A DESIGN PROCESS FOR GENERATING VISUALIZATIONS OF HEALTHCARE DATA IN EMERGENCY MEDICAL SERVICES

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Abstract: Visualization of health reports of patients' and their condition during golden hours is vital in emergency medical services. Present mobile technologies enable real-time data capturing by paramedics in ambulance and data visualization for analysis by team of doctors and nurses in hospital to deliver further treatment. Yet, difficulties in manual data model and existing mobile device constraints restricts following trivial porting approach in desktop computers, makes designing mobile visualizations a challenging task. This task requires considerable research effort to better understand how to design effective visualizations for manual data models used in mobile healthcare applications. In this paper, we present a study on different visualizing techniques in mobile context and propose a method for generating data visualization in healthcare systems. First, we discuss visualization techniques used in mobile systems and the challenges in designing visualization for mobile applications. Next, we present a visualization generation method using manual data model and steps in designing mobile data visualizations. We conclude by discussing how we can engineer effective visualizations based on manual data model that could benefit emergency healthcare services to deliver better care.

Keywords: Mobile Technology, Data Model, Visualization, Emergency Medical Service, Device Constraints

I. INTRODUCTION

While attending an emergency call, paramedics in an ambulance capture healthcare data to generate an ambulance call report (ACR), which provides information on patients' health condition. This report is vital and stored as a medical record in health record of the patient. Most of the emergency medical services (EMS) department follows manual data entry model for ACR generation and submission. Availability of electronic ACRs (e-ACR) on time for doctors in hospital will improve care services; however, still in most hospitals, emergency healthcare treatments depend on manual diagnosis [1]. There is a risk that critical medical errors may occur as a result of unknown information. Today, apart from manual conception, mobile devices are used in emergency healthcare environment for capturing vital data and sharing information on patients' condition, with other healthcare professionals for analysis and further treatment [2][3]. Here, visualizations play a vital role in facilitating data analysis.

Generating effective visualizations are challenged by liabilities in manual data collection and constraints in mobile devices that restricts common trivial porting approach followed in desktop computers. These restrictions demand considerable research effort in design methodology for generating effective visualizations. Though significant techniques have been proposed by researchers working in data visualization and visual analytics projects [4-7], limited work has been published so far on mobile data visualizations for EMS.

In this paper, we first present various visualization techniques used in mobile healthcare systems, followed by issues in manual data model and constraints in designing mobile data visualizations. Then we discuss the design process for generating visualizations, followed by steps in mobile visualization designing mobile systems. Proposed visualization designs apply interactive techniques such as touch and gestures supported by mobile devices such as smart phones and tablets. Finally, we conclude by discussing possibilities of engineering effective visualizations based on manual data model that could benefit EMS to deliver better care.

II. BACKGROUND

Healthcare data visualization is a rapidly expanding area of research. This is due to dramatic increase in volume and quantity of datasets that need to be analyzed for information retrieval on critical health conditions [8,9]. The first data visualization using medical data was designed in 1858, when Florence Nightingale used a polar-area diagram (also called a coxcomb chart) to demonstrate the relationship between sanitary conditions and soldiers' deaths compared to death from battle- field wounds. After this development, standardized charts and graphs have been used by several scholars, to generate visuals using specific types of healthcare data to quickly determine the need for appropriate interventions. Visual representations include, graphing vital signs data to quickly identify a rise or fall in physiological data, indicating the need for an intervention and Fishbone diagrams for laboratory results.

In general, visualizations are classified into six main categories [10]: i) **Data visualization** represent quantitative data with or without axes in schematic or diagrammatic forms using designs like text reports, tables, line chart, pie chart, histogram, and scatter plot ii) **Information visualization** is used in interactive interface to increase cognition or perception ability. This visualization transform data into manipulative images, through which users can interact, using data

map, tree map, clustering, semantic network, time line, and venn/ euler diagram. iii) **Concept visualization** are for viewing elaborate ideas, plan, and concepts based on mindmap, layer chart, concentric circle, decision tree, and pert chart. iv) **Strategic visualization** is a systematic approach for representing strategies of development, formulation, communication, implementation, and its analysis. Visual designs include organizational chart, strategy map, failure tree, and portfolio diagram. v) **Metaphor visualization** convey insight of information through graphics based on key characteristics of metaphor like metro map, story template, funnel that is employed. vi) **Compound visualization** is the complementary use of different graphic representation formats in one single schema or frame like in cartoon, rich picture, knowledge map, and learning map [11].

