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TECHNOLOGY TRANSFER IN MEDICAL INFORMATION SYSTEMS

The Potential for "Groupware" and its Implications

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Abstract

The practice of medicine is intrinsically a cooperative activity, involving not only a number of individuals but requiring access to a wide variety of types of data, produced and maintained by different people. Achieving seamless, integrated access to these data requires a new infrastructure of information systems that supports the construction of applications designed to incorporate and use external information resources. The term *groupware* may be used to connote this collective set of information resources and tools for access to them. Groupware will generate a variety of new kinds of products and services with implications for medical libraries, electronic publishing, and academic and professional collaboration.

Information technology applications in medicine and health care are often "vertically oriented" (VO) in that they are focused on specific, relatively limited domains, purposes, and functions. The marketing and distribution of VO applications are reasonably clear-cut; the individuals who are the intended users and whom the applications will affect can be identified readily.

This relatively straightforward situation does not apply when one considers a different class of technology—systems and applications that are "horizontally oriented" (HO) (8). HO applications were relatively less important until the advent of workstations and high-speed networking, as a result of which they are now a principal focus of development. The HO application is focused on communication, integration, and coordination among diverse activities. This was one of the principal motivations, for example, for early hospital information systems (initially motivated by the desire to facilitate the entry and communication of medical orders and the capture of charges for them) (3). In contrast, early VO applications in hospitals were focused on less global tasks centered within areas such as the clinical laboratory, the pharmacy, finance and accounting, or the medical record library.

A VO application is generally intended for use by a "power user," who uses the application continually for a relatively limited set of functions and who, therefore, is able to become proficient at performing them. Typical users have included billing clerks, receptionists, financial analysts, and laboratory technicians.

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To the extent that HO applications also have a limited range of functions, (e.g., early order-entry systems depended on users to perform all the data entry and communication tasks), they also focused on power users. However, most of the demand for HO capability comes from people who have not been heavy users of computers in the past and who have quite different needs.

THE NEW USERS

New categories of users include health care professionals, students, and managers; they are turning to the computer for help with problem solving, learning, and decision making. These users are beginning to require that a variety of services be available in an integrated, cohesive, consistent, and effortless fashion. A physician, for example, may wish to view the list of patients currently hospitalized or scheduled for the day; select a patient; review the patient's current laboratory results and medications; consult a differential diagnostic decision aid; revise the list of active problems and diagnostic hypotheses; obtain advice about the appropriate diagnostic test workup strategy before ordering a computed tomography or magnetic resonance imaging scan; consult reference material about the pharmacology, mechanism, route, and side effects of a contemplated medication; make a note to study a particular aspect of the patient's condition; do a literature search or retrieve a relevant portion of a textbook; view the patient's chest x-ray and ultrasound studies to see the findings that have been described in the radiology report; record the case in a research protocol; and send a message to a colleague to request a consultation.

The health care practitioner is not likely to become a power user of any single function of an information system but needs a range of services to be available. Furthermore, these services should work together to minimize redundant data entry, provide continuity, and increase efficiency.

The evolution of user populations raises a number of important issues. How are the new users identified, and how do their needs become known? Who are the purchasers of the systems? Who makes the decisions in obtaining systems for their use? Moreover, do systems even exist that can support the needs of the new users?

NEW DEMANDS ON SOFTWARE DEVELOPERS

This paper addresses some of these issues in order to facilitate the development of comprehensive applications aimed at horizontal integration and problem solving. The ideal system for this purpose is one that adapts to new needs and requirements; it will continually evolve in capacity and usefulness. Consequently, if successful, it will become (ultimately, if not initially) so broad in its scope and range of function that it will exceed the capacity of any single developer or supplier to devise, maintain, and update it. Therefore, we are entering a new phase in application development in which decomposition into functional components should be part of the design process. Applications should be assembled in an "erector set" fashion by recomposition of "plug-compatible" units. If this model is correct, it will demand a whole new set of development tools, vendors, and mechanisms for technology transfer.

