The Informatics Superhighway: Prototyping on the World Wide Web

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We have experimented with developing a prototype Surgeon's Workstation which makes use of the World Wide Web client-server architecture. Although originally intended merely as a means for obtaining user feedback for use in designing a "real" system, the application has been adopted for use by our Department of Surgery. As they begin to use the application, they have suggested changes and we have responded. This paper illustrates some of the advantages we have found for prototyping with Web-based applications, including security aspects.

INTRODUCTION

Common impediments to development of physician workstations include the demands of programming graphical user interfaces, restrictions on hardware platforms and inability to integrate necessary applications [1]. The World Wide Web is a client-server architecture which makes use of Internet protocols to integrate information sources [2,3]. Its principle mechanism is the exchange of files in Hypertext Markup Language (HTML) format which provides some basic layout capabilities and allows inclusion of references (called Uniform Resource Locators, or URLs) which point to additional document sources on the Internet. Web servers act as file servers for previously created documents and provide programs (called Common Gateway Interfaces, or CGIs) which can generate documents dynamically. Documents can include data entry fields and graphics. Web clients are available for most common user platforms and provide a standard way to display HTML documents, as well as other services such as managing user input, printing, and encryption services. Because of these capabilities, the World Wide Web paradigm has attracted considerable attention as a platform for development of clinical applications. We have taken advantage of our database and vocabulary servers at the Columbia-Presbyterian Medical Center (CPMC) to build a prototype clinical information browser [4,5]. Descriptions of similar efforts by other workers have already begun to appear in print [6,7]. The purpose of this paper is to describe our experience with one particular advantage of Web-based application development: rapid prototyping and development.

BACKGROUND

The development of applications at CPMC for use by physicians to access clinical data has been spared none of the impediments listed above. The first general-purpose application, called Results Review, required several man-years of development work [8]. It runs on an IBM mainframe, and is accessible using 3270 terminals (or PCs running 3270 emulation software). Although comprehensive in the types of data presented, Results Review is limited with regard to the flexibility of presentation methods. Using a character-based interface with no pointing device, it displays information for one patient and one report at a time. Users have requested additional views of the data, such as summary reporting and aggregation by doctor or service, but the mainframe environment has proved to be ill-suited for rapid application development and flexible presentation methods. We have therefore turned to other platforms, while retaining the mainframe as a data server.

One application, called the Resident Sign-Out Editor (RSE) runs on a midrange computer (IBM RS/6000) with PCs emulating VT100 terminals. RSE provides a more user-friendly front end (albeit still character-based) and a client-server architecture that permits more flexible data display. RSE was developed to allow medical housestaff to maintain patient lists and to download all clinical data (laboratory, radiology, pharmacy, etc.) for review on a patient-by-patient basis. The project programmer interacted directly with medical housestaff to determine their needs, show them his progress, and obtain feedback.

When RSE was offered to the surgical housestaff, we were surprised by their reaction: RSE would not meet their information needs in its current form. Like the medical residents, the surgical residents need to maintain patient lists. Unlike their medical counterparts, who review all data on one patient at a time, the surgical residents review data in an orthogonal manner: one *type* of data at a time, for all patients (e.g., latest blood count for all patients on the service). At the time, we did not have the programming resources required to alter RSE to create this view of the data.

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In 1994, we began experimenting with Web-based clinical information browsers integrated with on-line library resources [9]. With the decision not to adapt RSE for the surgical residents, it occurred to us that we could develop a second Web-based application, a "Surgeon's Workstation", to provide the displays being requested. We began to explore the possibility of building such displays as a way of obtaining user feedback. More than screen mock-ups, the displays would show real patient data. Based on the user feedback, we intended that the resulting displays would serve as a guide for future development in a more standard application environment, where "production" systems could be maintained, but where rapid prototyping was not feasible.

METHODS

Evaluation of the user needs was conducted through interviews with surgeons at all levels, from interns to the department chairman. We determined three types of requirements: data, organization (by service and attending), and presentation (patient lists and laboratory displays). Data requirements were generally met through HL-7 queries to the CPMC data server [10]. A server for the Medical Entities Dictionary (MED) [11] was used for translating coded data for display. Other data, not available from existing applications, were obtained through direct user input using HTML forms.

The Web platform is a Netscape HTTP server (Netscape Communications Corporation, Mountain View, California) on an RS/6000 and Netscape Navigator clients running on Macintosh computers on the local area network. The application uses preconstructed HTML documents coupled with CGIs written in C. The CGIs use preexisting C libraries to obtain information from the clinical data server and the MED server. Local files were developed on the Web server to maintain user-entered information.