Irrespective of visualization methods, different set of scales, shapes, and colors have been used with both small and large datasets rendered as visual diagrams to reveal patterns leading to knowledge discovery. Recent work at the IBM Thomas J. Watson Research Center has focused on a rule-based visualization tool which considers how a user perceives visual features like hue, luminance, height, and so on [12, 13].

Shneiderman's quote of "Overview first, zoom and filter, details-on-demand" [14] states the design philosophy of data visualization systems, including widely used commercial tools such as Spotfire (2D/3D scatterplots)[5], Eureka (tables with fisheye views and value bars, Inxight Table Lens)[6], and InfoZoom (tabular zooming and overview browser)[7]. These systems provide broad overviews of data sets, support selection and examination of individual data, and provide facilities for dynamic query. Starting with graphical and tabular constructs, visualizations are integrated in mobile systems such as: Lifelines[1] for visualizing patient records (figure 1(a)), UbiFit[2] to monitor physical activity in everyday life (figure 1(b)), AllScripts[3] for ambulatory EHR visualization (figure 1(c)) and Withings[4] app to manage medication regimes and improve adherence (figure 1(d)).

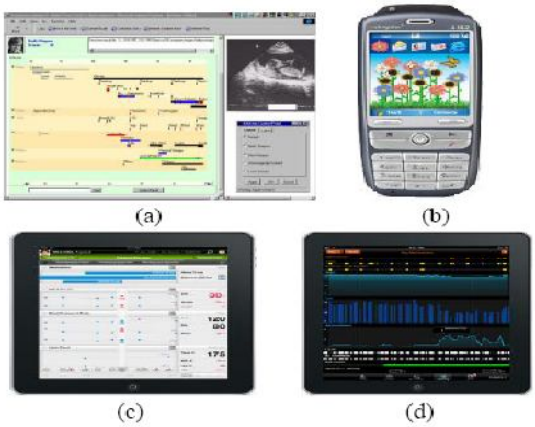


Figure 1: Visualizations in healthcare systems that followed domain-specific development approach: a) Lifelines, b) UbiFit, c) AllScripts, and d) Withings Personal Caregiver

Visual representation of medical data and adaptive interaction technologies enables healthcare professionals analyze their data, see and understand large volumes of information at once. To facilitate instant data analysis, mobile systems are built on human mind's ability to understand complex information visually. This paper focus on method of designing effective data visualizations for vital data analysis and represent it in meaningful form, which is easy to understand and interpret in critical healthcare environment.

III. CHALLENGES

The most important concept to consider when designing mobile visualizations is "context". Two key design issues to consider here are: i) context in which an application is used and ii) how information is visualized by users. Today, though mobile devices support on-the-fly and multi-modal data collection, touch screen interaction, rich visual displays and social media network – they also present their own design challenges. A typical method of designing visualizations for a dataset involves mapping data attributes to visual features (e.g., shape, size, spatial location, and orientation). Existing data system visuals designed for desktop computers are dysfunctional in latest mobile devices. The commonality between desktop and mobile system design is placing the user 5 in the center. Traditional design rules and approaches are not sufficient any more to meet out present and future requirements and user demands.

Manual Data Model

In this modern technological era, still the ACRs are manually prepared in many EMS ambulatory service departments. The ACR is an essential medical record for receiving hospitals to know about patient assessment findings, treatments provided and responses to treatments [15]. Following are constraints related to data capturing in emergency healthcare environment:

- In ambulance, paramedics pay less attention to data capturing and focus more on demanding treatment activities. Though essential, recording every data is time-consuming and tricky. This results in missing and wrong data entry in records.
- Paramedics have less cognitive resources for recording all vital data without mistakes and misinterpretation. They scribble on sticky notes and labels pasted on their arms and legs in emergency.
- In hospital, doctors need to be able to analyse current condition of the patient to decide treatment schedule in due course. To access data and retrieve required information in real-time is as such impossible.

