A Design and Implementation of an Electronic Physician Orders Entry System

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Abstract

The main objective of this project is to design and implement a physician order entry application for an electronic patient record system applying usability concepts. This application can improve the quality of care for patients by reducing redundant paper work, eliminating the task of order transcription and preventing medication errors. In order to achieve this goal, we had to go throughout the software development life cycle: planning, designing and implementing. The main application was an order entry module, but other tasks such as physical exams and discharge summaries are supported. A heuristic evaluation was performed by evaluators with knowledge of human-computer interaction and usability engineering. The results of this evaluation generated important information about usability problems that served to redesign the user interfaces of the modules. These evaluations demonstrated the importance of the concepts of usability and the main role the heuristic evaluation plays on the system.

Resumen

El objetivo principal de éste proyecto es diseñar e implementar un prototipo que maneje órdenes médicas electrónicamente tomando en cuenta los conceptos de usabilidad. Esta aplicación podría incrementar el desempeño en el trabajo de los doctores y enfermeras en el área de la salud y cuidado de pacientes, reduciendo los procesos redundantes, eliminando las transcripciones de órdenes y reduciendo los errores de medicamento que son típicos de sistemas de record de pacientes de papel. Para alcanzar ésta meta, tuvimos que pasar por un proceso de planificación, diseño e implementación. El sistema principal se basa en un módulo de entrada de órdenes médicas, pero otras tareas como exámenes físicos y la preparación del resumen del alta se realizan en un módulo de revisar y documentar récords de pacientes. Después que el sistema fue implementado, una evaluación heurística fue realizada con evaluadores/as con conocimientos de interacción humano-computadoras e ingeniería de usabilidad. Los resultados de esta evaluación produjeron información valiosa en términos de los problemas de usabilidad que sirvieron para el rediseños de los módulos. Estas evaluaciones demostraron la importancia de los conceptos de la usabilidad y el desempeño de la evaluación heurística y su real utilidad antes de poner un sistema en un escenario real.

To my mother:
I wish I could find the right words to describe the strong energy my heart feels for you. Hopefully someday time will set us up at a parallel destiny, and I'll be able take care of you as much as you took care of me.

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List of Acronyms

BWH	Brigham and Women's Hospital
CIS	Clinical Information System
Cs	Consults
Dx	Diagnosis
EPR	Electronic Patient Record
EOES	Electronic Order Entry System
HCI	Human Computer Interaction
HIPAA	Health Insurance Portability and Accountability Act
I/O	Intake / Output
IOM	Institute Of Medicine
IS	Information System
IV	Intravenous
Lb	Laboratories
PC	Personal Computer
PDA	Personal Digital Assistant
Rx	Medications
Tx	Others
UPRM	University of Puerto Rico-Mayaguez

Conceptual Definitions

Usability Engineering

Usability is a part of the system acceptability, which is when a system satisfies all the needs and requirements of its intended users. It applies to every aspect of the system with which a user interacts. The usability is based on five principles:

1. Learnability – The system should be easy to learn.
2. Efficiency – A high level of productivity is possible, the system should be efficient to use.
3. Memorability – The system should be easy to remember.
4. Errors – The system should have a low error rate, and in case of errors should be easy to recover from them.
5. Satisfaction – Pleasant to use, the system should gain the user acceptance.

Heuristic Evaluation

Heuristics are usability principles or 'rules of thumb', with which a product/ system design should be guided from. The heuristic evaluation in the context of this document is based on the following ten user interface design guidelines:

1. Simple and Natural Dialogue	The computer concepts should be as simple as possible.
2. Speak the Users' Language	Terminology should be user oriented and not system oriented
3. Minimize User Memory Load	Users should memorize the less possible.
4. Consistency	Keeping standards in all actions performed by the system
5. Feedback	The system should provide the user relevant information at all times.
6. Clearly Marked Exits	Provide for the user a way out in all situations.
7. Shortcuts	Users should be able to jump to the location the really want to deal with.
8. Good Error Messages	Suitable and user oriented messages.
9. Prevent Errors	The system should have mechanism to prevent errors
10. Help and Documentation	Text and tools to aid the user at all times in their interaction.

CHAPTER 1

INTRODUCTION

In the medical industry, patients' records are sacred documents. Medical records contain a patient's medical history, and information sometimes for future care. Government regulations like the Health Insurance Portability and Accountability Act of 1996 (HIPAA) require that these records be handled with the utmost confidentiality. In order to manage the thousands upon thousands of patients' records, some hospitals rely on sophisticated electronic medical records systems. In the past few years there has been some increase in the demand of computer-based record systems [Holbrook01]. However, the large majority of the hospitals in USA and PR do not have computer-based patient record systems. One of the main barriers hospitals are facing for acquiring them is their cost. The investment for these systems it's still relatively expensive since it has to be a very secure, reliable and stable system. Another barrier in the adoption of computer-based record systems is user resistance. It is very hard for humans to adapt to drastic changes. Physicians and nurses with experience with paper-based record systems may have difficulties adapting to a new computer-based system.

Computer-based patient record systems could solve many of the problems that are related with paper-based record systems. First of all, having a computer-based system can solve the problem of physical space for storing paper records. Computer-based systems can speedup the access to the records. Another thing with a Computer-based system would be the improvement of quality in the documentation. Also it can simplify the tasks of looking up the patient's clinical information. The maintenance of security and integrity of data would end up in a safer and more reliable environment. Computer-based systems would improve patient safety by checking for allergies, drug interactions and would help reduce prescription errors. In addition, paper-based systems can improve the satisfaction of clinicians [Rodríguez02a].

Most hospitals in Puerto Rico keep their patient's records in paper-based forms. This paper-based record systems have some flaws: just one person can have access to the record at certain time; looking up the patient's clinical information can be time consuming; nurses have to perform transcriptions of physicians orders which takes time an is error prone.

Most of these problems can be solved by switching from a paper-based system to an electronic record system. Such tool would provide the user with interfaces that would make the processes of entering, editing and saving data into a database easier for the users. This system also, would give flexibility by allowing more than one person to access the record of a certain patient in a faster and more efficient way, eliminating the need of transcribing orders. All of these advantages would definitely reduce the amount of errors because of unreadable text, and the problems with stored files.

Some of the computer-based patient record available in hospitals in USA and PR do not provide the user with appropriate tools to interact with them. Some of these systems are command prompt and text-based and do not provide any kind of tutorial, help or search tool for the user. Understanding the user's needs is essential in the design of usable systems. This understanding can be achieved by identifying and analyzing the users' tasks and by getting users involved in the conceptual design process

An Order Entry system is a component of a computer-based patient record system that allow physicians to enter clinical orders electronically (i.e. medications, laboratories, diagnostic studies, consults. Much of the immediate interest in the system is focused on medications order entry and its potential to reduce medication errors. Order Entry systems also have been shown to reduce costs by reducing the incidence of adverse events. These systems offer these benefits because it goes well beyond merely replacing paper orders with electronic ones. It makes relevant information available at the time of ordering and applies rules-based on logic to help the physician make optimal ordering decisions.

The main objective of the project described in this document was the design and implement a physician order entry module for an electronic patient record system. The system was tailored to the needs of physicians at the Centro Cardiovascular of San Juan and the Advanced Cardiology Center of Mayaguez. However, its functionality, simplicity and usability lends itself for any hospital in PR and USA. Once installed at a hospital the system will serve as a test bed for conducting medical informatics an nursing informatics studies on the used of electronic patient record systems.

The next chapter provides background information on existing computer-based patient's records and order entry systems. Chapter 3 provides a detailed description of the system. In Chapter 4 the methodology and results of the heuristic evaluation conducted to a prototype of the system are discussed. Finally, Chapter 5 presents the main conclusions of the project and some suggestions for future work.

CHAPTER 2

PREVIOUS WORK

In the field of health care mistakes can result in huge disasters, on the other hand since the release of the Institute of Medicine's report "To err is human," [Kohn99] there has been growing interest in electronic order entry as a tool for reducing medication errors in hospitalized patients. With electronic order entry, clinicians place orders through computer workstations linked to databases containing patient-specific clinical information and error-prevention software. A number of studies have demonstrated the potential of these systems to substantially reduce doses and medication errors [Bates98]. As a result, a large consortium of private and public purchasers is advocating implementation of electronic order entry at hospitals caring for its more than 30 million employees and beneficiaries [Milsten00]. According to their estimates, electronic order entry would prevent over 500,000 serious medication errors in the United States if fully implemented nationwide [Birkmeyer00].

While few dispute the potential for electronic order entry to reduce medication errors, many question whether hospitals can afford it. Electronic order entry requires that hospitals make substantial investments in information technology. On the other hand a huge asset would be achieved from reduced errors and increased efficiency.

In the next section various issues related with the acquisition and operation of electronic order entry systems are discussed. In section 2.2 various studies of electronic order entry systems are presented.

2.1 Electronic Order Entry Systems (EOES)

An Electronic Order Entry System (EOES) is a computer application that accepts physician orders electronically. It replaces the physician writing orders on an order sheet or prescription pad. The current interest in a physician order entry systems has been stimulated mainly by the Institute of Medicine (IOM) report, *To Err Is Human: Building a Safer Health System* [Kohn99]. The IOM report concluded that between 44,000 and 98,000 people die each year from adverse events in hospitals [Lindo99]. The ensuing public attention and debates about how best to move quickly to improve patient safety keep highlighting EOES as one important tool that is currently not much used in our health care system.

The value of EOES goes well beyond merely replacing a paper order with one entered on a computer. The biggest benefits of EOES is that the computer makes relevant information available at the time of ordering (patient allergies, costs of medications, etc.) and applies logic to help the physician in making the optimal ordering decisions. For example, the computer can check and issue a warning that the patient is allergic to a drug being ordered, point out possible interactions between the ordered medication and other drugs the patient is taking, or calculate the dose based on patient weight and age, thereby avoiding lack of information about proper dosing or arithmetic errors. Given the heightened interest in patient safety, the working definition of EOES used in the industry

must include decision support and other features that can add value during the ordering process.

Three major benefits of EOES are the reason this technology is such a hot topic today:

1. Much of the immediate interest in patient safety is focused on medication errors, which are reported to be the largest cause of adverse hospital events. Previous studies have shown that ordering is the largest source of medication-related errors and that computerized ordering can reduce these errors [Bates99].

2. There is a compelling case to be made that EOES can reduce costs. One study found that adverse drug events increased hospital length of stay by 1.74 days [Classen97]; another estimated that preventable adverse drug events increased stays by 4.6 days [Bates97]. Beyond the costs associated with adverse events, other research has shown reduced utilization of services, length of stay, and overall costs, when EOES is implemented [Tierny93]. One early adopter of EOES estimated that it saved more than $1 million in medication costs by guiding physicians to effective lower doses or alternative medications for just four medications [Teich96].

3. EOES can be a powerful tool for reducing unnecessary variation in care by encouraging recommended practices and increasing responsiveness to new information about patient status. One hospital found that when a decision was made to change the drug of choice, it achieved 94 percent compliance with the new recommendation in one week using computerized decision support [Teich96]. Though the current focus is on inpatient EOES, more information about errors and adverse events in ambulatory care is

emerging, and new products are being developed to provide similar benefits in ambulatory care. We should expect a broadening of attention and focus on computerizing prescription management very soon.

