MEDINFO 2007
K. Kuhn et al. (Eds)
IOS Press, 2007

Graphical Overview and Navigation of Electronic Health Records in a Prototyping Environment Using Google Earth and openEHR Archetypes

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Abstract

This paper describes selected earlier approaches to graphically relating events to each other and to time; some new combinations are also suggested. These are then combined into a unified prototyping environment for visualization and navigation of electronic health records. Google Earth (GE) is used for handling display and interaction of clinical information stored using openEHR data structures and 'archetypes'. The strength of the approach comes from GE's sophisticated handling of detail levels, from coarse overviews to fine-grained details that has been combined with linear, polar and region-based views of clinical events related to time. The system should be easy to learn since all the visualization styles can use the same navigation.

The structured and multifaceted approach to handling time that is possible with archetyped openEHR data lends itself well to visualizing and integration with openEHR components is provided in the environment.

Keywords:

information visualization; overviews; timelines; openEHR archetypes; medical informatics; medical records systems, computerized.

Introduction

Relating events in time plays an important role in getting an overview of a record. This paper first briefly provides an overview to and exemplifies some previous approaches to represent relationships between events and time. It then describes how Google Earth (GE) by simple means can be extended to become a prototyping environment capable of combining and extending the previous visualizations in a unified environment. New combinations and the use of time-lapse animation are also presented.

Currently some elementary script programming and XML authoring skills are needed to create the described visualizations, but we are extending the GE based environment with more tools and examples that will make it even easier to use by non-programmers. We have created Java based components that work 'behind the scenes' to provide easier translation from events in electronic health records (EHRs) to 2- or 3-dimensional space with optional time-based animation capabilities in the GE-based environment. Aggregation and summary functions are also handled by the components. The toolkit has a built in integration with openEHR[1] based data using the archetype approach to modeling, but could be connected to other data sources as well.

Towards end users this approach tries to exploit the ease of use in GE so that the user only needs to learn one way of navigating to use several different kinds of visualizations. Some functions are also provided to ease usability testing of developed visualizations. We are publishing our approach at an early stage, hoping to broaden the research community using it for future stages of further visualization development and usability testing. Color images and demonstrations illustrating the previous approaches and our prototyping environment can be found by looking up references, footnotes and the corresponding author's webpage.

Background

In the research field of Information Visualization, time series data have been of interest a long time. A number of approaches are exemplified below.

Linear time views

Improvements of overview and navigation of EHRs have been reported, e.g. by using graphical timelines, in the often cited LifeLines [1] project. The events visible on the timeline had short labels, and longer labels were revealed by pointing the mouse cursor at the event. The timeline view allowed visual correlation between events and also acted as a 'giant menu' that improved navigation since events could be 'clicked' to get direct access to detailed information in the EHR. Information categories, such as notes, medications, lab tests, were called *facets*[2] and were displayed as horizontal ribbons containing associated events. The user could control which facets should be open (showing events), or closed (showing a compressed 'silhouette' of the contained events without labels). Bade et al [2] explored visual timelines further and describe methods to show alerting qualitative levels in streams of quantitative data in compact ways. They also present methods for showing uncertainty of timepoint and value, trustability of data and periods of missing data. Further they suggest a method for interactive timeline distortion in order to decrease the screen space used by less interesting periods of time. Data from an intensive care unit was used to exemplify their approach and they included methods to compact high frequency data into efficient visual forms.

1 http://www.openehr.org/
2 The term facet will be used in the rest of the paper for information categories etc.

Polar time views

Time can also be represented in polar coordinates. One way is to do as in most 'analog' clocks where time runs clockwise around the circle. This has been explored in tulip plots[3], where different facets are represented as concentric arcs along the time circle. In order to investigate periodic patterns in time-series data, Carlis [3] and others have used spiral timelines where periodical data patterns surface visually if the period for a turn around the spiral corresponds to the periodicity in the data (e.g. yearly cycles of allergy symptoms).