Constraints related to limited cognitive resources and privacy and security issues insist use of effective design approach for generating mobile visualizations. The design approach need to focus on information at-a-glance that is easily understood with less cognitive resources and causes less distraction from primary care services

Mobile device constraints

Visualizing information on mobile devices has many constraints than traditional visualization [16]. In this section, we discuss the constraints taken into account while designing mobile visualizations for treatment provided and conditions. Mobile devices are characterized by following constraints:

- Limited displays due to small screen size, low resolution, and reduced color sets. Height/width ratio differs from normal 4:5 display ratio.
- Inadequate input peripherals restrict using traditional input methods like keyboard and mouse. Instead, input modes such as touch, pattern recognition, and sketch are available.
- Low computing power causes slow visualization.
- Lack of powerful, high-level graphics libraries.
- Signal loss and network interference issues slow down data retrieval process.
- Variability in mobile devices available in market demands redesigning of applications.

Due to these constraints, traditional visualization techniques such as graphs, bar charts, timelines and radial plots do not scale well on mobile devices. Tactlessly, some of these constraints will remain for a while and has to be addressed in design methodology.

IV. DESIGN PROCESS

Recently, researchers have introduced different methods, models, and guidelines for designing visualization. Simon *et al* [17] suggested the importance of user interactions in the visual analysis process. Munzner *et al* [18] divided the visualization design into four layers: domain problem characterization, data/operation abstraction design, encoding/interaction technique design, and algorithm design. Sedlmair *et al* [19] introduced a methodology with nine stages (learn, winnow, cast, discover, design, implement, deploy, reflect, and write) for conducting an effective design study. Lam *et al* [20] derived seven evaluation scenarios in visual analytics that provides useful guidance for designing an effective evaluation procedure. An interaction model called *semantic interaction* [21] allows users to interact with high-dimensional data in a two-dimensional (2D) view, in which the distances between data items in the view represent similarity between them. In a previous work, we proposed a five-point design approach (figure 2) to design visualizations for a healthcare system [22].

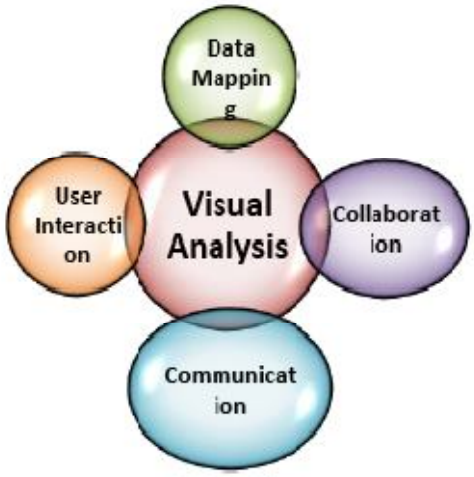


Figure 2: A five-point design approach

In this work, a well-defined common design approach [14][23] (shown in figure 3) is tested in generating visualizations for EMS system that generates electronic ACRs as required and shared with hospital doctors. This approach addresses above discussed constraints appropriately in each step of the design process. Using undefined approaches often result in typical errors, such as: impressive graphics that are unreadable or difficult to understand, getting lost in navigating the graphical space in a small screen, and intuitive graphics that provides misleading information.

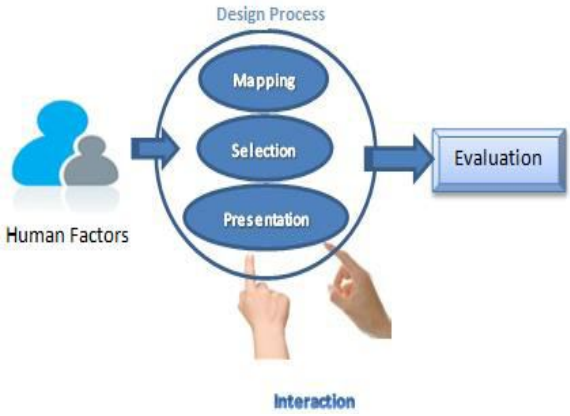


Figure 3: Steps in the design process

graphics that characterizes various visual features like shapes, colors, lengths, positions, animations, etc. Three main steps to be followed are:

i) *Mapping* is the process of connecting data objects and visual objects in an application by establishing relationships. The relationships need to be defined and followed consistently throughout the system.

ii) *Selection* is a filtering process that determines dataset to be analyzed for visualization. Using small datasets provides visualizations with information that might result in suboptimal or wrong decisions; using large datasets generates visualizations with unnecessary information that confuses users. Hence, it is essential to select appropriate datasets.

iii) *Presentation* is the process of generating visualizations for clear display as per screen size of operating mobile devices. Visualizations should not be too crowded with information nor expanded so that users need to navigate through the graphic space to retrieve information.