Groupware

The term *groupware* frequently is used to describe those software applications that facilitate cooperative or collaborative activities among individuals or work groups. A broader and more accurate view, held by Ellis et al. (4), is that groupware is "the class of applications, for small groups and for organizations, arising from the merging of computers and large information bases and communications technology. These applications may or may not specifically support cooperation."

Much of health care practice is a cooperative enterprise within and among groups. Software that facilitates access to, and interaction with, disparate information resources and the application of these resources to a current problem are particularly useful for health care. The information resources may be accessible via the information system of the health care institution, but it is increasingly likely that the growing panoply of resources that exist outside of the organization will be of value to the health care practitioner as well.

The Role of Standards

The ability to capitalize on diverse, distributed capabilities relies to a large extent on standards. Standardization is increasingly recognized as essential and is gaining respectability and advocates. Examples include the ASTM, HL7, and MEDIS efforts to standardize interfaces between patient care system modules (11,14); the Unified Medical Language System works (12) to provide a common interlingua for communicating between systems; the ACR/NEMA standard for transmitting medical images (1); the OSI/ISO standard for network communication (18); the efforts at standardizing graphic user interfaces, focusing on UNIX X-Windows, with higher level Graphical User Interface environments (15); and the interest in relational database technology and SQL as a common medium for inquiry.

Limitations on Standardization

However, standards are not always desirable, as they may inhibit progress if they are enacted too early. Furthermore, they may be less efficient than tailored solutions (e.g., the performance limitations of relational technology for certain large-scale databases). More important, perhaps, are an adequate functional decomposition of the application and a determination of how the component modules should interrelate, as well as separation of the content of the data and knowledge from the way they are put together and used.

Problem-based Rather than Paradigm-based Approach

It is also important, when working on a problem, to have the ability to apply an eclectic assortment of components to the solution (from a toolbox). Such a problem-oriented approach is likely to be much more useful, and quicker, than paradigm-based or model-centered approaches, which focus on a particular technology or model and try to find problems for which that technology or model can be used.

A CASE STUDY IN PROCESS

We have been working on one solution to the need for horizontal, integrative problem solving. Our work is focused on the development of capabilities to support medical education and decision making. These capabilities are intended to be used via the desktop workstation, which is the locus through which appropriate data and knowledge are accessed, organized, and presented to the user (7). The data and knowledge resources themselves may reside locally at the workstation or on local servers, may be obtained from institutional computer systems, or may be obtained via national or international networks. However, the workstation is the focal point for determining what is needed, providing the protocol and method for obtaining it, and for supporting the user interaction.

Ideally, although interaction of a user with a computer may involve access to a variety of systems, this interaction should be orchestrated by software at the workstation and should support seamless integration of the different sources. Currently, this does not happen. Instead, a user must access a variety of systems for these purposes, sometimes using different terminals or workstations. The functions are not only not integrated, they may not even be on the same network. The pursuit of an integrated approach opens new opportunities, but it also raises new issues.

Factors Inhibiting Horizontal Integration

Several factors, related to the distinction between VO and HO systems, currently inhibit technology transfer.

(A) ***Isolated, Specific Applications Without Broad Appeal.*** A hallmark of VO applications is that they address rather narrow domains. Thus, they do not have broad appeal; in fact, there is limited impetus for them to address a broader appeal. Their developers usually have a local rather than institutional or global perspective.

(B) ***Varying Platforms and Architectures.*** Assembling the optimum mix of applications is complicated by the fact that they often will involve a gamut of hardware, operating systems, programming languages, interface toolboxes, database architecture, and networking conventions.

(C) ***Embedded Data and Knowledge.*** Health care practitioners need to access data, seek relevant knowledge or decision support, apply it, and continue with other activities. They may wish to access the same knowledge in other contexts, e.g., for browsing, studying, testing and self-assessment, or writing reports. The content may be used in contexts that are quite different from those intended by the original author or provider; however, to the extent that the data or knowledge is embedded in particular applications, it is not available for these other purposes.