CGIs were developed to address three functions: user authentication/authorization (log-on), user data entry, and data display. Once the CGIs for log-on were written, sample display screens were developed and shown to the users. The users identified specific organizations of data and display features that they wanted and we responded by modifying the CGIs.

Usage statistics were collected on two systems: the central Clinical Information System (CIS) and the Web-based application. The CIS keeps track of each user and the specific data they review. The Web server provides standard methods for monitoring file access based on Internet address. Our application, in addition, keeps track of each user.

RESULTS

Initial Development

The surgical residents indicated that the application should keep track of patients (and organize the displays) by service (thoracic, plastic, vascular, etc.) and attending surgeon. These assignments were not available from the CIS, so HTML forms were developed to allow the users to enter the information. The residents also indicated that they would like particular sets of laboratory test results for each patient in the group, including two chemistry panels (Chem-7 and Chem-20), the complete blood count, and the urinalysis. Finally, they requested the ability to store brief notes for each patient. Based on this initial set of requirements, an application was developed in 3 weeks (see Figure 1). On seeing this first version, the residents indicated that they would like to use it as their primary access to clinical information. This gave us an opportunity to obtain additional feedback, but also increased the security requirements needed for deployment.

Security

Although Web servers provide log-on ID and password functions, there are no true "log-on" sessions; interactions between the client and server are "connectionless". However, we needed a method whereby a session could be created, maintained and terminated, in order to prevent unauthorized users from using information left on the Web client to obtain access to additional information. We created a mechanism whereby, when the user enters a log-on ID in the first HTML document, the application creates an HTML document for obtaining the password. This document is associated with a unique key which is invalidated once the user enters the password. The application ignores further attempts to log-on from this password document. In this way, an unauthorized user who gains access to the documents stored in the cache on the client can not reestablish a session with the server. After log-on, a second unique key (the "session key") is created which is required for all CGI functions in the application. Each HTML document contains the key and sends it to the server with each CGI function call. The "Log Out" function (see Figure 1) renders the key invalid and further calls to the CGIs fail. Similarly, the key becomes invalid if it is not used within a timeout period (currently 150 seconds).

The session key prevents unauthorized users from executing CGI functions, but it can not prevent such users from reviewing HTML documents already stored in the client's cache. We minimize this access by sending a series of blank screens to the client when the "Log Out" function is selected, displacing documents with patient information from the cache.

Finally, we take advantage of Netscape's standard security features. We restrict access to applications based on the Internet address of the client (at present, those in the CPMC domain), and we use Netscape's encryption capabilities to prevent interception of user passwords or patient data over the Internet.

collected. During June, surgeons used the CIS 2105 times for 78,891 minutes. During July, they used the Web application 420 times and the CIS 1797 times for 59,038 minutes.

In the first few days of implementation the users made several suggestions, leading to modifications (see Figure 2). The surgical residents noted that in addition to the summary-by-service displays for laboratory results, they would also like access to all the information available through the CIS. This was accomplished in a matter of minutes by adding a "CIS" button to the HTML document, providing a link to the original clinical browser application [5].

Current Service: GI-Endoscopy

Add Logout

Chem-7 Chem-20 Coagulation Studies Complete Blood Counts Urinalysis DISPLAY

Choose a Patient and select action Delete Modify Comments

	MRN	NAME	AGE	SEX	POD	ATTENDING	LOCATION	COMMENTS
1.	1234567	RAE,NORMA	57	F	14	Geller,Peter	M7HS 7225 01	NO
2.	3333333	WEBSTER,DANIEL	25	M	12	Whelan,Richard	M7HS 7231 02	NO
3.	7654321	LYNN,VIOLA	71	F	12	Whelan,Richard	M7HS 7233 01	NO
4.	1212121	SMITH,ANNETTE	71	F	16	Forde,Kenneth	M7HS 7250 02	NO
5.	3013013	ADAMAN,EVA	85	F	14	Whelan,Richard	M7HS 7250 01	NO
6.	2012101	SWANSON,SARA	59	F	10	Forde,Kenneth	M7HS 7256 01	NO
7.	0808089	PALACIOS,FERDINAND	62	F	30	Geller,Peter	M7HS 7258 01	NO
8.	2112121	FERNANDEZ,WILLIAM	47	M	14	Chabot,John	M7GS 7351 01	NO
9.	101234	DEERE,RUDOLPH	63	M	100	Amory,Spencer	M7GS 7354 01	NO
10.	2457349	THOMPSON,THOMAS	52	F	2	Whelan,Richard	M7HS 7233 02	NO

Figure 1 - Sample screen from Surgeon's Workstation, showing the patient list for the GI-Endoscopy Service. The MRN and POD columns contain the medical record number and number of postoperative days, respectively. Users can add a patient, log out, select a laboratory display for all patients, or select individual patient functions. For individual patients, the user can delete the patient from the service, modify information such as service and attending, or add a comment. The information on this screen has been altered to protect patient confidentiality.

