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Review Paper

Next Generation - Health Professional Workstations

1. State-of-the-Art

Introduction

This article presents a new look for IMIA Yearbook review articles. In addition to reviewing the existing state-of-the-art for health professional workstations, it synthesizes both what was learned during IMIA's 1993 Working Conference on Health Care Professional Workstations and what has been accomplished in the past months by the conference's cochairs.

This paper breaks from traditional "review articles" in that it takes a forward-looking stance and forecasts what might constitute a next generation health professional workstation (NG-HPW), and suggests the processes which are necessary to reach this goal in the next two years.

In 1985, Blois wrote a hallmark paper about the health professional workstation in which he first described the concept of anticipatory computing [1]. He challenged informaticians to devise a workstation that could predict user needs and provide an environment that knows about its users, their preferences, and what kind of information they will need within a given context. Nearly ten years after Blois' insightful article, informaticians are just beginning to create the NG-HPW. Two new information technologies are needed to realize his farsighted vision:

1. Advanced systems-engineering processes and tools to build complex systems,
2. Associate systems which act as responsible, intelligent intermediaries between health professionals and supporting systems.

Advanced Systems Engineering

Building complex intelligent systems, such as the NG-HPW, demands systems-engineering processes which go beyond typical "waterfall", spiral, or object-oriented models of system development [2]. A new approach, called domain-specific systems architecture (DSSA), attempts to overcome limitations of previous methods by defining system-independent objects and formally defined messages among those objects [3]. These high-level system objects (also called components) consist of aggregated roles and responsibilities which could include intelligent decision-making behaviors. For instance, a temperature-checking object could monitor and judge based on user defined criteria, then take a set of pre-specified actions without requiring human interaction. DSSA also formally specifies the messages the temperature-checking object could send and receive.

The scenario-based engineering process (SEP) is one method used to create DSSAs for various domains. It focuses on user-defined scenarios (what the users actually do in the specific domain), structured analysis and decomposition of typical tasks and objects, encoding of business rules, and development of a multi-dimensional domain model and reference requirements. By focusing on user scenarios and rapid prototyping of emerging system components, the SEP transitions from the real world to automation. Early and intimate user involvement in model definition, validation and verification of the model and domain requirements, and use of the prototypes are critical to the success of SEP.

To create a system, domain requirements are selected (i.e., a nursing or physician workstation) and are used to direct the choosing of appropriate components. The components are organized using the architecture description rules. Standards are enabled as constraints on the reference architecture. Over time, as new features are needed (via new requirements) or new technologies requested, additional components are designed. Scenarios or other mechanisms are used to guide the derivation of requirements, revision of the architecture, and extension/modification to existing components. The exceptional power of DSSA approach is realized when it is used to generate new versions of systems by using available components or by modifying selected ones. Typically this approach substantially reduces the level of effort, cost, and risk for repl cation of the architecture as opposed to creating a new system.

Associate Systems

Originally developed to augment the pilot's ability to handle information in high-performance aircraft, associate systems both react to inputs from the user and take the initiative to collect and provide information in an autonomous fashion [4]. This architecture realizes Blois' vision for anticipatory computing. Associate systems anticipate user needs, gather the appropriate information proactively, and present the information in the form and fashion which the user desires. The associate system architecture contains three collaborating subsystems: a human-computer interface (HCI) manager, a context/task (C/T) manager, and an information broker (IB) [5,6].

The HCI manager displays information in formats based on user's preferences. It also provides a consistent dialog metaphor across all applications supported by the system. When a health care professional accesses a patient record, the HCI manager provides a context-relevant view of the entire patient record regardless of whether the data were retrieved from one database or a network of information systems. Therefore, the user is given the impression that the information is obtained from a single information source that is "tuned" to his/her specific needs and tasks. The HCI manager has access to a variety of different display media. It uses its presentation strategies, models of communication goals, knowledge of the user's current schedule and context, and available resources to optimize information transfer to the user.

