Integrated Web-Based Viewing and Secure Remote Access to a Clinical Data Repository and Diverse Clinical Systems

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Abstract: The advent of the World-Wide-Web protocols and client-server technology has made it easy to build low-cost, user-friendly, platform-independent graphical user interfaces to health information systems and to integrate the presentation of data from multiple systems. The authors describe a Web interface for a clinical data repository (CDR) that was moved from concept to production status in less than six months using a rapid prototyping approach, multi-disciplinary development team, and off-the-shelf hardware and software. The system has since been expanded to provide an integrated display of clinical data from nearly 20 disparate information systems.

Introduction

The explosive growth of the Internet and the World-Wide-Web (WWW) has resulted in the ready availability of inexpensive, platform-independent, graphically-based, *n*-tier client-server software tools.[1,2] These tools are well suited to the rapid development of web-based, user-friendly interfaces to legacy hospital information systems, bedside clinical systems, clinical data repositories (CDRs), and other sources of biomedical information.[3,4] Web-based interfaces find ready acceptance among caregivers, many of which are already using a web browser at home for information or entertainment, and require relatively little user support or training.[5,6,7,8]

We describe the use of a rapid prototyping strategy, clinician participation in the development team, and off-the-shelf software to build and deploy a World-Wide-Web-based viewing system, called "Web/VS," for a clinical data repository (CDR) and other clinical systems at Cedars-Sinai Medical Center in Los Angeles, California. The Web/VS system has been in production since June, 1998. It currently receives over 5500 logins per day and serves 25,000 web pages of clinical data per day.

Historical Context

Cedars-Sinai Medical Center (CSMC) is an 820-bed university-affiliated, not-for-profit hospital with 400 staff physicians and researchers, several free-standing residency and fellowship programs, and over 2000 non-employee attending physicians. CSMC is a part of the Cedars-Sinai Health System (CSHS), which has 10,000 employees and multiple business units including a managed care network.

The CSMC clinical data repository (CDR) receives information from the hospital's ADT system and other clinical information systems via real-time HL-7 interfaces. It captures patient demographic and census data, clinical laboratory results, blood gases, and full-text reports of many types (imaging, anatomic pathology, histories and physicals, consultations, operative reports, etc.). The CDR contains approximately 1,000,000 patient demographic records, 2,000,000 case records, 100,000,000 individual test results, and 2,000,000 full-text reports.

The CDR was originally implemented in 1992 using RDB™, a DEC proprietary database, and ran on a 2-node DEC Alpha™ cluster under OpenVMS™. During 2000-2001, the database was remodeled, normalized, and migrated to Oracle version 8.1.6 running on an IBM RS/6000 SP2 cluster under AIX. All historical data was salvaged, cleaned, remapped, and loaded into the new schema, and all real-time interfaces were converted.

The original user interface to the CDR was a character-based application implemented in DECForms™ using DEC's ACMS transaction manager, and accessed from various points throughout the medical center via dumb terminals or desktop computers running terminal emulation software. The terminal-based interface was extremely inefficient and employed function keys and menu conventions that were non-intuitive to clinical users. Moreover, the design of the interface allowed only one result to be viewed at a time. Remote access to clinical data was provided via a rotary bank of PPP dial-up lines that required special security software on a hospital-owned PC running Microsoft Windows version 3.1 in the physician's office. Only about 10 percent of the medical staff were able to take advantage of the dial-up capability.

During 1998, a new web-based viewing system for the CDR, called "Web/VS," was implemented and deployed alongside the legacy character interface.[9] Over time, multiple clinical systems in addition to the CDR were brought under the umbrella of Web/VS security, logging, and navigation. Secure remote

access was made available via encrypted sessions, ISP accounts, and two-factor authentication ("something you have, and something you know"). The web interface met with enthusiastic user acceptance, and the character interface was decommissioned in 2000.

Materials and Methods

The Web/VS application is implemented in Microsoft's Active Server Pages™ (a Visual-Basic-like programming language) using the Microsoft Active Data Objects™ (ADO) component. The ADO layer communicates with the CDR using standard ODBC function calls and Oracle drivers. For maximum compatibility with a broad variety of web browsers, the web application does not use any client-side ActiveX, VBScript, DHTML, or Java applets.

The Web/VS application is load-shared on four web servers. running Microsoft Windows NT Advanced Server™ version 4.0 and Internet Information Server version 4.0. Each server has dual 800 MHz Pentium III CPU's, 1 GB of RAM, and a mirrored pair of hot-pluggable system drives. Additional machines host a certificate server and a software firewall (CheckPoint FireWall™ version 4.0). The firewall node has four network ports and serves as the interface and control point between the campus network (Intranet), the secure web servers, the public web servers, and the hospital's Internet Service Provider (ISP) [Figure 1].