If EOES is such a great idea, why is it not used more widely? The first papers relating benefits of physician ordering were published years ago, and some computerized ordering systems have been in use for a decade. Three primary reasons for the lack of diffusion are:

- Many hospital executives and most vendors of hospital information systems believed that physicians would not use computerized ordering.
- Demand was low, few products were developed, and those that were available were not perfected.
- Technical and process complexities of implementing EOES translate into significant investment with no guarantee of success.

2.1.1 Issues in the Adaptation of the EOES

Health system executives and trustees are recognizing that they need to take a hard look at EOES as one element of an overall patient safety strategy. The first question they are likely to ask is, “If inpatient EOES is such a good idea, why have so few hospitals implemented it to date?” For many years, hospital executives and most vendors of hospital information systems believed that physicians would not use computerized ordering. Given the ample evidence that EOES can improve patient safety and the

growing number of implementation success stories, the time is right to start challenging those assumptions.

A second reason for the slow adoption was that, because demand was low, few EOES products were developed, and those that were available were not perfected. The current increased interest and sense of urgency to address patient safety are stimulating the vendor market to improve existing products and introduce new ones. The complexities of the undertaking both technology and process and the resulting cost and risk are another reason for lack of adoption in the past and residual hesitancy today. However, both patient safety and cost pressures present a clear imperative, and advances in technology, combined with greater industry experience, have increased the likelihood of success. Implementing EOES takes a concerted effort, strong will, perseverance and a significant capital investment. Organizations are starting to understand the need to learn as much as possible from the pioneers who preceded them, to increase their speed of adoption and likelihood of success. The early adopters who contributed much of what we know about the power of EOES were mainly academic medical centers with homegrown systems and residents performing most of the order entry. The success stories now also include community hospitals and community practice physicians. All tell the same story: Successful EOES is not a technology implementation but a redesign of a complex clinical process integrating the technology at key points to enhance and optimize ordering decisions.

2.1.2 Importance of Technology

EOES is not a stand-alone application but rather a module of a clinical or hospital information system. Hospitals best positioned to adopt EOES are those with clinical systems from a vendor that offers EOES capability. Any institution replacing a hospital information system should carefully evaluate EOES features as part of the decision. Because of the complexity and long lead times for developing this application, few if any organizations today are likely to choose the path of internal development. When examining EOES applications, it is necessary to differentiate between basic products focused on capture and transmission of the order ("order communication") from those designed for use by physicians (EOES), which incorporate interactive decision support and check for allergies, drug interactions, correct dosage, etc. Certain "must-have" features ensure improvements in medication safety and quality, as well as other features that are important for ease of use and implementation. Scenarios depicting typical clinical situations are effective tools for determining the system's fit with workflow and acceptability to physicians. Physicians themselves are the best judges of what technology will help them. Purchasers also can benefit from contacting reference sites that are similar to theirs, both in terms of environment and objectives. Beyond features and functions, EOES needs to be highly responsive exhibiting quick response time to speed physician ordering sessions, and reliable, to support the critical ordering process without interruption, 24 hours a day, seven days a week.

2.1.3 Resistance to the Change

There have been cases where physicians were not happy with computerized ordering systems and at least one was highlighted in a much cited publication [Massarro98]. Even in successful implementations, there have been concerns and actual experience that computerized ordering takes more time [Tierny93, Teich96]. Many of the initial implementations were in teaching hospitals where residents did most of the order entry. Whether staff and community physicians will adjust, has been an open question with little documented experience. However, as illustrated in the case studies discussed later, there are growing numbers of success stories; including some from community hospitals and others involving staff physicians in direct entry. Despite this, many executives still feel that "our physicians are not ready to accept computerized ordering." Given ample evidence that computerized physician ordering improves patient safety, we think it is the right time to start challenging assumptions about physician readiness.

2.1.4 Managing the Complexity and Cost of an EOES

Computerizing orders also requires standardizing practices that are mostly local and, for physicians, also personal. Today, the urgency of addressing patient safety provides a clear imperative for hospitals to focus on being successful with EOES, rather than debating its importance. In California's current, often precarious, fiscal environment, hospital executives understandably scrutinize costly projects more critically and expect substantial value. However, successful organizations have achieved significant cost savings from EOES, in addition to gains in patient safety and quality, to offset the

investment. Technology options are greater and more affordable now, and there is more industry experience in what it takes to be successful. Leveraging these advantages in a focused, high-profile effort should decrease the cost, time and risk, and increase the likelihood of success. All hospitals have limited money for both capital investment and for funding operations. That makes costs a very important consideration in any change making it one of the most challenging barriers to sub pass.

2.2 Studies Using Electronic Order Entry Systems

At Boston Brigham and Women's Hospital (BWH) is a 720-bed urban teaching hospital with a set of integrated clinical applications and implementation experience, which has provided much of the research on the power of physician order entry to avoid adverse order-related events and improve overall quality of care [Teich96]. Clinical decision support is a core component of the EOES, part of a conscious effort to intervene at the point of care during the ordering process in a number of ways:

- Provide extra information to the order (e.g., dose related test results).
- Prevent adverse events (20 times a day an order is written that is contraindicated because of patient allergy; 400 orders each day are changed in response to a computerized alert or warning [Kabcenell98].
- Suggest better care processes.
- Standardize when desirable (e.g., by suggesting dose and frequency for a medication order).

- Enable more cost-effective care (e.g., by suggesting a lower-cost medication of equal efficacy).

Decision support incorporated into the ordering process includes order sets and templates, specially designed screens for every type of order (medication, blood products, etc.), extensive use of defaults based on a study of 300,000 orders, automatic displays of relevant patient information and alerts, warnings and other ordering suggestions [Teich96, Metzger95].

One of the major challenges of EOES is capturing structured orders without adding to the time taken by the manual order writing process. EOES was designed to include several different modes for physician ordering: assisted mode (prompts for required fields) and quick mode (free-text order interpreted into a standard order). The latter feature, which was thought to be critical for physician acceptance, is actually used a very small percentage of the time (about 8 percent of all orders [Kabcenell98]. Most physicians prefer orders sets or templates (35 percent of all orders [Teich96, Metzger95]. Although EOES is not time neutral, many of the design features combine to keep additional time to a minimum.

EOES rollout at the (BWH) was very carefully orchestrated and included pilots, pauses and efforts to minimize dual processes [Teich96, Metzger95]. The system was designed to require only orientation-style training, and head-nurses were stationed in clinical areas for a period of weeks as each clinical area went live. Users also received a lot of attention after rollout, retraining, coaching and proactive feedback loops leading to fixes. Physician leaders of system development also believe that tailoring the system to

accommodate the differing information flows of different clinical situations was critical to integrating EOES into the work processes of every unit and clinical service. Some of this study highlights are:

- Boston Brigham and Women's Hospital has provided much of the research evidence demonstrating the power of computerizing physician ordering.
- The homegrown EOES was designed to require only orientation-style training, but head-nurses were available on nursing units as the system was rolled out.
- Different types of clinical decision support are designed into the system to improve clinical practice and speed physician entry time.

In New York at Montefiore Medical Center, the quest for a Clinical Information System (CIS) that supported Physician Order Entry started more than 10 years ago [Davis 99]. The goal then, as it is now, was to improve the quality of patient care and reduce medication errors by getting the physicians in front of better information at the time of ordering. Unfortunately, financial issues and state project approval slowed the process for years. However, in 1994 Montefiore resumed the CIS selection project with a project team of more than 25 people, including 12 physicians. The team focused on both inpatient and outpatient ordering requirements.

Then Montefiore decided to take a phased implementation approach to build a solid clinical information database before installing EOES. The first phase included patient registration, laboratory and radiology results reporting, and pharmacy profiles. In Montefiore it was believed that this clinical information was as the call the "carrot" the physicians needed to move to the next phase that included EOES. Separate physician

groups were established to address the design requirements for front-end or end-user view, laboratory ordering, radiology ordering, pharmacy ordering and automated rules and alerts. Once the initial designs were done, there were physician retreats to test workflows and information flows using different patient scenarios. Designs were refined, and then selected high-priority system enhancements were made by the vendor. It was this level of involvement; commitment and communication that helped physicians understand what they would be gaining from using the system. For these units there has been a 100 percent transition from paper order forms to online physician order entry for all types of orders. After the inpatient units are done, the ambulatory centers will follow. An important lesson learned from this implementation is to listen constantly and respond to feedback. Some of this study highlights are:

- Inpatient units using EOES have 100 percent online ordering by either residents or attending physicians.
- EOES can be very successful but takes a long time to make the transition. Implementation in phases can bring early wins and start to demonstrate benefits.
- Success requires physicians with expertise, physician involvement in the design and implementation, and ongoing support to build on new functionality.
- Constant communication and responsiveness to feedback are critical for success. Multi-year projects easily can lose support and momentum if progress is not communicated effectively.

At Florida Sarasota Memorial an electronic patient record (EPR) was identified as a key project to support its strategic plan initiative to develop an integrated care delivery system [Ash 98]. Their philosophy was "technology does not improve patient care, the redesign of the care workflow does." Examples of how this philosophy was put into practice include:

- Clinician-led project team with Information Systems (IS) support. Typically, the reverse is followed, where IS leads the project and has supporting Physician and Nursing committees.
- "Shock to the Future" implementation approach. This approach encompassed a physical redesign of the patient care units to accommodate the process and technology changes brought about by the project. This approach balanced "high tech" with "high touch." Sarasota saw the redesign as necessary to create an environment where caring and computers were totally compatible, thus eliminating one more barrier to using the computers.
- Continuous physician education that Sarasota coined as "Adopt a Doc." Nurses provided round-the-clock assistance to physicians new to learning the system to help change ordering patterns and minimize resistance.

In May, a total of 338 physicians, out of a medical staff of 640, accessed the system from on campus, home and the office. Out of the sample selected, 80 percent encompassed admitting physicians. They placed orders that account for about 28 percent of all orders placed in the system. These numbers are expected to increase over time. Functionality supported by this new system includes order entry/results retrieval, patient

charting, checking for duplicate orders, computerized physician order templates, and rules-based clinical decision support. The hospital concludes that physician use of an automated resource management tool has a major impact on a hospital's bottom line because physicians control a high percentage of variable costs. The project has achieved several qualitative benefits, including improved chart accuracy and access, enhanced data security and increased physician, patient, and staff satisfaction. Although not measured, the hospital also believes that medication errors are reduced due to increased legibility of orders and reduced duplication of tests. Sarasota is continuing to make enhancements to the system and provide more patient care information electronically to the clinicians. They saw this as one very important step toward their original 1994 goal of an electronic patient record. Some of this study highlights are:

- Significant cost savings and qualitative benefits were achieved as a direct result of this initiative.
- Using the "Shock to the Future" approach allowed changes involving physical environment, process, and technology to be done in concert with care delivery as the overall focus.
- Clinician-led project management approach was the key to gaining physicians' acceptance.
- Changes are not immediate and resistance should be expected. Staff needs ongoing training to assimilate changes to the care delivery process.

