Improving Usability through Enhanced Visualization in Healthcare

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Approval

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Dedication

I dedicate my work to my parents and family who encouraged and supported me in every aspect of life. Also to my wife who is continuous source of motivation.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

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I would like to take this opportunity to express my gratitude to my supervisor Dr. Hamid Mukhtar and members of advisory committee for valuable guidance during this tenure.

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Table of Contents

List of Figures

List of Tables

Abstract

Data visualization has gained significant importance since the demand for software applications providing abstract view and pattern identification has increased. To meet the demand, a number of data visualization techniques and best practices have been proposed as well as adopted in many disciplines. However, data visualization is not as advanced in healthcare software applications as compared to other scientific fields. This results into limited support provided to the healthcare practitioners by software applications. Moreover, poor usability of healthcare applications is another major hurdle in adoption of electronic healthcare systems rather than traditional paper based methods. This thesis is an effort to develop a usable Electronic Health Record (EHR) system (for Obstetrics), integrating different data visualization techniques. The implemented system has been evaluated using standard usability evaluation methods. The evaluation indicates that using appropriate data visualization techniques in healthcare systems results in enhanced usability. Furthermore, the results also prove that better data visualization helps in improved quality of care in healthcare information systems.

Chapter 1

Introduction and Motivation

This chapter describes the basic concepts involved in this research. The contents of this chapter can be summarized as: background and motivation for this study, hypothesis, expected results and methodology to get and evaluate the results. Finally, it presents the structure of this thesis document.

1.1 Introduction

Data visualization is not a relatively new topic. Although data visualization gained boost in 1980's due to the availability of computers but its roots can be tracked well before. Recently several visualization techniques have been proposed and adopted to view large amount of data as demand of software providing abstract view of data and identifying trends is increased.

The work presented in this thesis proposed different ways to effectively visualize the patient progress to improve the quality of care. Visualization techniques included in this thesis are general and easy to understand for end users that are discussed in later section of this document.

1.2 Motivation

With advancement in information technologies complex data is generated at unexpected rate. To effectively visualize complex and multidimensional data visual analytics techniques are adopted. However, visualization in healthcare is not as advanced as compared to other scientific disciplines.

Maternal Mortality rate is very high in developing countries. Very high patient rates and low rates of available skilled resources are among fundamental causes. Insufficient availability of temporal history of mother and child is also another major cause. As patient history is maintained for almost nine months during pregnancy period causing problem for physician to analyze patient health conditions. Any missing information may result in loss of mother or child life.

1.3 Hypothesis

Hypothesis for this thesis work is described below:

- Usability of healthcare software can be increased by improving visualization
- Better visualization of obstetric patient's clinical data can support in decision making

So null hypothesis for this thesis work can be formulated as:

- Usability of healthcare software can not be increased by improving visualization
- Better visualizations of obstetric patient's clinical data do not support in decision making

1.4 Expected Results

The objective of this work is to improve the usability of healthcare applications using visualization techniques. It will be easier for physician to adopt our proposed system. Our system will also help the physician to view the patient consolidated information. Hence, increasing their efficiency and helping in making decisions.

1.5 Methodology

An obstetrical electronic health record system was developed to evaluate the hypothesis. This system has the capability to handle real patients clinical information so that the performance of proposed system can be evaluated in real scenarios.

1.6 Structure

Initially an intense literature survey is presented to discuss the concept of usability and visualization. Usability section comprises of: usability definition provided by different standards and its attributes and evaluation techniques for software usability. In visualization section we discussed: visualization definition and its attributes, categories of visualization, stages of visualization, and visualization in healthcare. In next chapter we present our proposed system and details of its components. In the later sections, we present the evaluation results of our proposed system and areas for future research.

Chapter 2

Literature Survey

This chapter presents a survey of literature work related to usability and visualization. It will help in understanding the insight of these topics and exploring the important perspectives in software applications. Moreover, it will also helps in refining the research problem by effectively analyzing the state of the art work that has been already done.

This chapter can be divided into two major parts: usability and visualization. In usability section focus is on presenting an overview of usability by defining usability and methods to evaluate software usability. Second, the literature survey provides an overview of visualization by defining data visualization, why data visualization is important, categories of data visualization, stages involved to collect and visually represent the data, and lastly role of visualization in healthcare is discussed.

2.1 Defining Usability

Usability can be defined as the ease to complete a particular task. Number of ISO standards have defined usability, however, ISO 9241-11 definition is considered as standard which is as follows:

> "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." [3]

- Effectiveness: Degree of completeness to achieve a specific goal
- Efficiency: How accurately resources have been used to achieve specific goal

- Satisfaction: Degree of acceptance of product to user
- Context of Use: Environment including physical and equipment in which user is using the product

Jakob Nielsen defines usability as a quality attribute which includes five components [4]

1. Learnability: What is the level of ease for users to perform basic tasks during their first encounter with design?
2. Efficiency: How quickly tasks are performed by the user after learning the design?
3. Memorability: What is level of effort to regain proficiency in performing after a period of not using it?
4. Errors: Number of errors made by user, level of severity of these errors, and level of ease to recover from these errors?
5. Satisfaction: Was it a pleasant experience for users to use the design?

In software engineering IEEE standards are considered as substantial like ISO. IEEE standard 1061 defines usability as:

> "Usability is the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component." [5]

Usability has been defined by several standards that have similarities and differences with one another. However, most of them include usability in quality attributes of software application. Usability components include: utility, simplicity, safety, accessibility, and few others. These components are inter dependent and should be prioritized according to nature of software application being developed.

2.2 Evaluating Software Usability

Evaluation techniques play vital role in determining the usability of software application. The evaluation techniques extracted from literature [6] [7] can be divided into three major types that are: inspection, testing, and inquiry.

2.2.1 Usability Inspection

In usability inspection developed application in inspected by professional experts to evaluate the degree of usability. These professional can be categorized as usability engineers, software engineers, or software quality assurance engineers. Usability inspection methods are briefly explained below:

Cognitive Walkthrough: Evaluators explore the set of actions performed to complete the specific task in cognitive walkthrough technique. Ease of use and effectiveness of these actions is evaluated. Working prototypes can be evaluated using this technique. Hence, it can be performed during design phase, reducing the time and effort in implementation phase. This method does not provide quantitative data regarding effectiveness.

Feature Inspection: This approach uses feature inspection as a way to analyze the software application usability. Use cases of application are used by the evaluators to evaluate the understandability, organization, and accessibility of features without any nominal problems. Quantitative assessment is not possible in this method as well.

Heuristic evaluation: In heuristic evaluation method, evaluators use set of defined usability principles to evaluate the usability of the software application. This is the most commonly used usability inspection methodology. There have been many usability evaluation heuristics presented by groups and individuals, but Jackob Nelson's set of heuristics [8] are mostly used and considered as most effective. These heuristics can be summarized as:

- User should be informed about the change in the state or status of the system
- System should be more compatible to real word terminologies and familiar languages should be used instead of computer language.
- In case of any mistake user should be able to correct that mistake by undo or redo.
- System should be consistent by following similar behavior throughout the application.
- System should be error prone to user inputs by applying validation checks on the data.

- Memory load efforts of the user should reduced by providing recognition rather than recall.
- Short cuts to complete the actions should be provided to make the system flexible and efficient.
- A space efficient design should be produced by removing the irrelevant information.
- Help user to identify, understand, and correcting the errors by showing meaningful messages.
- Wherever required, help documents should be created and conveyed to the user.

2.2.2 Usability Testing

In usability testing, set of task or procedure are defined and user use the system or prototypes to complete those specific tasks. End results of system usage are assessed by the evaluators to identify the aid provided by system to user in accomplishing the tasks. Approaches followed to carry usability testing are mentioned below:

Coaching Method: In this approach user used the system under the supervision of system or domain expert. Expert answers the user's question regarding usage of application. This approach is used to measure the guidance or help required to use specific software application. Software application is can not be categorized as usable if higher number of questions are asked by the user.

Performance Measurement: This is the most appropriate approach to provide quantitative measurement. Quantitative data of both application capability and user ability can be measured. In this testing technique application is used by the user and on the basis of usage certain data is collected to depict the conclusions. Measurements taken by the tester during system usage can be described as:

- Time considered to complete specific task
- Number of errors produced during the system usage
- Time taken to correct those errors

- Usage of available features in the system

Measurement of these values directly proportional the skill level of participants. Participant with higher skill level can help in concluding better results.

Question-Asking Protocol: In question-asking protocol, tester ask questions to user while using the software application. For example type of question can be , “ Way to log out from the system?” This helps in identifying whether user know how to perform task or not.

2.2.3 Usability Inquiry

In usability inquiry, usage experience is inquired from the user to explore their satisfaction and problems related to usability faced during interaction with system. User can also be inquired about the questions related to the usability of the software. Methods used for usability inquiry can be categorized as:

Field Observation: In this approach, user is observed by tester in real working environment during the completion of different tasks. Usability problems faced during real working environment can be observed easily using this approach. As achieving usability is an iterative process, identified problems are fixed in later version of application.

