Pictorial Visualization System with Patient Portal for Problem-based Electronic Medical Record

By

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Abstract

The use of electronic medical records (EMRs) has yet to reach its potential for information visualization and achieve corresponding expected outcomes. Current EMR systems show numerous health data with large amounts of texts, which are sometimes integrated in various tables. This type of presentation presents difficulties in promptly determining medical conditions or quickly finding desired information given the volume of texts that needs to be read. Amid these problems, researchers and developers have not explored the creation of easy and intuitive user interfaces for visualizing EMRs.

To bridge the gap between current EMR and ideal EMR systems, we propose a prototype web-based pictorial visualization system that can be used by both patients and doctors. The system allows spatial interactivity through representations of human body images (front and back views) and temporal interactivity through interconnected time axes. Medical histories are classified using 11 physiological systems to enable efficient browsing of selected information. This classification enables physicians to quickly understand patients' health conditions and accordingly make medical decisions, which are useful in emergency rooms and intensive care units.

Acknowledgments

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Contents

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Abbreviations

2D	Two Dimensional
3D	Three Dimensional
ARF	Align-Rank-Filter
CESAR	Canadian Energy System Analysis Research
CMS	Centers for Medicare and Medicaid Services
CPT	Current Procedural Terminology
CSS	Cascading Style Sheet
D3	Data Driver Document
DOM	Document Object Model
EMR	Electronic Medical Record
ER	Emergency Room
HIMSS	Health Information and Management Systems Society
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
ICD	International Classification of Disease
ICU	Intensive Care Unit

IO	Input / Output
IOM	Institute of Medicine
ISO	International Organization for Standardization
InfoVis	Information Visualization
NDC	National Drug Code
PHR	Personal Health Record
POMR	Problem-oriented Medical Record
RDBMS	Relational Database Management System
REST	Representational State Transfer
RUQ	Right Upper Quadrant
SOAP	Subjective information, Objective information, Assessments and Plan
SQL	Structured Query Language
SVG	Scalable Vector Graphics

Chapter 1. Introduction

Medical records serve as a central repository of patients' medical histories and play an essential role in patient care. In recent years, electronic medical record (EMR) systems have increasingly improved and contributed to medical efficiency and hospital productivity. An EMR, which is a longitudinal electronic record of a patient's health information, is considerably more effective than paper-based documentation because of the advantages that it offers in terms of storage, information sharing and information retrieval. A report from the Centers for Medicare and Medicaid Services (CMS) indicated that approximately 80% of eligible hospitals and more than 50% of professionals have adopted EMRs [1]. Nevertheless, their acceptance in clinical practice continues to lag behind their potential and expected outcomes because the medical data that accompany EMRs are often voluminous, complex, disorganized [2] and difficult to integrate. Given the alarming rate at which the volume of medical records is growing, important information is constantly difficult to obtain, thereby seriously hampering a physician's diagnostic reasoning and the efficiency with which he/she works. Because of the limited time that health care professionals can devote to receiving data, reviewing and extracting the records that they need in a few minutes are challenging tasks.

Current EMR systems have not realized their promising potential as digital information sources from which medical data can be structured and visualized to maximize the convenient extraction of target information. EMR systems should enable physicians to quickly incorporate or retrieve various types of medical information, such as medication administration, physical assessments, referrals, patient complaints (e.g., symptoms), medical histories, diagnoses, tests, procedures, treatments, medications and discharge and immunization data. Information visualization (InfoVis) is one method by which the value of electronically available medical data can be increased [3]. Given that InfoVis presents medical data in intuitive, understandable, recognizable, navigable, and manageable formats, users can rapidly extract useful information from medical records.

Another important issue for consideration is the likelihood that patients will want to take an active role in managing their health. Research has shown that two-thirds (65%) of patients are interested in electronically accessing their own personal health information [4] and want to monitor their illnesses through awareness of their symptoms, diagnoses, medications and treatments. In such cases, a useful resource is the personal health record (PHR), which facilitates patient involvement in health care. The problem is that many PHR systems are physician oriented and do not offer practical functionalities for patients.

1.1 Analysis of Current EMRs

1.1.1 Commercial EMR Systems

Many commercial EMR systems combine text-based methods of record keeping with modern table and graph formats. Most vendor systems support the completion of physicians' daily clinical tasks and administrative tasks. Popular commercial EMR systems, such as EpicCare [5], Allscripts [6], and eClinicalWorks [7], offer functionality for problem lists, electronic prescriptions, allergy checks, medication management, order management and billing. These systems therefore contain various texts, such as documents, orders and notes. A frequent mode of visualization in commercial EMR systems is the flowsheet, which is widely used in intensive care units (ICUs). It contains key medical variables for a single patient over a given period and thus emphasizes trends and abnormal values. Numerous other systems, such as IBM Watson Health [8] and Oracle Health Sciences [9], often include automated analysis techniques that are based on machine learning and data mining.

Despite the advancements achieved with current systems, the availability of medical information does not necessarily translate to effective support for health care providers in complex daily tasks. Substantial medical information is classified in ways that fail to satisfy physicians' requirements. Many doctors complained that they are compelled to spend 1–2 more hours on documentation-related activities during each shift, thus leaving them less time for actual patient care with the use of EMRs [10]. Under this situation, physicians have no way of determining a patient's overall health problems in time. Current EMR systems facilitate the rapid incorporation and collection of medical data but lack necessary functionalities for temporal queries and exploratory analysis tasks.

1.1.2 Prototype EMR Systems in the Literature

A considerable number of EMR approaches have been proposed to support high-level decision making and effective searching in the medical domain. LifeLines [11], the web-based interactive visualization system (WBIVS) [12], KNAVE II [13], LifeLines2 [14], LifeFlow [15] and OutFlow [16] are timeline-based tools used to organize and display medical records. These tools use dots to indicate time events and line segments to represent periods at which medical events occur along a horizontal time axis. Moving the mouse pointer over a line or double clicking on any line enables access to more details, while graphical attributes, such as color and line thickness, improve system display. Some other systems, such as Midgaard, focus on bodycentric data layouts that support patient data mapping with a template of the human body [17]. The Five Ws system [18] also uses a human body template presented at the center of a sunburst visualization, which allows doctors to immediately determine which parts of a patient's body are diseased and evaluate disease severity on the basis of color codes [19].

Although prototype EMR systems enable physicians to retrieve medical data on demand and provide valuable assistance for data analysis and decision making, most of these systems do not offer spatial and temporal medical information combined with a configuration that reflects within-medical record relationships. Few of these systems also support the classification of information on diseases. Ultimately, these deficiencies hinder the physician-patient link that enhances physicians' views and observations of medical conditions and self-treatment practices.

1.2 Motivation

Existing usability problems in current EMR systems were identified by the Health Information and Management Systems Society (HIMSS) [20] and typically revolve around the failure to adhere to EMR design principles, such as simplicity, naturalness, consistency, minimized cognitive load, efficient interactions, forgiveness and feedback, effective language use, effective information presentation and context preservation. The problems highlighted by the HIMSS underscore the need to find novel, integrated and intuitive ways of visualizing medical records. Correspondingly, the main motivation behind this work is the desire to determine a method of clearly displaying medical information in integrated views that show all kinds of medical data and the relationships among these data. A system underlain by these attributes is expected to enable a comprehensive description of patients' health information so that physicians can quickly understand their health conditions. The system would offer use efficiency and reduce cognitive load—affordances that necessitate an easily perceivable and uncluttered user interface that presents important medical information. Medical information is typically inaccessible to patients, who are thus frequently under-informed about their own treatment courses [21]. This work aims to address this problem by establishing a patient-centric information display system. Our system focuses on providing an interactive display for doctors to navigate and extract patient's medical information easily, and for patients to record and track their personal medical conditions and history.

1.3 Objectives

The core goal of this thesis is to design and implement a pictorial visualization system that displays spatially and temporally classified medical information over a problem- and position-based interface. An ideal EMR system should offer rapid and intuitive access to information in easily digestible amounts and meaningful formats. The interfaces of our system can resolve the inconvenience presented by longitudinal data and convert such data into structured form that reflects patients' medical histories, treatment plans and other related information. The spatial arrangement of medical records aligns with the principles that underlie the design of problem-oriented medical records (POMRs). Through our system, physicians can communicate directly with patients and exchange information on medical issues. We also provide a useful patient portal, which not only contains medical histories collated by health care professionals but also allows patients to enter symptom, self-medication and self-treatment data into the system.

The anatomical position-based display of the visualization system features clickable front and back images of the human body as an interactive navigation interface, which links to a description of health conditions to help patients/doctors quickly incorporate new records and easily review medical data. The system also consists of two clickable/zoomable timelines that show historical records on a common time axis. The first is the icon-based timeline, which reflects spatial medical events (diagnosis, medication, treatment, medical imaging and laboratory testing), and the second is the continuous timeline, which displays temporal data. Finally, the system's major disease display allows doctors to immediately obtain insights into important issues from complex historical records.

1.4 Contributions

The position- and problem-based interactive visualization system features two integrated displays, namely, the PHR and EMR interfaces, to enable physicians to view medical data, communicate directly with patients, and exchange information on medical issues with them. The contributions of this work are detailed as follows:

- We design two user interfaces with different input and output functions accessible to patients (i.e., PHR interface) and physicians (i.e., EMR interface) to ensure the simplicity and usability of the visualization system. The viewing and information exchange enabled by the system contributes to the derivation of health outcomes that can be better than those achieved with existing PHR systems. With the system, patients can monitor their health by entering symptoms (denoted by a dotted circular indicator) and self-medication/self-treatment data (represented by a solid circular indicator) for mapping into a position in a 2D representation of the human body.

- Medical information is spatially structured in the system. We use a problem- and anatomical position-based display with front and back views of a 2D representation of the human body. The system supports the use of several circular indicators (solid colored circle for diagnosis, dotted black circle for symptoms and solid black circle for patient self-medication/self-treatment), which can be located in the front or back view. This feature enables physicians to rapidly access and understand a patient's history and determine the presence of diseases.
- Our system contains an integrated physiological system and 11 individual physiological systems separated by color codes. These enable disease classification and allow doctors to survey and focus on certain diseases without delay. The individual physiological systems are the skeletal, muscular, immune, reproductive, cardiovascular, respiratory, digestive, nervous, endocrine, urinary and skin systems.
- The system offers two clickable/zoomable timelines that show historical records on a common horizontal time axis. The icon-based timeline shows spatial medical events that are clickable to obtain related information (e.g., medicine name, dosage, disease severity, treatment type). The continuous timeline displays temporal data from disease onset to recovery.
- Three types of information filtering are adopted to help users quickly access information.
    - The time filter can be used to perform scroll bar-navigated viewing of medical records for a selected year.
    - The button for the physiological systems or that for medical events can be clicked to access medical records on the basis of timelines. For example, users can apply

filtering so that they view only the medicines intended for the digestive system over a given timeline.

  - Our system provides a major disease timeline display. Some important medical events can be recorded as a major disease, and the timeline shows the events related only to major diseases.

1.5 Thesis Structure

The remainder of the thesis is organized as follows:

- Chapter 2 provides a background to EMRs, including basic definitions, concepts, users and components. It also presents an analysis of existing EMR systems and prototype PHR systems. Some popular commercial EMR systems are also examined.
- Chapter 3 discusses the system design and implementation. It begins with a description of the system's workflow and high-level architectural framework, after which it presents the techniques/tools used in the proposed system. The chapter likewise details the system's user interfaces and components.
- Chapter 4 presents users' feedback for the system. We use criteria for the usability of information visualization and the EMR criteria formulated by the HIMSS. Comments by two physicians and the benefits and limitations of our system are discussed.
- Chapter 5 concludes the thesis. It summarizes the components of the system and the advantages derived from it and briefly presents potential future work.

Chapter 2. Literature Review

This chapter discusses related research on EMRs, InfoVis and existing prototype EMR systems and commercial systems. First, we provide a background to EMRs, including EMR definitions, users, components and structures. Second, we present relevant background regarding InfoVis and visualization techniques. Finally, we discuss the advantages offered by existing prototype EMR systems and commercial systems.

2.1 EMRs

EMRs are usually defined in accordance with the definition of the International Organization for Standardization (ISO) [22]; that is, they are documents commonly used to describe past, current and prospective patient conditions in digital form, which allows health care professionals quickly and effectively to capture clinical data [23]. An EMR also includes information regarding patient demographics and administration, scheduling, billing, decision support, access control and policy management, order management, guidelines and terminology; recording, querying and analysis of population health; recording, querying and analysis of the services provided by health care professionals; recording, querying and analysis of business operations; and resource allocation [22]. Figure 2-1 illustrates a workflow in an integrated health information environment [24]. The figure should be read from the inside out, starting at the level of the EHR environment, from which some basic information on patient health and identification, drug data and e-prescriptions, among other data are available. The next level is the full functionality dimension, which comprises other hospital services, such as decision support, guidelines and protocols. The third level is the provider dimension, which presents additional services for public or private health information facilities. Figure 2-1: A health information environment presents the general landscape of EMR usage in a healthcare institution [22].

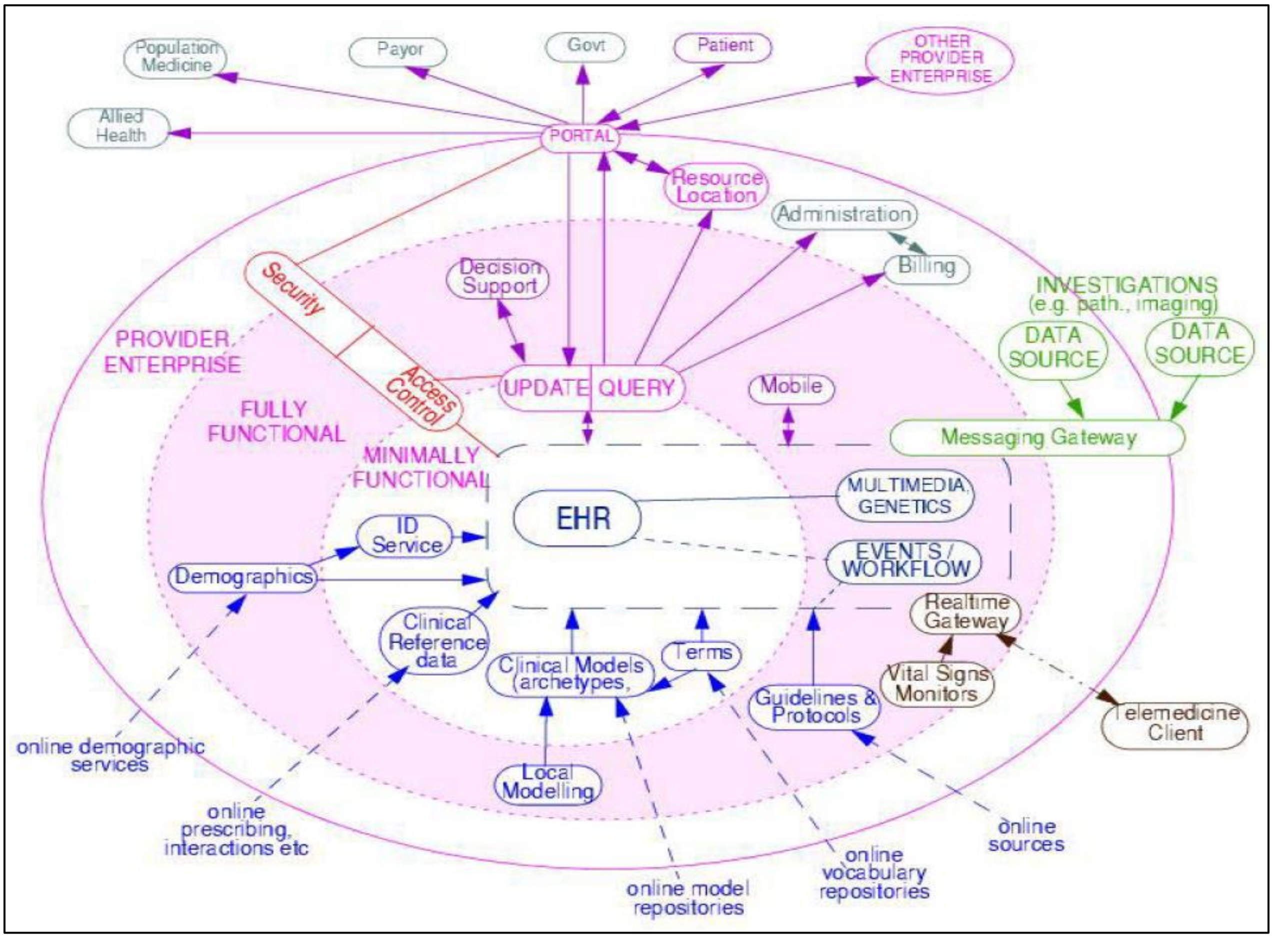


Figure 2-1: A health information environment [24].

2.1.1 Users and Components of an EMR System

EMRs are used by different health care professionals and some administrative staff, depending on health care situations. EMR users include [23] physicians, nurses, radiologists, pharmacists, laboratory technicians, clerk or administrative staff, secretarial staff and patients or their family members. The specific EMR system components that are accessed by EMR users are listed below.

- **Physicians**: Referrals, symptoms, medical histories, physical examinations, diagnoses, tests, procedures, treatments, medications, discharge data
- **Secretarial staff**: Procedures, problems, findings, immunization data
- **Pharmacists**: Medications
- **Nurses**: Daily charting, medication administration, physical assessments, nurses' admission notes
- **Patients/family members**: Histories, diaries, tests

2.1.2 EMR Structures

The structure of an EMR system has changed over time, with the earliest classification of EMR systems provided by the American Nurses Association [25]. Existing structures can be roughly categorized into three groups: time-oriented, source-oriented and problem-oriented medical records [26]. The traditional source-oriented structure has been used in hospitals since 1900 [27], and the time- and problem-oriented structures emerged around 1970. Currently, most EMR systems combine all three structures.

2.1.2.1 Source-oriented Medical Record

In a source-oriented medical record, data are grouped and organized in accordance with a hierarchy that reflects suppliers or sources of information. Sources can be individuals, such as physicians, nurses and secretarial employees, who are involved in a patient's care process. They can also be laboratory sources, such as tests (clinical chemistry, hematology, etc.), specimens (blood, urine, etc.) and substances (sodium, potassium, etc.) [27]. Source-oriented medical records facilitate the organization of medical information, but obtaining a complete medical record of this structure for each patient is difficult because of the presence of fragmented and separate medical providers.

2.1.2.2 Time-oriented Medical Record

By virtue of the label, time-oriented data are those related to time. Thus, a time-oriented EMR contains data on medical histories and physical examinations in structured form, and all medical data can be displayed in a flowsheet (2D data × time matrix) that enables the visualization of health evolution over time [28]. Each patient's medical data contain related laboratory values, a drug list and a partial list of major clinical manifestations [29]. A time-oriented summary can serve as the entire medical record, but access to detailed records is a separate additional option. A number of existing EMRs allow users to interact with data and time, as with browsing and searching with the help of a time axis. Figure 2-2 presents Midgaard temporal data with medical events on three linked time axes [30]. The Midgaard system integrates the display of different measurements (e.g., blood gas and blood pressure) and corresponding temporal abstractions at the overview level.

2.1.2.3 POMR

POMRs, which were introduced by Lawrence Weed [31], contain an index list that defines each medical problem. Specifically, notes are taken for each problem that corresponds to a patient, and each problem is described on the basis of subjective information, objective information, assessments and plans (SOAP) [32] [33].

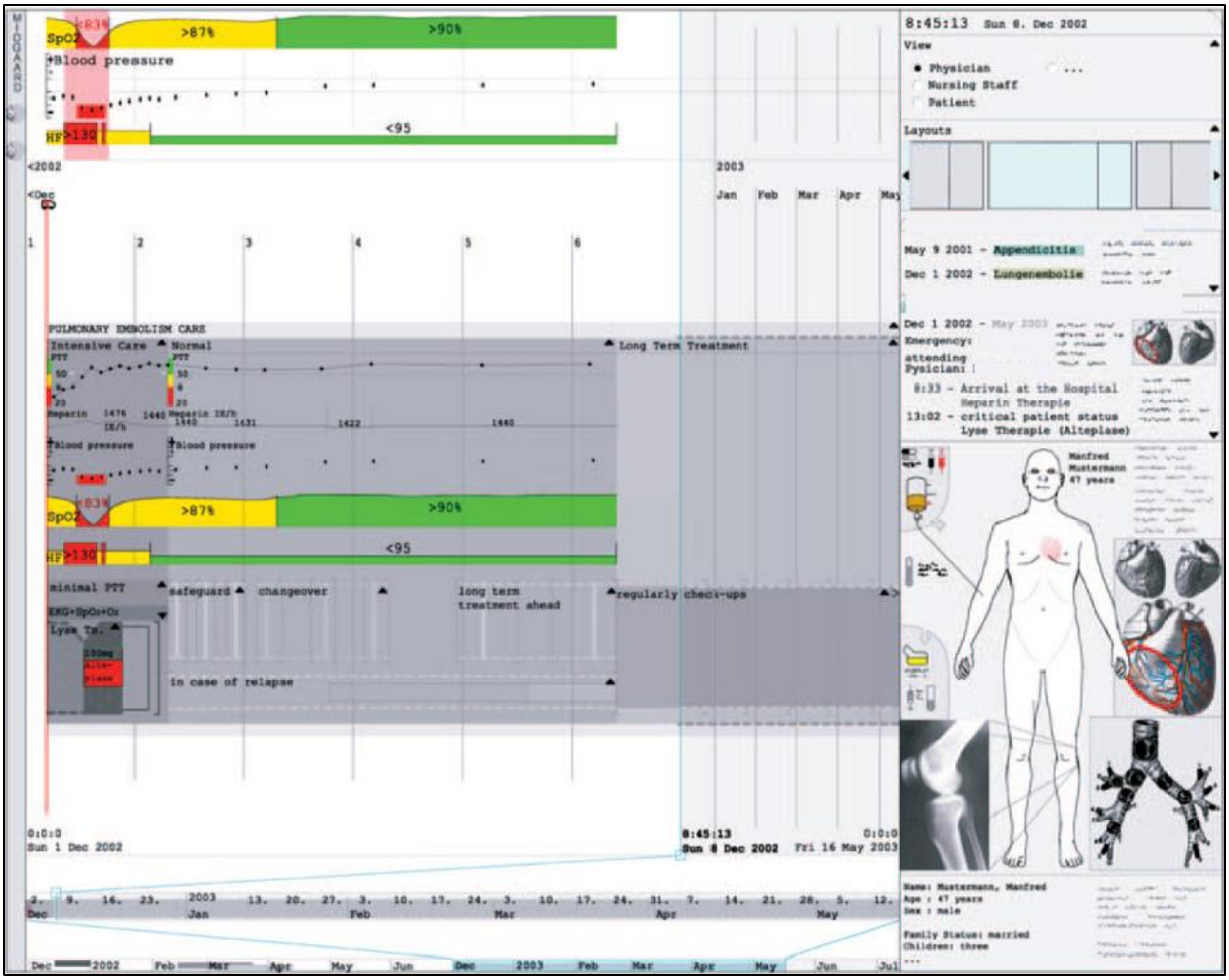


Figure 2-2: User interface of Midgaard [30].

- **Subjective information** [33]: Subjective observations include a patient's descriptions of pain or discomfort, the presence of nausea or dizziness, when a problem first started and other descriptions of discomfort or illness described by the patient.

- **Objective information** [33]: Objective observations include symptoms that can be measured, seen, heard, touched, felt or smelled. Included, as well, are vital signs, such as temperature, pulse, respiration, skin color and swelling.
- **Assessments** [33]: Assessments provide information on the diagnosis of a patient's condition. In some cases, the diagnosis may be clear, such as a contusion.
- **Plans** [33]: A plan may include laboratory and radiological tests ordered for a patient, medications prescribed, treatments performed, patient referrals, patient disposition, patient directions and follow-up directions for the patient.

A POMR consists of a complete list of a patient's problems and provides progress notes related to each problem rather than the usual notes on present illness. Two principles underlie the structure of a POMR. The first is focus on individual problems, which means that a set of relevant medical data are associated with a single problem. For example, the associated medical information displayed for a patient with diabetes mellitus [27] includes a selection of medical data, such as blood glucose level and insulin medication. The second principle is that an SOAP within a medical record should reflect a physician's manner of thinking [27].

2.2 InfoVis

InfoVis focuses on representing data in a way that is easy to understand and manipulate for such data to be useful in daily life. InfoVis is connected with interaction and visual representation for improved interactive demonstration of data and information [34]. This section briefly introduces InfoVis, after which it presents some popular InfoVis programming toolkits

(Improvise, Google Charts API, Google Map API and data-driven documents (D3)). Representative InfoVis techniques and InfoVis examples are also discussed.

