of projects and defines requirements for a generic ISO 13606 based data visualization method. In order to do so it starts with a systematic search for studies on EHR user interfaces.

**Methods:** In order to identify best practices visualization methods were evaluated ac-

cording to the following criteria: limits of application, customizability, re-usability. The visualization methods were compared by using specified criteria.

**Results:** The review showed that the analyzed projects can contribute knowledge to the development of a generic visualization method. However, none of them proposed a model that meets all the necessary criteria for a re-usable standard based visualization method. The shortcomings were mostly related to the structure of current medical concept specifications.

**Conclusion:** The analysis showed that medical data visualization methods use hardcoded GUI, which gives little flexibility. So medical data visualization has to turn from a hardcoded user interface to generic methods. This requires a great effort because current standards are not suitable for organizing the management of visualization data. This contradiction between a generic method and a flexible and user-friendly data layout has to be overcome.

making use of humans' natural visual capabilities" while Card et al. define visualization as "the computer-assisted use of visual processing to gain understanding" [4, 5]. In our research we add to this by defining data visualization as a process of consecutive transformation of domain knowledge into a user operable interface (as shown in ►Figure 1) where each step adds new knowledge to the definition of a user interface, which is "the system by which users interact with a machine" [6].

Only when you separate the visualization function from the content to be visualized the interface will become independent from the structure and content of the EHR. Therefore the medical concept definition needs to be separated from the visual modeling thus providing the freedom to make the solutions reusable not only on the conceptual level but on the visual level. It will allow a precise adaptation of both the content and the interface that is critically important for the acceptance of the EHR by the doctors [12, 13, 15].

The objective of this paper is to review projects devoted to the implementation of an EHR user interface in order to try to generalize the trends of the UI developments as well as to identify main problems and requirements.

Visualization methods are widely used in many domains but medical data is special in many aspects and the visualization methods have to take this into account. The major facts that make medical data unique and that must be reflected in the methods are [18]:

1. Medical data has many ethical, legal, and social implications [51];
2. Medical data asks for a very acute interpretation;

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## 1. Introduction

The user interface, i.e. the visual layer of a software application, is the first thing a user meets when starting an application [1]. It affects the user's perception not only of the data but also of the underlying sys-

tem. A user interface also provides interoperability between the system and user to enable a user to find and interpret the content correctly [2, 3].

Visualization is defined by Gershon et al. as "the process of transforming data, information and knowledge into visual form

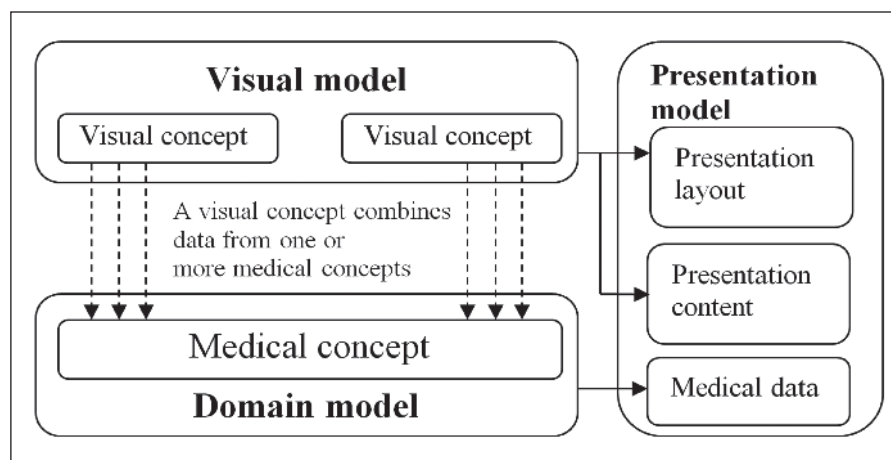


Figure 1 Dual model architecture for medical data visualization

A customizable and platform independent user interface will have to allow a user to specify data layout according to his/her needs. This is especially vital when a doctor has to switch between different EHR systems [52].

3. Medical data of different sources is very heterogeneous;

EHR systems can aggregate data from different sources. Even the format of data that is stored within one EHR system can change over the period of time. However, the data is to be presented to the user in a unified way [53].

4. The existence of several medical data standards (openEHR<sup>a</sup>, ISO 13606<sup>a</sup>, HL7<sup>b</sup>) each of which offers its own specific data structure.

The data model usually contains more data than a user requires and wants to have presented on a screen. However, it does not provide a lot of information that is useful for the definition of a visual layer. Modern EHR systems provide multi-user functionality and each user needs specific data

to be presented in a special way. Different data types prove to be challenging for visualization methods. The complex information structures that need to be broken down into the simple data type constituents. This can be demonstrated by “Blood pressure”. The common visual form for blood pressures consists of two numbers of the type Physical Quantity separated by a slash (Systolic/Diastolic).