Questionnaires: In this approach, user needs to answer a questionnaire after using the product. The questionnaire comprises of questions regarding user experience, application rating, and usability problems. This approach is believed to be easiest and effective way to get end user response as in most of the questionnaire user is asked multiple choice questions. There have been number of questionnaire proposed to evaluate the usability of application. Most commonly used questionnaires includes: Questionnaire for User Interface Satisfaction, System usability scale and Software Usability Measurement Inventory.

Interviews: Similar to questionnaire, this approach also uses set of questions to evaluate the usability of application. However, instead of selecting the options to answer like questionnaire, user answer questions verbally during an interactive session between user and interviewer. Interviewer can help user to understand the asked question that is not possible in questionnaire helping to get detail information.

In addition to these discussed evaluation techniques many other evaluation techniques have been proposed that are specific to a domain [9] [10]. Usability evaluation techniques comparison on the basis of effectiveness and usefulness is presented in [11] [12] [13]. However, selecting usability evaluation technique solely depends on the nature of application being developed and type of available resources to evaluate usability.

2.3 Data Visualization

Data visualization is a way to present data in graphical way [14]. Data visualization aims to communicate quantitative data clearly and efficaciously through graphical aids. There have been many definitions of data visualization but definition by Card et al. is considered as standard and widely used.

> "The use of computer-supported, interactive, visual representations of abstract data to amplify cognition"[15]

According to this definition data visualization has three major components which includes:

1. Creating visual representation: Visually representing data by the means of graphical techniques i.e. charts, maps and hierarchical trees.
2. Concentrating on abstract data: To convey meaningful information quickly and effectively data visualization depends on mapping abstract data to compact visualization.
3. Including interaction: Interaction lies at the heart of data visualization. User can dynamically change the mapping of data by changing colors, zooming and scope of data by applying filters.

Aiger et al. defined three major components that every visualization technique should focus [16]

1. Expressiveness: Reducing noise and showing only meaningful data.
2. Effectiveness: Obtaining explainable visual representation of data by addressing human visual system cognitive abilities and context related information.
3. Appropriateness: The degree to which visualization provides benefit to achieve a specific task with respect to cost-value ratio.

2.4 Reason for Visualizing Data

Visual representation helps in revealing the inside of data [17]. Data visualization tools are being widely adopted in several disciplines for data exploration, data mining, information retrieval, and hypothesis generation [18]. Visual analytics tools popularity is increasing due to their efficiency in identifying patterns, exploring relations, and detecting anomalies in the data. Benefits of visualization can be described as:

- Expand Working Memory: Help in expanding human working memory by reducing cognitive load using visual aids.
- Reduce Research: Providing space efficient visualization to represent large amount of data.
- Identifying Patterns: Easy to identify patterns through visually explicit representation.
- Monitoring of Large Data: By providing aggregated views it become easier to monitor the large amount of data.

However, mentioned benefits are of no use for organizations that cares more about the quality of data. Data visualization also helps in analyzing the data and provides three key insights of the data:

Is the data complete? Completeness of data can be easily identified using visualization. Area with gaps over the graph shows the missing data. Visualization can be helpful in identifying the patterns of missing data as well.

Is the data valid? False data can be identified and removed using traditional statistical analysis. However, this process is laborious and expensive. On the other hand collected data can be easily preliminary visualized to find trends indicating problems in complete data.

Is the data well-organized? Organizational challenges of data can be highlighted using data visualization process. Visualization can provide insight into better way of organizing data that optimize the data collection process.

I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

Figure 2.1: Raw Data from Anscombes Quartet [1]

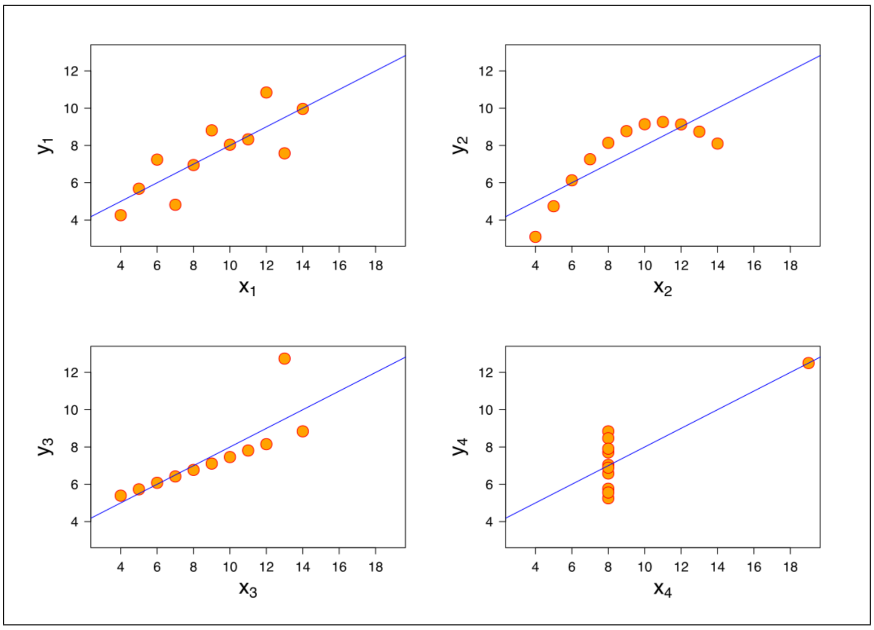

Figure 2.2: Graphical representation of Anscombe's Quartet [1]

Data visualization helps in seeing the unseen. Even large data volumes can be analyzed effectively and efficiently, making easy to identify the underlying patterns that not obvious to people before. Visualization make easier to share ideas with people from different backgrounds even speaking different languages. In 1973, a statistician Francis Anscombe demonstrated the importance of visualizing the data graphically [1]. He constructed four data-sets called Anscombe's quartet with almost similar statistical properties i.e. mean, variance, correlation, and linear regression. These data-sets appeared very different when graphically represented. Table 2.1 represents x and y values of four data-sets that are graphically represented in 2.2.

2.5 Categories of Visualization

For any data-set number of available visualization techniques is very large. Hence, selecting appropriate visual encoding for data is a challenging task. To help in making this process more effective visualization is primarily divided into five major categories on the basis of nature of data [19]. These categories are describe below.

2.5.1 Time-Series Data

Mostly used form of data visualization is time oriented data that deals with group of values changing with the passage of time. Many domains deals with time-varying data including finance, science and public policy. Index charts are an ideal selection where relative changes are preferred over specific values. It is type of line chart that is used to depict the changes against collection of time-series data in percentage at specific index point. Such as it can be used in stock exchange as investor are more concerned with growth rate rather than specific price. Stacked graphs are another type to deal with time-series data. It is a type of area charts that stacked over each other, helping in understanding aggregated patterns to identify the direction of data. However, negative numbers can not be depicted in stacked graph making it difficult to precisely identify the patterns. Small multiples are an alternative to stacked graphs which show each series separately instead of stacking on each other. This helps in interpreting each sector's patterns more easily. Horizon graphs space efficient that are used to display condensed data. Negative values are depicted by mirroring or off setting to positive values to save the space.

2.5.2 Statistical Distributions

Statistical distributions are used to unveil how numbers are distributed to understand the statistical features of data. There exist many visualization techniques to assess the distribution, however we will provide an overview of most commonly used info-graphics. Stem-and-leaf plots are helpful in assessing group of values using frequency distribution. These are an alternative to histograms. It bins number according to first significant digit and based on second significant digit values are stacked. Q-Q (quantile-quantile) plots are used to represent the quantiles of first data set against the quantiles of second data set. Plotted values for similar quantiles lie along the central diagonal and if linearly related, values lie along line. Scatter plot matrices are used to identify the relationship among multiple values. It is difficult to present multivariate data, SPLOM helps in visual inspection of relation among multiple variable through multiple scattered plots. Multivariate data can be statistically visualized by the aid of parallel coordinates. Data is represented on parallel line rather than displaying it in two dimensions and corresponding point are connected using lines. It is space efficient graph that helps in showing so many variables simultaneously in compact space. It can also help in finding patterns in the data.

2.5.3 Maps

Geographical data is normally represented using maps, various map designed has been proposed and adopted. Flow maps are used to represent the movement with respect to time and space. Flow lines encode large amount of information by line strokes with variation in width and colors. Choropleth maps shade the area according to the statistical values of variables e.g. depicting the population density in different stated of America. Graduated symbol maps are an alternative to choropleth map. These maps use symbols to represent the value of variables that size change according to its value. These symbols may includes simple shapes i.e. circle as well as complex shapes i.e. pie charts. Cartograms, is another type of maps used to depict geographical data. In cartograms shape of region is directly proportional to value of statistical variable associated to that region. For example, number of obese people in each state can be presented using circular area.

