THE MEDIGATE GRAPHICAL USER INTERFACE FOR ENTRY OF PHYSICAL FINDINGS: DESIGN PRINCIPLES AND IMPLEMENTATION

Yoder, Joseph W., Schultz, Donald F., Williams, Ben T.

University of Illinois & University Park Pathology Associates.

Abstract

The solution to many of the problems of the computer-based recording of the medical record has been elusive, largely due to difficulties in the capture of those data elements that comprise the records of the Present Illness and of the Physical Findings. Reliable input of data has proven to be more complex than originally envisioned by early work in the field. This has led to more research and development into better data collection protocols and easy to use human-computer interfaces as support tools. The MEDIGATE System (**M**edical **E**xamination **D**irect **I**conic and **G**raphic **A**ugmented **T**ext **E**ntry System) is a computer enhanced interactive graphic and textual record of the findings from physical examinations designed to provide ease of user input and to support organization and processing of the data characterizing these findings[27,30]. The primary design objective of the MEDIGATE System is to develop and evaluate different interface designs for recording observations from the physical examination in an attempt to overcome some of the deficiencies in this major component of the individual record of health and illness. KEYWORDS: Medical, Record, System, Physical Examination, Interactive Graphical Interface, Vocabulary, Hypertext, Object-Oriented, Semantic Network, and GUI.

I. Introduction

Since the inception of medical computing three decades ago there has been extensive discussion of the value of developing an interactive computer-based clinical record system for the practitioner to provide routine decision support for patient care and for the capture of both contemporaneous and longitudinal data important to clinical epidemiology, quality assurance, risk management, and the development of increasing varieties of experiential based reasoning. Although there has been some limited success, the development of a comprehensive computer-based record system has been elusive primarily due to difficulties in the capture of data elements of the Present Illness and of the Physical Findings, as well as in logistic issues such as information entry and retrieval at the site of care or need and interface issues.

The primary objectives of the MEDIGATE System are to elucidate findings from the physical exam and to investigate and implement an interface for the collection of these findings. This system should be rapid and easy to use, reduce error, facilitate interactive processing and immediate user feedback, and capture quantitative and qualitative clinical data. This report is concerned with the characterization of a usable interface for the input of physical findings and with its implementation in the MEDIGATE System.

II. Background

The importance of accurate acquisition and recording of the history and physical examination has been apparent since the origins of modern medicine in the 19th century. As early as the mid 60's, the processing of pictorial information for use in the medical field offered promise of dramatic and significant contributions to the health sciences[29]. Concepts of the interactive graphic medical record system were investigated and implemented on the PLATO (**P**rogrammed **L**ogic for **A**utomated **T**eaching **O**perations) system at the University of Illinois in 1974[22,23,24,25], using an approach for the input of data from physical findings that has been used in paper form in several contexts and that has since been termed "direct manipulation" in the vocabulary of interactive design[14,15,16].

By the mid eighties, increasing use of images and graphics was seen within the medical community along with increased awareness of a need for alternative design of computer systems in terms of mixed initiative dialogs in human interfaces[5,6,11,12,17,19]. Over the past few years, techniques such as PLATO's direct manipulation have been deemed useful but with an evident need for enhancements as in the work reported here[27,30].

Clearly, a medical computer system must embody some notions of clinical context, concepts, and methods of anticipation, clinical inference, and data acquisition. Concern for clinical inference

has often posed a trap in earlier efforts which led to the development of systems that primarily focused on diagnostic inference. Such emphasis may be in conflict with the variety of methods that the physician has developed in order to efficiently acquire and record information about the patient, as, for example, in the physician's concern in describing findings in a way that supports dynamic observations of change. Thus, the construction of any system for input of physical findings should support methods that debrief the individual physician as rapidly as possible and in a way that is cognitively satisfying. This system should also provide means for the user to access current medical techniques and knowledge sources.

III. Interface Requirements

Clinical data are often incomplete, highly subjective, qualitative, non-standardized, and sometimes ambiguous and difficult to verbalize. Contemporary interface designs have often not afforded appropriate tools to encapsulate and organize data of these types[27, 30]. Interfaces have often not provided the freedom to capture the richness of inherently graphic and pictorial findings particularly germane to essentially topographic domains as the physical examination, and there is consequent lack of confidence in the results of the processing owing to potential incompleteness and ambiguity of the data. It may be possible to use imaging techniques such as radiologic localization or ultra sound to provide more meaningful references in an individual case than that of arbitrary topographical markings such as Right Upper Quadrant.