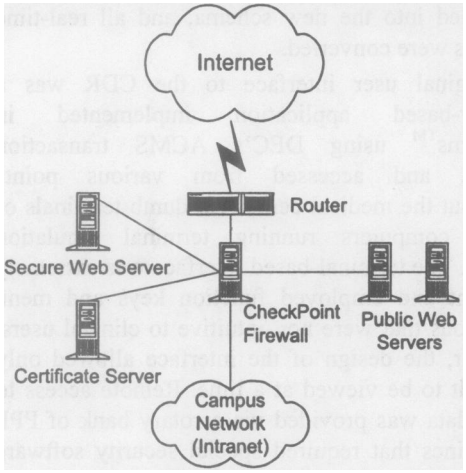

Figure 1. A software firewall controls network traffic between the Internet, the Intranet, the public web servers, and the secure web servers.

The Web/VS User Interface

In order to use Web/VS, the user connects to the web server using a standard web browser and enters an CDR account name and password. Web/VS then displays a patient selection screen that is divided into two panes [Figure 2]. The left pane offers a simple search interface based on patient name, medical record number, nursing station, or hospital service. Initially, the right pane displays the user's "personal patient list," which is managed by the user, and also (in the case of physicians) the names of any inpatients for which the user is the admitting or attending physician of record.. After any search is executed, the right pane displays a list of patients matching the search criteria. The patient list includes unit locations and room numbers (for inpatients), medical record numbers, birthdates, full name, and last view date, and can be sorted by name, medical record number, or room number as the user prefers.

The user proceeds from the patient selection screen by clicking on a patient name with the mouse. This takes the user to a result display screen that is again divided into two panes. The left pane contains a menu of different result types and formats: lab tests, flowsheets (spreadsheet-like presentations of common test groups such as CBCs, electrolytes, and liver function tests), blood gases, text reports, waveforms, images, and so on. The right pane is initially populated with the "recent lab results" for the current patient, and is refreshed whenever the user selects a different result type, report format, or date range from the menus in the left pane [Figure 3]. In most cases, the user does not need to touch the keyboard again after a successful login.

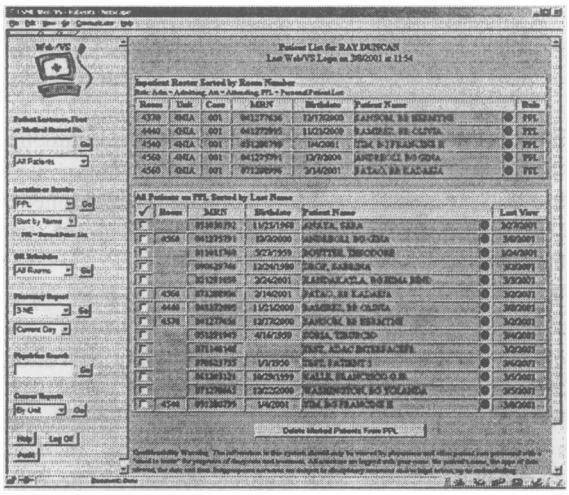

Figure 2. After login, the user first sees a simple search interface and his or her "personal patient list".

Each access to patient data is logged with the user's ID, the patient name and medical record number, the date and time, the type of access, and the specific data element accessed. Log entries are stored within the relational schema and are retained indefinitely.

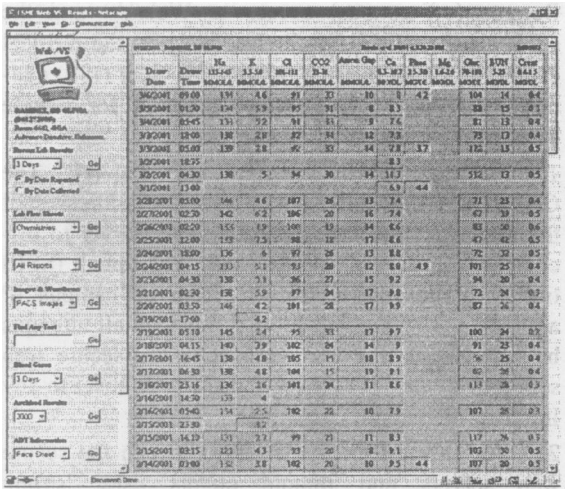

Figure 3. After a patient is selected, a variety of report types and data types are available. Configurable flowsheets make it easy to review and compare results.