InfoVis is the study of visual representations of abstract and complex data; it reveals hidden patterns for the purpose of reinforcing human cognition [35]. If a dataset is excessively large and contains too much text, tracking ideas from the entire dataset will be difficult. A report from the US Institute for Medicine (IOM 2011) stated that “information visualization is not as advanced in parts of clinical medicine as compared with other scientific disciplines” [36]. Currently, InfoVis is widely used in many sectors that require data analysis [37], such as business [38], science [39] and sports [40].

2.2.1 InfoVis Toolkits

InfoVis has attracted considerable research attention and development. Researchers have introduced a number of tools that provide rich options for visually exploring data. This section describes some programming toolkits that are popularly used to present live data and allow user interaction.

- **Improvise**: Improvise [41] is a fully implemented system, in which users interactively build and browse multiview visualizations of relational data via simple shared-object coordination. It enables users to interactively load data, create views, specify visual abstractions and establish coordination. Improvise is written in Java, and visualizations are saved to and loaded from a disk by using an XML document. Improvise and the documents produced with it are independent of platforms. It allows users to build highly coordinated visualizations combined with live properties and coordinated queries (Figure 2-3).

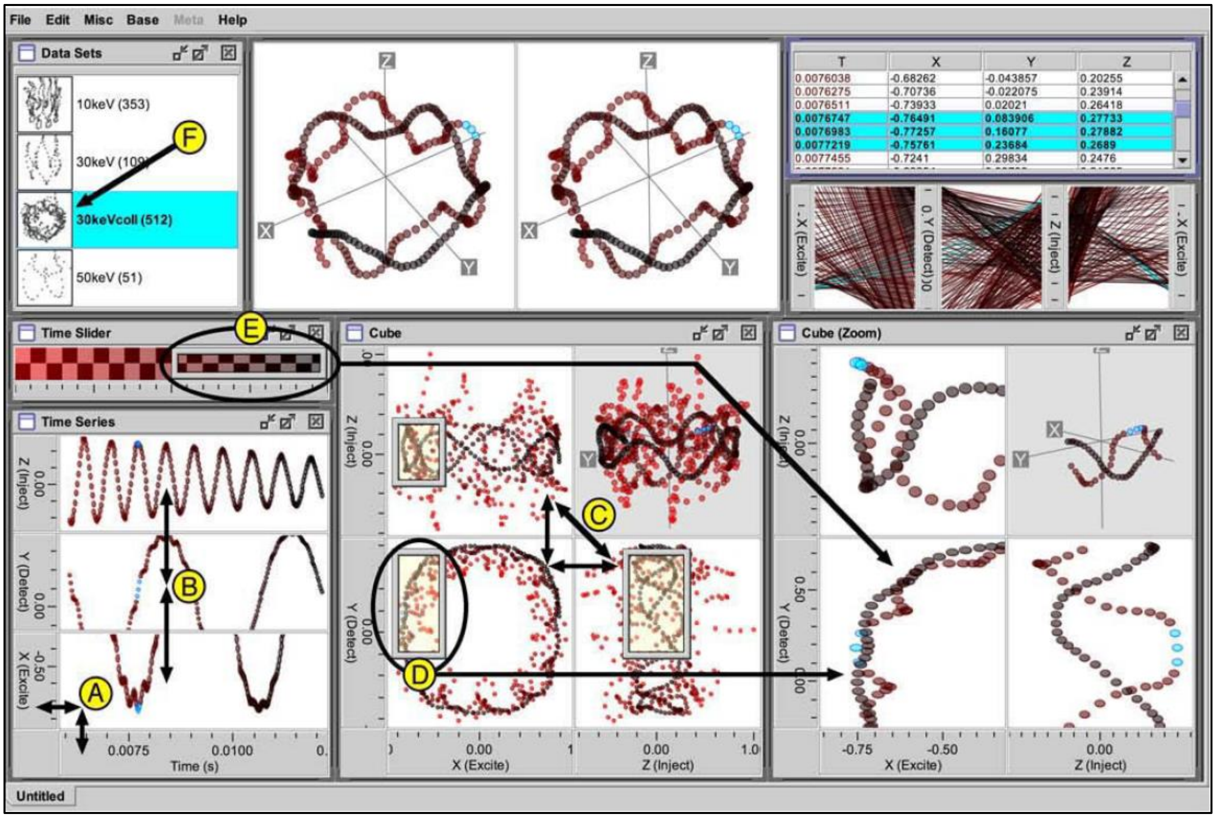


Figure 2-3: Visualization of a simulated ion trajectory in a cubic ion trap using Improvise [41].

- **Google API**: With Google Chart Tools, users can create charts from data sources and display them on various browsers and platforms because Google Charts are based on HTML5. Google API supports many basic chart types, including pie charts, scatter charts, gauge charts, line charts, bar charts, treemaps, combo charts, line charts, bar charts, column charts and area charts [42]. Google Charts can also be used to display other types of visualized information, such as timelines. Users can create a variety of visualizations by combining Google API toolkits. Figure 2-4 shows a visualization of geocoded data from Wikipedia articles [43]. The designer intended to allow users to search and acquire directions to the location of a Wikipedia article.

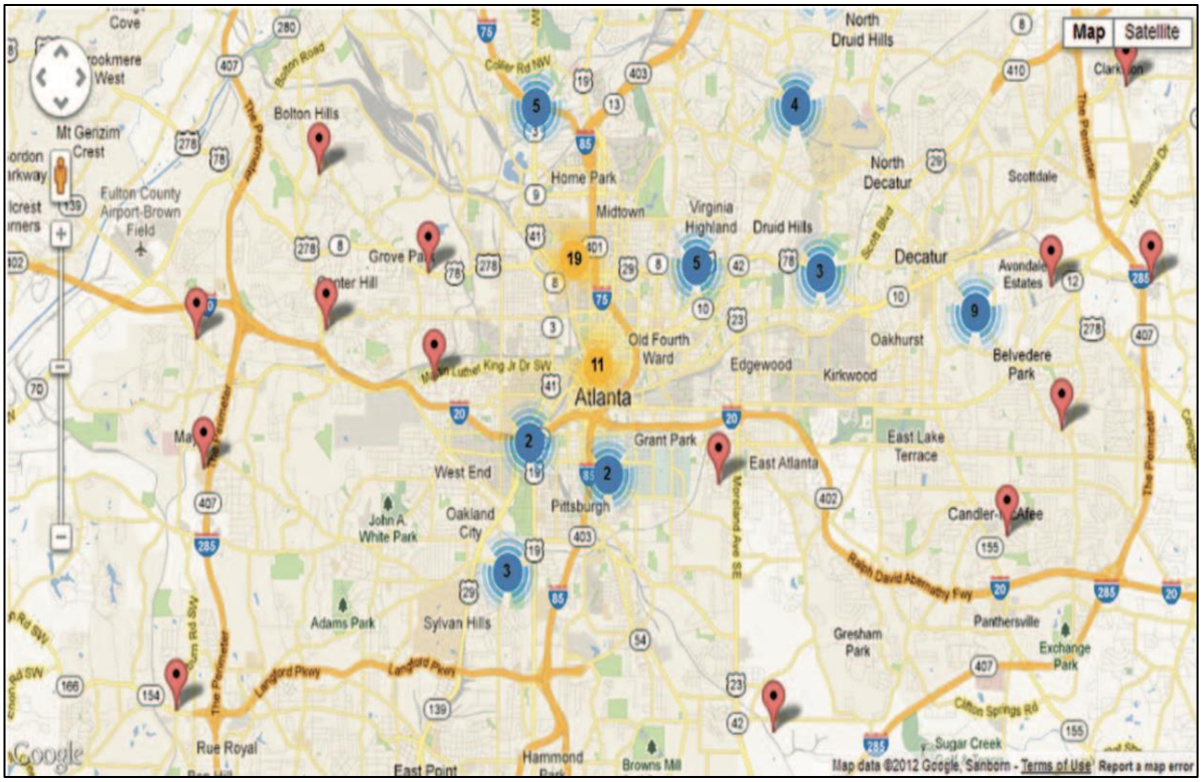


Figure 2-4: Google API Toolkits was used to create this visualization of geocoded Wikipedia articles. The circles are marker clusters. Users can conduct spatial queries on the map [43].

- **D3**: D3 is a very popular toolkit used to display InfoVis data on the web. It is a JavaScript library that brings data to life by using HTML, SVG and CSS [44]. D3 enables the direct inspection and manipulation of data for conversion into a Document Object Model (DOM) that exposes the hierarchical structure of page content. For example, users can use D3 to generate an HTML table from an array of numbers or use the same data to create an interactive SVG bar chart with smooth transitions and interactions [45]. D3 ensures easy dynamic visualization and fast implementation as well as supports large datasets and dynamic behaviours for interaction and animation. Figure 2-5 shows interactive visualizations built with D3.

Figure 2-5: Some interactive visualizations built with D3. Left to right: Calendar view, chord diagram, choropleth map, hierarchical edge bundling, scatterplot matrix, grouped and stacked bars, force-directed graph clusters and Voronoi tessellation [44].

2.2.2 InfoVis Techniques and Examples

InfoVis design highly depends on underlying data and then the best approach to displaying the data is chosen. Different data have different characteristics and patterns, which need specific techniques for visualization. In dealing with data, understanding information distribution is usually key to solving many problems. In this section, we describe several popular InfoVis techniques and InfoVis-based analyses of different data types.

- **Treemap**: In the 1990s, tree structures represented by node-link diagrams grew too large for effective use, thus prompting the development of treemaps, which display trees in a space-constrained layout [46]. A treemap displays tree-structured data by using a set of nested rectangles. Each branch of the tree is shown in a rectangle, which can be divided into smaller rectangles to illustrate sub-branches. Leaf nodes are often characterized by different size attributes to show proportion and different colors to show specific data. A treemap enables users to compare nodes and sub-trees even at varying depths in a tree, thereby affording users the legibility required to simultaneously display thousands of items on a screen. A successful application of treemaps for product search and display was achieved by Hive Group (Figure 2-6). The treemap provides daily updates on more than 34,000 products from Amazon.com, thus allowing users to view all the products, compare prices and refer to customer ratings. Such treemap can help users immediately find what they need to make a purchasing decision.

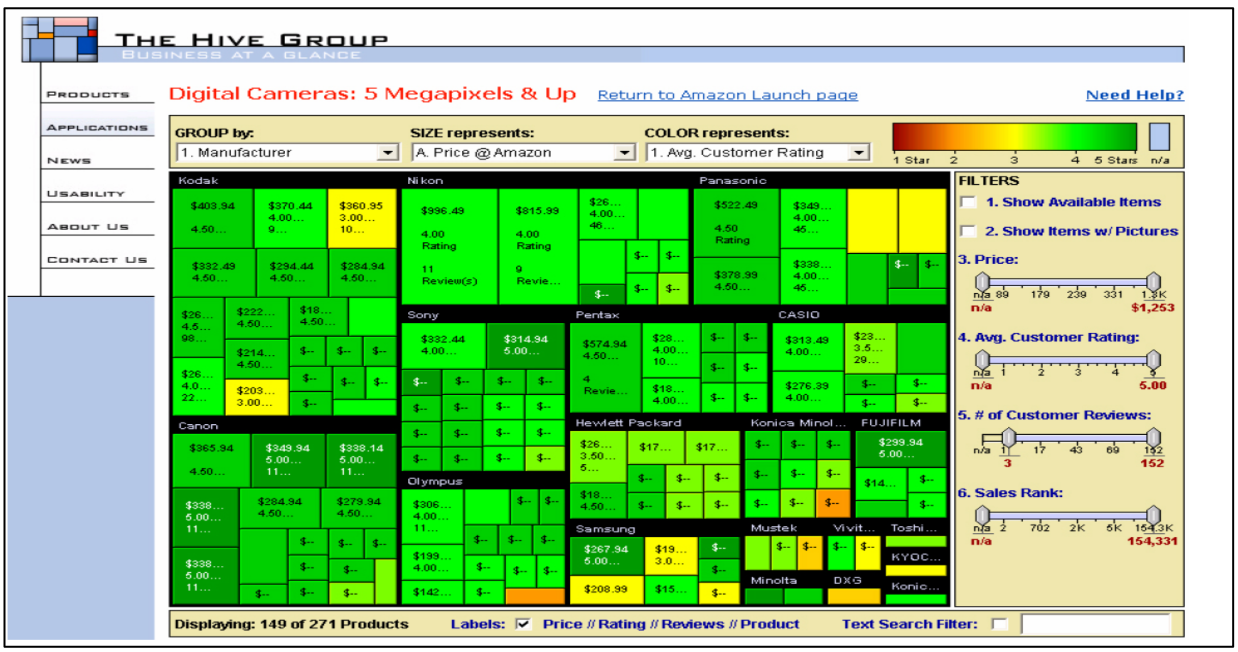


Figure 2-6: Treemap that displays Amazon's digital camera offerings, grouped by manufacturer, sized by price, colored by average customer rating [47].

- **Parallel coordinates**: Parallel coordinates were first designed by Alfred Inselberg [48] in the 1970s as a way of visualizing individual data elements in multivariate datasets. Only several dimensions can be shown on most standard charts, but parallel coordinates can help illustrate many dimensions. Each dimension is drawn with parallel lines on a vertical axis, and each data element is represented as a polyline along dimensions [49]. Specifically, the lines in parallel coordinates connect different variable values, which measure multiple aspects of an item, such as home value, farm acreage and average income (Figure 2-7). Figure 2-7 consists of 3,138 lines, one for each county in the United States. The parallel coordinates can be used to compare and highlight the factors required in interactive analysis. In this case, a user can look at the profiles of the 10 counties with the largest populations. Highlighting the values of the populations automatically highlights the corresponding lines.

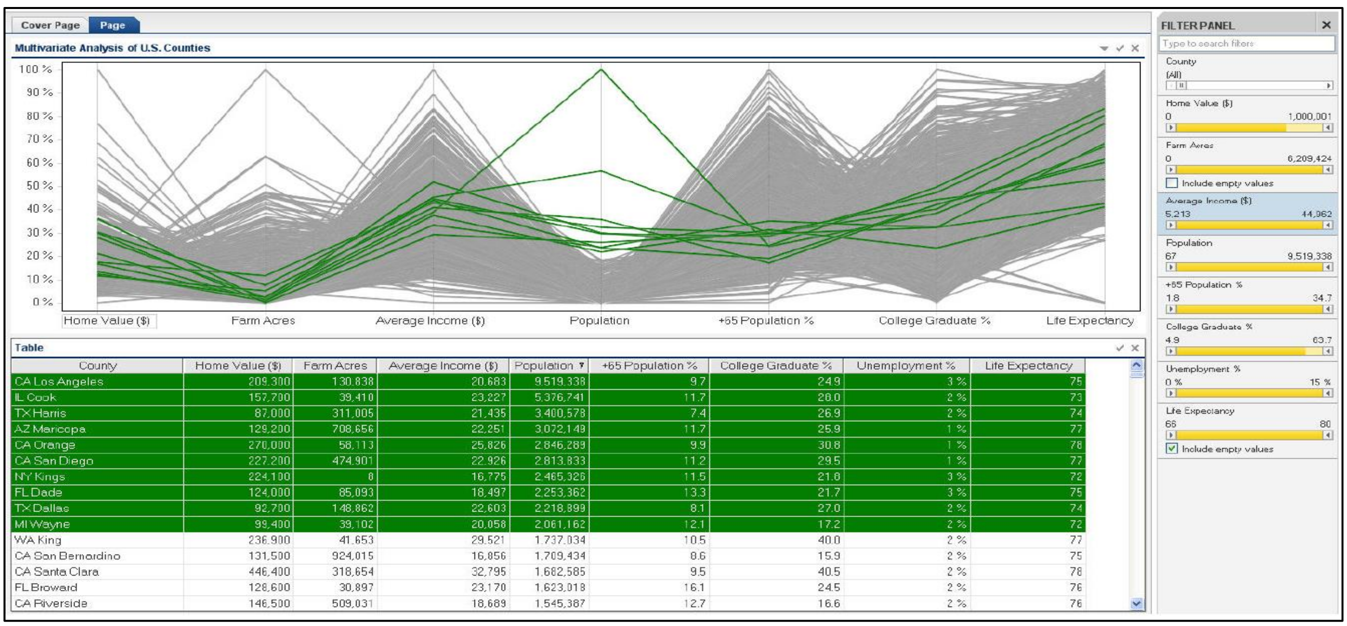


Figure 2-7: Parallel coordinates showing multivariate analysis of US counties, highlighting the 10 counties with the largest populations [49].

- **Sankey diagram**: A Sankey diagram is a type of flow diagram, wherein width illustrates flow quantity. One of the early examples of a Sankey diagram is Charles Minard's Map of Napoleon's Russian Campaign of 1812 [50]. Generally, a Sankey diagram visualizes energy distribution and transformation processes. It presents directed weighted graphs that satisfy flow conservation: the sum of incoming weights for each node is equal to outgoing weights [51]. Canadian Energy System Analysis Research (CESAR) created Canada's energy systems [52] by using a Sankey diagram. The systems show sources and usages of energy and emissions across Canada and therefore helps people understand the challenges that we face and identify alternative pathways to a more sustainable future. Canada's 2010 energy system [53] is shown in Figure 2-8, where resources are positioned on the left-hand side of the diagram, and services appear on the right-hand side.

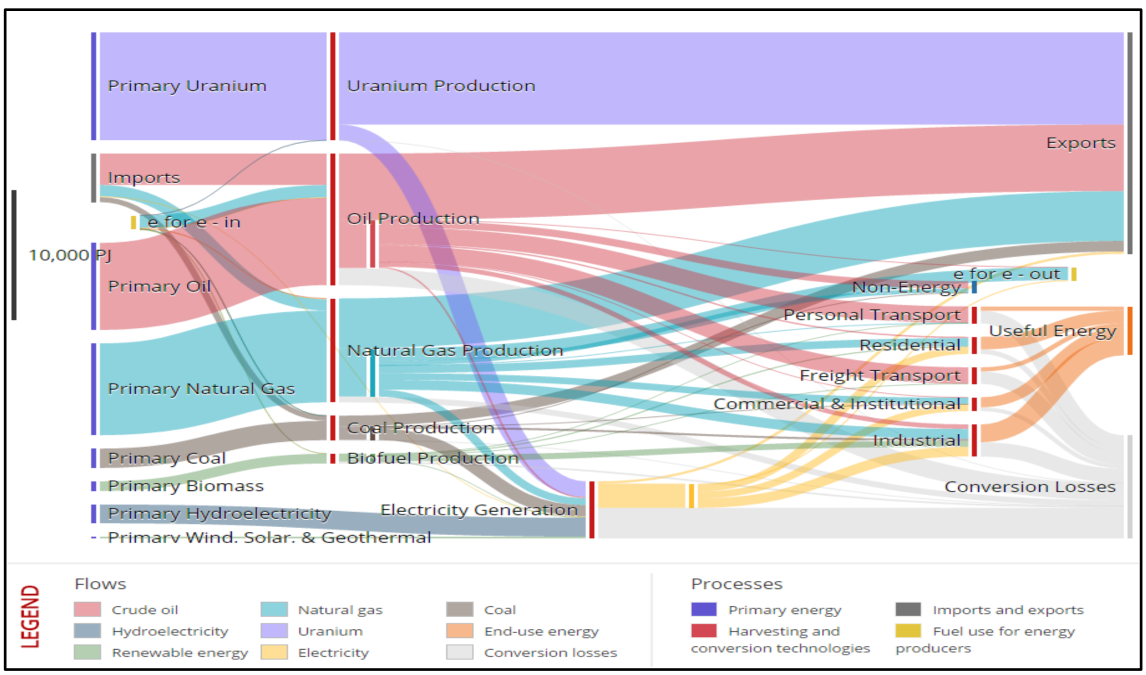


Figure 2-8: Sankey diagram showing Canada's energy system in 2010 [54].

- **Force-directed graph**: A force-directed graph interactively represents network visualization, thereby enabling the easy rearrangement, filtering and exploration of connected data. A force-directed graph is essentially a physics simulation. Because nodes possess a negative charge, they repel one another; each link binds to its corresponding nodes and holds these links together. The pushing and pulling forces work on the network to enable the identification of spots where adjacent nodes can be positioned near, but not excessively close, to one another [55]. Neal Caren [56], from the University of Carolina, generated a network of sociology by using a force-directed graph to display the relationship of two works cited in the same journal article (Figure 2-9). Each node in the network corresponds to a paper that was cited in journals between 2008 and 2012. Links were created between the two works when they were cited in the same article [57]. The graph serves as a good representation of contemporary trends in sociology. Some of the areas involve large quantities of works that are frequently mentioned together, whereas other areas are more sparsely connected.

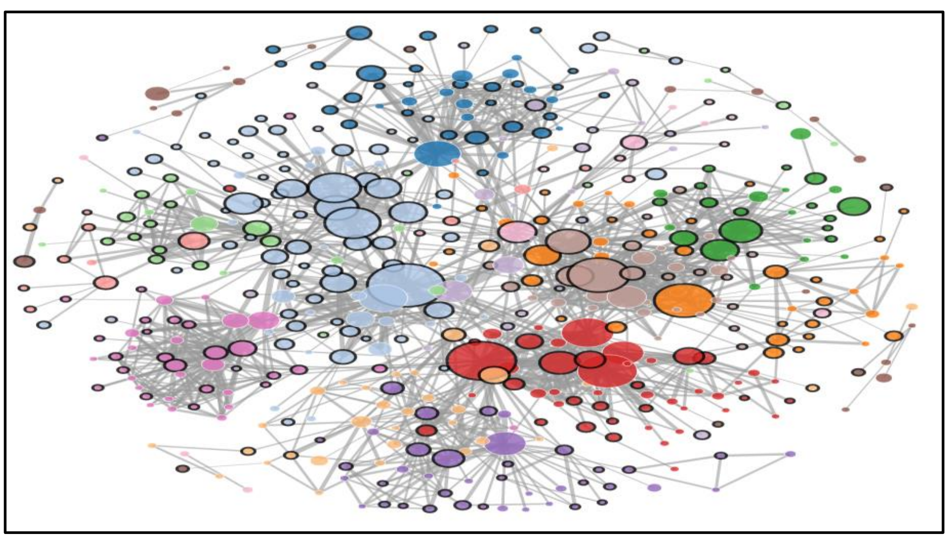


Figure 2-9: Force-directed graph showing a sociology citation network [56].

From several InfoVis toolkits and techniques in previous two chapters, InfoVis can represents large dataset and convey meaningful information quickly. Since EMR system contains a large amount of dataset, we adopt Google Visualization API and D3, which make our system interactive for use.

2.3 Existing EMR Systems

Numerous visualization approaches have been proposed for medical patient records, and new systems are emerging because of the extensive use of EMRs. This section describes state-of-the-art prototypes of InfoVis systems for EMRs and PHRs and discusses interesting commercial EMR systems, such as EpicCare, Allscripts and eClinicalWorks.

2.3.1 Prototype Systems

As previously stated, medical decision making is a complex process that requires physicians to retrieve useful data from large amounts of information, such as patient status, medical history and past and ongoing treatments. All this information is integrated in an EMR. This section comprehensively describes the most representative prototypes of EMR and PHR visualization systems, complete with figure descriptions.

2.3.1.1 Prototype EMRs

- **Lifelines**: Lifelines was developed and released in the late 1990s by the University of Maryland [58]. It is one of the earliest systems for visualizing patient data summaries, with the system featuring graphical attributes, such as colors and lines, to show patient medical events. On the basis of electronic health data, Lifelines provides a timeline of a single patient’s historical events; time is displayed on a horizontal axis, and medical events (problems, allergies, diagnoses, laboratory tests, imaging, medications, immunizations and communications) are listed on a vertical axis [59]. The system centers on the display of many medical variables on the same screen so that users can effectively retrieve information.