It is crucial to design ways that make clinical information more complete, such as having the physician check for additional findings, explicitly specifying items that were examined versus those not examined, and creating a better representation of the clinical data set by using standardize vocabularies and definitions such as the work currently being done with UMLS[10] and SNOMED[3].

The ordering of regions examined is variable depending upon individual patient's problems, physicians' proclivities and specialties, and/or external standards such as routine/normal

examination forms. An invariant sequential approach will not accommodate these needs. Previous research[25] has shown both the value of allowing for guided entry of findings along with the ability for free-form entry of findings. Thus the need for a system design that supports flexibility and capability of anticipating of the physician's style is very important. The MEDIGATE System has integrated both of these approaches.

Levy and Lawrance[8,9] point out that in order to encourage the use of computers in health care settings, there must be incentives and training programs for using these systems. Positive reinforcement and on-line guidance can be strengthened through a well developed interface that allows for quick data entry that is simple and intuitive.

The above highlight important requirements to be considered in the development of a usable interface for the collection of physical findings:

- Enumerate and Characterize the set of physical findings.
- Describe the method of acquisition by the observer/physician.
- List the user's needs and idiosyncrasies.
- Provide a system that is obvious and intuitive, thus easy to learn and to use.
- Build a system that can be used under many different conditions.
- Map into standard vocabularies such as those provided by UMLS/SNOMED.
- Map into different imaging techniques such as Magnetic Resonance Imaging.

IV. Design Principles of MEDIGATE

The MEDIGATE System[1] was developed to address some of the interface problems noted during the PLATO based research, with current database and data analysis needs in mind. The primary function is to provide an intuitive user interface that is more natural for the physician to use and that may also be employed as a front-end for existing medical record and consultation systems.

The interface requirements posed challenging problems which led to the decision to incorporate into the MEDIGATE System the following characteristics which satisfied most of the needs for a dynamic interactive user interface: 1) an object-oriented approach, 2) menus that allow multiple ways of giving the same command, 3) an interface where the user can give most commands at virtually any time, 4) multiple windows allowing the user to move around the system with ease, and 5) an elaborate graphical interface that is adaptable to the users' needs.

The approach of the MEDIGATE System involves a departure from earlier interface design efforts. Rather than attempt to use the system as a great equalizer to blindly prompt the physician in a rigid, predefined unalterable sequence for additional information and to provide diagnostic advice, an explicit attempt is made to parallel the physician's current decision making and

---

1 The MEDIGATE System was developed through support from University Park Pathology Associates and LifeSpan Research Institute.

information gathering style, providing prompts only when relevant to the current context. The basic system for input of the physical findings is similar to graphic pen to paper approaches with which users are more familiar, thus allowing higher degrees of freedom for the capture of relevant data.

The MEDIGATE System presently focuses on aiding the practitioner in developing and maintaining the record of findings from the physical exam. The system utilizes a pre-defined object-oriented approach that allows the physician to graphically and textually describe the findings during an examination by the drawing of appropriate object-oriented graphics or icons representing the observations on a pictorial representation or caricature of an area of the body. The system also allows for free-text entry. Once an instance of a finding has been specified, the user can then indicate attributes of that finding by selecting the appropriate attributes and modifiers from a menu presented conjointly with the graphic. With different iconic designs, a composite of multiple findings in a given location may be created, thus depicting graphically a state of related findings.

One issue of design and development involves the nature of the background figure in the active window on which the examiner-user "places" the icon indicating a finding. The important issue is the ease and clarity with which the examiner is able to record the findings through the relational landmarks on a topographic sketch. This sketch should vary with individual differences and these

may be made more specific with reference to imaging techniques. Furthermore, the choice of the optimal figure or caricature may depend on the input device to be used. In the PLATO implementation[26], input was by touch using an infrared grid over the interactive graphic display panel - though convenient, resolution was limited and immediate proximity to the examiner, and hence, often, to the subject, was required. Current mouse and trackball input devices along with the advent of pen-based computing not only provide much higher resolution for input but also support greater flexibility in the placement of the input monitor, leading to less intrusion on the attention and curiosity of the patient.