Various approaches for medical data visualization have been developed one of theme is the model-view-controller (MVC) paradigm [15]. Within the MVC paradigm the task of visualization is being related to the modeling of the view. This does not define the exact presentation layout but renders the model (for example the ISO 13606 data model [17]) into a form suitable for building a GUI. This approach allows different views on one model.

So at the moment we know how to store medical data and can apply efficient techniques to build user friendly interfaces, however, there exist in literature no generally accepted approaches of how to transform knowledge from domain model to interface model. We also lack a generic visualization approach for processing standard based medical data independent from its content. The problem can be solved on the model level by providing semantic interoperability not only for the medical data exchange process, but for the data visualization process as well.

Even though standard based medical data visualization is considered one of the

major tasks of the ISO 13606 community [18], so far the requirements on visualization have not been defined. A number of projects developed visualization methods and models for medical data. These projects use different approaches on medical data visualization, different technologies and standards. Our survey concentrated on evaluating “application limits”, “customizability”, and “re-usability” of the approaches. The criteria definition was based on recent publications [7, 8, 20–22, 54, 55] on medical data visualization and serve to identify the methods with a potential to become a starting point for the development of a standard based medical data visualization method. The review did not evaluate the “usability” of the provided solutions – where usability is according to The National Institute of Standards and Technology “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use” [19].

Currently healthcare professionals are the main users of EHRs [8]. However, there are indications that the involvement of patients will improve healthcare, and that a personalized access to the patient’s electronic health record will support patient empowerment [9–11]. Visualization models and methods can provide flexibility to the data presentation and thus cover the needs of the users with different backgrounds and requirements [7].

## 2. Methods

A literature search for studies on EHR data visualization methods was made. The research had the goal to define the state of the art of medical data visualization and to study the weak and strong points of the current approaches to medical data visualization. The search included the following scientific databases and journals: Medline, Cochrane Library, CINAHL, EMBASE, sciencedirect.com and ACM Digital library. The inquiry focused on studies which go beyond the implementation of the user interface and which have the potential to be re-used in further projects. The following queries were used: “EHR

<sup>a</sup> The OpenEHR and ISO/EN 13606 architectures incorporate the so-called dual-model approach. This technique is characterized by the fact that it separates knowledge from information [47].

<sup>b</sup> HL7 v3 is the widely accepted standard for the electronic interchange of healthcare information. Besides many artifacts it comprises mainly the Reference Information Model (RIM), vocabularies refined models, storyboards and implementation specifications [50].

data visualization”, “EHR user interface” and “Medical data visualization”. The reviewed papers were purposefully chosen to cover the whole process from the first works on the medical data visualization to the most recent projects. The papers represent different approaches on medical data visualization. In addition to the papers, the projects’ web-sites that contained the project presentations, technical specifications and authors’ commentaries were studied. The search was performed from April till May 2011.

The following criteria were used to characterize the visualization methods:

**Limits of application** – generality of the approach is and if it can be applied to standard based data without knowing their structure in advance [20].

**Customizability** – possibility to adjust the GUI to the users’ own needs regarding both the visual layout as well as the dataset used in the EHR [21].

**Re-usability** – the limitations in the application of the approach: such as a restriction to a certain dataset or type of medical data and its potential to be extended to other projects [22].

Besides, the methods were analyzed according to:

1. Problems revealed within the project.
2. Main difficulties faced while implementing a visualization project.
3. Tools used to visualize medical data and to build user interfaces.

### 3. Results of Description and Evaluation of the Projects

The queries resulted in 1846 papers. The titles of the papers were analyzed by one of the two reviewers who applied exclusion criterion 1 and inclusion criterion 1 (►Figure 2). In the second step the abstracts of the papers were analyzed in detail.

Then 15 papers were chosen after applying exclusion criterion 2 and inclusion criterion 2 by both reviewers. Other papers were mostly related to medical imaging or were limited to a single GUI implementation. Four projects – some of them described in more than one of the papers –

