

Interactive Medical Record Visualization based on Symptom Location in a 2D Human Body

by

Yongji Jin

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Abstract

An electronic medical record (EMR) is “an electronic record of health-related information on an individual.” EMRs are widely used in healthcare organizations and have many advantages over traditional paper-based medical records, such as their efficiency and reduced storage needs.

However, the use of EMRs has not yet reached its full potential. The numerous items of medical data are always shown with redundant and complex text contained in various monotonous forms and tables. It is hard for users to obtain useful information in a short timeframe.

We propose a prototype system to intuitively and interactively visualize patients’ medical records. Navigation is improved through graphics-based and interaction-based visualization. Our interface features clickable two-dimensional (2D) images of a human body, on which the symptom locations are the starting point of the navigation. In addition, interactive and classified history visualization is also provided. Finally, some pertinent suggestions and comments from medical professionals are discussed.

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Table of Contents

Contents

Abstract.....	ii
Acknowledgements	iii
Table of Contents.....	iv
List of Figures.....	viii
List of Tables	xiv
Abbreviations.....	xv
Chapter 1. Introduction	1
1.1 Current Visualization Systems for EMRs	3
1.2 Objective	4
1.3 Contributions.....	5
1.4 Thesis Organization.....	6
Chapter 2. Literature Review.....	7
2.1 Medical Record	7
2.1.1 Primary Components	7
2.1.2 Medical Coding.....	11

2.1.3	Requirements for Medical Records	13
2.2	Electronic Medical Record.....	14
2.2.1	Benefits of EMRs Compared to Paper-based Medical Records	14
2.2.2	The Development of the EMR Systems.....	18
2.3	Information Visualization (IV).....	20
2.3.1	Introduction.....	20
2.3.2	The History of IV	22
2.3.3	IV Examples.....	27
2.3.4	IV Techniques.....	32
2.3.5	IV Toolkits	37
2.3.6	IV Evaluation Criteria.....	39
2.4	Existing EMR systems	43
2.4.1	EMR Visualization Prototype Systems.....	43
2.4.2	Commercial EMR Systems.....	50
Chapter 3.	System Design and Implementation.....	61
3.1	Requirements for Our Visualization System.....	61
3.2	User Interface Design.....	62
3.2.1	Start Page	62
3.2.2	Patient Information	63

3.2.3	Five Physiological Systems	66
3.2.4	Location-based Symptoms.....	67
3.2.5	Timeline-based and Icon-based History Records	73
3.2.6	Color-based Blood Test Display.....	78
3.3	System Implementation Overview	80
3.3.1	System Architecture.....	80
3.3.2	Benefits of Web-based System	83
3.3.3	System Performance Optimization	85
3.4	Limitations	86
Chapter 4.	Discussion	88
4.1	Requirements Check	88
4.2	Comparison with Other Systems.....	92
4.2.1	Comparison between Five Ws and Our System	99
4.2.2	Comparison between Two Patents and Our System.....	100
4.3	Informal Feedback.....	101
Chapter 5.	Conclusion.....	104
5.1	Contributions.....	105
5.2	Future Work	106
References	108

Publications by Author 126

List of Figures

Figure 2.1: (a) Paper-based medical record. (b) Electronic medical record.	17
Figure 2.2: Visual analytics combine scientific disciplines to enhance distributing the work between humans and machines [50].	21
Figure 2.3: The time distribution of events considered milestones in the history of IV [52].	22
Figure 2.4: Planetary movements shown as cyclic inclinations over time, by an unknown astronomer, appearing in a 10 th century appendix to commentaries by A. T. Macrobius [52]. ...	23
Figure 2.5: Graph of determinations of the distance, in longitude, from Toldo to Rome [52].	24
Figure 2.6: William Playfair’s 1821 time series graph of prices, wages, and the ruling monarchs over a 250-year period [52].	25
Figure 2.7: (a) A portion of Dr. Robert Baker’s cholera map of Leeds, 1833, showing the districts affected by cholera [52]. (b) A dot-map created by Dr. John Snow [1813–1858] shows the deaths from an outbreak of cholera in 1854 in London [52].	25
Figure 2.8: Visualization of historic weather-station data for the UK between 1880 and 2013 [71].	28
Figure 2.9: Visualization of immigration flows in the US in 2012 [72].	29

Figure 2.10: Displaying the Salmonella typhi genome as a circular plot. The tracks from the outside represent: forward CDS; reverse CDS; pseudogenes; Salmonella pathogenicity islands (red); repeat regions (blue); rRNA and tRNA (green) [73].	30
Figure 2.11: Facebook Network Visualization [74].	31
Figure 2.12: Citation Network Visualization [75].	32
Figure 2.13: Correlation between the life expectancy, fertility rate, and population of several countries [77].	33
Figure 2.14: Tree map for displaying the iTunes Top 100 on February 27, 2006, grouped by genre, sized by chart position, and colored by 24-hour change in chart position [79].	34
Figure 2.15: Car modeling in the 1970s and 1980s with MPG, cylinder, displacement, power, weight, MPH, and year [82].	35
Figure 2.16: Timeline of major technological advancements [84].	35
Figure 2.17: Using a data flow diagram (DFD) to present the process of a student registration system [87].	36
Figure 2.18: Simple diagram of a semantic network illustrating the directed nature of relationships [88].	37
Figure 2.19: Timeline [8] – Visualization of personal medical histories. Horizontal lines represent the events and episodes in a single patient record. The line color, height, and captions are used to convey information. A detailed panel to the right shows further information about a selected item such as an ultrasound image.	44

Figure 2.20: Lifelines 2 [92] – Visualization of records of temporal categorical data. (a) Shows each individual record. (b) Shows the aggregation of events over time. (c) Contains controls to basic operators: align, rank, and filter. (d) Shows controls for event distribution and grouping. 45

Figure 2.21: KNAVE-II [96] – Provides an overview of an oncology patient’s data: (a) On the left, a browser of the domain ontology allows the user to add abstract concepts and raw data variables for visualization. (b) In addition, there is a string search for concepts. (c) Abstract concepts have an ordinal scale and duration. They are represented with line segments similar to Lifelines. (d) Line plots display numerical raw data. 46

Figure 2.22: Five Ws [18] – The two coordinated displays of the 5W system. (a) The radial (patient overview) display using an integrated body map, along with the user interface. (b) The corresponding sequential (diagnostic reasoning) display using the same color coding. 47

Figure 2.23: EMR visual representation with a human figure and a timeline [117]. 49

Figure 2.24: Human image-based EMR visualization with indicators [118]. 50

Figure 2.25: Market Share of commercial EMR systems [112]. 52

Figure 2.26: Interface of the Epic EMR system [123]. 53

Figure 2.27: Interface of the Allscripts EMR system [124]. 54

Figure 2.28: Interface of the eClinicalWork EMR system [125]. 54

Figure 2.29: Interface of NextGEN EMR system [126]. 55

Figure 2.30: Interface of GE EMR system [127]. 56

Figure 2.31: Allscripts Wand Timeline [116] shows an overview of a patient’s diagnosis, medication, vital signs, lab values, and encounters along a horizontal time axis.....	57
Figure 2.32: Interface of WatsonPaths [121]. (a) WatsonPaths’s medical scenario analytics. (b) The solution provided by WatsonPaths.	60
Figure 3.1: Start page of the system: the far left side is a login box, next to the login box is a select box, the right side is a navigation board, and a clickable 2D human body is placed in the center of the page.....	63
Figure 3.2: The interface used to create a new patient’s record. The input box for entering a new patient’s basic information is highlighted in red on the left side of the page.....	64
Figure 3.3: Interface for a female patient [105].....	65
Figure 3.4: Interface for a male patient [106].....	65
Figure 3.5: Five physiological systems: from left to right, the skeletal, muscular, cardiovascular, digestive, and nervous systems are displayed [100] [101] [102] [103] [104].	67
Figure 3.6: (a) Record a new symptom, including its location information and symptom type. (b) Symptom locations are labeled with colored circles.	68
Figure 3.7: (a) All kinds of the problems are displayed on the home page. (b) Only skeletal problems are displayed on the skeletal system page. (c) Only muscular problems are displayed on muscular system page. (d) Only cardiovascular problems are displayed on the cardiovascular system page. (e) Only digestive problems are displayed on the digestive system page. (f) Only nervous problems are displayed on the nervous system page.....	69

Figure 3.8: (a) Symptoms are labeled with colored circles and displayed on the human body. (b) A pop-up box, which will appear when clicking on a symptom location, is used to add, display, and retrieve medical records..... 70

Figure 3.9: The red border means this pop-up box belongs to skeleton problems: (a) A pop-up input box used to insert diagnosis information. (b) A pop-up input box used to insert treatment information. (c) A pop-up input box used to insert medication information. (d) A pop-up input box used to upload scanning images and insert related notes. 71

Figure 3.10: The red border means this pop-up box belongs to skeleton problems: (a) A pop-up box for displaying the latest diagnosis information. (b) A pop-up box for displaying the latest treatment information. (c) A pop-up box for displaying the latest medication information. (d) A pop-up box for displaying the latest scanning results. 72

Figure 3.11: Icon-based and time-line based history record display..... 73

Figure 3.12: The full page of history records. Navigation buttons and icons are placed on the upper part of the page, which can be clicked to filter medical data..... 74

Figure 3.13: (a) All diagnosis history for all symptoms. (b) All treatment history for all symptoms. (c) All medication history for all symptoms. (d) All scanning history for all symptoms. (e) All blood test history for all symptoms..... 76

Figure 3.14: (a) A patient’s full history of skeletal problem. (b) A patient’s full history of muscular problem. (c) A patient’s full history of cardiovascular problem. (d) A patient’s full history of digestive problem. (e) A patient’s full history of nervous problem. 77

Figure 3.15: Information displayed by clicking on the icons. The border color for each icon indicates which physiological system it belongs to. 78

Figure 3.16: Display of blood test results. A table of three sets of blood test results for the same individual. Red highlighting is used to indicate an abnormal index..... 79

Figure 3.17: Display of blood test results. Graph-based visualization of the trend of each index in the past three tests. The red spot shows abnormal results; blue shows normal results... 79

Figure 3.18: System architecture. 80

Figure 3.19: Entity-relationship model of our database. 83

List of Tables

Table 1: Comparison with other systems (compared by their interactive features).	95
Table 2: Comparison with other systems (compared by items).	98
Table 3: Comparison between our system and two patents.....	101

Abbreviations

2D	Two Dimensional
3D	Three Dimensional
AMA	American Medical Association
AMC	Academic Medical Center
CDS	Coding Sequence
CG	Computer Graphics
COSTAR	Computer Stored Ambulatory Record
CPT	Current Procedural Terminology
CS	Computer Science
CSS	Cascading Style Sheet
CSV	Comma Separated Value
D3	Data Driver Document
DFD	Data Flow Diagram
DNA	Deoxyribonucleic Acid
DOM	Document Object Model
EMR	Electronic Medical Record

ER	Entity Relationship
GPU	Graphics Processing Unit
HCI	Human Computer Interaction
HELP	Health Evaluation through Logical Processing
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
ICD	Interactional Classification of Diseases
IO	Input / Output
IOM	Institute of Medicine
IV	Information Visualization
JSON	JavaScript Object Notation
MPG	Mile Per Gallon
MPH	Mile Per Hour
NDC	National Drug Code
PNG	Portable Network Graphics
SNP	Single Nucleotide Polymorphism
SOAP	Simple Object Access Protocol
UI	User Interface

UK	United Kingdom
UX	User Experience
WHO	World Health Organization
XML	Extensible Markup Language

Chapter 1. Introduction

The term medical record, also called a health record, has existed for a long time. In fact, it can be traced back to the days of Hippocrates, who is considered the father of Western medicine [1]. Hippocrates defined a medical record as an entity that must meet two basic rules: (1) It should accurately reflect the patient's past disease history. (2) It should indicate the probable cause of his/her disease. These two basic goals remain today and are now reinforced by the additional functions and features enabled by the electronic storage, computing, transmission, and processing capabilities of the electronic medical record (EMR), which is a longitudinal electronic record of patient health information [2]. The development of EMRs can be divided into two main time periods: before and after the 1980s [42]. The earliest research and implementation of EMR systems began in some academic medical centers in 1960s. Since the 1980s, EMRs have become more and more powerful because of the rapid development of computer and information technology and are widely used in healthcare organizations today.

EMRs include various types of information such as problems, diagnoses, symptoms, treatments, immunizations, allergies, medications, X-ray results, vital signs, radiology reports, progress notes, patient demographics, laboratory data, and others. Hence, referring back to the two fundamental rules proposed by Hippocrates, an advanced and comprehensive electronic system not only enables superior storage and mobility of medical records (improving rule 1), but also supports further advanced and accurate reasoning with regards to the probable cause of a disease (improving rule 2). What is more important is that the EMRs are dedicated to improving evidential medicine as an acceleration of growth in the field of modern medicine. In addition to

these key features, EMRs have many advantages over traditional paper-based medical records, such as their efficiency and reduced storage needs [3].

However, nothing is perfect. Although the EMRs have many advantages, as mentioned above, EMR use in clinical practice is still not fully accepted and has not reached its full potential [3]. As the volume of medical records is growing at an alarming rate, important information and an overview of clinical records are always hard to retrieve and obtain, seriously limiting physicians' diagnostic efficiency. We consider the improperly sorted, arranged health data and the fragmented, non-intuitive, non-interactive display of health information are the main causes.

As a goal, we believe the ideal EMR system should be interactive and intuitive, integrating and displaying comprehensive information in an easily digestible and meaningful format. An uncluttered, interactive, navigable user interface should be integrated in the EMR system to support and reinforce clinical decision-making and allow for rapid, simple input/output (IO). Moreover, it should also have the ability to work on health data directly and immediately, thus minimizing the need for multitasking and allowing the healthcare provider to focus mainly on the health problem to achieve the best therapeutic result.

Interactive visualization is considered the most appropriate approach to achieve such a goal. There is a famous saying, "A picture is worth a thousand words," which means that a large amount of related data can be most effectively conveyed with visual representations (e.g., images, graphs). Good visualization can make it possible to quickly retrieve and obtain useful information from numerous types of complex data. Consequently, in this thesis, we would like to propose an interactive visualization system to better represent medical records.

1.1 Current Visualization Systems for EMRs

To date, only a few approaches have been proposed for visualizing patients' medical records. The most common paradigm is to organize and display the health records along the time axis. In 1983, Tufte [4] described timelines as a frequent and powerful form of visual design. The early work using timelines for medical records was proposed and implemented by Powsner and Tufte [5]. They constructed a graphic summary using a table of individual scatterplots of relevant medical variables such as test results and treatment data. Many recent works in that direction include CDDV [6], VIE-VISU [7], LifeLines [8], and LifeLines2 [9], in which medical records are distinguished by their inherent aspects (e.g., symptoms, problems, diagnosis, treatments, tests results, medications). These systems have the following two features: (1) color is used to show normal or abnormal states and indicate the disease severity or type; (2) line segments can be zoomed and panned to reveal more or fewer details. Many other systems have also embraced this type of medical data visualization, such as the KNAVE-II [10] and VisuExplore [11], and Midgaard [12]. Another widely used paradigm is a flowchart, as applied in medical algorithm maps [13] and other systems [14] [15], where health records are visually represented as a logical execution sequence of plans (like a pipeline).

Today, a number of modern EMR systems not only offer timeline views or flowchart diagrams, but are also starting to support body-centric data layouts. This is because clinical data often have some relation to human anatomy. For such data, a template of a virtual human body is an intuitive, quick, and simple means to provide an index to the corresponding part of the human body. For example, the system presented in [16] gathers close-ups of required radiological data around a rendered human body and the system Midgaard [12] provides a visualization method

that maps collected patient records to an image of the human body. What is more, the Five Ws system, proposed in [17], [3], and [18], also presents patient records with a radial display integrated on a human body map. This system allows physicians to use a red dot to mark the location of symptoms in the body and present the corresponding diseases in a sunburst tree around this body.

1.2 Objective

Although there are many advantages to the visualization systems mentioned above, there are also several drawbacks, such as too much text, a lack of interactivity, fragmented and non-intuitive displays. The interfaces are still filled with unreadable text, boring tables and complex navigations. Consequently, we can conclude that intuitive user interaction systems to visualize EMRs have not been well explored yet.

The goal of our work is to design and implement an intuitive, interactive EMR visualization system which is integrated with a minimal amount of textual data and easy navigation.

To achieve this goal, we propose a web-based interactive visualization system to intuitively illustrate health information with graphics and images instead of redundant text. Our system focuses on an interactive display of a two-dimensional (2D) image of the human body to support body-centric data layouts. A clickable 2D human body is exploited to denote symptom locations. These symptom locations are labeled with colored circles, which are the starting point of the interactive navigation. By clicking on these symptoms, users can easily add, insert, and update information and also navigate corresponding physiological systems and obtain detailed

information, such as symptom type, severity, and Interactional Classification of Diseases (ICD) codes. Furthermore, to provide a better layout of health records, interactive icons are integrated into a timeline to illustrate the history records, and various colors are used in blood tests to help users distinguish normal or abnormal indices of test results.

1.3 Contributions

We have designed and implement a graphics-based, image-based and symptom location-based EMR visualization system integrated with a minimal amount of textual data and simple navigation. We made the following major contributions:

- Our system is integrated with a graphics-based and image-based interface to provide intuitive visual representation of health data.
- In our system, the diseases are divided into different categories of physiological systems, such as skeletal, muscular, cardiovascular, digestive, and nervous systems. This is very helpful for users to better understand the disease.
- Our system provides a clickable 2D image of the human body to support body-centric data layout. Symptom locations are indicated with colored circles on the body. Moreover, an easy navigation is provided in our system. Users can click on the symptom locations for further health information.
- Our system provides a novel history record by integrating the timeline and icons. Users can easily and accurately retrieve and extract useful records with the help of meaningful icons and a powerful filtration function.

1.4 Thesis Organization

The remainder of this thesis is organized as follows:

- Chapter 2 introduces the background and related works of this research. First, we present the basic concept of medical records and conventional EMR systems. After that, we propose the idea of visualization and describe several visualization applications, techniques, and toolkits. Finally, we introduce some existing medical record visualization systems.
- Chapter 3 introduces our approach to visualizing the medical records. This chapter is divided into two parts: a visualization description section and a system architecture section. In the visualization description, we introduce the user interface and features of our system. Additionally, the system framework and the technologies we used are presented in the system architecture section.
- Chapter 4 includes a comparison between our system and other EMR systems, together with some informal feedback.
- Chapter 5 concludes the thesis and highlights the contributions of this research. Future works are also discussed.

Chapter 2. Literature Review

This thesis topic is based on two major research fields: medical records and information visualization (IV). In this chapter, we introduce the research background of these two perspectives. First, we introduce the general idea of medical records, including the basic components, medical coding, and requirements. Following that, we present some benefits of EMR and the development of EMR system. We also demonstrate the relevant background of IV, including visualization examples, techniques, toolkits, etc. Finally, we also demonstrate an overview of some existing EMR visualization systems, including visualization prototype systems and commercial systems.

2.1 Medical Record

The medical record is a powerful tool that includes patients' previous health conditions and treatments [19]. It allows physicians to track their patients' medical history as well as identify potential issues for diagnosis and is now widely used in hospitals, clinics, and other healthcare organizations. The primary purpose of medical records is to help physicians optimize the use of resources and provide comprehensive and high-quality healthcare to their patients [20]. By using this useful tool, physicians can determine the course of healthcare and offer patients the best treatment.

2.1.1 Primary Components

As mentioned before, a medical record is a living document that stores patients' story relevant to their healthcare (e.g., diagnosis, treatment, scanning results, test results, and clinical notes). In

addition to merely telling the story, a complete and accurate medical record needs to include compulsory information (e.g., personal identification information, medical history, and medication history). As time goes by, medical records continually develop and change. However, the common information remains unchanged over time and all medical records should contain it. Some common components of medical records are as follows:

- **Personal Identification Information** – This is the information that can be used on its own or with other information to identify an individual [21]. When a patient goes to a hospital to see a physician, the first thing the physician does is check the patient’s personal identification information. In general, personal identification information is on the first page of the medical record. Just as deoxyribonucleic acid (DNA) makes every human being special and unique, each patient’s medical record must have specific personal identification information such as his/her name, gender, address, birth date, and government-issued identification number. Such personal identification information helps physicians distinguish their patients and provide accurate treatment to each patient.
- **Basic Medical Profile** – A basic medical profile must be maintained in each patient’s practice chart, which contains a brief summary of essential information about the patient. This can help physicians quickly obtain a picture of the patient’s overall health information. This information could include elements such as risk factors, allergies, drug reactions, and others [22].
- **Family Medical History** – A family medical history is a collection of health information about a patient and his/her relatives [23]. It contains all the health

information from three generations of the family. Family members share similar genes, living environments, lifestyles, and habits. These factors may offer clues to medical conditions that probably exist and spread among a particular family. Being aware of these clues, physicians can determine whether an individual, other family members, or future generations may be at an increasing risk of developing a particular condition. Therefore, having detailed knowledge about a family's medical history contributes to an individual's preventive measures and reduces the risk of disease.

- **Diagnosis History** – Medical diagnosis is the process of determining which disease or condition explains a patient's symptoms [24]. The information required for diagnosis is typically collected from a history and physical examination of the person seeking medical care. The diagnosis history is the collection of patients' previous diagnoses. This information provides physicians with all the details of patients' health conditions, enabling physicians to provide proper healthcare.
- **Treatment History** – The treatment history is a document recording all the therapy patients have received. Given this information, physicians have knowledge of what has succeeded and failed. As a consequence, physicians are able to save treatment time, and for patients, the expenditure on medical services is also reduced.
- **Medication History** – When a patient sees a doctor, one of the most important things the doctor needs to do is to determine what medications the patient has taken before and what he/she is allergic to. The medication history details what medications the patient has taken, is very important for diagnosis, and needs to be accurate. Otherwise, it can lead to improper treatment. To emphasize the importance and necessity of the

medication history in treatment, the National Institute for Health and Clinical Excellence published regulations and guidelines in December 2007 [25] requiring all physicians and patients to have the responsibility of following the medication history policy after each treatment.

- **Scanning Test** – A scanning test is a common image test that has been used for decades to help doctors view the inside of the human body without having to make an incision. One of popular scanning methods is X-ray test, and it has become a key element in the identification, diagnosis, and treatment of many types of medical conditions. Today, different types of X-rays are used for specific purpose. For example, mammograms are used to examine the breasts and a barium enema is used to detect bowel problems.
- **Blood Test** – A blood test is a laboratory analysis performed on a blood sample that is usually extracted from a vein in the arm using a needle, or via finger prick. Blood tests are widely used in health care to determine the physiological and biochemical states, such as disease, mineral content, pharmaceutical drug effectiveness, and organ function. Blood tests help physicians check for certain diseases and conditions and they also help check the functions of your organs and show how well treatments are working.
- **Clinical Notes** – Clinical notes are the notes that are made contemporaneously regarding physician-patient encounters. They are always completed by physicians after patients visit the hospital. Good clinical notes are included in accurate and comprehensive records and have a positive effect on healthcare [25]. Physicians always

retrieve patient information from brief and professional clinical notes; therefore, the significant information from patient encounters needs to be included in them.

2.1.2 Medical Coding

Medical coding, or medical classification, is the process of transforming medical diagnostic descriptions into medical code numbers. This procedure is usually taken from a wide range of medical record sources (e.g., clinical notes, laboratory/radiologic results). Many institutes such as government health programs and private health insurance companies use it to track diseases and health conditions. Although many different medical classifications have been proposed, they occur into the following groups:

ICD - The International Classification of Diseases (ICD) is the standard diagnostic tool for epidemiology, health management, and clinical purposes [26]. This medical classification is generated and listed by the World Health Organization (WHO). The ICD contains codes for diseases, signs and symptoms, abnormal findings, complaints, social circumstances, and external causes or injuries. Because of this, the ICD has been used by healthcare professionals, researchers, health information managers, and health information technology coders to classify diseases and other health problems.

After a long period of development and evolution, an extensive amount of data and many functions have been integrated into the ICD. The latest and enhanced version of the ICD is the ICD-10, the development of which started in 1983 and was completed in 1992. It contains more than 14,400 different codes and allows the tracking of any diagnosis. The ICD-10 has been translated into more than 43 languages and its international version has been used in over 110

countries. Some of these countries, such as Canada, China, the US, South Korea, Japan, and Australia, have modified the international version to adapt it to their own healthcare systems.

CPT – The Current Procedural Terminology (CPT) is a uniform medical code set that is published and maintained by the American Medical Association (AMA) [27]. It provides reliable nationwide communication among physicians and other healthcare providers, patients, and third parties thanks to the standard coding format. As one of the most important groups of medical coding, the CPT is similar to ICD-9 and ICD-10 coding, but instead of including a diagnosis on the claim, it identifies the services rendered.

The first version of the CPT was developed and published by the AMA in 1996, and it continues to be updated by releasing new versions every few years. The first version contained not only surgical procedures, but some other sections regarding medicine, radiology, and laboratory procedures. Later, in 1970, the second edition expanded the terms and codes for the designation of diagnostic and therapeutic procedures in the application of surgery, medicine, and the specialties. Since then, four-digit coding was replaced with a brand new five-digit system. Currently, the CPT is widely used through the US and Canada because of its well-organized coding and descriptive services.

NDC – Unlike the above two systems, the National Drug Code (NDC) is rarely used worldwide. The NDC is a specific drug identifier that is used in the US for humans [28]. Each NDC contains 10 digits and 3 segments. The first segment identifies the drug labeler or vendor. Following this, the second set of numbers is the product code, which identifies the composition of the product.

Finally, the third set is used for identifying the drug package (size and types). The labeler and product code contain 4–5 as well as another 3–4 digits out of 10 digits, respectively. The remaining 1–2 digits belong to the package code. Consequently, it has three combinations, 4-4-2, 5-3-2 and 5-4-1.

2.1.3 Requirements for Medical Records

As discussed above, a medical record is a living document that details a patient’s story. To be an excellent storyteller in the medical field, several requirements should be met. Specifically, to ensure comprehensive and high-quality care for patients, a good medical record needs to be legible and regulatory [130].

- **Legibility:** As one of the most important indicators, the regulation requires that medical records be legible. This information is expected to be understood by all physicians and professionals and therefore, using conventional medical short forms is permissible. However, due to a variety of errors from abbreviations and poor handwriting, misunderstandings of medical records are quite common. Several studies have been reported on this legibility issue [19] [29] [30] [31] [32]. To address this problem, it is necessary for physicians to provide explanations and demonstrations to patients of abbreviations used in their medical record.
- **High-Level Privacy:** Apart from legibility, there is a great deal of extremely private information and huge amounts of data in medical records. Hospitals and physicians have the responsibility of protecting patients’ information and ensuring it is stored in a secure environment [128]. For example, a login system that contains users’ identification and passwords can be a good solution for hospitals to establish a secure system. Physicians must use sufficiently secure internet to access medical record systems to protect patient privacy.

- **Big Storage:** On the other hand, as times goes, the amount of patient data is increasing at a high speed and the storage of medical records has become an important issue [129]. As result, healthcare organizations are dealing with large datasets of medical records and have the responsibility to provide enough storage to guard against this rapid growth. A variety of enterprise-class database systems have been developed to handle it. Recently, the cloud computing technique has been leveraged to store large amounts of medical data in the cloud side, which is good for the sustainable development of the medical record system.

2.2 Electronic Medical Record

An EMR is a computer- and internet-based medical record. It has paper charts in a digital format and contains the standard medical and clinical information gathered in one healthcare provider's office [33]. EMRs go beyond the data collected in the provider's office and include a more comprehensive patient history. EMRs and the ability to exchange health information electronically can help physicians provide higher-quality and safer care for patients. Beyond that, as EMRs are stored through the computer and the internet, the data can be shared by different healthcare organizations, such as hospitals, clinics, and other health offices [20]. This section describes the state of EMRs, their advantage over paper-based medical records, and the development of the EMR system.