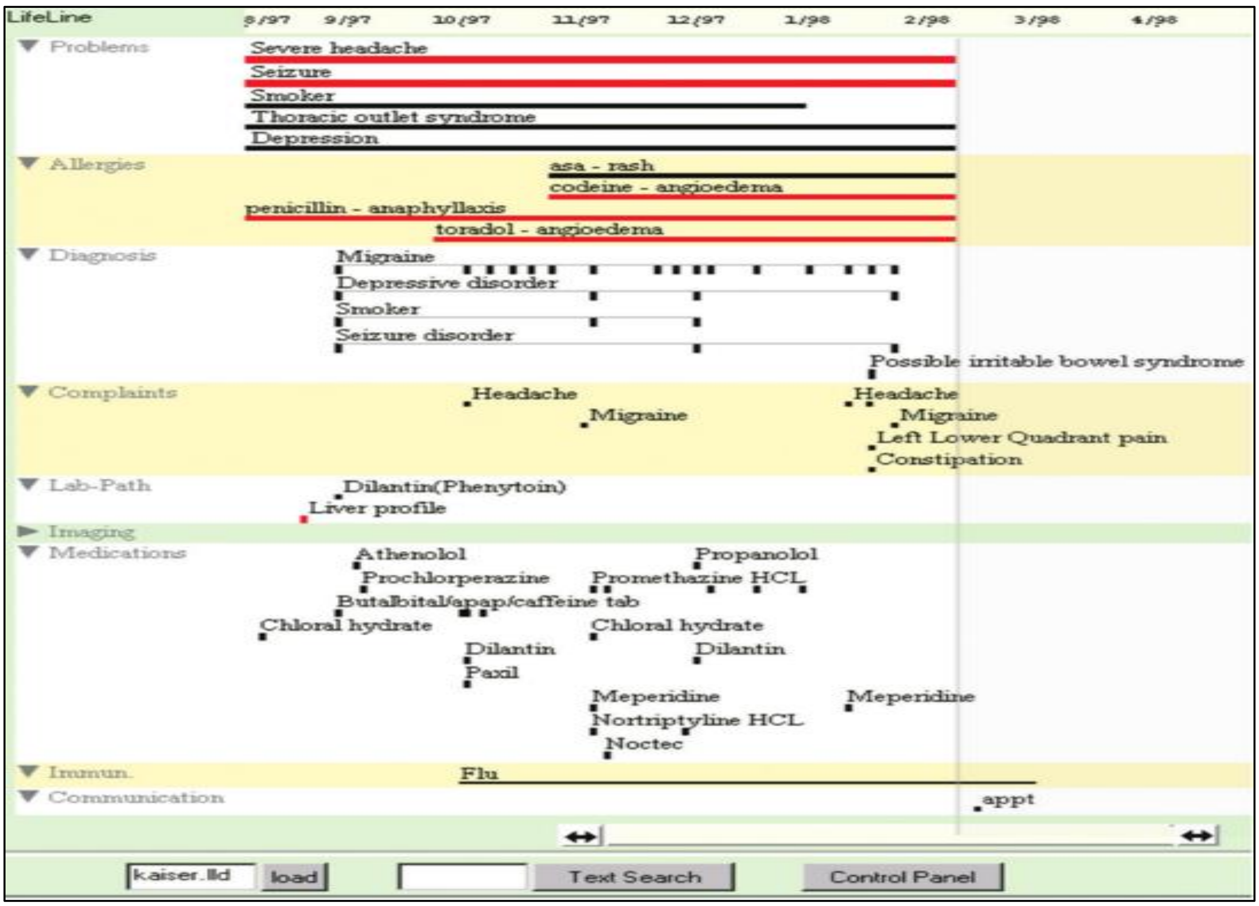


Figure 2-10: User interface for Lifelines [58].

Figure 2-10 shows 32 different events. Lines are segmented on a horizontal time axis, to which users can zoom and pan to view more or fewer details; line color and thickness illustrate relationships and significance, respectively. Users can also double click on any line segment to access relevant documents and images. Along the vertical axis, people can choose different types of events, such as notes, tests and medications.

- **Lifelines2** [60]: Lifelines2, an extension of Lifelines, enables the effective display, search and querying of multiple patients' medical records. Some researchers found that users are more likely to see both numerical and categorical data when looking at patient records [61]. In Lifelines2, therefore, each patient record has a common timeline and a list of color-based categorical variables (Figure 2-11). Users can switch timeline views from a range of periods to absolute calendar views to see the number of events or detailed events. Lifelines2 also comes with the Align-Rank-Filter (ARF) framework, which enables users to manipulate the visualization of temporal event data [62]. For example, users can align all records by a specific event type (e.g., heart attack), and every record's documentation of a first heart attack is aligned vertically. Other records that do not document heart attacks are filtered out.

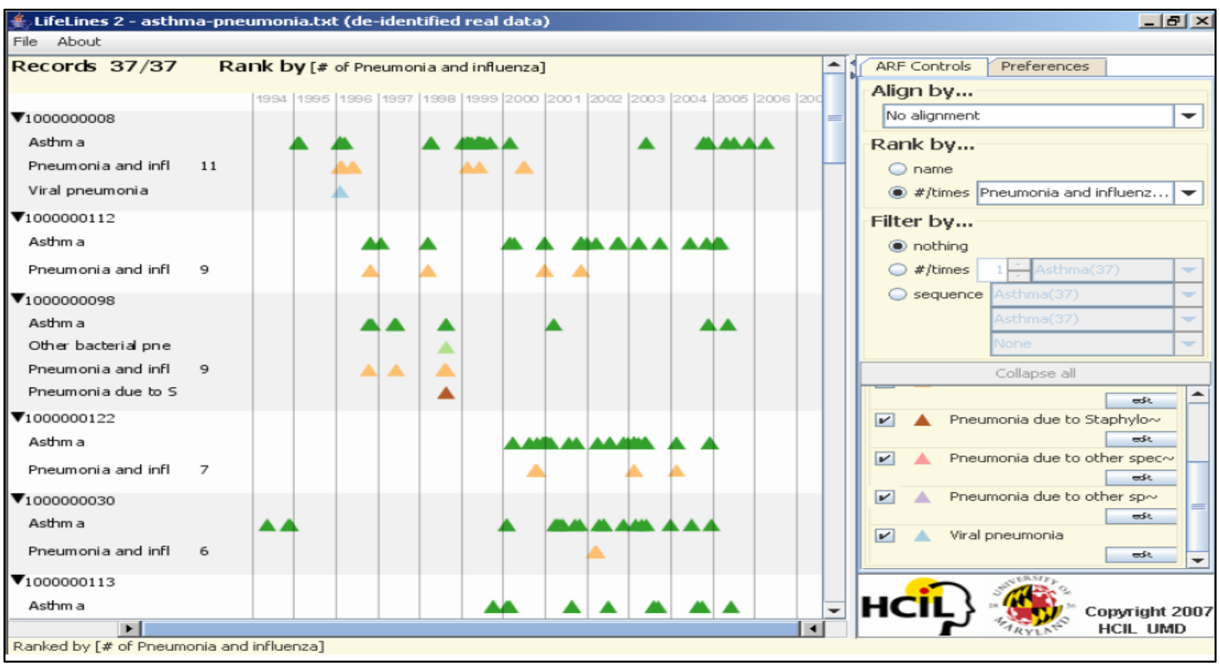


Figure 2-11: User interface for Lifelines2 [60]. Each row shows a record, with its ID on the left. Each record contains several types of events listed below the ID. Each type is color coded, with a colored triangle on the timeline.

- **VIE-VISU** [63]: VIE-VISU is a system that presents a patient's status in the last 24 hours of stay in ICUs. Metaphorical graphics are used to illustrate the highest number of parameters (15 variables in total) for a patient's situation. These parameters include circulation (blood pressure, heart rate, etc.), respiration (breathing frequency) and fluid balance (total fluid intake and output). Through repetition of a graphical object in 24 frames, an ICU patient's situation is presented in one display. Each glyph (Figure 2-12(a)) uses the same measures and scale so that doctors can easily compare them and identify an abnormal situation. VIE-VISU generally shows 24 glyphs, one per hour (Figure 2-12(b)).

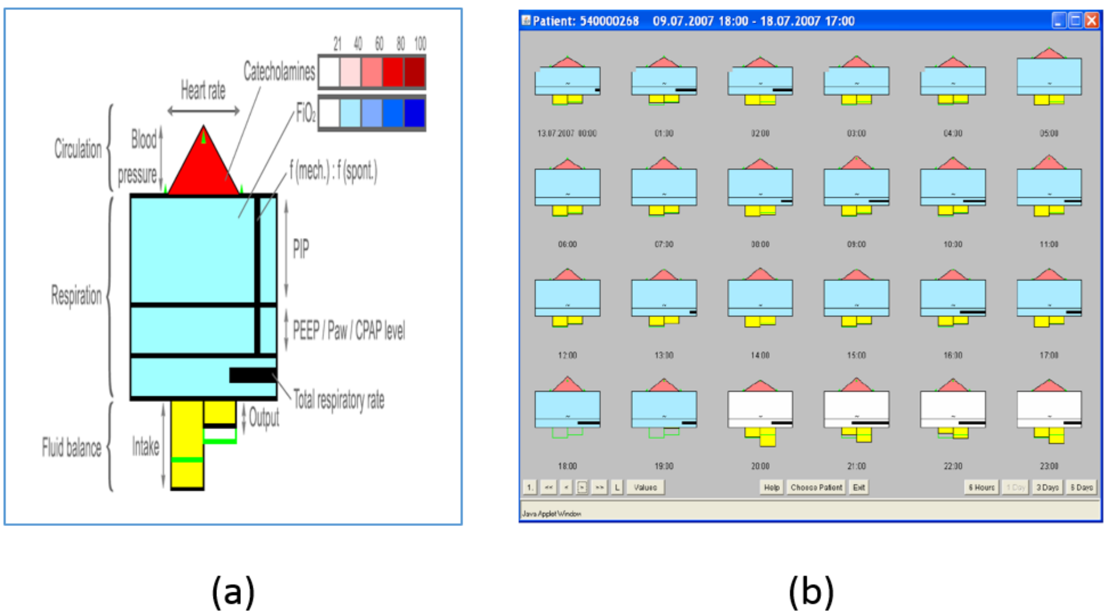


Figure 2-12: VIE-VISU [63]: (a) Visual encoding of medical variables in VIE-VISU. (b) Default VIE-VISU user interface.

- **VISITORS** [64]: VISulizatIon of Time-Oriented RecordS (VISITORS) is the first system that focuses on groups of patients, for whom intelligent temporal analysis and InfoVis techniques [65] are combined (Figure 2-13). The system fosters decision making based on high abstractions and allows users to search raw data. The VISITORS system entails five steps in accessing patient records: (1) specification, (2) retrieval, (3) visualization, (4) interactive exploration and (5) knowledge-based analysis. The results of usability testing indicated that the system is useful for exploring longitudinal data that physicians need to make clinical decision [64]. The drawback to VISITORS is that its user interface needs simplification because learning how to navigate the system usually entails a long time [59].

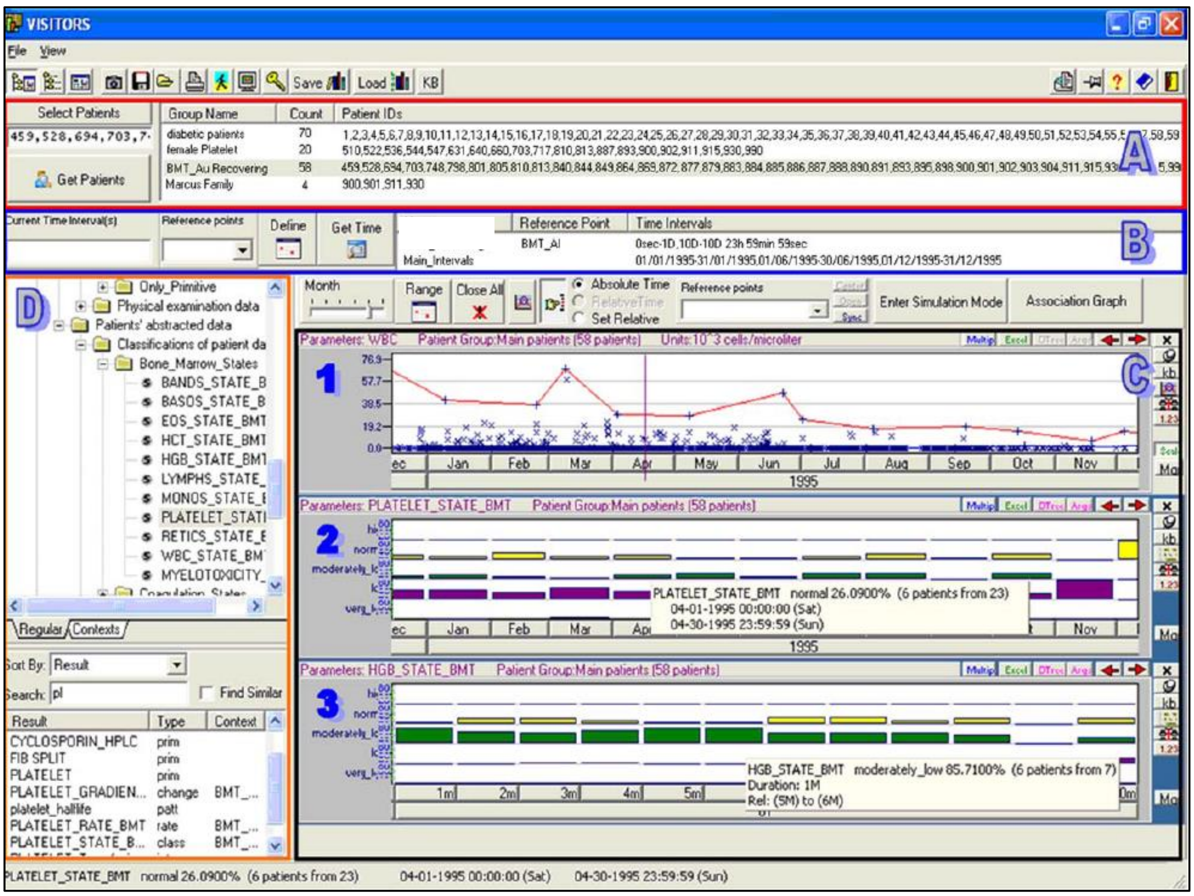
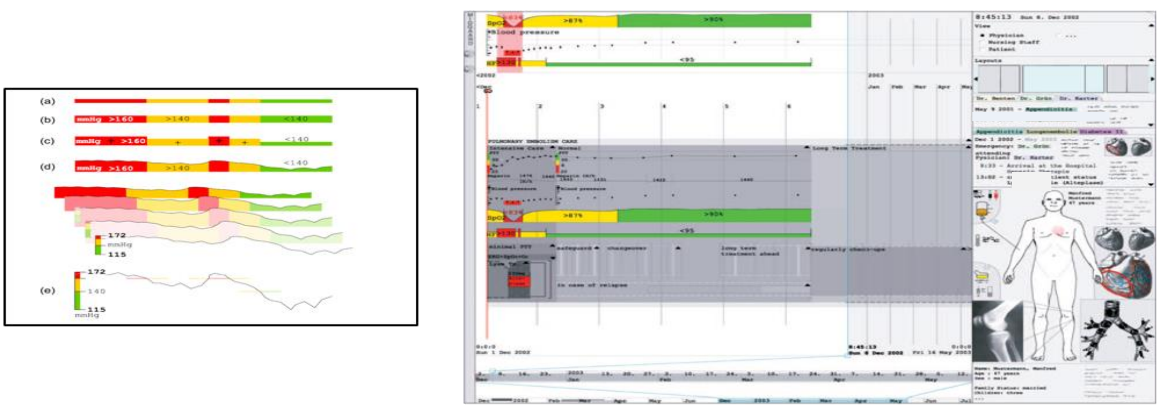


Figure 2-13: The VISITORS main interface for showing patient status [64]. (a) Lists of patients. (b) Lists of time intervals. (c) Data on a group of patients' white blood cell count raw concept (graph 1), data overview of monthly distribution of platelet-state values (graph 2) and monthly distribution of the values of hemoglobin-state concept (graph 3). (d) Medical ontology.

- **Midgaard** [66]: Midgaard is a visualization system designed for ICUs. It provides a time visualization and navigation technique that connects overviews and details, pan and zoom functions and focus and contextual features [67]. Depending on zoom level and available screen area, Midgaard provides details (Figure 2-14(a)) over three visual formats: (a–b) a colored background, (c) colored bars and (d) area charts or (e) augmented line charts. A time series of blood pressure measurements, for example, can be abstracted to periods of normal blood pressure (green), increased blood pressure (yellow) and critical blood pressure (red). The system likewise provides three connected timelines to enable users to obtain both an abstract data overview and a more finely structured view. At the bottom of the screen appears a fixed overview of data and their full temporal range [68]. Finally, the Midgaard system comes with a visualization method that connects patient medical records to a 2D representation of the human body (Figure 2-14 (b)).



(a) (b)

Figure 2-14: Midgaard's [66] (a) steps in resizing or zooming in on the representation of a data stream. (b) Screenshot of the implemented prototype for intensive care and long-term patient treatment.

• **MIVA** [69]: The Medical Information Visualization Assistant (MIVA) provides valuable assistance for large and diverse data analysis and decision making in ICUs. This system can show medical data from related biometric devices that are used by health care providers in an ICU; it also has a built-in decision-making process that displays abnormal data in visualized form for improved response to a patient event that requires immediate attention [70]. Figure 2-15 is a MIVA screenshot, in which point plots show changes in numerical values over time. The gray band in the background denotes the normal range of a variable, to which users can zoom and pan. The clinical and intervention notes entered by clinicians at the top of the screen are designated with icons above the visualization display.

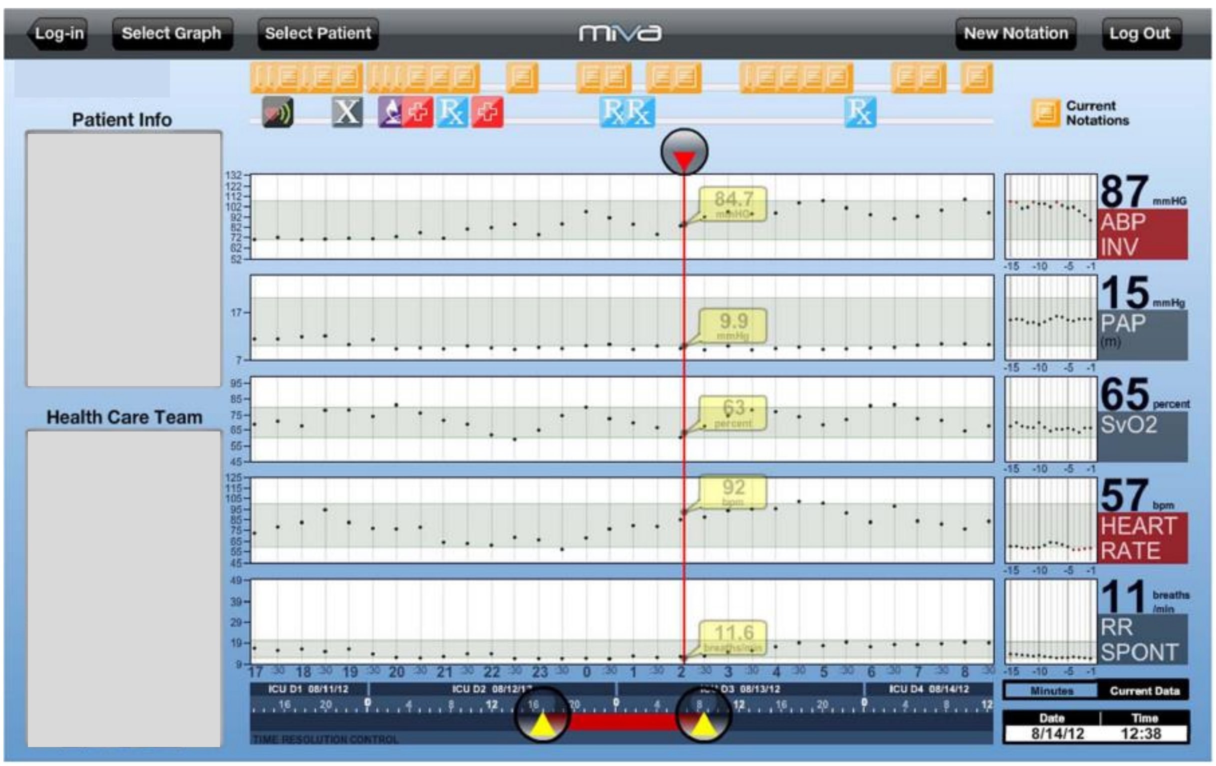


Figure 2-15: Screenshot of MIVA [69], with the control panel and data visualizations. Clinical and intervention notes are entered by clinicians at the top, designated with icons above the visualization display.

• **Five Ws**: The Five Ws system [71] has become a popular EMR system because it presents various medical history data, including current symptoms, history of present illness, previous medication, previous and ongoing treatments, allergies, family history and other related information. In the system, a patient is represented as a radial sunburst visualization that captures all health data, which serve as a quick overview for an examining physician [59]. The patient's body map functions as a navigational feature, to which users can zoom in to access additional anatomical details. On the basis of a physician's medical diagnostic chain, the system captures all aspects of a patient's medical data in narrative form that reflects the who, when, what, where and why of the patient's condition [72]. To summarize, this system provides a hierarchical radial display with an integrated body outline (Figure 2-16) and a sequential display for diagnostic chains (Figure 2-17) [71].

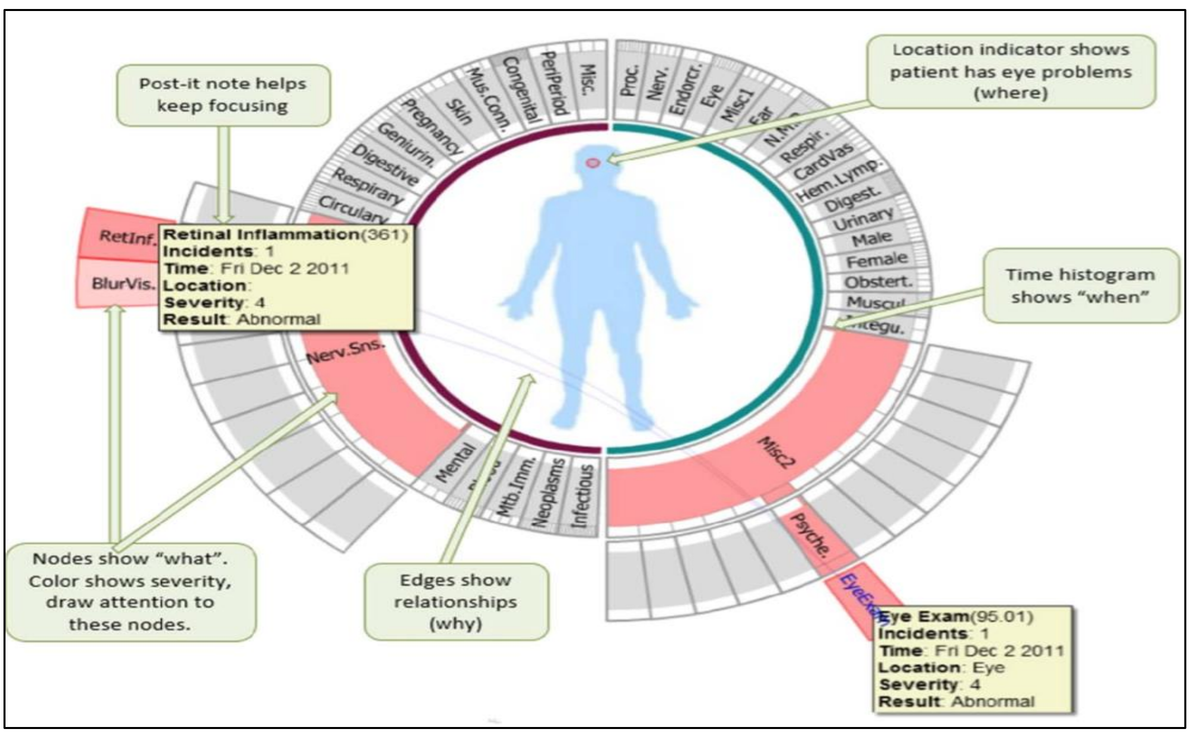


Figure 2-16: Radial display with body map, along with ICD name in Five Ws system [71].

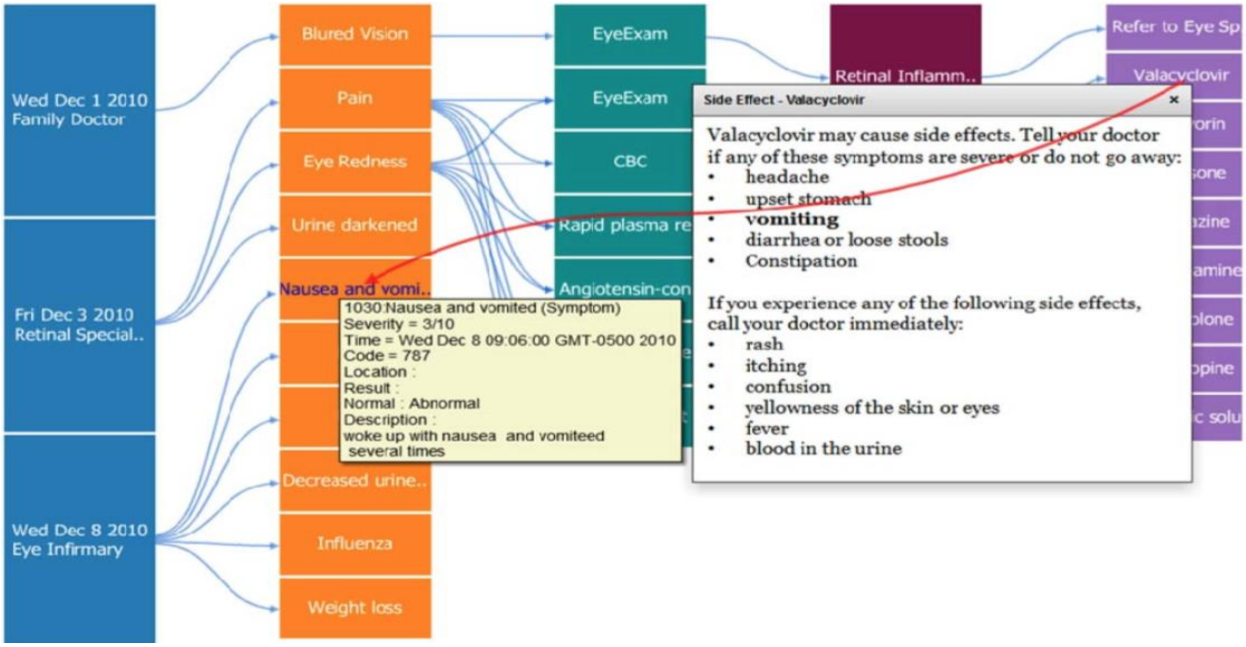


Figure 2-17: Diagnostic reasoning display using color coding in the Five Ws system [71].