(D) ***Proprietary Constraints and Concerns.*** Any consideration of releasing components (either data or program modules) for the use of others invokes concerns about proprietary interests. These issues inhibit cooperation and sharing; entirely new perspectives are needed.

(E) ***Lack of a Critical Mass of Functionality.*** When applications are isolated and unintegrated, a user's ability to solve problems is limited by insufficient resources. This in turn may discourage the user from working to learn the operation and capabilities of the tools that are available.

(F) ***Lack of Adaptability.*** Isolated programs may not be required to adapt to other contexts or situations, but such adaptability may be critical for their use when they are transferred to an integrated problem-solving environment.

(G) ***Idiosyncratic, Inconsistent Operation or Interface with Users.*** When they are developed independently, applications rarely utilize conventions for interaction with the user that are consistent with those of other applications. Graphical User Interfaces, such as those popularized for the Macintosh computer by Apple Computer, Inc., are an attempt to overcome this. From the beginning, published user interface guidelines and a user interface toolbox, as well as personal productivity program tools that utilized the conventions, helped to establish de facto standards that many developers continue to follow. While these guidelines are useful, they are quite generic and do not relate to detailed behavior of specific kinds of applications, such as those for database retrieval and analysis, problem solving and decision making, knowledge-base browsing, and education.

Aims of Our Approach

We are developing methods for overcoming the barriers identified above through a software architecture to:

(A) ***Support the Building of Complex Applications.*** The use of a workstation to integrate diverse educational and decision-support activities is a complex task that involves (i) functional decomposition of the required component activities; (ii) identification of modular tools to support each class of activities; (iii) data and knowledge for each of the component activities; and (iv) methods to compose, organize, and integrate these components as required for particular purposes. Modular tools are programs for storing, retrieving, displaying, and printing a specific kind of data or knowledge, as well as for responding to users' actions associated with that data or knowledge.

(B) ***Provide for Multiple Types of Data and Knowledge Types and Modular Tools to Handle Them.*** As noted above, applications typically will require multiple forms of data and knowledge at various stages of the application and for various purposes, depending on the problem being solved or the task being performed. These may include text, images, diagrams, tabular presentations, animations, manipulations of models, or presentations of the results of probabilistic or heuristic analysis or inference.

The data or knowledge needed by applications can be classified into specific categories, for which specific tools can be developed to author, assemble, store, retrieve, display, manipulate, or otherwise utilize them. Each specific kind of data or knowledge may require its own unique tools (10). A particular collection of data or knowledge, required at a particular point in an application, is termed an *entity*. Associated with each entity is the tool that is capable of manipulating it, e.g., a text, picture, spreadsheet, simulation model, animation, or analysis. A database of these entities can be used in a particular application.

Applications can be constructed through accessing particular data or knowledge entities (using their appropriate tools) and by composing or organizing the various entities in sequences and presentations that are appropriate for the task.

One result of this modularization process is that the same data or knowledge can be used or combined in entirely different ways as needed, i.e., they can be readily "repurposed." An example is the use of a database of images illustrating classical x-ray findings for (i) teaching, (ii) aiding in diagnosis by comparison with the descriptions of a current case, (iii) problem solving in a simulated-case exercise, (iv) examination and testing, and (v) illustrating an electronic textbook exposition of a disease process.

(C) ***Foster "Plug Compatibility."*** The ability to achieve the above objectives is enhanced if there are standards for the invocation of modular tools, for passing parameters, and for supervising the sequence of interaction. We believe that standards soon will be established for common types of data such as text, tables of numbers, or even bibliographic records. The standardization of more complex types of data or knowledge will require more time (e.g., parameters for decision analysis, an expert system rule base, or hypermedia content) (6). Standards are in fact evolving for network communication of various categories of clinical and administrative health care data in patient-care information systems.