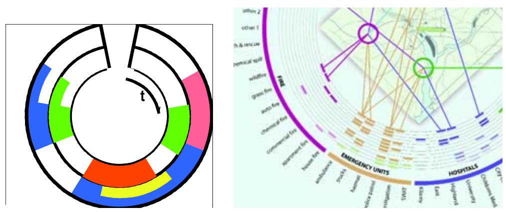

*Figure 1- **a** (left) A tulip plot[3] shows time clockwise and shows facets as concentric arcs. In Figure **b** (right) from [4] Livnat et al. put time radially outward and facets around the circle.*

Livnat et al. [4] use a polar coordinate system in an alternative way by putting the time axis radially outwards and distributing facets around the circle. Many polar representations leave space in the middle in order to avoid clutter. That space can be used to convey additional information. Livnat et al. put maps or network charts in the center and then relate the events around the circle to them using lines.

Time overlaid on maps and images

Kapler & Wright [5] describe a combined temporal and geospatial display, GeoTime, by putting a time (z-)axis perpendicularly upwards from a more or less flat (xy-)map. Events are shown further away from the map surface the further away they are in time. Kapler et al. also describe methods for aggregation of items based on proximity or defined regions.

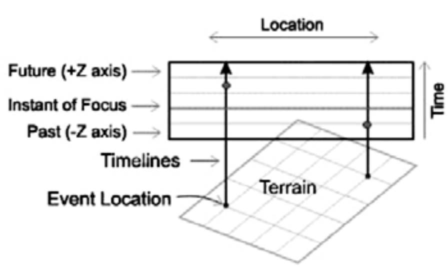

Figure 2 – GeoTime from [5]

Region based data entry

In Clinergy/Pen&Pad[4] [6] maps or charts of the body and organ systems are used as one way to specify parameters for data entry into an EHR. The user can point to coarse or detailed regions on the body charts and zoom in further to more detailed areas. The symptoms etc. available change depending on active region.

Visualization dimensions and variables

In [7] (section 4.3) parameters to use for visualization are summarized by Andrienko as being *dimensional* (referring to position in space and time plus various arrangements of display space) or *retinal* (size, shape, color, texture, orientation etc.) A recommendation is given that referrers of the dataset should be represented by dimensions and that attributes of the referrers should be represented by retinal variables.

Materials and methods

Archetypes

Archetypes are promoted by e.g. the openEHR foundation and the standards body CEN[5] as formalism to support modeling of clinical information structures and improved semantic interoperability between EHR systems. A detailed description of archetypes is outside the scope of this paper, see [8] for details. For the purpose of discussion they can be thought of as design descriptions of limited parts of the information structure in EHRs. Many such parts are then combined into hierarchies that constitute an EHR.

There are different aspects of time in a healthcare setting and for the purpose of recording they need to be treated carefully. The openEHR foundation has developed specifications for EHR systems and the topic of 'time' is extensively discussed in [9].

The information generated (e.g. using several *observation* archetypes) for a care event is collected into a *composition* that can be signed by clinical staff and put under version control. They can be flagged as being either *event compositions* that are intended for recording care events, or *persistent compositions* used for items of long term interest such as medication list, vaccination history, allergies etc. Compositions can contain entries of different kinds referring to events in the past (symptoms started a year ago) present or future (planned actions). In [10] *history* structures for *point events* and *interval events*, (possibly periodic) are defined. Methods for structuring e.g. long timeseries of measurements into compact summarized interval forms are described; this interval approach has some interesting similarities with summary approaches in [2].

3 Inspired by http://www.cas.lancs.ac.uk/alcd/visual/tulip_plots.html that refers to Barry, J.T. et al (1990) Graphical exploration of work history data. *Quad. Statist. Mat. Appl. Sci. Econ Sociali*., **12**, 65-74.