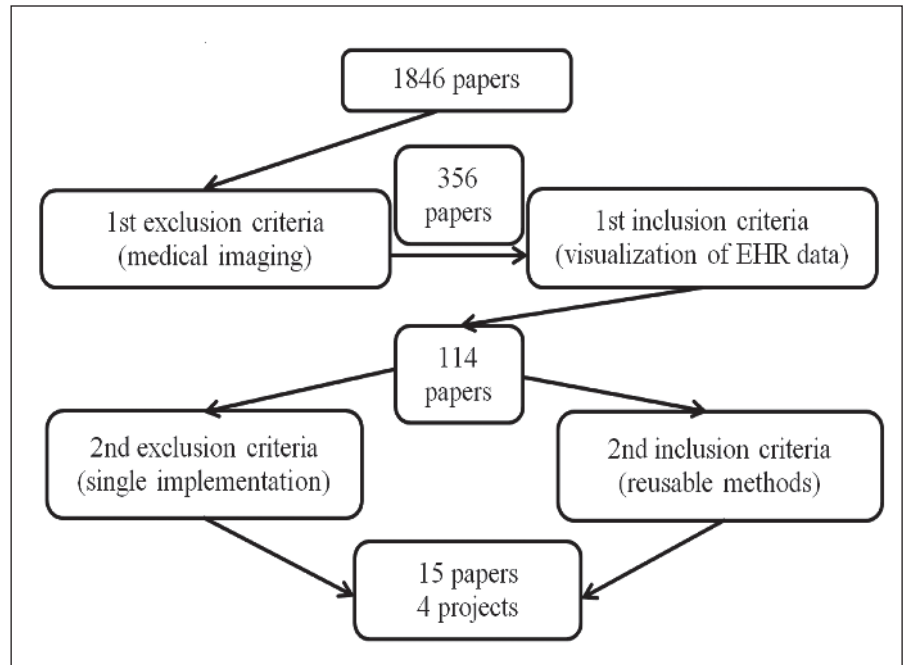


Figure 2 Paper selection process

that met the inclusion and exclusion criteria were analyzed in detail.

#### 1. Inclusion criteria:

- The papers had to deal with the visualization of EHR data;
- The papers had to describe visualization methods which had to have the potential to be reused.

#### 2. Exclusion criteria:

- Papers on medical imaging;
- Papers limited to a single GUI implementation without any re-use potential.

Four projects that met the requirements of the research were analyzed in detail (see ►Table 1). The selected projects have different goals in terms of end-user requirements, but the general task of each project is still to present medical data to the user.

Another project the Opereffa (open-EHR REference Framework and Application) [23], which is being developed at University College London seems very promising. Opereffa develops a web based application which uses Java Server Faces as well as JavaScript and XML (AJaX) to implement the presentation layer. All archetype data fields are stored as a structure that consists of an attribute and its value in

a single generic table. The Opereffa project is under development at the moment and has implemented the openEHR specifications only partly. The Opereffa project demonstrates the high potential of the archetype based visualization methods. XML data structuring is proved to be a proper technology for visualization data storage. Unfortunately the information provided is not sufficient for the analysis. Therefore, it was not included in our review. However, the approach that the project develops is interesting and we feel it can advance standard based medical data visualization.

## 4. Visualization Methods

### 4.1 LifeLines Project

Authors apply LifeLines in the analysis of complex electronic medical records to visualize temporal relationships between treatments, consultations, disorders, prescriptions, hospitalizations and other events. Similar events are organized into facets, which can be expanded and collapsed to provide an increasing or decreasing level of detail. Color notations and line thickness are used to indicate the import-

Project	Goal and description of the project
Lifelines/LifeLines2 projects	The Lifelines project provides a general visualization environment for personal histories. All the medical data can be presented on one screen as a set of graphical time series. Lifelines2 [24–29] advances this work to multi-patient views.
The PropeR project	The Proper project aims at developing a generic visualization method based on the simplified version of CEN 13606 (now ISO/EN 13606) that will be implemented in the web-application [30–33].
GastrOS project	The project’s goal was to develop a method for the dynamic creation of a GUI which is as intuitive and user friendly as any one manually designed. GastrOS’s core functionality is handled by a model driven structural data entry (SDE) component, which uses it as an operational template to dynamically construct appropriate GUI forms [34–35].
MUDR electronic health record	The goal of the project was to develop a set of web-based, highly interactive graphic modules that are integrated in a personal health record to provide an easy and pleasant way for patients to browse through their historical data [37–38].

**Table 1**  
Summary of retrieved studies on medical data visualization

**Table 2** Characterization of the visualization methods used in the reviewed projects

Project	Limits of application	Customization possibility	Re-usability
Lifelines project	Common visual concepts only: no general approach to the architecture	Only minor properties like color are customizable	The concept of the data presentation as timelines can be re-used in other projects
The PropeR project	As the solution is based on the ISO 13606 standard, it is suitable for standardized medical data visualization	The project aims at making generic visualization blocks but there is no tool provided for the customization of the visual layout	The approach leads to a flexible GUI, which can adapt to information structures that were not predefined within the receiving system
GastrOS project	The solution is based on the archetype and reference models of the openEHR standard and is generally applicable	The interface is customizable through the number of GUI directives that determine the layout of the widgets	The solution is able to generate structured data entry forms on the fly based on the underlying domain model
MUDR electronic health record	The solution was developed for a specific EHR, however it can be re-used in other projects	A user can adjust the interface according to his/her needs	The results of the GUI design research can be re-used in other projects

ance and relationship of events. The problematic parts of the graphics caused by the high density of data can be handled by a zooming functionality allowing users to compress and stretch the time scale at any location.