2.3.1.2 Prototype PHRs

Few user interfaces for PHR systems have been developed because some PHRs are integrated into EMRs [73] [74]. This section discusses pure PHR systems.

- **WellMed Personal Health Record**: The WellMed system is a web-based application developed by the University of Maryland in 2002 to enable patients to enter their own information into their PHRs [75]. The system is aimed at providing patients opportunities to update their medical information (e.g., diagnoses, medications, laboratory tests, diagnostic studies and immunizations). Figure 2-18 shows a sample patient’s past and current medication information, which contains the medicine name, date, intake frequency and disease symptoms. The system also allows patients to add medications or remove current medications.

- **PatientKB**: Patient knowledge base (PatientKB) [76], developed in 2006, is a tool that links data from a patient's medical record with relevant health information. It is used to connect to the ISCO patient database, from which patient numbers and diagnosis items can be extracted and from which patients can simply and easily review medical information. The system helps patients quickly understand their health conditions by providing medical summaries, diagnostic and treatment data, appointment data and web search functionality. Figure 2-19 illustrates how patients are provided customized, secure and convenient access to medical details (diagnoses) and relevant information.

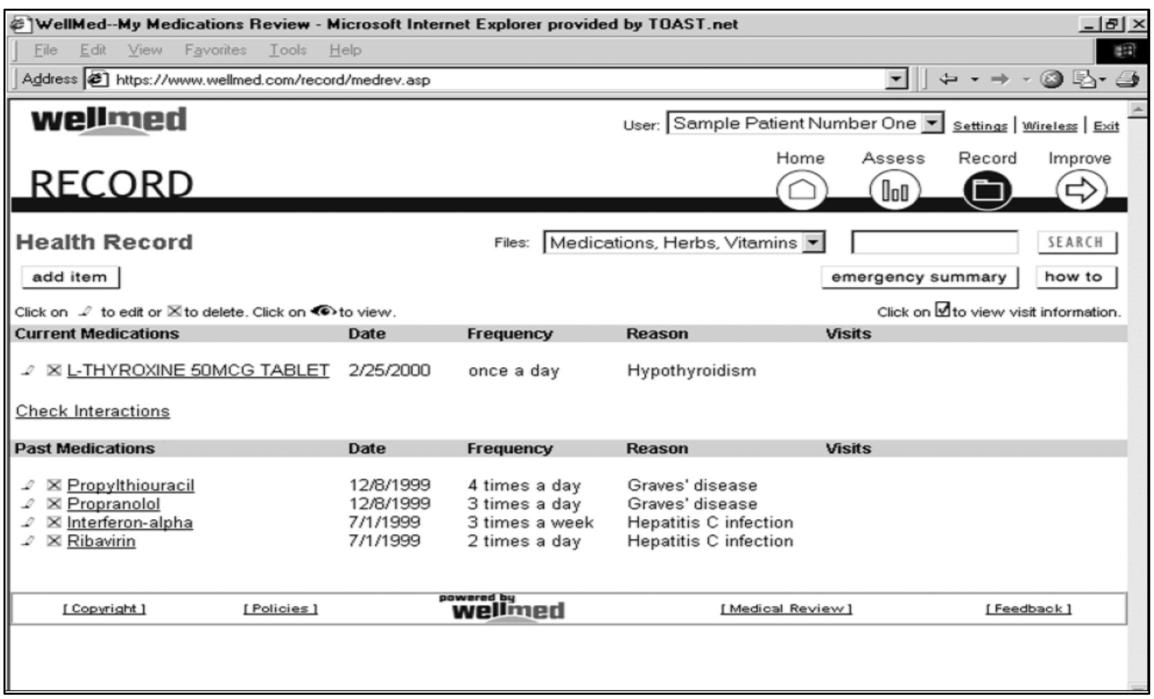


Figure 2-18: WellMed Personal Health Record screen displaying current and past medication information [75].

Figure 2-19: Patient diagnoses page in PatientKB [76].

2.3.2 Commercial EMR Systems

Extensive work has been devoted to examinations of scientific state-of-the-art commercial EMR systems. The Electronic Health Records (EHR) Incentive Programs [77] noted that as of July 2016, 337,432 health care providers have participated in the meaningful use of certified EHR technology (Figure 2-20). The extensive adoption of EHR technology dictates an inquiry into existing commercial systems. However, a number of difficulties are encountered in describing and comparing commercial systems [68]. Many of them require payment and adherence to legal requirements, thereby limiting access to medical professionals. They are acquired from national or regional software providers and are unavailable to the public. Finally, screenshots are not always available. Given these restrictions, access to the cases documented in a system, internal evaluations or the acquisition of user population data are unlikely.

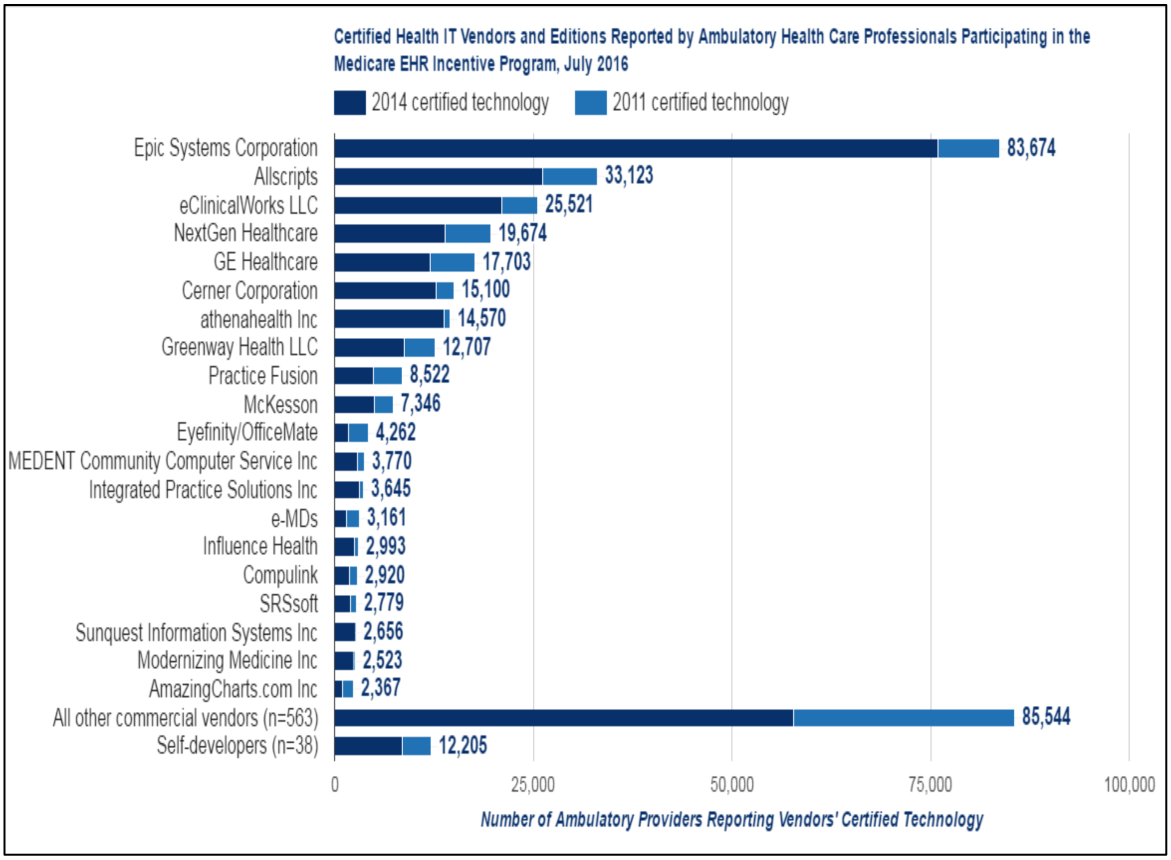


Figure 2-20: Professional EMR vendors as of July 2016 [77].

Despite these limitations, nonetheless, many materials [78] [79] and websites [80] [5] provide general descriptions and user (e.g., professionals, nurses and administrative staff) comments regarding commercial systems. This section presents an overview of the commercial EMR systems available in the market and describes several popular systems.

Figure 2-21 illustrates the overall market share of EMR systems in 2015, as reported by SK&A [80], which is a leading provider of US health care information solutions and databases. The most popular EMR products have changed minimally over the course of a year.

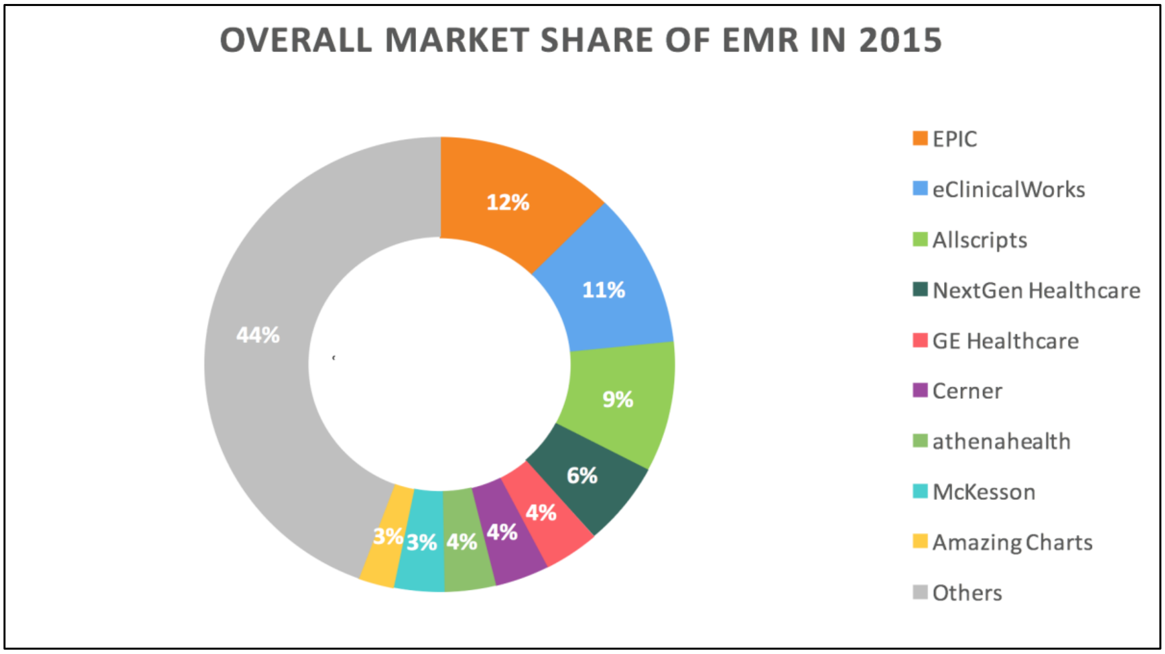


Figure 2-21: Overall market share of EMR in 2015, provided by SK&A [78].

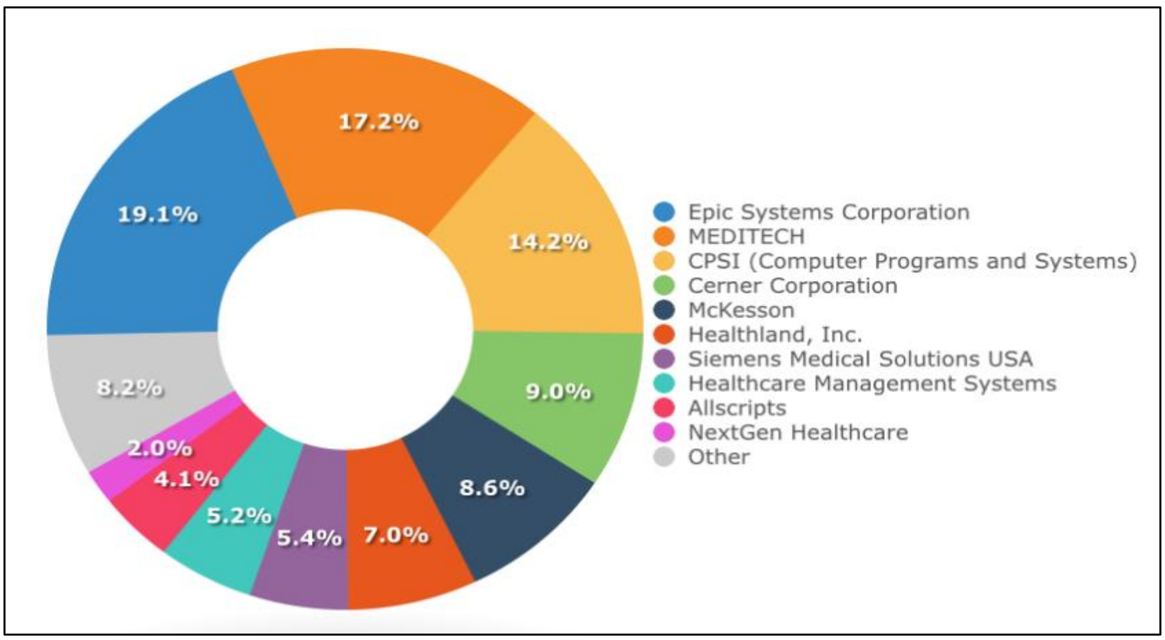


Figure 2-22: Hospital meaningful use market share in 2014, provided by the CMS [79].

The CMS provided an EMR system market share report based on hospital attestations [79] (Figure 2-22). The top 10 account for over 90% of the market, and the top three alone account for more than half of it. Numerous high-quality EMR systems are available in the market. The most popular commercial systems are presented below.

- **EpicCare**: EpicCare, which accounts for the largest market share (11.6%) among the top systems, comprises medical history data, test results, drug guides and new and old orders. Epic is a private employee-owned corporation founded in 1979, making it one of the oldest players in the healthcare IT sector (Figure 2-23) [5]. EpicCare is an application with multiple modules that can be used by physicians and other health care professionals to deliver clinical care to their patients. It is designed to create most of the workflows for patient care. It includes module dashboards that combine and display clinical and financial metrics and have the ability to create templates that are easily navigable between documents and notes (Figure 2-24) [81]. EpicCare also provides a patient portal and an e-prescription platform, supports telemedicine options that allow doctors to communicate with patients via a video platform and offers mobile and tablet functionality.

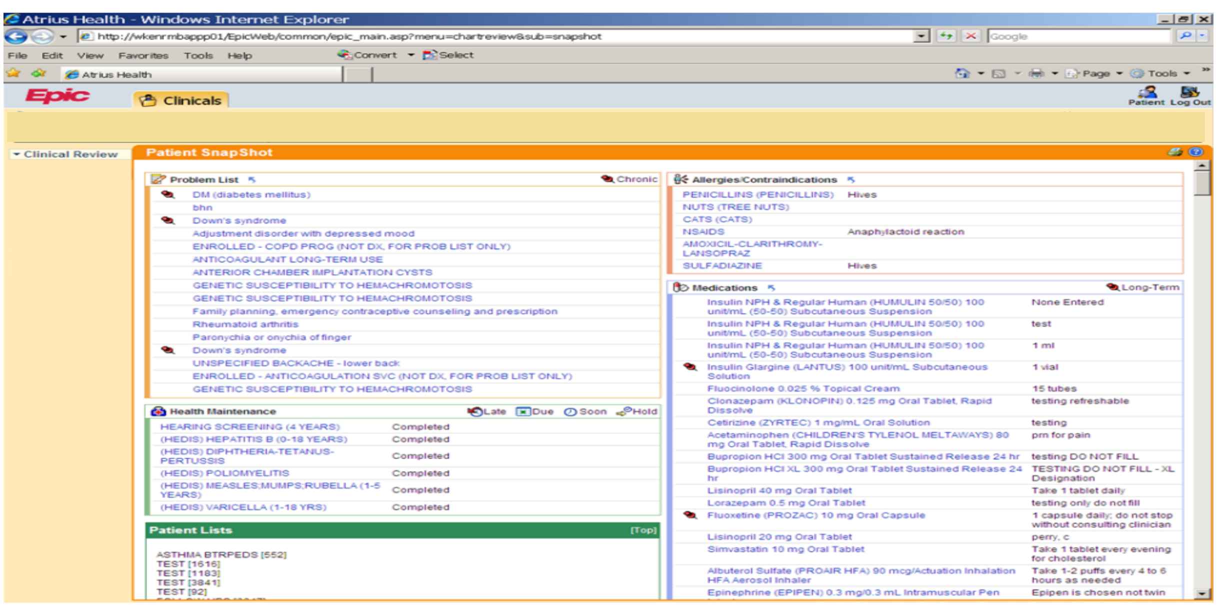


Figure 2-23: User interface provided by EpicCare [81].

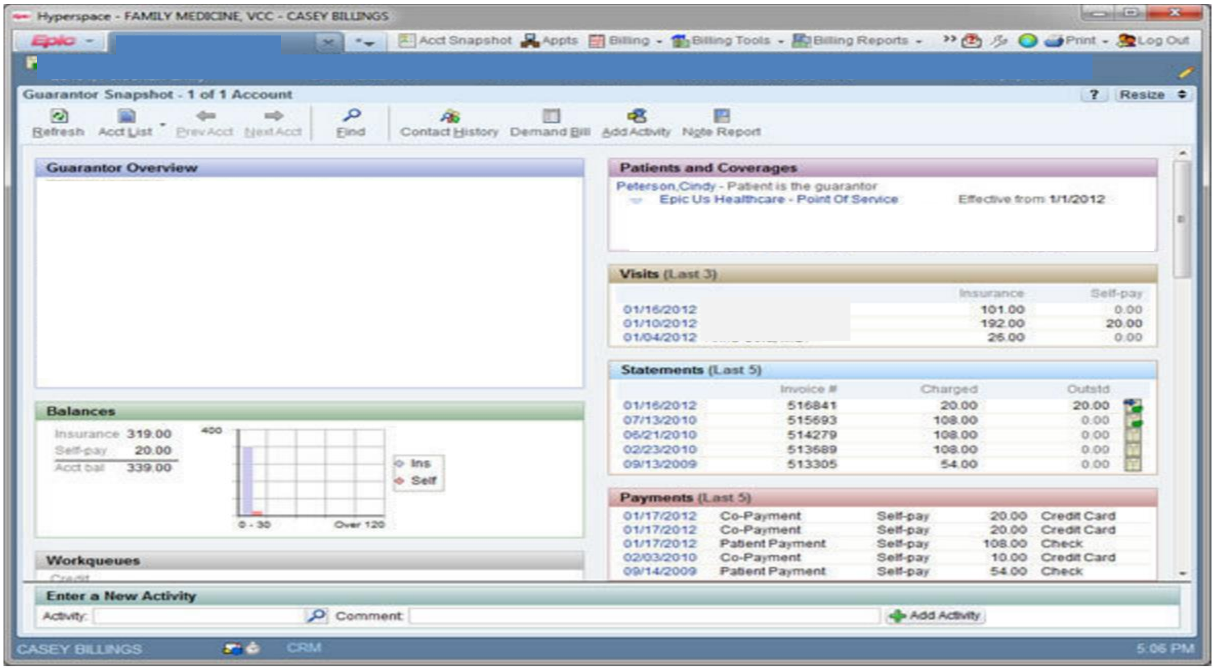


Figure 2-24: EpicCare for patient records [81].

- **eClinicalWorks**: eClinicalWorks has become a leader in medical care, having a 10.2% share in the market. It offers appointment management, e-prescription, a patient portal, the eClinicalMobile feature, electronic health exchange and voice recognition (Figure 2-25) [7]. Health and Online Wellness or Healow [82] is the system's patient portal (Figure 2-26Figure 2-25), which allows patients to input lifestyle and wellness data as well as health data from mobile apps. Safety is guaranteed by the providers, stating that a patient's health record and personal profile can be securely transported and shared by the patient in his/her personal health care network. Software Advice shared some very positive comments regarding this system [82]. In an urgent care note for example, a user indicated that he uses eClinicalWorks daily to drop claims, process electronic funds, make payments and perform overall functions needed for day-job duties.

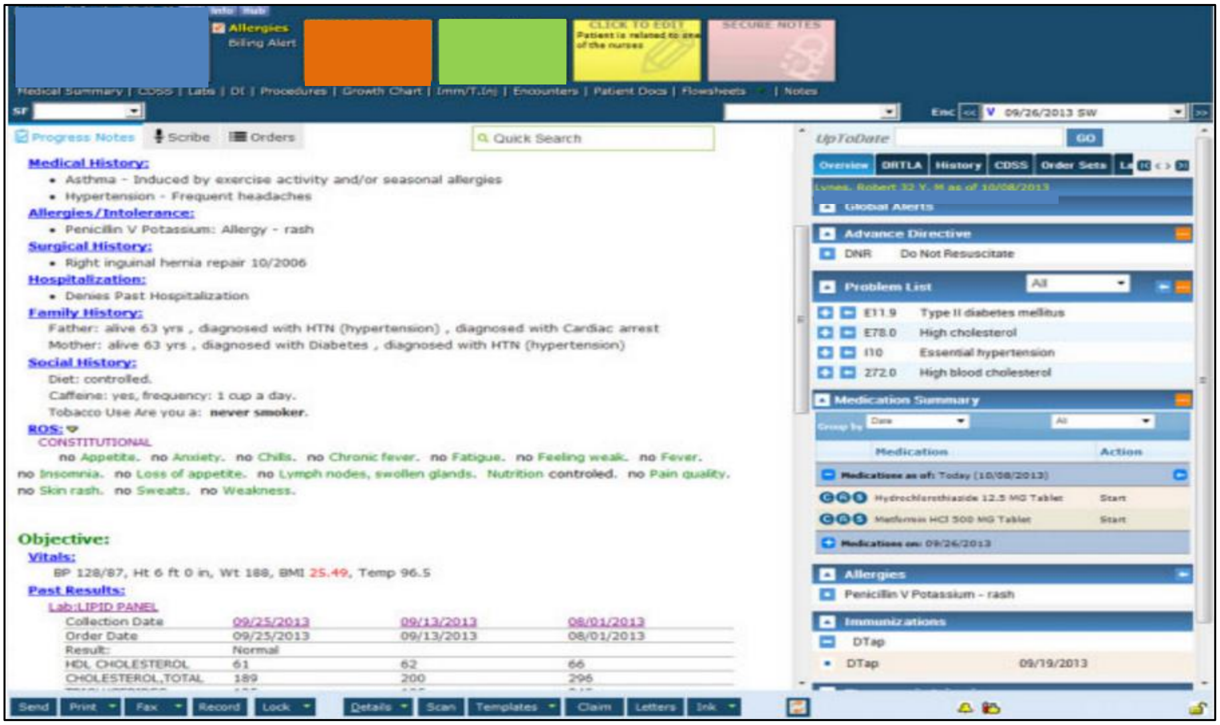


Figure 2-25: eClinicalWorks progress note [7].