2.2.1 Benefits of EMRs Compared to Paper-based Medical Records

Before the development and popularization of computers and networks, paper-based medical records were the main way to store patients' health data. Before the 21st century, despite the development and benefits of EMRs, most treatment and relevant medical information documents

were written by hand in paper records. This was not without reason. Dick et al. [34] noted that traditional paper-based medical records are used widely due to their portability, simplicity, and familiarity to users. Even now, some patient-related information is still recorded manually. Nevertheless, there are many problems with paper-based medical records, such as their access, incompleteness and confidentiality leakage [35]. With the rapid development of science and computer technologies, EMRs have become more and more popular and most of the traditional paper-based medical records have been replaced by EMRs. In comparison with paper-based records, the benefits of EMRs are as follows:

- **Costs** - Many types of costs are associated with paper-based medical records. One of the most expensive costs is medical record duplication, which consumes a large amount of material resources [36]. In addition, it is necessary to hire staff to organize, distribute, and manage these documents, which also costs more in terms of labor resources. Moreover, to keep the physical integrity of the documents, it is certainly necessary to spend money to protect the copies from water, fires, and other risks. However, by using EMRs, these costs can be reduced significantly, and for healthcare organizations, a positive financial return on their investment will result [35]. EMRs do not require much labor power, time, and material resources and a physical storage space is not required. In a previous study [37], Davis demonstrated that although some initial costs are required to implement an EMR, the costs will decrease over time. Consequently, EMRs cost less than the paper-based medical record system.
- **Legibility** – Paper-based medical records are often not legible, which can contribute to medical errors [38]. As we all know, most physicians have poor penmanship, and very few

have good handwriting. Figure 2.1 (a) illustrates the problems with a paper-based medical record. Despite the fact that clinicians used templates, it is still difficult to read paper-based medical records and obtain useful information from them. In comparison, EMRs (Figure 2.1 (b)) are easy to read and obtain information from because the type font is more standard than paper-based records. According to a Harris Interactive Poll in 2006, around 60% of physicians believe that the use of EMRs reduces the amount of medical errors because of their improved readability [39].

- **Accessibility** – The biggest problem for paper-based medical records is the lack of access to the records. Only one physician can access the medical record at a specific location at a given time. Other physicians who want to access this record have to wait until it is available for them to use. This is a significant issue when a patient travels from one place to another for further treatment. To share the patient’s paper medical records with other physicians, the paper records should be packaged first and then mailed to other physicians. This costs a considerable amount of money and time due to the lack of accessibility. However, using EMRs, physicians can access the same records at the same time online. The work in [40] and [41] illustrates that EMRs allow healthcare professionals to access records via a website, email, and other specific applications. By sharing the resources online, regardless of the time and place, we can improve the utilization of resources and provide better healthcare to patients.

THYROID HISTORY AND PHYSICAL

NAME: _____ AGE: 42 DATE: 12/18/03

TX: P

C: _____ Improved Stable Worst

1- Hypothyroid

2- Hyperthyroid

3- _____

4- _____

HYPER:

PALPITATIONS: 3 TREMORS: 3 ANXIETY: 3 WT LOSS: 3

HEAT INTOLER: 3 SWEATING: 3 WEAKNESS: 3 HAIR LOSS: 3

DIARRHEA: 3 INSOMNIA: 3 VISION: 3 RASH: 3

MENSTRUATION: _____ OTHERS: _____

HYPO:

FATIGUE: _____ DRY SKIN: _____ COLDNESS: _____ MUSCLE SPAS: _____

SLEEPINESS: _____ CONSTIPA: _____ VOICE CHAN: _____ WT GAIN: _____

EDEMA: _____ MENSTRUATION: _____

NODULE:

DATE FOUND: _____ PAIN: _____ DYSPHAGIA: _____ SOB: _____

VOICE CHAN: _____ HX OF RADIATION: _____ FHx: _____

ALL OTHER SYSTEMS: _____ PSFHX REVIEW: 2-20-03/12/03

PE: WT: 204.4 HT: _____ B/P: 119/70 P: 72 PAIN: 0/10

EYES: CONJ: _____ EXOPHT: 3 R: _____ L: _____

THYROID: _____

LYMPH: C: _____ SC: _____ BRUITS: _____

LUNGS: 2-2-03 HEART: 112/70

ABD: 2-2-03 INT: _____ PULSE: 72 EDEMA: 3

NEURO: _____ DTRLS: _____ SKIN: _____

LABS: TSH: _____ TT4: _____ T3U: _____ FTI: _____ FT4: _____ T3: _____ FT3: _____

AMA: _____ TG: _____ TGA: _____ CBC: _____ LFTS: _____

THYROID US: _____

TYTHYROID UPTAKE/SCAN: _____

RECORDS REVIEWED: _____

I: 1. 2. 3. 4.

P: 1. 2. 3. 4.

LABS: TSH: _____ THYROID PROFILE: _____ TT4: _____ FT4: _____ T3: _____

FT3: _____ AMA: _____ TG: _____ TGA: _____ CBC: _____ LFTS: _____

US: _____ THY UP/SCAN: _____ FNABX: _____ FNABX US _____

RTO: _____ WKS _____ MOS _____ YR _____

(a)

Assignable Cause Code: Turning Center, Fixture Moved

Reason: _____
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 User: 05676 (Previous: 05676)

Reason: _____
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 User: 05676 (Previous: 05676)

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 LSL: 2.745 (Previous: 0)
 User: 05676 (Previous: 05676)

Reason: _____
 Last Edited: 2004/01/20 10:18:03 (Previous: 2003/12/17 00:19:11)
 LSL: 0 (Previous: 2.745)
 URL: 0 (Previous: 2.759)
 LRL: 0 (Previous: 2.741)
 User: 05676 (Previous: <None>)

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Reason: 5
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 User: 05676 (Previous: <None>)

Subgroup Information: 1075464235

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 Last Edited: 2004/01/30 12:08:15 (Previous: 2004/01/30 12:30:55)
 Flaq: Disabled (Previous: Complete)
 User: 05676 (Previous: 05676)

(b)

Figure 2.1: (a) Paper-based medical record. (b) Electronic medical record.

- **Storage** – The amount of patient data is increasing at a considerably high speed. The storage for this large amount of medical data has thus become the top priority issue for healthcare organizations. These organizations have the responsibility to provide effective measures to store patients’ medical records. Many hospitals need to use a physical storage space to store paper medical records. However, the use of EMRs can help healthcare organizations save considerable physical space and use fewer resources to store these records. Most medical records are currently stored in an extremely large set of hard drive whose storage capacity is thousands of times of the physical storage. This storage mode is easy to control and manage.
- **Security** – There is a great deal of personal and private information in the medical records. Hospitals and physicians have the responsibility to protect patients’ private information and ensure that all the medical records are stored in a safe environment. Paper medical records are easily damaged or stolen if someone breaks into the physical storage space. It is therefore necessary to hire a professional security team to protect these paper records, which requires significant resources that are unnecessary in EMRs. EMRs can provide high-precision security by using the most advanced network security system. For example, network firewalls, encryption algorithms, and identification systems can provide almost perfect security for the EMRs.

2.2.2 The Development of the EMR Systems

As described above, EMRs are expected to achieve significant improvements over paper-based medical records and satisfy regulations as well as the public’s requirements. As a consequence, different types of EMR systems have been developed by academic medical centers, industries,

and the government. The development of EMR systems can be categorized into two major time periods: before and after the 1980s [42]. Early efforts began in the 1960s, when academic medical centers developed their own EMR systems. Since the 1980s, due to their benefits in industries, leaders have devoted significant effort to forming organizations to promote the use of electronic medical information.

The first EMR system was created in the 1960s in the United Kingdom (UK), known as the clinical information system [43]. This project was supported by the government and academic medical centers (ACMs). Based on this system, in the mid-1960s, Lockheed developed the product, which was handed down to the vendors Technicon, TDS Healthcare, as well as Eclipsys [44]. It had a significant effect on the development of EMR systems and influenced the development of many later systems due to its ideal properties (e.g., high processing speed and flexibility in that many users are allowed in the system simultaneously) [34]. At the same time, many other systems have also been developed such as Health Evaluation through Logical Processing (HELP) [45] and the Computer Stored Ambulatory Record (COSTAR) [46]. The University of Utah developed HELP, which was activated in 1967. It was the first system to integrate clinical data accumulation and the decision support. In 1968, COSTAR was developed by Massachusetts General Hospital in collaboration with Harvard. This EMR system was implemented with the MUMPS programming language.

Since the 1980s, more concerted efforts have been devoted to developing and improving the performance of EMR systems. A technical report, published in 1991 and revised in 1997 by the Institute of Medicine (IOM) [34], argued that use of EMRs is one of the key components in improving patient records, facilitating the conversion from paper-based medical records to EMRs. These findings attracted the attention of private industry, and supporters formed the Computer-

Based Patient Record Institute (CPRI) to further its development. In 2000, the IOM was collaborating with HL7, an electronic standards organization, on the development of electronic standards so that the components of an EMR can communicate more easily [34]. In 2004, EMR systems have appeared in the national political forum, indicating widespread concerns about their effect on public health.

2.3 Information Visualization (IV)

IV refers to visual representations of abstract data to reinforce human cognition [47]. It is currently a popular research area and attracting more and more attention in both academic and industrial environments. This is a powerful method that helps people to easily analyze and identify the significance of huge and complex data with visual representation. In this section, we present three IVs. We first give a brief introduction of data visualization. Subsequently, the history, applications, and methods of data visualization are then presented. Finally, we introduce some open-source visualization toolkits (e.g., D3.js, Google Charts, and JavaScript InfoVis) and evaluation criteria.

2.3.1 Introduction

With the explosion of data and its accompanying effects, information has become an integrated part of human life and facilitates new approaches toward innovations. With the advent of the information industry, society has entered into an era of information exploration. Large amounts of information and data are generated from various kinds of sources, often containing different content and stored in different formats. For example, individuals can generate a countless amount of data every day (e.g., chatting records, mailing records, schedules, news). With the

growing amount of data, it is becoming increasingly difficult to represent such information in a useful manner so that the user can use it efficiently. In other words, for the sake of understanding and extracting knowledge from stored data or information, representing such massive data is the main challenge and also a ubiquitous task.

Visualization is considered an effective way to represent a significant amount of data because it provides mental models of the information [48] [49]. It refers to a visual user interface and makes huge amounts of unreadable information intelligible by providing insight to the user [50]. The main purpose of visualization is to create an interactive representation of information and take advantage of humans' perception and cognitive abilities to solve problems. After being visualized, information and data can be precisely, clearly, and efficiently represented by visual objects, including images, charts, animations, bars, and maps.

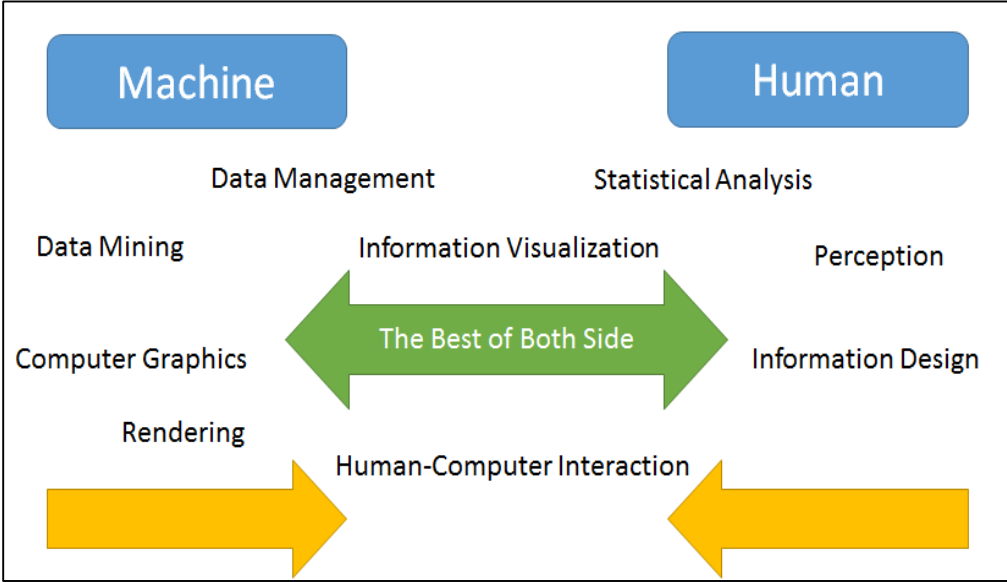


Figure 2.2: Visual analytics combine scientific disciplines to enhance distributing the work between humans and machines [50].

As the combination of the above concepts, IV represents abstract data to enhance human cognition. This is an interdisciplinary field of science that involves human computer interaction (HCI), computer science (CS), computer graphics (CG), computer vision, psychology, and business processes. This visual analytic describes the combination of multiple disciplines to reinforce the communication between humans and machines and is illustrated in Figure 2.2. Researchers in these fields have promoted the emergence of IV. Although there are many definitions for IV, the most referenced one, which was proposed by Card et al. [51] in 1998, is “the use of computer supported, interactive, visual representations of data to amplify cognition.”

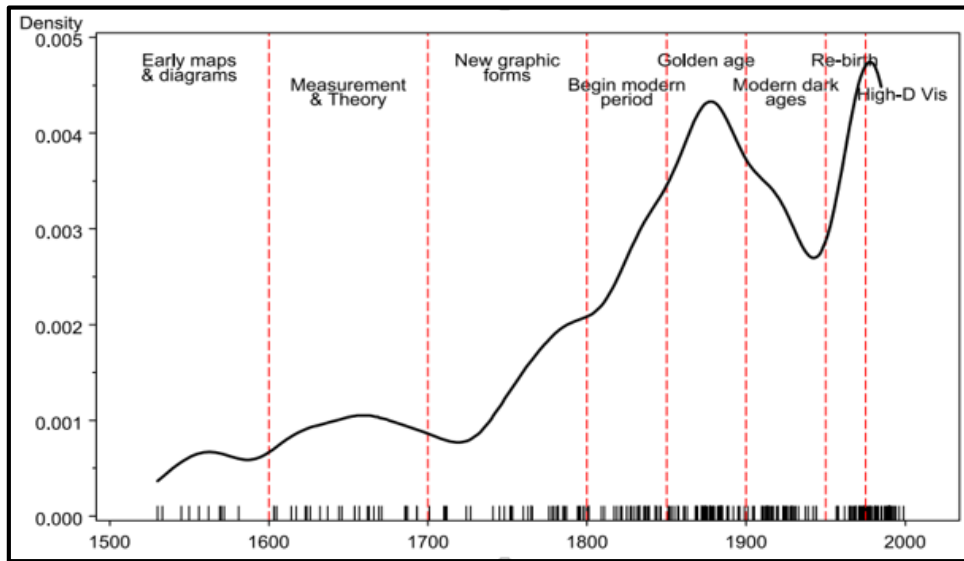


Figure 2.3: The time distribution of events considered milestones in the history of IV [52].

2.3.2 The History of IV

IV is usually regarded as the product of the development of modern science and technology [52] [53] [54] [55]. In fact, statistical graphics and data visualization have existed for quite a long time, ranging from drawings on caves illustrating successful hunting activities to the complex dashboards at present aggregating millions of rows of data. To have a better understanding of the

present and future trends in the area of IV, it is necessary for us to know the relevant historical context. Figure 2.3 provides a graphic overview of the developmental history of IV.

Before the 17th century, visualization technology was mainly used to make maps. Most of the maps used geometric diagrams to display roads, markers, and cities. Among them, the earliest one to describe information quantitatively is an anonymous 10th century multiple time-series graph (Figure 2.4), described by Funkhouser [56] and reproduced by Tufte [57]. It illustrates the changing position of the seven most prominent heavenly bodies over space and time. Following this, a theoretical graph of distance vs. speed appeared in the work of Nicolas of Cusa. By the 16th century, techniques and instruments were fully developed for measuring physical quantities and geographic positions. These early steps comprise the beginning stage of IV.

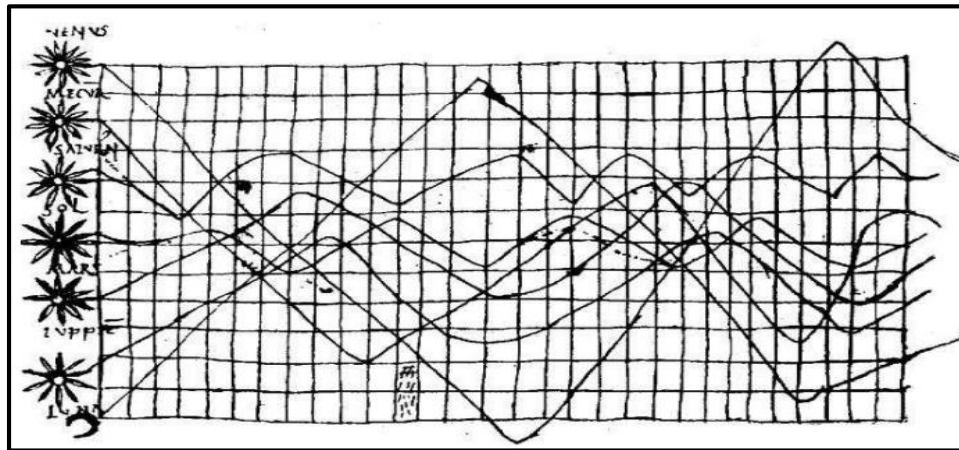


Figure 2.4: Planetary movements shown as cyclic inclinations over time, by an unknown astronomer, appearing in a 10th century appendix to commentaries by A. T. Macrobius [52].

With the progress of human civilization, the need for more accurate and quantitative mapping of the physical world continued increasing. Thus, by the 17th century, the most important problem became the need to provide a more precise physical measurement of time,

distance, and space for astronomy, surveying, map making, navigation, and territorial expansion. In the early years of the 17th century, the first visualization for statistical data was created by Van Langren (Figure 2.5) [58]. It was a one-dimensional line graph with the X-coordinate representing the estimated longitude difference between Rome and Toledo by 12 different astronomers. By putting the information in one table, Van Langren successfully visualized the wide variations in an estimate.

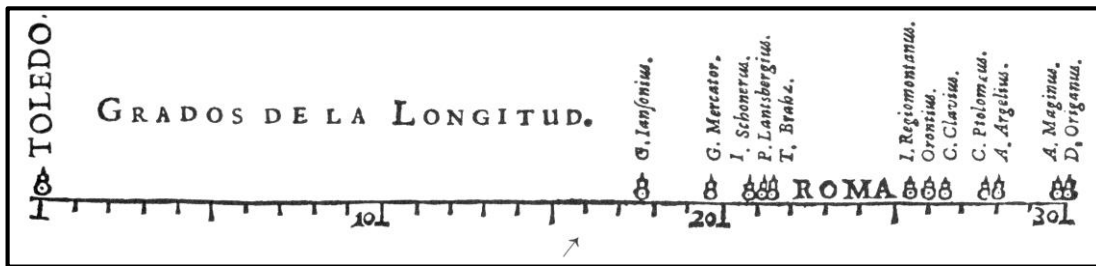


Figure 2.5: Graph of determinations of the distance, in longitude, from Toledo to Rome [52].

Trials of the thematic mapping of geologic, economic, and medical data were first made close to the end of the 18th century. It was then that abstract graphs of functions, measurement errors, and sets of empirical data were adopted. The development of visualization in this century was progressed rapidly, and many visualization methods were innovated in this era. As one of the greatest representatives, William Playfair invented many well-known graphs that are still using today (e.g., line, bar, pie, and circle charts). Figure 2.6 is one of his works, which demonstrates the patterns and trends of the prices of wheat, wages, and the ruling monarchs between 1565 and 1820 [59].

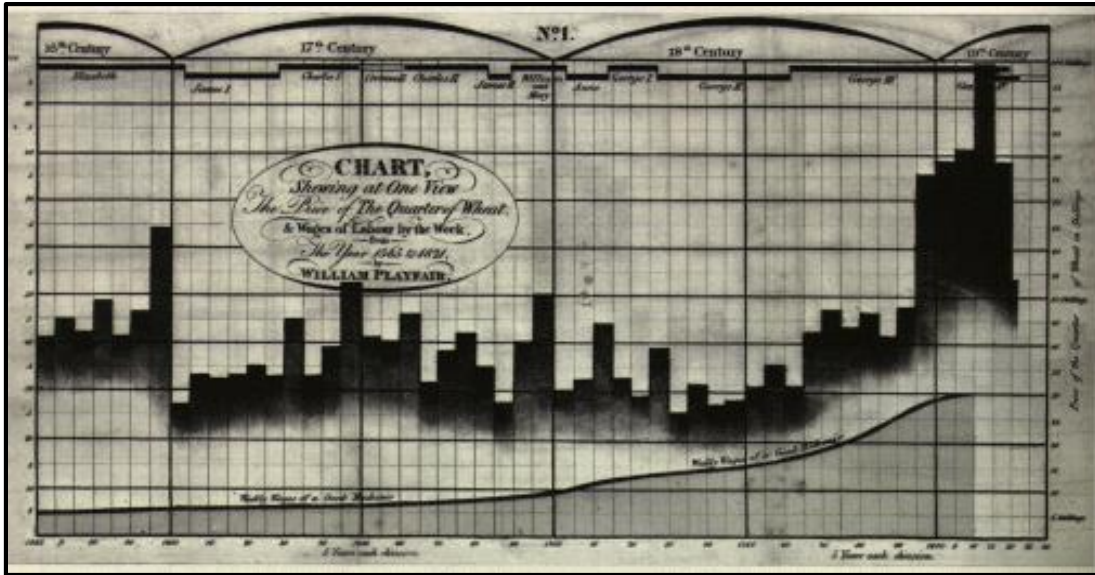


Figure 2.6: William Playfair’s 1821 time series graph of prices, wages, and the ruling monarchs over a 250-year period [52].

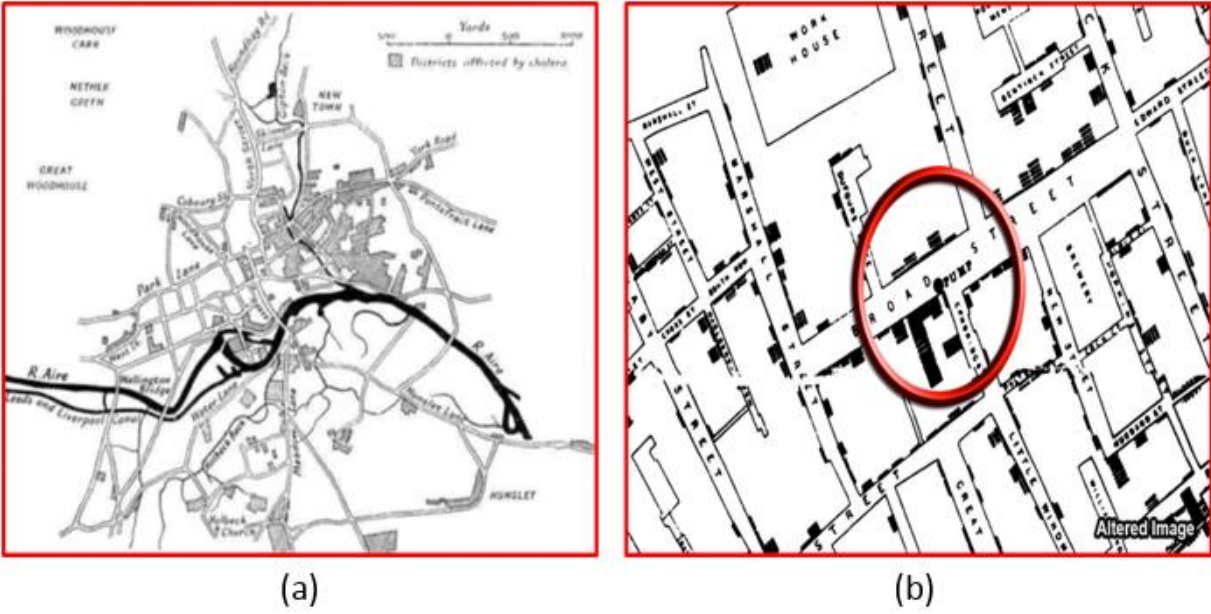


Figure 2.7: (a) A portion of Dr. Robert Baker’s cholera map of Leeds, 1833, showing the districts affected by cholera [52]. (b) A dot-map created by Dr. John Snow [1813–1858] shows the deaths from an outbreak of cholera in 1854 in London [52].

The first half of the 19th century was the beginning of modern graphics. With the rapid development and innovation of design and technique, this period witnessed explosive growth in statistical graphics and thematic mapping. Among statistical graphics, most of the modern forms of data displays were created, such as pie charts, histograms, timelines, and others. Thematic mapping developed from single maps to powerful atlases that depict data in different fields or topics (e.g., sociology, economics, and medical science). Figure 2.7 (a) shows the well-known disease map of cholera, the districts of Leeds affected by cholera in 1832, which was created by Dr. Robert Baker [60]. As all the important conditions for the rapid growth of data visualization were established by the mid-19th century, the development of visualization entered its golden age in the second half of the 19th century. During this period, many widely known visualization applications appeared, and among them, the most representative graphical display is a dot-map (Figure 2.7 (b)), created by Dr. John Snow to describe the deaths from an outbreak of cholera in London, 1854.

As Figure 2.3 illustrates, under the mushroom growth of statistical graphics and thematic cartography, the “Golden Age” of IV appeared in the late 1800s. By contrast, its estimated density plummeted in the early 1900s, called the “Modern Dark Ages.” Only a few graphical innovations were proposed during this period, and the enthusiasm for visualization was substituted by the rise of quantification and formal models in the social sciences. Fortunately, despite the influence of this zeitgeist, data visualization began to rise from dormancy in the mid-1960s. This was spurred significantly by several developments [61] [62] [63] [64] [65]. The work in [61] is a landmark, which issued the recognition of data analysis as a legitimate branch of statistics distinct from mathematical statistics. In France, Jacques Bertin organized the visual elements of graphics according to the features and relations in data [62]. Two interactive

statistical applications [64] and [65] were also developed for the processing of statistical data during this age. Under these promotions, IV has finally blossomed into a flourishing and vibrant research area at the end of the 20th century. Various advanced methods and techniques were developed accordingly, the details of which can be found in [67] [68] [69] [70].

2.3.3 IV Examples

IV plays a significant role in different contexts and has been widely used in various areas. It makes complex data more accessible, understandable, and efficient to users via the information media such as graphics, tables, and charts. Today, IV insights are being applied in many areas; a few examples are presented below.

- **Climate Data Visualization:** Nowadays, visualization is widely used in climate research. With increasing computational power, large weather datasets are generated increasingly for the analysis of climate impact and other related applications. However, it is becoming a challenging task to identify the underlying properties, such as patterns and statistical relations among weather data. To address this issue, a variety of methods and tools (e.g., 2D-maps, 3D-globes, time charts, and scatterplots) are proposed to visualize weather data in both independent and interactive ways, such as weather forecasting and ship monitoring. Figure 2.8 visualizes the historic weather-station data for the UK in the period of 1880–2013. With the help of data-driven documents (D3), the weather data are superimposed onto a map-projection of the UK.

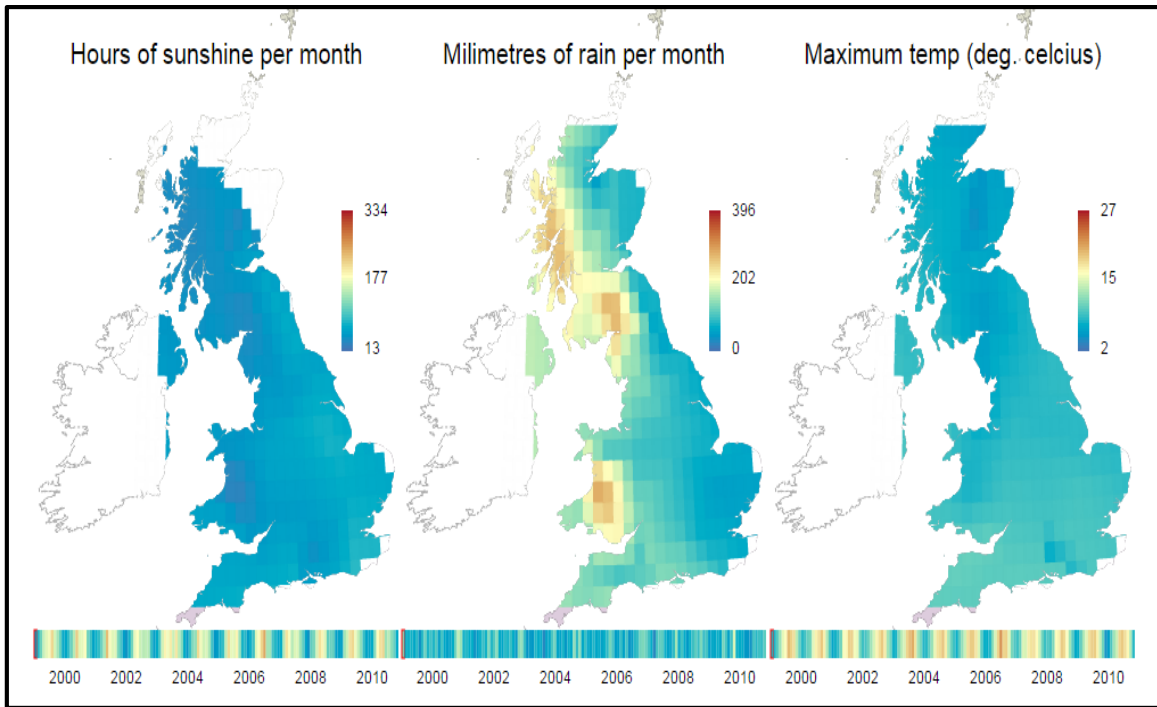


Figure 2.8: Visualization of historic weather-station data for the UK between 1880 and 2013

[71].