The context/task (C/T) manager is the central component and supports tracking and managing multiple activities and learning of users needs and preferences. It links user tasks, potential paths (sets of operations that occur in sequence), and the specific pieces of information that are necessary for the successful completion of the tasks. The C/T manager invokes the most appropriate problem-solving method for the successful completion of the task, based on task criticality, available resources and schedule. The C/T manager coordinates the flow of messages and commands between itself and the HCI manager. It informs the information broker (IB) which data sets, information, and knowledge are required to satisfy current and expected user tasks and handles alerts or warnings generated by its components or received by the information broker.

The IB interfaces the associate system with existing information and network resources. It takes data retrieval requests from internal formats and queries local or external systems using a uniform domain specific terminology such as the Unified Medical Language System (UMLS). The IB takes necessary actions to retrieve or transmit the needed data. It extracts the appropriate data from various local and external systems and converts any data from external formats. It transmits data entered by users to those local or external systems, while handling any format conversions automatically. Thus, the IB encapsulates the NG-HPW from different databases and systems.

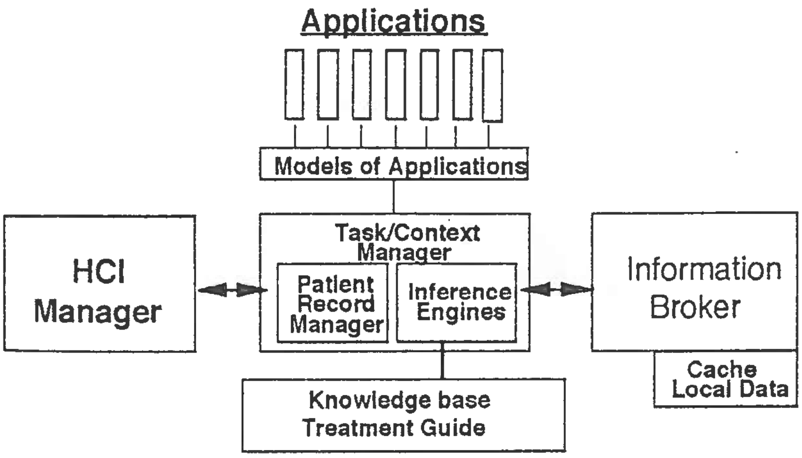

Figure 1. Architecture for NG-HPW Associate System

The implications of the associate system are significant both in the speed of information delivery and the ease of user/interface interaction. Because the user interface is isolated from the other subsystems, the user does not need to learn the intricacies of accessing each remote information system. Instead, the clinician trains the NG-HPW, which learns and can be tailored to his/her individual preferences. As the clinician uses the NG-HPW, its learning components develop a more detailed model of user needs and anticipate user tasks. When associate systems are fully implemented it will be the computer that needs to learn how the user operates, rather than the user needing to learn how the computer operates.

2. Updates on the 1993 IMIA Working Conference

The business of the working conference held in Washington, D.C., in June 1993, was accomplished in large part by five breakout groups headed up by ten cochairs. These groups addressed five areas: Functional Requirements; User Interfaces; Data and Knowledge Management; Processing; and Sharing and Communications. Their cochairs continue to be involved in the working group on workstations formally recognized by IMIA in September 1993.

In the pages that follow, the cochairs extract and update their reports, as originally published as a special issue of the *International Journal of Bio-Medical Computing* (MJ Ball, JS Silva, JV Douglas, P Degoulet, S Kaihara, eds. 1994;34, see also [7-9]).

2.1. Functional Requirements as an Integral Part of the Design and Development Process (R.A. Greenes and M.F. Collen)

With the continual refinement of the health care delivery system, the health information infrastructure, and informatics technology in general, the development of the functional requirements of the next generation health professional workstation (NG-HPW) will remain an ongoing process.

A variety of approaches for developing functional requirements of the NG-HPW were considered at the working conference, including:

1. Literature reviews, including solicited and published papers obtained from a variety of sources,
2. Consensus development by the members of the working group, and
3. Scenario-based engineering processes (SEP), an example of the domain-specific systems architecture (DSSA) approach in which multiple scenarios are developed that define the components of a system and component interactions.