There is also the possibility of getting more realistic landmarks from current imaging techniques such as Magnetic Resonance Imaging, Computerized Axial Tomography, Radiological and Echo Scan. Whether or not this will provide meaningful information for more accurate analysis has yet to be determined.

An important tactical design is to minimize the number of explicit frame selections required of the examiner by embedding such selection in pre-determined sequences and/or sets of frames sensitive to the environment of care, the patient, and the practice and custom of the examiner. These factors should determine not only the sequence of examination and input but also the level of detail involved at each stage.

In order to maintain the integrity of the database it is vital that the examiner not be prompted to

respond to queries at a level of detail beyond that of their basic observations; it is only in this way that the system can "know" the level of detail implied by the examiner when s/he uses broad categories such as "within the normal range" or "normal to percussion and auscultation," as well as to be assured that the database thus secured does not contain surplus and/or spurious findings[27]. Similarly, the examiner must be able to defer or leave out portions of the examination without generating operational complexity or other user penalty, and must be able to express uncertainty regarding any observation for which input is provided. Finally, the vast majority of observations (somewhat over 95%)[25] can be anticipated and properly characterized through appropriate system design. Provision must, of course, be made for input by free text of the other 5%.

Since the majority of observations from portions of the physical examination are normal most of the time, the custom of physicians has been, on paper forms, to simply and rapidly check off "normal" when appropriate for each of the regional or physiologic systems into which the physical examination is divided. The difficulty here is that there is no way for an external observer to know - according to the individual training and custom of the examiner, the environment of care, the problem presented during that clinical encounter, and the like - what elements of the physical examination the particular user has actually explored, and hence, what s/he intends to imply by "normal" or other term of art. In the MEDIGATE System, an essential component of an initial customization is that the user specify at the outset those variables that the user-examiner

customarily/routinely means to imply when using default indicators such as "normal." This routine set of findings generates data input and associated text that is considered “normal” for a particular region.

Thus the resulting collection of findings is less ambiguous and through the use of thesauruses, it can map into the standardized vocabularies such as those provided through UMLS and SNOMED making it possible for better analysis. Hence, the resulting database (and narrative report) has greater reliability and validity than when assumptions as to the meaning of default indicators must be made by external users of the database.

There are a number of advantages achieved by the use of direct manipulation techniques, by the use of core defaults of routine sets of findings, and by the use of automatic text generation: 1) Entry is easy and expedient; 2) By not relying on user memory, omission of findings is minimized; 3) Quality assurance is improved; 4) Risk management is enhanced; and 5) Record keeping for later use is facilitated.

V. Interface Specification and Utilization of MEDIGATE

The interface for the physical examination in the MEDIGATE System consists of a series of frames depicting the whole body and regions of the body; e.g., head, neck, chest. Each region has an associated set of physical examination findings[2]. These are grouped in relation to a primary category - usually in reference to a body system; e.g., abdomen region: gastrointestinal system and posterior chest: pulmonary (lung) system. Significant portions of other systems may be included; e.g., major blood vessels in the abdomen region.

The starting physical exam window contains a table of contents to which the user has immediate access (see Figure V.1). Some of the body regions have an "N" in the box to the immediate left. This designates what the physician routinely checks for and defaults to "N" for "Normal". Further frames or the regions of immediate concern may be selected at any time by clicking on the appropriate region of the whole body caricature or through a menu.

The order of frames may follow a sequence tailored to the user's custom, or a sequence that s/he has altered for a specific patient, or a sequence determined by external but pre-defined programs such as those dependent on complaints, patient response forms, questionnaires, site and/or

---

2 The MEDIGATE database structure of findings was generated by Donald F. Schultz, M.D., based upon early work on PLATO along with the categorization of medical findings as found in clinical texts such as DeGowin[4], Merck Manual[2], and Mosby's Guide[13].

circumstances of the patient encounter, or follow-up protocols, but always with the option of overriding such pre-defined sequences to call up any desired input frame on demand.