4.2 The PropeR Project

The GUI model of the PropeR project is based on the idea that a GUI consists of building blocks called “widgets”. A “widget” in this approach is a platform-independent display unit that contains presentation knowledge for a single data type. These widgets can be mapped to classes of the ISO 13606 Reference Model. The second level is represented by “views”, the definitions of a screen. “Widgets” are converted to specific versions by using “views”. “Profiles” tailor the “views” to the local environment, they implement localized presentation knowledge and they

manage the conversion of information to match user expectations to avoid interpretation errors.

4.3 GastrOS Project

GastrOS’s visualization method is based on the model driven structural data entry (SDE) component which takes in an operational template and dynamically constructs appropriate GUI forms. The SDE follows the model-view-controller paradigm, stating that the presentation logic is completely independent from the logic for handling and persisting openEHR reference model objects. If the domain model changes, then the SDE will automatically generate updated GUI forms that reflect these changes, without any need for modifying the program code. SDE first parses the input operational template into a tree-like data structure. Each archetype object acts as a template for the data to be entered

and stored while a GUI widget is used to represent it. The SDE defines a set of mapping rules to determine what kind of GUI widget will create which specific data element.

4.4 MUDR Electronic Health Record

A universal communication interface between application layer and presentation layer (the user interface) provides a means to define a user interface for different environments and operating systems. The structured data can be entered either directly by selecting the appropriate items from the tree structure of the knowledge base or by using dynamically created forms. The printable reports and user entry forms are created dynamically following the definitions in XML documents. The multimedia data are processed using the



**Table 3**

Problems

Project	Revealed problems
Lifelines project	Problems of data overloading arise when a lot of data is collected in the EHR, the number of categories, the number of lines or the number of events can increase significantly. Setting up the GUI requires manual adjusting
The PropeR project	A generic GUI will result in a suboptimal display where the structure of the information is used as the only basis to derive the presentation rather than displaying the information in a form familiar to the user. It was found that it is not possible to support the definition of an optimal display format while keeping the GUI generic
GastrOS project	The current openEHR template specification does not define the means to provide any GUI related information. So to make the visualization more flexible and customizable additional layout data has to be managed on a separate layer.
MUDR electronic health record	No evidence of any problems were revealed within the project

**Table 4**

GUI implementation technologies

Project	Implementation technologies
Lifelines project	The current prototype of Lifelines is implemented in Java and runs as a web-application on the Internet
The PropeR project	The project uses the Cocoon Forms Framework that is based on XForms and is suitable for data entry as well as for data display and the XML User Interface Language (XUL)
GastrOS project	The system was developed using the .Net platform and C# programming language. The GUI was dynamically constructed by a structural data entry (SDE) component that parses the input XML based operational template, which allows changing the user interface automatically in case the archetype is changed
MUDR electronic health record	The communication between client application and application layers was implemented using an XML-based communication protocol. The XML documents are transported by an HTTP protocol between client application and HTTP server. The CGI scripts executed by the HTTP server provide the interface for the application layer running as Windows NT service

functionality of the Java Media Framework API.

#### 4.5 Characterization of the Visualization Methods

In order to find the strong and weak points of the proposed approaches and to identify best practices the visualization methods were evaluated according to the following criteria: **Limits of application, Customizability, Re-usability**. The characterization (► Table 2) of the visualization methods applied in the reviewed projects was based on the results and conclusions sections of the papers [24–28, 30–38].

The shortcomings found in the projects (► Table 3) were mostly related to the structure of the current medical concept specifications. The methods that allow the most generality and reusability are based on the archetype data model of ISO 13606 and openEHR. However, the visualization

methods that are based on the data structure do not produce an optimal presentation layout. It does not allow the user interface to be really generic and to work without manual data addition and adjustment of the layout. This means that the topic of generic visualization methods for “archetyped” data requires further research. The general and re-usable methods based on the archetype data structure [41] do not provide the best presentation layout as shown in ► Table 3. We think that research should advance the medical concepts modeling methods in a way that can provide a basis for standard based data visualization.

### 5. Discussion

Visualization methods cover a large field ranging from usability, the knowledge how the data is organized and displayed, to the knowledge how generic concepts for a

standardized data are implemented. The projects (except LifeLines) developed presentation layers copying the layout of the paper doctors’ letters. We think that this approach needs to be replaced by modern graphical design methods [48, 49] and that an approach like the one implemented in “LifeLines” advances the idea. The visualization methods point in two main directions: standardization of the visual layout (like LifeLines) and implementation of additional model layers (GastrOS, Proper, and Opereffa).