One recommendation for defining specific functional requirements involves the development of a comprehensive model of the domain of the entire health care delivery system, within which the NG-HPW subdomain is delineated. Using this domain model, and after evaluating the various approaches available for the development of functional requirements, a comprehensive set of functional requirements for NG-HPWs in different environments needs to be developed, evaluated, and made available in shared libraries.

Although the clinical and technological changes of the past year have not been very significant, it is evident that the major health care reforms under consideration in the United States Congress will have a great impact on the administrative functions of all health care information systems. When implemented, these reforms will lead to new requirements for the NG-HPW.

2.2. Major Issues in User Interface Design (P.C. Tang, V.L. Patel)

Lack of good user interfaces has been a major impediment to the acceptance and routine use of health care professional workstations. Health care providers and the environment in which they practice place strenuous demands on the interface for the next generation health professional workstation (NG-HPW).

Recommendations outlined at the working conference include:

1. Improving pen-based technology to emulate pen and paper in virtually all aspects,
2. Developing knowledge-based techniques that support contextual presentation of information, and
3. Developing new strategies and reliable metrics to evaluate user interfaces of the NG-HPW.

Methodologies and technologies from a number of emerging areas promise to have important implications for the design of NG-HPW user interface. The rapid development and application of multimedia and hypermedia technology with the improved integration of text, graphics, and images have led to the development of a number of clinical workstations that incorporate advanced graphical display capabilities.

In the past, a considerable amount of work was conducted in the area of radiographic image display. This research, which is beginning to become incorporated in the design of interfaces for more general clinical use [10], can be utilized in the development of the NG-HPW user interface.

The practical application of speech recognition has been identified as an area of long-term development. However, promising experimental medical applications have begun to appear which incorporate speech recognition for input of continuous, speaker independent speech [11].

In the area of determining user needs, a number of new methodologies from cognitive research have recently been refined, which hold considerable potential in the assessment of end-user requirements and difficulties. Video recordings of end users as they interact with workstation interfaces can provide much richer data on system usability and key aspects of human-computer interaction than is otherwise possible.

In a recent study, video recordings were made of physicians as they thought aloud and physically interacted with a computer-based tutorial program [12]. Computer-based techniques for the analysis of the video recordings were developed and refined in order to examine the video tapes and determine user difficulties, preferences, and learning patterns.

This technology is currently being extended to an in-depth cognitive evaluation by the Patel group of computerized patient record software that allows for the entry of data by physicians using pen-based input [13]. Another promising area of current research involves the application of various techniques from ethnography [15] to determine more fully the context in which systems will be used.

2.3. Medical Data and Knowledge Management by Integrated Medical Workstations (C.G. Chute, J.H. van Bemmel)

The reliability of data and the validation of knowledge are critical issues that may determine the ultimate utility of the next generation health professional workstation (NG-HPW). Continued research is necessary to facilitate an evolution toward commonality in patient data and knowledge representation in the NG-HPW. Data and knowledge are both optimally represented in decentralized information networks, although the confidentiality, ownership, and security of this information must be respected and assured.

As noted at the working conference, a number of recommendations concerning data and knowledge management should be considered in the continuing development of the NG-HPW, including:

1. The distributed model of knowledge and data is strongly recommended over that of the centralized model (see also [15]),
2. Definitions and standards should be developed for designers of encoding systems, knowledge bases, and clinical databases, analogous to the model represented by the Unified Medical Language System (UMLS [16]),
3. All developments regarding data and knowledge should satisfy legal and ethical concerns, including privacy and ownership.

2.4. Design and Processing Issues (P. Degoulet, C. Safran)

The next generation health professional workstation (NG-HPW) constitutes the natural bridge between health professional end users and the healthcare system that can provide transparent access to distributed patient data, knowledge sources, and processing services [17]. However, the NG-HPW must not be limited to the immediate working environment of the user. Instead, it should also provide access to information sources that exist locally or outside the institution [18].