4 A Clinergy demo can be downloaded at http://www.opengalen.org/sources/software.html

5 EN13606, 'EHRcom', see http://www.centc251.org/

Google Earth

Google Earth[6] (GE) is an application that enables navigation of a digital globe with satellite imagery and map data. Developers can add new content in the form of XML files and images that can either be locally loaded into GE as files or published on a web server. If a server is used, then dynamic features such as reporting the current view of the user or updating previously loaded information are available.

Placemarks are icons with an optional text label that can be placed anywhere in a GE map. They can be clamped to the ground or put at an arbitrary height above the ground. When single clicking a placemark, a detailed description in the form of a 'text balloon' containing e.g. HTML-formatted text, possibly including images and hyperlinks, shows up. Double-clicking a placemark can change the 'camera' view of GE to a suitable position stored in the placemark by the placemark author. Hyperlinks in placemark description can be followed to related information that can either be a web page that opens in a built in or external web browser, or another set of GE objects (more images, placemarks etc.) that opens within the main GE navigation view. In this environment, these features can be used to go deeper and deeper into the EHR content. Transitions to the stored camera view in a placemark can be used as an efficient way to zoom in and position the view to a suitable angle that fits the next level of detail used in the EHR visualization.

Results

By placing an arbitrary image to be used as background over a piece of the globe we can hide the map and use that area as a 'desktop' for visualizations unrelated to the original map content. Initial tests show that most of the system features described in the introduction chapter can be reproduced in GE based visualizations. Linear and polar timelines can be added as images or drawn using built in GE geometric objects on top of the desktop.

We have also experimented with placement of notes that have relation to body parts (finding site of a tumor etc.) on organ system charts inspired by Clinergy. The notes are placed as placemarks above the relevant anatomical part in the chart and time is (as in [5]) represented by distance from the map. Just like real objects in a pile, old notes are at the bottom close to the map, and newer information is stacked above. By using the GE feature of region based loading and display of details, controlled by 'level of detail' (LOD) settings, different versions of a visualization piece can be shown depending on how close the user zooms in. If there are many notes in one region, they can be summarized into a single node indicating the number of notes when viewed at a distance, but shown as individual notes when zooming in. This has an effect similar to the region based aggregation discussed by Kapler et al. [5].

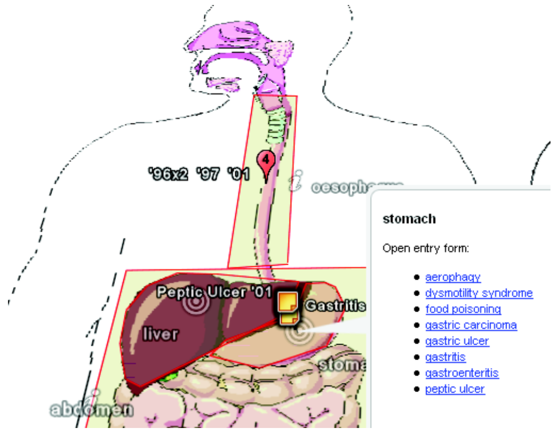

Figure 3 - A screenshot from Google Earth showing a tilted region based visualization in the prototyping environment. The abdomen region has been zoomed in so that subregions are visible. Two previous notes relating to stomach are seen, with the most recent one on top. The oesophagus region is too far away to show subregions and indicates that it contains four previous notes. A stomach related entry form selector has been opened by clicking the stomach 'target'.

Since it is possible to open web pages within GE, placemarks or information about current view can be used to select and open web based entry forms. This allows us to facilitate display and 'Clinergy-style input' in the same view. The usability of this combination remains to be tested. Maybe it is better to switch between dedicated viewing mode and a dedicated entry mode. Two-dimensional data like X-ray images or ECG plots are easy to show directly in GE. By using LOD, images with higher resolution can be fetched incrementally and shown when zooming closer to a low resolution thumbnail image.