Following above steps, a high-level *interaction design* on visualizations for information retrieval and H*uman factors* such as perception and cognition are considered. The generated visualizations must be quickly browsed by human eyes and easily interpreted by users. To confirm this result, *evaluation* tests should be conducted using HCI practices. Mobile visualizations are tested with additional metrics such as distractions and clarity of displays.

V. THE SCENARIO

In this section, first, a work flow scenario in EMS environment from early research projects is presented [24][25]. Next, the design approach discussed in section 4 of this paper is applied for the scenario to investigate suitable mobile visualizations that would benefit healthcare professionals and EMS. The datasets used to generate visualizations in this section are test data obtained from the scenario presented here.

a) The Scenario

Medical emergency arises at anytime, anywhere, and for anyone. Irrespective of cause of an emergency, patient needs immediate attention and treatment to survive. In case of accidents or major health problem, attenders of the patient make a call for an ambulance in EMS department, to shift the patient to nearby hospital for treatment. In ambulance, patients receive primary medical service from paramedics, who work along with doctors in emergency care unit of the hospital. Depending upon the health condition, a paramedic monitor and provide treatment to a patient until hospital is reached. An e-ACR is prepared and transferred to the hospital data server by the paramedic in transit. At hospital, a patient receives treatment from one or more professionals for health recovery. Healthcare professionals involved in the task works collaboratively until the patient condition is stabilized. Figure 4 presents an entity- relationship existing in this scenario.



Figure 4: An entity-relationship model of this scenario

In this scenario, the paramedic uses a 7" tablet to capture health data – both formal and informal – in different formats like text, image, audio and video. These data are transferred and stored in a data server initially; an e-ACR is generated and stored in the electronic health record (EHR) of the patient. First, this report is shared with EMS team for discussion.

Based on requirement, it is shared further with other healthcare providers for feedback. This information sharing includes visualizations generated from datasets transmitted from the ambulance. These visualizations are service-oriented and displays condition information.

b) Design process

Visualizations of the scenario are generated using the steps of design approach presented in section 4.

1. Mapping Process: Three main classification of dataset prevails in this scenario:

a) Call History: This dataset includes call details, ambulatory service, vehicle and paramedics details.

b) Patient assessment: This dataset contains patient demographics, medical history and Medication details.

c) Treatment: This dataset captures treatment details, vital signs, medications, and other observations.

As first step, a database is structured to store all type of data objects in a Microsoft SQL database server. The data objects are classified based on data types and stored as tables. In general, five classes of data are analyzed for mobile visualizations. They are: text, image, maps, physical objects, and abstract data. A table consists of data objects related to an entity and its elements in the scenario. For example, Treatment is an entity and its elements include professional-id, patient-id, treatment description and incident-date. For above scenario, nine tables are created. A unique identifier of a table is marked as primary key and primary keys of other tables are marked as secondary key. Relationships between data objects are mapped between primary keys and secondary keys of tables as shown in figure 5. Similarly, relationship between visual objects in interface design and data objects are mapped using its properties. Thus, accurate and quick data retrievals from databases are achieved for generating visualization.

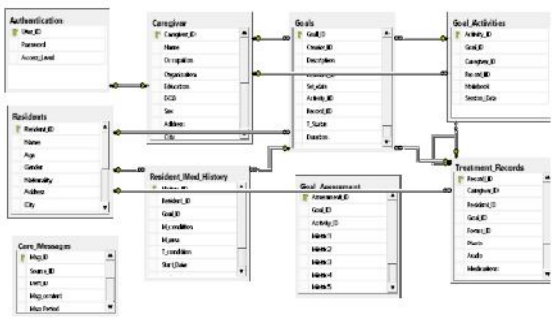


Figure 5: Mapping process for data visualization

2. Selection Process: In this step, datasets required to generate visualization is selected. For each treatment,

the service provided by a professional is recorded as a session. Each treatment has multiple sessions and at end of each session, healthcare professional generates a report on condition of the patient. These reports are collected in patients' EHR for future treatment. An algorithm for selection of dataset using report scheme is presented below.

i *Create an empty directed graph G = {V, E}*
ii *Create a 5_h random initial solutions (V set)*
iii *Create the hierarchical polling set P using V*
iv *Present polls in P for reporting and update reports in E*
v *Calculate the recovery in patients using fitness function f(v), where v ε V*
vi *Estimate overall recovery in patients, r(v) by sorting the vertex v by f(v)*

Here G represents overall condition, V is treatment session metric used for measuring G over time, E is the number of received reports, and P is the poll for reporting on each treatment session. Summarization of data is performed by synthetic surrogate fitness function. Optimizing this synthetic fitness function would provide educated guesses of user preferences. The optimized datasets are used for generating visualization.