The examiner-user interacts with a graphic caricature, in the active window, of the region of the body that is the subject of attention. The physician may quickly enter the current findings by: 1) duplicating, placing and copying pre-programmed graphics and/or icons on the topographic caricature, 2) drawing in the findings freehand style as they are noted, or by 3) mapping to a pre-defined grouping of findings and modifying the findings to match the specific findings for the patient in question (Retrograde Maps[3])[27]. Retrograde Maps (RMaps) were suggested by Ben Williams[21] in the mid 70's as a method to allow the physician to select a pre-defined grouping of findings, thus enabling for the quick entry of the findings.

The idea of RMaps can be thought of as a frame. A frame is a collection of semantic net nodes and slots that together describe a stereotyped object, act, or event[28]. The RMaps within the MEDIGATE System are frames that consist of collections of findings that the physician can quickly map to and modify in order to match the specific findings for the patient in question. The retrograde map serves as a reminder of findings usually associated with a disease process, as well as a reminder of key findings that may differentiate other disorders with a similar presentation.

---

3 To the best of the *authors'* knowledge, the term "Retrograde Mapping" was first coined by Ben T. Williams, M.D.

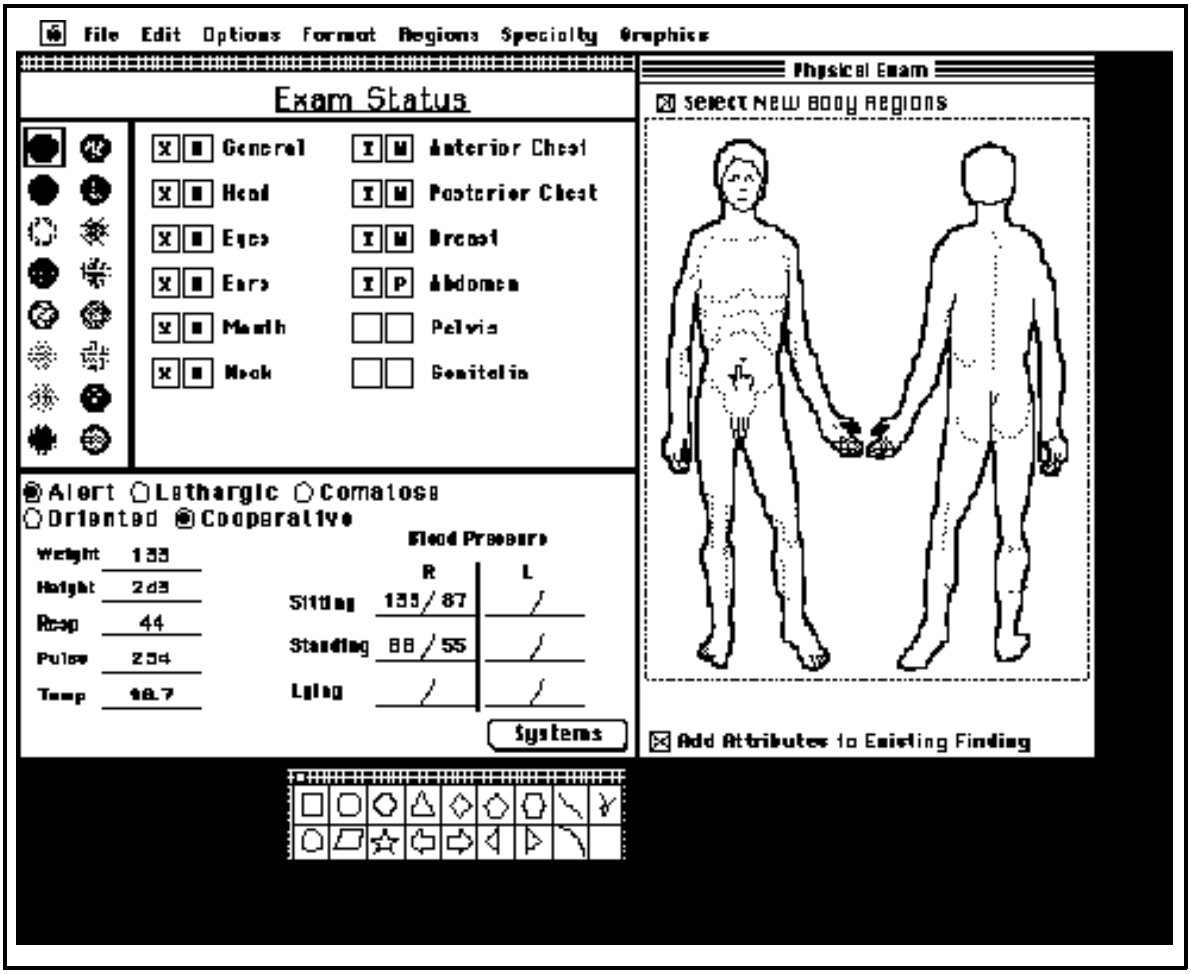

Figure V.1 -- Physical Exam Window

Thus, the examiner places a given instance of a finding (object) in the desired location. These objects are selected from a hierarchical listing of classes of objects. The specific instance of the

finding (object) encapsulates the given frame of knowledge about itself - i.e., each finding "maintains" the attributes that are important to its characterization. Hence, once a given instance of the object has been placed in the desired location, the examiner may select attributes about the object through the knowledge-base of information contained within the object specified. A listing of attributes to be selected is displayed by hierarchical menus and is also used for generation of the narrative notes of the physical findings and then for passage of the finding to the database. Some attributes are also computer generated through graphical placement of the object as in a specific sub-division of a region; e.g., Abdomen: Right Upper Quadrant. This saves user time and reliance on human memory. Upon completion of the exam, the physician will have immediate feedback as to which regions have been checked along with a note of any problem areas denoted by "P" (see Figure V.1). In this patient "N" has been automatically replaced by "P" in the abdomen region.

