Physicians' Workstations: Integrated Information Management for Clinicians

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Abstract

This paper describes a project to specify, design, develop, and evaluate a physician's workstation for use in patient care. We conducted an ethnographic study of physicians' information needs in an outpatient setting, from which we derived a set of functional specifications for a physician's workstation. We have implemented an experimental prototype using an open systems, client/server architecture, and are exploring research issues in heterogeneous database integration, object-oriented database technology, model-based reasoning, and semantic integration. We plan to evaluate our workstation prototype in a clinical setting to assess its impact on quality of care and health care costs.

Introduction

The objective of the Physician's Workstation Project is to develop a set of cooperative, knowledge-based information management tools within a clinical information system for use by physicians in ambulatory patient care. We provide physicians with patient context-sensitive tools to retrieve, display, and manage patient and domain information. This paper provides an overview of the project. We first discuss the basis for our functionality objectives, then describe the overall functional goals with examples from our current prototype, discuss technical issues explored by the prototype, and conclude with plans for evaluation. We will formally evaluate our workstation prototype in an outpatient clinical setting to test whether physicians' use of clinical information management tools facilitate delivery of high quality, cost-effective patient care.

Ethnographic Study

Functional specifications for a physician's workstation must be based on a thorough understanding of the physician's information processing tasks and the work flow in the clinic. We conducted an ethnographic study of physicians' information needs in the outpatient setting [1]. Using patient visits as the context of physician work, we studied patient information needs occurring during these patient encounters and demonstrated that paper-based medical records hampered clinical decision-making. Physicians clearly had difficulty *finding* information in the chart. We also abstracted from physicians' needs for information, a set of *prototypical questions* concerning patient data. These questions showed that physicians requested patient data in a specific context (e.g., trends of related parameters with relevant medications); simple lookup access to patient data did not adequately answer their questions. We translated these information requests into functional specifications for our physician's workstation [2].

Physician's Workstation Prototype

The physician's workstation functionality can be summarized in four high level goals. We seek to provide physicians with the following: 1) Ready access to distributed patient information, 2) Effective presentation of information, 3) Clinical decision support tools, and 4) Integrated access to information resources.

The following sections describe a few of the applications being developed in our physician's workstation prototype.

Patient Status Display

Upon selection of a patient, the first panel presented by the system is the Patient Status Display. This display contains status information to readily establish a patient context for the physician. Demographic information, active problems, current medications, drug allergies, and recently completed lab tests are visible from this top level display. In addition, visit-related data are easily reviewed: vital signs, reason for visit, recent (since last appointment) clinic visits or hospital admissions and the physicians involved, future appointments, and an up-to-date health maintenance record. These data are integrated from multiple databases within the institution. Alerts (described in a later section) are displayed in the middle of the Patient Status Display and are generated by the knowledge server, using embedded domain knowledge.

Patient Details Display

Data should be presented to physicians in such a way that important information is highlighted. Graphics, trend plots, and clustering of parameters are a few examples of helpful presentation techniques [3,4,5]. Tailoring the presentation of patient data for a specific patient would normally require patient-by-patient customization of each presentation by the physician. Our physician's workstation provides default customizations for displaying patient-specific data by using embedded domain knowledge to interpret the patient context and infer what parameters are *relevant* for a given patient. The physician may easily customize a patient's display further, based on individual preferences.

Users invoke the Patient Details Display (see Figure 1) from the Patient Status Display. A patient-specific display of lab results, medications, and problems is presented to the physician using smart defaults. Figure 1 shows an

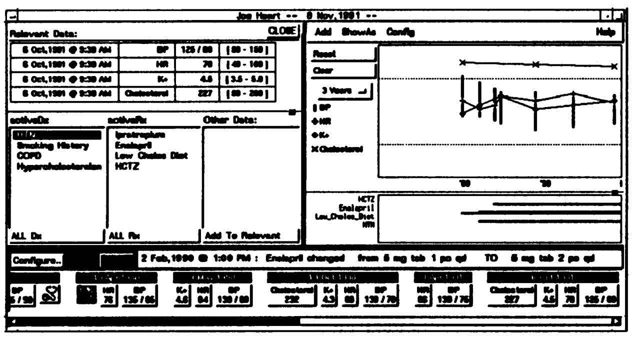

Figure 1. Patient Details Display

example of smart filtering. The physician has selected (highlight shown) hypertension as the problem focus within which to view patient data. The system has applied a hypertension filter, derived from the embedded physiology model, to display relevant disease parameters (blood pressure, heart rate), relevant medications (enalapril, HCTZ), and relevant labs (potassium is affected by enalapril and HCTZ; cholesterol is affected by HCTZ).