The Regenstrief Institute of Indiana was the first institution to study computer-based patient record systems in a randomized trial [McDonald 96]. Physician orders entries, rather than notes, were targeted because orders have more obvious structure (making computer entry easier) and offer more opportunities for shaping practice patterns through computer feedback. As is the practice when any RMRS application is developed or enhanced, rapid prototyping with continual user feedback was used to incorporate user experience with integrating order entry into routine tasks. This requires periodically pulling back and redesigning screen or workflow, when users indicate that the initial approach is inadequate. When the order entry system was initially deployed, users provided clear feedback that the original design for constructing order instructions using the multiple-field approach was much too cumbersome. The system was removed from use and a better solution was rapidly implemented and installed. Evolution of the order entry interface has now incorporated hundreds of changes, most of them stimulated by user feedback. Decision support incorporated into order entry includes order sets, passive disease or symptom-based choice lists, comments embedded in choice lists with links to reference materials, dynamically constructed choice lists, counter-detailing messages, cost data, past results data relevant to the order, blocking rules (to redirect ordering intent), standing orders and guidelines/suggested orders. Some of the principles used to guide design of decision support are that reminders must be actionable, concise, patient- and task-specific, available at the time of care, constructed to make the task easier, reasonable at least one third of the time and appropriate to the available data. Both formal and informal processes result in new decision support logic. Users are encouraged to

submit suggestions for new rules and enhancements to existing ones, each of which is reviewed for feasibility. The physician development team published some of the earliest research validating the effects of inpatient EOES on resource utilization. In a randomized controlled clinical trial, they examined the charges for each admission and for specific categories of orders. The physician teams using EOES generated charges that were 12.7 percent lower; bed charges, diagnostic test charges and drug charges were also reduced. Reductions of similar proportion were found for hospital costs, and the mean length of stay was 0.89 days shorter [Tierny99]. Some of this study highlights are:

- EOES provided some of the first research evidence that computerizing physician ordering can reduce costs.
- Rapid prototyping, heavy user involvement, and unwavering executive support over many years are all viewed as critical to success.
- Regenstrief is known for its deep experience with clinical decision support and for institutionalizing processes for physician feedback.

2.3 Medical Informatics Research at the University of Puerto Rico-Mayaguez Campus

Researchers at the University of Puerto Rico, Mayaguez Campus, have conducted various studies about computer-based patient record systems. Two early prototypes served as the based for subsequent prototypes and usability studies. The first prototype was a nursing documentation system developed by Emily Angarita [Angarita97, Rodriguez97] that provided interfaces for documenting medication administration, vital

signs, Intake/Output and daily assessment. The second prototype was an application for handling inpatient/outpatient laboratory orders developed by Rafael Muñoz [Muñoz97]. The works done by Angarita and Muñoz served as the base for the development of a prototype of an electronic patient record system [Murillo03]. This prototype provided separate windows allowing to view the patient's record and to enter physicians' orders. The main purpose of this system was for physicians to be able to lookup patient demographic information, medication, lab results, diagnostic studies results, primary care problems lists, physical exams, notes and summaries of preview patient visits. Also Physicians were able to add new problems and notes, order medications, laboratories, and diagnostic studies, request consultation with other physicians, and discontinue medications.

This prototype was used to conduct a study of physicians' interaction with text-based vs. graphical-based electronic patient record systems [Rodriguez02a, Murillo03] and another study of physician interaction with paper-based vs. graphical-based patient record systems [Rodriguez02b, Murillo03]. The first study [Rodriguez02a, Murillo03] followed a within-subjects experimental design. Nineteen resident physicians with experience using the text-based system were asked to perform eleven tasks on each of the systems. All the participants were given a short tutorial session on the graphical system before they performed the tasks and when they finish on both systems the participants were asked to fill out a subjective user satisfaction questionnaire.

The study demonstrated that a graphical-based interface could significantly reduce the time it takes physicians to complete typical tasks on an electronic patient

record system in comparison with a text-based interface. Overall, user's satisfaction shows the participants more satisfied with the graphical-based system than with the text-based system.

The paper-based vs. graphical-based patient record systems study [Rodriguez02b, Murillo03] followed a within-subjects experimental design. Seventeen resident physicians participated in the study of which, only five of them had some experience using electronic patient record systems. They were asked to perform twelve tasks that involve looking up the patient's and documenting the patient's record and ordering medications, laboratories and diagnostic studies. All the participants were given a short tutorial session on the graphical-based system before they performed the tasks on this system. After performing the tasks on both systems the participants were asked to fill out a subjective user satisfaction questionnaire. Some of this study highlights are:

• The study demonstrated that physicians make the transition from a paper-based patient record system to a graphical-based electronic patient record system with minimal training.

• Increasing the overall time to complete typical tasks and with significantly more satisfaction with the new system.

CHAPTER 3

DESCRIPTION OF THE APPLICATION

3.1 Introduction

This chapter describes the interfaces that the physicians will use to view patients' records, document the patients' condition, and enter orders for the patients. The interfaces are developed using the JAVA programming language. The patients' records are kept on an MS SQL database that is accessed through the physicians' interfaces.

The physicians' interfaces consist of two modules: a module for reviewing and documenting records, and a module for entering physicians' orders. For the purpose of this project the following interfaces were developed: the physical exam and discharge summary interfaces of the reviewing and documenting module and all the interfaces of the ordering module. A general description of the reviewing and documenting module is presented in the next section with special emphasis on the physical exam and discharge summary interfaces. The ordering module is described in section 3.3.

3.2 Login and Patient Selection Interfaces

Health Insurance Portability and Accountability Act known as HIPAA impacts all areas of the health care industry and was designed to improve the efficiency of health

care by standardizing the exchange of administrative and financial data, and to protect the privacy, confidentiality and security of health care information. In compliance with the HIPAA law only authorized users will have access to the modules. In order to use the system a user is required to enter a login name and password on a login window like the one shown on figure 3.1. In case the user trying to login is not an authorized one, another window will inform the user that her/his user name or password was not registered by the system (see figure 3.2).

Figure 3.1 User Login Interface

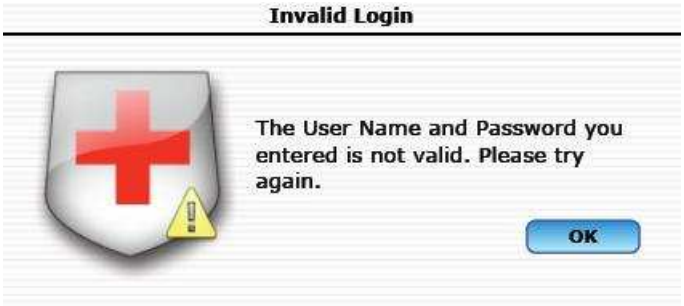

Figure 3.2 User Name and Password Not Valid Message Window.

After the user authentication is confirmed, a window with a list of patients like the one shown in figure 3.3 will be displayed. By default, the list that will be displayed will be the one of the physicians' patients currently hospitalized. Each entry on the list indicates the patient's name and room number as well as various icons that indicate pending physicians order for the patient. A patient can be selected from the list by double clicking on its name or by clicking on its name a selecting the Open button at the bottom right position of the window.

Figure 3.3 Patient List Window

3.3 Reviewing and Documenting Module

After a patient is selected, the reviewing and documenting module window is displayed (see figure 3.4).

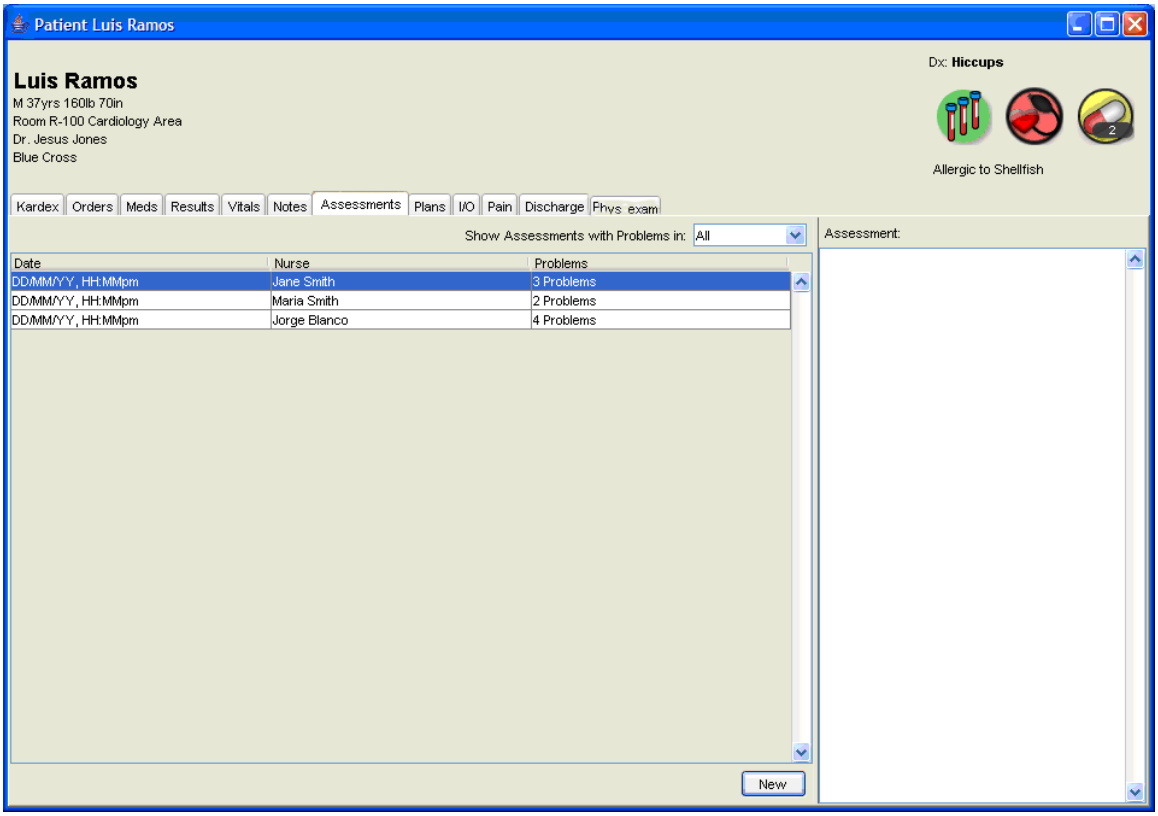

Figure 3.4 Reviewing and Documenting Module Window.

The name of the patient is indicated at the top left follow by relevant general information. The diagnosis and allergies of the patient as well as various icons that indicate pending physicians order for the patient are shown at the top right portion of the window. A set of tabs provides access to the user interfaces for reviewing and documenting the patient record. The orders tab provides a list of all the physician's orders and the actions taken to execute them. The Meds tab provides a list of all the medications prescribed for the patient with information on how, when and by whom they were administered. The results tab provides the results of diagnostic studies and laboratories. The vital signs tab provides a record of the vitals signs of the patient. The notes tab provides a list of all the notes that were generated by the health care professionals that

have intervened with the patient and have documented the condition of the patient. It also provides a means for writing new notes. The I/O tab provides a record of the patient's fluids balance.