The standards such as ISO/EN 13606 and openEHR provide medical concepts with a clear structure that can be used to form a data presentation level. However, generic visual medical concepts can only be applied on standardized medical data to a certain extent. We feel that the ISO 13606 data model is one that can become a basis for a generic visualization method. As shown in table II archetype based solutions

provide the most generic and re-usable visualization methods. The advantages of other approaches have also to be taken into account. The experience collected by the reviewed projects will be used as a basis for defining the requirements to the visual medical concepts for the ISO 13606 data model.

The review showed that the presentation data should be stored separately from the medical data [31, 32]. The most capable technology used in the reviewed projects is XML – an open standard that allows easy access and transformation of the data. The most common interface implementation technologies are either Java or .Net frameworks. The reviewed analysis of the projects shows that an architecture where the visual model is separated from the data model seems to be preferable. A dual model approach allows separating medical knowledge (expressed in for example ISO 13606 archetypes) from visual knowledge and presentation layer implementation. This allows more of roles division.

The task of visualization can be divided into main subtasks. The aggregation of data that is to be presented to a certain user (doctor's profile may combine data from different medical concepts e.g. blood pressure, blood sugar, HbA1C for a diabetologist), the organization of the data that contains the properties regarding the presentation layer (e.g. text size, color, diagram type) and the building of the user interface. So to produce an efficient GUI we will need at least two layers in addition to the archetype layer. The content layer and the presentation layer

The Content layer describes the content-related presentation knowledge. The data is aggregated in visual groups that combine data fields from different archetypes. Visual groups define platform independent visual blocks to specify a layout for each archetype data field and group different archetype elements into visual groups. Each visual group can contain a specification of visual tools that can be used to build a user interface. The archetype structure must be taken into account (e.g. compositions, entries). This will allow building a visual layer based on the ISO 13606 archetype model that will take into account the

different perspectives on the medical data of doctors and patients.

The presentation layer defines the GUI. It defines the appearance of visual groups and individual data fields (widgets). A widget is a platform-independent display unit that contains presentation knowledge of a single data type or of a combination of data types. Widgets can be mapped to classes of the ISO 13606 Reference Model. There are several types of widgets: data-oriented widgets such as: "PQ", "Codded Text", visual group oriented widgets such as "list", "table" or "diagram".

Another important part of this study is the analysis/representation of the patients' perception of the medical data. The way the doctors perceive visual layout of medical data has been studied [42]. While the medical data representation features like the position of the elements, size and other important properties are widely agreed, none of the reviewed projects studied the patients' perceptions of the electronic health record data. Most of the projects are doctor oriented and do not consider patients as users of EHR systems. They do not propose interface tools that make the medical data accessible to patients. However, studies [43] have shown that patients recognize the potential benefits on their healthcare and on relationships with health professionals and that they are interested in supporting the therapy process by accessing the EHR [43]. Involvement of patient will, however, require a study of the way patients – who are not medical professionals – perceive EHR data. So far no evidence was found that the access to the personal data influences the health status of the patients [44]. It could, however, be shown that the patients feel that the advantages of electronic health records outweigh the disadvantages [45]. Patients are mostly concerned about security, confidentiality, understanding their records, and the accuracy and completeness of the data. This should be considered while developing a visualization method for the patients. One potential benefits of a multi-user visualization method could be the involvement of patients by filling in the results of observations made at home. An intuitive and friendly user interface will benefit home monitoring systems that have the potential

of patient empowerment, influencing patients' attitudes and behaviors and increasing desirable medical outcomes [47]. This can optimize the work of the medical organization, reduce costs and help establish a quick, transparent and trusted communication between a patient and a doctor.

## 6. Conclusion

The storage, retrieval, and exchange of patient data are no longer the only key factors for the successful EHR. Usability plays an important role in the successful implementation and acceptance of an EHR system. Data storage and exchange standards provide a good basis for medical data visualization methods. However, the limitations of the standards remain a serious barrier. They do not allow defining the optimal layout based only on the structure of the data. The review identified the main trends in the development of standard based reusable GUIs. The most efficient development seems to be the implementation of a higher level visual model based on data exchange standards.

The reviewed projects are doctor oriented and almost do not consider patients as active users of EHR systems. They do not propose solutions that make the medical data accessible to patients. However, studies [43] have shown that patients recognize the potential benefits, which an access to their health records has on their healthcare and on the relationship with health professionals. This needs to be considered in future developments.