2.5.4 Hierarchies

Most of the available data can be organized into natural hierarchies e.g. spatial entities of counties, states, and countries; chain of command in business organizations or governments and software packages. Type of visualizations to effectively represent hierarchical data are discussed in this section. Due to space efficiency most commonly used way to represent hierarchical data are node-links diagrams. Node-link diagram is similar to two-dimensional tree where each node has a link to its parent node as branches in trees. A space-filling alternative of node-link diagram is adjacency diagram. In adjacency diagrams nodes are represented as solid areas and child nodes are placed adjacent to parent nodes to show their position in hierarchy. Enclosure diagrams are another space-filling method that used containment instead of adjacency to represent the hierarchy. A child node is packed in its parent node and depth of hierarchy can be identified by the size of parent node.

2.5.5 Networks

Relationships can be explored using network visualization, such as friends or group of people with common interests. Most commonly used visualization to present networks includes different techniques that are briefly discussed one by one. Force-directed layouts are common and non-rational visualization technique to model network graph as physical system. Network nodes are represented as charged particles that repel each other and links are suppressed springs that are used to connect related nodes together. Arc diagrams are another method to represent networks that links nodes with circular arcs in one dimension. Arc diagram may not be effective as compared to two-dimensional layout. However, cliques and bridges can be easily identified when nodes are ordered properly. Matrix views are most commonly used network visualization by mathematicians and computer scientists. Each value (x,y) in adjacency matrix represents link from one node to another. The use of colors instead of text helps in understanding the values more quickly. As line crossings are impossible to use in matrix views, cluster and bridges can be spotted using effective sorting of nodes.

2.6 Seven Stages of Data Visualization

The process of collecting and visually representing the data involves following steps: [20]

1. Acquire: Initially raw data is acquired from available resource.

2. Parse: Data is parsed into categories to convert into meaningful data.

3. Filter: Only data of interest is selected and else is removed.

4. Mine: Applying statistics or data mining strategies to find patterns. This helps in understanding data before starting visual analytics.

5. Represent: Finally data is represented using different basic visualization techniques including charts, list, or tress.

6. Refine: Once basic presentation of data is ready next step is to improve the representation through more clear and comprehensive visualization.

7. Interact: Last step is allowing user to interact with the system to manipulate the data features. Adding interaction will take visualization to next step.

However, it is not necessary that all of them are involved in each visual representation. Their count may varies depending on the nature of data. These stages are inter dependent and decisions on earlier stage have impact on later stages. Figure 2.3 shows how these stages are interlinked.

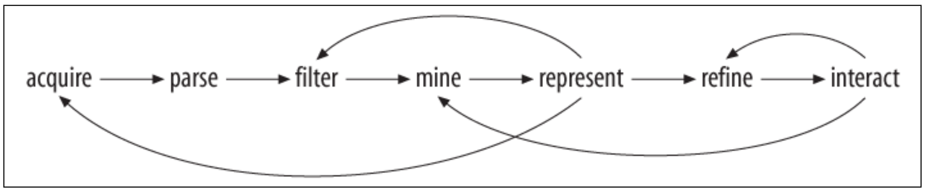

Figure 2.3: Interactions between the seven stages

Representation is interlinked with acquire and filter stage as the change in representation of data due to physical (age, gender, geographical) or equipment (specification, internet speed or others) may result in re-filtering data or even acquiring data again from data-set. During visual refinement due to user interaction with the system there may be a need of repeating mining stage.

2.7 Data Visualization in Healthcare

With advancement in technologies data is being generated at very higher rate in healthcare. Increase in the data is 30% to 50% in most of the organization [21]. Hence causing a problem for physicians and policy makers to depict the actual situation and taking appropriate actions accordingly. Critical analysis of data can help in improving the healthcare and the life standards.

Recently many organization has introduced electronic health record (EHR) system to replace the paper based system. EHR can be defined as:

> "Patient past, present and future clinical information in electronic form that are maintained to a subject of care"[22]

However, emphasize is on providing faster and cheaper EHRs instead of improving quality of care. Unfortunately quality of care is slightly improved using EHR systems and even there exist some examples where quality was decreased [23]. Information visualization and visual analytics can play a vital role to overcome such problems [24] ultimately improving the quality of care. According to a report from US institute of medicine [25] field of clinical medicine lacks behind from other scientific disciplines in usage of information visualization.

2.7.1 Visualization of categorical data

Categorical data is used to represent the features and also called qualitative data. Event-oriented horizontal time lines are used to represent the categorical data most commonly. Time is represented from left to right on x-axis and event occurring at specific time interval are represented using dots or icons on time line, rectangles are used to represent the event occurring over a period of time. These events are usually grouped on y-axis by some categorization. Events are differentiated by the means of colors, sometimes shapes and size of icons are used to express the additional information.

In healthcare categorical data includes: complaints, diagnosis, treatments, and drugs. Categorical data in healthcare can play a vital role in decision making. Previously focus has been on numerical data and visualization techniques that represent single record, however efforts have been made in recent past to visualize categorical healthcare data.

Lifelines2: Lifeline2 [26] is newer version of Lifeline [27]. Lifeline facilitate the visualization of single patient record summary. However, in Lifeline2 selected subset of records of multiple patients can be visualized. Figure 2.4 displays the multiple patients record. Each record is vertically stacked and events (asthma and pneumonia diagnosis) are displayed using colored triangles on time line. User can interact with the system using control panel on the right side. It provides a mean to quickly explore the data and identify temporal patterns for selected records and also helps in comparing the time span among occured events.

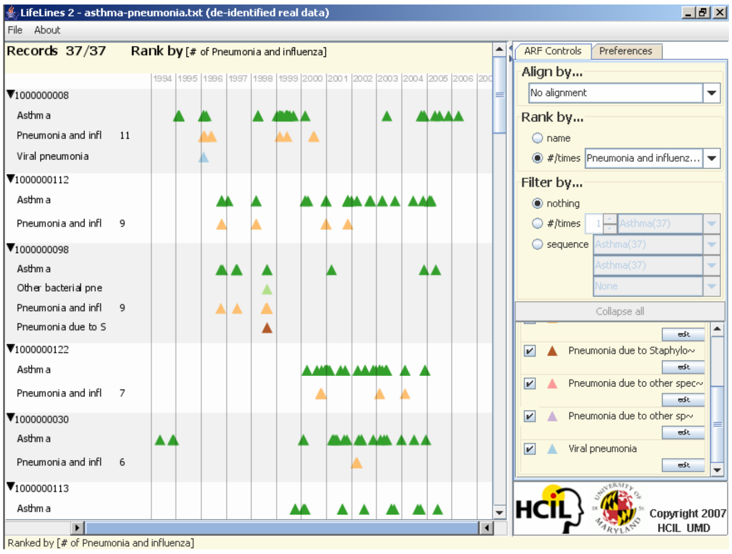

Figure 2.4: Lifeline2: Displaying Asthma and Pneumonia and influenza for multiple patients to see the co-occurrence

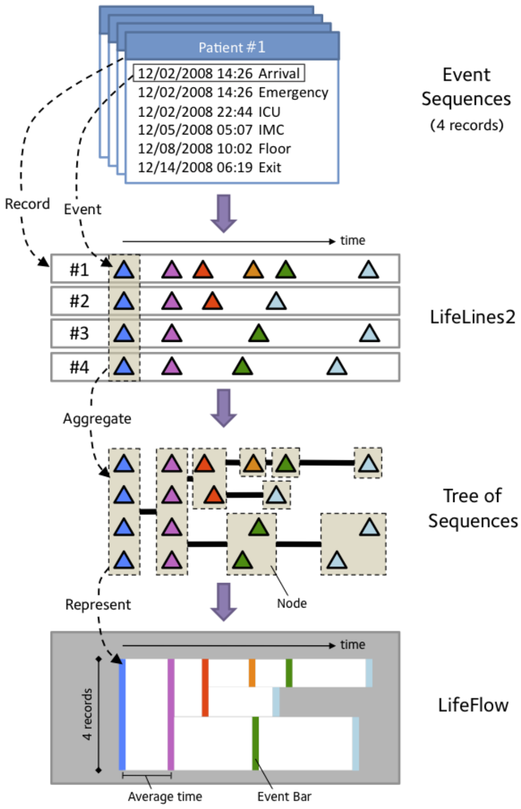

Figure 2.5: LifeFlow: Converting event sequences to LifeFlow

LiefFlow: LifeFlow [28] is an interactive visualization system that is used to represent event sequences. User can easily understand sequence of events in shorter period of time. LifeFlow system encompasses two parts: visually representing aggregated event sequences into one picture and allowing user to explore data by allowing to interact with the system. Figure 2.5 instances the transition of clinical event sequences to LifeFlow visual representation. Initially raw data is displayed on horizontal time line using colored triangles to represent events (similar approach to Lifeline2 [26]. All records are aggregated based on the sequences forming a data structure called tree of sequences. Then converted into LifeFlow visualization by representing tree node to an event bar.