The physical exam and the physician discharge tabs are described in the subsequent two sections.

3.3.1 The Physical Exam Interfaces

The physical exam tab allows physicians to enter a physical exam for a patient. When this tab is selected a window like the one shown in figure 3.5 is displayed. The physical exam consists of three forms that can be displayed on the right side of the window. The forms are selected form the list provided on the left side of the window. The first form (the default) is the Patient History Form. When this form is selected the window shown in figure 3.5 is displayed. This window provides text fields and check boxes for documenting the patient's health history.

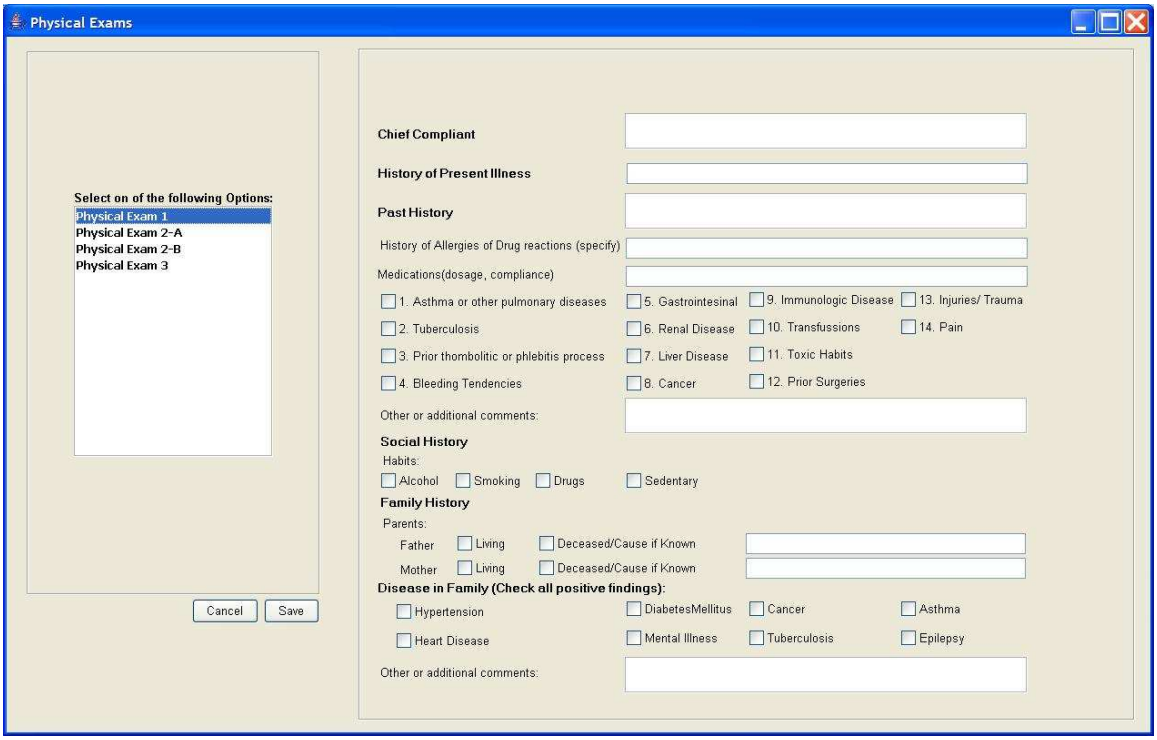

Figure 3.5 Patient History Form.

The second form of the physical exam is the Review of System Form (figure 3.6). When one of the checkboxes of this form is selected a text field area will appear on the right side of the checkbox label as shown in figures 3.7. The physician can use this text field to document on the corresponding selection.

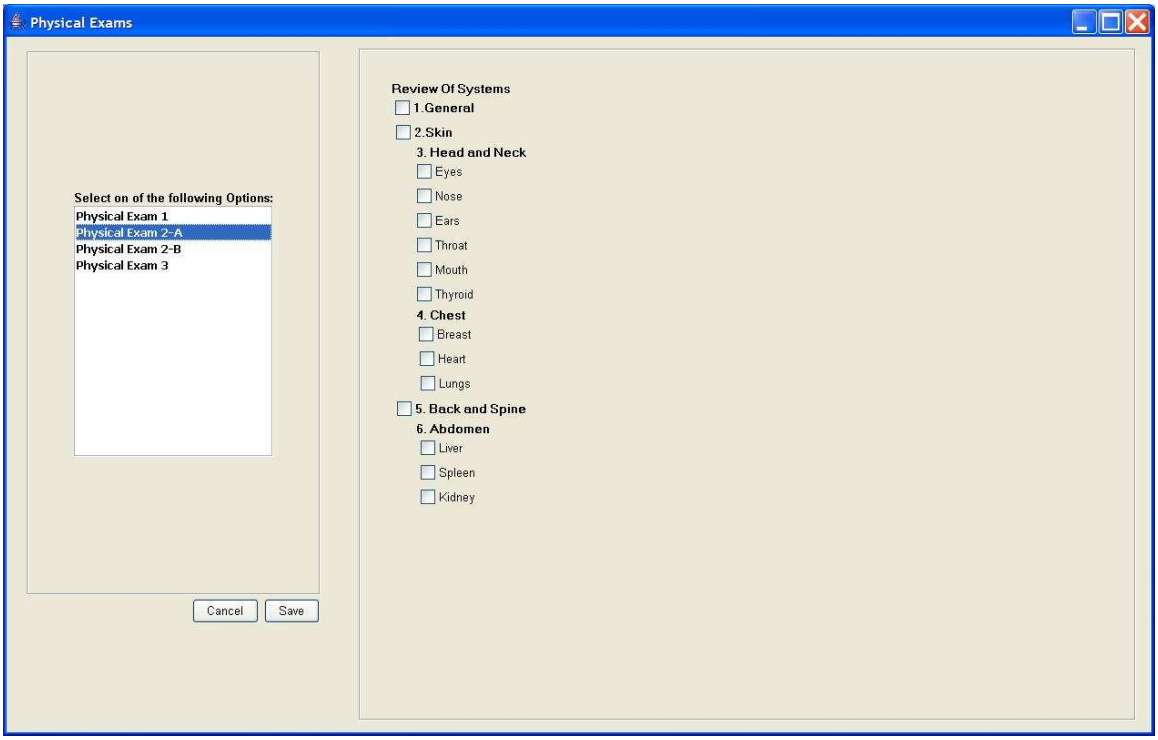

Figure 3.6 Review of Systems Form.

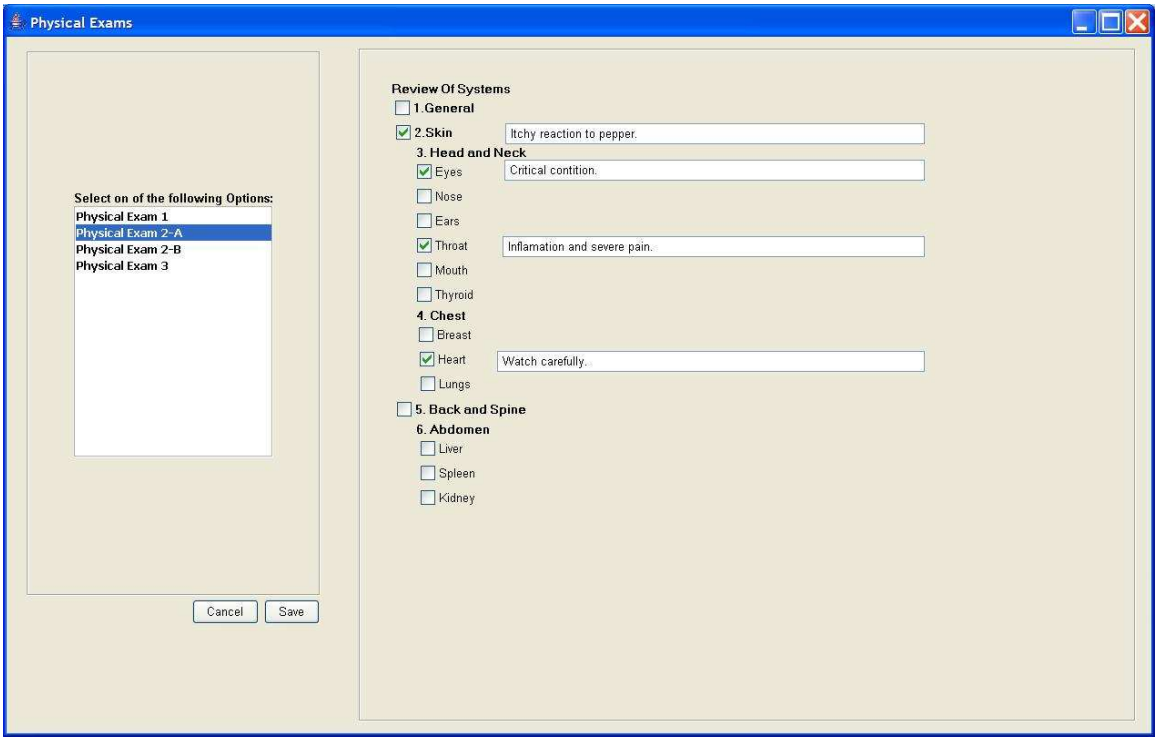

Figure 3.7 Text Field Displayed after a Checkbox is selected (Review Systems Form)

The third form of the physical exam tab is the Physical Examination Form (figure 3.8). This form provides a series of checkboxes for various examination systems and text fields for documenting the diagnosis impression and treatment plan. If an abnormal checkbox is selected a text field will appear for the physician to document on the abnormal condition (see figure 3.9).