(D) ***Facilitate Cooperative Development and Sharing.*** The principal consequence of this modular approach is that it allows applications to be assembled by incorporating libraries of content and utilizing libraries of tools. This means that applications can build on prior work and on the contributions of others. The emphasis can thereby be placed on developing methods of integration, not on developing entire applications from scratch.

(E) ***Enable Extension and Adaptation.*** The individual developer of an application may need to provide additional tools, which may in turn be contributed to the communal library. The author also may make available resources of data or knowledge. For those applications that require unique types of data or knowledge or unconventional formats, specialized tools must be adapted. This approach permits evolution toward standards while allowing the use of diverse data and knowledge until the standards are in place. It also allows the libraries of data, knowledge, and tools to grow.

(F) ***Support Multiple Views and Models for Various Applications.*** A final goal is to develop a number of paradigms for composing and organizing data and knowledge entities for specific purposes in order to make it easier to develop applications for those purposes. Examples include targeted problem solving, tutorial-based learning, simulated-case problem solving, general inquiry, exploration and browsing, testing, and monitoring and critiquing.

Methods

The technical methodologies we use are beyond the scope of this paper and are described in more detail elsewhere. However, this section provides a brief summary of the major features.

(A) ***Kernel Framework.*** The DeSyGNER (Decision Systems Group Nucleus of Extensible Resources) Toolbox is a kernel software environment that enables an author to construct or access data or knowledge entities using a collection of tools provided for that purpose (9). The kernel supports access by multiple users, sharing of data, versioning (to make a user's data consistent in the event of an editing change in the shared copy), and other generic services.

(B) ***Extensible Tool Set.*** The entity tool set provides support for a variety of types of data and knowledge, currently including hypertext, pictures, charts, tables, algorithmic flow chart representations of logic, and various models of probability and inference. Others can be added readily by obeying the conventions of the DeSyGNER kernel. Entity tools are based on "object-oriented programming," which facilitates the inheritance of features of a new entity type from one that is similar to it, with selective overriding and specialization of functions as needed. Entity tools are capable of performing such functions as retrieving, storing, and displaying entities of that type, performing any required manipulations, interacting with a user, and interpreting links into and out of their displays.

(C) ***Modular Data and Knowledge Entities.*** Each entity type has its own form of storage. Databases are constructed of the data and knowledge entities used in an application with an indication of the entity type it represents. Retrieval of an entity involves invocation of its tool. Thus, any number of discrete "chunks" of data and knowledge can be made available in the form of entities, to be used as required.

(D) ***Flexible Compositional Tools and Shell Environments.*** To facilitate the development of applications, "shell environments" are built on top of the DeSyGNER kernel that facilitate specific ways of composing or organizing data and knowledge entities. These shell environments allow entities to be assembled into various structures, such as page layouts, hierarchical book layouts, protocol-based sequences, hyperlinked collections, and semantically indexed collections. Several graphic and browsing paradigms are supported for traversing the data and knowledge. The shells support both the writing of applications and the interaction with users.

(E) ***Applications.*** Using the above components, an application is built as a third layer (on top of an appropriate shell, which is itself layered on top of the kernel). Applications are currently being developed or used in a variety of areas to support clinical decisions, queries, browsing in electronic books, tutorial learning, simulated case-based problem solving, the development of clinical skills, and self-examination and testing.

PRODUCTS

Our development strategy has resulted in a variety of potential products in the following categories.

DeSyGNER Toolbox

The DeSyGNER Toolbox itself is an essential component of all applications. It consists of a kernel plus a library of frequently used or essential entity tools.

Tools Library

As the toolbox is extended to support additional types of entities, either by ourselves or by users, these can be offered for distribution to other users.

DeSyGNER Shells

Shell products are required to support specific kinds of applications, both for programming and use, although one might acquire a user-only version which would not support programming. A series of shells is envisioned that will evolve in capabilities. In addition, users may build their own shells, which again could be offered for distribution.