2.7.2 Visualization of numerical data

Numerical data is used to represent the measurement and also call quantitative data. Numerical data is often used to compare differences in values at different time intervals. Different visualization techniques are used to represent numerical data. However, bar charts and line charts are the most commonly used visualization techniques. X-axis is used to represent event and y-axis displays corresponding values. Sometimes, numerical values are transformed into categorical values to identify the abnormal values such as low/normal/high or using color scheme.

In health care numerical data includes: vital signs and laboratory test results. Numerical data is expressive and easy to understand. By visualizing numerical data graphically physician can explore underlying patterns which may help in making decisions.

2.7.3 Health 2.0

A term Health 2.0 was introduced back in 2010 [29] which suggest some strategies for health informatics technologies analysis. Health 2.0 divides healthcare into three overlapping domains:

Personal health information: In recent years patients have become more curious about their health. The availability of health gadgets and applications has increased their awareness. Health informatics applications has helped patient's a lot to record their diet plan, exercise schedule, medications and nutritional supplements. They can easily monitor health progress and update plans accordingly. Several patient's portals provide the ability to communicate with other patients and sharing success stories as well.

However, presenting patient comprehensive visual health information to both patients and physicians still one of the major challenges. There is a need of advanced visual analytics strategies to find a patient with specific sequence of events. Studies also show that patients prefer playful timelines with sound and animations aid over simple timelines.

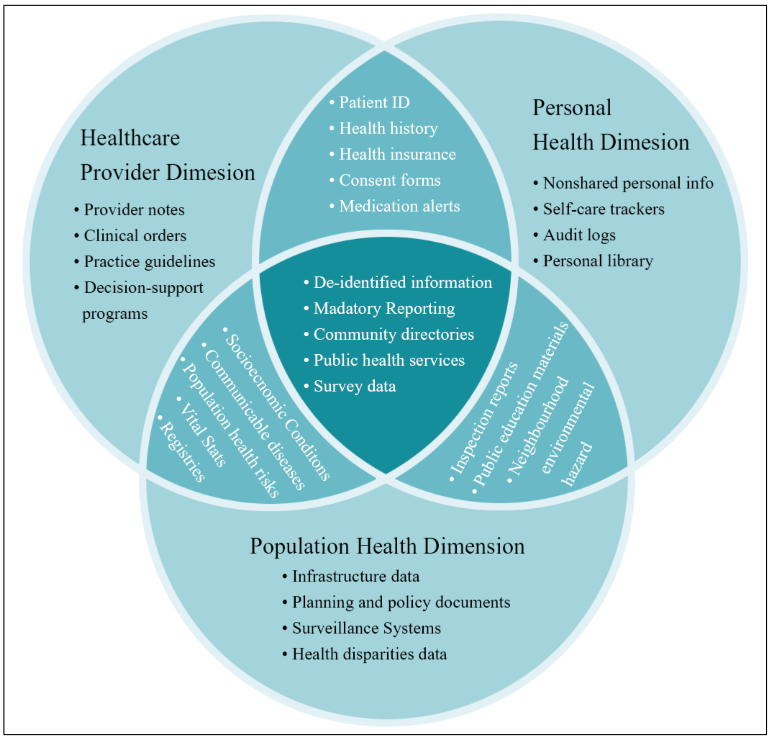

Figure 2.6: Health 2.0 overlapping domains

Clinical health information: EHRs are being widely adopted by physicians. Increasing amount of data being stored in EHRs including histories, medications and lab results needs exceptional ability to depict the patient progress while having look at specific data values. There are some efforts to design single patient visual histories, however any widely adopted designed have not proposed yet. Growth chart is one of the visualization success stories to compare child's growth with relevant population.

Now a days health organizations wants to analyze their performance by understanding the patterns for different scenarios. Interactive visualization can be useful to present these patterns. These patterns can also be used to analyze existing clinical data exposing data quality problems and anomalies. Physicians can also identify group of patients matching the selection criteria with the help of visualizations.

Public health information: Different agencies are collecting healthcare data to help in policy making. However, exploring the huge amount of data and finding relationship among that data remains a challenge. Solutions can be defined for national or local health organizations using visual analytics to respond against any infectious disease. Preemptive measures can also be taken by identifying the patterns for individuals who can be the at the risk.

2.7.4 Improving visualization in healthcare

Shneiderman et al. proposed seven practical issues that should be addressed to improve visualization in healthcare [30]

Offering busy clinicians timely information in the right format: Presenting an overview of patient histories to busy clinicians remains a challenge. Visual analytics can help physicians to view tailored information to identify anomalies in the data. If there is need they can drill down data to identify the risk and taking earlier measurements accordingly. Visual dashboards can also help in evaluating the workload of staff and equipment utilization helping in effective resource utilization.

Moving toward an ecosystem of visual tools: There is need to develop interfaces having visual presentation for different types of end users including physicians, patients and caregivers. Such interfaces will improve the patient's life quality. Visualization can also reduce the impact of low literacy and different language on patient's health.

Facilitating team decision making: Individual decision making can be shifted to team decision making by development of interoperable healthcare systems. Such teams can include primary care physician, specialist physician from remote location, patient and caregivers. Dealing with legal liabilities is also another issue in team decision making.

Characterizing and understanding similarity: Visualizations can play a vital role to help physicians in case of rare diseases. Allowing physicians to query EHR database using interactive interfaces can help in finding the similar scenarios. Even they can select the sequence of problems to find the patients with similar disease and then they can study the treatment procedure.

Visualizing comparative relationships: Comparing a group of patients is one of the major problems for health researchers. Visualizations can facilitate researchers by providing differences and comparative analysis. This may help in evaluating the methods and treatments in different scenarios.

Presenting risk and uncertainty: Healthcare data-sets are complex with uncertainty and incomplete data entries. Analyzing such type of data for making decisions and policies presents exceptional challenges. Showing weather forecast with uncertainty is acceptable but not in case of medical data. Interactive visualizations can help in dealing with well known problems of medical communication including presenting treatment procedure risk, medications or failure to act.

Evaluation: Designer is an important entity in creating interactive healthcare system. Because poor design may increase the risk of misunderstanding, hence reducing the quality of patient care. Visual interface designers have to learn health and healthcare to produce design that are according to the needs of end users. Moreover, prototypes should be tested in real environments to evaluate the efficiency of designs.

Chapter 3

Proposed System

In this chapter, we present our proposed system. An electronic health record system for obstetric specialty was developed that combines different visualization techniques studied during the literature review to visually represent the data. Initially, we discussed work-flow of obstetric department and information flow for obstetric patient. Later section of this chapter provides an overview of system architecture.

3.1 Problem Analysis

This research was carried out in collaboration with obstetric hospital named Medicsi (www.medicsi.com). They already have an implemented system, however, that system lacks usability and has three serious drawbacks that includes:

1. System workflow does not match the real environment workflow and system does not provide classified information also. Hence, increasing the learning curve.

2. Viewing patient progress is difficult and time consuming process as system does not provide consolidated view of the details.

3. System does not provide decision support to the user, hence reducing the efficiency.

Initially we performed analysis of the existing system to get the deeper understanding and knowledge of domain. We also worked with physicians and staffs to get better hold of requirements.

3.2 Requirement Gathering

In this sections we provide an overview of the obstetric department workflow and information flow for an obstetric patient.

3.2.1 Obstetric Department Workflow

Without identifying the standardized process to do the work may result in complex and confusing user interface causing trouble for end users. Workflow can be defined as:

> "Set of task, grouped together that are performed by set of resources to achieve a specific goal" [31]

Commonly, there is lack of interest in how information is processed and organized in real working environment during software development. Following failures can be observed in healthcare applications designed without identifying and evaluating prior workflows:

- Failure to achieve higher rates of productivity.
- Failure to define easiest way to see patients and visit documentation.
- Failure to identify specific roles for data processing and organization.
- Failure to depict gaps between components of the system.

Mostly, the goal of defining and analyzing workflow is to improve efficiency. Performing prior walk-through to understand integration between information flow and workflow helps in optimizing the process in advance.

The first step in the process is to understand and design the workflow of obstetric department. This will help in identifying the major components of the system and also the roles of specific users. To have a closer look on real working environment we spent time in obstetric department and observed the actual process. Figure 3.2 represents the workflow of of obstetric department. We identified four actors involved in the system on the basis of diversity of tasks related to them. These actors includes:

Front Desk Officer: Once patient get checked in front desk officer is responsible for patient registration in case of new patient and appointment scheduling. Appointment scheduling is not the part of our system, it will be carried out on the paper.

Nurse/Medical Assistant: Nurse or medical assistant are responsible for patient rooming and validating the documents required for current visit e.g. lab results. Patient history and vital collection task is shared between nurse/medical assistant and physician. This may vary depending upon the patient health condition. Check out and billing process is also shared between nurse/medical assistant and front desk officer.