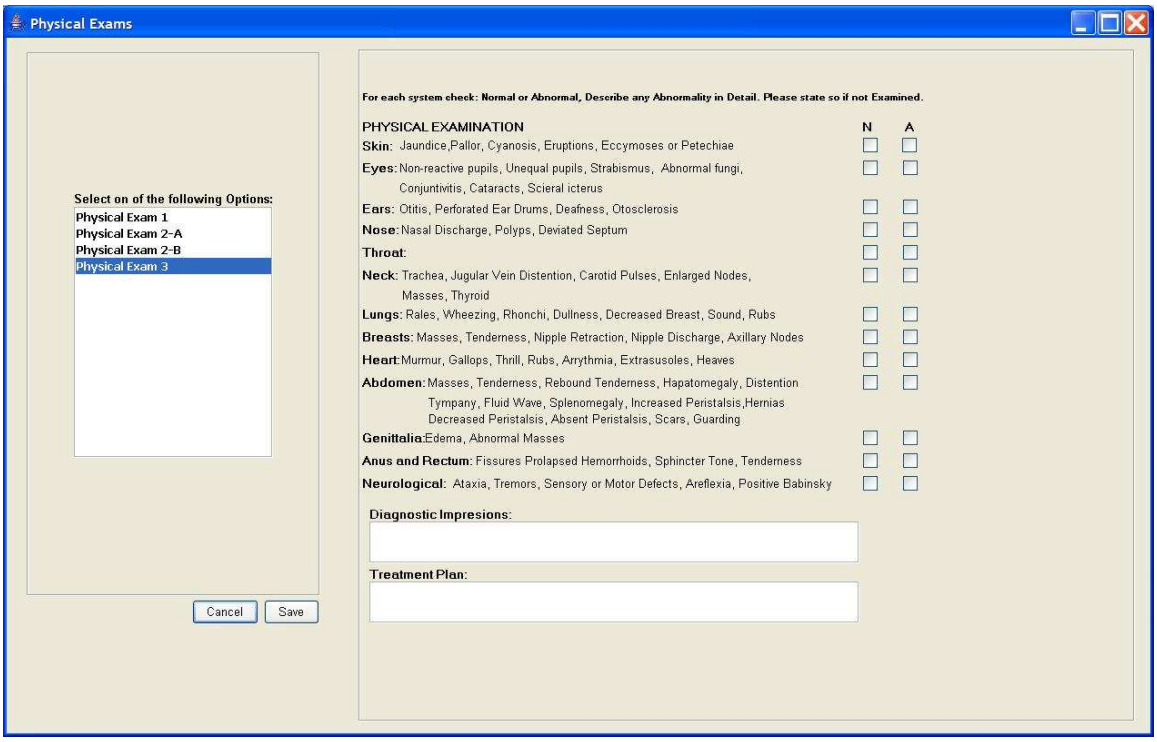

Figure 3.8 Physical Examination Form.

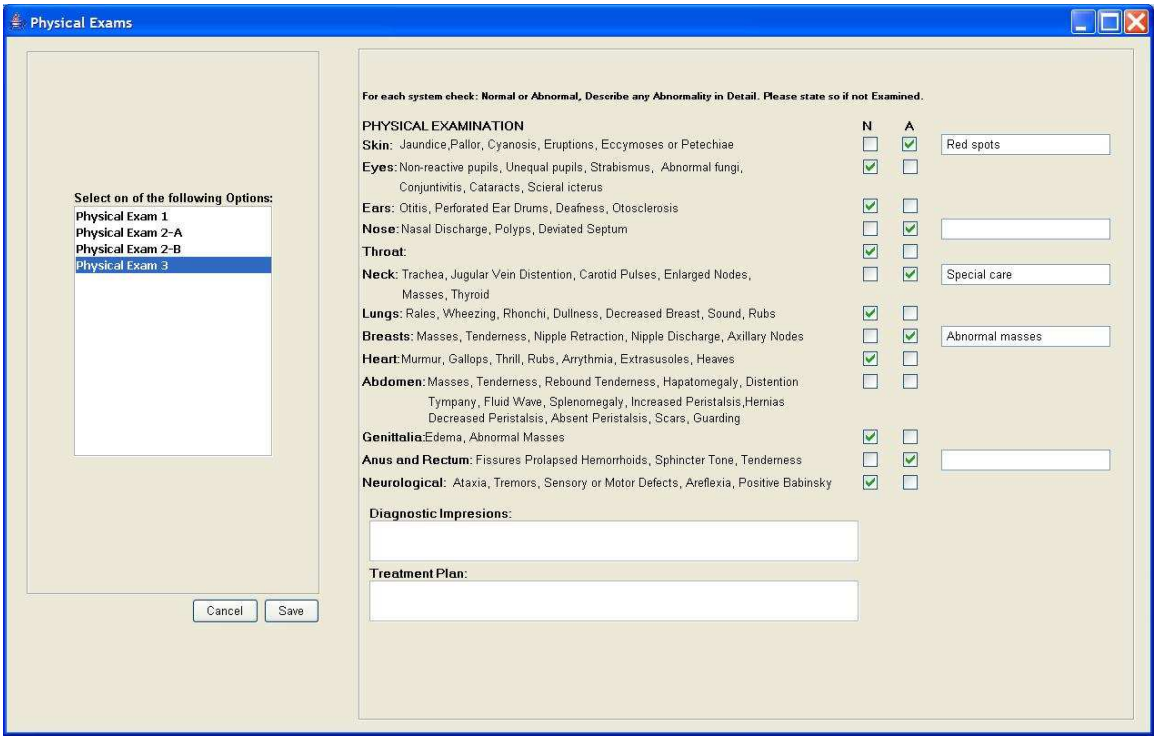

Figure 3.9 Text Field Displayed after an Abnormal (A) Checkbox is selected (Physical Examination Form)

3.3.2 The Physician Discharge Summary Interfaces

The discharge tab allows physicians to enter a discharge summary of the patient. It consists of two forms. The first form (the default tab) is the Patient History Form (figure 3.10). This form provides text fields and check boxes for indicating how the patient will be discharge from the hospital and what actions to follow upon discharge.

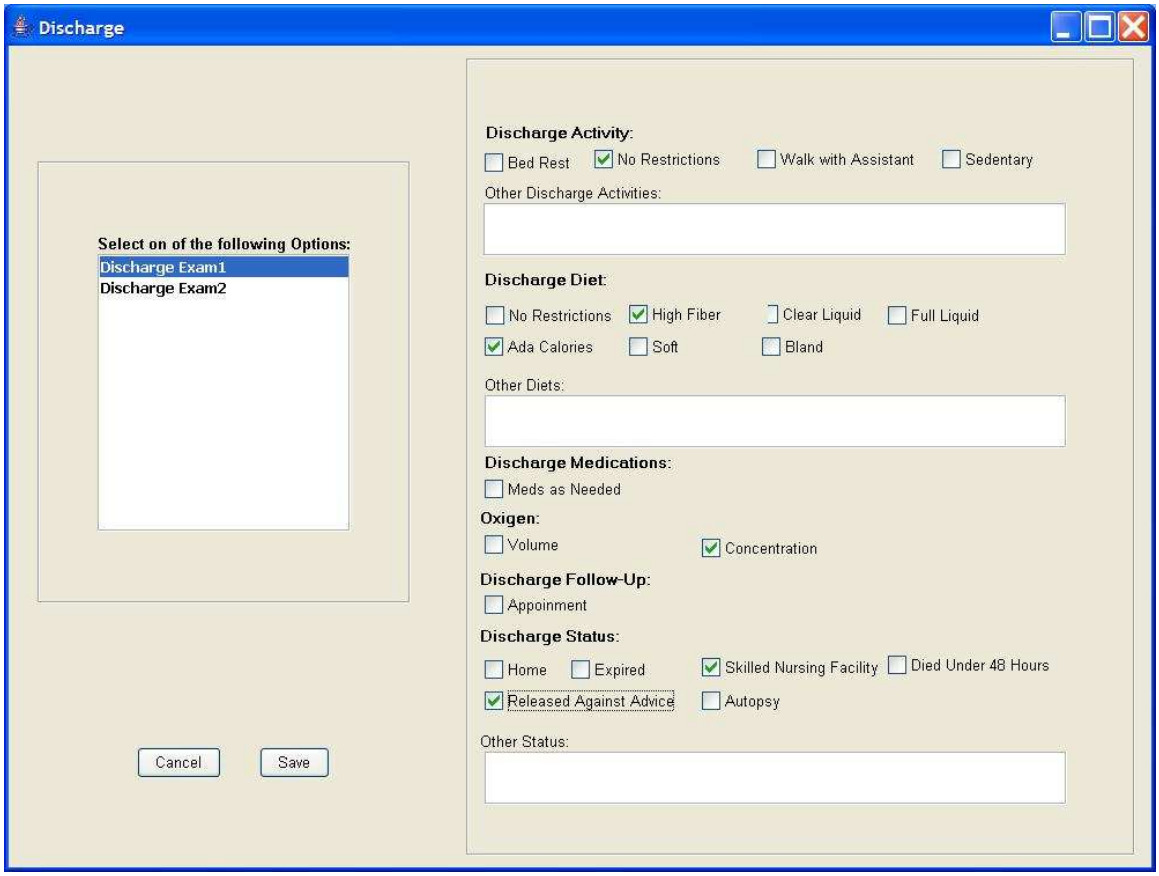

Figure 3.10 First Discharge Form

The second discharge form is shown in figure 3.11. It provides text fields for documenting a brief clinical history of the patient, pertinent findings of the physical exam, treatments to follow and problems identified. It also provides a mechanism for listing relevant laboratories and diagnostic studies. A list can be created on the right side of the center window by selecting a study or laboratory from the list provided on the left side of the center of the window and pressing the add button. An item from the list on the right can be removed by selecting it and pressing the Remove button.

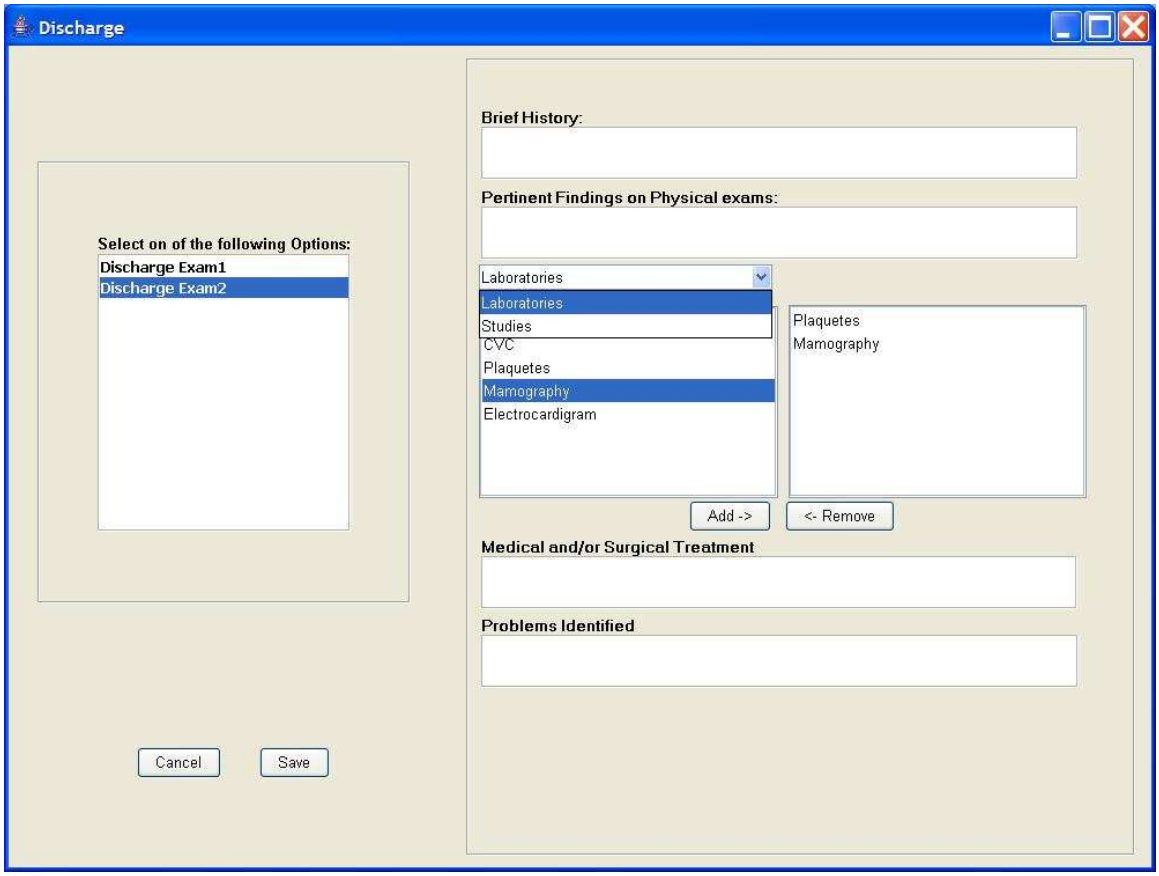

Figure 3.11 Second Discharge Form

3.4 The Physician Order Entry Module

The main interface of the Physician Order Entry Prototype shows the patient name, sex, age, weight and height at the top (See Figure 3.12). Below are several buttons that provide the physician various ordering options. These options are specifying a diagnosis (Dx), order medications (Rx), order laboratories (Lb), order diagnostic studies (Ds), order consults (Cs), and other orders or treatments (Tx). Each button displays a different interface at the left of the window below the buttons. At the right of the window a tree-like structure displays all the information that is generated by the physician as

he/she goes through the patient lookup. To provide a flexible interaction session, the information displayed can be hidden by topic. Thus, the user has the option of viewing all the information that has been generated or only the one that she/he wants to see by clicking on the specific category in the tree structure. An entry in the tree can be edited or removed by pressing the Edit or Remove buttons respectively. The orders are saved on the patient's record when the Order button is pressed. This action will clear the content of each category of the tree.