Initial User Response

Since implementation of the system, in April of 1995, the surgical residents have begun to use it as their primary means for accessing patient information. With April and May being training periods and June having the usual turnover in housestaff, July has been the first month for which stable statistics could be

A chief resident, the most avid user, carried out the data entry for the GI-Endoscopy Service. He requested the ability to assign a chief resident to each patient, in addition service and attending, and then to display the list of patients for each chief resident. The required changes to the patient data files and the CGIs took one day.

Another user was the Chairman of the Department of Surgery. He pointed out that one laboratory display that would be useful to him was the Stat Labs (blood gases). Adding this capability required no changes to the application but rather a change to the MED. The MED contains descriptions of a variety of laboratory displays, developed for several applications. For the surgical workstation application, a class of displays called "Surgery Displays" had been added to the MED and each relevant display was added as a member of the class. In order to respond to the Chairman's request, we simply added a link in the MED between "Stat Lab Panel" (a concept already represented in the MED) and Surgery Displays. The CGI which generates the patient list screen determines what displays to include using a query to the MED server, so Stat Lab Panel was automatically included in the display, as shown in Figure 2.

was to develop a prototype that would elicit user comments and alter the prototype in order to determine what a "real" application should look like. Based on initial user response and their response to changes based on that input, we believe our approach has met these expectations.

We were surprised to find that the surgeons had already deployed the hardware needed to run the prototype and were prepared to perform the data entry needed to make it work. With these two long-time obstacles removed, our prototype had the potential to become a working production system. Based on our initial offering, the Department of Surgery indicated that the system, as is, meets their needs for data access and were willing to make it their primary workstation. Usage statistics collected thus far indicate that this is indeed happening.

Current Service: GI-Endoscopy

Add | Logout

◇Chem-7. ◇Chem-20. ◇Stat Lab Panel. ◇Coagulation Studies. ◇Complete Blood Counts. ◇Urinalysis. DISPLAY

Choose a Patient and select action | Delete | Modify | Comments | CIS

	MRN	NAME	AGE	SEX	POD	ATTENDING	CHIEF	LOCATION	COM
1. ◇	1234567	RAE.NORMA	57	F	14	Geller.Peter	Steve.Libutti	M7HS 7225 01	NO
2. ◇	3333333	WEBSTER.DANIEL	25	M	12	Whelan.Richard	Anne.Sacher	M7HS 7231 02	NO
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Figure 2 - The revised application, based on initial user feedback. Note addition of the "Stat Lab Panel" to the Display list, the CIS button to the individual patient options, and the Chief Resident column to the patient list.

DISCUSSION

Our experience with development of the Surgeon's Workstation demonstrates that the Web technology and the CPMC clinical information architecture provide strong support for application development. When we originally conceived this project, our intent

The application development conducted thus far has demonstrated several capabilities of the Web-based approach. First, it is relatively easy to develop customized applications and to modify them in response to user suggestions. Second, it is even easier to incorporate preexisting components into an

application simply by exploiting the hypertext paradigm of the Web to tie applications together through buttons and links. Third, the Web server provides the capability for applications to make use of non-Web resources; in our case, the patient data and MED servers. Fourth, the graphical user interface features of the Web clients alleviate much of the burden associated with user interface development and, furthermore, free us from concern about supporting multiple hardware platforms.

A number of disadvantages of the Web-based approach have also come to light which may be of significance in some applications. First, the hypertext paradigm of linking documents may not be appropriate for complex user input functions where the user expects to modify data being displayed, when in fact, the client is displaying a new screen while continuing to cache the old data. Second, while the Web server provides some services (such as usage statistics and encryption), more are needed for complex application development. In particular, we have felt a need for a database management system to handle complex local data. Third, the connectionless approach used by the Web creates some additional overhead for application development. For example, every CGI in our application must check to see of the user's session key is still valid.

CONCLUSION

At present, there remains a considerable amount of novelty in being able to develop applications rapidly, for use on multiple platforms, integrated with our clinical information infrastructure, and able to access other Internet-based resources. Old impediments have fallen away, while new ones have arisen. Thus far, these new impediments have not proved serious. The ease of prototyping makes experimentation with application development inexpensive when compared with our current CIS. As a result, the Web-based approach has allowed us to make a quantum leap forward in application development at CPMC.

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