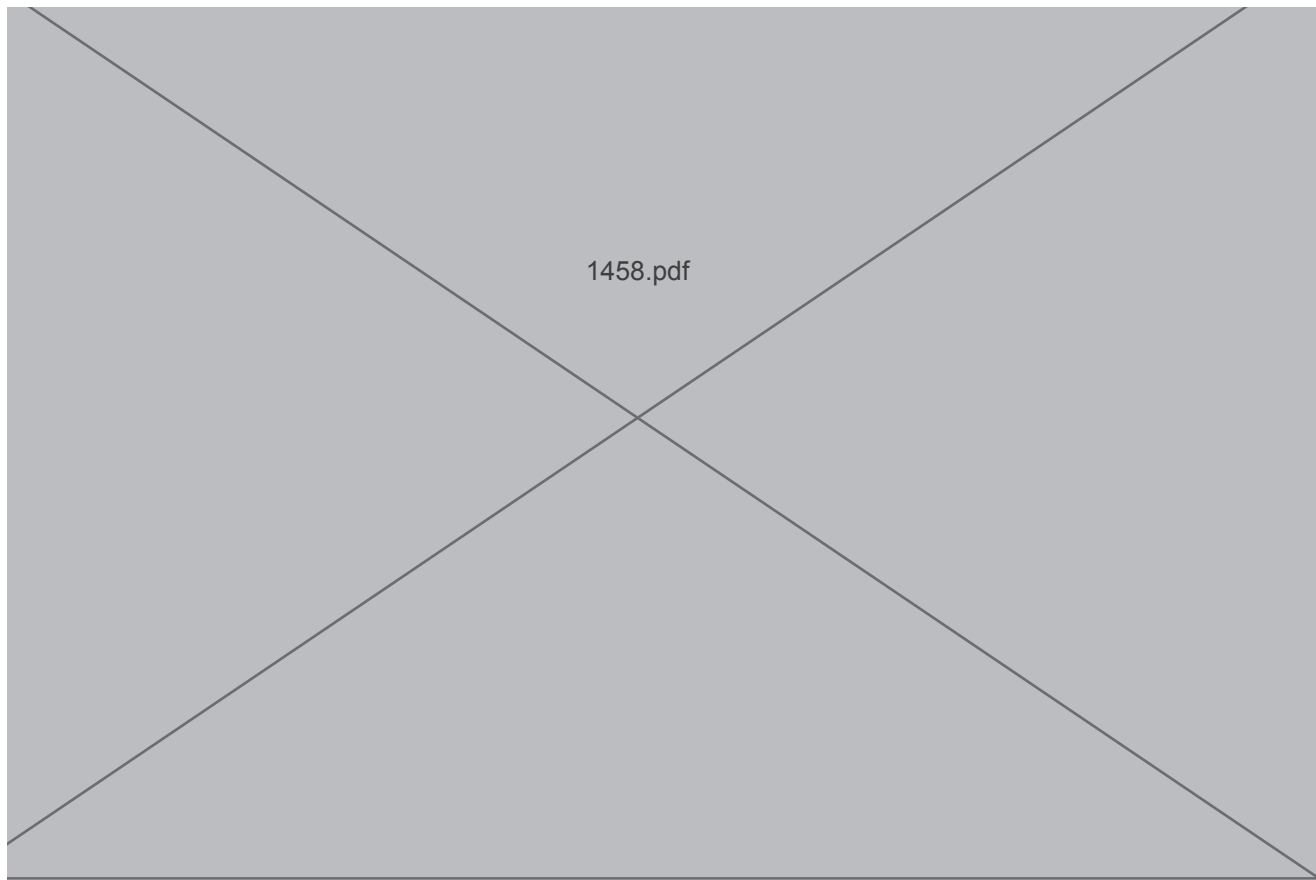
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## References