- **Immigration Data Visualization:** There is a growing interest in visualizing immigrant data to judge the tendency and distribution of immigration. For example, the US is an immigrant friendly country and many people around the world come to the US for a variety of reasons, such as the high standard of living and quality of education. There are 50 states in the US and immigrants are distributed in different states. The immigration flow in 2012 is visualized in Figure 2.9. The destination is presented on the right side, and the left describes where they are from. With the visualized graph, it can be seen that most of the immigrants are from Asia and North America, and the states that immigrants love are Florida, New York, and California.

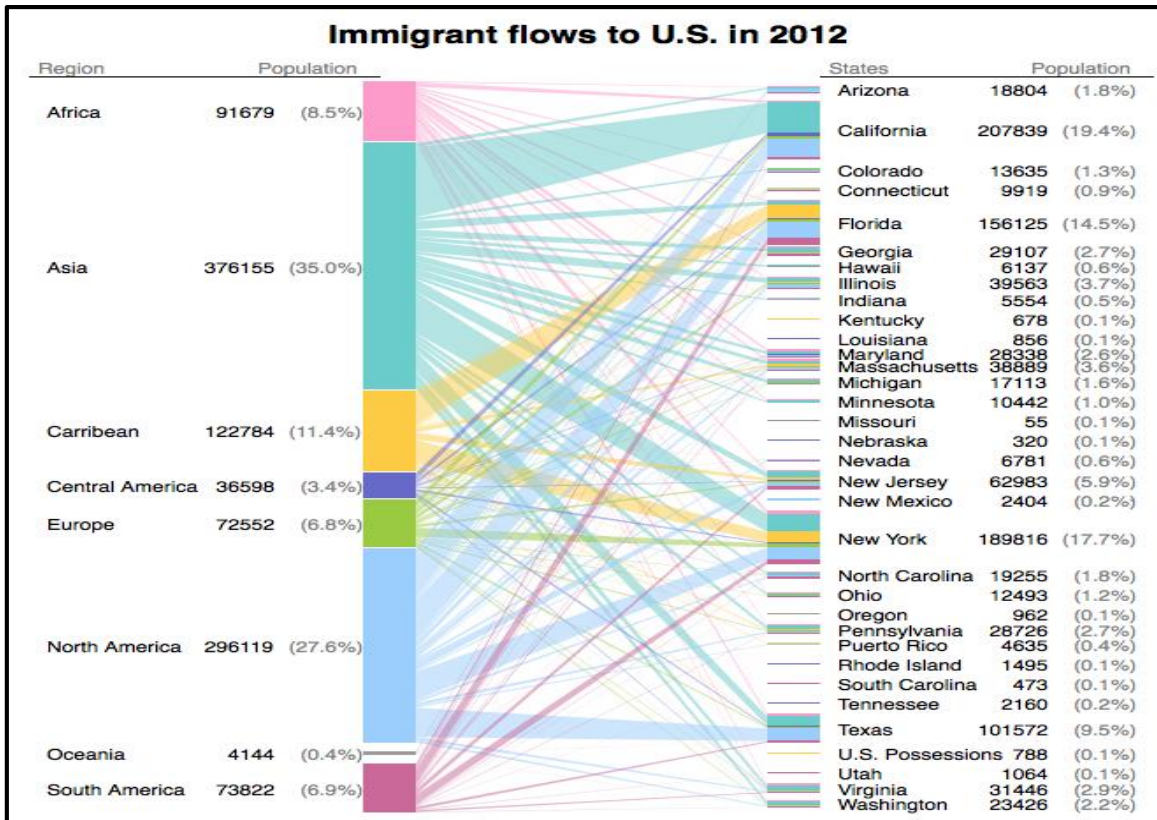


Figure 2.9: Visualization of immigration flows in the US in 2012 [72].

- **Genome Visualization:** By using IV, gathering information no longer appears as a major bottleneck in genome research. Relevant biological data on genes, transcripts, chromosomes, exons, and single nucleotide polymorphism (SNP) are available for the interactive visualization of circular or linear genome maps. It provides an opportunity for researchers to understand structural relationships in the genome better than just examining the sequence information alone. Figure 2.10 shows the *Salmonella typhi* genome as a circular plot. The tracks from the outside represent: forward coding sequence (CDS); reverse CDS; repeat regions (blue); rRNA and tRNA (green).

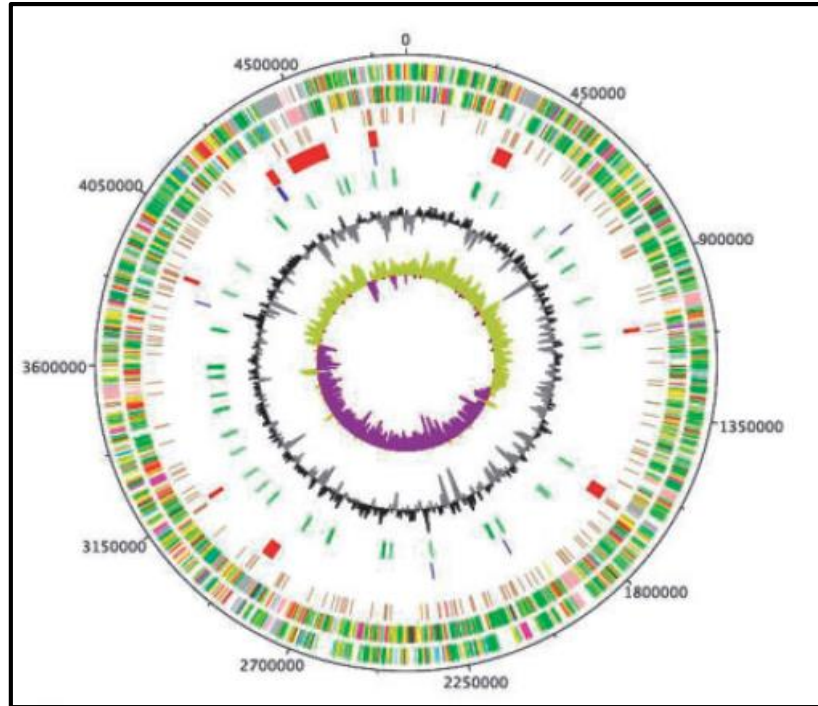


Figure 2.10: Displaying the *Salmonella typhi* genome as a circular plot. The tracks from the outside represent: forward CDS; reverse CDS; pseudogenes; *Salmonella* pathogenicity islands (red); repeat regions (blue); rRNA and tRNA (green) [73].

- **Facebook Network Visualization:** Facebook is known as an online social network of more than a billion persons. If you have started to use Facebook, you will find out that it is really hard to study, work and even live without Facebook. It is very useful because it helps you connect with the people who are important to you in your life, such as friends, family members and others. And you can also share photos, comments, and play games with friends. But as each Facebook user has many followers, it becomes difficult for a user to manage his or her own social network. Visualizing Facebook network is a good way to solve this problem. It can help users quickly find out the relationships between their followers, and this can help users use Facebook more effectively. Figure 2.11 shows an example of Facebook network visualization.



Figure 2.11: Facebook Network Visualization [74].

- **Citation Network Visualization:** Online scientific publications are becoming more and more popular today. The number of publications we can access is rapidly increasing. This makes it more challenging for researchers to pursue a topic, review literature, track search history or follow research trends. Using online resources (e.g., search engine and digital libraries) are helpful to find academic publications, but most of time the user ends up with an overwhelming amount of linear result to go through [122]. Citation network visualization is a good way to solve this problem. Visualization makes it easier to identify the research flow, connect publications, and find out similarities/differences between them. Figure 2.12 shows an example of citation network visualization.

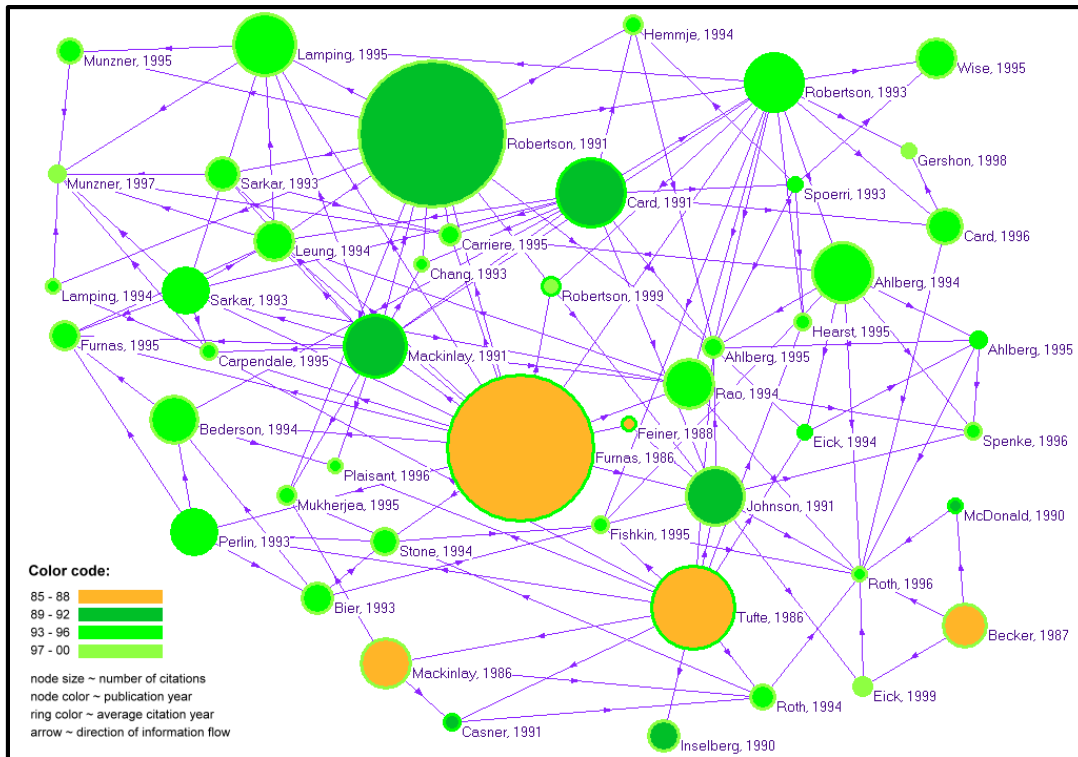


Figure 2.12: Citation Network Visualization [75].

2.3.4 IV Techniques

For the sake of analyzing huge and complex datasets, the preprocessing task of transforming them into a meaningful representation is unavoidable. To address this issue and convey information maximally, a number of visualization techniques have been developed during the last few decades. In this section, we describe several commonly used data visualization techniques, such as tree map, timeline, and others.

- **Bubble Chart:** A bubble chart displays three-dimensional (3D) data in a two-dimensional (2D) plane [76]. Each entity with its triplet (v_1, v_2, v_3) is represented by three numeric values: positions along x- and y-coordinates, respectively, as well as the size of the bubble. Bubble charts can be considered another form of a scatterplot, in which the data points are

replaced with bubbles. For each bubble chart, a bubble is distinguished from others in terms of its size and position. Used in this way, Figure 2.13 illustrates the correlation between the life expectancy, fertility rate, and population of a few countries using a bubble chart plot.

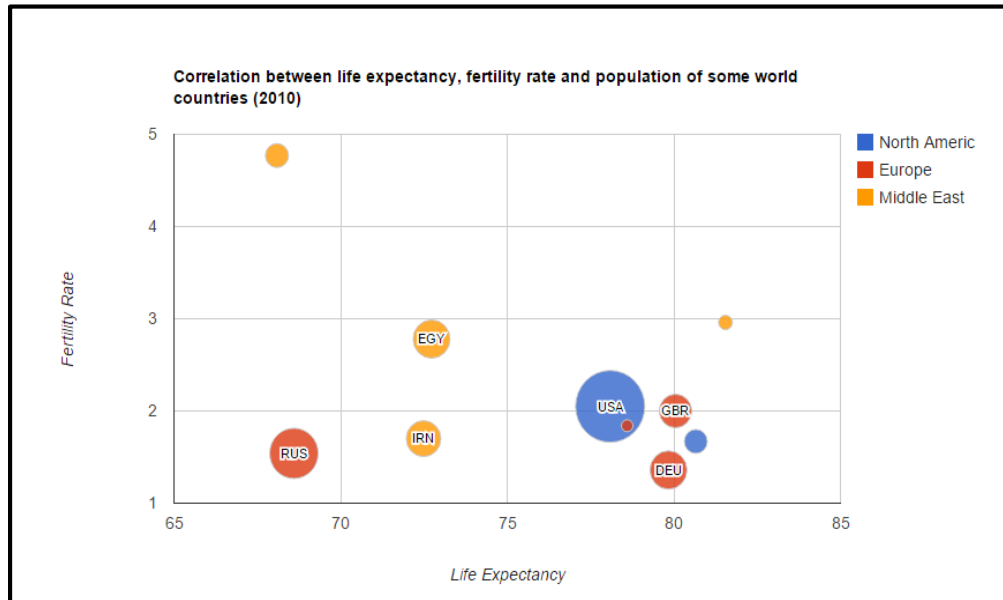


Figure 2.13: Correlation between the life expectancy, fertility rate, and population of several countries [77].

- **Tree Map:** Tree mapping is a method used to display hierarchical information with nested rectangles and was proposed by Johnson et al. in the early 1990s [78]. The basic idea is that for a specific tree, each branch is represented as a rectangle, which is then divided into smaller rectangles to illustrate sub-branches. This decomposition process is cycled until there is no sub-branch. Each dimension on the data is proportional to an area of a leaf node's rectangle. Generally, to show a separate dimension of the data, different leaf nodes are given certain colors. When the correlation between color and size dimensions are created with a tree structure, the patterns can be easily recognized, whereas this would be difficult to identify in other ways, such as if a specific color is particularly relevant. Another advantage

of the tree map is that, by construction, the space can be efficiently used. As a consequence, thousands of items will be displayed on the screen simultaneously. Figure 2.14 displays the iTunes Top 100 for February 27, 2006.



Figure 2.14: Tree map for displaying the iTunes Top 100 on February 27, 2006, grouped by genre, sized by chart position, and colored by 24-hour change in chart position [79].

- **Parrallel Coordinates:** This is one of the most famous visualization techniques that is used to plot individual data across many dimensions. Each dimension is related to a vertical axis and each data object is displayed as a series of connected points along the dimensions/axes [80]. This technique was invented by Phil Bert Maurice d'Ocagne (fr) in 1885 [81] and is an effective way to display multi-dimensional data. Figure 2.15 shows an example by exploiting the tool D3. It describes car models released in the 1970s and 1980s and also shows their MPG (mile per gallon) cylinder, displacement, power, weight, MPH (mile per hour), and year.

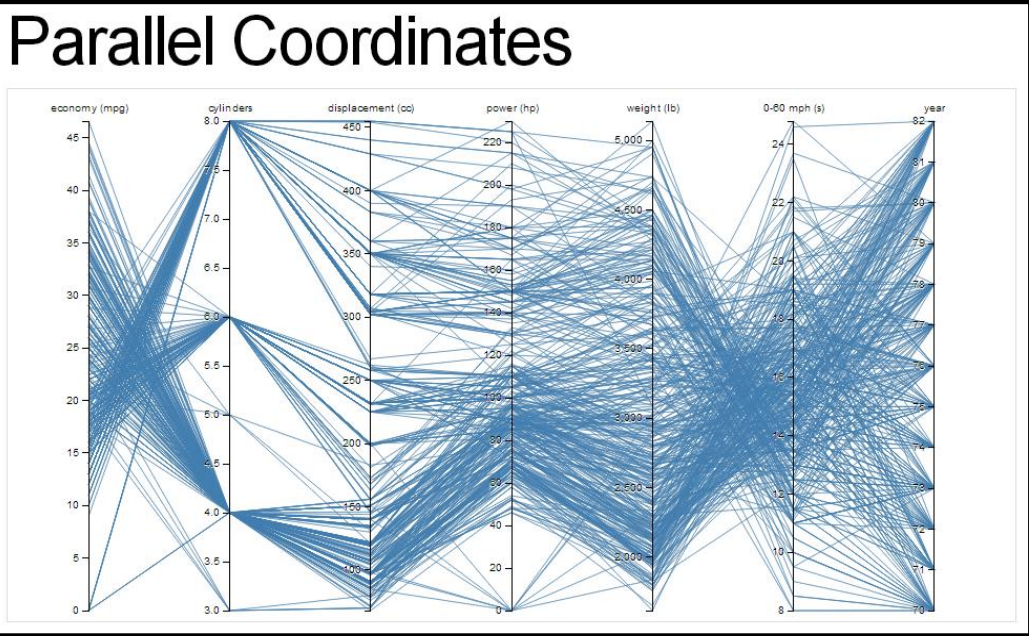


Figure 2.15: Car modeling in the 1970s and 1980s with MPG, cylinder, displacement, power, weight, MPH, and year [82].

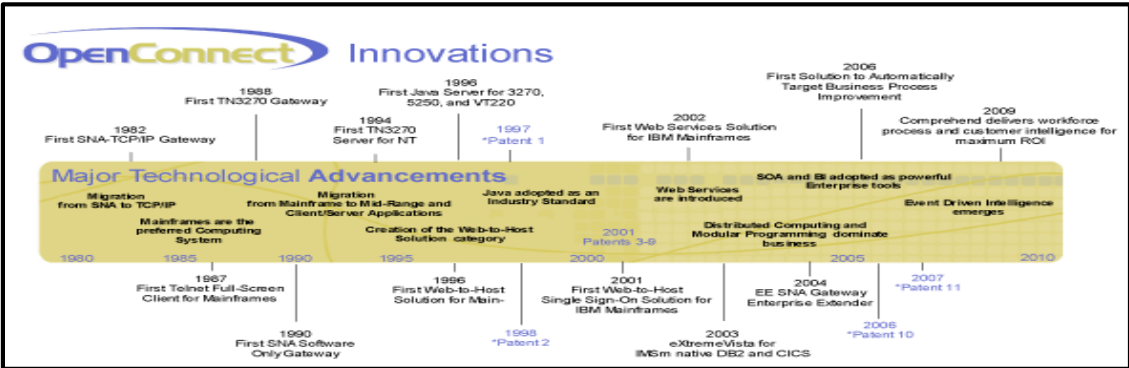


Figure 2.16: Timeline of major technological advancements [84].

- **Timeline:** A timeline is a method to represent a list of events in chronological sequence [83]. All the events are drawn along a straight bar labeled with dates to enable users easily understand the relationship between different events. In general, most timelines are linear (horizontally or vertically) and events are represented by images and text. This technique is usually used in research laboratories to help researchers fully understand the order of

historical events and take up new research subjects. Several studies have exploited this method to visualize data and information. Figure 2.16 shows an example of a timeline.

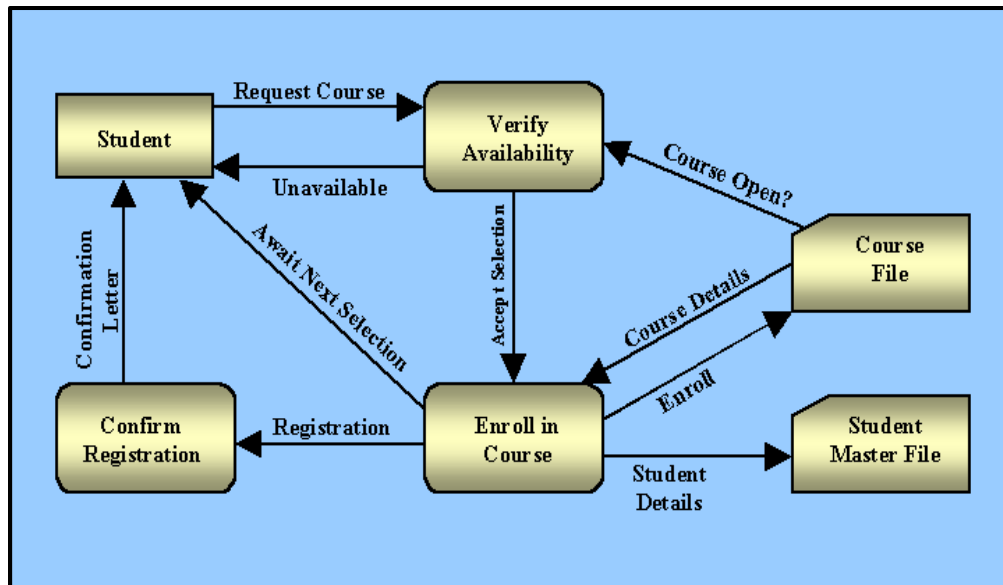


Figure 2.17: Using a data flow diagram (DFD) to present the process of a student registration system [87].

- **DFD :** A DFD is typically used as a preliminary step to create an overview of a system. This method represents the processing of data in a system to obtain the transformed information. In other words, a DFD illustrates how the data are processed and stored and shows the flow of data through the entire system. It is applied to visualize data processing at different levels. Level 0 creates an overview of the whole system and based on this, level 1 of the DFD elaborates on more details of the system's process [85] [86]. Following this, further processing such as of level 2 and level 3 provides a more specific detailed view. Figure 2.17 illustrates the process of a student registration system using a DFD.
- **Semantic Network:** As a visual representation of semantic relations between different concepts, a semantic network is a directed graph that consists of nodes and arcs; nodes

represent individuals or concepts, and arcs are labeled to represent the logical relationship between the concepts. Each concept is only represented by one node, and several arcs can have the same label. A semantic network is a knowledge representation schema based on human cognition and used to express ideas about groups of concepts. A semantic network is always used as a form of knowledge representation in natural language processing applications. Figure 2.18 shows a semantic network example. With this diagram, we can make the statement, "A fish is an animal that lives in the water." Or, "A bear is a mammal (a type of animal with vertebra) that has fur."

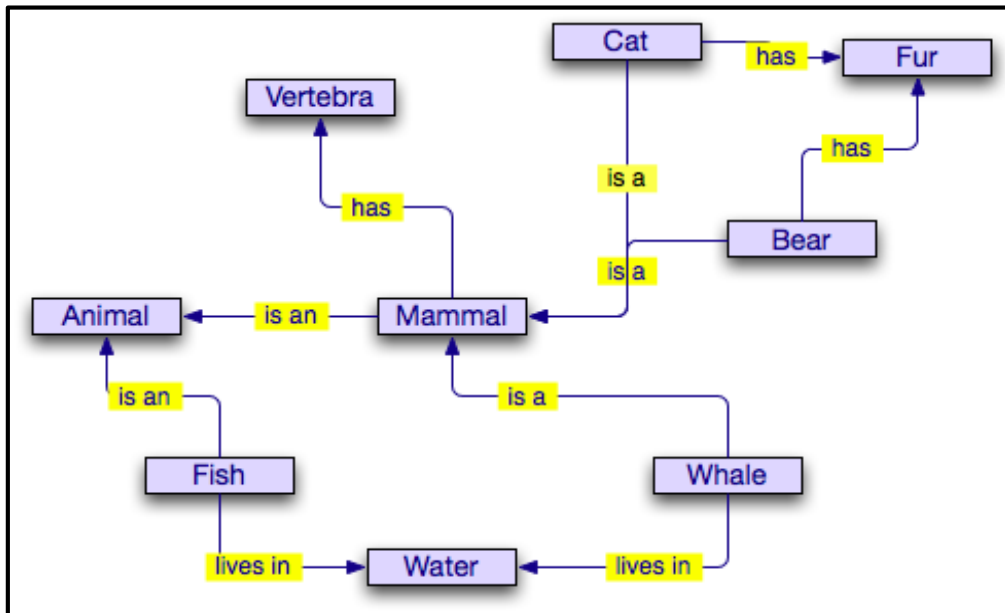


Figure 2.18: Simple diagram of a semantic network illustrating the directed nature of relationships [88].

2.3.5 IV Toolkits

As discussed above, information has become an integral part of human life. Applying visualization on raw data or information makes it easier for people to digest. Creating graphs and

charts is time-consuming, but these tools make it easier. If data are the new world currency, the web toolkits will be the exchange bureau on which they are traded. To make the tedious task of making visual graphs and charts easier, a large number of available data visualization tools that can help create useful, informative graphs have been developed. In this section, we present several popular web-based visualization toolkits.

- **D3.js:** As noted previously, D3 is an abbreviation for data-driven documents, which is a JavaScript library that renders some visual charts and diagrams from all kinds of data sources using Hyper Text Markup Language (HTML), Scalable Vector Graphics (SVG) and Cascading Style Sheets (CSS) [89]. It first appeared in the early 1990s and was initially capable of displaying static web pages only. However, in 2009, as various visualizations had already been developed, Stanford University created Protovis for generating SVG graphics from data [90]. With this toolkit, we are able to visualize many ideas in our mind. D3 library is a free, open-source and web-standard library and supports many good interventional functions to users. This library can help users bind data to the Document Object Model (DOM) and transform them into graphs afterwards. Moreover, D3 can handle multiple data formats, such as Extensible Markup Language (XML), Comma Separated Values (CSV), and JavaScript Object Notation (JSON), and some functions are provided to make it simple to loop through datasets.
- **Google Charts:** Google Charts is a good approach for users to visualize data on their websites. It creates a chart from data by a Portable Network Graphics (PNG) image and formatting parameters in an Hyper Text Transfer Protocol (HTTP) request. A large number of ready-to-use chart types have been provided to their users, from entry-level line charts to high-level hierarchical tree maps. Furthermore, this technique is especially useful for

specialist visualizations like geocharts and gauges, and user interaction controls and built-in animation are also included. For the function, this toolkit uses a new tag SVG, which is published together with the fifth revision of the HTML (HTML5) to render charts and also provides cross-browser compatibility and cross portability to smart machines, like android, iPhone, and iPad devices.

- **JavaScript InfoVis:** The techniques presented above are all 2D flat visualization libraries. The JavaScript InfoVis Toolkit provides tools for creating interactive data visualizations for the Web. With the latest released tag SVG and CANVAS in HTML5, this toolkit provides a way to import different media (videos, images, etc.) to web pages. It also allows the creation of Graphics Processing Unit (GPU)-accelerated 3D animations using the JavaScript language as part of a website without relying on proprietary browser plugins. The JavaScript InfoVis Toolkit was created by by Nicolas Belmonte and is free to use.

2.3.6 IV Evaluation Criteria

As many IV applications have been designed and implemented recently, the evaluation of IV has become a hot topic [99]. A good evaluation of usability studies is really helpful to understand the limitations and potential of a system. Two kinds of criteria for evaluating a visualization system are presented below.

2.3.6.1 Interactive Features Criteria

Information visualization systems has major components: representation and interaction [107]. The representation component mostly concerns the mapping from data to representation and how this representation is rendered and displayed on the interface. The interaction component

involves the interactive dialog between the system and the user, and it helps user to explore the complex data to discover insights. Although discussed as two individual components, interaction and representation are not mutually exclusive. For example, interaction with a system may achieve a change in representation.

Interaction is an important part of information visualization and a good visual representation is always achieved on the basis of a friendly interactive interface [107]. Without a good interaction, an information visualization system will become a static image. [119]. Although static images have analytic and expressive value, their usefulness might be limited as the data set grows larger with more variables [108] [109] [110].

From what we mentioned above, we can see that information visualization systems can be evaluated by their interaction features. For now, the user intent model proposed by Yi et al. [107] is a good way to evaluate an information visualization system. Based on the concept of user intent, seven categories of interaction are proposed in their study to rate information visualization systems. Each category is presented in more detail in following contents.

- **Select:** *Mark a subset of the dataset as interesting*

With the help of Select interaction techniques, users can get the ability to mark data items to keep track of them [107]. It is really hard for users to retrieve items which they are interested in, when numerous data items are displayed on a view, or when visual representations are changed. But if we make items of interest visually distinctive, users can easily keep track of them even in a big data set.

- **Explore:** *show me something else*

Explore interaction techniques provide users the ability to look over a different subset of data cases [107]. In general, users always see a limited number of data items at a time when they are using an information visualization system. There are many reasons such as the large scale of the data set, screen limitations and others. To solve this problem, information visualization systems always support *Explore* interaction techniques to help users examine a subset of the data to gain better understanding and insights.

- **Reconfigure:** *show me a different arrangement*

Reconfigure interaction techniques offer users different perspectives on to a large scale of data set by changing spatial arrangement of visual representations [107]. One purpose of information visualization is to reveal hidden characteristics of data and relationships between them. But a single visual representation is not enough to offers sufficient perspectives. To avoid this issue, information visualization systems always support *Reconfigure* interaction techniques which allow users to change the way data items are arranged to provide different perspectives on the data set.

- **Encode:** *show me a different representation*

Encode techniques provide users the ability to alter the fundamental visual representation of the data including visual appearance (e.g., shape, size, and color) of each element [107]. For example, by encoding height information to a map using a spectrum of color, users can easily know the height of a mountain.

- **Abstract/Elaborate:** *show me more or less detail*

Abstract/Elaborate interaction techniques enable users to adjust the level of abstraction of a data representation to satisfy their needs [106]. This type of interactions allows users

alter the representation from an overview down to details of each data sets. One example of Abstract/Elaborate techniques is zooming.