The time line at the bottom of the Patient Details Display provides a time navigation tool indexed by patient events (e.g., patient visit, lab test result). Each patient event is annotated with an icon (e.g., lab test, medication, PE) or actual patient data to help the physician locate landmark patient events.

Medication order entry

Ordering a medication encompasses a number of information processing tasks and spawns a number of subsequent tasks. Our system categorizes classes of candidate drugs available for a given indication (e.g., hypertension), pharmacologic mechanism (e.g., cardio-selective adrenergic beta-blocker), or formulary (e.g., Medicaid-approved). Once the physician selects a medication, a starting dose appears and relevant dose strengths, dose forms, and routes appear in the appropriate fields (see Figure 2). Each

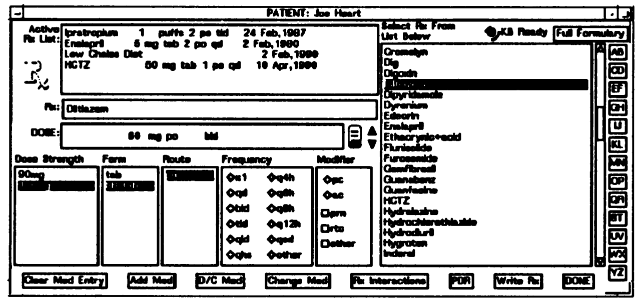

Figure 2. Medication Order Entry Display

selection of an option (e.g., dose form) narrows the subsequent options accordingly. This obviates consulting the Physicians' Desk Reference (PDR) to check the dose strengths available for a given dose form (S_R tab in the example). Quick selection by mouse clicks of the desired patient instructions is literally faster than writing out the prescription by hand.

The medication order entry application seamlessly integrates construction of a prescription with access to the clinic formulary, insurance formulary constraints, and PDR, while interactively checking for potential drug-disease, drug-lab, or drug-drug interactions. Submitting the prescription would send an electronic copy to the pharmacy.

Alerts

Providing relevant information during clinical decision-making has been shown in a number of situations to be accepted by physicians and effective at altering behavior (e.g., test ordering or medication ordering behaviors) [6-11].

Medication alerts. Medication alerts are generated during a medication order if the system detects an interaction between the drug and a patient's disease (e.g., propranolol and chronic obstructive pulmonary disease), an interaction between a drug and the result of a lab test (e.g., enalapril and high potassium), or an interaction between two or more drugs (e.g., enalapril and triampterene). Alerts are interactive; they are generated by the knowledge server when a potentially harmful medication is selected. This provides interactive decision support. When a condition which provoked an alert is cancelled or discontinued, the alert is automatically retracted. Alternatively, any alert can be manually "acknowledged."

Lab alerts. Lab alerts are generated by the knowledge server when a lab result satisfies one of the following conditions: 1) abnormal qualitative result, 2) clinically significant trend, or 3) special significance of a value or trend in a given context (e.g., rising serum potassium for a patient on enalapril).

Combinations of alert conditions increase the severity or urgency of the prioritized alert. Not all alerts are presented as textual system messages. Many of the routine alerts will manifest themselves as highlighted conditions (e.g., trends) on the patient details display of lab results.

Access to information resources

Domain information is becoming increasingly available on optical disks. Although most literature queries are patient-specific [12,13], contextual integration between the information resource (e.g., MEDLINE) and the query-provoking clinical situation is lacking. Context-dependent integration of information resources should allow the user to simply specify concepts from a patient's context and invoke a semi-automatic search to retrieve relevant literature abstracts or text excerpts. Answers to relevant domain questions should be readily available *during* a physician-patient encounter, in time to interactively affect clinical decision-making.