For instance, upon examination of the abdomen, the physician will select the abdominal region from the Exam Status window (see Figure V.1). This will open to the abdominal frame (see Figure V.2) which defaults to what the physician routinely checks for and finds as "normal" findings. This physician routinely checks for scars, tenderness, point pain, masses, and guarding. If none of these are present, then they are designated normal (i.e., the "N" in the box directly left to the finding). If the patient has "Normal" findings within the abdomen, the physician simply

clicks on the box to the left of the "N", generating an "X" to designate by an intentional affirmation that this patient has had all of these findings checked and they were normal. While most systems allow for the description of findings not checked to be listed as normal without any positive affirmation, thus possibly allowing for ambiguities, MEDIGATE forces the examiner to designate what has and what has not been checked. This constraint should minimize ambiguities and provide for a more complete database.

If there are abnormalities during the examination, a different procedure would follow. For example, during this abdominal examination, the physician notes the following findings: 1) Flat Contour, 2) Medium Wall, 3) Point Pain-Located Within The Right Lower Quadrant and Right Upper Quadrant, 4) Moderate Guarding-Located Within The Right Lower Quadrant, 5) Marked Tenderness-Located Within The Right Lower Quadrant and Left Lower Quadrant, 6) No Scar, 7) No Mass, 8) Bruit-Located in the midline area that is possibly an aneurysm and 9) Rash-Located Within the Right Upper Quadrant (see Figure V.2).

The findings that are immediately visible through the finding window can be entered through the selection of the appropriate findings and then modifying each finding from a menu of possible attributes. These findings can either be drawn in free-hand or by selecting an icon from a palette of pre-defined shapes and reproducing that shape on the topographic caricature. Access to other findings can be achieved through a couple of different means; either through the selection of