If recent time is of most interest, then logarithmic time scaling can be used both for linear and polar diagrams. Related effects can also be achieved by simply tilting the view in GE when looking from recent time backwards. We have not yet attempted to develop ways to distort several different regions of a timeline simultaneously as in [2]. It would be interesting to compare this to the usability and understandability of regular GE-based navigation. Separate parallel timelines can be used for documentation events (versions of compositions) and clinical event timing (e.g. observations) if visual separation is desired. Important information (Patient ID, allergy warnings etc.) can be shown e.g. in a corner by using 'screen overlays' that are fixed to the screen and not to the map surface.

Facets and aggregation

How to section categories of information into facets like LifeLines [1] did with medications, lab tests etc. is an interesting research problem. In a (potentially) highly structured EHR e.g. based on archetypes we see these fairly simple computable divisions, based on:

6 http://earth.google.com/

- archetypes used, based on groups manually listed when creating the visualization, or by archetype class (observation, evaluation, instruction etc.) or external ontologies and systems [11] for classifying archetypes.
- openEHRs ‘folder’ structure that e.g. can be used for linking entries to health problems, care episodes etc.
- terminology system entities used in EHR entries e.g. ICD diagnosis codes or codes from SNOMED CT’s main categories and/or grouping according to the target of relationships like ‘finding site’.
- provider of the entry (organization, role or profession, person).

Aggregation that is needed e.g. in zoomed out views can be based on facets and/or time. In some cases (e.g. in the openEHR class ‘History’) some events may already have been manually summarized at the time of data entry and this could of course be used. Another obvious aggregation is over ‘natural’ time chunks like ‘the number of entries per year’. In region based visualizations (body part maps etc.) geo-located aggregation based of the containment hierarchy of regions can be used. Better suited facets and aggregation can potentially be generated by decision rules and automated reasoning taking the above mentioned aspects and the current role and task of the user into account.

Time as a fourth dimension

In GE (from version 4) time is available as a fourth dimension. Objects (placemarks etc.) can be given time spans for validity. A time axis with sliders allows the user to select time span restrictions of what should be visible. By pressing the ‘play button’ the sliders can also be moved automatically which results in a time-lapse animation of changes over time. One way this can be used is to easily view previous states of the EHR in order to see how the medical picture grows over time. We want to explore if and how this can be used efficiently. We believe that a time-based view e.g. for the body/organ-system map where you can see information about problems etc. appearing (and possibly disappearing) over time may serve as a complement to using the z-axis to represent time. For medico-legal purposes it may also be useful to easily browse earlier states of the record. Clinicians will hopefully use the toolkit to find many other creative views and usages for time animations of EHR data – perhaps for studying the progress rate of diabetes complications etc. Users’ changes of ‘camera view’ can be time-stamped and recorded. This information can be used e.g. in usability studies to record where most time has been spent etc. Time-lapse replay of frames showing the view trail in different ways is possible. Another possible use of recording can be to highlight for users which views in an EHR that have been most visited by other users—analogous to which pages of large paper based record that carry signs of frequent reading. Recording of view trails can also be used for medico-legal logging purposes.

Intended use

We do not expect that clinicians will use the toolkit in every day use; rather it can be used by them and others as a prototyping tool to invent and explore designs that can be used as parts of descriptions when ordering more polished and specialized systems from system providers.

Existing clinical images, either literally used (e.g. growth curves and partographs/partograms) or conceptually used (e.g. care-flows) can be used as a basis for fast prototyping of overviews provided that they can be captured as images.

We are aiming at decreasing the programming knowledge required to create visualizations. A user will be able to use GUI features to select the kind of visualization they want, e.g. linear, polar, region based (Clinergy inspired) and which axis to use for what (time, facets etc.), start and end points, width/radius etc. Connecting to openEHR data sources and selecting what data to fetch currently requires some scripting[7], but we are investigating the possibilities to select nodes using our Archetype Editor [12] or archetype visualization and browsing tools. A use case scenario could be as follows.