We are experimenting with context-dependent queries of several information resources available on CD-ROMs. For example, selecting concepts (e.g, diseases, medications) from the patient context and selecting the "Literature" button in Patient Status Display would invoke a computer-assisted search of MEDLINE. We will use the UMLS [14] meta-thesaurus and semantic network to determine the semantic types of the selected concepts and their interrelationships, in order to assist with formulation of relevant search queries. Relevant information from the patient context (e.g., epidemiological data) would be automatically included unless otherwise instructed by the user. The user would be prompted to select topics to focus on or limits to apply to the search. Relevant information available on CD-ROMs will be immediately available to the clinician, allowing real-time effects on clinical decision-making.

Other functions

Other functions under development include the following: 1) problem selection, annotation, and update, 2) lab test ordering, 3) radiology report retrieval, 4) image retrieval (e.g., CT, MRI, Ultrasound, EKG, Holter, TMT), 5) health care maintenance reminders, 6) ICU flowsheet retrieval, and 7) appointment scheduling.

Physician's Workstation Architecture

We have designed and implemented an open systems, distributed client-server architecture for our prototype. Central inter-process communication is provided by the Broadcast Message Server (BMS) used in the HP SoftBench computer software development environment [15]. The ASCII messages passed among applications and servers follow a simple, system-defined communication protocol with flexible field definitions. Our broadcast message-passing scheme allows encapsulation of applications. The system architecture and communication protocol used in our prototype is further described in a separate paper [16].

The open systems architecture supports modular extensions by using standard operating systems (UNIX, DOS), programming languages (C, C++), database interface languages (SQL), networking protocols (TCP/IP), windowing environments (X Window System), and user interface tools (OSF Motif Widgets). We are committed to supporting evolving content and communication standards as they become available (e.g., PACS, UMLS, MEDIX, HL7) [17]. Where there are currently no mature universal standards, we have substituted publicly described protocols (e.g., SoftBench BMS, OSQL [18]), until universal standards are established.

Technical issues

Prototype solutions to technical issues were developed for the physician's workstation system. This section describes three technical areas under investigation.

Heterogeneous database integration in an object-oriented database

Applications need uniform access to distributed sources of patient data and domain knowledge. We use an extended version of the Iris object-oriented database [19] to integrate data from heterogeneous sources. Iris has four primary roles in our prototype: 1) Heterogeneous database integration, 2) Object-oriented data modelling, 3) Knowledge base / database integration, and 4) Low level reasoning.

Using Iris' embedded programming language [20] and foreign function capability, we are interfacing Iris to a MUMPS-based hospital information system [21] (the Veterans Administration's DHCP hospital information system [22]), a commercial relational database, a waveform database, and another object-oriented database. Application access to patient data will be viewed through a single, global, object-oriented schema. This encapsulation of data effectively isolates applications from the physical data storage model, while providing a stable, high-level data model for all applications.

Knowledge base

The knowledge base for the physician's workstation currently consists of a limited qualitative model of cardiovascular physiology, and frame-based classification hierarchies of medications, diseases, and measurements (lab test results, symptoms, and signs). The crux of the knowledge base is the physiology model, represented as a qualitative causal network [23]. Our approach is inspired by work in qualitative model-based reasoning of Long and colleagues [24]. We have added new semantics for relations and a different traversal algorithm. The model consists of a set of physiologic parameters linked by qualitative causal influences. A physiologic parameter can be a measurable parameter (e.g., blood pressure), an internal physiologic parameter (e.g., left ventricular contractility), or a convenient amalgam (e.g., "beta-2 state" represents a combination of the sympathetic outflow and the expression of beta-2 receptors in various tissues). A causal link can be a positive influence, negative influence, or conditional influence. There is an associated strength of the influence, strong or weak. A conditional influence is activated only when the conditions attached to the arc are satisfied (e.g., presence of a disease, abnormal value of a physiologic parameter)

The physiology model is specialized for a given patient by associating patient-specific bindings to relevant parameters and influences (see Figure 3). This patient-specific model forms the patient context used by the physician's workstation applications. The patient's diseases are converted to model bindings by referring to the relevant disease frames in the knowledge base (e.g., the blood pressure parameter is given a binding of "++" in a patient with hypertension). Lab test results are translated into qualitative values and then bound to the relevant parameter in the model. Treatments, such as medications, act on specific parameters in the model, imparting a positive or negative perturbation. These effects are propagated along influence arcs according to strength, sign, and conditions on the arcs [23].