- **Filter:** *show me something conditionally*

Filter interaction techniques provide users the ability to change the set of data items being presented based on some specific conditions [107]. By using this kind of interaction techniques, users can specify a range or condition, so that only data items which meet these criteria can be presented. Other items not satisfying the condition or out of the range will be hidden from display.

- **Connect:** *show me related items*

Connect interaction techniques are always used to show hidden data items that are relevant to a specific item and highlight relationships between data items [107]. By using this type of interaction techniques, users can better understand the relationship between many data items. And it is really helpful for users to interactively retrieve, obtain and compare data items they are interested in.

2.3.6.2 Review Criteria

- **Functionality-** A good visualization system should provide many functionalities required by users.
- **Efficiency-** The efficiency should be considered in each visualization system. By improving the efficiency, users can achieve a better performance.
- **Effectiveness-** Dose the visualization make a positive effective in use?

- **Usability-** The usability can be evaluated from two aspects. First, how easily can the users interact with the system? Second, are the information provided in a clear and understandable format?
- **Usefulness-** Is the visualization useful in process of actual application?

2.4 Existing EMR systems

As presented before, for now, EMR systems are the primary way to store patient healthcare information (e.g., diagnoses, symptoms, treatment notes, medication history). In the following contents, we give a brief introduction of EMR systems, including EMR visualization prototype systems and commercial EMR systems.

2.4.1 EMR Visualization Prototype Systems

As we have mentioned before, in clinical practice, the use of EMRs has not fully achieved its potential and expectation yet. Many factors have hindered the adoption of EMR systems, such as non-friendly user interfaces, and fragmented, inefficient display of medical data. Therefore, a significant number of approaches for the visualization of medical records have been proposed to improve these disadvantages. In this section, we propose an overview of existing EMR visualization prototype systems.

- **Lifelines:** As one of the earliest systems of the visualization of medical histories, Lifelines was developed by Plaisant et al. in 1996 [91]. It used numerous line segments to represent the medical records, personal histories, and other types on biographical data. The horizontal axis is used to describe the temporal duration and location of events, respectively. It also uses different colors and line-thicknesses to indicate the importance and relationship of events

(Figure 2.19). For example, red represents higher severity and green represents a cure. This technology provides zooming functionality that allows physicians to compress and stretch the segment along a time axis, and as the consequence, various medical variables can be visualized on the same screen.

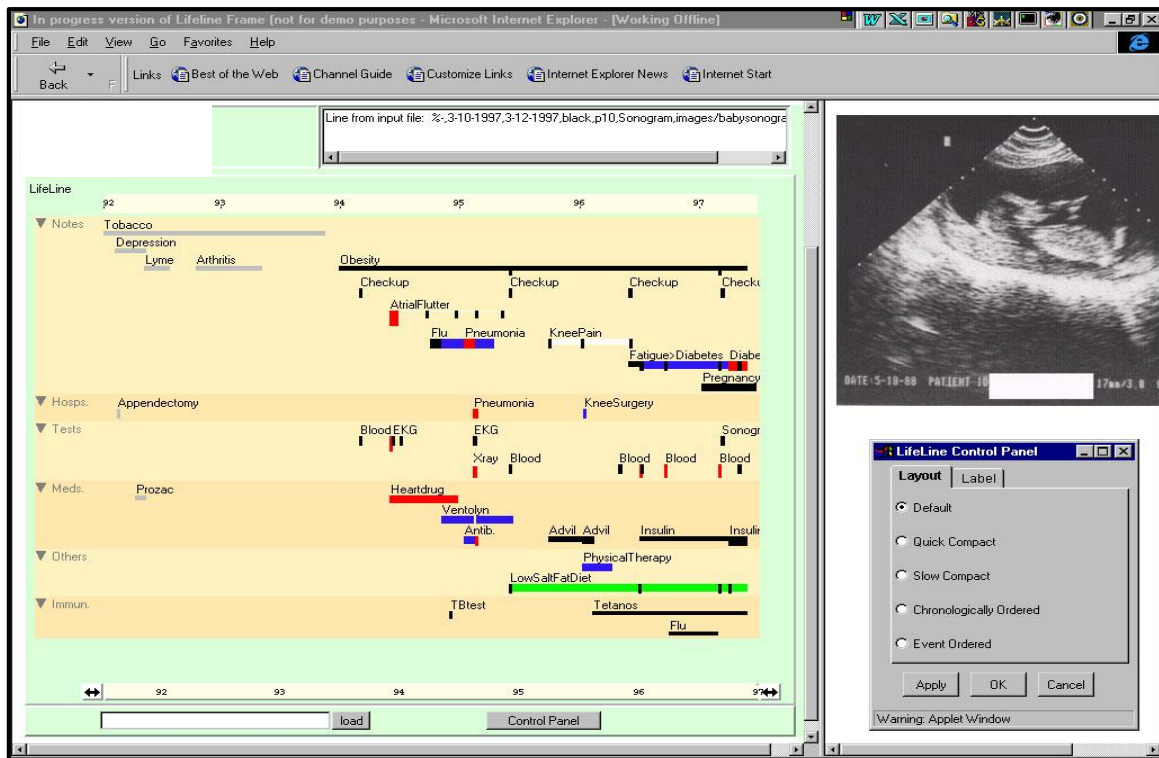


Figure 2.19: Timeline [8] – Visualization of personal medical histories. Horizontal lines represent the events and episodes in a single patient record. The line color, height, and captions are used to convey information. A detailed panel to the right shows further information about a selected item such as an ultrasound image.

- **Lifelines2:** As an extension of Lifelines, Lifelines2 was proposed by Wang et al. in 2008 [9]. It allows the user to analyze records from multiple patients simultaneously and facilitates comparative visualization of records by sorting, aligning, and filtering. With these operations, the system is particularly suitable for observational research. For example, to better

understand health and treatment issues, researchers are able to analyze data from different studies. Figure 2.20 shows an interface of Lifelines2 for visualizing the record of temporal categorical data. The system employs the interaction technique (Figure 2.20 (a)), complemented by temporal summaries frameworks, which are histogram-like charts (Figure 2.20 (b)). The controls for both basic operators such as align and rank as well as event distribution (Figure 2.20 (c) and (d)) are also involved. Several studies in [93], [94], and [95] have evaluated that the system simplifies analysis tasks significantly, and medical physicians can learn the interface in a short time period.

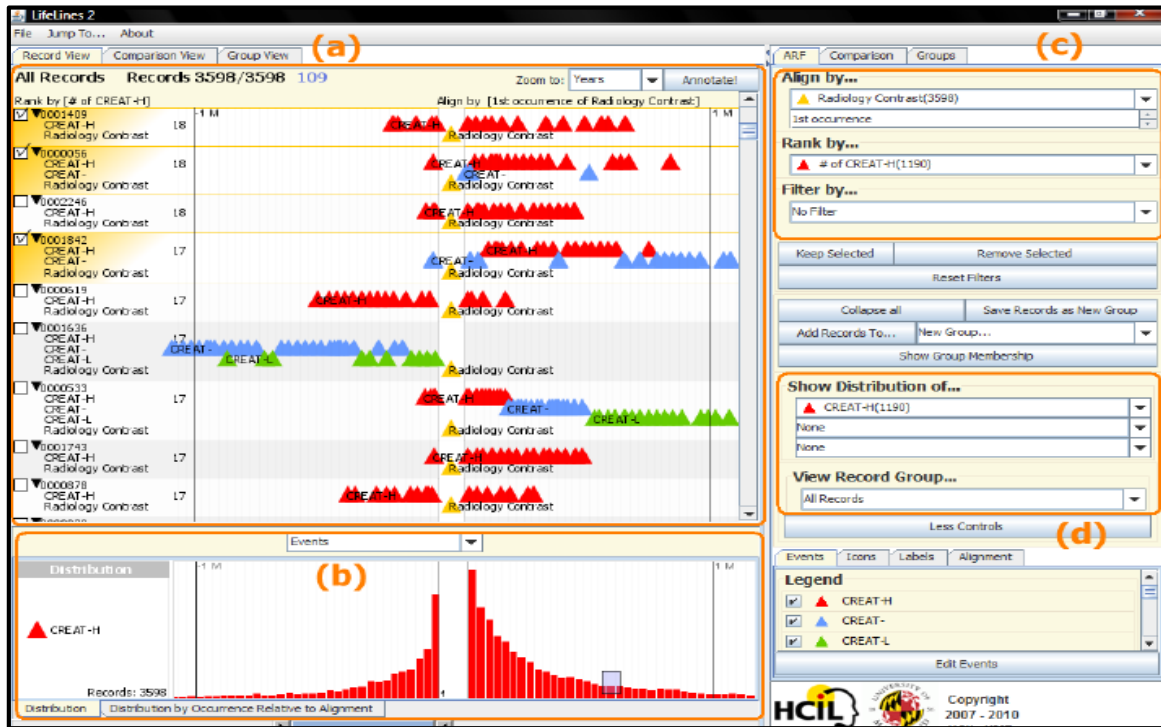


Figure 2.20: Lifelines 2 [92] – Visualization of records of temporal categorical data. (a) Shows each individual record. (b) Shows the aggregation of events over time. (c) Contains controls to basic operators: align, rank, and filter. (d) Shows controls for event distribution and grouping.

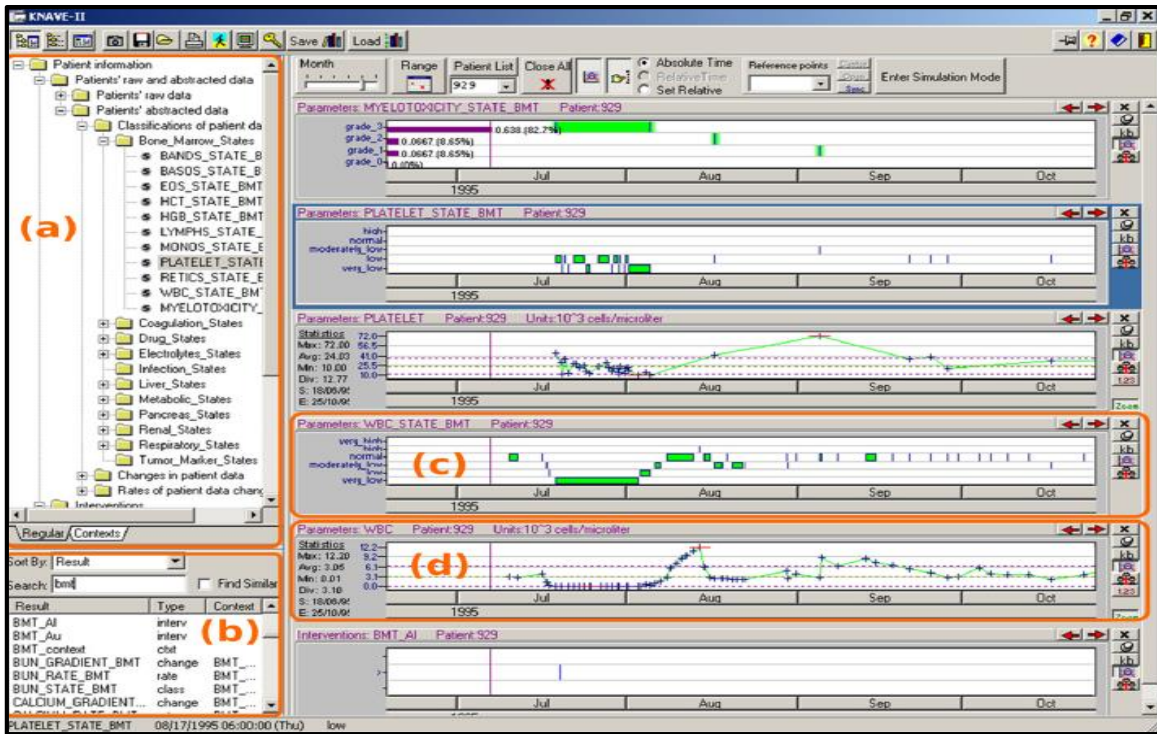


Figure 2.21: KNAVE-II [96] – Provides an overview of an oncology patient’s data: (a) On the left, a browser of the domain ontology allows the user to add abstract concepts and raw data variables for visualization. (b) In addition, there is a string search for concepts. (c) Abstract concepts have an ordinal scale and duration. They are represented with line segments similar to Lifelines. (d) Line plots display numerical raw data.

- **KNAVE-II:** Knave II is a web-based tool for visualizing and exploring clinical data, with a specific focus on time-oriented raw data [10]. It uses clinical knowledge and temporal data abstraction to visualize raw data from an EMR and summarize them (Figure 2.21). The underlying architecture uses standardized vocabularies and mappings to project local data sources. As the result, users are able to access multiple remote databases even without knowing their structure and vocabulary. The complete KNAVE-II tool is implemented by including two components: (1) a user-interface module to display the windows, and (2) a

computational module, which analyzes information obtained from the media. It has been evaluated in several studies by expert clinicians in different medical domains, such as oncology, which involve the monitoring of chronic patients [97] [98].

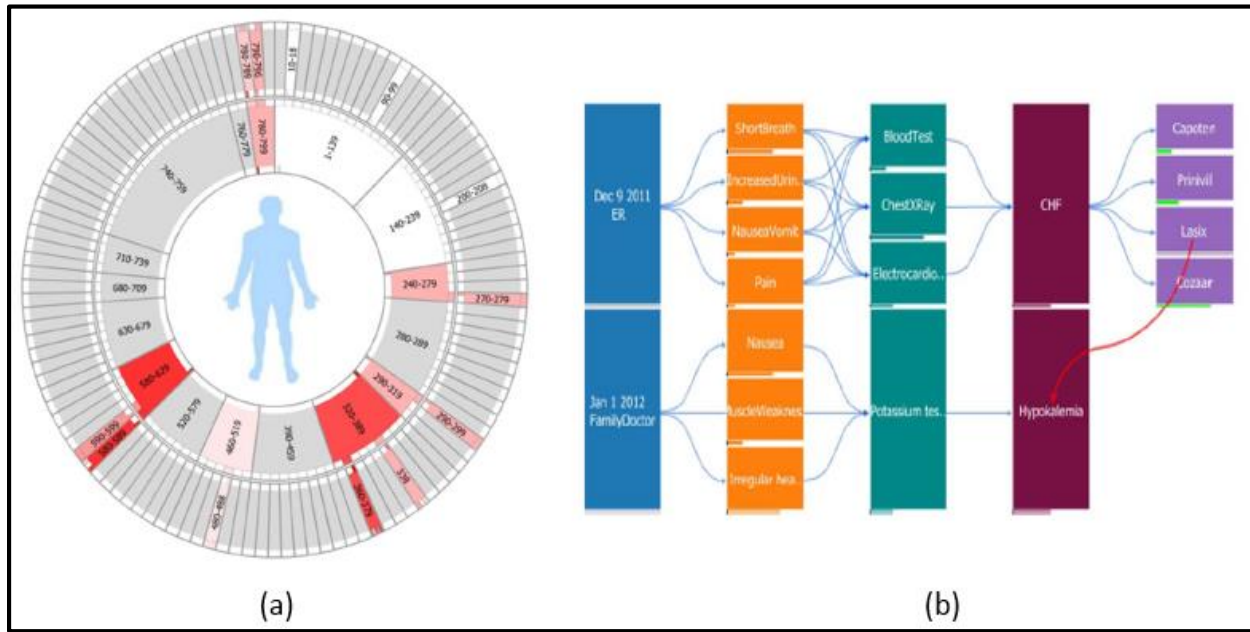


Figure 2.22: Five Ws [18] – The two coordinated displays of the 5W system. (a) The radial (patient overview) display using an integrated body map, along with the user interface. (b) The corresponding sequential (diagnostic reasoning) display using the same color coding.

- **Five Ws:** The five Ws is a popular concept for information gathering in journalistic reporting, research and police investigations. It captures all aspects of a story or incidence: who, what, where, when, and why. In the work [17], Zhang et al. proposed a framework involving a series of cooperating types of visual information to display and demonstrated the use of five Ws within a healthcare informatics application. By representing a patient as radial sunburst visualization integrated with a human body, this system provides a quick overview of both past and present health conditions of the patient. Figure 2.22 shows the user interface of this

system along with the two types of displays it offers (radial display and sequential display). The detail of this system can be found in [18]. With this framework, the needed time and effort to access patients' medical information will be reduced significantly. Another interesting finding is its support in medical coding. Since users can easily switch between medical terms and ICD codes, this system can be used by both physicians and coders, whether the ICD9 code or the new ICD10 code. This system implemented in [18] used the Action Script and the Flare visualization toolkit. To store patient histories such as visit IDs and codes with the structured database, the back-end server was first implemented in Java and Java EE. Furthermore, the communication between the interface and the server was achieved by exploiting BlazeDS.

- **Electronic Health Record Timeline and the Human Figure:** This is a patent publication of the United States (Pub. No. US 2009/0192823 A1) [117]. The user interface of the system is shown as Figure 2.23. From the figure, we can see that a human body is placed on the left part of the interface and a timeline of clinical events is displayed on the right part of the interface. Users can draw a dot or a circle on the human body to mark the location of symptom. Each dot or circle is linked with an indicator (labeled with numbers, such as 530, 538) as shown in Figure 2.23. These circles and dots can visually indicate an outcome of diagnosis (e.g., good, bad, unknown). Then users can drill down each of the indicators to retrieve and review detailed information. For example, a user can hover over or click on an indicator (530-538) to see a corresponding report. In addition to this, users can also review the EMR timeline by clicking on the corresponding indicators as shown in Figure 2.23.

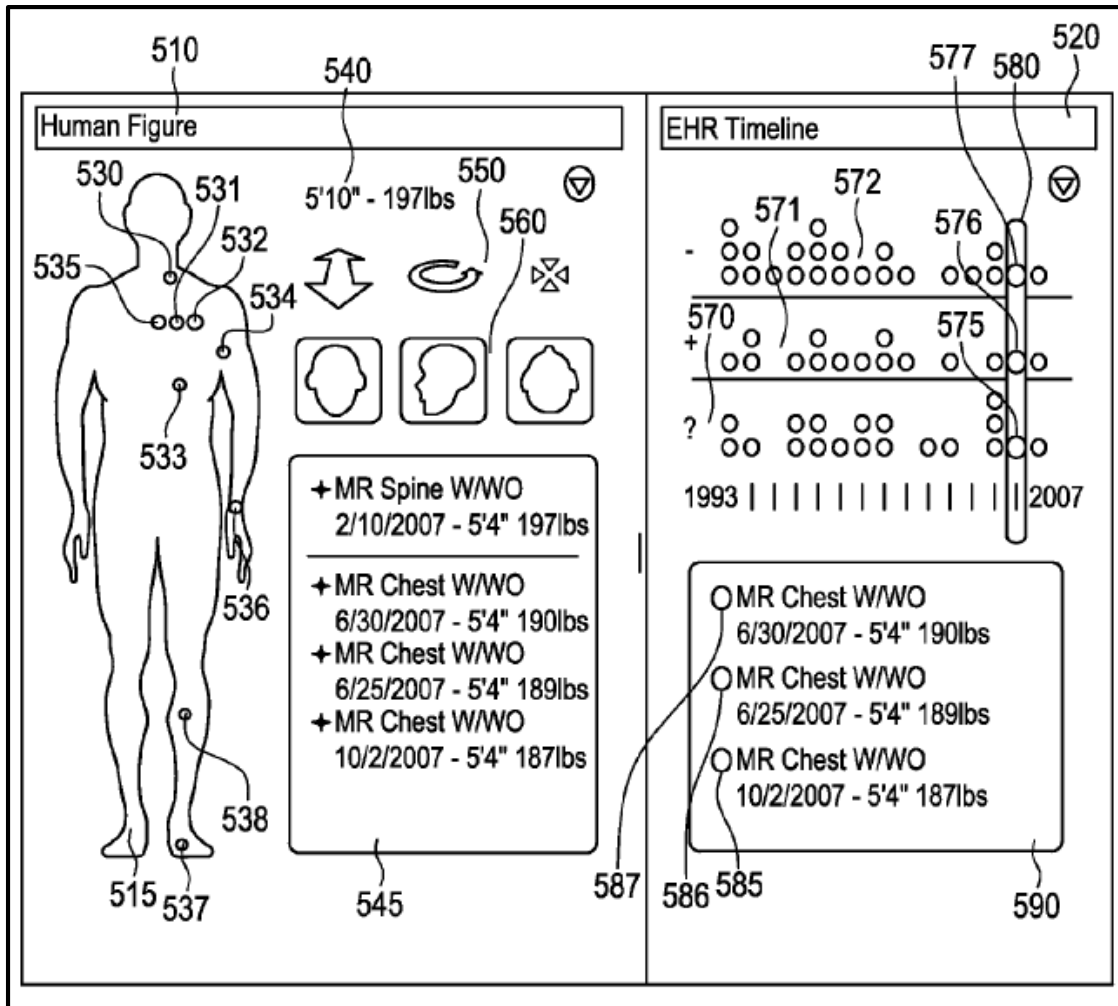


Figure 2.23: EMR visual representation with a human figure and a timeline [117].

- Systems and methods for a seamless visual presentation of a patient's integrated health information:** This is a patent publication of the United States (Pub. No. US 2011/0161854 A1) [118]. The user interface of the system is shown as Figure 2.24. From the figure, we can see that several human bodies are placed on the central part of the interface. Each human body represents a specific physiological system. For example, the first body indicates muscular system and the second body indicates cardiovascular system. In this system, each diagnosis, treatment, exam and result is linked to a particular body system and location of a patient. In Figure 2.24, we can see that some indicators (labeled with numbers, such as 131,

139) are located at locations of human bodies. Each indicator is connected to a specific clinical event or physiological system. By selecting a physiological system view (131-134) or an indicator (135-139), users can retrieve and obtain more detailed information they wanted.

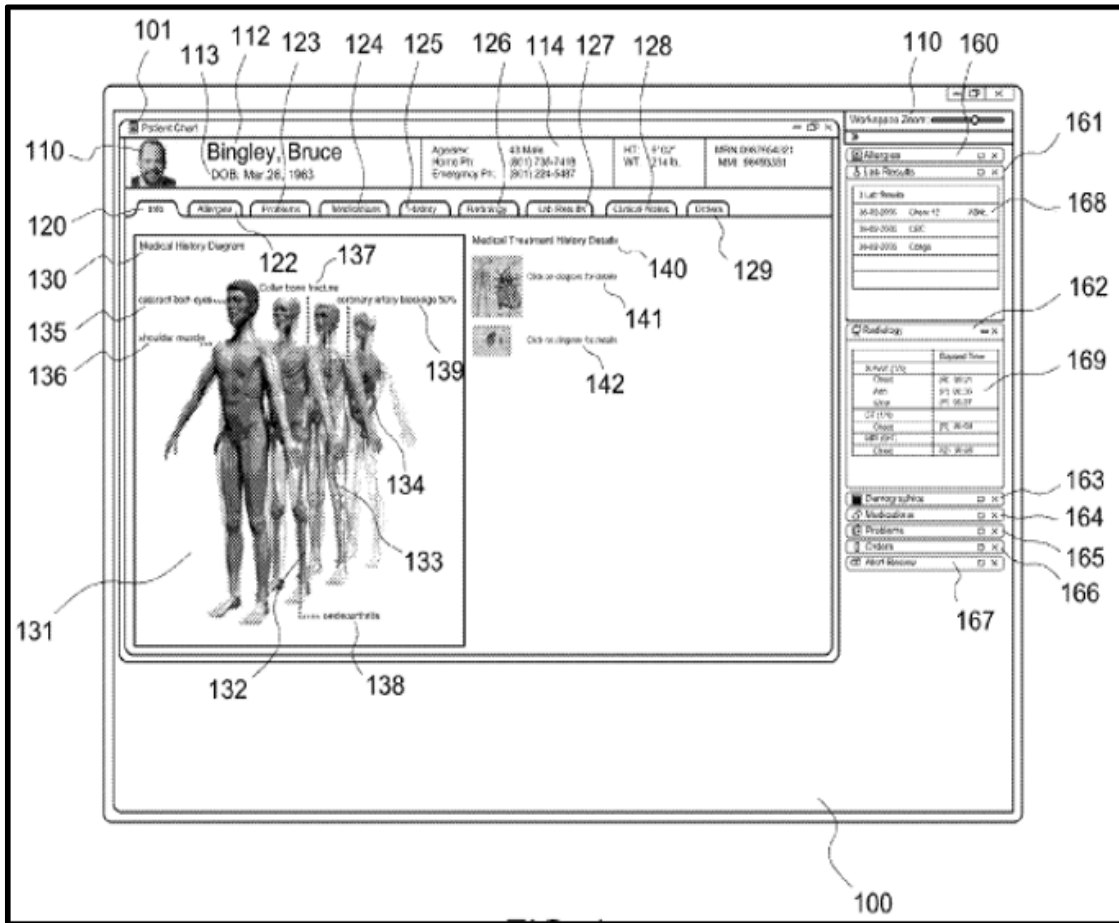


Figure 2.24: Human image-based EMR visualization with indicators [118].

2.4.2 Commercial EMR Systems

All the above EMR visualization systems we have mentioned above was conducted based on literature search in academic publications and patents. This method allows us to give an extensive view on the scientific state of the art, but it is still not fully representative for the commercial EMR systems deployed in the health care sector.

However, there are some difficulties in surveying these existing commercial EMR systems [111]:

- It is hard to get the access to these systems. Commercial EMR systems are always customized for each health care organization [111]. Usually they are acquired from professional software providers and always designed and implemented in-house by professional health care institutions.
- Information about these commercial EMR systems is not readily available to outside reviewers [111]. The details of these systems are not made public due to customizing for individual customers. Even if some capabilities are available, the article rather describes the systems in general and technical terms than it elaborates on UI, interactions, or visualizations. What is more, screen shots of these systems are not always available, either.
- Some academic publications report on the evaluation of their systems, but such information seldom available from software providers [111]. For instance, we are unable to get access to a commercial system case studies or internal evaluations.

Therefore, in the following sections, we first give an overview of popular commercial EMR systems (Figure 2.25). After that, we introduce some visualizations in commercial EMR systems. Finally, IBM Watson and Medical Records Text Analytics is presented.

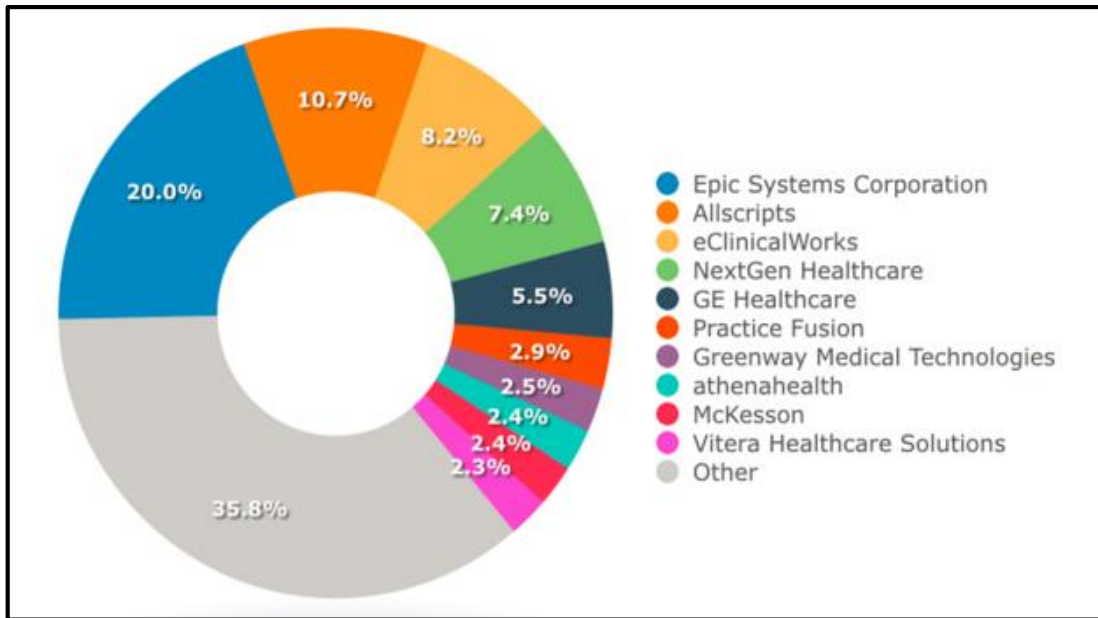


Figure 2.25: Market Share of commercial EMR systems [112].

2.4.2.1 Market Share of Commercial EMR systems

In this section, we are to present the top five popular EMR vendors around the world.

- **Epic Systems Corporation** [113] – The market share of Epic is 20.0%. Epic Systems Corporation is a titan of healthcare information technology. Epic caters its services to mid-sized and large practices and hospitals. Epic offers an integrated suite of health care software with a hierarchical database. Their system supports all the functions related to patient care, including registration and scheduling system for clerks; clinical system for physicians, nurses, emergency personnel, and other care providers; ancillary systems for lab technicians and radiologists; and billing systems for care providers as well as insurers [131]. Epic provides a patient portal that allows patients to login and access their records. In addition, this system also allows physicians to communicate with patients via video platform [132]. Figure 2.26 shows the interface of Epic EMR system.