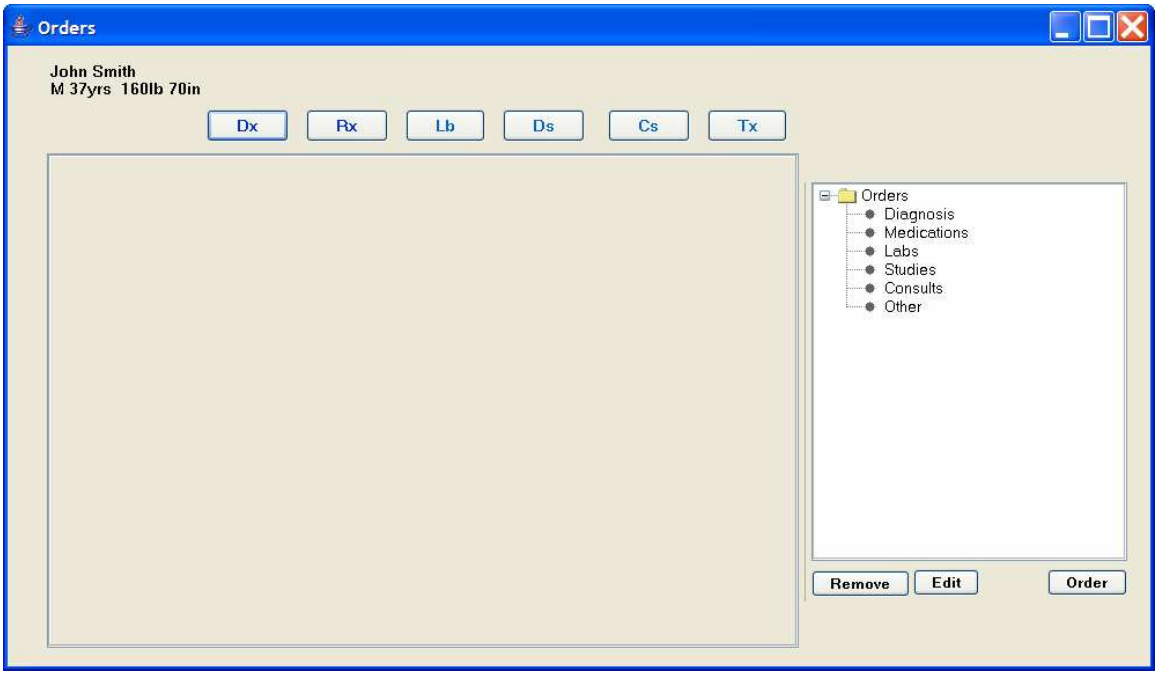

Figure 3.12 Physicians Orders Module Window.

3.4.1 Diagnosis Interface

When the Diagnosis button is selected, an interface with two lists is displayed at the middle left side of the window (See Figure 3.6). The list on the left corresponds to all diagnosis. A diagnosis can be added to the list of the right by selecting it and pressing the Select button. A text field is provided on top of the list on the left side with auto-complete properties to help the user do their search faster and more efficient. A diagnosis can be removed from the list on the right by selecting it and pressing the Remove button. The diagnosis selected will be reflected on the tree-like structure after the Ok button is pressed.

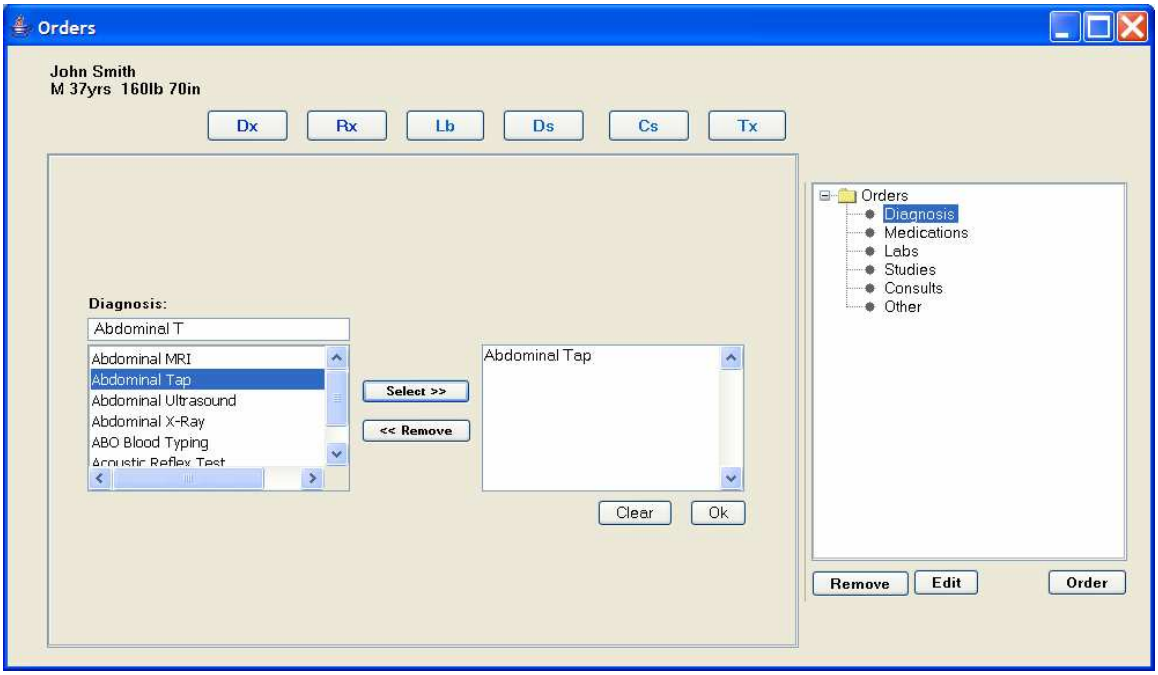

Figure 3.13 Diagnosis Interface.

3.4.2 Medications Interface

When the Medication button is selected, an interface with two lists will be displayed at the middle left side of the main screen (See Figure 3.8). The on the left corresponds to the physicians specialties in the field of health care. That list will default to the physician's specialty. When specialty is selected a list of common medications prescribed by physicians of that specialty appears on the list at the right side. Both list has an text auto complete field for facilitating the search of a specific item. As the name of the item is entered the lists adjust to show the items that match the text entered. Text fields are also provided to specify the medication's dose, route, quantity and details for administration. The Clear button clears up all the fields for ordering the medication while the Ok button makes the medication order to reflect on the tree.

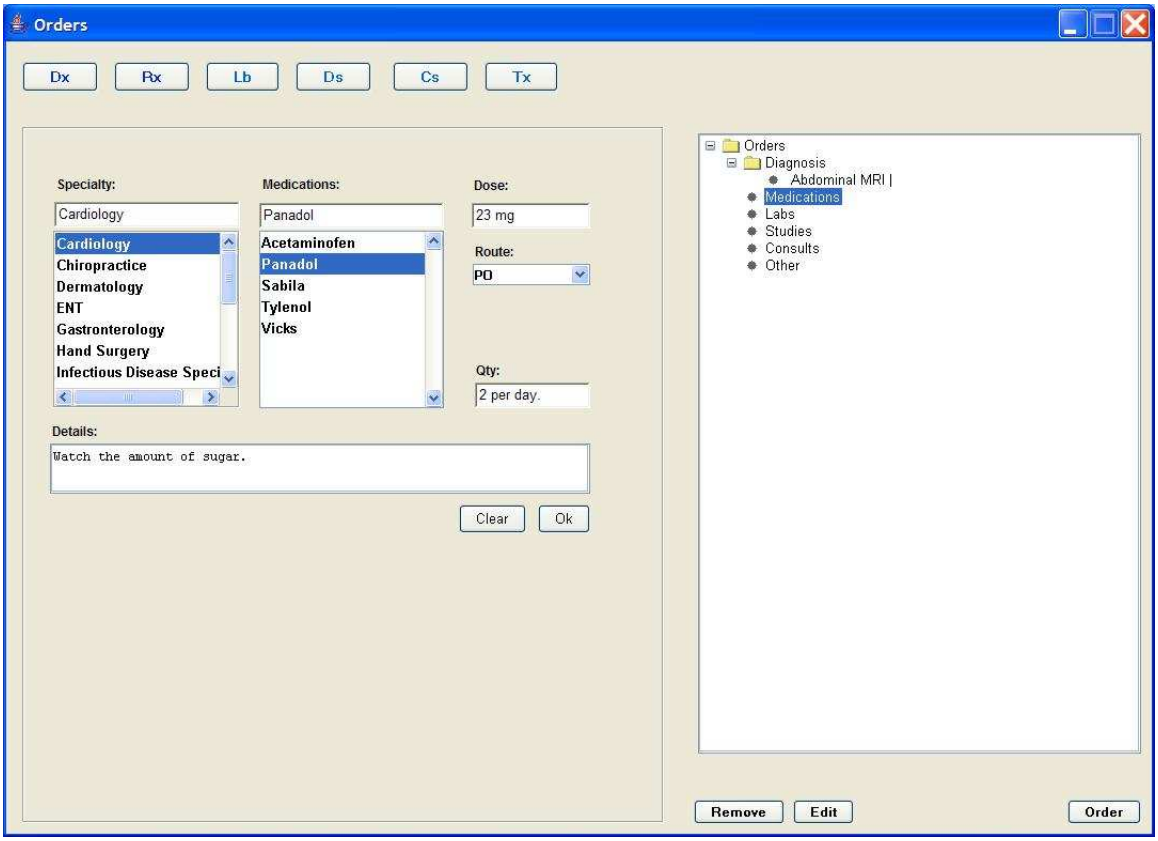

Figure 3.14 Medications Interface.