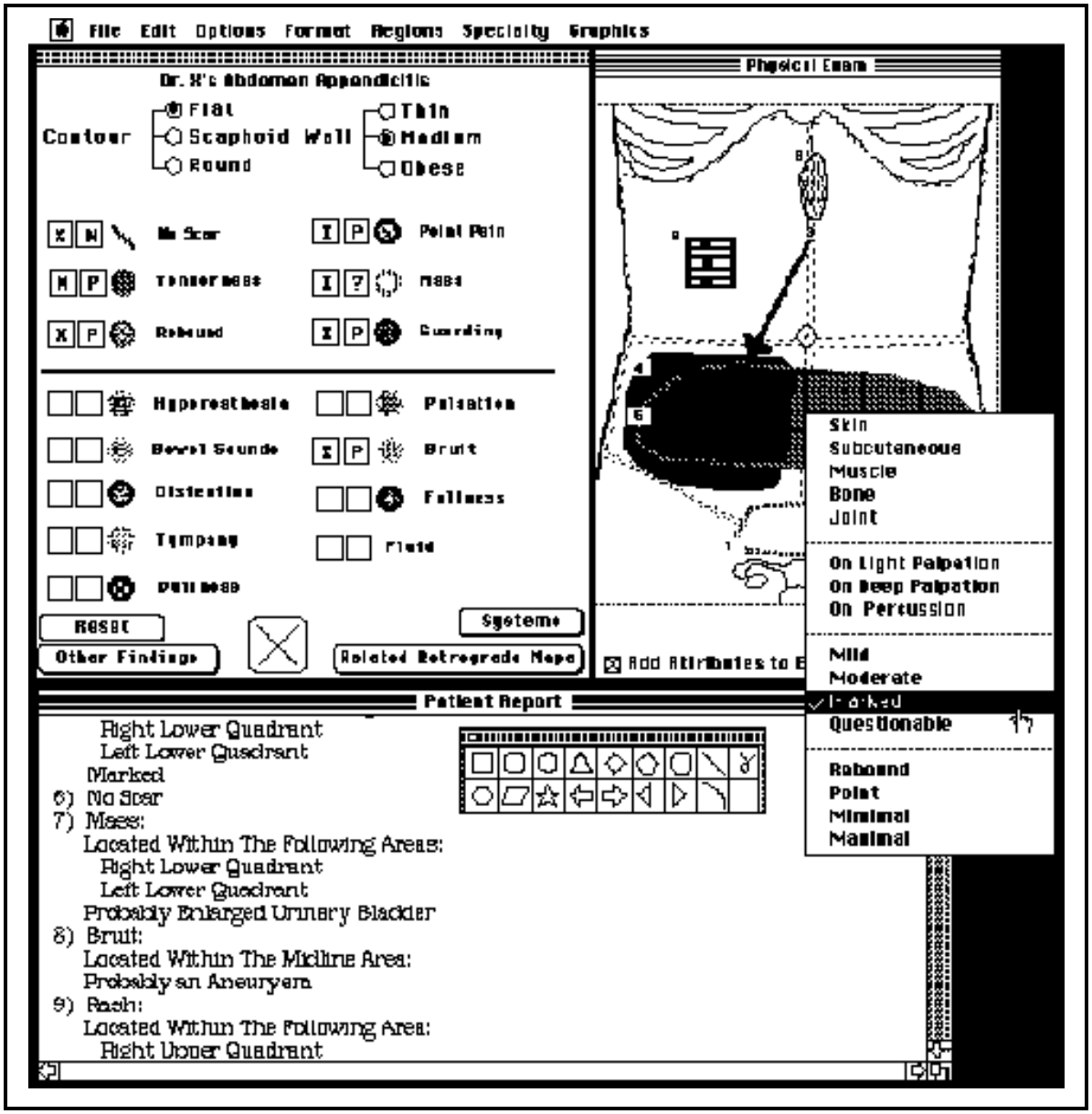

Figure V.2 -- Abdominal Frame of Physical Exam

"Other Findings" or through the selection of findings based upon "Systems". Once an abnormality is noted, other abdomen findings are immediately displayed. Here the physician is able to select Bruit and free-hand draw a diagram showing its location and shape. However, rash is not available as an immediate finding within the abdomen frame. To enter this finding, the examiner can simply open the skin or dermatological findings window by selecting it from the "Systems" menu and enter the rash finding along with its attributes.

After entering the attributes for a specific finding, text designating the appropriate attributes of that finding such as "Tenderness" is generated and displayed in the *Patient Report* Window (see Figure V.2). Note that in this example, "Tenderness" has the following attributes associated with it: Location Within the Right Lower and Left Lower Quadrants and Marked. The locations are automatically generated by the previously defined sub-divisions (noted by dotted lines) while the "Marked" attribute was selected from a pop-up menu. The text for these attributes is generated by an expert algorithm designed specifically for the MEDIGATE System. The text generation algorithm can be customized to accommodate an area of practice or the examiner's preferences. A crucial concern is the ongoing feedback to the physician provided by the developing textual report.

VI. Future Work and Ideas

Currently the MEDIGATE System has only been fully incorporated into the abdomen and chest regions. Although work has been done towards completing the other topographic regions, this is still incomplete. Thus, the database needs to be enhanced to incorporate the principles developed throughout and to include complete listings of findings within each body region. The MEDIGATE program should also include hierarchical listings of findings in the different body systems, such as the orthopedic system.