Presenting Data From Diverse Systems

The clinical data types that can accessed via Web/VS include:

- Clinical laboratory results
- Laboratory flow sheets for common test groups
- Cultures and sensitivities
- Blood gases and pulmonary function tests
- Transcribed reports (histories and physicals, surgical reports, consults, imaging reports, etc.)
- Electrocardiograms including 12-lead tracings
- Echocardiogram reports
- PACS images (MR, CT, and ultrasound)
- Cardiovascular surgery database extracts
- Emergency department database extracts
- Labor and delivery database extracts
- Neonatal ICU database extracts
- ICU point-of-care summaries (vital signs, ventilator settings, and intake and output)
- ICU nursing notes, MARs, and pathways
- Physiologic monitoring waveforms and alarms
- Complex formatted reports as PDF files
- Anatomic pathology images
- Patient demographic data and face sheets
- Allergy and advanced directive status
- Operating room schedules
- Census reports by unit and service
- Medical staff directory

The primary source of data displayed by Web/VS is the clinical data repository. Data is received into the CDR via real-time HL-7 interfaces from multiple source systems, and is integrated and organized for viewing using unique identifiers that are shared by all of the source systems, such as the patient's medical record number and case number, the admitting, attending, ordering, or reporting physician's identifier, and so on.

However, Web/VS also makes data available for viewing that is not stored in the CDR but rather in other, highly specialized or department-based systems [Figure 4]. The systems fall into three major categories.

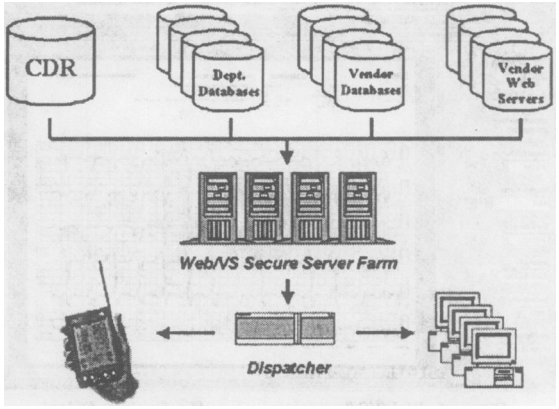

Figure 4. Web/VS displays data from many diverse clinical systems within a single security, logging, and navigation interface.

Systems in the first category are Oracle databases and applications that were developed internally to support the needs of clinical departments. Since we designed each data model and understand the content, it is easy for us to reach into these databases from Web/VS using an ODBC connection, and display summaries and reports to support patient care. All accesses via Web/VS are listed in daily reports that are emailed to the database "owners." Examples of such systems are the neonatal ICU outcomes database and the pathology image database.

Systems in the second category are vendor applications that do not support outbound HL-7 interfaces to the CDR, but are based on Oracle or other RDBMS back-ends that Web/VS can access directly. In these cases, we obtain the data model from the vendor or reverse-engineer it, then build a Web/VS module that queries the database using a unique patient identifier and formats a summary that is displayed to the user as a Web/VS "report." Examples of systems in this category are CyperPlus's EmStat™ in the emergency department, and Hill-Rom's WatchChild™ in labor and delivery.

Systems in the third category are vendor packages that rely on proprietary database technology but are bundled with their own specialized web servers. In this situation, we simply wrap the Web/VS navigation and logging around pages delivered from the foreign system's web server. When a user requests a report from Web/VS that relies on an

external web server, Web/VS logs and then redirects the access, attaching the appropriate patient identifier and providing any necessary security tokens. Systems in this category include the central stations for Viridia physiologic monitors, the Kodak/CEMAX PACS system, and the Marquette MUSE™ ECG system [Figure 5].

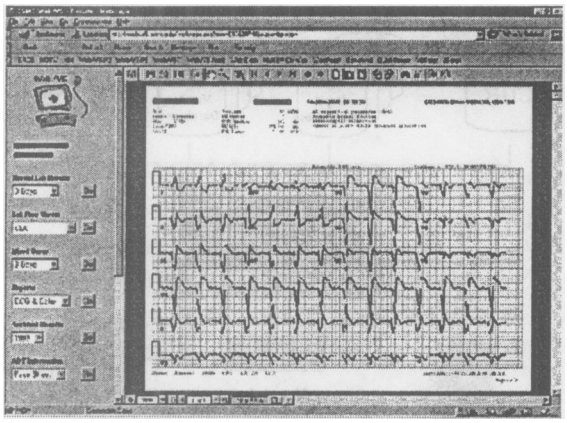

Figure 5. Web/VS "wrapping around" a foreign clinical system's web server. The EKG in the results pane is delivered to the user by the MUSE web server.