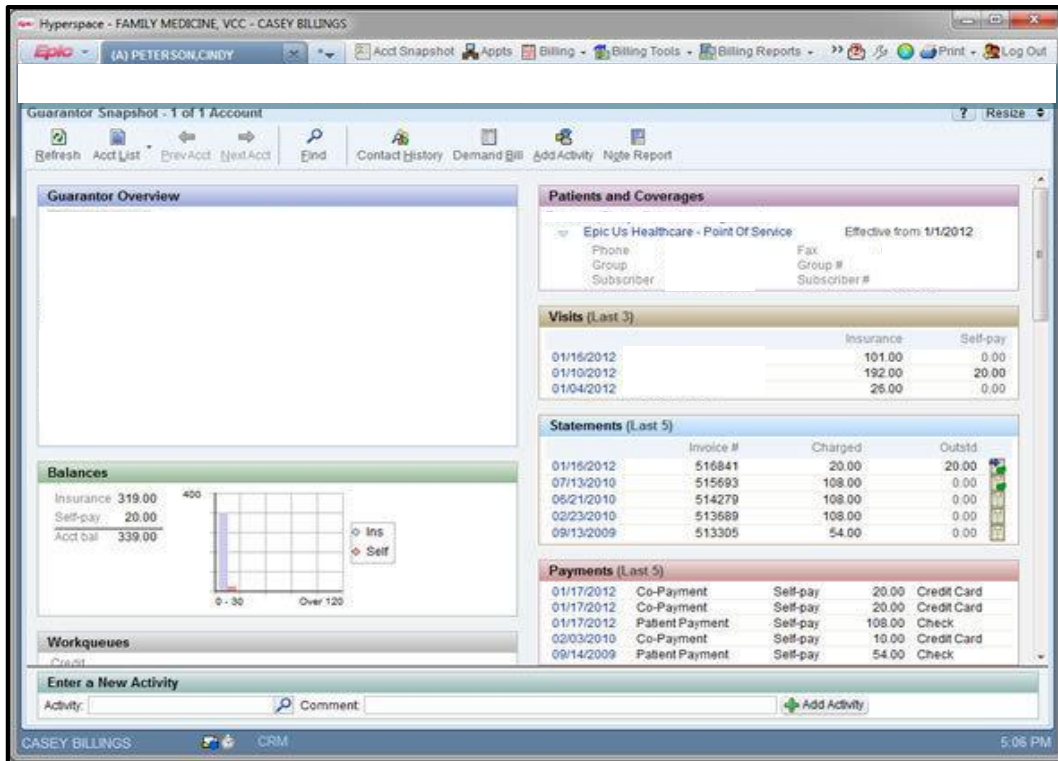


Figure 2.26: Interface of the Epic EMR system [123].

- **Allscripts** [113] – The market share of Allscripts is 10.7%. Allscripts is one of the most popular EMR vendors that cater to small and mid-sized practices. This system is designed and implemented for ease of use, allowing users to keep track of their most important information through a convenient, one-glance layout. This system offers a patient portal that allows patients to login and access their records, appointment and billing [133]. Figure 2.27 shows the interface of Allscripts EMR system.
- **eClinicalWorks** [113] – The market share of eClinicalWorks is 8.2%. eClinicalWorks is one of the most popular EMR vendors in the southern states and New England, with over 30% market share among the top five vendors in those regions. This system supports ICD-10 search feature, which helps health care providers to find an ICD-10 code with ease [134]. Figure 2.28 shows the interface of eClinicalWorks system.

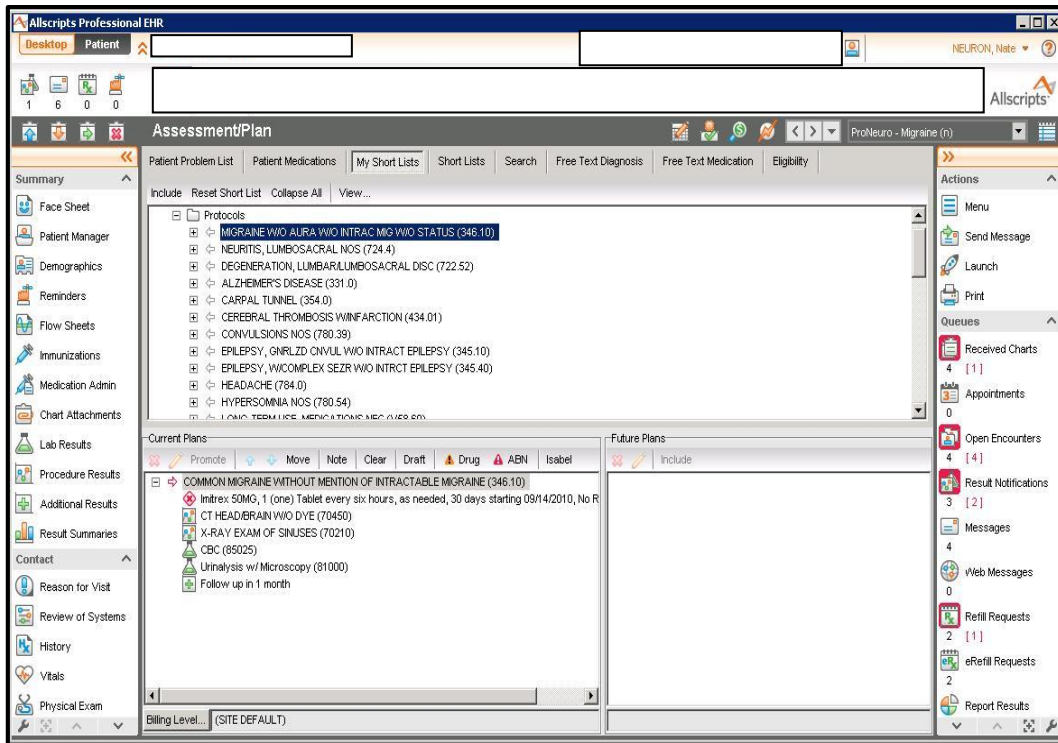


Figure 2.27: Interface of the Allscripts EMR system [124].

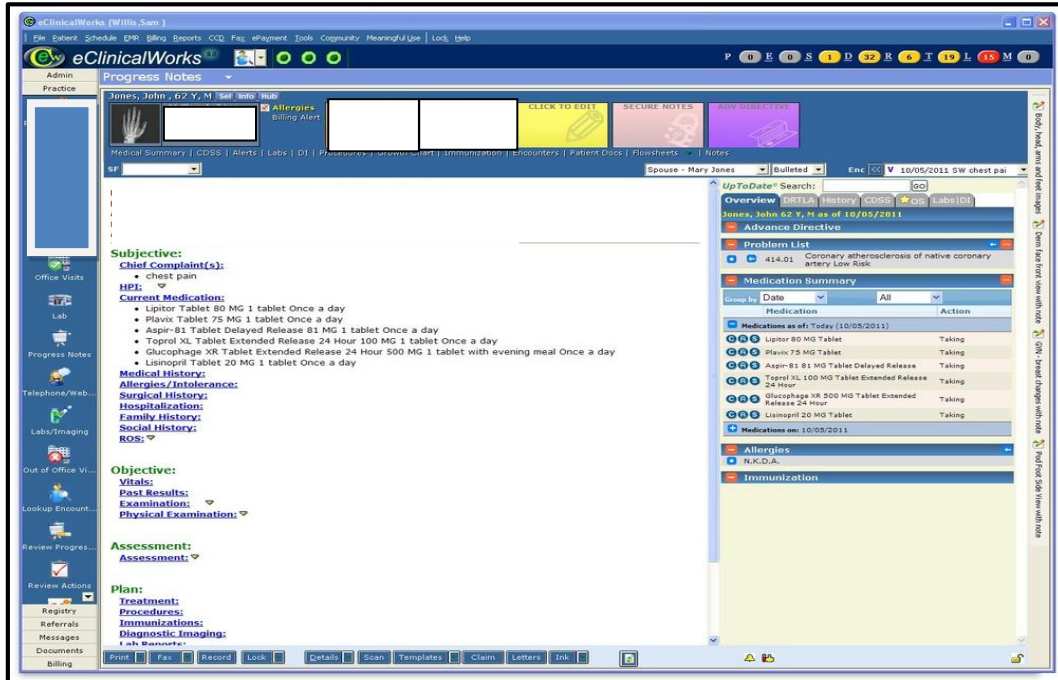


Figure 2.28: Interface of the eClinicalWork EMR system [125].

- **NextGen Healthcare** [113] – The market share of NextGen Healthcare is 7.7%. NexGen’s ambulatory EMR solution was designed with heavy input from physicians. This software provides a powerful, intuitive interface that helps reduce errors and maximize efficiency and accuracy. NextGen also offers revenue cycle management, health information exchange and patient portal applications [135]. Figure 2.29 shows the interface of NextGen EMR system.

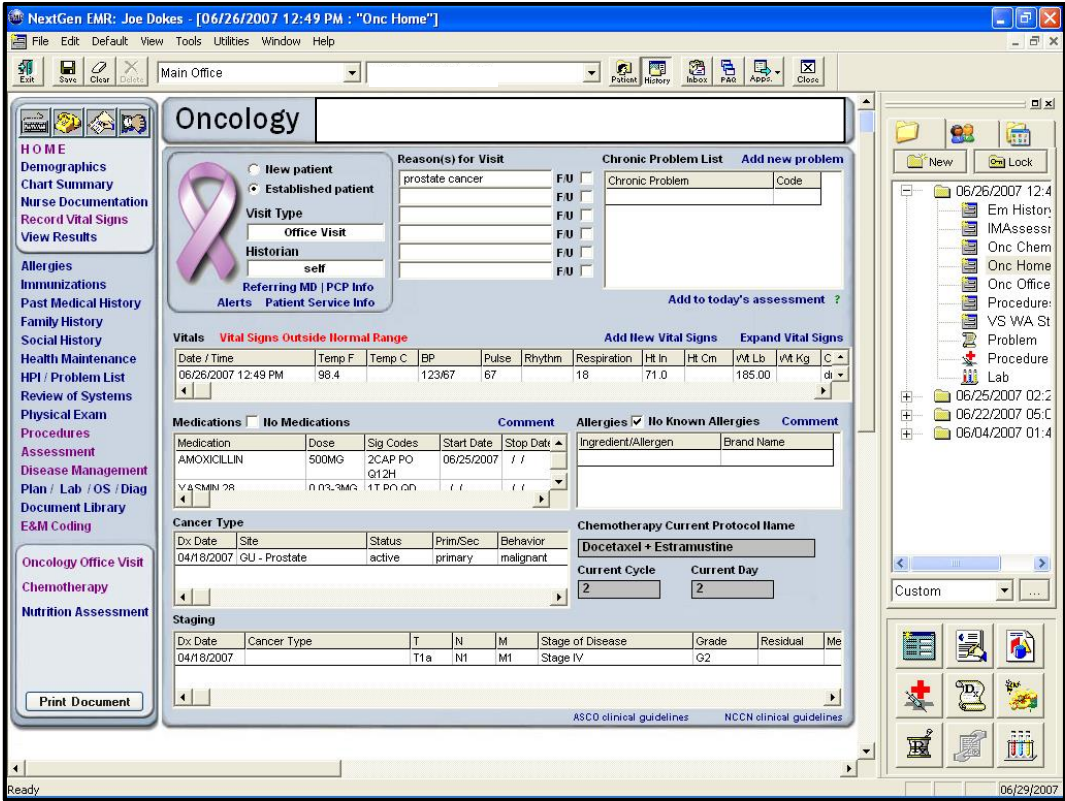


Figure 2.29: Interface of NextGEN EMR system [126].

- **GE Healthcare** [113] – The market share of GE Healthcare is 5.5%. GE is a large company, and it caters to the needs of large practices. GE’s Centricity EMR is designed to integrate with practice management software to provide powerful solutions. This system offers Clinical Messenger to support communication with patients and other practices involved in a patient’s care [136]. And an interface engine supports the integration of the program with

third party systems to share lab reports, billing data, clinical notes and related data. Figure 2.30 shows the interface of GE EMR system.

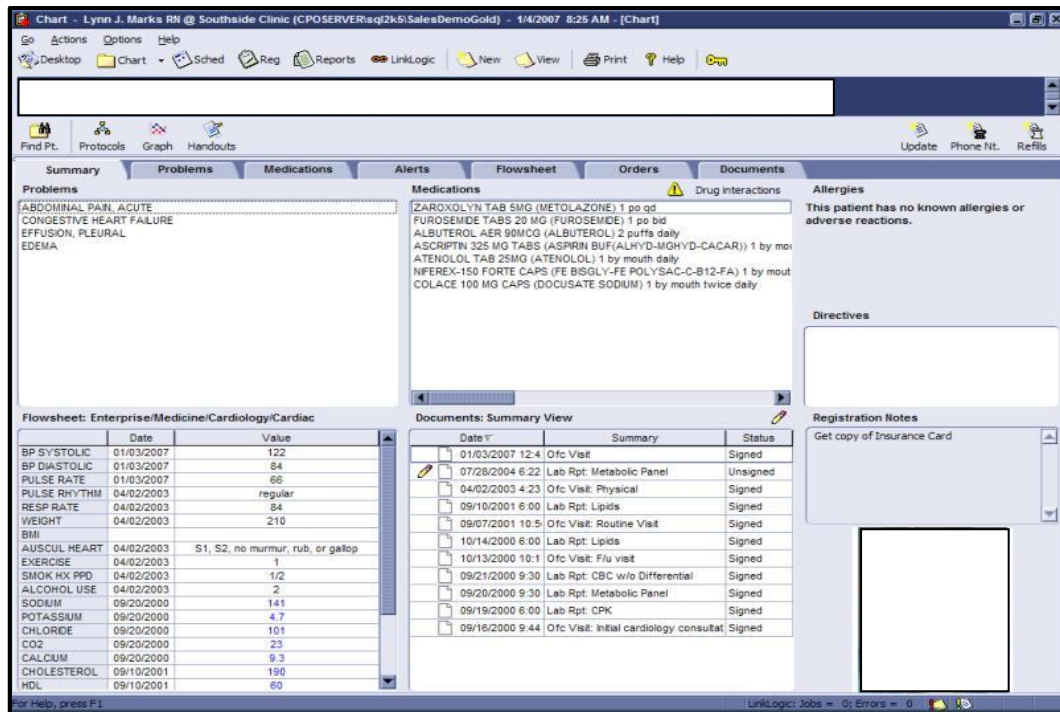


Figure 2.30: Interface of GE EMR system [127].

2.4.2.2 Common Visualizations in Commercial EMR Systems

One of most frequent visualizations in commercial EMR systems is the flowsheet [111]. It contains key medical variables for an individual patient over a period of time (e.g., 1 month, 1 week, or 24 hour) and thus highlights abnormal values and changing trends [114] [115]. The electronic flowsheets are a combination of spreadsheets with line or point plots. The horizontal axis of plots and the spreadsheet columns using a same timescale. On the vertical axis, variables are always displayed either as marks in a line or point plot or as numbers in a spread sheet row. In addition, there are some plots that use different icons along the horizontal time axis to display medication overview. Abnormal values are also highlighted in the plots and spreadsheets.

Also beyond flowsheets, some other interactive visualizations can be found in commercial EMR systems. For an example, Allscripts Wand TimeLine (Figure 2.31) illustrates an interactive overview of patients' medical data for mobile devices. It features line plots for numerical variables and Lifeline-based line segments and icons for encounters and medication [111]. The system offers details of these data items in tooltips and can highlight items which are related to a diagnosis, which were selected from the list in the top. In addition, users can reorder panels, open or close them, and configure the presentation. Moreover, they can also interactively pan and zoom the time axis or highlight a date with a vertical line [116].

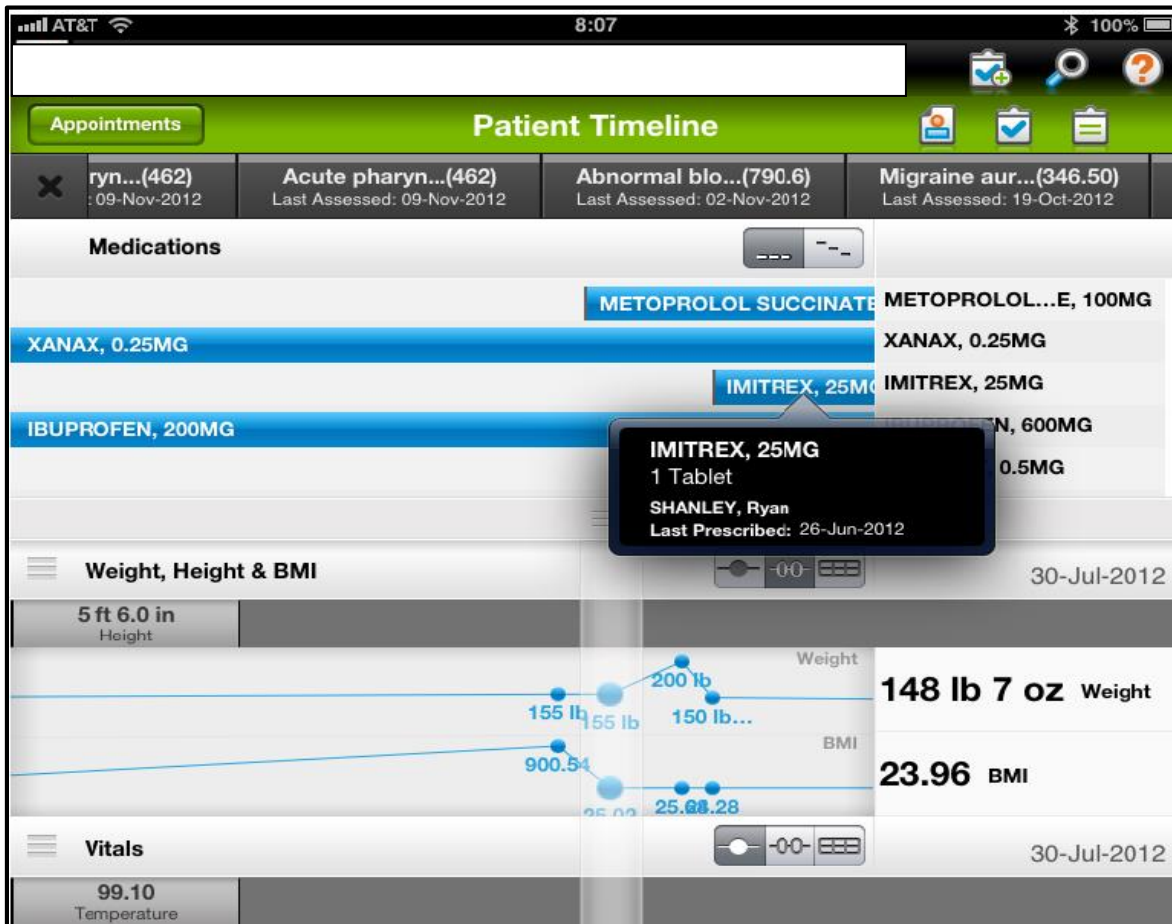


Figure 2.31: Allscripts Wand Timeline [116] shows an overview of a patient's diagnosis, medication, vital signs, lab values, and encounters along a horizontal time axis.

In conclusion, there is some adoption of visualization methods in commercial EMR systems. It is obvious that the most widely applied visualization technique is flowsheet, which always use simple line and point plots.

2.4.2.3 IBM Watson and Medical Records Text Analytics

IBM Watson, developed by IBM, is a cognitive system which has the ability to answer questions posed in natural language. Watson can find and understand the clues in questions by using machine learning, statistical analysis and natural language processing [120]. In addition, it can compare and rank the possible answers, and finally give them to users.

With the research collaboration with faculty, physicians and students at Cleveland Clinical Lerner College of Medicine of Case Western Reserve University, IBM has published two cognitive technologies which can be used by Watson. The two projects are “WatsonPaths” and “Watson EMR Assistant”, and they are expected to help health care providers (e.g., physicians, nurses) to make accurate decisions and find out new insights from EMR.

- **WatsonPaths**

WatsonPaths is a cognitive system that can explore a complex scenario and draw a conclusion like physicians do in real life [121]. When a medical case is presented, WatsonPaths can extract important information based on the knowledge it has learned from professional medical people and from medical literature. When a physician enters a summary about patient, WatsonPaths takes natural language questions as input and produces possible answers of most likely diagnosis or most appropriate treatment as output. At first, WatsonPaths breaks down the input scenario into several pieces of important information

(like keywords) with the help of natural language processing as shown in Figure 2.32 (a). Afterwards, WatsonPaths analyzes such information with the help of machine learning and represents the solution in a graphical model (flowsheet) as shown in Figure 2.32 (b).

- **Watson EMR Assistant**

IBM is also using Watson to explore how to navigate and process EMRs to find out the hidden insights within the data. The large amount of health data within EMRs presents huge value in transforming clinical decision making, but is always difficult to absorb. Watson's natural language processing capabilities make it possible to process an EMR with semantic understanding of the contents. This can help physicians efficiently and quickly extract useful information from massive amount of complex medical data. The goal of the Watson EMR Assistant research project is to develop a technology that will collate keywords in the past medical history and present to the physician a problem list of clinical concerns [121].

←

Case #710564

Scenario

A 73-year-old retired nurse had finally convinced her husband, a 75-year-old retired English teacher, to see a physician for his condition. Over the past several years, the man had experienced a gradual decline in his ability to initiate and perform simple voluntary movements. He now moved much more slowly, his face was often expressionless, and most distressing of all to him, he had continual tremors, which were particularly obvious when he was drinking his afternoon tea. Upon examination, his physician further noted bradykinesia (slow movements), increased muscle rigidity (but normal muscle strength and reflexes), a decreased blinking frequency, and a slow, shuffling gait. He immediately referred the man to a neurologist.

Solution

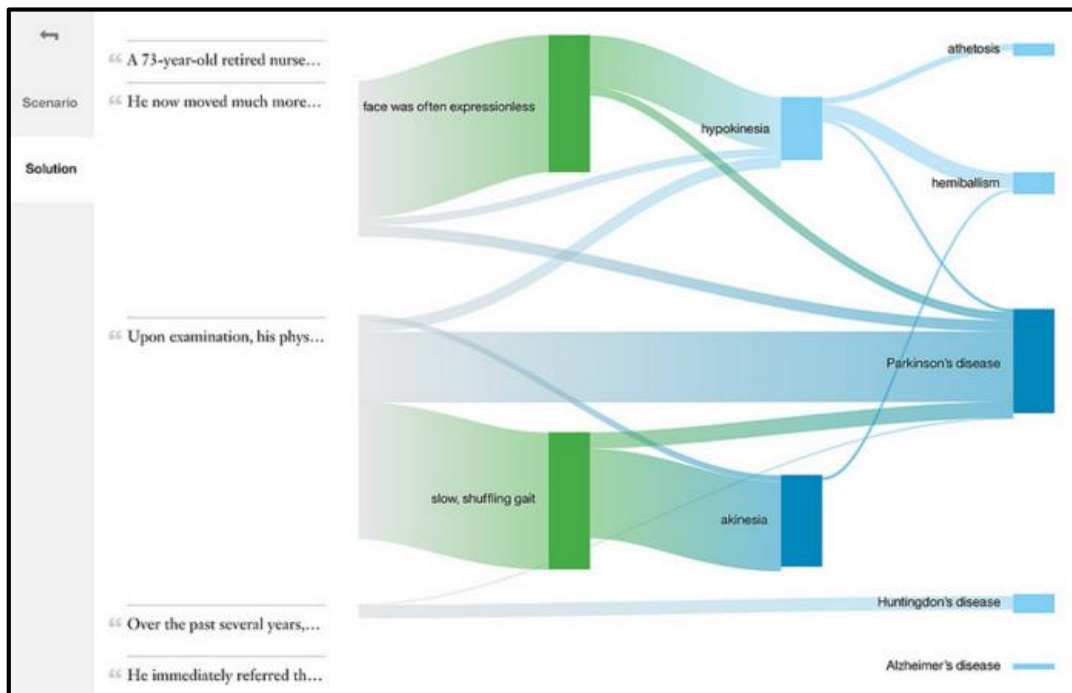
Which of the following disorders is the MOST likely diagnosis?

Watson believes that the following patient details are significant

- bradykinesia
- face was often expressionless

▶ Scenario excerpts also used in Watson's solution

(a)



(b)

Figure 2.32: Interface of WatsonPaths [121]. (a) WatsonPaths's medical scenario analytics. (b)

The solution provided by WatsonPaths.

Chapter 3. System Design and Implementation

In this chapter, we discuss how we have designed and implemented a set of graphic components and integrated them into our web-based medical record system. Before introducing our system, we first propose some requirements and components of an EMR visualization system which should be considered in our research. Second, we would like to provide a detailed visual description of our system, such as features, functions, and the user interface. After that, we give an overview of our system, including the architecture, benefits and performance of the system. Finally, some limitations are listed.

3.1 Requirements for Our Visualization System

In previous two chapters, we have discussed some requirements and components of medical records, EMR and visualization system. They are listed below.

- **Requirements for Medical Records posed by Hippocrates:** (1) It must accurately reflect the past disease history of a patient. (2) It should help indicate the probable cause of a patient's problem.
- **Primary Components of Medical Records:** (1) Personal Identification Information. (2) Basic Medical Profile. (3) Family Medical History. (4) Diagnosis History. (5) Treatment History. (5) Medication History. (6) Test result display. (7) Clinical Notes.
- **Requirements of EMR:** (1) costs. (2) Legibility. (3) Accessibility. (4) Big Storage. (5) Security.

- **Evaluation Criteria of IV:** (1) Functionality. (2) Efficiency. (3) Effectiveness. (4) Usability. (5) Usefulness.

These requirements, components and evaluation criteria are significantly considered in our research, and we designed and implemented our visualization system based on them. We will discuss what we have achieved and what remains for future work in the Chapter 5.

3.2 User Interface Design

In this section, we propose our approach to design an intuitive, interactive user interface (UI) and easy navigation. As the main feature of our system, a clickable 2D human body is placed in the center of the page to provide a body-centric data layout. Symptoms are labeled with colored circles, which are the starting point of the interactive navigation. By clicking on these symptoms, users can easily add, show, and retrieve information. Besides, we also propose how we used icons and timelines to improve the display of history records and how we used color attributes to improve the display of blood test results.

3.2.1 Start Page

The start page of our system is shown in Figure 3.1, which is the entry point of our system. This layout is designed with the help of Bootstrap, which is a popular front-end framework for developing a friendly user interface on the web. A user login box is placed on the far left of the page. By using this login box, users can create a new patient's record or select an existing patient's record. Next to the login box, there is a select box, which is used to input the symptom location information and disease type. Some navigation bars on the right side of the page are leveraged to link to other pages for further health information. A clickable 2D human body is

placed in the center of the page to interactively display health information. Symptoms' locations can be marked on this human body and these locations are used as a navigation.

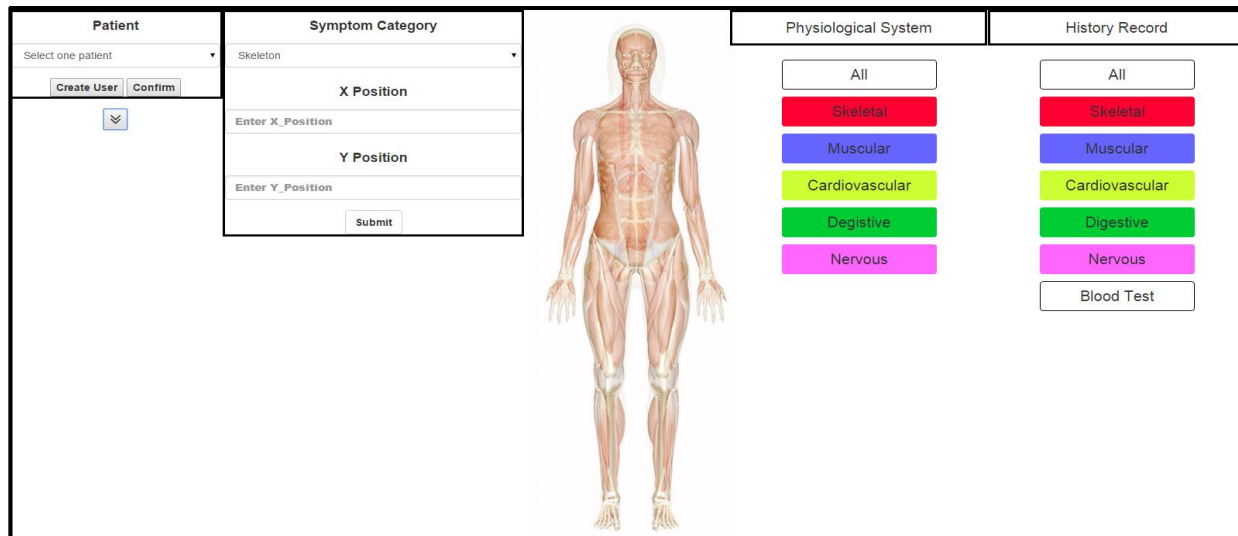


Figure 3.1: Start page of the system: the far left side is a login box, next to the login box is a select box, the right side is a navigation board, and a clickable 2D human body is placed in the center of the page.