An overview based on a sketch of a tree of significant blood vessels and a linear timeline diagram for lab values is sketched on a whiteboard during a meeting. It is then captured by camera and the pictures are transferred into the GE based environment and anchored to the desktop on the map next to some previously developed overviews. Hierarchical regions containing each other are drawn and named on the ‘vessel tree’ and then mapped to entities in the archetype or terminology used in the EHR. For the lab result timeline the start- and endpoints on the time (x-)axis are marked in the image. Then the different lab value fields are mapped to positions for intervals and marked on the facet (y-)axis forming (possibly overlapping) ribbons along the diagram. Finally, color, icons, aggregation and summary strategies for the lab value plots are chosen.

Discussion

The technical solutions behind these extensions for GE are not very complex[8], instead it is more the possibilities for rapid development and evaluation that are of interest. Will the solutions be easy and efficient enough to be used by clinicians? If so, how will that affect the future development of interaction with EHR data? Will more efficient overviews and interaction possibilities be put into real clinical every-day use and would that have an impact on medical practice? Early feedback from clinicians and medical informaticians that have seen the current prototyping system has been positive and has resulted in comments like: “It opens up some new ways of thinking”, “This would be nice when seeing new patients in primary care, but less useful for patents I already know well.”, “[It] can change your cognitive level of interaction with the information” and “Information that is subtle or hidden beneath the surface might be found easier”.

Future work

The prototyping environment presented in this paper is a prerequisite for planned user studies. Usability aspects of the visualization creation process will be one of the first

7 http://freemarker.sourceforge.net/

8 The approach can easily be reproduced by others. We intend to release a version of our solution as Open Source.

aspects to evaluate. Another aspect to study is the usability for end users of different created visualizations.

This paper focused on the ‘dimensional’ aspects of visualization – where to place information entities. How to create concise and efficient text labels has not been focused, neither have the ‘retinal’ parameters [7] (color, shape etc.). Systematic selection and use of icons and pictograms has not been the focus of our studies yet. Adding a structured approach to icon use along the lines of VCM by Lamy et al. [13] looks promising.

Our focus has been on viewing EHRs of individual patients one at a time, but the visualization principles would be applicable to studies of groups of patients as well.

The normal use of GE is to relate information to geographic positions, here we have not discussed this, but future work could include relating entry and retrieval of EHR content related to positions. In, e.g., ambulatory or distributed care EHR content and maps could be accessed in the same environment. We have started a location related experiment by using a map of a hospital ward as background image in GE and then placed the EHR visualizations for patients in their respective rooms.

If visualizations in GE are flat and the tilt function is not used, then the environment essentially becomes a zoomable 2D interface. Even though 3D visualizations often are more appealing Chen [14] (section 6.6) summarizes several 2D vs. 3D studies and concludes that increasing an interface from 2D to 3D is unlikely to improve the users task performance ‘unless additional functions are provided so that users can have greater controls of objects in 3D interfaces’. Hence comparative studies of visualizations dependent on 2D and 3D respectively should be preformed. We believe that access to ‘multi touch’[9] interfaces or hardware[10] dedicated to 3D interaction can affect user performance in 3D.

Conclusion

The capability and usability of geographical information systems of today like GE combined with the push for more structured and semantically well defined EHRs can in combination be used to create a powerful environment for prototyping overviews and interaction style for EHR systems.

We have summarized and unified approaches that may be used to create visualizations of temporal, casual and possibly anatomical relationship between events.

Acknowledgments

This work was performed in the framework of the EU-funded Network of Excellence entitled Semantic Interoperability and Data Mining in Medicine (SemanticMining). We want to thank SemanticMining network members, the OpenEHR community and Isabella Scandurra (Centre for eHealth, Uppsala University) for feedback during our work, Ocean Informatics for providing test data from their EHR Bank and the authors of [4] and [5] for permission to reuse illustrations.

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erisu@imt.liu.se,
http://www.imt.liu.se/~erisu/ (demo & images available)

9 E.g. http://cs.nyu.edu/~jhan/ftirtouch/

10 E.g. SpaceNavigator by http://www.3dconnexion.com/

11 Web links to references available at http://www.imt.liu.se/~erisu/