3. Presentation

With selective and easy to access datasets, the challenge is to create effective and supportive visualization that are appropriate to the query, the emergency incident and the user. Depending upon the dataset, discrete data types are visually encoded in different dimensions for improving cognitive calculations, memory, and decision making. Effective designs widely used for visual data encoding include trends, comparisons, correlations, maps, networks, hierarchies, text reports, and multi-dimensional data diagrams. These designs are generated with different graphical elements (size, shape, colour, dimension, etc.,) to meet the requirement.

Along with encoded diagrams, designs for mobile data visualization are enhanced with interactive techniques like touch, gesture, motion, and media. These visualizations are developed using high resolution graphic libraries for clear and intuitive screen displays. In this step, two-dimensional visualizations are generated for information delivery like present condition of a patient, healthcare professionals attending a patient, treatments provided to a patient, reports on treatments, and patient condition over a period of time. The outcome of this step is investigated in following section and result is presented in conclusion.

By refining visual representations and exploiting interactions, it is possible for users to learn about the mapping of data objects and visual objects. With appropriate use of interactive technique and cognition resources, users can interactively play in graphic spaces, visually perceive query results and observe real-time changes in data by watching change in color areas. Limitations and problems arise mostly in selection and presentation process. These problems can be solved using appropriate selection algorithms and by refining presentations using intuitive design approach or visual reference approach.

VI. INVESTIGATION

In this section, we investigate the efficiency of data visualization in emergency healthcare context. Two main classifications of visualizations are investigated here:

- *Formal data visualization:* This visualization uses datasets extracted from e-ACR. They are systematic and structured data captured periodically by paramedics during treatments. This data will be of type: text and/or images; by analysing text or images or both datasets, visualization is generated to display information on treatment provided by paramedics. These visualizations are often in structured report format with text and/or image content. Figure 5 shows designs proposed for formal data visualization.



Figure 5: Formal data mobile visualizations

Visualizing text on mobile devices is restricted because of the small screen size. This restriction allows only few lines of text to be displayed as shown in figure 5, which affects the readability and causes issues in other important tasks such as browsing websites, reading ebooks, and selecting long menus. This is presentation problem arises mainly in static text; whereas in dynamic text this problem does not occur due to limited text data. Hence, it is appropriate to use dynamic data for formal visualizations of patients' condition.

- *Informal data visualization:* The data types used mostly for informal visualization are: images and abstract data as shown in figure 4. Image data occupy significant memory space for loading and processing; thus reduces computing speed. Visualization of images on mobile devices requires techniques that reduce scrolling and zooming operations. Images of photographs works well in mobile visualizations rather than images copied from websites and documents.

Informal visualizations mostly contain automatically generated images as a result of analytical processing of selected datasets. In emergency healthcare system, informal visualization contains both auto-images and photos. Figure 4 shows two mobile visualization designs.



Figure 4: Presentation of visualizations for a) condition of patients and b) reports submitted during treatments

In proposed visualizations, temporal abstract data is used for visualization of formal and informal data periodically. Extemporal abstract data is used for brief content such as appointments in calendar and reading of medication measures. These data enables precise data visualizations that allow development of useful, intuitive and productive mobile healthcare applications. In this section, we discussed about mobile visualizations, device constraints and need for design approach to generate mobile visualizations

CONCLUSION

This work was conducted to determine the efficient use of data visualization for emergency healthcare data, what steps to be in design process for mobile context, and what research has taught us to date. Although there is increasing interest in visualization of electronic healthcare data, few techniques have been found to effective and efficient to display large and complex data in EHRs. The new buzzword in healthcare is 'big data', often used in conjunction with data analysis. Most studies have found that visualization of healthcare data requires techniques that will handle not only 'big data', but the temporal complexity of constantly changing variables found within health data. Disciplines such as computer science, engineering, and genetics have developed visualizations to improve presentation, analysis, and understanding of data. The healthcare provider community has not yet taken advantage of these methods or significantly explored the use of new visualization techniques to accelerate the use and understanding of healthcare data. We have identified important findings reported in the literature that can help guide future research needed to explore, refine, and retest visualization techniques. Only then will stakeholders begin to take advantage of the wealth of knowledge within EHR data.

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