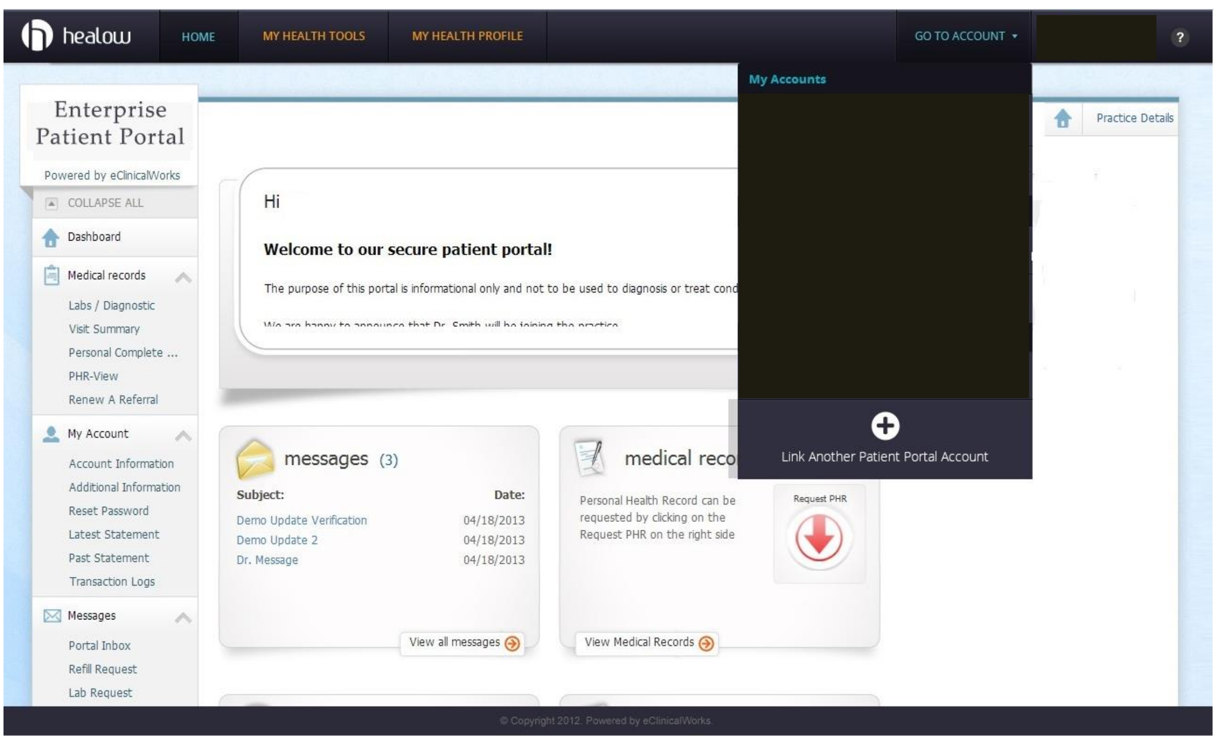


Figure 2-26: Healow patient portal for eClinicalWorks [82].

- **Allscripts**: The market share of Allscripts is 8.7%. It is aimed at small to mid-size medical practitioners and provides e-prescription, medical billing and patient scheduling functionality [6]. The intuitive and interactive interface alerts physicians to potential allergies and interactions. Pharmacies can send electronic refill requests directly to a provider (Figure 2-27). An important feature of Allscripts is the Dragon Medical speech recognition solution, which enables a physician to complete patient documentation without clicking on a note [83]. For example, the system automatically captures dictated prescriptions without the need for clicking. The user-friendliness of the design stems from its simultaneous display of all relevant medical information and laboratory results (Figure 2-28).

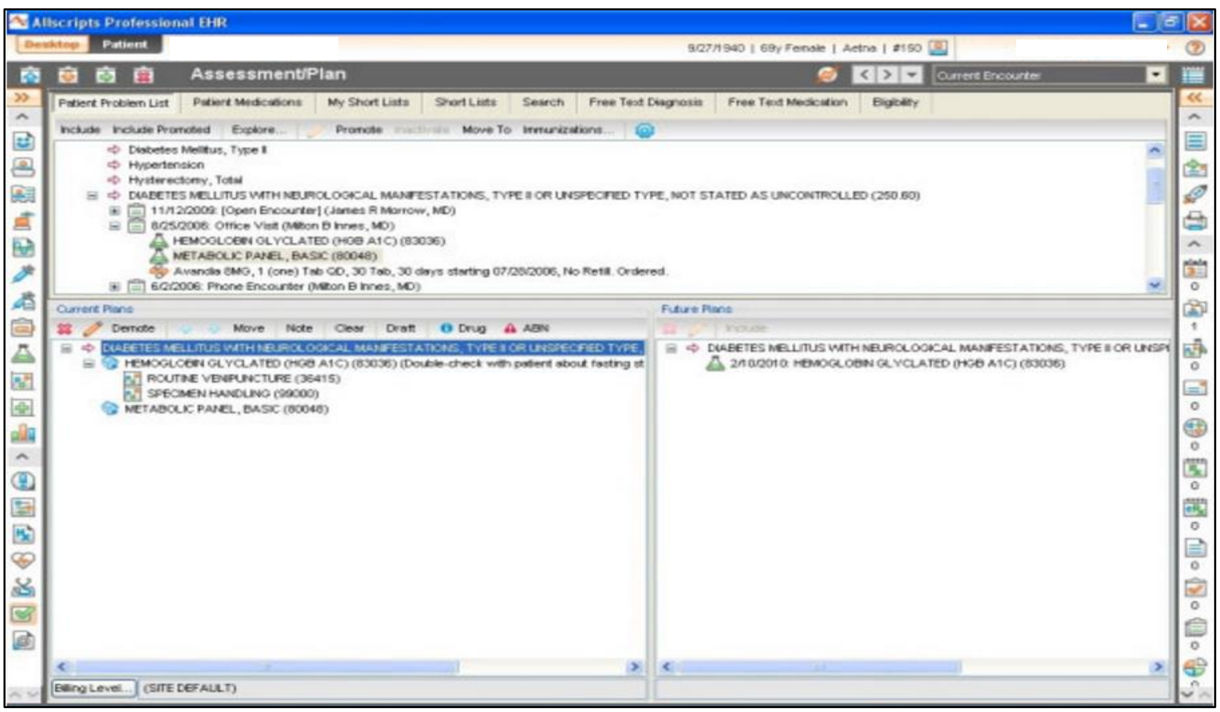


Figure 2-27: Allscripts [6] assessment and plan after recurring order.

Figure 2-28: Timeline view of a patient record in the Allscripts iPad App [84].

Chapter 3. System Design

This chapter comprehensively explains the techniques used in our system design and implementation process. It begins with an overview of the proposed system, including the system workflow and the high-level architecture, and proceeds to a discussion of the technologies and tools used to build the system. The chapter ends with a description of the system's user interfaces and components.

3.1 System Overview

In this section, we present the system's workflow and high-level architecture. The discussion encompasses the system structures (time-, source- and problem-oriented structures) attached to the system.

3.1.1 Requirements for Our System

The main feature of our system is making an easier way for physicians to do their job with the patients. Therefore, they can easily prescribe, track and update medications for any patients. We have discussed and demonstrated old system designed by Yongji Jin [98] with medical professionals, and collected some information in hospital as our system requirements.

3.1.2 System Workflow

The basic requirements of the temporal and spatial interfaces are similar but characterized by different workflow constraints for patients and physicians (Figure 3-1). A typical workflow in the proposed system is as follows.

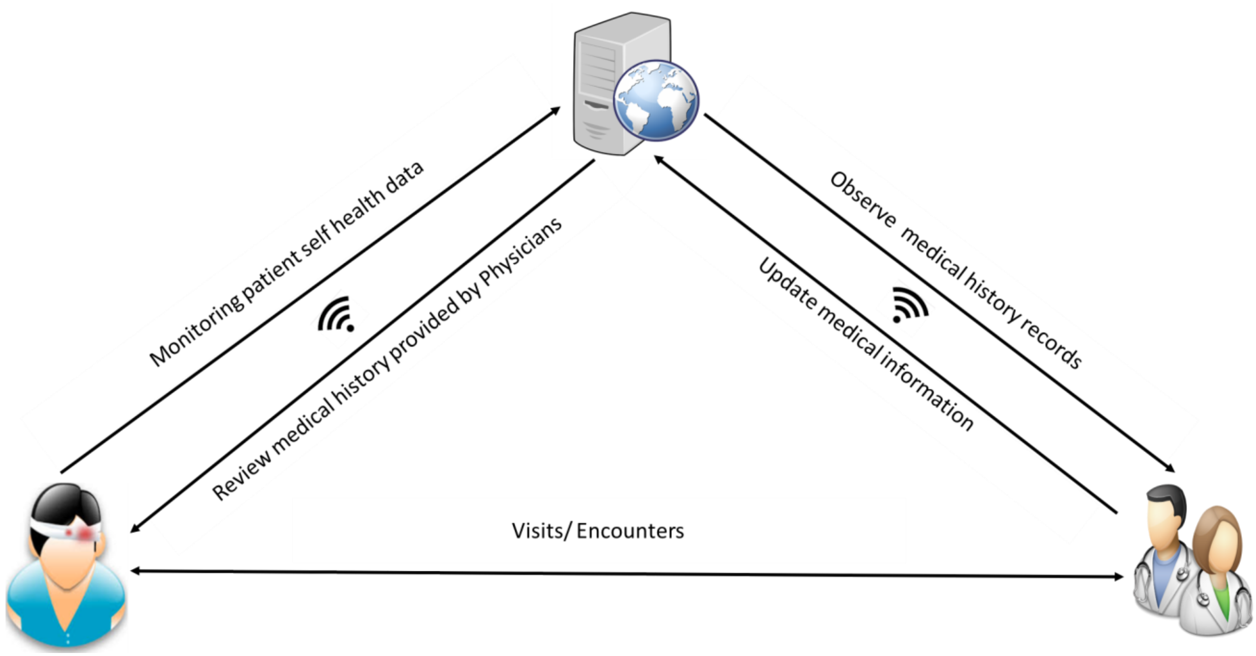


Figure 3-1: System paradigm.

- **For patients**:
    - Add symptom to the PHR system and communicate such to physicians.
    - Review medical events, such as diagnoses, medications and treatments, in the historical timeline.
    - Add additional information on self-medication and self-treatment and convey this information to physicians.

    - Add information regarding the duration of the symptom to the PHR system.

- **For doctors**:
    - Observe symptoms.
    - Make a diagnosis and prescribe medication, medical imaging, medical tests and/or treatments if necessary.
    - Verify and record allergies.
    - Browse medical history records.

These steps may all be executed within one visit or may gradually progress over a given period, but the overall workflow usually proceeds in this manner.

3.1.3 System Architecture

Figure 3-2 shows the high-level system architecture that allows the sharing of medical information between the two interfaces. Figure 3-3 represents system architecture in technologies and tools. The rules that govern the sharing of clinical data are described below.

- A patient may always view EMR data if a physician allows it, but he/she cannot modify the data. The patient has the option to add and modify a description of a symptom before consulting a physician.
- A physician may always view PHR data and modify some of the data upon patient consent. A physician can view a duration-based timeline only after a patient has entered a recovery time for a symptom in the system.

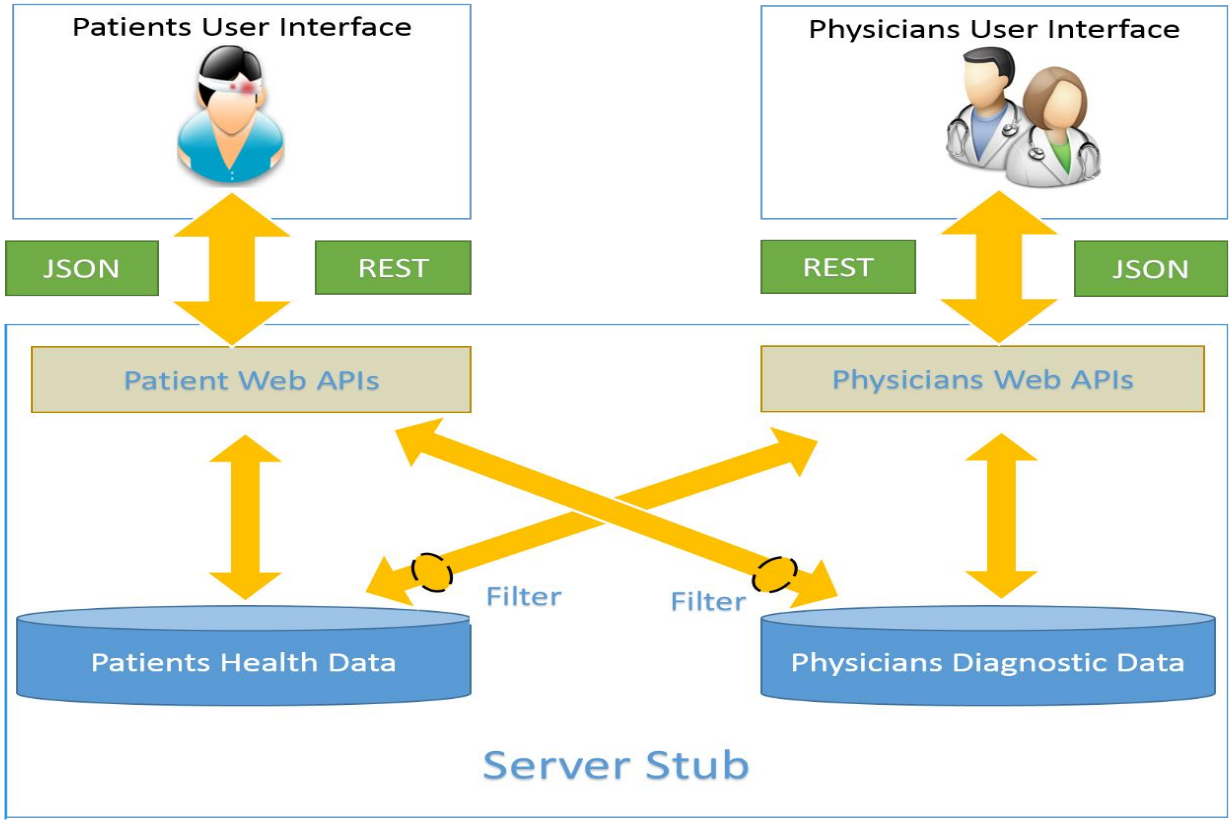


Figure 3-2: High-level architecture of the system.

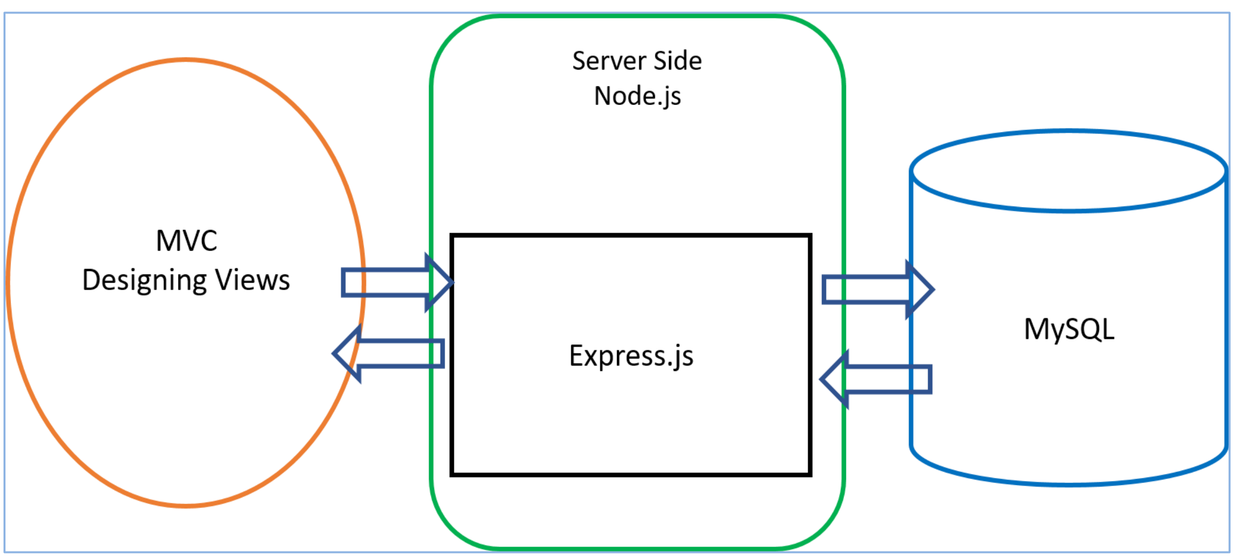


Figure 3-3: System architecture and technologies and tools

3.2 Classification of Medical Data

3.2.1 Display for Multiple Physiological Systems

We classify medical data into multiple physiological systems that are viewable over a clickable user interface. Eleven of these systems are currently incorporated into our prototype. The display for the physiological systems is color coded, thereby allowing doctors especially different specialists to quickly survey and focus on certain diseases. These physiological systems are the skeletal, muscular, immune, reproductive, cardiovascular, respiratory, digestive, nervous, endocrine, urinary and skin systems. By looking at the human image on the system (Figure 3-4), doctors can rapidly determine disease type on the basis of the color codes. The system also enables the viewing of either only one physiological system or an integrated version.

3.2.1.1 Position-based Medical Information

Medical records can be divided into a series of sections, each one associated with patient symptoms that may be perceived as a problem. This problem can be spatially displayed within a representation of the human body. In our system, we use a stylized human body as a map for a structured and intuitive information layout, and we provide circular indicators that reflect medical information. As stated in Section 3.2.1, different colors refer to different physiological systems; we use the same color code to display a disease in the corresponding physiological system. For each indicator, users can enter/view medical record data, such as diagnosis, medication, treatment and medical imaging.

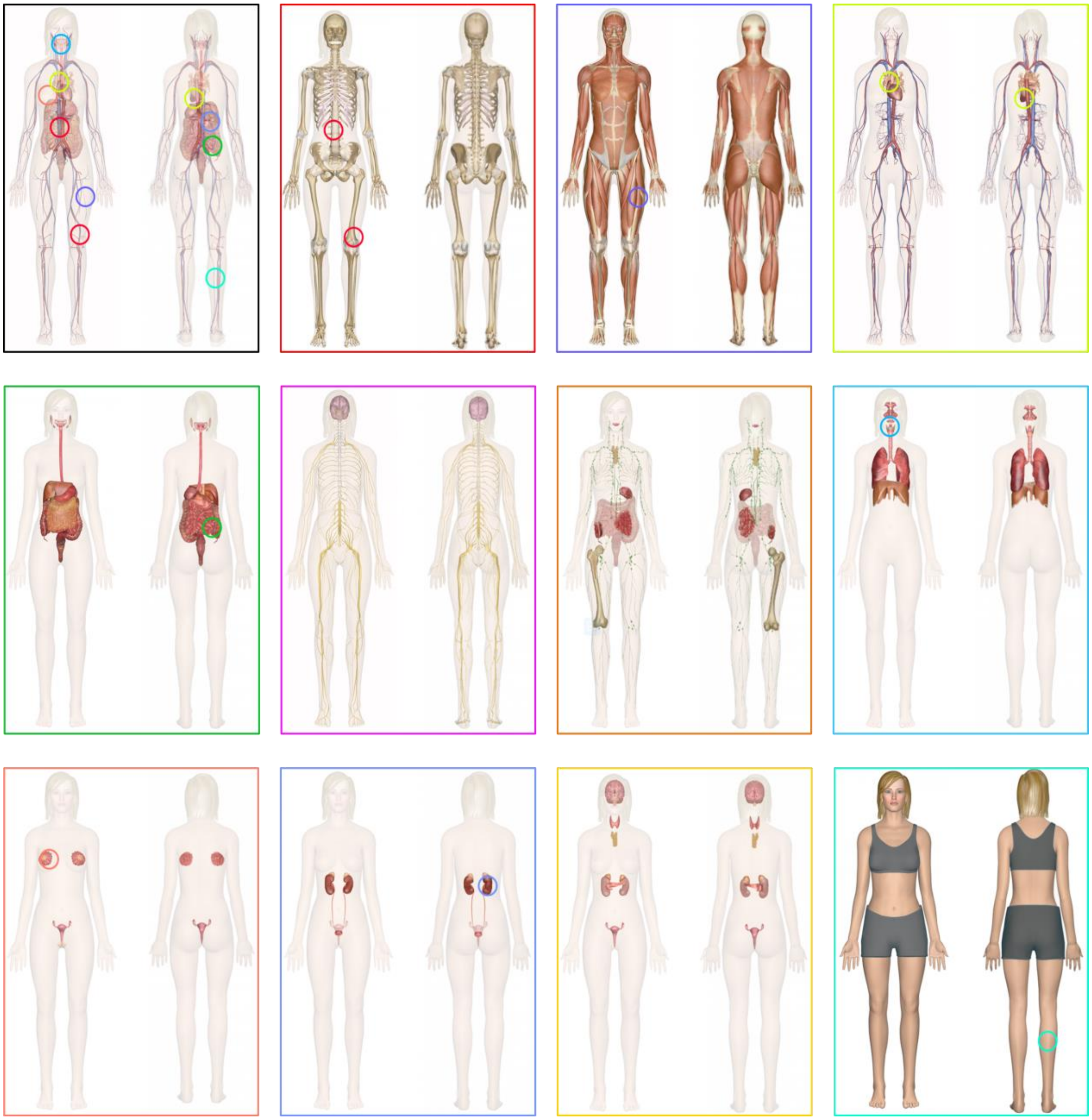


Figure 3-4: Display of integrated system and physiological systems in front and back views. The diseases are partitioned into 11 physiological systems so that the information can be easily accessed on the basis of disease groups. Left to right: integrated, skeletal [85], muscular [86], cardiovascular [87], digestive [88], nervous [89], immune [90], respiratory [91], reproductive [92], endocrine [93], urinary [94] and skin systems [95].

3.2.1.2 Non-localized Medical Information

Not all information can be localized on the basis of position, but for information that can be organized in this manner, we encode data on a 2D representation of the human body, in which information items are linked to appropriate body locations. To display problems that are impossible to reflect on the basis of body location, our system offers a whole-body representation. Figure 3-5 (a) shows a visualization that indicates whole-body itching.

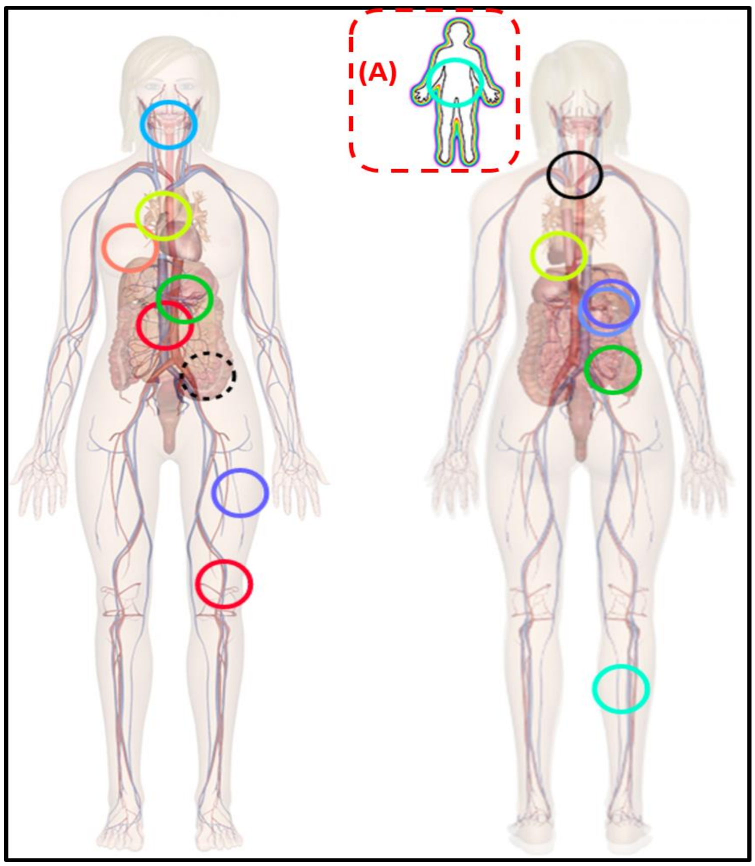


Figure 3-5: Position-based medical information on a 2D representation of the human body. (a) Whole-body problem.

3.2.2 Laboratory Tests

Laboratory testing, with reference to the processing of blood, urine or other bodily substances, and reporting results to physicians are part of medical information documentation in any electronic medical record. Laboratory data in EMRs advance the monitoring of a patient's health conditions and support fundamental clinical decision making [96]. To best serve users, electronic laboratory data should be flexible and appropriately formatted. To prevent users from missing medical data when rapidly viewing large tables, the proposed system highlights abnormal results in red, thus directing attention to these results (Figure 3-6).

Trend monitoring is also possible with a click on a certain index. Specifically, data can be selected for a graphical display of trends across time (Figure 3-7) after a physician's selection of an index.

URINALYSIS CHEMICAL				
UrineGlucose	NEG	NEG	NEG	NEG
UrinePillirubin	NEG	NEG	NEG	NEG
UrineKetones	NEG	NEG	NEG	NEG
UrineSpecificGravity	1.005 - 1.030	1.018	1.028	1.018
Urine Blod	NEG	NEG	NEG	NEG
Urine PH	5 - 8.000	7.5	7.5	6.5
UrineProtein	NEG	NEG	NEG	NEG
UrineUrobilinogen	< 32.999	3.2	10.2	11.2
UrineNitrite	NEG	NEG	NEG	NEG
UrineLeukocytes	NEG	NEG	POSITIVE	POSITIVE

Figure 3-6: Laboratory test display provided by our system. Abnormal results are highlighted in red.