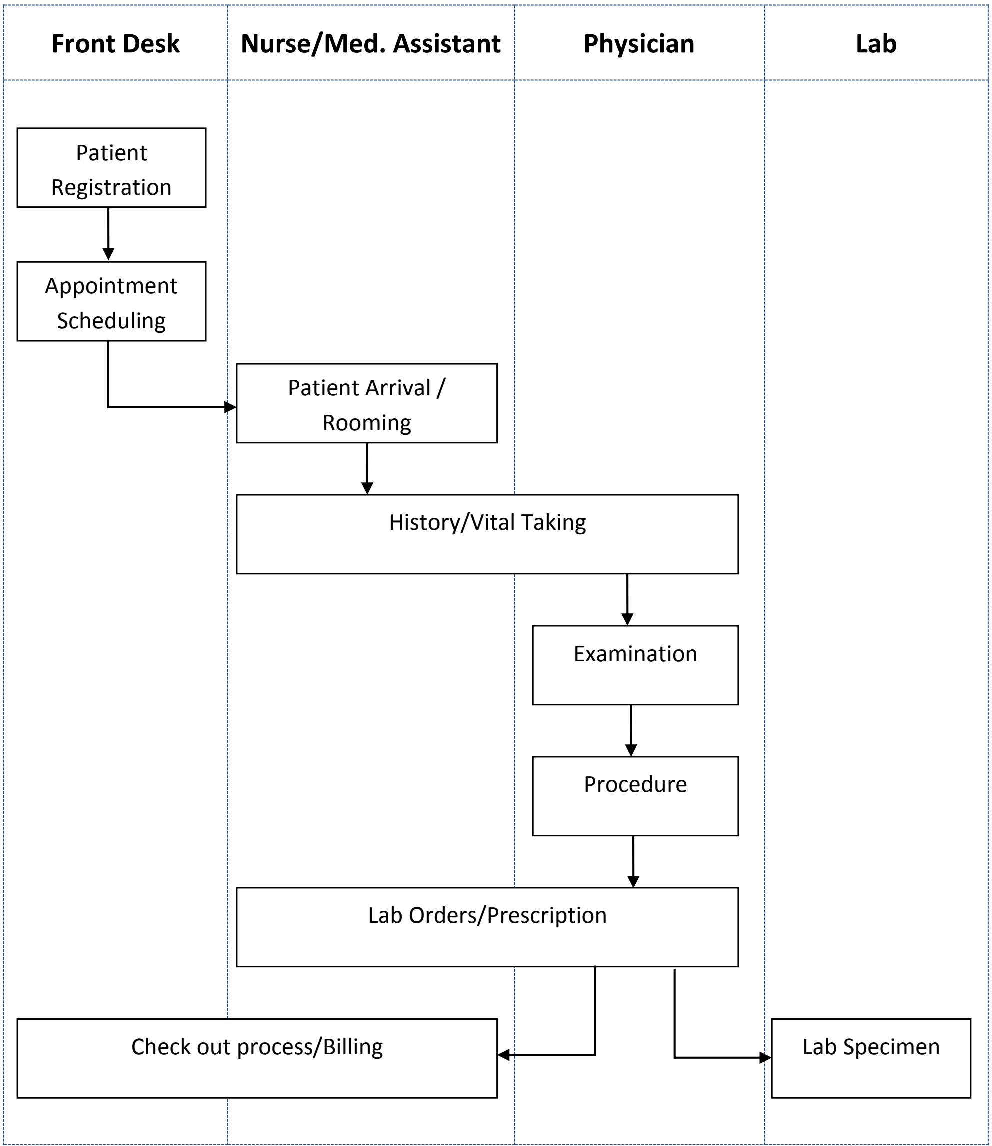

Figure 3.1: Work Flow Diagram in Obstetrical Department

Physician: Physician examine the patient and if there is need he perform procedure as well. Prescription and Lab order is also shared between physician and nurse/medical assistant depending upon the complexity of medications and lab orders.

Lab: Some hospitals also provides the facility of collecting lab specimens at the hospital. That is why we have mentioned it in workflow, however, our system only manages patients lab results.

3.2.2 Obstetric Patient Information Flow

This section provides an insight of system components and how information flows among these components. We have logically grouped information during pregnancy in three groups that includes: antepartum period, labor and delivery period and postpartum period (after discharge from hospital). A document is maintained for each period that summarize the care during that specific period and also shared if needed. Each period is briefly explained below:

Antepartum Period: During a normal pregnancy mother experiences several encounters that helps in tracking the pregnancy progress. Diagnostics test are also performed during antepartum period and result is maintained with other care record. During initial and subsequent visits following information is added or updated:

- Patient demographics
- Menstrual and obstetric history
- Medical history including surgical history and social history
- Family history
- Active medications
- Allergies and adverse reactions
- Vitals
- Laboratory results

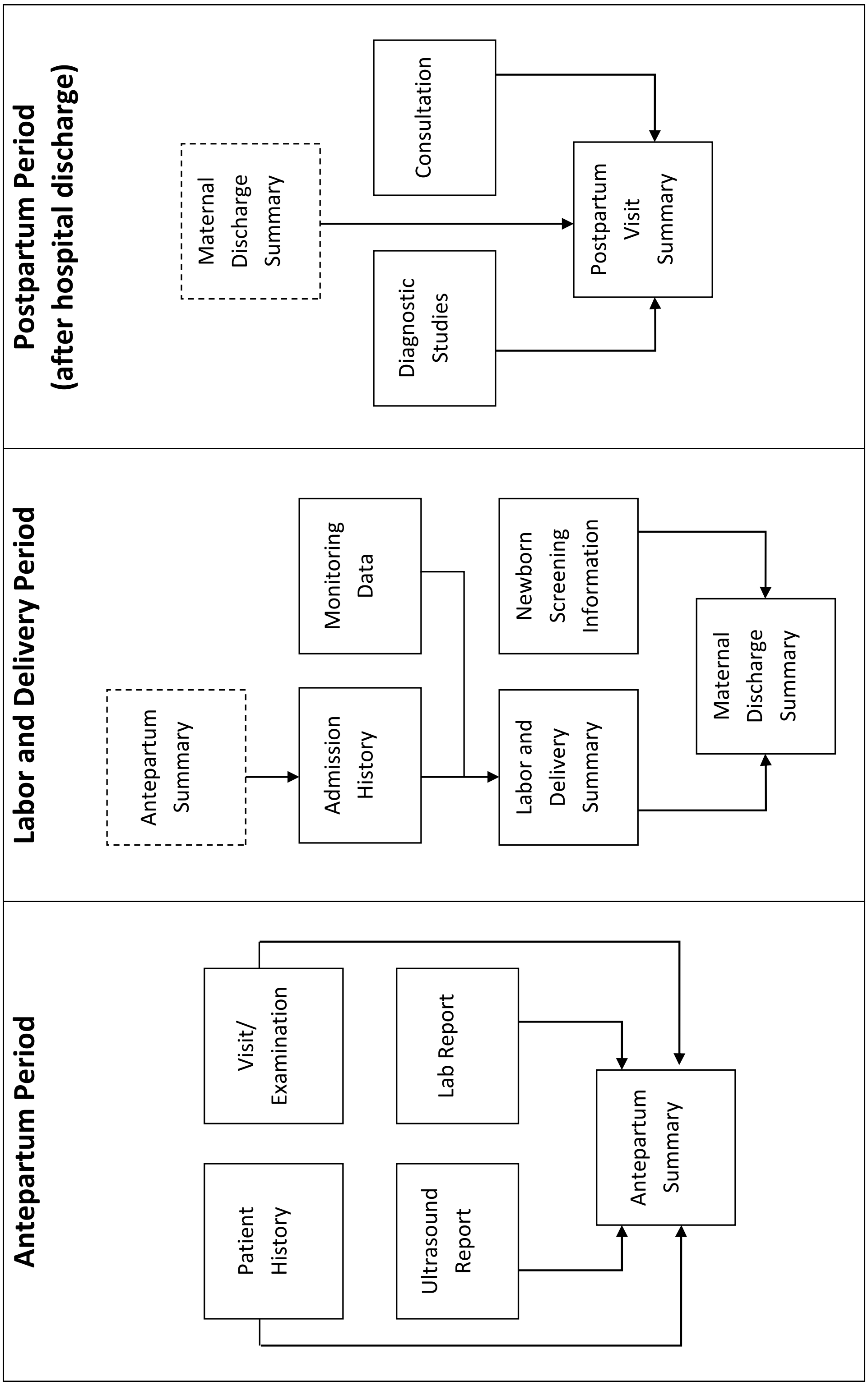

Figure 3.2: Information Flow Diagram in Obstetrical Department

Labor and Delivery Period: Prior documents maintained during antepartum period are shared during labor and delivery period. Physical examination is also done during the admission in labor. Mother may receive anesthesia as the labor progress. Mother and fetus health is continuously monitored and documented during labor. After delivery summary of labor and newborn is produced and shared with concerned persons.