Content Archives—"Snippet" Libraries

Data and knowledge entities can be assembled into archives, independent of particular applications, as resources for developing applications. Examples of such "snippets" of useful content could be citations of core medical research articles; definitions of medical terms; classic anatomy, x-ray, or pathology images; disease profiles; or medical taxonomic terms and semantic relations. The value of these, although limited initially, is potentially great once they have reached a critical mass of content.

Knowledge Bases

A knowledge base is an organized collection of entities that are used to support education, problem solving, or inquiry into a particular domain or subject area. These usually include the control information about how the data and knowledge are organized, linked, and presented. In that sense, they may be thought of as applications, although their execution may require the kernel and an appropriate shell.

Bundled Applications

For some purposes, it might be appropriate to combine a kernel, shell, and knowledge base into a bundled application, which can be considered a product in itself.

MARKETS

The potential markets for the above products depend on the extent to which modular approaches to software engineering become predominant and the speed with which functionality converges on the networked workstation. Recent trends in the business community (21) make it clear that networked groupware applications should be major markets for the 1990s. However, the medical information systems market has a long history; some products are still based on designs from the late 1960s or early 1970s. Therefore, change may be slow to come to some sectors.

We have chosen to focus initially on medical education, because it is a relatively untapped market and it does not have a prior history of commitment to an approach that is no longer suitable, and which would thus serve to inhibit innovation. The other reason we chose to target education is that its approaches are closely related to those for decision support, especially in view of the current high interest in case-based problem solving as a paradigm for medical education (20). (This paradigm has been promulgated by McMaster University for many years [17] and is endorsed strongly by the Harvard Medical School's New Pathway Program in General Medical Education [22].)

Our view is that as educational and decision-support resources become increasingly robust, as students who have used them become house officers and then clinicians, and as increased access to these resources becomes available through networked workstations (initially in academic medical centers), there will be a growing demand for their use in conjunction with clinical information systems and personal productivity and communication tasks. Interfaces to clinical and academic networks and systems concurrently will become increasingly available and will push the industry to provide these capabilities or support interface to them.

Our potential markets are thus, in order of maturation:

- Developers—writing tools, content libraries, kernels;
- Medical schools—curriculum applications;
- Students—skill-building and problem-solving exercises, self-assessment, tutorial tools, knowledge bases;
- Individual practitioners—decision aids, knowledge bases, self-assessment, continuing medical education; and
- Hospitals, HMOs, group practices—knowledge bases, decision aids, guideline/protocol support.

MARKETERS

The approach that we describe is not traditional but is beginning to move into the mainstream. Lotus Development Corp. (21) has recognized, for example, the need for a change in its market to emphasize tailoring, service, and customizing to support groupware. HIS markets have traditionally emphasized these aspects but have not had modular products. Groupware ideally is somewhere in between a customized application and a completed product in that it can be assembled from completed components to a large extent but requires support of the supplier to adapt it to the users' particular needs.

We envision the following means of distribution and marketing:

- Computer vendors—kernel tools;
- Systems houses—kernel, optional tool library, content libraries, shells, integration services;

- Publishing companies—shells, knowledge bases, applications; and
- Medical supply companies (e.g., pharmaceuticals, x-ray equipment, laboratory supplies)—knowledge bases, applications.

APPROACHES IN NONTRADITIONAL MARKETS

The above marketers likely will have only limited interest and/or success initially because of the novelty of the products. Therefore, we are pursuing the following additional routes:

(A) Medical schools—packaging of curriculum and supporting materials, distributed largely through mail order or third-party distributors, including publishers. The primary financial risk and responsibility for maintenance and support will be borne by the medical schools.

(B) Researcher/entrepreneur/university relationships—joint ventures, spinoffs. The responsibility and risk will be shared between the academic researcher/developer, the university, and the commercial enterprise.