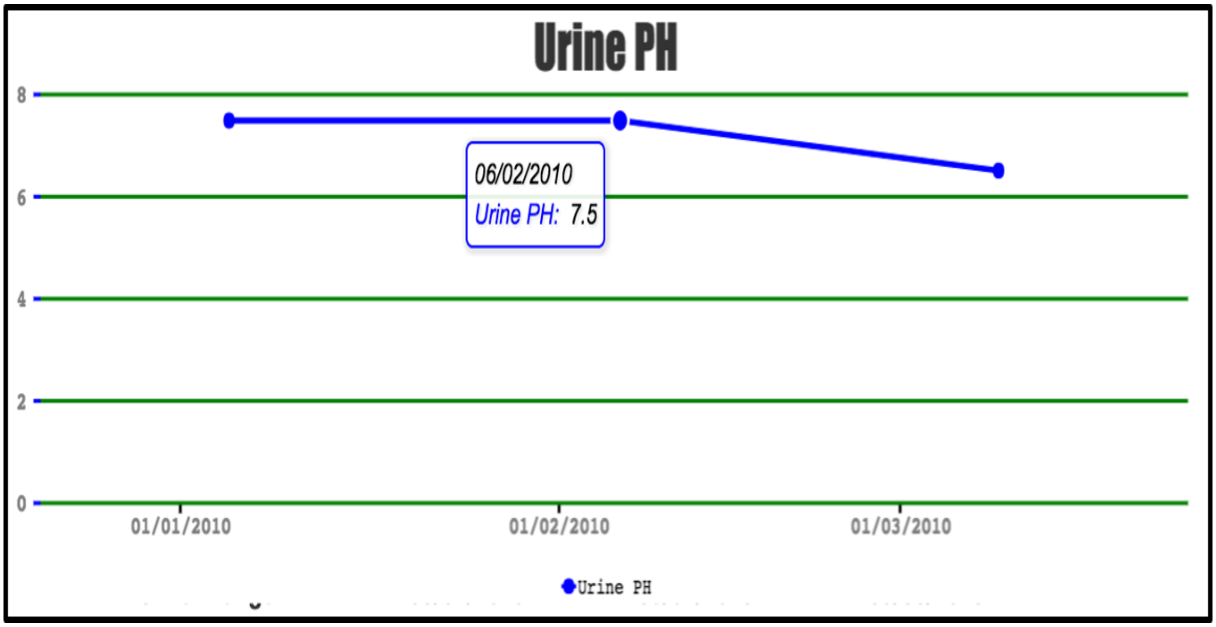


Figure 3-7: Graphics of trend display across time. For example, urine PH is represented when users select urine PH in Figure 3-6.

3.2.3 Medical Imaging: Position Particular

As part of an EMR, medical images have always been important components that support clinical decisions [97]. Medical imaging is usually prescribed for a position-based symptom but can also be requested as part of a regular checkup. An image may reflect conditions related to a particular physiological system but can also support the derivation of additional information on the basis of that system. The proposed system therefore provides an extra means of collecting and displaying all medical images on one webpage (Figure 3-8), and all of the medical imaging are saved in database.

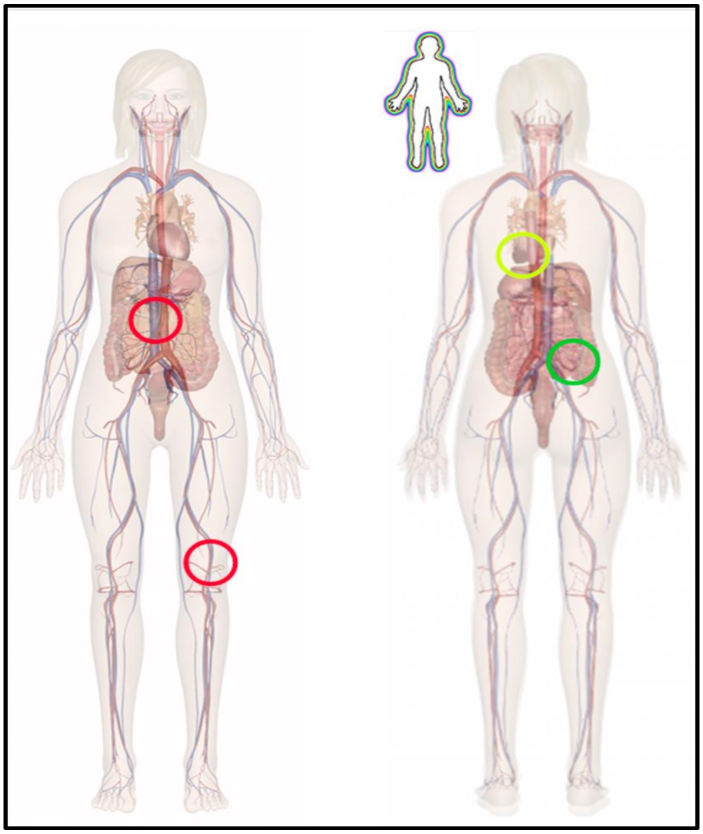


Figure 3-8: Medical data related only to medical images are displayed.

3.3 User Interface

3.3.1 Spatial User Interface

3.3.1.1 Medical Professionals

Figure 3-9 illustrates the interface for EMR viewing. Component (A) of the interface shows the navigation bar that enables a user to switch between the different functionalities of the system. Component (B) shows a patient’s information, medical profile and family medical history. Component (C) displays the front and back views of the human anatomy, whose parts are selected from 11 physiological systems (skeletal, muscular, etc.) and one integrated system.

The dotted black circles on the interface indicate symptoms, and the solid black circles reflect whether a patient has engaged in self-medication or self-treatment. Diagnostic information is denoted using a solid colored circle, wherein color reflects a specific physiological system. Component (D) contains buttons that correspond to the physiological systems or the integrated system. Clicking on these buttons changes the human anatomy views in Component (C). Component (E) presents a button that enables doctors to add a colored circle to an anatomical location on selected physiological human body images. Component (F) illustrates a doctor's management panel for medical events (symptom, diagnosis, medication, treatment and medical imaging), and Component (G) is a year scroll bar with which users can view the anatomical locations of symptoms and diagnoses for a selected year.

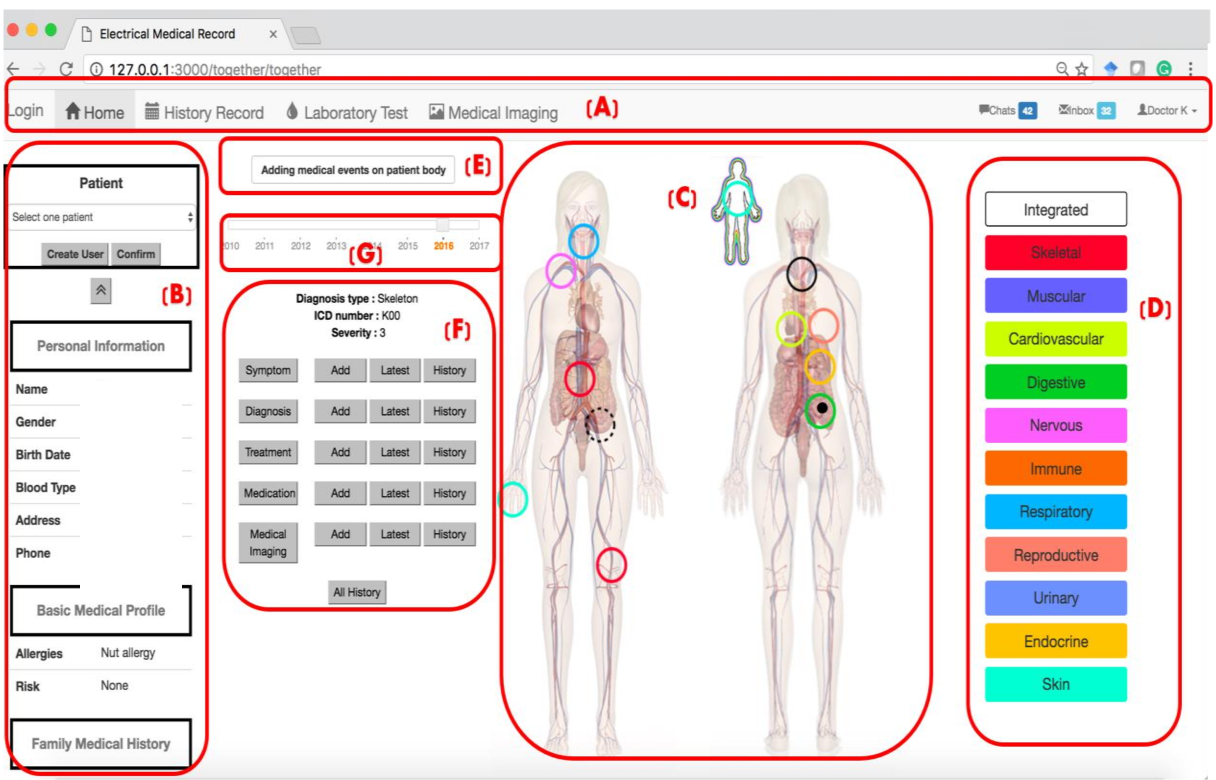


Figure 3-9: EMR user interface for medical professionals.

3.3.1.2 Patients

The user interface for PHR viewing is shown in Figure 3-10. This interface is similar to the EMR interface, except for Components (E) and (F). Component (E) of the PHR interface presents two options for a patient: the addition of a symptom with a black dotted circle and the entry of information on self-treatment or medication with a black circle. Component (F) shows detailed information for a circle on a human anatomy image. If the circle is created by a physician (coloured circle), a patient can see related medical information, such as diagnosis and medication. The patient can also add or modify symptom-related information, such as descriptions, specific dates, severity and recovery time, with the option of sending these details to a physician.

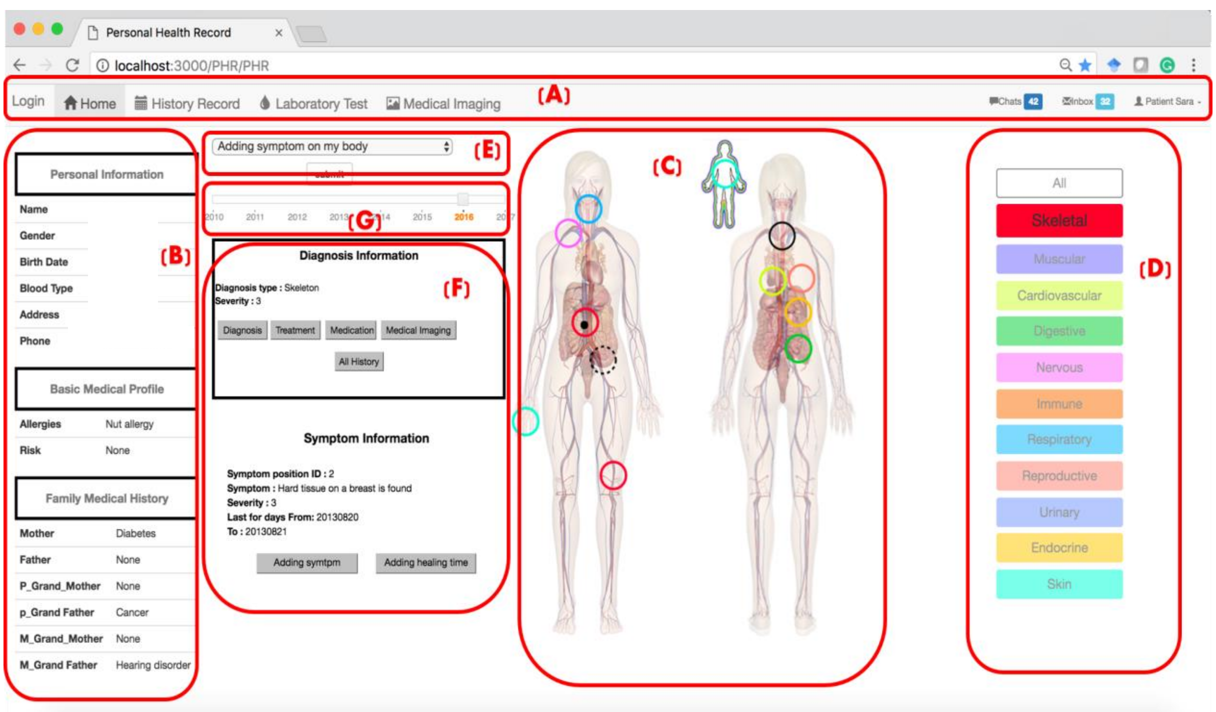


Figure 3-10: PHR user interface for patients. The interface is very similar to that for EMR, except for (E) and (F).

3.3.1.3 Recording and Inserting Medical Events Using Position-based Indicators

Continuing Yongji Jin's work [98], our anatomy-based method of displaying medical information (drawing circles on problem location) is a problem-oriented approach that affords physicians access to more detailed clinical events related to a given problem. Physicians can add a new colored diagnosis circle by clicking on the corresponding position in the 2D representation of the human anatomy. After the button that adds medical events on a patient body in the panel is clicked, the circle with a color that corresponds to a certain physiological system is added. Such events include diagnosis, medication, treatment and medical imaging, which are entered into the system by physicians (Figure 3-11). Clicking on a location activates a corresponding pop-up box, in which new health data can be inputted. Users can then retrieve additional details by clicking on the pop-up box for each of the circular indicators. Even when a new record is uploaded, all records continue to be maintained automatically and transferred to the patient interface. The system provides a summary that reflects all of a patient's problems in human graphical views with disease classification that enables health care professionals to better understand patient health conditions. The system also comes with interactive navigation that shows problem details, accessed by a single click on a circle or a double click that directs a user to anatomical views of a given physiological system.

A patient's well-being depends on correct diagnoses and treatments, indicating the value of involving patients in their own health care. Our system provides two options (adding symptom and adding self-medication/self-treatment data) on the panel that allows patients to enter symptoms (including feelings, severity, duration, and recovery time) and self-medication/self-treatment data. The black circles are to be manipulated by patients when they want to incorporate symptoms and information on self-medication/self-treatment. These circles, however, are unrelated to a particular physiological system, considering the limitations in the medical knowledge of patients (Figure 3-12).

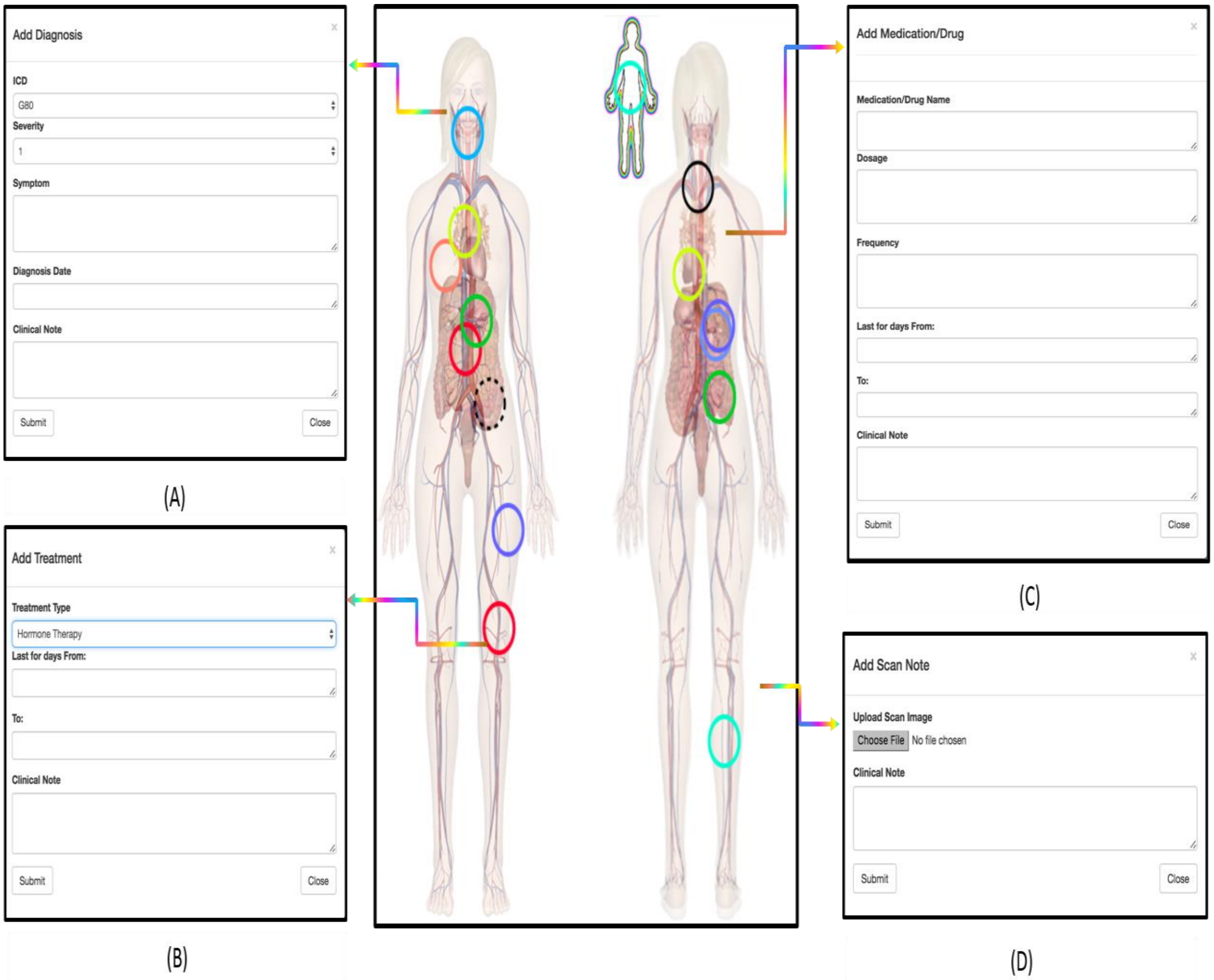


Figure 3-11: Adding health records by clinking corresponding colored circular indicators for diagnosis, treatment and medication (to be done by medical professionals). Colorful arrows illustrate that such medical events can be added using each colored circle.

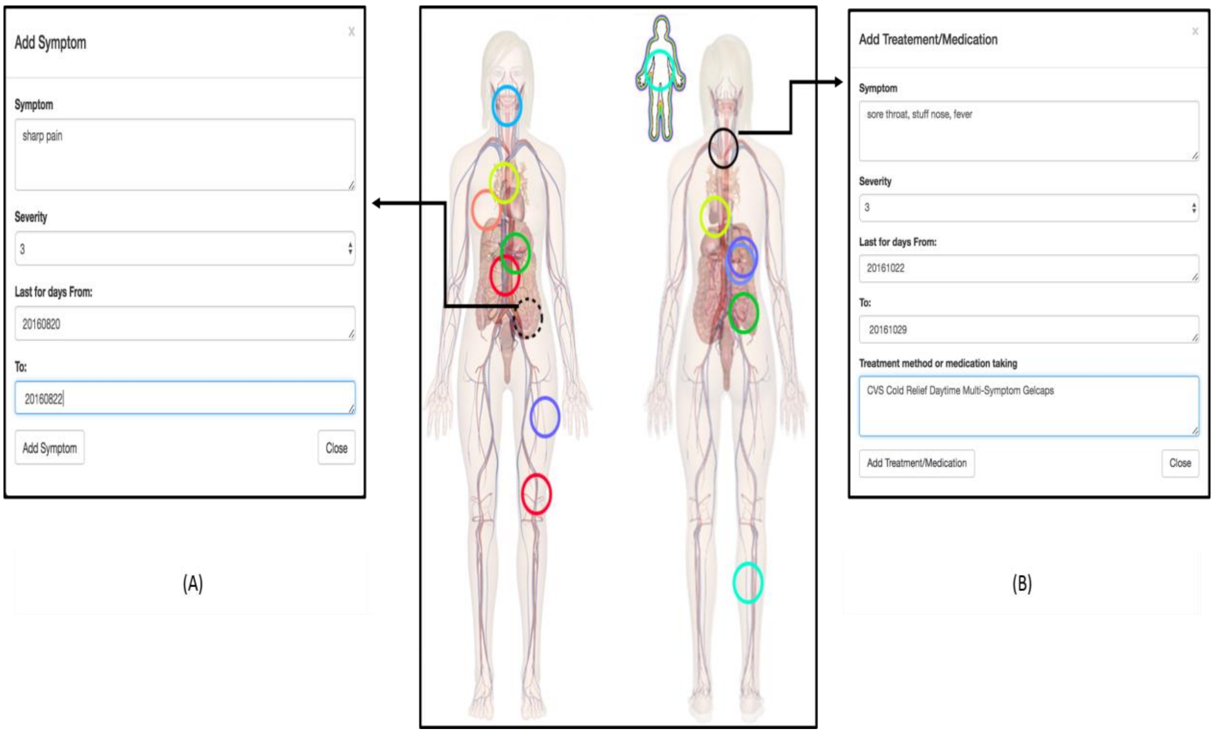


Figure 3-12: Adding symptoms, self-medication and self-treatment by clinking corresponding black circular indicators (to be done by patients).

Our system also provides different medical information for different users. Patients, for instance, can add and edit information on symptoms and self-medication/self-treatment by clicking on a specific black circular indicator (Figure 3-13 (a) and (b)). For colored circular indicators, which are used by health care professionals (Figure 3-13 (c)), patients can access only problem-based diseases and click on medical events to view details (Figure 3-13 (d)). A similar process is displayed for health care professionals.

3.3.2 Temporal User Interface

Temporal data are time-stamped data, such as previous diagnoses, treatments, medications, treatments, medical imaging and prescribed laboratory tests. These can be regarded as events in the medical domain. Every medical event is assigned a time tag—a feature that brings forth another user interface for reflecting events on a timeline.

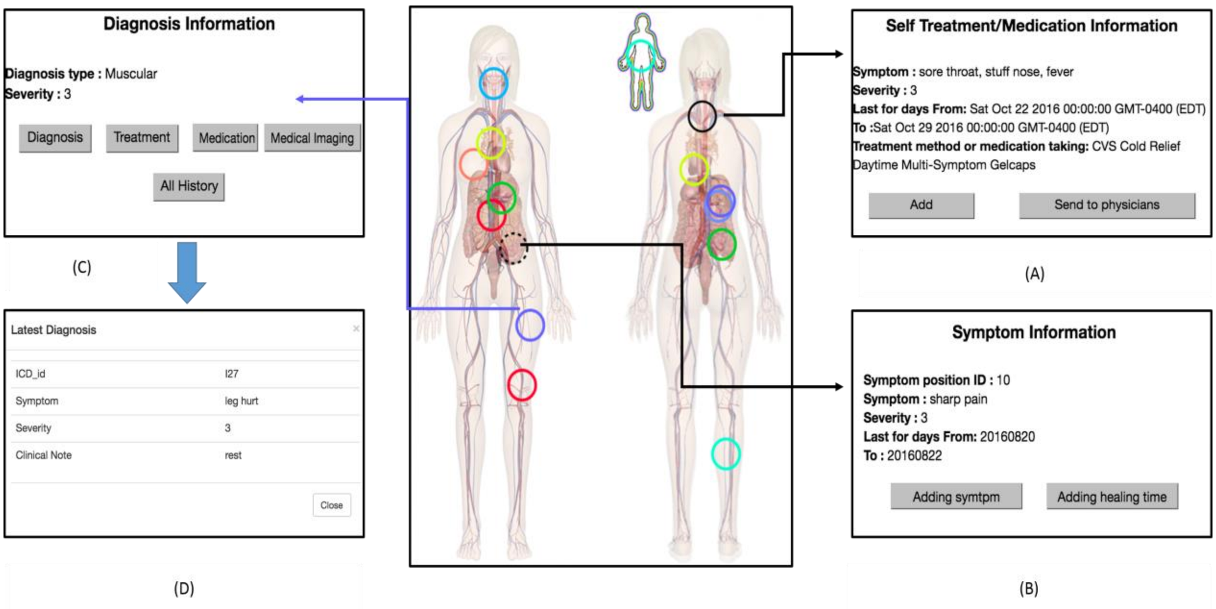


Figure 3-13: Displayed medical records for circular indicators (used by patients).