Postpartum Period: After few days of delivery followup visit with obstetric provider is performed. During this visit mother health is examined and if necessary medications are prescribed.

3.3 System Architecture

Software architecture plays an important role and act as a bridge between system and implementation [32]. We followed three tier architecture for this system, Figure 3.3 represents the high level system architecture. It is a client-server architecture in which information presentation, application logic and data management functions are maintained as independent modules [33].

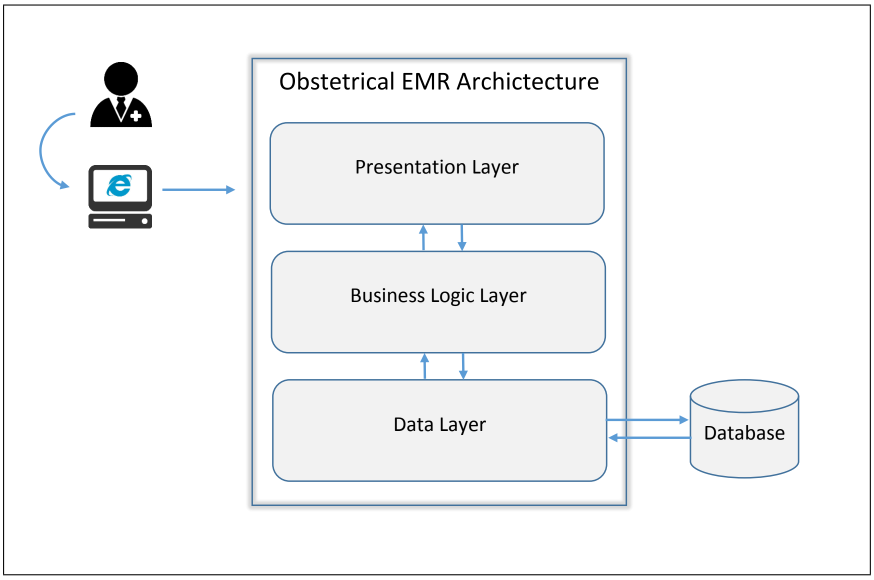

Figure 3.3: High Level System Architecture Diagram

Presentation Layer: This is the top most layer of the system through which user interacts with the system. Here our focus is on presentation layer (GUI) as visualization deals with presentation of data.

Application Logic Layer: Application functionality is implemented in this layer. It is also known as business logic layer.

Data Layer: Data access layer is responsible for data persistence. Data access layer exposed an API to provide access to application layer to stored data.

Chapter 4

Implementation

This section provides an overview of implemented system's major functionality. In our proposed system we have used different visualization techniques to overcome drawbacks that were identified during analysis of existing healthcare systems. Our system addresses two important research questions which were identified during literature review and can be summarized as:

- How to present patient consolidated information
- How to identify anomalies in patient healthcare data?

4.1 Representing patient consolidated information

As discussed earlier in most of the cases obstetric patient's history is maintained for almost nine months. Which makes it difficult for the physicians to keep track of healthcare being provided over that period of time. Visualization can play a vital role to overcome this problem.

Overview of patient visits: During each visit it is necessary for physician to get an overview of past visits. Normally patient herself provides the visits history of physician has to go through all visit to get an overview. In both cases there are chances of errors. Figure 4.2 provides a timeline view of patient visits including patient reason for visits and physician's remarks during that visit which makes it much easier for physician's to get an overview of past visits.

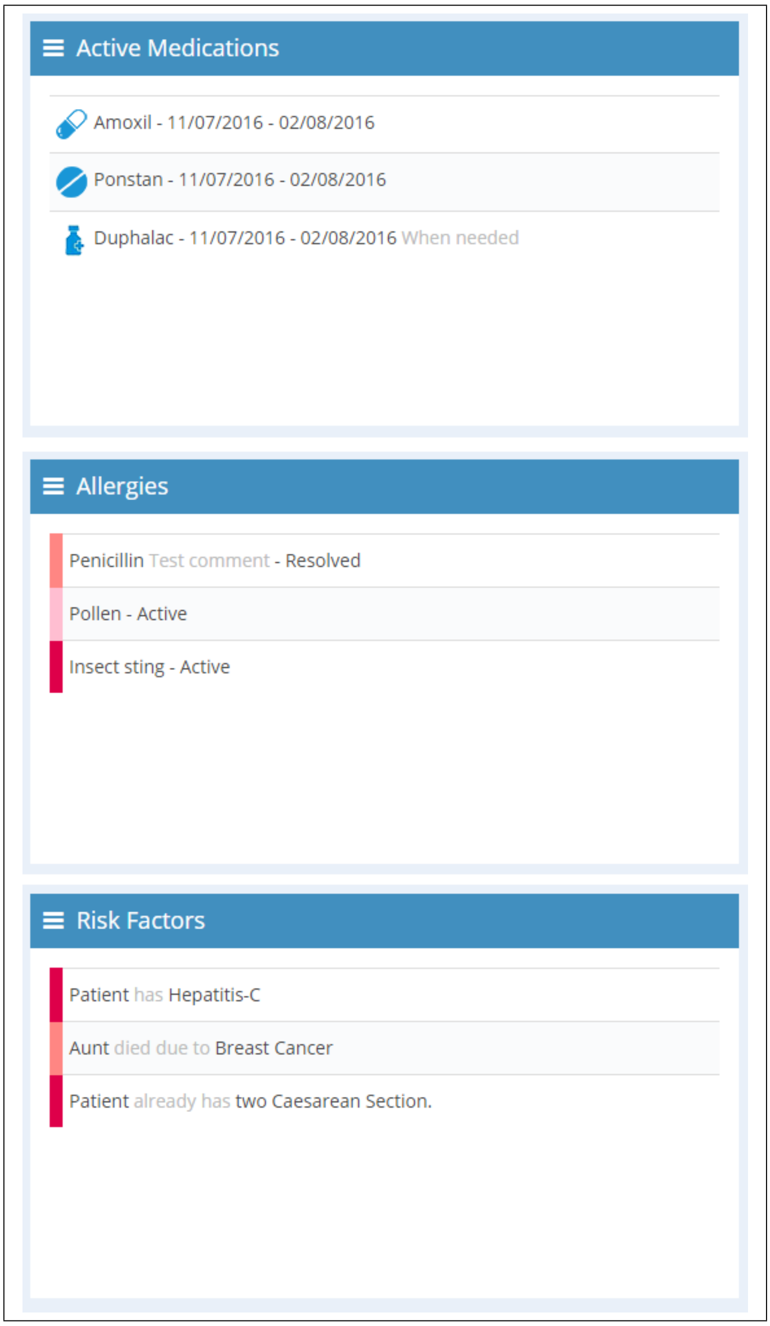

Figure 4.1: Presenting consolidated information

Risk factors identification: There are several risk factors involved with patient and child's life due to patient's past medical history, medications and allergies. Our system also highlights these risk factors and level of risk associated with each. Figure 4.1 provides an outlook of implementation in our system.

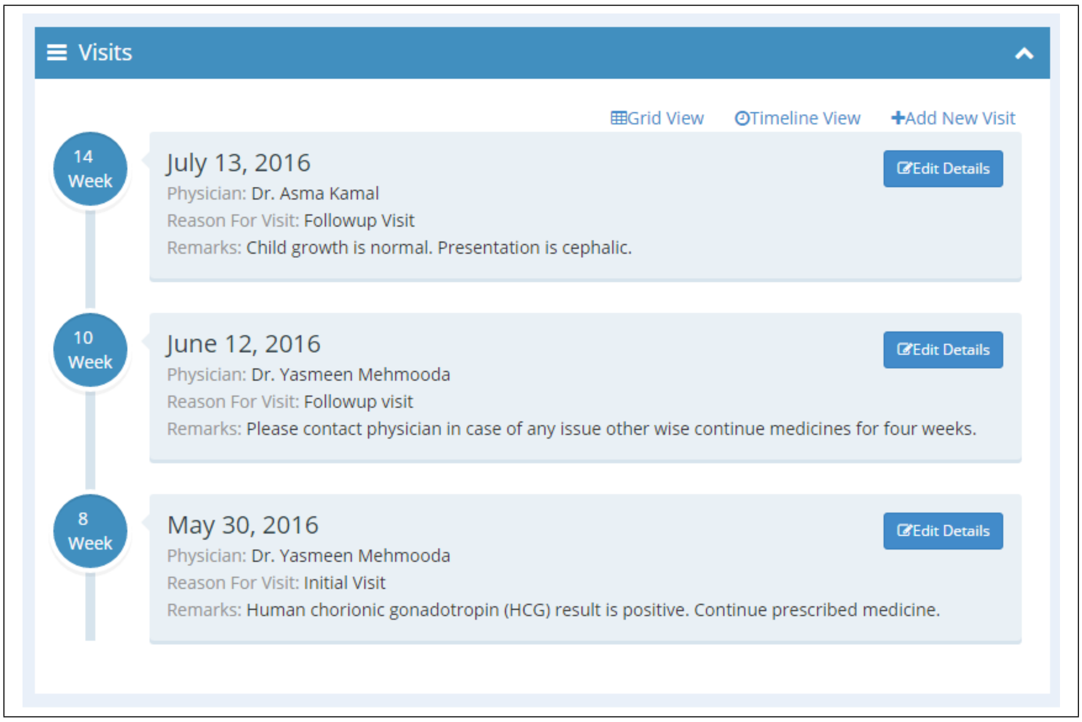

Figure 4.2: Timeline view of patient visits

4.2 Identifying Anomalies

Identifying anomalies in patient data is a major problem faced by physicians. Also viewing temporal history of patient lab results to monitor progress is another challenging tasks. Figure 4.3 provides an overview of how this problem is coped in our implemented system.