(C) Clinical system linkage—value-added reseller. Niche markets are identified which specialized companies may find attractive, if they couple with and enhance existing products in existing markets. The potential attraction here is for products that add to or integrate with these existing systems, that provide access to knowledge bases, teaching aids, etc. Particular applications might focus on clinical care guidelines and protocol management, transaction monitoring/event detection/logic modules, and workstation-based interfaces to patient-care systems.

(D) Medical professional organizations or consortia—jointly sponsored and supported by constituents. The professional society or consortium approach has particular appeal, because the collective enterprise has the potential to enhance the value of the products through multiple contributions, help build critical mass, provide an endorsement to create demand, attract vendors, and attract external funding.

(E) Government agencies—subsidized databases. Government information has been a major driving force in developing the market for information services, e.g., the MEDLINE database developed by the National Library of Medicine. The pricing strategies adopted in making these available have helped to subsidize the private sector value-added resellers of both on-line services and CD ROM products. Future development of public networking services such as the Internet will be driven by such publicly funded databases and will play a critical role in access to and dissemination of other information resources (13).

The Coalition for Networked Information was formed in March 1990 by EDUCOM, CAUSE, and the Association of Research Libraries to address "the policy questions and the technical, operational, and economic challenges implicit in a national electronic infrastructure" (2).

H.R. 3695, a bill sponsored by U.S. Congressmen Conyers and Horton (19), put forth a number of specific principles for dissemination, which (as of March 12, 1990) included among the provisions a policy of unrestricted redistribution and a restriction that publicly funded databases can only be charged for by the U.S. government on the basis of marginal cost. These provisions have profound potential implications for the subsidy of developments by the public sector, for the price of third-party products (competition from the government will drive prices toward marginal cost), and for issues of control over data during redistribution.

IMPLICATIONS FOR SOCIAL/ORGANIZATIONAL STRUCTURE

The new models engendered by groupware activities may eventually alter the way people communicate, obtain information, and interact. This has implications for the infrastructure of our organizations and the channels of authority and responsibility, which may not be appropriate and will need to adapt. For example, easier communication is fostering a shift from vertical to horizontal perspectives in development. New opportunities and markets are available. New ways to finance and pay for services must be devised that are consistent with the new relationships. New responsibilities and structures will need to evolve to accommodate them.

Who Owns the Data and Knowledge?

The data and knowledge are provided by someone, either under communal sponsorship, by outright contribution, or by explicit financial arrangement. But it is difficult to foresee how the communal data and/or knowledge will be used in the future as they are excerpted and incorporated in applications. These applications may be developed by others, who may want to distribute them.

Who owns the right to use and profit from them? What constitutes a copy (5)? Is it a reproduction of the mass-storage file, a display of the item, or a printout of it? Or is it all of the above? Should a meter record a royalty for its original contributor every time it is accessed, as in Nelson's "Docuverse" model (16)?

Or should individuals contribute because they get unlimited access to the collected content, which has advantages beyond their individual contributions? An example here is the gene bank. Products can be derived using the information in the common pool, but wholesale copies of the pool cannot be made. What constitutes an allowable amount? In the electronic age, how do we revise copyright laws that were designed to protect wholesale reproduction of journals or books but do allow copies of individual pages or articles and allow reproduction (with attribution) of paragraphs, etc., in other works?

One of the difficulties in approaching these problems is that the data or knowledge may be repurposed in ways and contexts that the original author could not have anticipated, much more freely and variably than ever before. What, if any, restrictions need to be imposed for these uses out-of-context or in different contexts?

How to Provide, Disseminate, and Update?

Equally important concerns relate to mechanisms within an organization by which data and knowledge, and the tools to support them, are disseminated, maintained, and updated. How are responsibilities for these functions allocated among the developer or provider, the telecommunications group, the data processing group, the media production facility, the library or documentation center, etc.? How should services be charged, e.g., per use, per account, or as general overhead allocated to departments?

What Are the Connections, Pathways, and Resources Needed by Users?

Finally, how does the organization adapt to the flow of information and the particular channels of communication and professional interaction that become established as a result of increased network-based access to information?

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