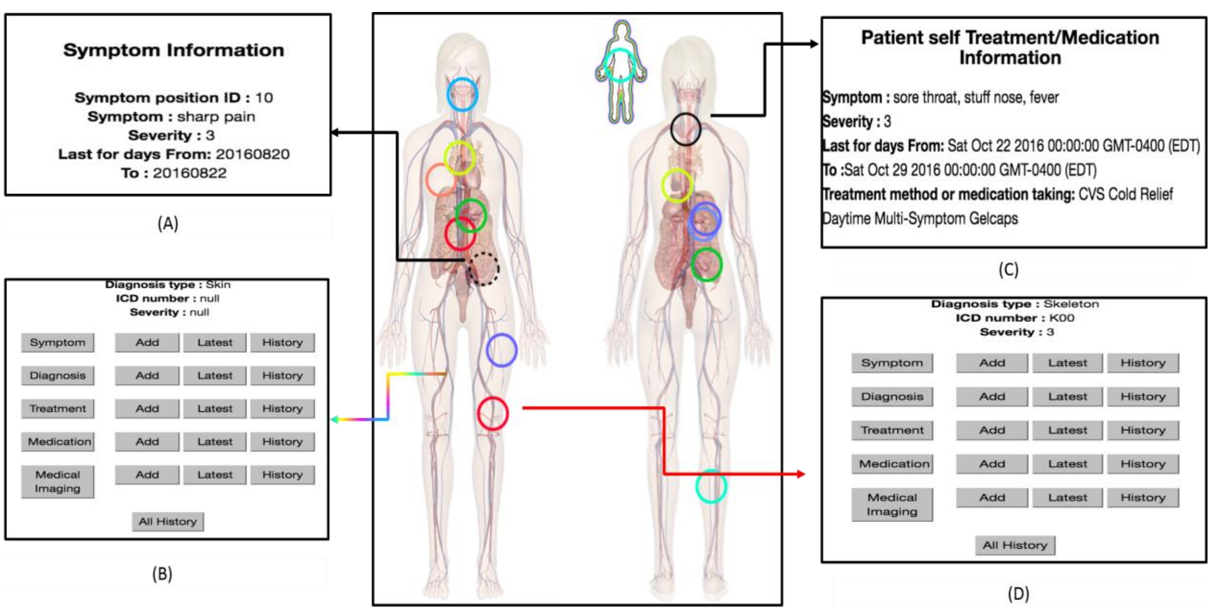
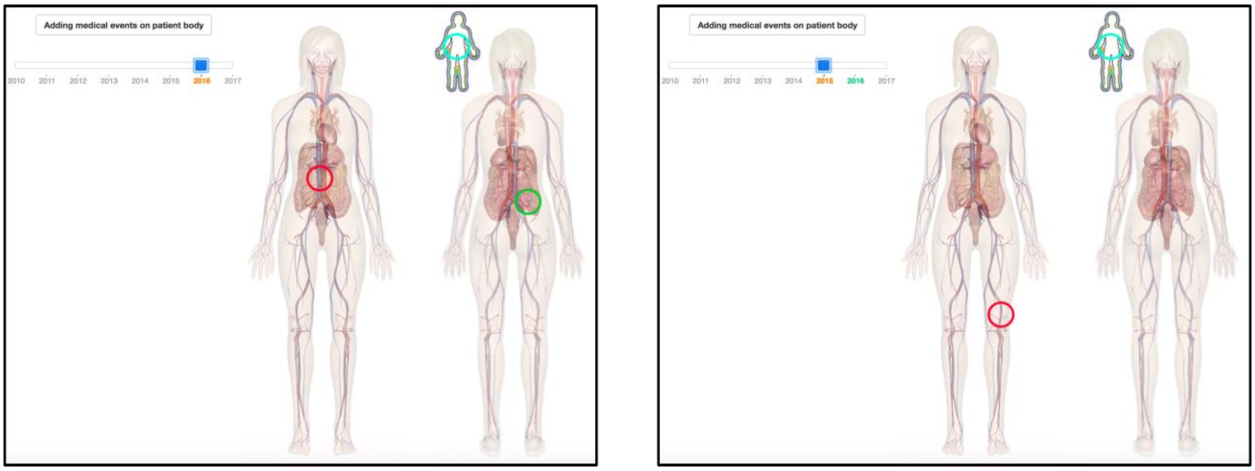


Figure 3-14: Displayed medical records for circular indicators (used by health care professionals).

3.3.2.1 Time Scroll Bar

A time scroll bar is displayed on the main page of the visualization system, and it prompts users to select a specific year to filter medical events for that period.



(A) (B)

Figure 3-15: Time-filtered pictorial interface for viewing medical records. (a) Medical information for 2016. The patient has appendicitis problems, and the skeletal parts of the belly are shown. (b) Medical information for 2015. The patient experiences problems in her right knee.

3.3.2.2 Historical Timeline

3.3.2.2.1 Historical Timeline for Medical Professionals

The system provides zoomable medical history displays with event- and duration-based timelines. Diagnoses, medical imaging, treatments, medications and laboratory tests are classified and represented as different icons. Figure 3-16 (b) shows a duration-based timeline that is used when an event lasts for a certain length of time. The navigation buttons and corresponding icons at the top of the page (Figure 3-16 (a)) help users quickly filter information to limit displays to their selected physiological systems or medical events.

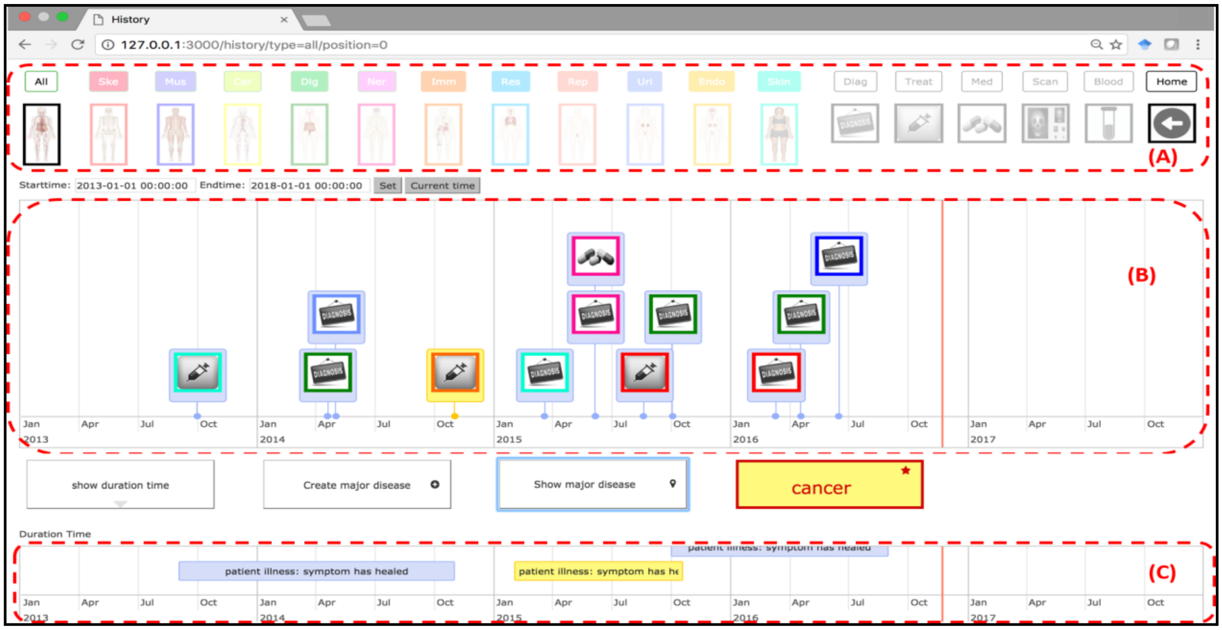


Figure 3-16: EMR timeline display. The horizontal line denotes time information, and the icons represent diagnosis, treatment, medication, medical imaging and laboratory testing. This display has filters for physiological systems and medicine events. The button at the bottom can be clicked to show or hide duration timelines and create and show major diseases.

3.3.2.2.2 Historical Timeline for Patients

Our PHR system has an extra feature for supporting continuous medication timelines that show medicine names, dosages and frequencies of intake. Such timelines remind patients to take their medicines, as prescribed by a physician (Figure 3-17).

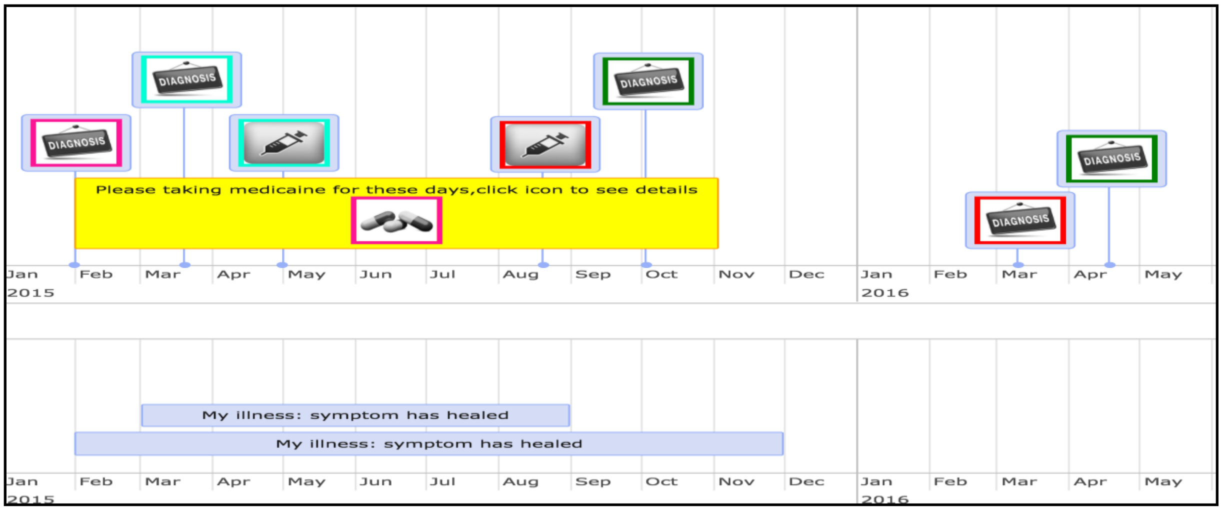


Figure 3-17: PHR timeline display. The timeline is very similar to that for EMR, but the difference is in the medicine display. A continuous medication timeline is provided to show the days during which patients take their medication.

3.3.3 Arrangement of Major Medical Events

Most severe disease events are documented and displayed as major medical events. When doctors navigate a patient's medical history, there are a great many of medical events. However, the physicians are concerned primarily about major events, such as cancer, rather than minor conditions, such as a cold or an ear infection. Our system provides a display for major diseases in a historical timeline, thereby enabling doctors to define/document certain events under a major medical occurrence. This definition/documentation, in turn, allows doctors to quickly obtain insights into important issues should there be a need to do so at a later time. When a major event is chosen, only related events are displayed (Figure 3-18).

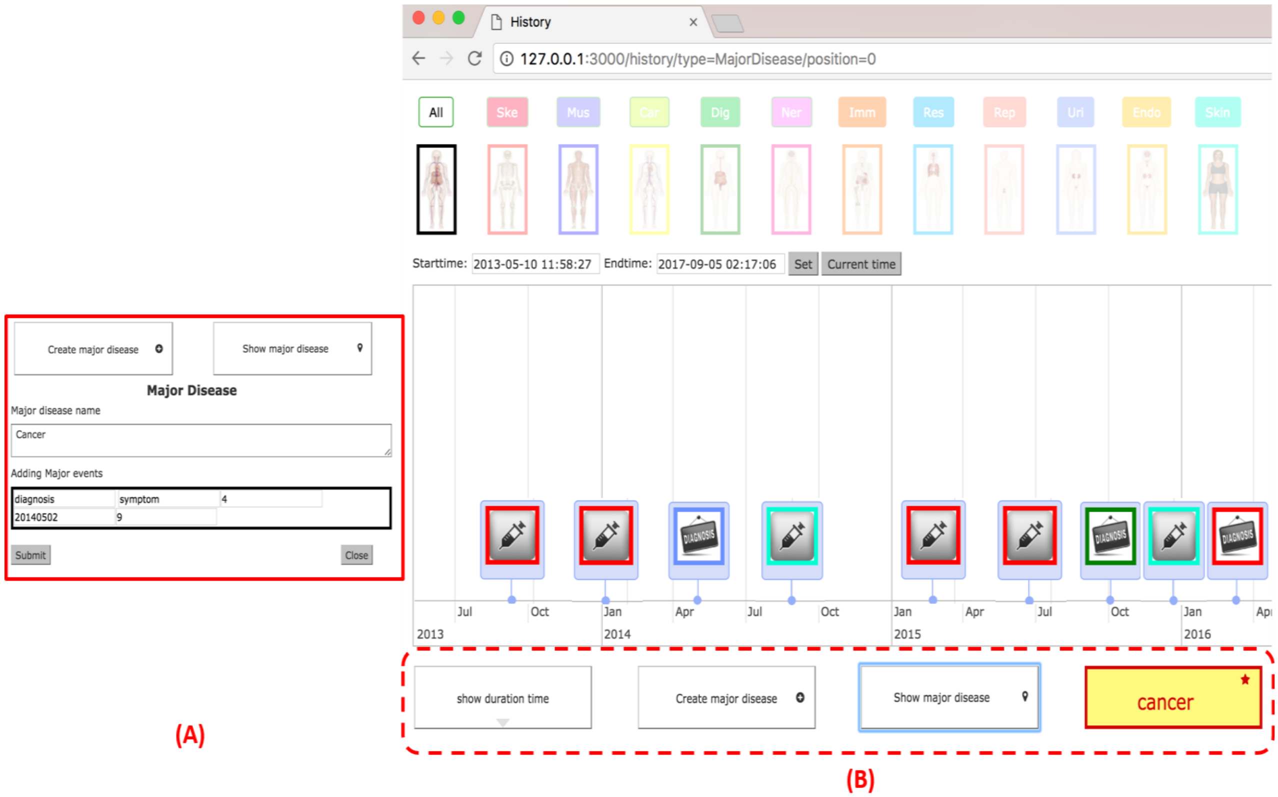


Figure 3-18: Major disease timeline display. An important medical event can be documented as a major event. For example, events related to cancer can be selected to display the major event.

3.4 System Technologies and Tools

3.4.1 REST Web Service

We use the Representational State Transfer (REST) web service in our system. REST is an architectural style that is characterized by simplicity of interfaces, visibility of communication and modifiability and portability of components [99]. Compared with a traditional web service, the REST server dispatches only data for an end point and not a webpage. That is, when a user wants to develop a new related app, he/she can create this app over the application data of an existing system. This is very convenient for the one-time creation of application logic and consumption by clients.

3.4.2 Node.js

Node.js, also called Node, is a server-side JavaScript environment [100]. It is based on Google's runtime implementation (Chrome's V8 JavaScript engine) that focuses on performance and low-memory consumption. Unlike processes in most other modern environments, a Node process does not rely on multithreading to support the execution of business logic; it is grounded in an asynchronous I/O event model [101]. Node.js is used to implement the REST HTTP server. All API calls are executed asynchronously. We use Node.js as a back-end framework for our system because it provides an event-driven, non-blocking I/O model that makes for a very lightweight and efficient application. Node also has a shallow learning curve because it is basically a JavaScript framework that runs on the server side.

3.4.3 Server Componentization with Express.js

Express.js [102] is a Node.js web application server framework that provides a robust set of features for web and mobile applications. Node.js is a low-level I/O mechanism, which means that considerable work (e.g., parsing payload, cookies, storing sessions, selecting correct route patterns) needs to be re-implemented [103]. We choose Express.js because it enables the easy creation of web applications and services. For example, we can write a small REST API server in plain Node.js and then write it in Express.js. The latter takes five to tenfold less time and fewer lines of code.

3.4.4 EJS Template

Two popular view engines are available for Node.js: Jade and EJS. Jade is characterized by short syntax, thereby allowing the fast and clean writing of code. However, it is not designer friendly and does not differentiate between tags and variables, thus making code very confusing [104]. Furthermore, HTML needs to be converted into Jade; if an HTML structure becomes complicated, the corresponding code may be convoluted or difficult to follow. As for EJS, it is very close to pure HTML and uses the same syntax. It therefore requires replacement of dynamic components with the variables passed from Express.js items. The drawback of EJS is that it is not as powerful as Jade and does not have blocks by default. Although Jade is a sophisticated tool, we choose EJS for our system because its syntax is very easy to learn and understand.

3.4.5 MySQL Database

MySQL is a popular open-source relational database management system (RDBMS) that was developed, distributed and supported by Oracle Corporation [105]. Similar to other relational databases, MySQL stores data in tables and uses structured query language (SQL) for database access. Our system uses MySQL because it is mostly used to store web applications and runs on all major operating systems (Linux, Windows, OS X and UNIX). Figure 3-19 shows the entity relationship model of databases in our system. Based on Yongji Jin's work [98] (all of tables he designed are highlighted in red), we provide 17 tables with internal connections. For a patient's table, we provide personal information, basic medical information and family history, whereas for a doctor's table, we provide the doctor's name, hospital information and specialization. In terms of problem location, table "s_position" refers to the symptom location entered by patients, and table "d_position" refers to the location to which self-medication/self-treatment is applied. Table “position_ doctor” refers to diagnosis locations edited by physicians. Table “medication,” “diagnosis,” “lab_test,” “treatment” and “scanning” is designed for physicians to insert new medical events. Table “scanning” refers to all of themedical images and “lab_test” refers to blood tests and urine tests. Table “symptom” and table “p_diagnosis” are intended for patients to add health conditions. Table “history” is for the collection of medical events added by doctors and displayed in a point timeline. Table “symptom history” is intended to document time data from symptom onset to recovery period; such data are displayed in a duration-based timeline. Finally, table “major disease” collects data on severe medical events, such as those related to medical imaging, diagnoses, treatments, medications and laboratory tests.

3.4.6 Google Charts API

As discussed in Chapter 2, Google Charts is a very popular InfoVis tool for improving interactive user interfaces. We use Google Charts to display events in a timeline chart, which visually depicts how a set of resources are used over time [106]. The timeline is developed in JavaScript and can run in every browser without additional requirements. In the timeline, events are presented in two formats, which can be displayed either on a single date or over a range of days (start to end date). Users can freely move and zoom into the timeline by dragging and scrolling [107]. The timeline provides an enhanced graphical interface because all medical events are displayed in a time-oriented structure and require zooming in and out for access to details.

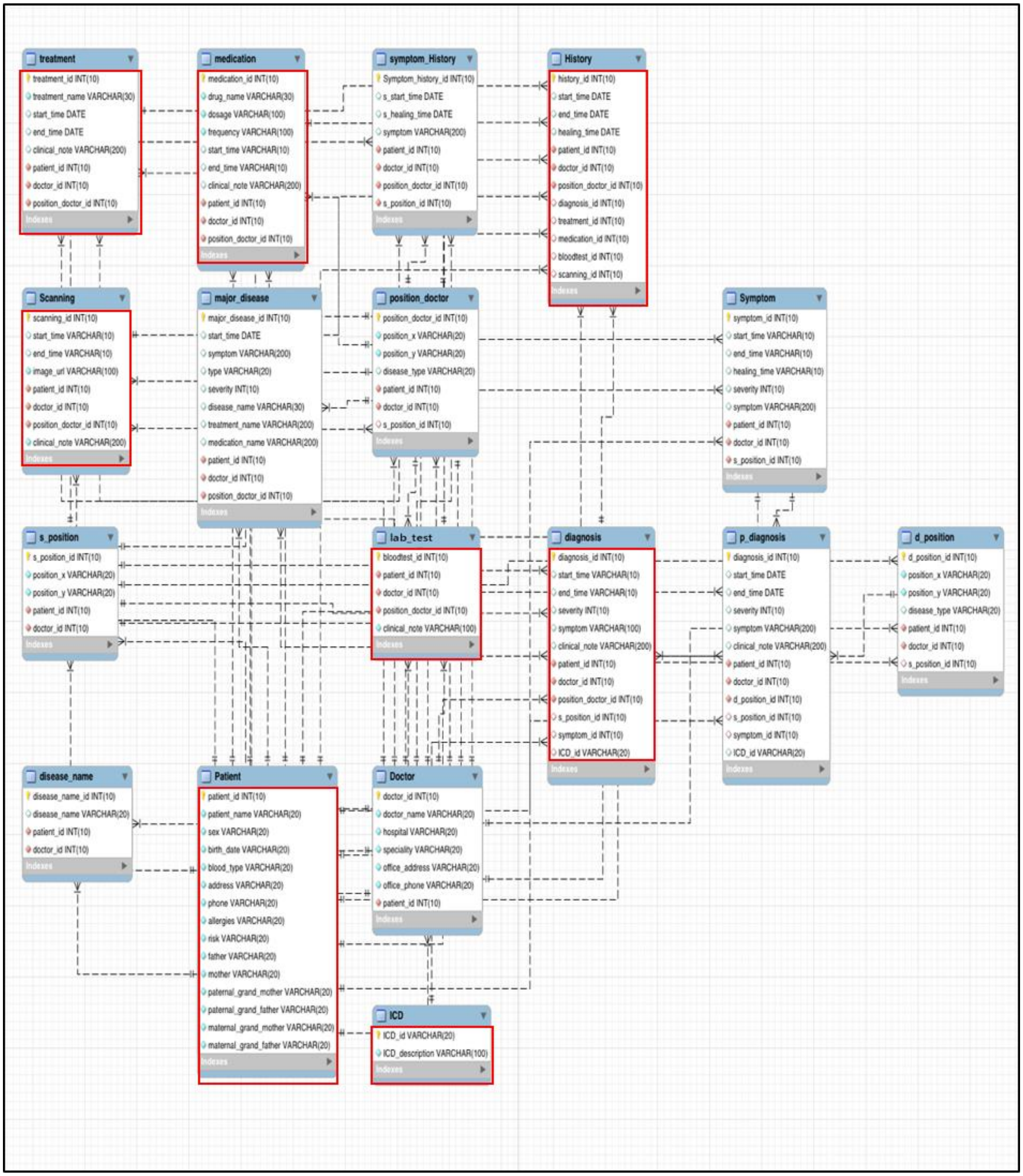


Figure 3-19: Entity relationship model of the database.

3.4.7 D3.js

As indicated in Chapter 2, d3.js is a JavaScript library for manipulating and displaying interactive data. It can help bring data to life by using HTML, SVC and CSS and attached data to a DOM. Our system uses d3.js because it is easy to use in generating interactive and intuitive charts and customizable and renderable graphics.

Chapter 4. Evaluation

In this chapter, we focus on the evaluation of our system. We introduce the evaluation criteria for both InfoVis and the EMR interface and describe the process that underlies the assessment. A case study is then presented, after which the decisions made regarding the prototype system are discussed.

4.1 Evaluation Criteria

ISO 9244-11 standards [108] defined usability as the "effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in a particular environment." A critical requirement, then, is to evaluate whether a system is easily and effectively used in accordance with appropriate criteria. Given that our system is a prototype visualization system for EMRs, both InfoVis criteria and EMR evaluation methods and metrics are presented in this section.

4.1.1 InfoVis Evaluation Criteria Used for EMRs

As the InfoVis field matures, researchers and practitioners have attempted to identify the numerous factors that contribute to the success of InfoVis systems. Shannon and Weaver [109], whose work expanded communication systems, stated that the success of an information system can be measured at three levels, namely, the technical, semantic and effectiveness levels. The technical level revolves around the accuracy and efficiency of a system that produces information; the semantic level centers on the success with which information conveys intended meaning; and the effectiveness level refers to the effect of information on end-users. Building on these concepts, DeLone and McLean [110] sub-divided success measures into six distinct categories, which constitute what is called the D&M IS success model. The model encompasses system quality, information quality, usage, user satisfaction, individual impact and organizational impact. System quality pertains to an InfoVis system itself in association with system quality attributes (e.g., usability, ease of use). Information quality focuses on the attributes of system output (e.g., accuracy, completeness). Usage measures the consumption of system output, with attributes that include level of use and number of queries. User satisfaction measures users' attitudes and responses to a system and the information that it conveys as well as both overall and decision-making satisfaction. Individual impact has to do with the effects of information on users, including understanding and improved individual productivity. Organizational impact measures the effects of information on organizational performance. Figure 4-1 illustrates the three levels of information put forward by Shannon and Weaver, along with DeLone and McLean's IS success model. With the given criteria, we measured system success on the basis of various aspects, from system scalability to user satisfaction.

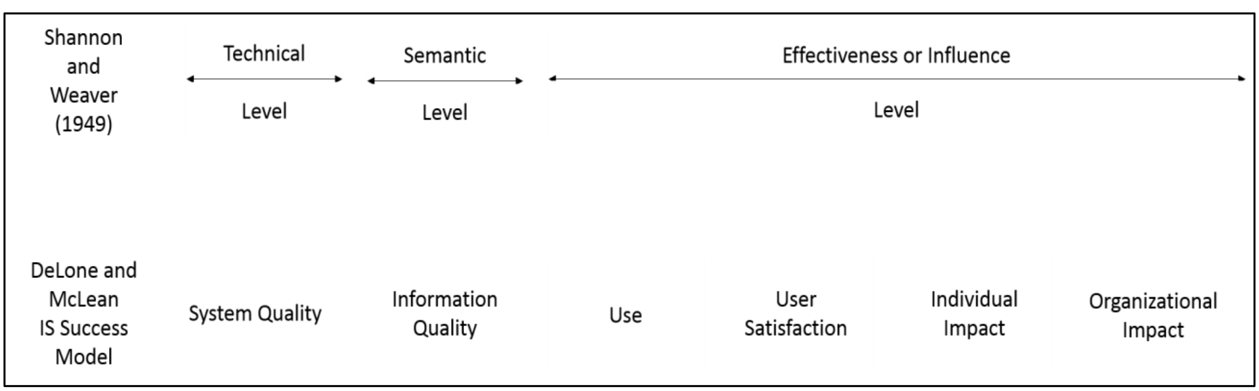


Figure 4-1: Categories of information system success [109].

A survey on EMR systems [23] analyzed a considerable number of EMR systems on the basis of the information quality criteria [110] mentioned above. A more detailed discussion of the criteria under Shannon and Weaver's levels is provided below [109].