First chart illustrate an example of showing anomalies in patient blood pressure readings. Green points depict normal blood pressure, orange for prehypertension and red for hypertension.

Second chart uses a visualization technique to display different lab results

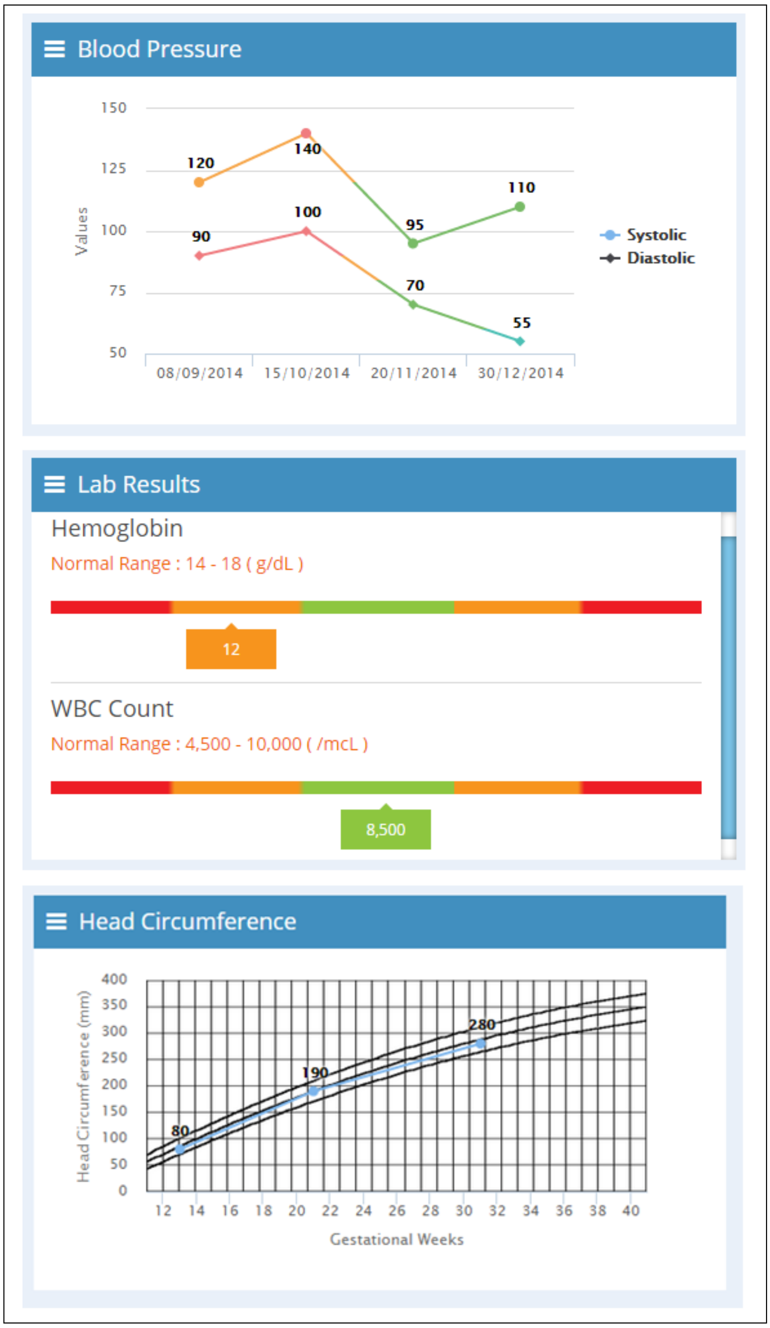

Figure 4.3: Identifying anomalies in patient data

readings. Multiple readings can be displayed on single range scale for a specific lab test. Hence making it easier for physician to identify the normal and below or above normal values.

Third chart demonstrate the way to monitor ultrasound values for fetus head circumference. Similar charts have been designed to monitor other variables of ultrasound.

4.3 Equipment

This section provides brief overview of equipment and technology used during development and deployment of our proposed application.

4.3.1 Development

Microsoft Visual Studio 2013 development environment is used during implementation. Front end technologies used for this application includes: HTML 5, CSS 3, jQuery and Bootstrap. ASP.NET framework 4.5 is used for backend development. Microsoft SQL Server 2014 is used for database.

4.3.2 Deployment

Application is deployed on server running Microsoft Windows Server 2012 and IIS 8 web server.

Chapter 5

System Evaluation

In this chapter, we present the scenarios in which our implemented system was used. This evaluation process is conducted on multiple patient's self generated data in order to present authentic results. As discussed earlier in first chapter the hypothesis for this thesis work can be described as:

- Usability of healthcare software can be increased by improving visualization
- Better visualization of obstetric patient's clinical data can support in decision making

So null hypothesis for this thesis work can be formulated as:

- Usability of healthcare software can not be increased by improving visualization
- Better visualizations of obstetric patient's clinical data do not support in decision making

5.1 Evaluation Methods

To evaluate and compare the usability and decision support provided by our proposed system with already developed system, we used two most known usability evaluation methods Single Ease Question (SEQ) and System Usability Scale (SUS).

5.1.1 Single Ease Question (SEQ):

Single Ease Question provides a way to estimate ease or difficulty while performing a task. It is a numeric scale with values ranging from one (very difficult) to seven (very easy). Regardless of its simplicity SEQ is considered equally well or even better than other questionnaires to measure application usability. [34] [35]

5.1.2 System Usability Scale (SUS):

System Usability Scale (SUS) is another reliable tool to evaluate the usability of software systems. It produces reliable results on small sample sizes [36]. This form consists of ten question that can be graded from one (strongly agree) to five (strongly disagree). Appendix B provides the detail of standard System Usability Scale questionnaire.

5.2 Questionnaire

This section provides an overview of questionnaire survey that was conducted to evaluate proposed system. The contents of questionnaire can be observerd in Appendix A. The ultimate goal of this survey is to investigate if physician found our proposed system more usable than the existing system being used to maintain obstetric patient data.

5.2.1 Questionnaire Layout

The questionnaire has been divided into four logical segments. These sections are briefly described below in order of their appearance. A complete questionnaire can be found in Appendix B.

Participant personal background: This section captures information about participant personal information. The information collected in this section is age, gender and relative working experience in field of obs and gynecology.

Participant computer skills: This section is used to gain knowledge of participant computer skills. Participants self assessed computer skills are asked to get sense of their confidence while using system. Internet use and website browsed during a week that help in understanding how broader user experience is to use different systems.

System usage: Participants were asked to use both systems on the basis of predefined set of six use cases and evaluate decision support provided by these systems. Level of difficulty to perform each use case is assessed through through Single Ease Question (SEQ) rating scale.

System Usability Scale (SUS): At the end of the session System Usability Scale (SUS) form was filled by users for both systems for higher level usability assessment.

5.2.2 Recruitment of participants

Physicians from obs and gynecology department of a government hospital name Holy Family Hospital participated to evaluate the system.

5.3 Data

This section provides an overview of data captured during evaluation process. Each participant individually tested the system and before starting the test an oral orientation was given to each participant. The orientation includes an overview of both applications and use cases to perform while testing.

5.3.1 Participants personal background

As mentioned earlier basic information of participants evaluating the application is collected. A summary of participants involved in evaluation process is given table 5.1.

Table 5.1: Characteristics of subject individuals

Sr.	Individual	Gender	Age	Work Experience
1.	I1	Female	28 years	2 years
2.	I2	Female	26 years	1 year
3.	I3	Male	32 years	4 years
4.	I4	Female	30 years	3 years
5.	I5	Female	27 years	2 years
6.	I6	Female	29 years	2 years
7.	I7	Female	31 years	3 years
8.	I8	Female	28 years	2 years
9.	I9	Female	25 years	less than 1 year

5.3.2 Participants computer skills

Most of the participants rated their computer skills as intermediate. However, one participant has expert level self assessed computer skills.

5.3.3 Single Ease Question (SEQ)

Table 5.2 provides an overview to participant's satisfaction level to perform each use case using SEQ scale. Figure 5.1 provides graphical representation for same. Average user satisfaction level of participants evaluating both application is shown in table 5.3 and figure 5.2 provides graphical representation as well.