Although it is very easy for the user to quickly move to a body region such as the abdomen and enter findings for that region, it is still difficult for the physician to quickly enter normal findings that s/he routinely checks for. As discussed earlier, work has been done towards quick entry of routine findings through the Exam Status window, but the front end interface still needs enhancement so that these routine checks can be done just as quickly as the physician does now, still retaining the ability to go deeper into the system upon demand.

Recently, much development has been done with pen-based computers. Pen-based system are not only more natural for the physician to use but also brings the view closer to the action, thus providing more direct continuous control which will provide for higher precision. As previously noted, written records can not be as precise as with MEDIGATE without much effort. This is

because MEDIGATE emphasizes completeness and precision, and suppresses ambiguity by its use of the current technology which promotes: 1) accuracy (graphical feedback), 2) verification with immediate feedback, and 3) the teasing out of subtleties from clinical data. By the blind implementation of a medical record with a pen-based system, there will still be the problems of ambiguity, inaccuracy, and incompleteness that are associated with hand-written records.

Pen-based systems built on a good interface incorporated with proper constraints would provide the user with a tool that they are familiar with (the pen) and also provide them with a way to organize their data better, along with the other benefits that are provided by the processing power of a computer. This would provide the physician with continuous control methods such as scribing, drawing, and gesturing for obtaining more qualitative and quantitative data. There are still unresolved problems associated with handwriting recognition techniques that some of the methods being studied by fuzzy logic may help answer and make pen-based systems available as a valuable interface tool.

Multimedia technology is also progressing at a promising rate and the integration of audio and video links that provide for immediate reference may also be a powerful addition to any medical information system. This could allow for the examiner to call up a medical reference and/or a video picture of a procedure of concern, thus getting immediate feedback and reminders. Telemedicine[18,20] is of importance in such areas as consultations and telemetric situations as in the

hospital Emergency Department. Thus, the recording of findings can be collected and graphically displayed at a remote site for evaluation and decision making.

It is also critical to tie any system into a common vocabulary such as the work being done in UMLS and SNOMED. This provides meaningful use of information across different database systems. In order to interact with these vocabularies, it is imperative to associate a coding for the graphics indicating the findings along with their respective locations. There also may be a way to map from the coding of the location to a specific subset of symptoms.

Finally, there have been many advances in the use of the Intranet and Internet that allow users of different systems to share information. With the advent of the World Wide Web (WWW) information, that was only available through articles in journals which may take weeks or months to become published and disseminated, is now available within minutes to hours of production. MEDIGATE can utilize current searching techniques and immediately access new information as the need arises in a clinical or research situation for diagnostic, treatment or other medical purposes. Also, JAVA[7] and ActiveX[1] has made it so that full-blown applications can be developed and run on the WWW. This makes it possible to implement the MEDIGATE system for use on the WWW and new releases can be immediately accessed along with any new mappings to systems such as UMLS, SNOMED, and the like.

VII. Summary and Conclusions

The solution to many of the problems attendant upon the computer-based recording of the medical record has long awaited the advanced technological development of computer hardware and software systems. Reliable input of data has proven to be more complex than originally envisioned by early work in the field. This has led to more effort into the development of good interfaces. The characteristics of the user are very important to the development of a good interface system.

In the past, most medical information systems have not utilized many of the tools of software engineering, especially in the area of interface design. Recently technological advances in computer science have provided some means to meet the complex needs of the medical community.

Components of the medical record system are examined as repositories of medical data, each with characteristic problems of input and retrieval. In early systems, the focus was primarily on the storage and processing of the data rather than on the problems associated with the collection and display of the data and the associated issues of interface design.

An adequate interface system must be concerned with the cognitive and manipulative style of the user together with the characteristics of the data. Additional software engineering techniques can be developed to utilize this principle to provide for an easily useable interface.

The MEDIGATE System has been developed with current technology to study some of the problems in interface design. The design employs an object-oriented approach through the direct manipulation of graphical objects, along with hypertext approaches and semantic networking to build a system that is more natural to the user.