3.2.2 Patient Information

In this section, we first introduce how to create new records for new patients using our system. Subsequently, we present how our system displays patient information in an intuitive way.

3.2.2.1 Create a New Record for a New Patient

The registration function is an essential function in any EMR system. There will always be new patients visiting the physician's office every day. Before starting the first diagnosis, physicians need to know patients' basic individual information and create a new record to store them for the future visit.

The registration interface of our system is shown in Figure 3.2. When users click on the create user button on the upper-left corner of the page, a pop-up box (highlighted in red box) will appear under the button. Users can enter the personal information (e.g., name, gender, allergy, blood type) of the patient and submit the information to the database using this pop-up box. This information will be reserved permanently in the data storage for future treatment.

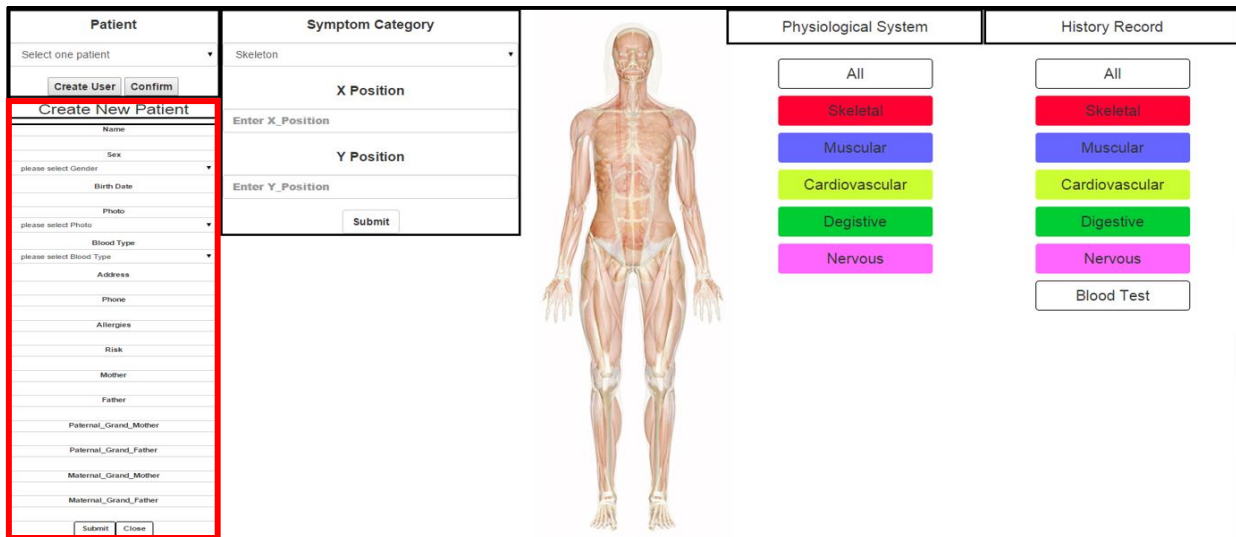


Figure 3.2: The interface used to create a new patient’s record. The input box for entering a new patient’s basic information is highlighted in red on the left side of the page.

3.2.2.2 Patient’s Basic Information Display

Patients can be divided into two types by gender: female and male patients. According to the differences between their physical structures, the diagnosis and treatment of men and women differ in several ways. If there is a feature that can intuitively show the patient’s gender in the interface, it ensures the provision of accurate care.

Our system uses two different kinds of background images to visually represent the female and male patients. Figure 3.3 shows the interface for a female patient and Figure 3.4 shows the

interface for a male patient. Users can distinguish the patient’s gender at a glance, and it saves time compared to reading the patient’s information.

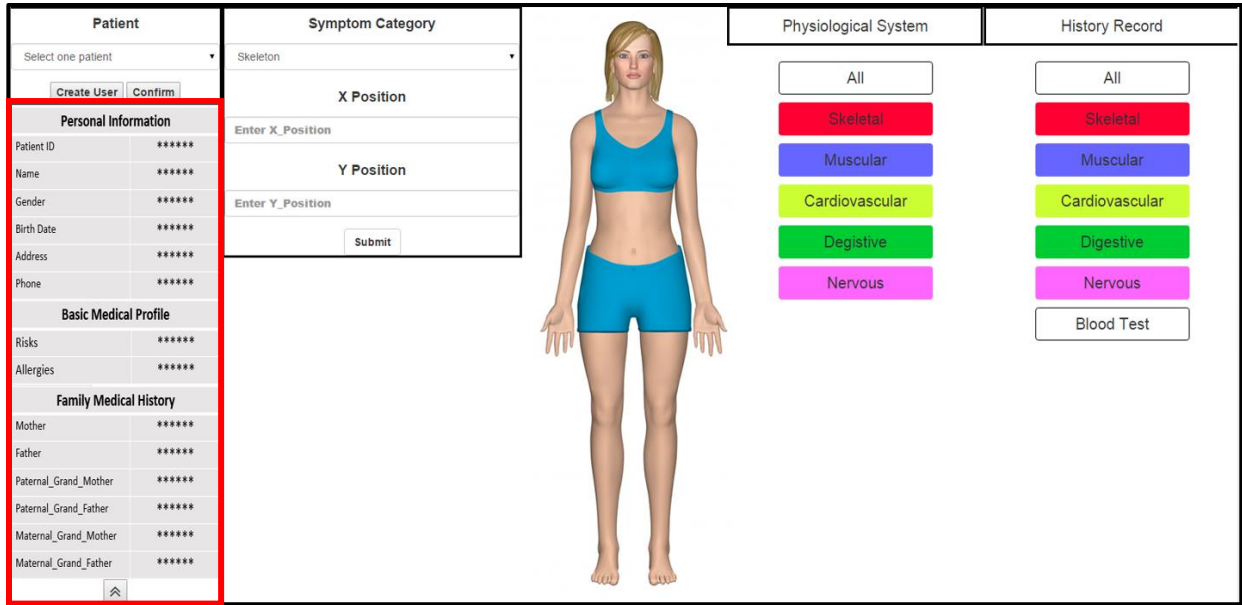


Figure 3.3: Interface for a female patient [105].

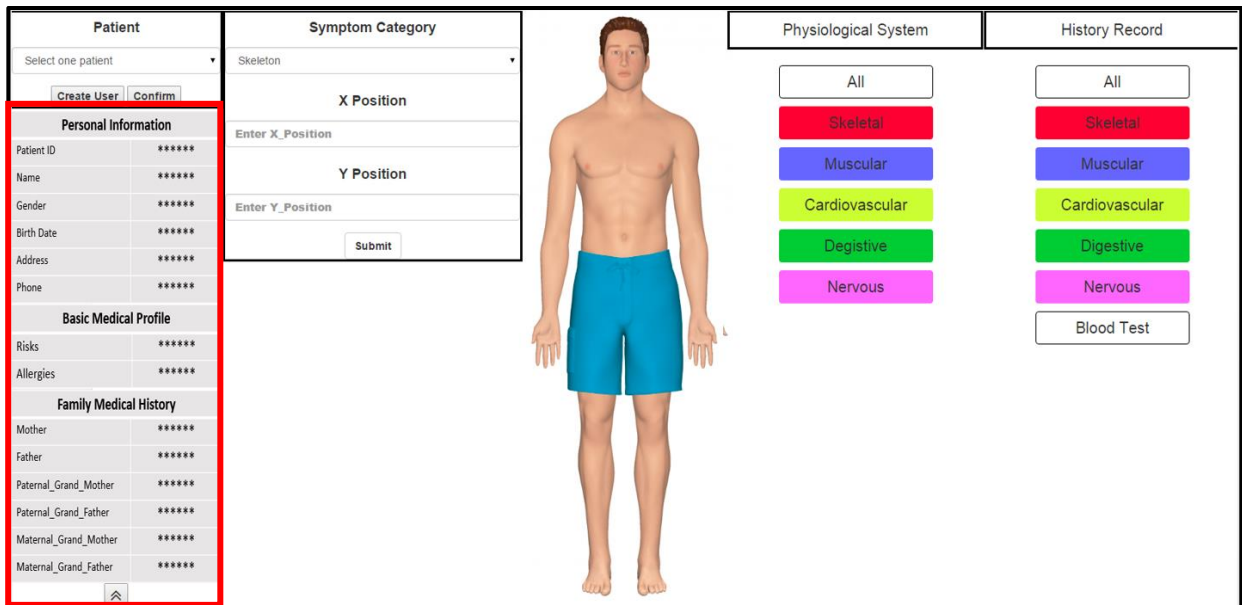


Figure 3.4: Interface for a male patient [106].

Individual Information / Basic Medical Profile / Family Medical History – A cumulative summary of patients’ basic information must be maintained and displayed in each EMR system’s interface. The “snap shot” of the patient generally contains his/her individual information, basic medical profile, family medical history, and others. These kinds of information allow physicians or other healthcare professionals to quick get a picture of the patient’s overall health condition. Our system supports a table (highlighted in the red box on the left side of Figure 3.3 and the left side of Figure 3.4) to provide a quick patient information display. Furthermore, we also use an angle-double-up button to hide the information and an angle-double-down button to show the information, which can raise the utilization ratio of interface spaces.

In the following section, we introduce our system with a default 2D human body, as shown in Figure 3.1.

3.2.3 Five Physiological Systems

The human body consists of many physiological systems. Each system consists of two or more organs and contributes to the maintenance of the homeostasis of itself, of other systems, and of the entire body. Classifying diseases according to different physiological systems could be a good way to display medical records.

Five physiological systems (skeletal, muscular, cardiovascular, digestive, and nervous systems) are used in our system to visually represent health data, as shown in Figure 3.5. With the help of these rich, detailed anatomical figures, our system offers a novel way to manage and visualize health information. These body images allow users insert and retrieve patients’ health records in an intuitive and interactive way.

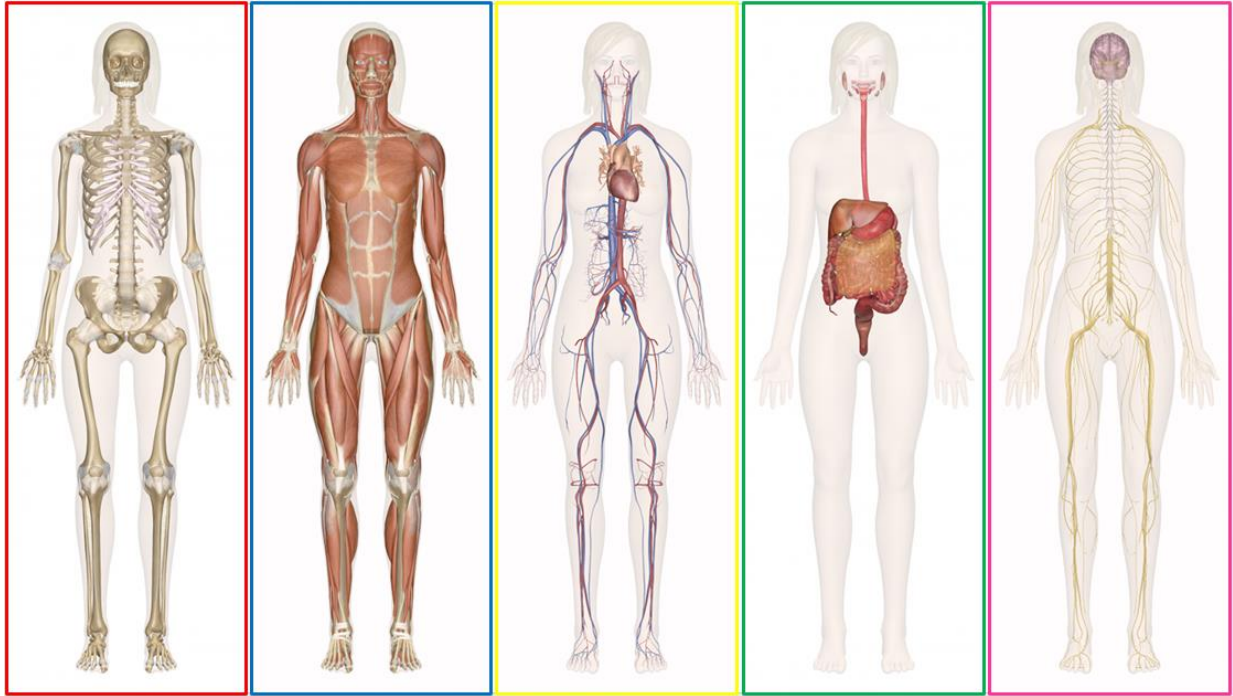


Figure 3.5: Five physiological systems: from left to right, the skeletal, muscular, cardiovascular, digestive, and nervous systems are displayed [100] [101] [102] [103] [104].

3.2.4 Location-based Symptoms

In this section, we first introduce our approach to mark symptom locations on a 2D human body. Then, our approach to insert and show medical records will be presented.

3.2.4.1 Marking the Symptom Location on a 2D Human Body

As mentioned before, the 2D human body displayed in our interface is clickable. When the user single-clicks on the human body, the location information will be calculated and entered into the X-position and Y-position boxes automatically, as shown in Figure 3.6 (a). After the location coordinates are obtained, a given symptom also should be classified into a particular physiological system using the drop-down menu in Figure 3.6 (a). Afterwards, these two kinds of

data will be transmitted to the database by clicking on the submit button. As soon as the data are inserted into the database, the interface will load the information automatically and display the symptom on the 2D human body with a circle (Figure 3.6 (b)). In order to provide an intuitive and quick way to distinguish the problem type, our system uses different colors to label different physiological system symptoms. Similarly, each physiological system has a corresponding colored navigation button that maps to the corresponding circle. This is illustrated in Figure 3.1. Moreover, to provide better interactive visualization, we applied different kinds of mouse events to show health information. To be more specific, single-clicking on a colored button (Figure 3.1) provides user with an easy way to navigate to a corresponding physiological system page (Figure 3.7). To support more intuitive navigation, the system also allows users to double-click on colored circles to achieve the same effect (Figure 3.7).

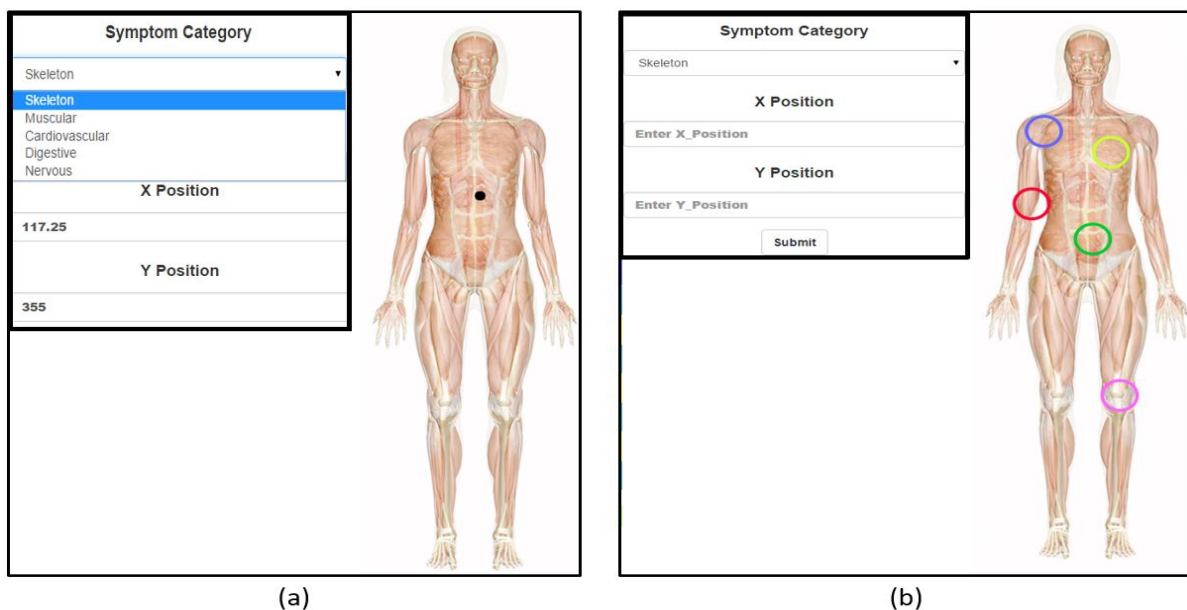


Figure 3.6: (a) Record a new symptom, including its location information and symptom type. (b) Symptom locations are labeled with colored circles.

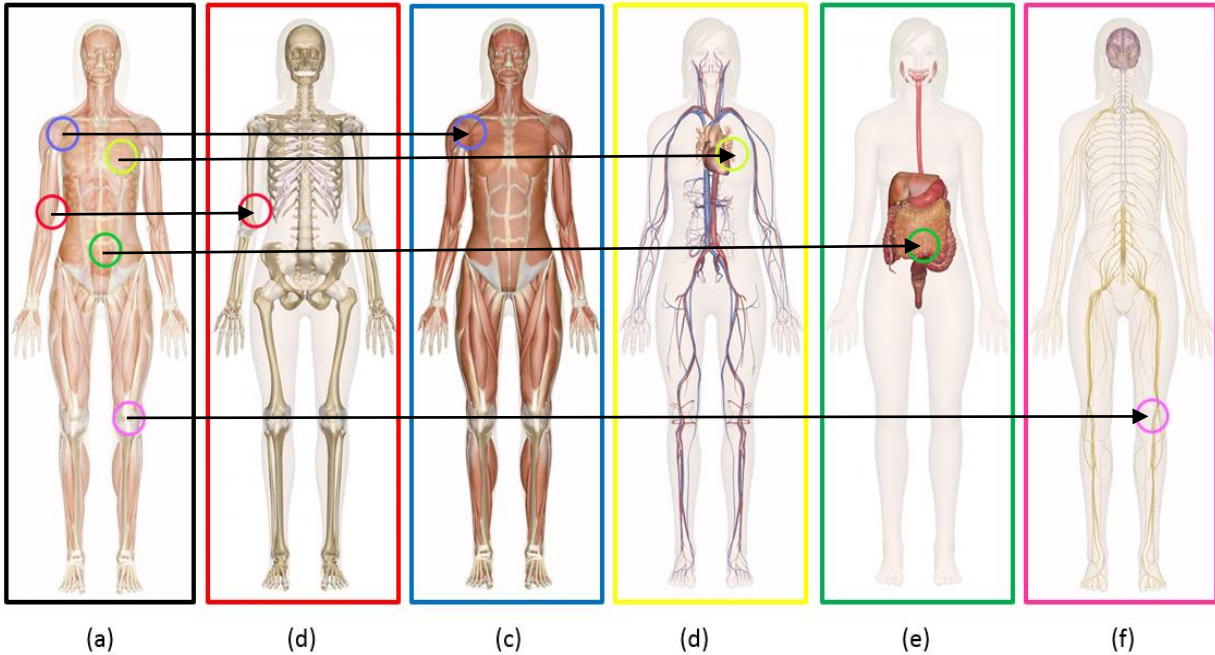


Figure 3.7: (a) All kinds of the problems are displayed on the home page. (b) Only skeletal problems are displayed on the skeletal system page. (c) Only muscular problems are displayed on muscular system page. (d) Only cardiovascular problems are displayed on the cardiovascular system page. (e) Only digestive problems are displayed on the digestive system page. (f) Only nervous problems are displayed on the nervous system page.

3.2.4.2 Insert Medical Records for Specific Symptoms

Intuitive and interactive navigations are provided in our system to allow users to quickly input records of each symptom. For each symptom, users can click on the symptom locations to enter health records since all the insert functions are integrated in each symptom.

Clicking on a symptom location (Figure 3.8 (a)), a corresponding pop-up box will appear, as shown in Figure 3.8 (b). Basic symptom information and some navigation buttons are included in this pop-up box. The brief symptom description allows the physician to have a

preliminary understanding of the symptom. Users can use these buttons to navigate to a corresponding interface to add new records, show the latest records, and check the history records. For example, when a user clicks on the add diagnosis button, a pop-up input box (different border color indicates different type of physiological systems) will appear, as shown in Figure 3.9 (a). In this input box, users can input the ICD number, severity and symptom descriptions, and clinical notes. After submitting this information, it will be transmitted to the database and stored permanently for future works. The addition of treatment information and medication information are also designed and implemented in the same way (Figure 3.9 (b) and Figure 3.9 (c)). Moreover, the system also provides an upload function to allow users to upload the scanning results, as shown in Figure 3.9 (d).

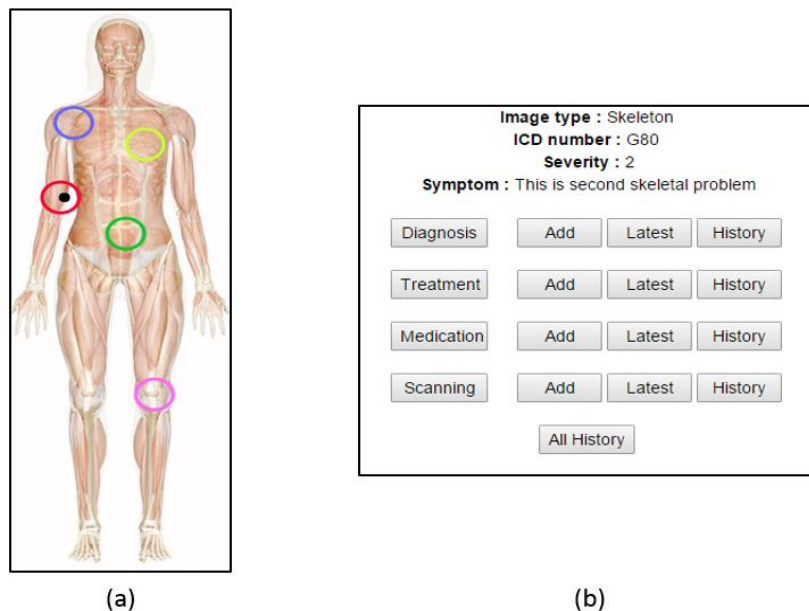
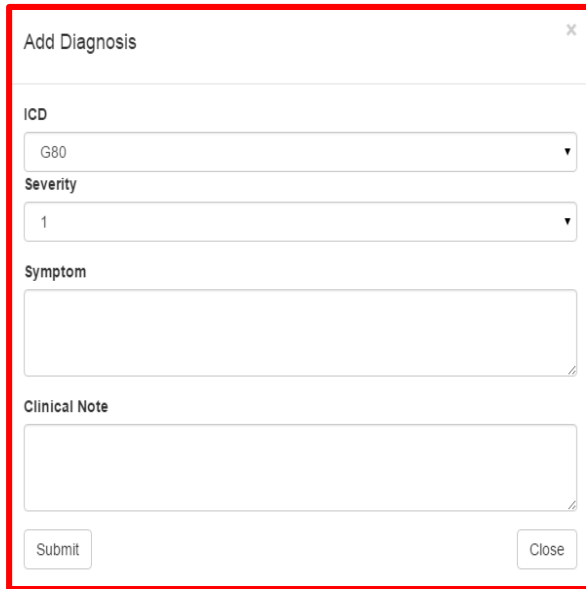


Figure 3.8: (a) Symptoms are labeled with colored circles and displayed on the human body. (b) A pop-up box, which will appear when clicking on a symptom location, is used to add, display, and retrieve medical records.



Add Diagnosis [Close]

ICD
G80

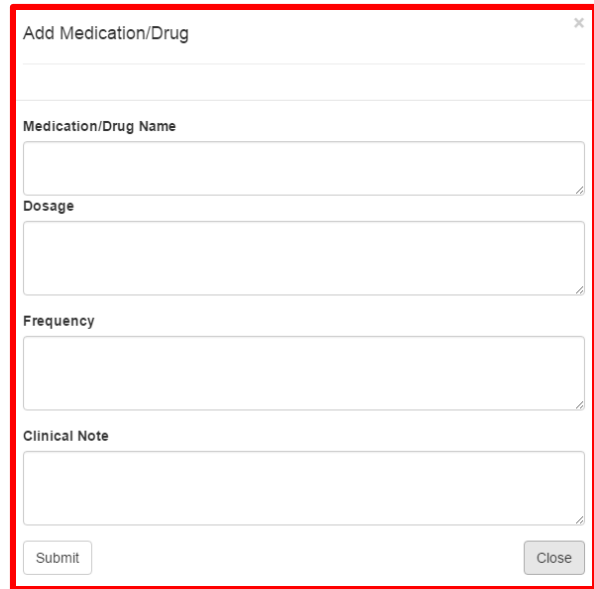
Severity
1

Symptom

Clinical Note

Submit [Close]

(a)



Add Medication/Drug [Close]

Medication/Drug Name

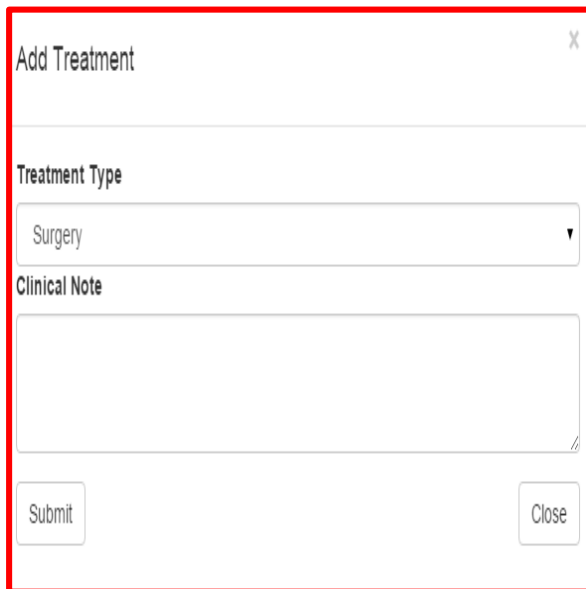
Dosage

Frequency

Clinical Note

Submit [Close]

(c)



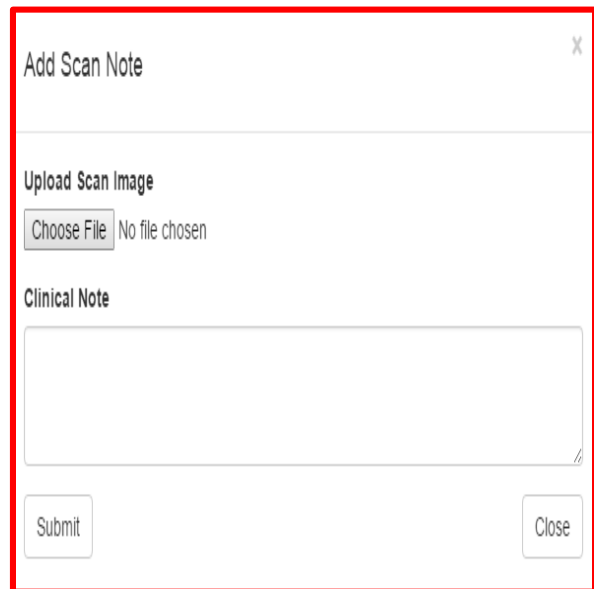
Add Treatment [Close]

Treatment Type
Surgery

Clinical Note

Submit [Close]

(b)



Add Scan Note [Close]

Upload Scan Image
Choose File No file chosen

Clinical Note

Submit [Close]

(d)

Figure 3.9: The red border means this pop-up box belongs to skeleton problems: (a) A pop-up input box used to insert diagnosis information. (b) A pop-up input box used to insert treatment information. (c) A pop-up input box used to insert medication information. (d) A pop-up input box used to upload scanning images and insert related notes.

Latest Diagnosis	
ICD_id	G80
Symptom	This is second skeletal problem
Severity	2
Clinical Note	This is second skeletal problem

Close

(a)

Latest Treatment	
Treatment Name	Radiation Therapy
Clinical Note	This patient needs a radiation therapy

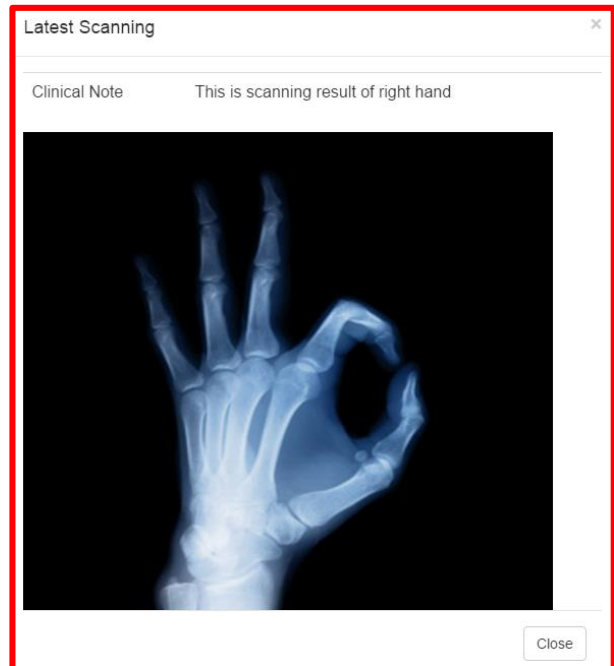
Close

(b)

Latest Medication	
Medication Name	Asprin
Dosage	4 mg / time
Frequency	4 times / day
Clinical Note	This patient needs some Asprin

Close

(c)



(d)

Figure 3.10: The red border means this pop-up box belongs to skeleton problems: (a) A pop-up box for displaying the latest diagnosis information. (b) A pop-up box for displaying the latest treatment information. (c) A pop-up box for displaying the latest medication information. (d) A pop-up box for displaying the latest scanning results.