Table 5.2: Average SEQ score for each use case

Use case	Proposed System	Medicsi System
Use Case 1	4	2
Use Case 2	5	1
Use Case 3	5	4
Use Case 4	6	2
Use Case 5	5	2
Use Case 6	4	4

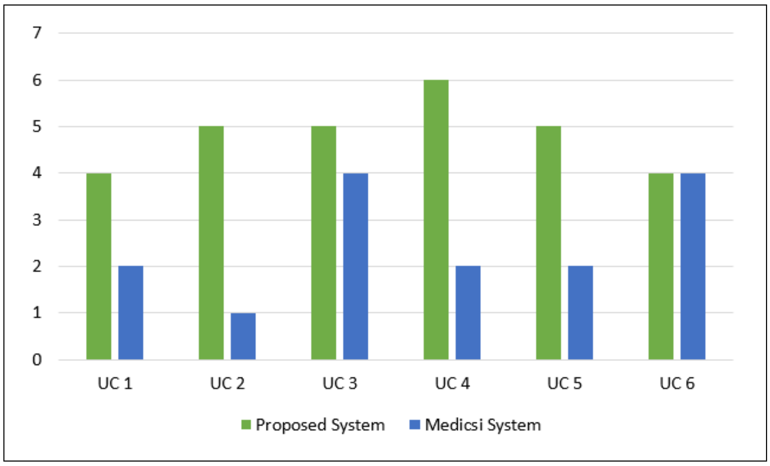

Figure 5.1: Average SEQ score for each use case

Table 5.3: Average SEQ score for each application

System	Average SEQ Score
Proposed System	4.9
Medicsi System	2.5

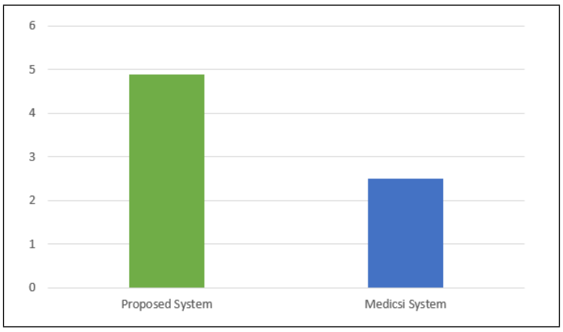

Figure 5.2: Average SEQ score for each application

5.3.4 System Usability Scale (SUS)

This section provides an overview of data captured during evaluation process. Each participant individually tested the system and before starting the test an oral orientation was given to each participant.

Table 5.4: Average SUS score

System	Average SUS Score
Proposed System	80
Medicsi System	45

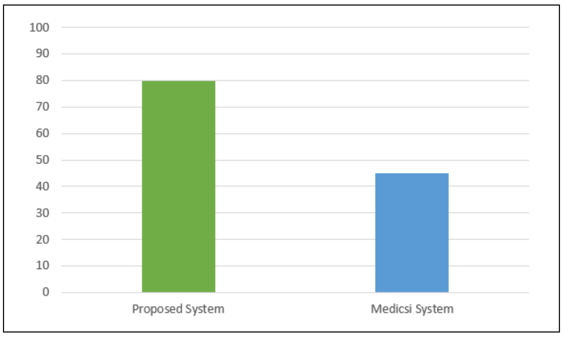

Figure 5.3: Average SUS score

Chapter 6

Results and Findings

In previous chapter we presented data captured during the evaluation process. Proposed hypothesis can be analyzed in the light of collected data. In this chapter we will be discussing possible results that can be depicted from evaluation data analysis.

On the basis of analysis of evaluation results we can claims that health-care systems equipped with visualization techniques are better than systems not providing visualization. It is much easier for users to get overview of patient progress at any stage of pregnancy.

Also it can be claimed on the basis of results that by improving visualization, usability of healthcare system can be increased. User feels much comfortable to perform tasks on system having better user interface.

Visualization also helped in improving patients quality of care. As by using our proposed system it was much easier for physicians to identify anomalies in patient data which makes it much easier to evaluate patient condition and taking appropriate actions on the basis that condition.

The participants of evaluation process has found our proposed system much easier to use than the other available system. Also we have proved our claims in the light of evaluation results. So, in general it can be concluded that by using visualization techniques our system got higher level of usability and user satisfaction to perform different healthcare data analysis tasks. The system which is not equipped with better visualization has less usability and task level user satisfaction.

Chapter 7

Conclusions and Future Work

This chapter summarized the work completed during thesis by providing an overview of proposed method, evaluation and findings on the basis of results. Later section describes possible future dimensions in this work.

7.1 Conclusions

In this work we developed an EHR for obstetric specialty that focuses on improving usability and patient healthcare. We used different visualization techniques to represent patient healthcare data that helps physicians to monitor patient overall progress, anomalies in the data, and associated risk factors to patient health.

Through using different usability analysis tools i.e. Single Ease Question (SEQ) and System Usability Scale (SUS) we proved that our proposed system helps in monitoring patient progress and identifying anomalies in the data. Hence, improving patient healthcare process. Physicians who have used our system during the evaluation process, have preferred it over the system being used already.

7.2 Future Work

This thesis work provides number of research dimensions for future work. In this section we will be discussing possible future dimensions that we intend to work in future and also those that are open to researcher

During the evaluation process of this work original patient data is not used and we used self manipulated data. As our proposed system has capability to handle real-time patient data, so in future we aim to analyze it with original data. Also we would like to compare our proposed system with more state of the art EHR software systems to produce more authentic results.

We have used already available generic visualization techniques to present patient healthcare data. However, researchers can propose new visualization techniques in reference to obstetric patient data. It can produce much effective results.

Moreover, our proposed system is designed to handle obstetric patient data. Researchers can use this system as baseline for developing systems of other medical specialties and results can be very encouraging for other specialties as well.

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Appendices

Appendix A

Questionnaire

Personal Background

1) How old are you? (enter number of years)

2) Gender
   a) Male
   b) Female

3) Relative Experience
   a) <3 years
   b) 3 to 6 years
   c) 7 to 10 years
   d) > 10 years

Computer Skills

4) How do you consider your computer skills?
   a) Novice
   b) Intermediate
   c) Advanced
   d) Expert

5) How often do you use the Internet?
   a) Never to once a week
   b) 1 to 3 times a week
   c) 3 to 5 times a week
   d) Every day

6) How many different websites do you visit in a week?
   a) 0 to 1
   b) 2 to 5
   c) 5 to 10
   d) 10+

Figure A.1: Questionnaire preliminary questions

Application Usage

Use application on the basis of following scenarios and rate decision support provided by the system.

1) Measure patient vitals progress

1 2 3 4 5 6 7

2) View patient active medications

1 2 3 4 5 6 7

3) View patient allergies

1 2 3 4 5 6 7

4) View lab result carried out during pregnancy

1 2 3 4 5 6 7

5) Monitor patient progress

1 2 3 4 5 6 7

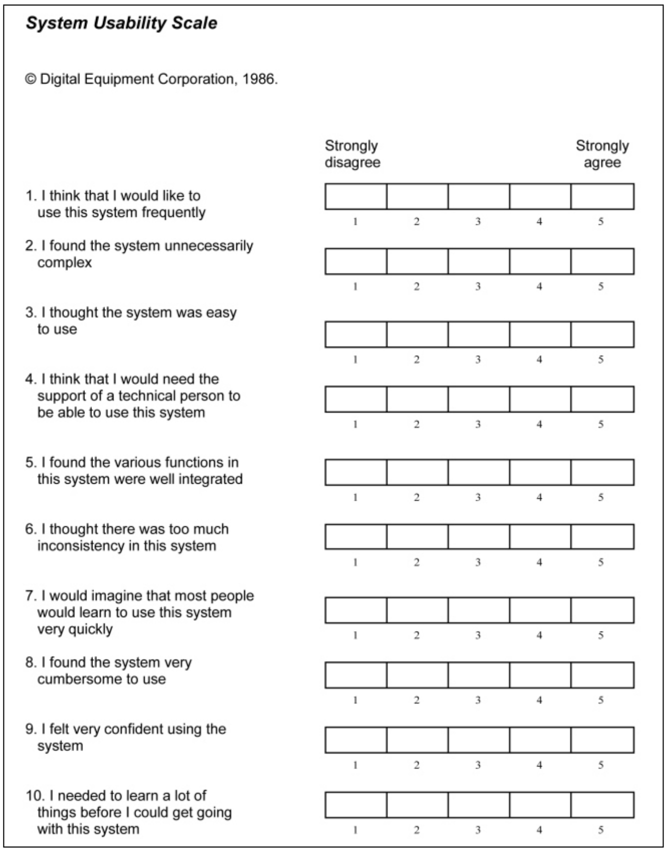
6) Risk factors involved during pregnancy

1 2 3 4 5 6 7

Figure A.2: Questionnaire system usage evaluation

Appendix B

System Usability Scale



System Usability Scale

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Figure B.1: System Usability Scale form [2]