- Shneiderman B. Designing the User Interface: Strategies for Effective Human-Computer Interaction (3rd edition 1997). MA: Addison-Wesley Publishers; 1997.
- Gigerenzer G, Gaissmaier W, Kurz-Milcke E, Schwartz L, Woloshin S. Helping doctors and patients make sense of health statistics. *Psychological Science in the Public Interest* 2007; 8: 53–96.
- Brodie K, Carpenter L, Earnshaw R, Gallop J, Hubbard R, Mumford A, Osland C, Quarendon P. Scientific Visualization, Techniques and Applications. Springer Verlag; 1992.
- Gershon N, Eick SG, Card S. Information visualization. *ACM Interactions* 1998; 5 (2): 9–15.
- Card S, Mackinlay J. The structure of the information visualization design space. In: *Proceedings of the InfoVis'97 IEEE Symposium on Information Visualization*. Los Alamitos: IEEE Computer Society Press, 1997. pp 92–99.
- Green TRG, Petre, M. Usability analysis of visual programming environments: A 'cognitive dimensions' framework. *Journal of Visual Languages and Computing* 1996; 7: 131–174.
- Schönhage B, Eliëns A. A flexible architecture for user-adaptable visualization. In: *NPIV '97: Proceedings of the 1997 workshop on New paradigms in information visualization and manipulation*. pp 8–10.
- Smelcer JB, Miller-Jacobs H, Kantrovich L. Usability of Electronic Medical Records. *Journal of Usability Studies* 2009; 4 (2): 70–84.
- Riet A, Berg M, Hiddema F, Sol K. Meeting patients' needs with patient information systems: potential benefits of qualitative research methods. *Int J Inf* 2001; 64 (1): 1–14.
- Ralston JD, Revere D, Robins LS, Goldberg HI. Electronic Personal Health Records Come of Age. *American Journal of Medical Quality* 2006; 21 (3) (suppl): 5–15.
- Ralston JD, Revere D, Robins LS, Goldberg HI. Patients' experience with a diabetes support program based on an interactive electronic medical record: qualitative study. *British Medical Journal* 2004; 328 (7449): 11–59.
- Linder JA, Schnipper JL, Tsurikova R. Barriers to electronic health record use during patient visits. *AMIA Annu Symp Proc* 2006. pp 499–503.
- Schellhase KG, Koepsell TD, Norris TE. Providers' reactions to an automated health maintenance reminder system incorporated into the patient's electronic medical record. *J Am Board Fam Pract* 2003; 16 (4): 312–317.
- Koppel R, Metlay JP, Cohen A, et al. Role of computerized physician order entry systems in facilitating medication errors. *JAMA* 2005; 293 (10): 1197–203.
- Burbeck S. Application Programming in Smalltalk-80: How to use Model-View-Controller (MVC). [Internet]. 1992. Available from: <http://st-www.cs.illinois.edu/users/smarch/st-docs/mvc.html>.
- Cios KJ, Moore GW. Uniqueness of medical data mining. *Artificial Intelligence in Medicine* 2002; 26: 1–24.
- Martínez-Costa C, Tortosa MM, Fernández-Breis JT. An approach for the semantic interoperability of ISO EN 13606 and OpenEHR archetypes. *Proceedings of Journal of Biomedical Informatics* 2010. pp 736–746.
- EN13606 Association Board meeting protocol, 2011. Available from: [www.pangea.upv.es/en13606/images/docs/association/MinutesDublin201101.pdf](http://www.pangea.upv.es/en13606/images/docs/association/MinutesDublin201101.pdf).
- Gaithersburg MD. Common industry specification for usability requirements NISTIR 7432. National Institute of Standards and Technology; 2007.
- Peleg M. Sharable Appropriateness Criteria in GLIF3 Using Standards and the Knowledge-Data Ontology Mapper. *Proceedings K4CARE*; 2009. pp 64–75.
- Seffah A, Donyae M, Kline RB, Padda HK. Usability measurement and metrics: A consolidated model. *Software Quality Journal* 2006; 14: 159–178.
- Manhas S, Vashisht R, Sandhu PS, Neeru N. Reusability Evaluation Model for Procedure Based Software Systems. *International Journal of Computer and Electrical Engineering* 2010; 2 (6): 1793–8163.
- Kohl CD, Garde S, Knaup P. Facilitating secondary use of medical data by using openEHR archetypes. *Stud Health Technol Inform*. 2010; 160 (2): 1117–1121.
- Wang TD, Wongsuphasawat K, Plaisant C, Shneiderman B. Extracting Insights from Electronic Health Records: Case Studies, a Visual Analytics Process Model and Design Recommendations. *J Med Syst*. 2011; 35 (5): 1135–1152. Epub 2011 May 4.
- Wongsuphasawat K, Guerra Gómez J, Plaisant C, Wang TD, Taieb-Maimon M, Shneiderman B. LifeFlow: Visualizing an overview of event sequences. In: *Proc of the 29th ACM Int Conf on Human Factors in Comp Syst*. New York; 2011. pp 1747–1756.
- Plaisant P, Rose A. Exploring Lifelines to Visualize Patient records. Poster summary in 1996 American Medical Informatics Association Annual Fall Symposium Oct. 26–30, 1996. AMIA, Bethesda, MD: AMIA; 1996. p 884.
- Plaisant C, Shneiderman B, Mushlin R. An information architecture to support the visualization of personal histories. *Information processing and management* 1998; 34 (5): 581–597.
- Wang TD, Plaisant C, Quinn AJ, Stanchak R, Murphy S, Shneiderman B. Aligning temporal data by sentinel events: discovering patterns in electronic health records. *CHI '08: Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems* 2008. pp 457–466.
- <http://www.healthinfodesign.com/principles.htm> (last accessed 22.06.2011)
- van der Linden H, Talmon J, Tange H, Grimson J, Hasman A. PropeR revisited. *Int J Medical Inform* 2005; 74 (2–4): 235–244.
- van der Linden H, Austin T, Talmon J. Generic screen representations for future-proof systems, is it possible? There is more to a GUI than meets the eye, *Computer methods and programs in biomedicine* 2009; 95: 213–226.
- van der Linden H, Schuler T, Chen R, Talmon J. Generic screen representations for future proof systems--is it possible? Two-model approach to a generic GUI. *Stud Health Technol Inform* 2007; 129 (Pt 2): 1122–1126.
- van der Linden H, Kalra D, Hasman A, Talmon J. Inter-organizational future proof EHR systems. A review of the security and privacy related issues. *Int J Med Inform* 2009; 78 (3): 141–160.
- Atalag K, Yang HY. From openEHR Domain Models to Advanced User Interfaces: A Case Study in Endoscopy. 2010 Health Informatics New Zealand Conference, Wellington, November 2–4, 2010.
- Atalag K, Yang HY, Tempore E, Warren J. Model driven development of clinical information systems using openEHR. *Stud Health Technol Inform* 2011; 169: 849–853.
- Hanzlicek P, Spidlen J, Heroutova H, Nagy M. User interface of MUDR electronic health record. *Int J Med Inform* 2005; 74: 221–227.
- Hanzlicek P, Spidlen J, Nagy. Universal electronic health record MUDR. *MStud Health Technol Inform*. 2004; 105: 190–201.
- Spidlen J, Hanzlicek P, Riha A, Zvárová. Flexible information storage in MUDR(II) EHR. *Int J Med Inform* 2006; 75 (3–4): 201–208.
- Garde S, Hovenga E, Buck J, Knaup P. Expressing Clinical Data Sets with openEHR Archetypes: A Solid Basis for Ubiquitous Computing. *Int J Med Inform* 2007; 76 (S3).
- Beale T. Archetypes: Constraint-based domain models for future-proof information systems. In: *Eleventh OOPSLA Workshop on Behavioral Semantics: Serving the Customer*. Seattle, Washington, USA: Northeastern University; 2002. pp 16–32.
- ASTM E2369, Standard Specification for Continuity of Care Record (CCR)
- Nygren E, Hendriksson P. Reading the medical record 1 and 2. *Computer Methods and Programs in Biomedicine* 1992. pp 1–39.
- Pyper C, Amery J, Watson M, Crook C. Access to Electronic health records in primary care – a survey of patients' views. *Best Paper Selection for: IMIA Yearbook of Medical Informatics 2006: Assessing Information Technologies for Health*. Haux R, Kulikowski C, editors. *Methods Inf Med* 2006; 45 (Suppl 1): 41.
- Ammenwerth E, Schnell-Inderst P, Hørbst A. Patient Empowerment by Electronic Health Records: First Results of a Systematic Review on the Benefit of Patient Portals. In: Stoicu-Tivadar L, Blobel B, Marcun T, Orel A (eds.). *E-health Across Borders without Boundaries. Studies in Health Technology and Informatics Volume 165*. Amsterdam: IOS Press; 2011. pp 63–67.
- Pare G, Jaana M, Sicotte C. Systematic review of home telemonitoring for chronic diseases: the evidence base. *J Am Med Inform Assoc* 2007; 14 (3): 269–277.
- Bird LJ, Goodchild A, Sue H. Describing Electronic Health Records Using XML Schema, XML Asia Pacific 2000, Sydney, Australia.
- Rinner C, Janzek-Hawlat S, Sibinovic S, Duftschmid G. Semantic validation of standard based electronic health record documents with W3C XML Schema. *Methods Inf Med* 2010; 49 (3): 271–280.
- Hansen CD, Johnson C. *Visualization Handbook*. Academic Press; 2004.