The level of detail and understanding provided by the qualitative model is that which is sufficient to define which clinical findings are *pertinent* to a given patient context. We use information from the knowledge base to configure patient-specific displays and to generate patient-specific alerts. This perspective allows us to derive practical benefit from embedded domain knowledge without solving the unresolved problems in diagnosis.

Shown in Figure 3 is an example of the relevant portion of the model which generates a medication alert when a drug, propranolol, is ordered that would exacerbate the patient's existing pulmonary disease, COPD, causing bronchospasm (parameter highlighted in bold outline in Figure 3).

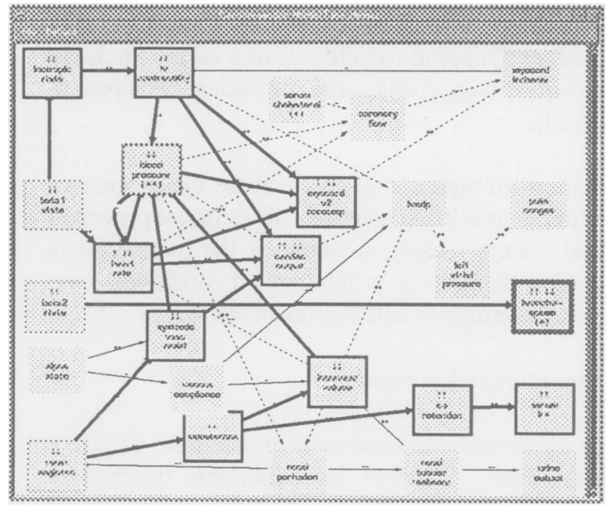

Figure 3. Knowledge-based alert generation

Knowledge base editor and presenter

Maintenance of the knowledge base is facilitated by a graphical editor. The physiology model is presented as an influence diagram. Parameter nodes and influence arcs can be created, modified, or deleted graphically with automatic updating of the knowledge base. Diseases, medications, and measurements are represented in frames which the domain expert can edit and reload.

Semantic integration in the user interface

Physicians seek patient information (data in its clinical context), not just isolated patient data. In our system, applications are spawned within a given patient context and messages are passed among applications along with their contexts [16]. We call this level of contextual user interaction and contextual inter-process communication *semantic integration*. Semantic integration within our physician's workstation allows applications to execute their prescribed tasks within a shared patient context, a cooperative style which more closely mimics physician interaction.

Evaluation

Any new technology in health care should be prospectively evaluated for its clinical utility and cost-effectiveness. We are collaborating with the PACE project (Pilot Ambulatory Care and Education) [25,26] sponsored by the Western Region of the Department of Veterans Administration. Their initiative includes a formal evaluation of the impact of an ambulatory care information system on quality of care, cost of care, patient satisfaction, and provider satisfaction. We plan to test our physician's workstation prototype as part of PACE. In a multi-armed clinical trial, we will compare our knowledge-based approach to presentation of patient information, including alerts, with usual patient data retrieval methods available in DHCP. Only in a clinical site where physicians actively use the system in ongoing patient care is one able to evaluate the clinical utility of a physician's workstation. We will use the results of the evaluation to assess our design and implementation and to stimulate improvements to our prototype.

Summary

The Physician's Workstation Project is a multi-year program to specify, develop, and evaluate a clinical workstation used by physicians to care for patients in the outpatient setting. We employed ethnographic methods to capture and analyze information processing tasks occurring in actual clinic practice, and subsequently derived system functional specifications. Technical issues have been identified and prototype solutions implemented. We have integrated our solutions using an open systems, client-server architecture designed to operate in a heterogeneous computer environment. We continue to extend the functionality of the prototype and plan to evaluate our physician's workstation in a formal clinical study, where the impact on quality of care and cost will be assessed.

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