3.2.4.3 Showing the Latest Medical Records for Specific Symptoms

Our system also provides a quick way to display each symptom's latest medical records. Users can click on the latest diagnosis button (Figure 3.8 (b)) to look over a symptom's latest

diagnosis. As soon as the button is clicked, a pop-up display box will appear to show the detailed information of the symptom's latest diagnosis, as shown in Figure 3.10 (a). The display of treatment information, medication information, and scanning results is also designed and implemented in this way, as shown in Figure 3.10 (b), Figure 3.10 (c), and Figure 3.10 (d). And different border color indicates different type of physiological systems.

3.2.5 Timeline-based and Icon-based History Records

The history record is an essential component of any medical record system. In medical records, a patient's history includes all past medical information, such as diagnosis records, treatment records, scanning results, blood test results, and so on. In our system, this information is illustrated interactively and intuitively with a combination of icons and a timeline, as shown in Figure 3.11. In contrast to existing systems, the icons we used here are clickable. Each icon has colored border and the color is used to indicate which physiological system it belongs; users can recognize the information of interest at first glance of the icons, and click on them for details.

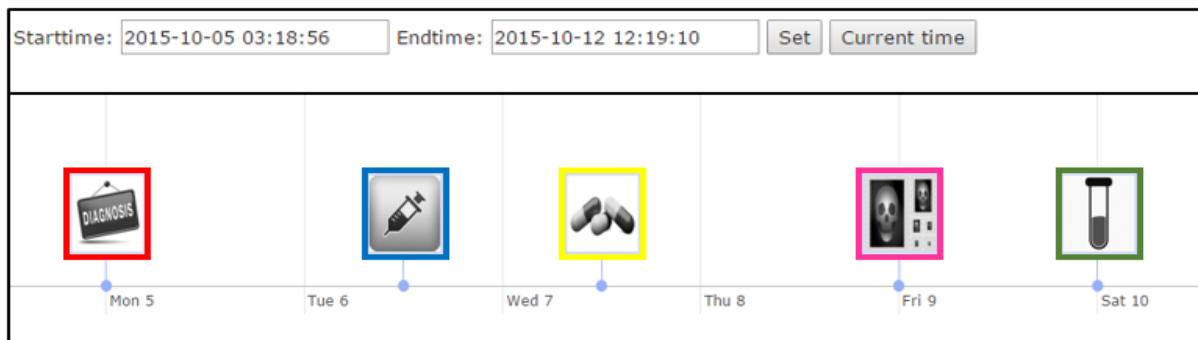


Figure 3.11: Icon-based and time-line based history record display.

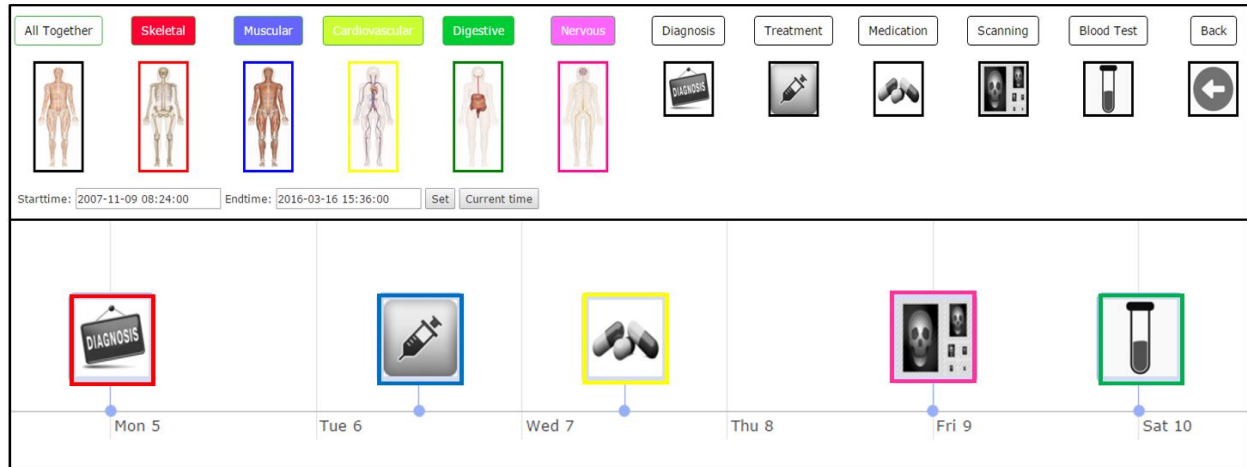


Figure 3.12: The full page of history records. Navigation buttons and icons are placed on the upper part of the page, which can be clicked to filter medical data.

Some navigation buttons and icons are placed on the upper part of the full history record page (Figure 3.12). Users can click on these buttons to filter out unwanted information and obtain what they wanted. This will be explained in detail below.

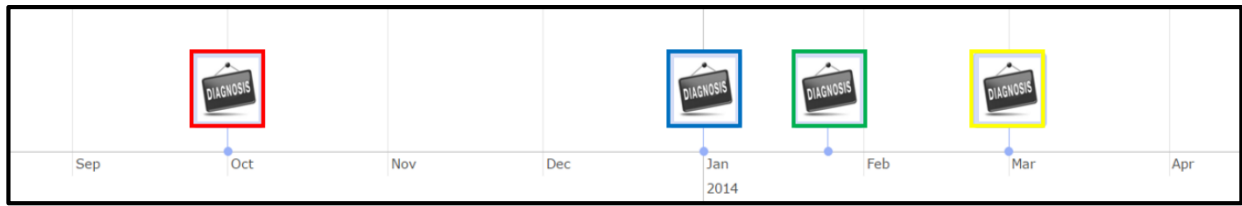
- **Diagnosis button or icon:** All diagnosis history for all symptoms will be obtained by clicking on this button (Figure 3.13 (a)).
- **Treatment button or icon:** All treatment history for all symptoms will be obtained by clicking on this button (Figure 3.13 (b)).
- **Medication button or icon:** All medication history for all symptoms will be obtained by clicking on this button. (Figure 3.13 (c)).
- **Scanning button or icon:** All scanning history will be obtained by clicking on this button (Figure 3.13 (d)).
- **Blood test button or icon:** All blood test history for all symptoms will be obtained by clicking on this button (Figure 3.13 (e)).

- **Skeletal button or icon:** A patient's full history of skeletal problem will be obtained by clicking on this button (Figure 3.14 (a)).
- **Muscular button or icon:** A patient's full history of muscular problem will be obtained by clicking on this button (Figure 3.14 (b)).
- **Cardiovascular button or icon:** A patient's full history of cardiovascular problem will be obtained by clicking on this button (Figure 3.14 (c)).
- **Digestive button or icon:** A patient's full history of digestive problem will be obtained by clicking on this button (Figure 3.14 (d)).
- **Nervous button or icon:** A patient's full history of nervous problem will be obtained by clicking on this button (Figure 3.14 (e)).

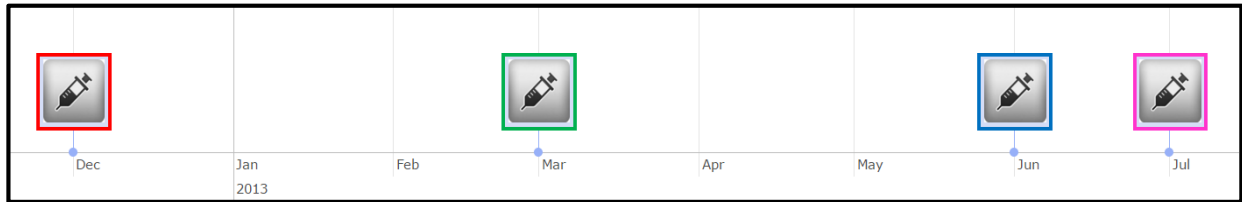
In order to improve our filtration and navigation systems, we also connect the symptom location to the history records. Users can click on five history navigation buttons in Figure 3.8 (b) to navigate to the history record page to check the corresponding history information they want.

- **Diagnosis history button:** All diagnosis history for one symptom will be displayed.
- **Treatment history button:** All treatment history for one symptom will be displayed.
- **Medication history button:** All medication history for one symptom will be displayed.
- **Scanning history button:** All scanning history for one symptom will be displayed.
- **All history button:** All kinds of history for one symptom will be displayed.

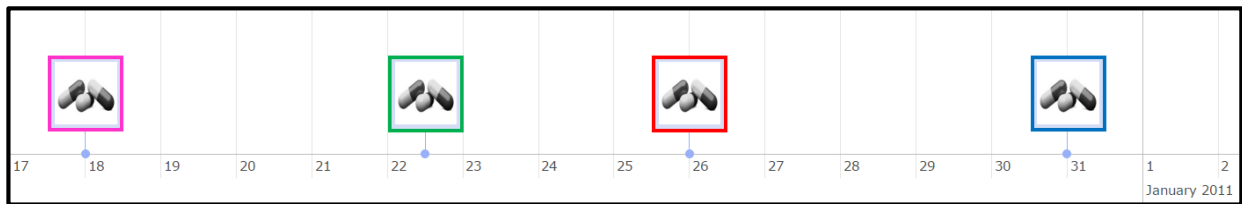
After filtering out unwanted data and obtaining what they want, users can click on the icons display in the timeline to review the detailed history records. (Figure 3.15).



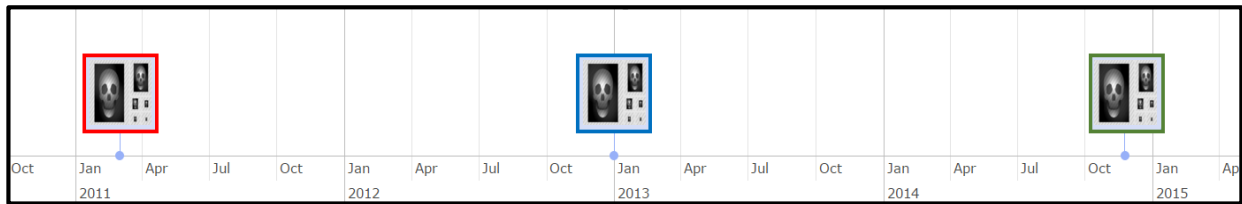
(a)



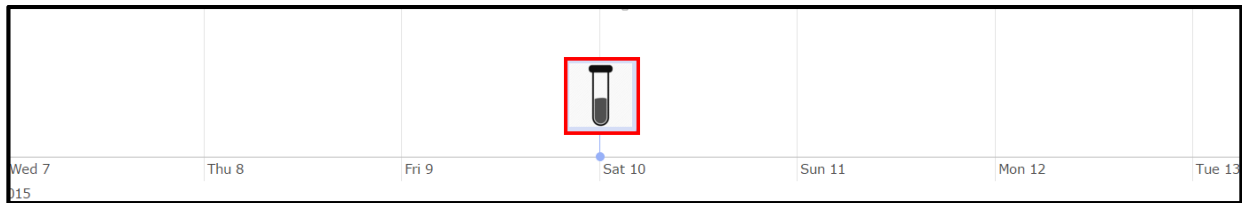
(b)



(c)

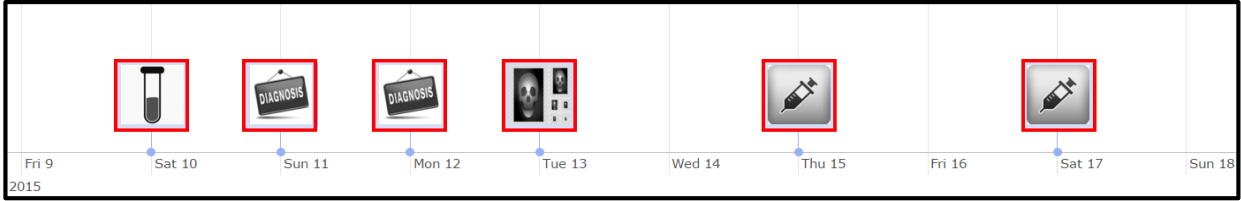


(d)

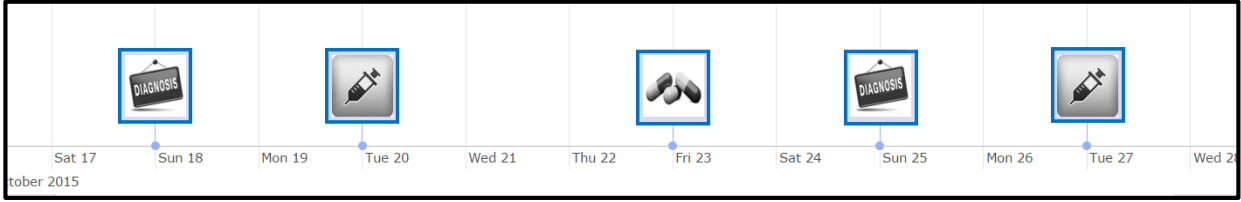


(e)

Figure 3.13: (a) All diagnosis history for all symptoms. (b) All treatment history for all symptoms. (c) All medication history for all symptoms. (d) All scanning history for all symptoms. (e) All blood test history for all symptoms.



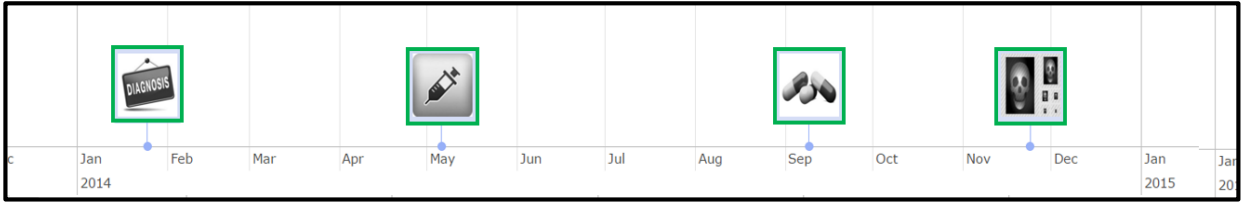
(a)



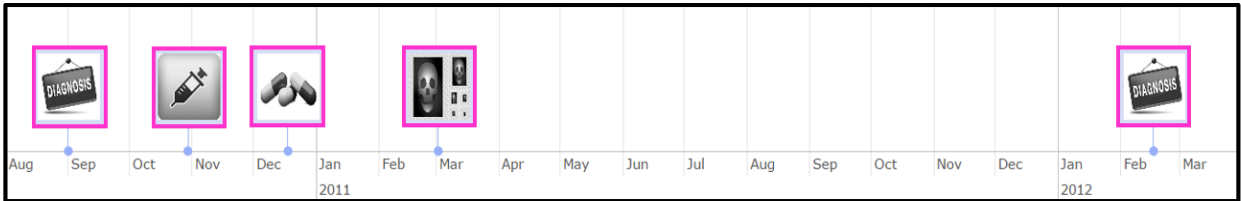
(b)



(c)



(d)



(e)

Figure 3.14: (a) A patient’s full history of skeletal problem. (b) A patient’s full history of muscular problem. (c) A patient’s full history of cardiovascular problem. (d) A patient’s full history of digestive problem. (e) A patient’s full history of nervous problem.

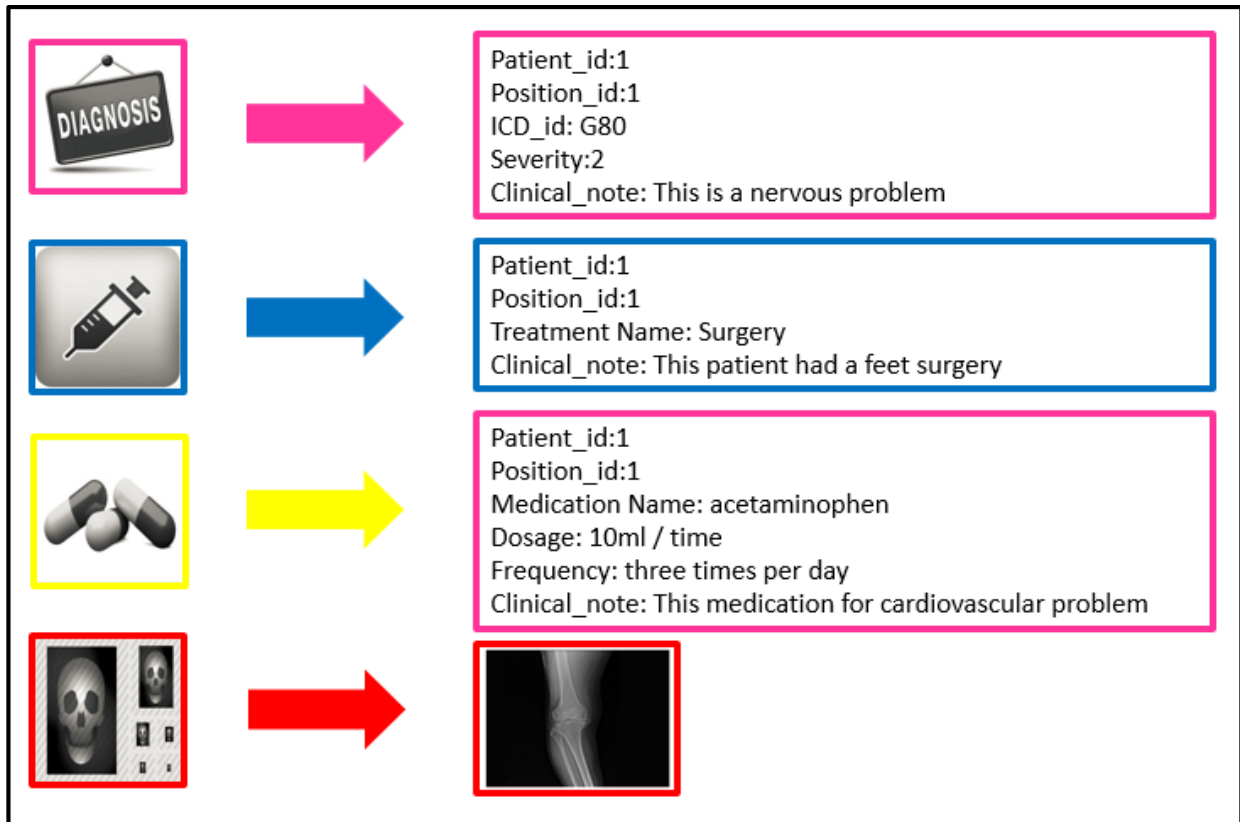


Figure 3.15: Information displayed by clicking on the icons. The border color for each icon indicates which physiological system it belongs to.

3.2.6 Color-based Blood Test Display

Blood testing involves a laboratory analysis performed on a blood sample and is often used in healthcare to determine physiological and biochemical states. Conventional blood test results displays use a monotonous table format and text, making it difficult to determine whether the index is normal.

In our system, the abnormal index is highlighted in red and can thus be easily noticed (Figure 3.16). We also provide a way to monitor the trend by clicking on the specific index because this changing trend can help physicians better understand a patient's health condition.

This is illustrated in Figure 3.17. The index trend is represented by a line graph with red and blue spots to mark abnormal and normal results, respectively. In our future work, we can also use this kind of method to display other types of test results.

Code	Normal Range	05/01/2015	06/02/2015	09/03/2015
AST	<=30.99	17	19	18
ALT	<=35.99	8	20	10
TSH	0.35 - 5.0	1.9	5.9	3.9
Free T4	12 - 22	17	19	19
Hb	115 - 155.000	119	139	129
Hct	0.33 - 0.450	0.34	0.44	0.54

Figure 3.16: Display of blood test results. A table of three sets of blood test results for the same individual. Red highlighting is used to indicate an abnormal index.

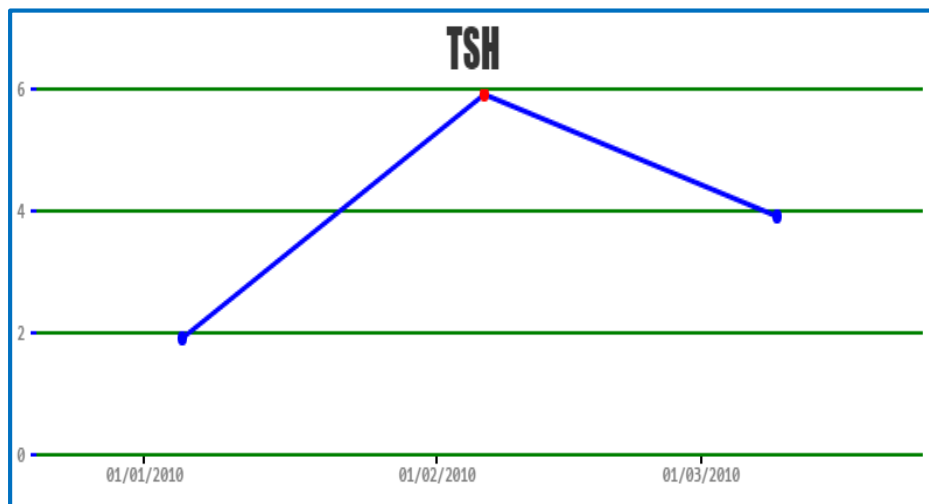


Figure 3.17: Display of blood test results. Graph-based visualization of the trend of each index in the past three tests. The red spot shows abnormal results; blue shows normal results.

3.3 System Implementation Overview

In this section, we provide an overview of our system's implementation from the following three perspectives. First, we present the architecture of our system. Second, we demonstrate some benefits of web-based systems. Finally, we explain how we optimized our system's performance.

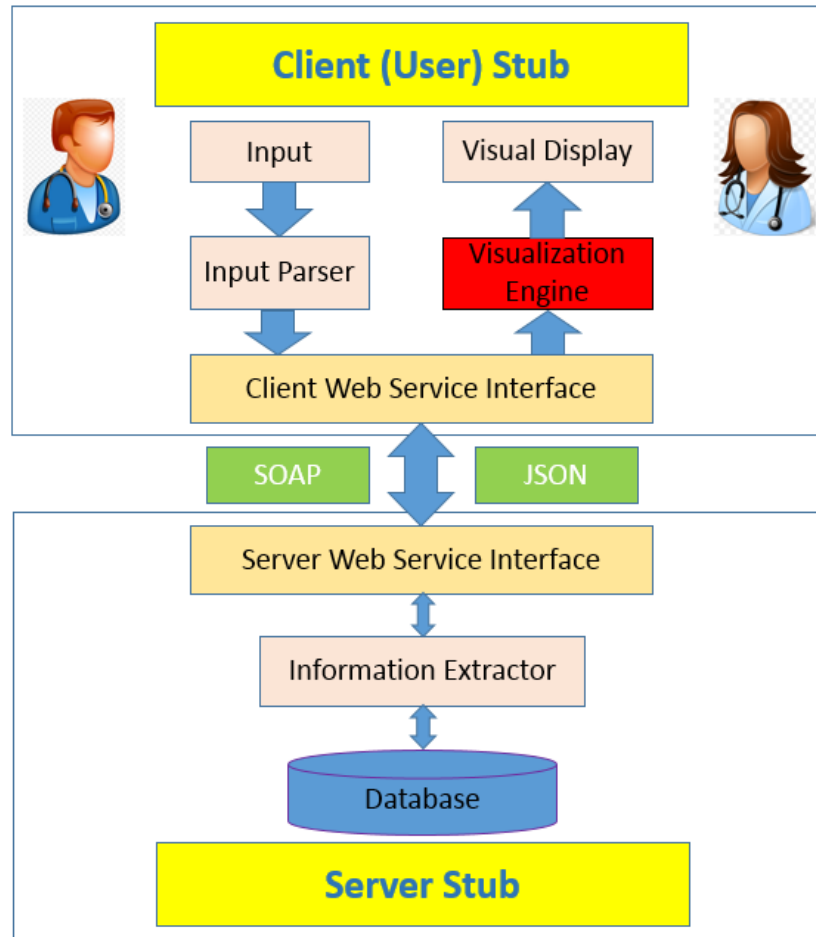


Figure 3.18: System architecture.

3.3.1 System Architecture

Our system is a web-based system. It is designed and implemented on the basis of the client-server framework. The overall architecture of our system is illustrated in Figure 3.18. It consists

of two major parts: a client (user) stub and a server stub. The client stub involves the following components: input, input parser, a client-side web service interface, visual processing engine, and a visual display interface. These components are implemented by display and visualization technologies (e.g., HTML, CSS, JavaScript, jQuery, Ajax, Bootstrap, and D3.js). Accordingly, we leverage Java, Java EE, and a MySQL database to implement the server stub components, including a server-side web service interface, a database extractor, and database storage. Finally, the communication between the client stub and the server stub is over the Simple Object Access Protocol (SOAP) web service, and the data transmission format we used is JSON.

To better understand the working process of our system, it is necessary to know the principle and functions of the components and the related technologies that were applied. In the following contents, the components and technologies are described in detail.

- **Input:** This is the entry point of the whole system, and all interactions between the user and the system occur in this component. It provides users the capacity to enter, edit, delete, and visualize data with interactive devices, such as a keyboard, mouse, and others.
- **Input Parser:** The Input Parser receives data (e.g., textual information, mouse commands) from the input component and then analyzes them to obtain the true meaning of the sentence. These parsed and extracted data play an important role in improving the system's performance.
- **Client/Server Web Service Interface:** These two interfaces are the essential parts of our system. They are used to ensure that the web service is working under a stable and safe environment. Moreover, they are also responsible for matching the request from the client side and the response from server side.

- **Information Extractor:** This component is used to filter numerous types of complex data and extract useful information from it. The information extractor organizes and structures the data.
- **Database (MySQL):** Medical records are stored in forms of schemas, tables, queries, and views in the database component. In our system, we constructed our storage with the help of MySQL since it is an open-source relational database management system and a popular choice of database for use in web applications. The medical code ICD is also stored in the database. The entity-relationship (ER) model of our database is shown in Figure 3.19.
- **Visualization Engine:** This is the component that is mainly responsible for visualizing data extracted from the database. Most of the visualization techniques and toolkits are applied here, such as HTML, CSS, JavaScript, jQuery, D3.js, and others.
- **Visual Display Interface:** This is the user interface that is used to show the ultimate visualization outcomes, such as images, charts, timelines, and etc. This interface also allows users to easily, quickly, and intuitively access our system with some interactive functionalities.
- **SOAP:** Our web service is implemented with the Simple Object Access Protocol (SOAP). It is a protocol specification for exchanging structured information in the implementation of web services in a web application. In our system, the SOAP web service interface provides the simplified communication between the client and server stubs.
- **JSON:** JSON is an acronym for JavaScript Object Notation, is an open standard format that used human-readable text to transmit data objects consisting of attribute-value pairs. It is

considered the primary data format in our system because it is widely used in visualization JavaScript libraries such as D3.js and AJAX.