49. Aigner W, Miksch S, Schumann S, Tominski C. Visualization of Time-Oriented Data. Human-Computer Interaction Series. Springer; 2011.
50. López DM, Blobel B. Architectural approaches for HL7-based health information systems implementation. *Methods Inf Med* 2010; 49 (2): 196–204. Epub 2010 Mar 8.
51. Hoerbst A, Ammenwerth E. Electronic health records. A systematic review on quality requirements. *Methods Inf Med* 2010; 49 (4): 320–336. Epub 2010 Jul 6.
52. Poissant L, Pereira J, Tamblyn R, Kawasumi Y. The impact of electronic health records on time efficiency of physicians and nurses: a systematic review. *J Am Med Inform Assoc* 2005; 12 (5): 505–516.
53. Bettencourt-Silva J, De La Iglesia B, Donell S, Raymond-Smith V. On Creating a Patient-centric Database from Multiple Hospital Information Systems. *Methods Inf Med* 2011; 50 (5): 210–220.
54. Klimov D, Shahar Y, Taieb-Maimon M. Intelligent interactive visual exploration of temporal associations among multiple time-oriented patient records. *Methods Inf Med*. 2009; 48 (3): 254–262. Epub 2009 Apr 20.
55. McKinlay A, McVittie C, Reiter E, Freer Y, Sykes C, Logie R. Design issues for socially intelligent user interfaces. A discourse analysis of a data-to-text system for summarizing clinical data. *Methods Inf Med* 2010; 49 (4): 379–387. Epub 2009 Dec 21.



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