In designing the NG-HPW, it is necessary to consider at least three points of view. First, from the end-user's point of view, the workstation is an environment which provides context-relevant information and processing facilities for better patient care, easier access to contextual or general knowledge, continuing education, and personal use (e.g., electronic mail, agenda planning, text processing) [19,20]. However, as the workstation is more than a simple data entry/consulting device, its design must reflect to the end user that it is an intelligent electronic associate. Second, from the engineer's point of view, the workstation is a hardware/software framework that provides the functionalities required by its end users. It includes at least some interface management, storage, communication, processing, and control facilities. Physically, these facilities can be combined in the same box (e.g., a microcomputer or workstation) or distributed (e.g., the combination of an X-Window terminal and computer facilities). As the NG-HPW will be a virtual device, its development should benefit from a software engineering approach and its architecture should rely on accepted reference models [21,22]. Third, from the decider's point of view (e.g., the hospital administrator), the NG-HPW looks like a new apparatus to be integrated into the organization, to be evaluated from a medical, social, and economic perspective.

The Need for Integration and Reuse

Despite the fact that health care professionals have acquired significant experience using dumb terminals and microcomputers to access hospital information systems and scientific or educational networks, the intelligent NG-HPW remains at the conceptual or prototype stage. This incites questions about both the integration of the NG-HPW and the reuse of legacy systems.

Functional integration is of immediate concern for the end-users of the NG-HPW. Selection of the required functions can be derived from a thorough analysis and understanding of health care professional activities, experiences with prototypes, reviews of the current literature, and consensus building among developers. Most importantly, the NG-HPW must provide a user-centric interface that hides the complexities and different interfaces of implemented applications.

Technical integration relates to the way the different components of the workstation contribute to a coherent environment. This can be considered in four dimensions:

1. *Presentation Integration*: Do the different tools have a common ap-

pearance and behavior?

2. *Data and Knowledge Integration*: Are all of the different medical objects fully considered?
3. *Communication Integration*: How do the various tools exchange information? Is semantic integration achieved?
4. *Process/Control Integration*: Is collaboration between the various tools achieved and how?

Management integration refers to the means by which the workstation becomes a part of the enterprise information system, facilitates the collaborative work of the health care professionals, increases quality and performance, and enables evolution and changes at the organizational level.

Reuse of existing systems is essential because these systems are too far-reaching and costly to be discarded in full and rebuilt from scratch. The integration and reuse are often conflicting goals [22]. For example, the success of office-integrated products (e.g., the combination of a text processor, a worksheet, a graphic system, and a database) offers hope that the latest versions of modularity and reuse may be functionally and technically achieved. Constitution of a meta database (e.g., through an object-oriented model) facilitates transparent access to heterogeneous information repositories and semantic integration [23,24], but limits the dynamic inclusion of new components (i.e., new data structures have to be declared in the meta database to be transparently accessed).

Integration Issues

Considering these integrative aspects of the workstation and the previous recommendations from the IMIA Working Conference [17,18,20,25], three main areas for further investigation should be recognized:

1. *The functional area.* What are the NG-HPW's capabilities?
   - Refinement of the NG-HPW domain (from various actor perspectives),
   - Development of goals/criteria for functional integration,
   - Evaluation of prototypes/experiences regarding the fulfillment of functional criteria.
2. *The technical area.* How should the functionalities be implemented?
   - Development of reference architecture(s) for the NG-HPW,
   - Development of goals/criteria for technical integration and component reuse,
   - Evaluation of tools/components as regards integration and reuse experience with collaborative development, promotion of reusable software libraries, etc.).
3. *The management area.* How will the NG-HPW affect the process/results of care and the cohesion of the organization?
   - Define the requirements for the optimal installation of the NG-HPW into the organization information system by network services including wide area connectivity; selection of standards (e.g., presentation, communication, development, etc.); and migration strategies,
   - Development of goals/criteria for management integration, including criteria for quality, cost, and actor satisfaction (e.g., the patients, the health care professionals, the educators),
   - Evaluation of demonstration projects and testbeds.