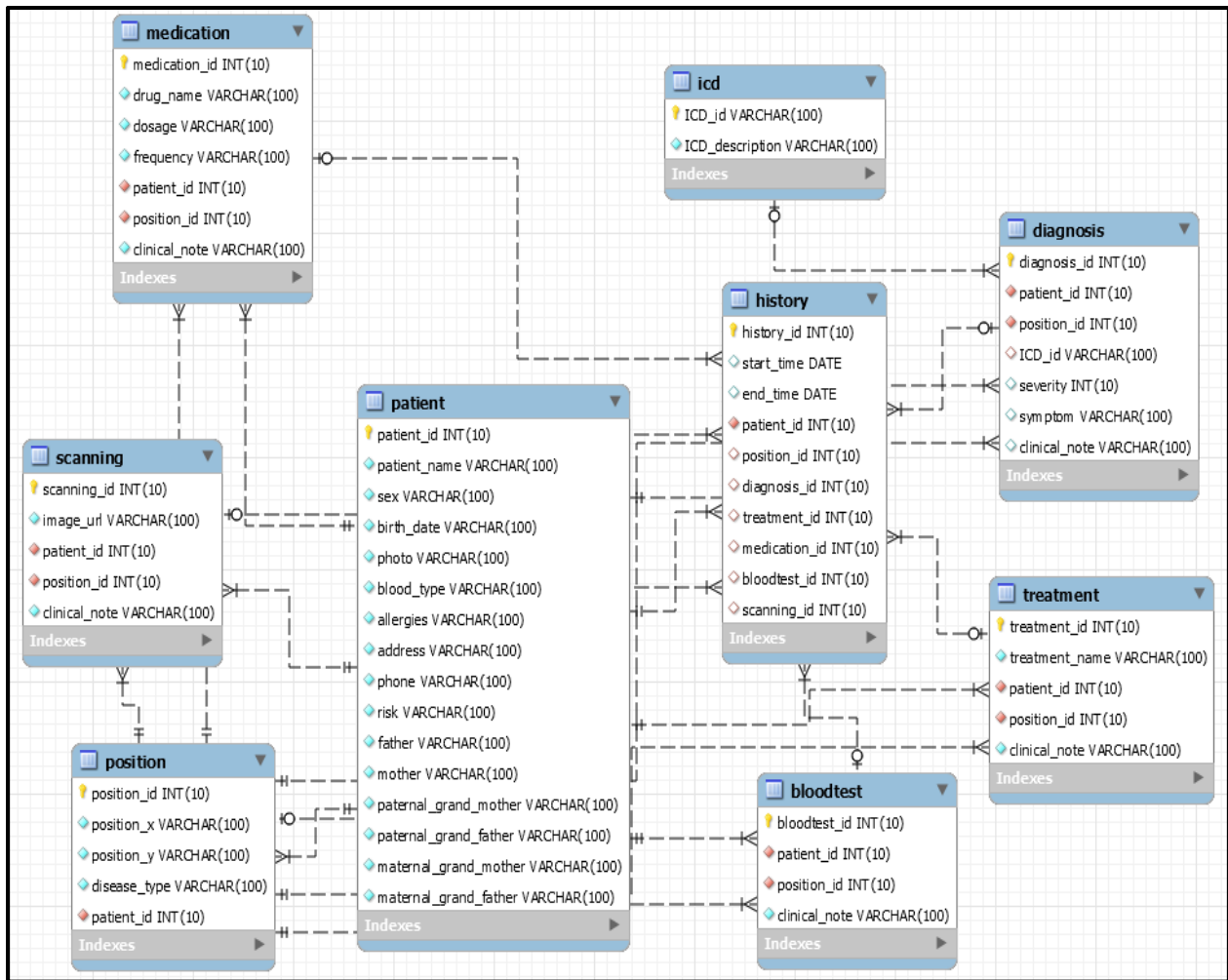


Figure 3.19: Entity-relationship model of our database.

3.3.2 Benefits of Web-based System

In the old days, most of the previous conventional EMR systems worked on the base of desktop software. But in recent years, web-based EMR systems have been providing a new way to store, display, and share medical observations. These systems can be very useful not only for caregivers, but also for patients and their relatives/friends to monitor and communicate important

health information (long-term goal). In this section, we are to present some advantages with web-based systems.

- **Convenient:** Web-based system gives physicians an opportunity to access the system from anywhere with an internet connection at any time and allows physicians easily to add, insert, modify, update, and delete patient records just by using a simple web browser (e.g., Internet Explorer, Chrome, Firefox, and Safari).
- **Safe:** With traditional software, physicians save data on their computers, USB drives, or portable hard drives. This is not as safe as it sounds. These devices can be stolen, and computers are rarely backed up properly; it is unlikely that everyone's machines are up to date with the latest security patches and updates. But, with a web-based system, medical data are stored on secure, always updated, backed up daily enterprise-class servers in a state-of-the-art, highly-secure data center.
- **Everything together in one place:** A key advantage of web-based system is that all the data are centralized and accessible over the internet from any computer at any time because of the server is shared by these users and all the users can access this server simultaneously. You can get to it from anywhere.
- **Cross-platform:** Software used to only be available on certain platforms, e.g., Windows software, Mac software, Linux software, UNIX software. Web-based system works on any platform with a web browser and internet connection. Mac, Windows, and Linux are all supported.
- **Always using the latest and greatest:** Unlike conventional software that requires you to download and install updates yourself, web-based system can be updated automatically as

long as you are internet connected. Whenever you use web-based system, you are always using the latest and greatest version.

3.3.3 System Performance Optimization

Navigating through a large amount of graphical data with a simple web browser can be difficult. Since the data all reside on the server side, it is important for us to minimize the exchange of graphical data (e.g., charts, images) between the server and browser in order to maintain good application performance and to continue to offer a good user experience (UX). A combination of techniques such as caching and dynamic data upload can be used at runtime to solve this problem. Furthermore, it is better to try to render the graphic views or images on the client than sending large amounts of graphic data across the network between the server and the client.

To solve the problem mentioned above and improve the system's performance, it is necessary to design a graph container that can meet the following requirements:

- Parse the data and render a graphic view on the client side, rather than sending more graphic data across the network between the client and server.
- Minimize the exchange of data between the browser and server in order to maintain better system performance.
- Easily add, remove, or modify a particular data visualization module.
- Provide features at runtime to offer pluggable rules to compare data between observation types.

In our system, we have implemented the visualization engine in the client stub to reduce the graphic data exchange between the server and client, as shown in Figure 3.18. This plays an

important role in improving the system's performance and provides a better UX. Moreover, by using a combination of popular web technologies and libraries, such as HTML, HTTP Request (GET/POST), JavaScript, jQuery, JSON, D3.js, and other graphic components on the client side, we managed to make our system more responsive than conventional EMR systems.

3.4 Limitations

The main limitations of our system are listed below.

- Five categories of physiological systems are involved in our EMR visualization system to help user to distinguish diseases. But they are still too general and not enough to cover all diseases. For example, some health problems cannot be visually represented by using these five physiological systems, such as mental problem, skin cancer and others.
- Some functions are integrated in our system to allow users to enter, display and retrieve medical records. But our system does not have an analysis function to help users to analyze medical data. A good data analysis function can enable physicians to discover the insight of the data set to provide patients a better health care. This is one of our shortcomings.
- Only a limited number of 2D images are available in our system. For example, some diseases might be located at the back of the body, but our system only supports the front view of a 2D human body. Multiple 2D views (like back body) can help users to mark symptom locations more accurately.
- A patient's basic information is displayed in the user interface, such as personal identification information, basic medical profile and family medical history. But they are still too simple

and insufficient to know a patient well. For example, the history of infectious diseases is not showed in our system.

- As our goal is to propose a prototype, the security and storage were not handled well in this EMR. For example, the storage capability is not big enough and the database structure is too simple, which limits the scalability of the system.

Chapter 4. Discussion

In this chapter, we first to check if our system satisfies the requirements of EMR system we mention in Chapter 2. After that we present the comparison between our prototype system and other EMR systems. Finally, some comments and suggestions from medical professionals are also illustrated.

4.1 Requirements Check

In the Section 3.1, we have discussed requirements, components and evaluation criteria of our visualization prototype system. They are considered during our UI design. In the following contents, we discuss what we have achieved and what are still remains for future work.

Requirements for Medical Records posed by Hippocrates:

- **It should accurately reflect the patient's past disease history**

We have achieved this goal. The history record has been illustrated interactively and intuitively with a combination of icons and a timeline (Section 3.2.5).

- **It should indicate the probable cause of his/her disease**

This is not achieved in our system, although we have provided many functions, such as history record display, blood test result display and latest record display, etc. This is part of our future work.

Primary Components of Medical Records:

- **Personal Identification Information**

This information is organized and displayed in our system (Section 3.2.2).

- **Basic Medical Profile**

This information is organized and displayed in our system (Section 3.2.2)

- **Family Medical History**

This information is organized and displayed our system (Section 3.2.2).

- **Diagnosis History**

This information is displayed with icons and timeline in the history record (Section 3.2.5).

Several functions are provided in our system to quickly add and display diagnosis data, such as “add diagnosis” function, “show latest diagnosis” function and “display diagnosis history” function, as shown in Figure 3.8 (b) and Figure 3.9.

- **Treatment History**

This information is organized and displayed with icons and timeline (Section 3.2.5). Several functions are provided in our system to quickly add and display treatment data, such as “add treatment” function, “show latest treatment” function and “display treatment history” function, as shown in Figure 3.8 (b) and Figure 3.9.

- **Medication History**

This information is displayed with icons and timeline in the history record (Section 3.2.5).

Several functions are provided in our system to quickly add and display medication data, such as “add medication” function, “show latest medication” function and “display medication history” function, as shown in Figure 3.8 (b) and Figure 3.9.

Requirements of EMR:

- **Costs**

We used many open-source technologies and toolkits to reduce our spending, such as HTML, MySQL, JavaScript, D3.js and others. The running costs are also minor as users do not require any special equipment to access the system. Just a simple internet browser is enough for running this prototype system.

- **Legibility**

As the large number of medical data is displayed with intuitive, interactive and meaningful graphics and images, we suspect the readability to be good, but this needs to be tested formally.

- **Accessibility**

Web-based system gives users an opportunity to access the system from anywhere with an internet connection at any time and allows physicians easily add, insert, modify and update medical records just by using a simple web browser.

- **Storage**

Though we have increased the storage capability by using MySQL database, the memory space is still not enough for storing the full medical data of a health organization. In the future work, our system's storage capability can be increased through more advanced storage devices.

- **Security**

Since we put more focus on the visualization part, the security has not been seriously treated in this thesis. In the future work, we can improve the system security in several ways, such as installing the data service in data layer, deploying a firewall and controlling the accessibility.

Review Criteria of IV:

- **Functionality-** To what extent does the system provide the functionalities required by the users?

There are many functions provided by our system for adding and displaying medical records, such as “add diagnosis” function, “add treatment” function, “add medication” function, “add scanning result” function, and “show history” function. In addition, a quick navigation function was provided in our system. Users can click on a symptom location to navigate to the corresponding physiological system.

- **Efficiency-** To what extent may the visualization help users achieve a better performance?

Many different kinds of mouse events have been applied on the symptom location of human body to provide quick inputting and navigating. This allows users to quickly add, retrieve and obtain useful information in a short time. Moreover, icon-based history record visualization makes a user understand the patient medical history in a glance, which also improves user’s working efficiency.

- **Effectiveness-** Do the visualizations provide value? Do they provide new insight?

We have divided the disease into five categories of physiological systems. Users can easily and quickly understand the disease and discover the insight of it with the help of color attributes and physiological system images.

- **Usability-** How easily can users interact with the system? Is the information provided in clear and understandable format?

In our system, a clickable 2D human body is placed in the user interface to support good interaction. Users can click on the body to mark the symptom location and enter and show medical data. In addition, interactive timelines and icons are also provided to enhance the interaction between users and system. Moreover, meaningful icons can help users to understand the basic idea of the information in a glance.

- **Usefulness-** Are the visualizations useful? How may we benefit from them?

The location-based symptom visualization can be very helpful for physicians to treat trauma patients since they suffer from pain in multiple locations of body (comment from medical people). In addition, the timeline-based and icon-based history record visualization might be very useful in emergency room, because physicians can quickly retrieve and obtain the patient's previous medical history in a short time (comment from medical people). Furthermore, this system perhaps also can be used by patients and their relatives and friends, because they can easily access the system and understand the health problem with graphics-based and image-based visualization (comment from medical people).

4.2 Comparison with Other Systems

As we have mentioned in Section 2.3.6.1, information visualization systems can be compared by their interactive features. Interaction is an integral part of information visualization and contributes many benefits of EMR visualization systems. Many interaction techniques are implemented by the systems we have introduced in Chapter 1 and Chapter 2. Therefore, we use

the user intent model proposed by Yi et al. [107] to compare our system with other EMR visualization systems. This categorization focuses on “what a user wants to achieve” and describes an interaction technique by one of seven user intents (see below). In order to provide an objectively comparison, we use the model with 20 sub-intent categories which are referenced from [111]. The comparison result is shown in Table 1.

1) **Select:** *Mark a subset of the dataset as interesting.*

- To keep track of selected items for a short term while the visualization is changed
- To manage groups, for example adding or removing patients to groups

2) **Explore:** *Show a different part of the dataset.*

- To navigate in time (e.g., panning and zooming the time axis)
- To add or remove parameters to the visualization
- To add or remove patients to the visualization

3) **Reconfiguration:** *Rearrange the visual layout of the dataset.*

- By repositioning items manually (freely or by some constraints)
- By sorting items along an axis
- By other adjustments of an axis (e.g., alignment to a relative timescale, distortion to see some items in focus and some in context)
- By applying another technique to avoid occlusion (e.g., 3D camera movement)

4) **Encode:** *Change the way each item of the dataset is represented.*

- By switching to a different visualization technique or opening it in a new view

- By varying visual encoding (e.g., map outcome to item color, encode severity as item size)

5) **Abstract/Elaborate:** *Show less or more detail.*

- By abstraction of one or more parameters (e.g., abstraction of a series of temperature readings over 37.5C into a period of fever or subsuming different medication as beta-blockers)
- By temporal data binning (e.g., aggregate parameter values either by fixed time intervals or for as long as they have the same value)
- By showing details of items (e.g., in a tooltip)

6) **Filter:** *Show ore highlight something conditionally.*

- By patient status without considering time or development over time
- By development overtime like event sequences (e.g., surgery after stroke) or value trends (e.g., increasing cholesterol) without time constraints
- By time constraints (e.g., relapse within 3 weeks after discharge, surgery in May 2009)

7) **Connect:** *show related data.*

- To show patient/patient group relationship
- To brush items in other representations
- To brush items for other variables at the same point of time or of the same patient

Table 1: Comparison with other systems (compared by their interactive features).

							No:US2009/019283 A1	No:US2011/0161854 A1		
									<p>●: Full support</p> <p>○: Partial support</p> <p>×: No support</p>	
Our System	Lifelines	Lifelines2	KNAVE-II	Midgaard	VisuExplore	FiveWs				
●	×	●	×	●	●	●	●	●	Keep track	Select
×	×	●	×	×	×	×	×	×	Manage groups	
●	●	●	●	●	●	●	●	●	Navigate in time	Explore
●	●	●	●	×	●	●	●	●	Add/Remove parameters	
○	○	●	×	×	×	●	×	×	Add/Remove patients	
●	×	×	×	○	●	×	×	×	Reposition items manually	Reconfigure
●	×	●	●	×	○	●	●	●	Sort items	
●	×	●	●	●	●	●	●	●	Adjust axis	
×	×	●	×	×	×	×	○	●	Development with time constraints	
●	×	●	●	●	●	●	●	●	Switch representation technique	Encode
●	●	●	×	×	×	○	●	●	Vary visual encoding	
×	●	×	×	●	●	×	×	×	Parameter abstraction	Abstract/Elaborate
×	●	●	●	●	×	×	×	×	Temporal data binning	
●	●	●	●	●	●	●	●	●	Show details of items	
●	●	●	×	×	×	●	●	●	Patient status	Filter
●	×	●	×	×	×	●	●	●	Development over time	
×	×	●	×	×	×	●	×	×	Development with time constraints	
×	×	×	×	×	×	×	×	×	Patient/group relationship	Connect
●	×	●	×	×	×	●	●	●	Brush in other representation	
×	×	×	×	×	×	●	×	×	Brush in other parameters	

Although all systems are designed and implemented for interactive exploration, the depths and foci in respect to user intents differ as shown in Table 1.

The *Select* intent, marking some items as interesting, is supported by most of the systems. Selection is always considered as a way for users to perform additional manipulations on the selected data. Most of the systems, including our system, allow users to keep tracking of items in a short time when visualization is changed. However, as shown in Table 1, only Lifelines2 provides features to allow users manage patients' data in groups.

The *Explore* user intent plays an important role in most of the systems. Table 1 shows that all systems support navigation in time. Panning and zooming the time axis are the most popular interaction techniques for navigating. Some systems (e.g., Midgarrd, VisualExplore) do not allow users to add or remove patients and some systems (like Lifelines2 and Five Ws) allow users to add and remove patients. Our system recently only allows users to add patients.

The *Reconfigure* intent is to allow users to rearrange the visual layout of the dataset based on the chosen visualization method. This goal is well achieved in our system. Our system allows users reposition items (e.g., dragging icons), and sort items along time axis, and show items they wanted (filter functions). Other systems (e.g., Five Ws, Lifelines2 and US2011/0161854A1) also offer some functions to enable users rearrange items. But Lifeline does not achieve this goal.

The *Encode* user intent allows user to change the way the data is represented. This goal is well achieved by most of the systems. VisualExplore and Midgaard provide different visual representation techniques to display numerical data, such as line plot, semantic zoom chart and bar chart. Lifelines2 includes a histogram display and parallel coordinates plot. Our system also

uses different physiological systems to display different kinds of diseases and also applies color attributes and line plot to show blood test results.

The *Abstract/Elaborate* user intent plays an important role in the reviewed systems. As shown in Table 1, all of the systems provide functions to show details about items. Parameter abstraction and temporal data binning are always used to fit large data volumes in the display or make them easier to understand. Only Lifelines and Midgaard satisfy these two categories.

The *Filter* user intent can show or highlight something important to physicians, and this can help them quickly extract useful information. This interaction technique is very helpful because most of the EMR systems work with large number of medical data. Some systems (e.g., Midgarrd, VisualExplore) do not support good filter functions. Five Ws and Lifelines2 are integrated with advanced filter functions, and their search functions can highlight all items with an implicit relationship with the search term. Our system and two patents (US2009/019283A1 and US2011/0161854A1) are all satisfied two of the three categories. Although we have provided filter functions to users to extract history records, they are still too simple. In our future work, we should support more complex queries to search more detailed information.

The *Connect* intent, which is used to show related items, is not well supported by these systems. The search function of Lifeline shows that their medical data contains some relationships, for example, tests and medications are linked to diagnoses. In our system, all diagnoses and treatments and test results are linked to a specific location of human body. Five Ws systems and two patents (US2009/019283A1 and US2011/0161854A1) also linked health problem to body locations. However, the relationships were not well illustrated in other visualization systems.

Table 2: Comparison with other systems (compared by items).

Items	Our System	Lifeline	Lifeline2	KNAVE-II	Five Ws	Allscripts	No: US2009/019283A1	No: US2011/0161854A1
Clickable human body	Yes	No	No	No	Yes	No	Yes	Yes
Symptom location	Yes	No	No	No	Yes	No	Yes	Yes
Timeline	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Icon	Yes	No	No	No	No	No	No	No
Amount of text	Little	A lot	A lot	A lot	A lot	A lot	Little	Little
Navigation	By clicking human body	By using button	By using button	By using button	By using button	By using button	By clicking human body	By clicking human body
History record	With timeline and icons	With text in tables	With text in tables	With text in tables	With text in tables	With text in tables	Line trend segment	Line trend segment
Physiological systems	Yes	No	No	No	No	No	No	Little
Color attributes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Line plot	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Point plot	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mobile device	No	No	No	No	No	Yes	No	No
Interact with other systems	No	No	Yes	No	No	Yes	No	No

We also compared our prototype system with other EMR systems by items as shown in

Table 2.

Five Ws system [18], two patents (US2009/019283A1 [117] and US2011/0161854A1 [118]), and our prototype system all integrate a human body in the interface to provide body-based medical record visualization. In addition, our system and the two patents also allow users to click on the body to navigate more detailed health information. By contrast, other systems use buttons to navigate.

Most of the systems offer timeline-based medical record display. In addition to this, in our system, icons are also integrated into a timeline to provide icon-based and timeline-based history record display. Other systems mainly support text-based and table-based history record display.

By integrating body-centric data display and icon-based and timeline-based history record visualization, our system and the two patents (US2009/019283A1 and US2011/0161854A1) interface contain less text compared to text-based and table-based systems.

Almost all systems (except the two patents) use colors to indicate normal or abnormal health condition, and all systems offer line and point plots to show changing trends.

Different from others, our system and a patent (US2011/0161854A1) use some physiological systems to distinguish health problems and diseases.

Some systems can interact with other systems such as Lifelines2 and Allscripts. This should be considered in our future work.

4.2.1 Comparison between Five Ws and Our System

There are some similarities and differences between the Five Ws system [18] and our prototype system. Both of Five Ws and our system provide a body-centric medical data layout and allow users to click on the body to mark symptom locations. However, there are still some differences

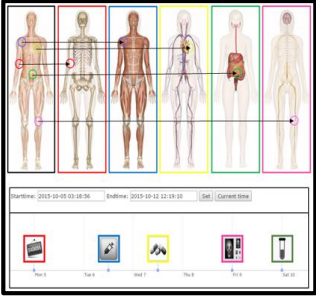
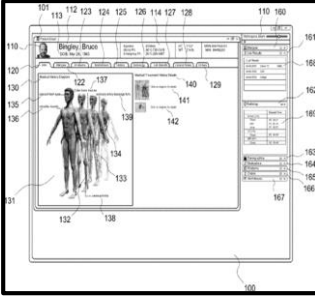
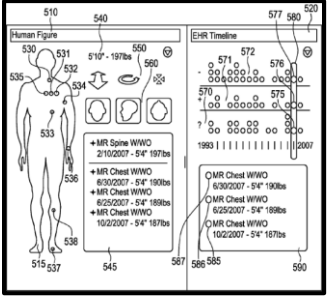
between these two systems. Our system allows users clicking on the symptoms to navigate to corresponding page for detailed information, but the symptoms in Five Ws are not clickable. And our system also provides five physiological systems (e.g., skeletal system, muscular system) to distinguish different kinds of symptoms. In addition, Five Ws still use lots of textual data to present medical records, but our interface integrates fewer texts. Moreover, our system offers timeline-based and icon-based history record display, but Five Ws applies many line segments to show this information.

4.2.2 Comparison between Two Patents and Our System

There are some similarities and differences between our system and two patents (US2009/019283A1 [117] and US2011/0161854A1 [118]). All these three systems use little text, and offer a clickable body to display medical records, but only our use color to convey structure and establish identity of our five physiological systems. The patent (US2009/019283A1) provides 2D and 3D human bodies, but our system and the patent (US2009/019283A1) only provide 2D body images. Our system and the patent (US2011/0161854A1) provide several physiological systems (e.g., skeletal system, muscular system), but the patent (US2009/019283A1) does not. Our system uses color to establish identity such as colored border to indicate which physiological system a symptom and medical history belongs, but other two patents have no use of color. Both our system and the patent (US2011/0161854A1) distinguish different diseases into different physiological systems; users can click on circles to see detailed information. However, in the patent (US2009/019283A1), the circles are only used to show outcome of diagnosis (e.g., good, bad, unknown). All systems provide timeline-based history

record display, but only our system integrates icons in the timeline. Table 3 shows the similarities and differences among three systems.

Table 3: Comparison between our system and two patents.

	Our system	No: US2011/0161854A1	No: US2009/019283A1
			
Human Body	Clickable & 2D	Clickable & 2D & 3D	Clickable & 2D
Color Attributes	Colored interface	Non-color interface	Non-color interface
Physiological Systems	Skeletal, Muscular, Cardiovascular, Digestive, Nervous	Skeletal, Muscular, Cardiovascular, Skin	
Symptom Location	Marked with colored circle; Users can click these circles for navigating.	Marked with circles. Users can click these circles for navigating.	Marked with circles. Users can click these circles to see outcome of diagnosis (e.g., good, bad, unknown).
History Records	Timeline- & Icon- based	Timeline-based	Timeline-based

4.3 Informal Feedback

To evaluate the usability of our prototype, we invited ten medical people (six physicians and four medical students) to participate in a simple informal survey. None had previous experience with our system and all medical people were familiar with current EMR systems. We gave each

participant a 10-minute tutorial on our system. The tutorial covered the idea behind the layouts, as well as the basic functions, including the insert and filter functions. Finally, we received some feedback from medical people to help us to improve our system in the future.

All participants felt that users could quickly and easily retrieve medical records by using our system, since the system provides different kinds of navigations such as symptom location-based navigation, icon-based navigation and others. In addition, three medical students also thought that even beginners could become familiar with it in a short time.

Eight medical people (six physicians and one medical student) showed great interest in the location-based symptom display, and five physicians among them thought it would be helpful for physicians to treat trauma patients since they suffer from multiple locations. However, the other two participants said that it may be not necessary for certain health problems like endocrine problems.

Seven participants (three physicians and four medical students) said that they liked the graphics-based visualization, as they can locate the desired information at a glance, and even beginners could likely retrieve data quickly. In addition, two medical students thought that the images and graphics would affect their mental map because it is easy to figure out where everything is. But on the other hand, three physicians said that they had already gotten used to texts and tables, and that graphics would make them uncomfortable.

All medical people believed that the five categories of physiological systems are helpful for obtaining a better understanding of health issues because they can illustrate problem in more detail. This could be helpful for health care providers to treat patients. Two physicians also thought that more user testing would be required to determine whether this categorization is

effective. Three physicians and two medical students also believed that these five categories are still too general, and that there should be more categories, such as endocrine system, immune system, urinary system and others.

All medical people said that our prototype system has provided a good way to display medical histories and also believed that the icon-based and timeline-based display could save them time compared to the text-based records they use. Four physicians and two medical students said that timeline is an interesting function and they liked it, because it can be zoomed and dragged which could help physicians to quickly retrieve history records. In addition, two physicians and two medical students also thought that the icon visualization provided an intuitive way to cognize the type of information. Moreover, two participants (one physician and one medical student) believed that the icon-based and timeline-based history records display could be used in the emergency room since it could help emergency room physicians to retrieve and obtain useful information they want in a short time

Two physicians believed that our system could be used by patients and their relatives and friends, because they do not have professional knowledge of medical science, but are desperate to more fully understand their illness. Patients' health problems could likely more easily be understood with the graphic-based, image-based visualization.

Chapter 5. Conclusion

A medical record is an important document including all the data of a single patient's medical history and care. The record contains information on past and present conditions, diagnoses, treatment, clinical notes, and laboratory tests. It is compiled primarily to assist physicians and other healthcare professionals in treating patients.

Before computer technologies were highly developed, patients' medical records were recorded on paper. However, with the rapid development of science and technologies, paper-based medical records have been replaced by electronic ones, known as EMRs. Today, EMRs are widely used in healthcare organizations and have many advantages, including the fact that they can store large amounts of information and are easy to search, more secure, and less expensive.

However, conventional EMR systems have not met their expectations or achieved their full potential. The large amount of medical data is always displayed with too much text, boring tables, and unfriendly navigation. It is challenging for users to obtain useful information in a short time period. One possible solution, intuitive user interaction to visualize EMRs, has not been well explored yet.

We presented an interactive visualization prototype system to enhance the usability of medical records. This system is implemented on the base of a client/server framework. It provides users with an opportunity to access the system from anywhere they can connect to the internet, at any time, with a simple web browser. In addition, it is integrated with an easy navigation through graphics-based and interaction-based visual representation. Our system

features a clickable two-dimensional (2D) image of a human body in the center of the user interface to provide a novel way to visualize medical records. The symptom locations are labeled with colored circles on the 2D human body and are used as the starting point of the navigation. Users can easily add, insert, and retrieve the medical records by merely clicking on symptom locations. Furthermore, the display of history records and blood test results is also improved. To provide intuitive and interactive visualization, we use timelines and icons in the history records. For blood test results, the system applies different colors to indicate normal or abnormal indices of test results and uses line graphic to monitor the trends of specific indexes.

Finally, we got some pertinent suggestions and comments from medical people to help us improve our system in the future.

5.1 Contributions

Some contributions of our research can be summarized as follows:

- Our system is integrated with a graphics-based and image-based interface to provide an intuitive visual representation of health data.
- Five different categories of physiological systems (e.g., skeletal, muscular, cardiovascular, digestive, and nervous systems) are applied in our system to help users better understand the disease.
- A clickable 2D human body is placed in the center of the interface to provide good interaction between users and system. In addition, our system provides an easy navigation for retrieving data by clicking on the symptom locations.

- Our system provides a novel way to display history record by integrating timeline and icons. Users can easily and quickly retrieve and obtain useful records with the help of meaningful icons and a powerful filtration function.

5.2 Future Work

Although we have proposed a novel way to interactively visualize medical records, there are still ways in which we can deepen our research and improve our existing system. We may take the following considerations into account for our future research.

- More physiological system categories can be added to cover a wider variety of diseases.
- A 3D human body can be applied to enhance the visualization and interaction. By using 3D rather than 2D, users can accurately view any and all components of the human body, such as joints, organs, and others. Consequently, the symptom locations can be marked more accurately in a 3D body.
- Multiple 2D views (e.g., front body, back body) can be used in our future study to provide more accurate symptom location information.
- A connection of multiple symptom locations can be established if they influence each other. This will provide a better understanding of the cause of diseases, as each symptom does not occur in isolation; there are connections between them.
- Real medical data can be applied in our future research. Even though we have consulted and got feedback from medical doctors and medical students, we have not obtained real patients' data.

- Storage capability and security should be handled well. More professional database structure and better security should be supported by our system.

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Publications by Author

"Medical Record Visualization Based on Symptom Location of 2D Human Body", Yongji Jin, Won-Sook Lee, lecture presentation in NextMed/MMVR22, April 7 - 9, 2016, Sheraton Los Angeles Downtown Hotel, Los Angeles, California.