3.4.3 Laboratories Interface

When the Laboratories button is selected, an interface with two lists will be displayed at the middle left side of the main screen (See Figure 3.15). The list at the left correspond all the different categories of laboratories. When a laboratory category is selected the list on the right displays the laboratories corresponding to that category. Both lists have auto complete fields for facilitating the searches on the lists. At the bottom of the interface a text field is provided for the physicians to provide details on how the test

should be performed. The Clear button and Ok buttons have the same functionality as on the Medication interface.

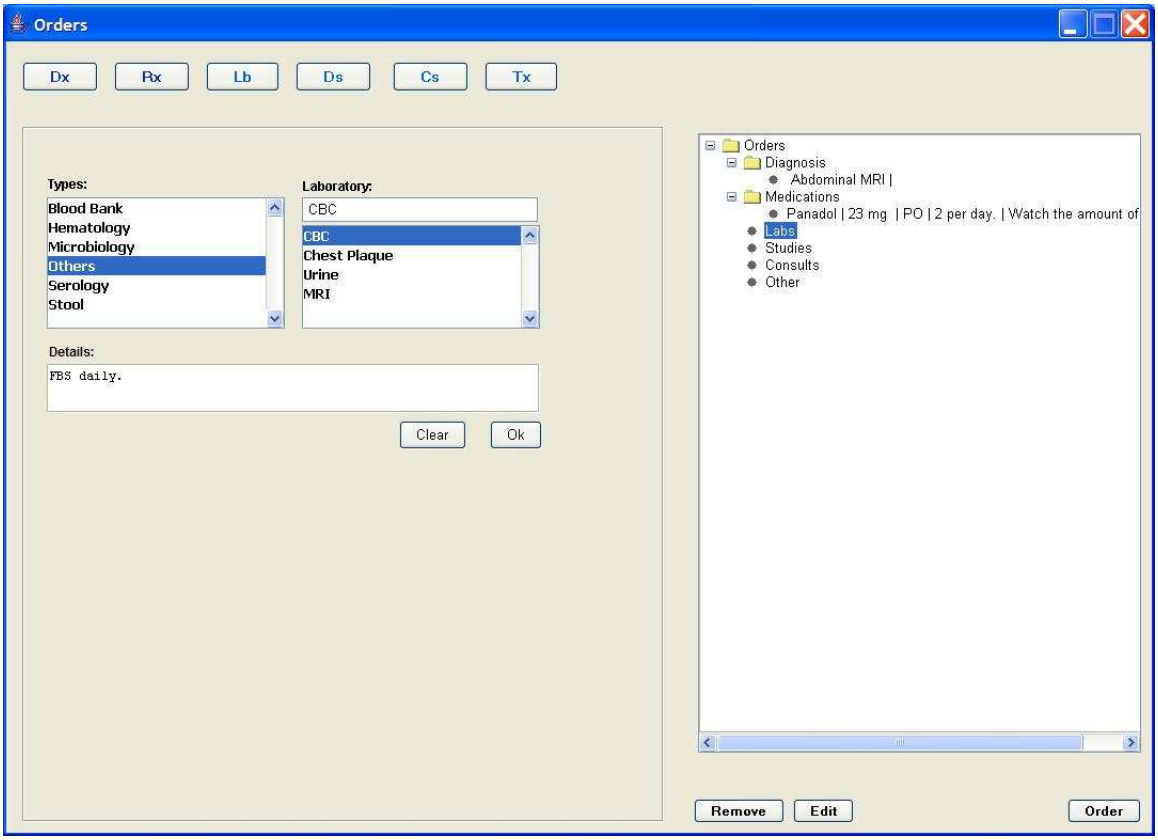

Figure 3.15 Laboratories Interface.

3.4.4 Diagnostic Studies Interface

The diagnostic studies interface is almost identical to the Laboratories Interface (See Figure 3.16). The main difference is that the list on the right corresponds to the categories on diagnostics studies and the list on the left to the studies corresponds to the selected category.

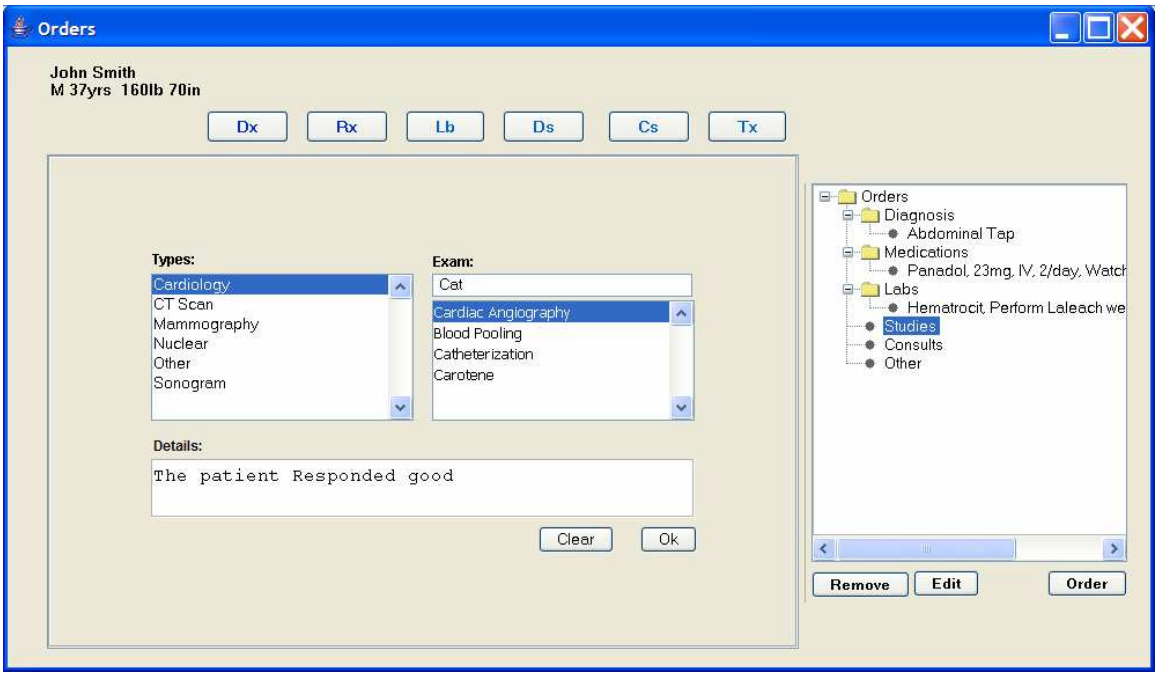

Figure 3.16 Diagnostic Studies Interface.

3.4.5 Consults Interface

The consults interface is also very similar to the Laboratories Interface (See Figure 3.17). For this interface, the list on the right corresponds to the physicians' specialties and the lists on the right to the names of physicians with that specialty.

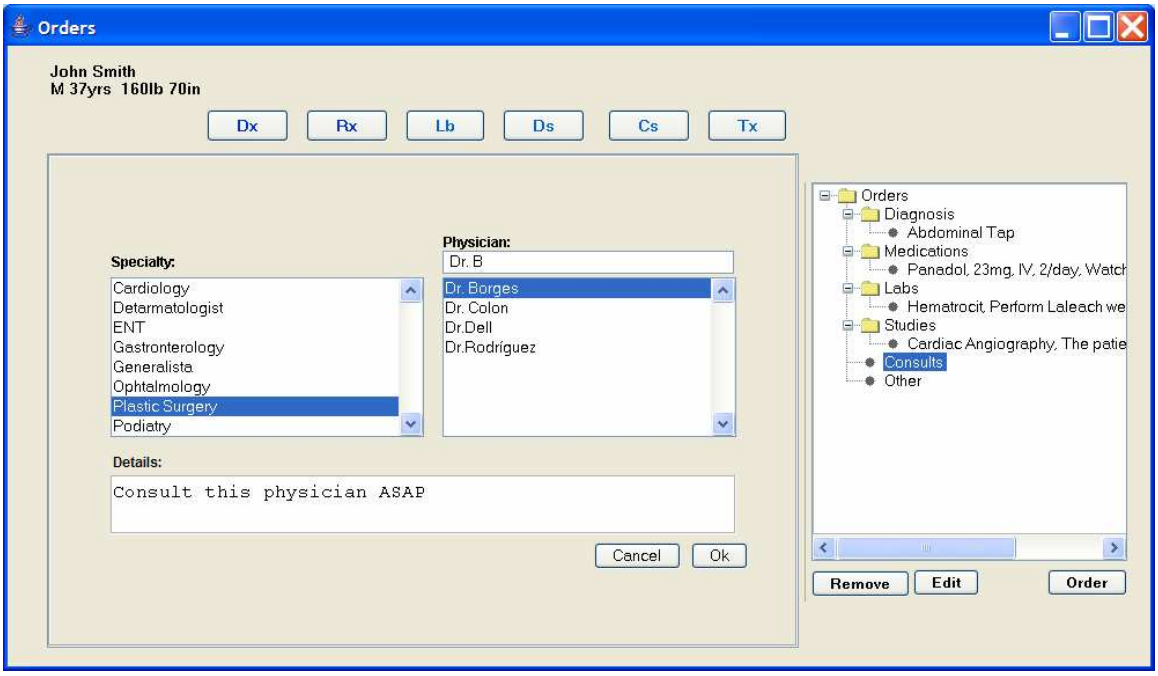

Figure 3.17 Consults Interface.

3.4.6 Other Orders Interface

The others interface is very different from the other ordering interfaces (See Figure 3.18). First, the interface has an I/O checkbox at the top of the interface allowing the physician to indicate if Intake/Output needs to be recorder. After that a text field is available for the physician to indicate if the patient needs any type of isolation from other patients and provide any other comment about it. Below are various radio buttons for specifying other orders. There is a text field at the bottom for specifying other kinds of orders. The Clear and Ok buttons have the same functionality as in the other ordering interfaces.

A few selections in form of radio button starting from the Hygiene to the Respiratory Therapy. Underneath each of the sections, the different options are provided for the physician to choose from, so to specify the detailed care the patient would need. Sections such as Hygiene, Ambulatory, Care of tube drainage, Physical Therapy, and Respiratory Therapy are provided for selection of the patients' treatment. As in other interfaces, a Text Area was placed at the bottom of the window for the physicians to write any kind of extra comments. The clear button will clear all the fields and reset the index of the list to 0. In the other, if the entry was correct, the physician will press the Ok button, and this will add all the data from this interface into the tree (See Figure 3.17).