2.5. Sharing and Communicating Health Care Information (J-R. Scherrer, H.F. Orthner)

Exchange of information among health care professionals requires the communicating parties to agree on a communication channel, an exchange protocol, and a common language. A great deal of progress has been made in the development of communication channels.

World Wide Web and Mosaic

At the working conference on the NG-HPW, both Lindberg [26] and Esterhay [27] emphasized the major interests being devoted to the new Internet search tools [28] emerging, such as "Gopher" and "Knowbots". Indeed, it was stressed that medicine will succeed in developing future intelligent agents to assist in utilizing computer networks [29].

The World Wide Web (WWW) [30,31] is a client server information system in the tradition of other TCP/IP information systems such as Gopher. WWW merges the techniques of networked information and hypertext to make an easy but powerful global information system which supports more sources of networked and local electronic information than any other networked information retrieval tool.

The WWW protocol is called HyperText Transport Protocol (HTTP), an information provider which makes available Hypertext Markup Language (HTML) documents. These documents can include links to other documents and resources on the network, creating a virtual hypertext web of interconnected information spanning the entire globe via Internet. Non-document resources are supported with virtual documents. Items such as Gopher menus and Wide-Area Information Systems (WAIS) indexes are converted to HTML and presented to the client application as hypertext documents on-the-fly.

With WWW, libraries have the opportunity to utilize a nonproprietary hypertext system to interconnect electronic information resources locally and provide links to the growing global network of information. Additionally, this web of information would benefit enormously from the organizational and information management skills utilized in libraries. Indeed, it is unlikely that the local collections of information will become reliable resources until librarians step in and sort out what resources are available and how to access them. It is currently the most advanced information system deployed on the Internet, and embraces within its data model most of the information included in previously networked information systems. WWW is an architecture which has the capacity to embrace any future advances in technology, including net networks, protocols, object types, and data formats.

The rapid growth of WWW usage is due in large part to the easy-to-use "Mosaic" interface. The Mosaic interface was developed by the NCSA (National Center for Super Computing Applications) in Champaign-Urbana, Illinois. The first official version of Mosaic appeared in April 1993 under X-Windows. The software supports communication with HTTP (the WWW basic protocol) and is distributed free of charge by NCSA in both MAC and Windows versions.

Broadband Exchange over Trans-European Links (BETEL)

CERN (an international treaty organization with 19 member states), located on the Franco-Swiss border near Geneva, provides accelerator facilities for particle physics experiments to a distributed research community.

The BETEL platform [32], operational since September 1993, is interconnecting FDDI rings of the four BETEL users, located in Geneva, Lausanne, Lyon, Sophia-Antipolis (Nice), in a fully meshed manner, via Cisco routers and ATM Terminal Adapters (TA) located at the user sites, 24 Mb/s optical fiber circuits,and an ATM Cross-connect located in France Telecom premises in Lyon.

All BETEL applications use the Internet Protocol (IP). Three main applications are as follow: teleteaching; Physics Analysis Workstation (PAW), or PAW/BETEL (visualization of particle physics events); and shift/BETEL (distributed metacomputing).

For example, PAW provides a "packaged" environment for typical physics users in order to ease the interactive analysis and visualization of physics data events. It is also extremely flexible, as it allows one to decouple the location of the cpu server (i.e., where the actual computation is performed). The location of the disk or tape server holding the data, and the location of the user.

Trans-European Telecommunications Networks

The Commission of the European Community's "White Paper" (Brussels, December 1993) stressed that the establishment of Trans-European telecommunications networks is a recognized precondition for the creation of the "common information area". Among the generic services, such fast public telecommunication networks will promote the development of teleworking, telematic applications, and distance learning.

The same applies to telemedicine which is designed in particular to give practitioners remote access to specialist centers of excellence, to provide diagnostic aids and a basis for deciding on treatment, and to contribute to exchanges of research results in the fight against serious illnesses such as cancer and AIDS.

It is estimated that the volume of public and private sector financing in the above-mentioned areas will amount to 150 billion ECU in the next ten years.

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