Security and Remote Access

Security and confidentiality of patient information has always been a high priority at Cedars-Sinai Medical Center. Upon hiring, every employee must sign a "need to know" agreement governing accesses to information systems, and all computer account request forms are cosigned by a department security contact who vouches for the user's need to know. Inappropriate accesses are cause for immediate termination. A detailed Clinical Systems Security Architecture was incorporated into the CSMC Technology Architecture Guidelines in 1999, and all new systems (whether built or acquired) are measured against this model.[10,11] The security architecture is compliant with HIPAA and HCFA guidelines.[12,13]

Web/VS and the CDR support CSMC's security needs in a variety of ways, including confidentiality warnings, detailed logging of all accesses or attempted accesses to patient data, and automatic daily surveillance reports listing accesses to "sensitive" data such as HIV tests and employee lab results. An interactive web-based tool is used by data security staff or HID staff to follow up on surveillance reports and perform ad-hoc audits of Web/VS accesses. Audits can be based on patient name or medical record number, user name, starting and ending dates, type of access, or any combination of these.

Remote (off-campus) access to Web/VS and the CDR can be gained by direct dial-up to the medical center, or via an Internet Service Provider (ISP) dial-up or broadband connection. Security for remote users is implemented at four levels:

1) **Firewall traffic control and alerts.** The CheckPoint firewall exposes only the addresses of the secure web servers and certificate server to off-campus users, and passes only encrypted (SSL) traffic to the secured servers from off-campus IP addresses. The firewall blocks and logs all attempts by off-campus users to connect to the secure web servers via non-HTTPS sessions or to connect to any Intranet (on-campus) machine.

2) **Data encryption.** All traffic between the secure web servers and remote clients uses "strong encryption," based on VeriSign digital certificates installed on the web servers and the Secure Sockets Layer (SSL) support built into the web server and browser.

3) **Client-server-level authentication.** CSMC acts as its own Certificate Authority (CA), and unique digital client certificates are issued to each remote Web/VS user after appropriate authentication. The certificate must be presented by the user's web browser and validated by the web server before a remote connection is allowed.

4) **Application-level authentication.** The user must supply a valid CDR login and password. The system enforces a password change at intervals determined by CSMC security policies.

On-campus users of Web/VS must supply a valid CDR login and password, but the encrypted (SSL) connection and two-factor authentication are not required, because campus network traffic is shielded from the Internet by the firewall. This reduces the processing load on the secure web servers.

Wireless remote access is supported by a special version of Web/VS customized for the Palm VII personal digital assistant (PDA) with built-in wireless modem. All of the Palm VII wireless network traffic is encrypted, and the web application also tracks the unique device ID of the remote Palm VII device. This allows stolen or lost devices to be locked out.[14]

Clinician and User Involvement

The physician community has been closely involved with the development of the Web/VS application from the beginning. In fact, most of the web application design and development has been done by clinicians who were also experienced programmers, although the bulk of the database and interface work was done by the EIS department's Oracle development team.

Quarterly user group meetings are held to solicit feedback from physicians, nurses, social workers, HID staff, and others. In many cases suggestions have been implemented and moved into production within one or two days. Dedicated support specialists, voice mailboxes and email addresses are available to assist clinicians. A mailing list allows the development team to rapidly distribute information to users about bug fixes and new features.

CDR and Web/VS utilization is tracked closely with a variety of automated reports generated from access logs and interface traffic data (an example can be seen in Figure 6).

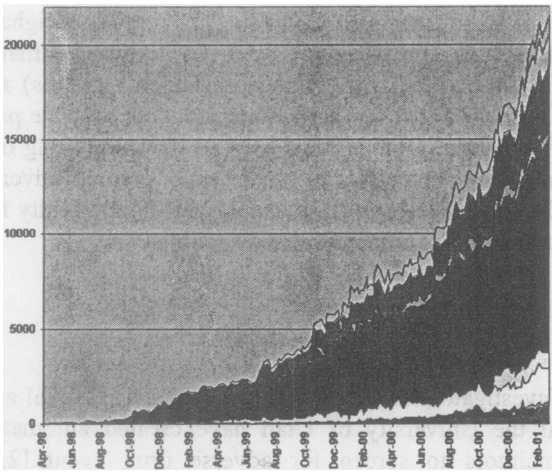

Figure 6. Web/VS utilization is tracked carefully. This graph shows the number of pages served by report type since the system went into production.

Discussion

The cultural and technological phenomenon of the World-Wide-Web has created new possibilities for high-performance, user-friendly, cross-platform user interfaces for clinical systems that could scarcely have been imagined even five years ago. Web-based applications drastically reduce deployment, training, and support costs, because most users are already familiar with web browsers and web application conventions based on their use in other contexts. Secure remote access is facilitated by web browsers' built-in support for encryption and digital certificates.

Web software technology is particularly well suited by its ease of programming and client-server nature to a rapid prototyping and enhancement strategy with short cycle times. Because of the clean division of function between the databases, the application servers, and the presentation services provided by the web browser, changes to the user interface can be made quickly and safely. This strategy can also provide breathing space for hospital IT staff struggling with the complex task of replacing legacy host-based information systems with modern *n*-tier client-server systems.

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