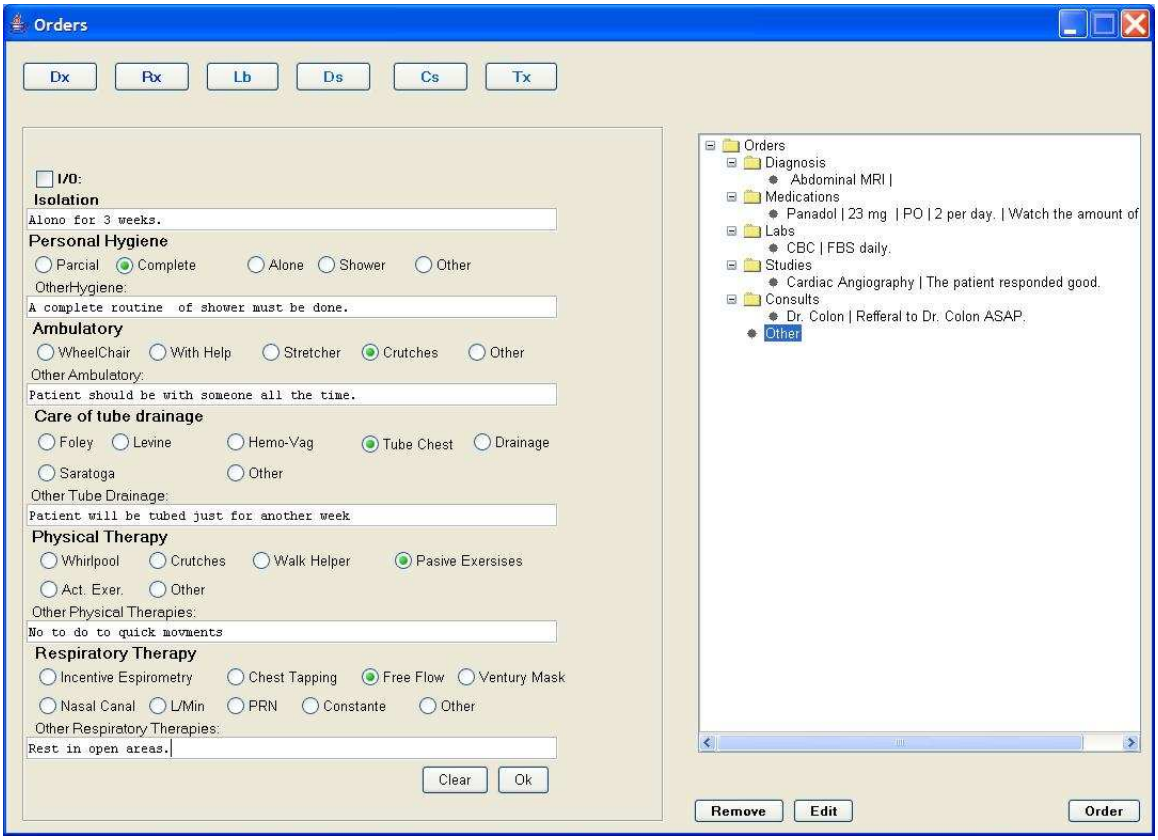

Figure 3.18 Other Order Interface.

CHAPTER 4

USABILITY EVALUATION OF THE PROTOTYPE

4.1 Introduction

The design of a good user interface requires that the characteristics and needs of the users be taken into account. A user-centered design can be achieved by incorporating usability engineering principles in the lifecycle of the user interface development. Usability is associated with five attributes of a system: learnability, efficiency, memorability, errors, and satisfaction [Nielsen93]. “Learnability” refers to the ease by which users learn to use a system and get some work done. “Efficiency” refers to the level of productivity that can be achieved with a system once the users have learned to use it. “Memorability” refers to the ease by which casual users can use the system without learning it again. “Errors” refers to the capacity of a system to reduce user errors. “Satisfaction” refers to the level of subjective satisfaction achieve by the users when using the system.

There are several techniques that can be used to improve the usability of a user interface throughout the development lifecycle. Heuristic evaluation and user testing are two of the most effective techniques. A heuristic evaluation involves the evaluation of a user interface based on a set of well-known interface design principles [Nielsen93]. This method requires that a group of evaluators with knowledge of usability principles evaluate an interface independently and identify potential usability problems. The result

of the evaluation is a list of potential usability problems. These problems are taken in consideration in the re-design of the user interfaces.

A usability heuristic evaluation was conducted for an early version of the prototype described in the previous chapter by four evaluators. The results of the heuristic were taken into consideration in the redesign of the early version of the prototype that resulted in the system described in the previous chapter. The results of the heuristic evaluations are presented in the next section.

4.2 Heuristic Evaluation

4.2.1 Procedure

Four evaluators participated in the usability heuristic evaluation. Each of the evaluators has knowledge of human interaction principles and usability engineering. They all had previously conducted heuristic evaluations. Each evaluator was given a short tutorial on the functionality of the system. In order to help them exercise the key elements of the interfaces they were asked to conduct the following typical physicians' tasks:

1. Select a diagnosis for a patient
2. Order medications
3. Order laboratory tests
4. Order diagnostic studies
5. Request a consultation with another physician
6. Specify patient's treatments

7. Document a physical exam
8. Prepare a discharge summary

Each evaluator was asked to focus on the following aspects:

1. Suitable graphics and colors.
2. Relevant information.
3. Constant feedback
4. Good consistency
5. Good Error Messages
6. Error's Prevention

4.2.2 Results

The lists of usability problems identified by the evaluators are presented in Table 4.1 through Table 4.4. Most of the problems encountered were catalogued as feedback and consistency problems.

1. Images that need to have tool tips representative.

2. Lack of images or Images required.

3. Tool tips over the tree structure.

4. Tool tips in all buttons from the main Panel of Orders.

5. Lack of visibility in the lists items.

6. Headings missing on lists.

7. Patient information missing.

8. Poor system orientation.

9. Some buttons are named different even when they performed the same task.

10. Button alignment is not the same in all interfaces.

11. Dose label does not provide examples of how the input should be specified.

12. Button enable when they are not supposed to produce any action.

13. Problems with focus on some action buttons

14. Fields not validated

15. List sizes different in all interfaces

Table 4.1 Usability problems identified by evaluator #1

1. Fonts of words are different in all interfaces.
2. The interface doesn't let you know where you are.
3. Lists are horizontal oriented, and in some lists are vertical.
4. Text fields are not validated.
5. The system doesn't let you know, if an actions was performed or not.
6. Vertical scrolls not available in all text fields.
7. Validate text fields to get just number where numbers are required.
8. Screens too big related to the information being presented.
9. No pop ups indicating if the user made a mistake.
10. Texts size not the same in all interfaces.
11. Buttons not validated.
12. Patient information doesn't have the same details in all interfaces.
13. No tool tips in the main screen buttons.

Table 4.2 Usability problems identified by evaluator #2

1. No heading in all interfaces.
2. No Defaults in selection fields.
3. No examples to know the right way to do the input.
4. Lack of tool tips in all buttons.
5. Some Panels have titles while others do not.
6. There were not any error messages letting know the user something went wrong.
7. Combo Boxes should have defaults
8. Lists should all have defaults selected.
9. Buttons in the interfaces are not at the same height.
10. No errors messages are given to the user.

Table 4.3 Usability problems identified by evaluator #3

1. Size of the buttons is not the same.
2. Height of the buttons is not consistent in all interfaces.
3. Interfaces are not loading defaults in their fields such as text fields, lists and combo boxes.
4. Font and size is not the same in all interfaces.
5. No focus on the selected button.
6. No Window title.
7. No title in all lists.
8. Tool tips missing in some buttons.
9. No messages indicating when the system has performed an action.
10. Text fields not validated.
11. Focus of the object being used not implemented.
12. Tree should let you know if a field is empty.
13. Text Fields Word Wrap is not validated.
14. Scrolls not use in all objects.
15. Buttons not disable when they should.
16. Interfaces wasting a lot of space.

Table 4.4 Usability problems identified by evaluator #4

4.2.3 Implications for Redesign

The results of the evaluations were considered in the redesign of the prototype system. The system described in the previous chapter is a result of the redesign after taking into consideration the usability problems identified. The aspects considered in the redesign were the following:

- The OK and CANCEL buttons were aligned.
- The interface area was more effectively used.
- Examples on how to specify input to the dose, and quantity fields of the medication order interface were provided.
- The relevant patient's information was included at the top of all interfaces.
- Defaults were provided for all lists and combo boxes.
- Tool tips were added to all the buttons of the interfaces.
- A title was added to all of the sub-panels and feedback was provided to identify the panel that was the focus of the interaction.
- Pop ups were added to indicate the following actions: adding, editing and erasing orders.
- The font type and size was made consistent in all the interfaces.
- Buttons with the same functionality in different interfaces were labeled with the same name.
- The separation between the buttons was made the same in all the interfaces.

CHAPTER 5

RECAPITULATION AND FUTURE WORK

The main objective of the project described in this document was the design and implementation of a physician order entry module for an electronic patient record system. Although the system was tailored to the needs of physicians at the Centro Cardiovascular of San Juan and the Advanced Cardiology Center of Mayaguez, its functionality, simplicity and usability lends itself for many hospitals in Puerto Rico and USA.

The system developed provides support for physicians to specify diagnosis and generate medical orders such as medications, laboratories, diagnostic studies, consults, I/O, diets, personal hygiene, physical therapy, respiratory therapy and ambulation. The ordering module features a series of buttons at the top that activate the interface for a particular order. This interface is displayed at the left side of the ordering window. It provides the physicians with different text fields and selection options for specifying the order. The details of the orders are displayed in a tree-like structure on an area at the right side of the interface. This interface design gives the physicians full visibility of their work. They can enter the orders on the left side of the window and constantly monitor the orders being entered on the right side of the window.

Some of the interfaces of the ordering module provide lists for the physician to select (medicines, diagnosis, labs, etc.). These lists are maintained in the database. When a physician needs to specify an item which is not in the lists the interfaces provide a text field for entering the new item. This item is added to the database but is labeled as

not validated until it is validated by the system manager. In this way the lists are dynamically upgraded by the physicians.

Support for physicians to document a physical exam and a discharge summary was provided with two separate interfaces. These interfaces were integrated on the record viewing module. They provided checkboxes, and text fields for the physicians to document the patients' condition. In some cases a selection of a checkbox requires written documentation on the item selected. To facilitate the work of the physician the selection of this checkboxes activates a text field as a reminder that the item selected needs to be documented.

The application described in this document will provide basic functions for physicians to enter medical orders and document the patient's health. The application can and must be improved in terms of the functions and the support it provides to physicians. One possibility for future work would be to provide defaults for medication doses and frequency. Also, in terms of medication, detection of drug-to-drug interaction or drug allergies should be implemented. Decision support in terms of the treatments suggested for a particular diagnosis should also be consider for future implementation. Finally, an alerts and reminders system should be add on to the electronic patient record system. This system can alert physicians on adverse incidents of a patient, abnormal laboratory and diagnostic studies results, pending orders, patient allergies and abnormal vital signs among other things. The system can remind physicians of to-do things such as orders that need to be issue for a particular treatment and reevaluation or discontinuation of an order.

The application described in this document will become an integral part of the first generation of an electronic record system designed for hospitals in Puerto Rico and the USA that will serve as a test bed for future research studies in medical informatics. It will certainly help conduct usability studies of physician interaction with different types of patient record systems (paper-based, desktop-based, PDA-based). It will also help to conduct an assessment of the impact of the technology on the clinical setting. Finally it will help develop a version of the system to provide physicians' access to the patients' records at bed-side using PDAs.

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