- **Technical level**
  - **System quality**: The most frequently used attributes in relation to system quality are ease of use (record keeping time), ease of learning, usability and savings in documentation and response times.
- **Semantic level**
  - **Information quality**: This type of quality is used to measure the input and output of an information system. The most frequently used attributes in a communication system are completeness, comprehensiveness, reliability, accuracy, legibility, consistency, relevance, format and availability. In EMR systems, the most prevalently adopted attributes are completeness and accuracy.
- **Effectiveness level**
  - **Information use**: This criterion measures end-users' consumption of system output, including level of use and number of queries.
  - **User satisfaction**: This criterion measures end-users' responses to the use of system output. The most frequently adopted attributes are user friendliness and users' attitudes toward a system.
  - **Individual impact**: This criterion measures the effects of information on the behaviours of end-users. The most frequently used attributes are improvements to

individual productivity and understanding of information. In EMR systems, these criteria include changing clinical work patterns, changing documentation habits and ensuring decision effectiveness.

- **Organizational impact**: The attributes most frequently employed in this regard are investment and increased work volume. In EMR systems, the prevalently used criteria are physician–patient interaction, effects on patient care and satisfaction with radiology services.

4.1.2 EMR Evaluation Methods and Metrics for Usability

With respect to medical records, the HIMMS published EMR usability principles and related evaluation methods, discussed as follows [111].

- **Simplicity**: Simplicity refers to a design’s effectiveness in providing medical information in a clear and convenient manner that allows physicians to quickly understand and incorporate patients’ health conditions. Given the complexity of clinical information, displays that are easy to read, important information that stands out and function options that are straightforward are essential to efficiency and patient safety.
- **Naturalness**: This principle refers to the reduction of cognitive load and errors so that users can familiarize themselves with an EMR system in a short period. Naturalness applies, as well, to terminology and the correspondence between workflow design and user tasks and expectations [112].
- **Consistency**: Consistency pertains to the extent to which a new system’s structure and functions match a user’s experience with other relevant software. The greater the

applicability of a user's prior experience to a new system, the higher the effectiveness of usage and the fewer the errors committed.

- **Minimizing cognitive load**: Such minimization refers to the reduction of the cognitive load required to use an EMR system so that physicians have sufficient time to concentrate on a task at hand. Two common methods of providing cognitive support to users are presenting all information needed for a task and displaying information that is organized on the basis of meaningful relationships [113].

- **Efficient interactions**: This principle centers on minimizing the number of steps that need to be taken to complete medical tasks. Examples of designs for efficient interactions include auto tabbing, the use of good default values, the provision of sufficiently large lists and text boxes that limit scrolling and the elimination of frequent switching between a keyboard and a mouse.

- **Forgiveness and feedback**: This principle denotes the provision of a system that can reduce user errors and enable recovery when mistakes are made by users. This is especially helpful under scenarios of limited training, wherein users commit errors in using a clinical information system or when such system imposes considerable cognitive load.

- **Effective use of language**: All language used in an EMR system should be concise and unambiguous. A system should also support meaningful and familiar terminology, with no terms related to computers, technology and databases (for example) included in the system.

- **Effective information presentation**: A system should be characterized by information readability for use in a complex clinical system. A substantial amount of relevant medical information can be displayed on a single screen. A critical requirement, therefore, is for a design to enable visualization at an appropriate density and with the use of meaningful color.

- **Preservation of context**: This principle refers to the minimization of interruptions and the delay of screen changes until a user has completed a task. A design must not compel a user to shift visual attention away from an area on a screen that he/she is currently reading or working on.

4.2 System Performance Checklist

We validated our system's performance on the basis of the criteria discussed in Section 4.1.

- InfoVis checklist
    - **Technical level (system quality)**: We used Node.js, which has a non-blocking event loop, as our high-performance server and minimized the complexity of SQL, table joins and data manipulation to guarantee improved performance. However, Node.js features a main thread of execution, thereby enabling simple concurrency. Executing thousands of requests per second is difficult; thus, we did not assess the system in terms of concurrent requests and average response times. Because the proposed system is a prototype, we are not in a position to discuss system quality in relation to large medical datasets and measure savings in loading time with a huge number of documents.
    - **Semantic level (information quality)**: Medical information is complex, and estimating the completeness and accuracy of a prototype before testing with medical professionals in real situations are challenging requirements. We consulted several

individuals regarding medical history components and collected medical information from medical websites and other relevant EMR systems. As for EMR systems, completeness was estimated on the basis of the number of clinical problems described by a diagnostic code [114]. In some EMR systems, hierarchical codes (e.g., ICD, CPT, and NDC) are used to describe the completeness and accuracy of medical information. In our system, a number of clinical problems can be described by a diagnostic code (e.g., ICD-10). Given that we focused on visualization, the quality of medical information was minimally treated in our thesis. Additionally, our system is not intended as a replacement for existing EMR systems but as an addition to user interfaces and link to an existing database. In future work, we will invite clinical staff to evaluate whether the classifications in our system can cover their databases and whether the diagnostic codes are correct through actual medical tasks and scenarios.

- **Effectiveness level**:
    - **Information use**: Our system provides an interactive platform from which users can view and insert medical information in a short period. We designed both conventional buttons and clickable images of the human body as navigational tools and three filters that enable the search of selected medical records in a particular year. These features will enable physicians to immediately obtain insights into a patient's conditions as well as minimize number of queries and level of use.
    - **User satisfaction**: Our system provides user-friendly and patient-centric interfaces. We gather some information comments from physicians to determine user satisfaction with the prototype.

- **Individual impact**: We provided a clickable 2D representation of the human body with physiological systems and a problem-oriented user interface that enables physician to quickly and intuitively extract a patient's medical history. By directly clicking on circular indicators of different colors on an anatomical location, physicians can visualize patient history data, such as medications, diagnoses and procedures. Such data are also shown by timeline. We provided zoomable medical history displays with event- and duration-based timelines, which can contribute to physicians' decision making.
- **Organizational impact**: Our system contains both numerical medical data (e.g., laboratory tests) and categorical medical data (e.g., diagnoses, medications and treatments). These are stored in an organized manner, thus enhancing physician–patient interaction.

- EMR checklist
  - **Simplicity**: Our system provides interactive navigation for users to insert or view patient health conditions. Clicking on the 2D human image to access details is a straightforward function that affords users ease of reading and understanding. A 2D human image is also provided for patients to aid viewing and comprehension of their medical conditions and treatments.
  - **Naturalness**: Our system uses problem-, source- and time-oriented structures that highly correspond with physicians' workflows. Both physicians and patients can therefore learn and familiarize themselves with our system.

- **Consistency**: Some of the timeline features (e.g., zoom in/out) can be manipulated, similar to those of other EMR systems. Such features render our system highly convenient. We likewise provided a functionality for inserting new records into a given position on the human body representation.
- **Minimizing cognitive load**: We provided problem- and time-oriented medical records, which are characterized by internal relationships. In the spatial interface, users can click on a location on the human body to enter new medical records, which are easy to understand. In the temporal interface, users can zoom in or out to view medical events and click on event icons to obtain more details. These manipulatory features are similar to a typical website, can reduce cognitive load.
- **Efficient interactions**: Our system comes with only two webpages. On the homepage, after the selection of a particular patient, related information appears, complete with problems indicators on the 2D body image. The other webpage presents all the data related to a patient's medical history on a horizontal time axis. These two webpages can minimize the number of steps that need to be taken to complete medical tasks.
- **Forgiveness and feedback**: Currently, this principle is not incorporated into our system. If health care providers click on the wrong button, the misunderstanding of diagnostic indicators will be reflected on the body image.
- **Effective use of language**: Our system provides terminology, such as ICD-10, that allows health care professionals to familiarize themselves with a given medical context. A graphical user interface is also supplied to patients so that those with limited medical knowledge can still understand their problems and health conditions.

- **Effective information presentation**: Our system supports color coding in the presentation of the 11 physiological systems. Meaningful information, such as diagnostic data, is denoted using circular indicators, wherein color reflects a specific physiological system. This feature effectively enables physicians to distinguish between diseases and make correct diagnoses.
- **Preservation of context**: We provided a minimum dialog box that allows users to focus on the 2D human image for the incorporation of new medical information, and we designed the time scroll bar in a way that helps physicians directly recognize medical records in the spatial view. In addition, the temporal interface supports three filters that can help users change models for different medical events or different physiological problems. Our aim is to provide convenience that eliminates the need for frequent changes in views.

4.3 Comparison with Existing EMR Systems

Given that medical events are priority EMR components, we strongly focused on the comparability of our system with others in terms of effectiveness in presenting medical information. A review by Kosara and Miksch [115] indicated that methods of measuring the effectiveness of medical information presentation can be classified into three types: recording measured data (e.g., blood glucose), recording incidents (e.g., seizures, pain attacks, etc.) and treatment planning (e.g., therapeutic steps). For each task, the authors established requirements and used these to assess visualization systems. We first briefly describe each task and then compare our system with others (Table 1).

- **Measured quantitative data**: Here, focus is directed mostly toward quantitative data and only minimally on periods of symptom occurrence.
    - **Intuitiveness**: Because measured data should effectively reflect patient status, a necessary requirement is for a system to be as intuitive as possible so that even users who are completely unfamiliar with an EMR system (but familiar with the EMR field) can immediately understand the data.
    - **Focus+context data**: InfoVis represents large data in a hierarchical manner, but detailed views are equally important. F+C data can combine values in a way that allows end-users to choose which ones to view.
    - **Viewing developments**: For measured data, viewing how values change must be easy to enable clinical staff to provide correct diagnoses and prescribe appropriate treatments in time.
    - **Finding patterns**: Sometimes, distinctive patterns in data (e.g., two weeks of fever) can serve as hints that facilitate the identification of problems by physicians.
    - **Discovering intervals**: Finding the intervals at which problems occur (e.g., every Monday, every 2 hours) is necessary.
- **Incidents and symptoms**: Apart from numerical data, incidents and periods of symptom occurrence are also important factors for physicians to determine causes and make decisions. The methods used in this regard are identical to those for recording data, except for viewing developments.

- **Treatment planning**: The most complex time visualization is needed for treatment planning. The specifications of therapeutic plans are often indicated in certain or uncertain time annotations and are accompanied with sub-plans, which are difficult to visualize.
    - **Allen's relations**: Visual representation should present all possible relationships between intervals. Numerous situations, such as A before B, A meets B, A overlaps B and A contains B, can occur.
    - **Temporal uncertainty**: Plans that are characterized by temporal uncertainty should be depicted in a way that eases data recognition while preventing neglect of data.
    - **Hierarchical decomposition**: Hierarchical decomposition is important in structuring a plan and ensuring the reusability of its parts because some plans may call for the development of sub-plans. A system should also allow users to select the level of information visible by simultaneously showing condensed and expanded levels.
    - **Different dimensions**: Different kinds of information about the same object should be visible at the same time. The option of choosing views of only certain tasks in a project is useful and necessary in enabling users to capture only the tasks that they need.

Table 1: Comparison with other systems by medical data types.

Aspects of data	Methods	Lifelines	MIVA	Midgaard	VIE-VISU	Lifelines2	VISITORS	Five Ws	EpicCare	eClinicalWorks	Allscripts	Our system
Measured data	Intuitiveness	√	√	√		√	√		√	√	√	√
	Focus+ context data	√	√	√	√	√	√		√	√	√	√
	Viewing developments		√	√	√	√	√		√	√	√	√
	Finding patterns	√	√			√	√					
	Discovering intervals						√					
Incidents and symptoms	Intuitiveness	√	√			√		√				√
	Focus+ context data	√	√	√		√	√	√	√	√	√	√
	Finding patterns	√	√	√		√	√			√	√	√
	Discovering intervals							√	√		√	√
Treatment planning	Allen's relations	√	√	√		√						√
	Temporal uncertainty							√	√	√	√	√
	Hierarchical decomposition		√	√		√	√					
	Different dimensions	√	√	√	√	√	√	√		√	√	√

Another important comparison criterion is the effectiveness of exploratory search. This feature cannot be analyzed in a standardized manner, but we delved into this component of our system by comparing several other components that may affect exploration. The results are presented in Table 2.

Table 2: Comparison by components.

Task type	Components	Lifelines	Midgaard
System operation	User interface	Amount of texts and number of tables	Timeline with text
	Navigation	Move mouse pointer over a line to read a long label	Timeline draggable and zoomable
	Color attributes	Show normal or abnormal states	Show normal or abnormal states
	Filter	Choose text, check box to show medical events	Hierarchical display shows numerical data
Medical data display	Symptom display	Text	No
	Diagnostic classification	No	No
	Terminology code	No	No
	Historical record display	Line segment in timeline	Show level of detail along time axis
Interaction with other systems	Mobile device	No	No
	Patient portal	No	No

Task type	Components	Lifelines2	MIVA
System operation	User interface	Amount of text and number of tables in multiple patients	Point plots in timeline
	Navigation	Timeline and buttons	Button and timeline
	Color attributes	Show normal or abnormal states	Show normal or abnormal states
	Filter	Rank, filter and save results as a new group of records	Variables can be added from a list or re-ordered by
Medical data display	Symptom display	Text	No
	Diagnostic classification	No	No
	Terminology code	No	No
	Historical record display	Triangles in zoomable time line	Point plots to visualize changes in numerical values, zoom and pan
Interaction with other systems	Mobile device	No	No
	Patient portal	No	No

Task type	Components	VISITORS	Five Ws	EpicCare
System operation	User interface	Number of line charts in raw numerical data with groups of data in text	Sunburst display with a human body	Amount of text and number of tables
	Navigation	Check box to select groups of patients	Button	Button
	Color attributes	Indicate normal or abnormal health conditions	Indicate normal or abnormal health condition	No
	Filter	Draw complex sequence of event relationships,	No	Buttons for visits, statements, payments
Medical data display	Symptom display	Texts and tables	Symptom location on the human body,	Text
	Diagnostic classification	No	No	No
	Terminology code	No	ICD-10, CPT, NDC	ICD-10
	Historical record display	Temporal abstractions among groups of patients	Use diagnostic reasoning	With text in tables
Interaction with other systems	Mobile device	No	No	Mobile and tablet
	Patient portal	No	No	Yes

Task type	Components	Allscripts	eClinicalWorks	Our system
System operation	User interface	Amount of text and number of tables	Amount of text and number of tables	Temporal interface shows historical events, and spatial interface shows medical information
	Navigation	Buttons	Buttons and timeline	Clicking on human body, timelines and normal buttons
	Color attributes	Show charges and payments.	No	Display normal and abnormal status (laboratory tests) and distinct physiological system (spatial and temporal interfaces)
	Filter	check box to show medical events	check box to show patient appointments	Physiological and medical event filter, time scroll bar in spatial interface and major disease filter
Medical data display	Symptom display	Text	Using POMR in text	Circle as indicator in POMR on 2D human image with color coding
	Diagnostic classification	No	No	11 physiological systems
	Terminology code	ICD-10	ICD-10	ICD-10
	Historical record display	show diagnoses and numerical data in timeline	With text in tables	Point event timeline internally connected with duration timeline, clicking function to find details
Interaction with other systems	Mobile device	Yes	Yes	No
	Patient portal	Yes	Patients can input their lifestyle and health data	Patients can view and insert health condition for physicians

4.4 Information Comments

To evaluate the usability and efficiency of our prototype, we invited physicians to participate in the study. This section discusses the analysis methods and corresponding results. The suggestions provided by the participants are also presented.

Inviting physicians to participate is difficult because their time is always stretched by multiple demands for attention in medical environments. Therefore, we involved only five physicians to give us information comments, none of whom have had previous experience with our system. We initially delivered a 20-minute tutorial about our system and showed a video on how to use the system, which contains basic functions (such as inserting new records and filtering by year) and shows the related PHR system. Subsequently, we simulated a patient situation, complete with a sample medical record that reflects more than 30 diagnoses, treatments and medications. We then recorded the length of time spent by the participating physicians on retrieving the medical information given in Table 3.

Table 3: Questions for physicians

Number	**Question**
1	What are the most severe diseases of the patient?
2	What are the symptoms and treatments related to the skeletal system (a particular problem on the patient body)?
3	How many different kinds of problems did the patient have in 2015?
4	What are the treatments that the patient had in the 2016?

All the physicians provided correct answers to all four questions at an average of 3.18 min (individual times = 2, 3, 5, 3.5 and 2.4 min). This is regarded as a positive result given that they have not previously encountered our system. Then, we received some feedback from these physicians to help us improve our system in the future.

Four of the physicians stated that our system improves the visualization of EMRs by both doctors and patients. Our system would allow them to promptly access patients' diagnoses, medical histories and laboratory tests. However, two of the physicians suggested reducing the number of clicks for the insertion of medical descriptions. Our system requires two clicks: one to activate the circular indicators and another to access medical events.

Three of the participants indicated the rapid acquisition and summarization of patients' medical histories as powerful features. These would enhance their ability to identify problems and determine treatment courses. However, the remaining physicians stated that the circular indicators for location may result in confusion as to which organ corresponds to a given problem. In the 2D representation of our system, organs are placed very close to one another, requiring better localization. In the digestive system, for example, the stomach, liver and gallbladder are very near one another. A single circle may encompass these organs.

All the physicians indicated that they would highly recommend the feature, which was evaluated as improving the efficiency of medical practice and the satisfaction of patients. They thought that the highly-visualized platform would allow patients to easily understand their medical conditions and that the system would improve communication between doctors and patients. They also regarded the system as facilitative of consultation. Patients would be able to consult their doctors beyond regular business hours or even remotely. This feature is be particularly useful for patients who are travelling and need health care in a country where a different language is used. Doctors would easily extract patients' medical histories with guidance from patients in any region or country. The drawback identified by the participants was the need to direct more focus toward security checks and guaranteeing the safety of patient information.

Overall, the feedback was positive, especially considering the fact that they used the system after such a short tutorial. Almost all the participants felt immediately comfortable in using our system. We also collected many valuable suggestions from the physicians:

- We were asked to create two interfaces for both existing EMRs and the new platform to allow doctors a choice before they decide on familiarizing themselves with the latter.
- Our system should consider the legality of documentation. Thus, terms of use and patient gateway privacy should be ensured for all patients who enroll in the patient health system. Because our system provides patient history records over the Internet, the system can easily inform family members of patients' health conditions. Delineating the terms and conditions for this situation is necessary.
    - Security functionality should be incorporated into the system.
- A function that allows physicians to determine new symptoms or new self-medication taken by patients should be developed.
    - In the current symptom platform, the spatial interface features only a yearly time filter, and the temporal interface has a zoomable time scale up to a day. Symptoms are not included in the timeline of our interfaces. This function can be easily incorporated.

- The indicators should be distinct from others so that physicians can easily differentiate indicators.
    - Adjustable circle sizes or segmented organ indicators may need to be incorporated into the location-based disease visualization.

4.5 Examples to Use

This section discusses two examples that demonstrate the benefits of using our system.

4.5.1 Example for Physician Decision Making

One of the example can be used in an emergency room. In the scenario, a female patient presented with acute pain in the right upper quadrant (RUQ)—a condition that can be caused by a variety of factors. Quickly accessing patient medical history plays a key role in differential diagnosis. The physician can use the system by clicking on several locations and circles in the spatial interface and clicking on icons in the temporal interface to check the corresponding organ diseases in the patient’s history. The detailed interaction between the physician and the system is as follows:

1: Verify if there is a GREEN CIRCLE in the area of the RUQ in the digestive system to determine disease history in the area. The circle indicates whether gallstones, which cause acute pain at any time, that are most asymptomatic exist, and whether the patient suffers from irritable bowel syndrome, chronic pancreatitis and other lesions that cause intestinal obstruction.

2: Verify if there is a YELLOW CIRCLE on the heart to determine disease history in the area. The circle indicates whether the patient has had an angiogram that reflects coronary artery blockage that may occasionally present as upper abdominal pain. It also indicates whether congestive heart failure may stretch the liver capsule, thus causing pain in the RUQ.

3: Verify if there is a BLUE CIRCLE on the respiratory system to monitor recurrent pulmonary embolism that causes infarction in the lower right lobe of the lung.

4: Verify if there is a PINK CIRCLE on the reproductive system to determine the presence of chronic pelvic inflammatory disease that can cause sharp and pleuritic RUQ pain.

This situation demonstrates that color-coded circles on a human body map for different physiological systems can advance diagnosis and assist a physician in sequencing relevant medical history data.

4.5.2 Example for Diabetes Complications

The other example is that on a specific clinical case intended to demonstrate the interactive system in action.

In the sample case, the patient is a 46-year-old female, whose mother suffered from diabetes. The patient had gestational diabetes at age 25 but recovered from this condition. She was found to have type 2 diabetes at age 30 and was prescribed Metformin to control her blood sugar. She has had two episodes of angina, and a blood test showed that her blood sugar was not well-controlled. Insulin was added as medication.

The scenario provided to the physician can be as follows: As the patient was cleaning at home in her slippers, her feet was accidentally pierced by a wire, causing a small wound. The wound was not deep or huge, so she simply cleaned it and covered it with plaster. The wound did not hurt or itch, so she assumed it would be cured. After a few days, however, the patient inexplicably developed a high fever, and her family sent her to the hospital.

The actions taken by the physician are as follows: To familiarize himself with the patient's history, the physician can click on the historical record and viewed the major diseases in the system. At this stage, he can view diabetes and determined the cause as diabetic foot. The wound caused serious ulceration of the foot, almost requiring amputation. Dealing with these complications in time is critical because they are highly likely to cause vascular occlusion and neuropathy when composition in blood sugar is high. Under such conditions, blood vessels appear as though they are soaked in sugar.

The functionality that allows patients to update their health data, such as symptoms, self-medication and self-treatment, helped avoid severe consequences. This case indicates that a patient's well-being depends on the timely provision of correct diagnosis and prescription of appropriate treatment and that our system offers functionalities that helped the physician address the case.

4.6 Discussion

Despite the positive results on user interaction with our system, several interesting and important factors present room for improvement.

- The current 2D human image with front and back views is non-zoomable. As previously stated, the stomach, liver and gallbladder are positioned very closely in the digestive system, thereby presenting difficulties in separately selecting the organs. Our system may need to support organ segmentation or a zoomable spatial interface.

- Our system provides severity information for a symptom, but not yet explicitly displayed in spatial user interface. Also, physicians are not easy to extract new symptom dragging the time scroll bar currently, in the future we can add a tracking change feature.
- Our system is currently web based, yet at times, users may not have access to an Internet connection. We therefore need to provide a new method of enabling certain operations (such as viewing current health conditions) that do not depend on network connection. We can use a cache to store resources that are accessible over a browser offline, granting users partial access to the system.
- Our system does not yet contain actual medical data and has not done formal software testing
- Its scalability has not been tested. Many patients and doctors are interconnected, and medical data are always voluminous. The system's scalability should be enhanced for it to handle large-scale operations, such as the frequent offloading of databases.Terms of use and a patient privacy policy should be ensured for all patients who enroll in the system to reduce the risk of unauthorized use. Our system should also consider the safety of patient information in transfers via the Internet.
- Currently, our prototype minimally conforms to the forgiveness and feedback principle in the event of errors in data entry. We need to minimize the likelihood of user errors and determine a way of reducing user errors and enabling effective recovery when mistakes are made while editing their personal information such as address or telephone. Also, we need to do validation of input. For example, typing F in blood type should not be approved.

Chapter 5. Conclusion and Future Work

5.1 Conclusion

We developed an interactive visualization system where medical data are navigated over pictorial-based user interfaces. Clicking on the anatomical location that corresponds to a medical problem enables the easy retrieval of related medical information, especially for physicians in emergency rooms and trauma departments. The multiple physiological systems and clinical event icons in the system represent categories of medical records. Our temporal and spatial graphical user interfaces provide an interactive, intuitive and effective platform for displaying health information. Our system is designed and implemented with a dynamic timeline, thus enabling the filtering of information within a given period. This feature means that medical data can be easily extracted. Our interface also boasts of access to a digestible amount of information. Through our system, physicians and patients can communicate directly with each other, exchange medical information and thereby improve the usability of EMRs.

5.2 Future Work

Notwithstanding the benefits of the proposed system, room for deepening our research and developing our prototype still exists. Our future work may involve the following considerations:

- To improve the accuracy of visual positioning for diseases, we can add multiple views or organ segmentation on the human body map.

- Currently, our system offers front and back view of female anatomy in spatial user interface. The system should add male anatomy so that medical information can be displayed more accurately. For babies, even though they have different body proportion, the anatomy is quite similar to adults and it is better to keep adult anatomy so that we can keep records from birth to death.
- Once we accumulate adequate medical data, we would like to improve the security and storage functionalities of our system so that it satisfies security and privacy requirements.
- Patients' family members can be involved in our future study to obtain insights that can reinforce correct diagnoses and appropriate treatments.
- Clinicians often use mobile devices or tablets as they perform rounds in a hospital. We can develop a method of displaying patient medical records on mobile devices.
- We can design an approach to integrating PHR administrative tasks, such as appointment scheduling or prescription renewals.
- We need to find a way to integrate our system with existing EMR databases.

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