Principles of the MEDIGATE System can be applied to newer technologies such as pen-based computers and voice recognition systems, thus allowing for greater flexibility and versatility in the user interface. MEDIGATE could be used as a core component for these emerging technologies, thus enforcing completeness, disambiguation, and precision.

It is envisioned that the principles embodied in the MEDIGATE System will play a significant role in future computer-based medical information systems by allowing for the capture of meaningful data and providing for display and utilization of the data, thus enhancing the quality of patient care, risk management, and clinical research.

References

[1] ActiveX, ActiveX Home Page, URL: http://www.activex.com, 1997.

[2] Berkow R., & Fletcher A.J.; The Merck Manual of Diagnosis and Therapy; Fifteenth Edition by Merck Sharp & Dohme Research Laboratories, Rahway, N.J. 1987.

[3] Cote R.A., Rothwell D.J., Palotay J.L., Beckett R.s., Brochu L., eds.; The Systematized Nomeclature of Human and Veterinary Medicine; College of American Pathologists and American Veterinary Medical Association, 1993.

[4] DeGowin R.L.; DeGowin & DeGowin'ssBedside Diagnostic Examination; Fifth Edition by Macmillan Publishing Company, New York 1987.

[5] Engelbrecht R.; "Experiences in Designing Human-Computer Interfaces for Doctors' Office Computers"; Proceedings of the IFIP-IMIA Second Stockholm Conference on Communication in Health Care, Stockholm, Sweden, Peterson H.E. & Schneider W. ed, pp. 219-233, 1985.

[6] Ikeda H., Ohtomo M., & Kambe M.; "Intelligent Access of Health Care Databases"; Proceedings of the IFIP-IMIA Second Stockholm Conference on Communication in Health Care, Stockholm, Sweden, Peterson H.E. & Schneider W. ed, pp. 257-260, 1985.

[7] JAVA; JAVA Home Page; URL: http://java.sun.com, 1997.

[8] Levy A.H. & Lawrance D.P.; "Data Acquisition and the Computer-based Patient Record"; in Aspects of the Computer-based Patient Record, M. J. Ball and M. F. Collen, Eds., Springer-Verlag, New York, pp. 125-139, 1992.

[9] Levy A.H. & Lawrance D.P.; "Information Retrieval"; in Aspects of the Computer-based Patient Record, M. J. Ball and M. F. Collen, Eds., Springer-Verlag, New York, pp. 146-152, 1992.

[10] Lindberg D.A.B. & Humphreys B.L.; "UMLS Knowledge Sources: Tools for Building Better User Interfaces"; in Aspects of the Computer-based Patient Record, M. J. Ball and M. F. Collen, Eds., Springer-Verlag, New York, pp. 121-125, 1992.

[11] Mandil S.H.; "The Relevance of Images and Graphics to Primary Health Care"; Proceedings of the IFIP-IMIA Second Stockholm Conference on Communication in Health Care, Stockholm, Sweden, Peterson H.E. & Schneider W. ed, pp. 45-66, 1985.

[12] Reichertz P.L.; "The Need For Alternative Design Of Computer Systems For Improved Human-Computer Communication"; Proceedings of the IFIP-IMIA Second Stockholm Conference on Communication in Health Care, Stockholm, Sweden, Peterson H.E. & Schneider W. ed, pp. 85-97, 1985.

[13] Seidel H.M., Ball J.W., Daines J.E., Benedict G.W.; Mosby'ssGuide to Physical Examination; The C.V. Mosby Company, St. Louis 1987.

[14] Shneiderman B.; "The Future of Interactive Systems and the Emergence of Direct Manipulation"; Behavior and Information Technology, **1**(3):237-256, 1982.

[15] Shneiderman B.; "Direct Manipulation: A Step Beyond Programming Languages"; IEEE Computer, **16**(8):57-69, Aug. 1983.

[16] Shneiderman B.; Designing the User Interface: Strategies for Effective Human-Computer Interaction; Addison-Wesley, Reading, Mass 1987.

[17] Solheim B.G. & Hansen R.; "Actual Problem For Human-Computer Communication In Hospital Laboratory Systems"; Proceedings of the IFIP-IMIA Second Stockholm Conference on Communication in Health Care, Stockholm, Sweden, Peterson H.E. & Schneider W. ed, pp. 81-84, 1985.

[18] UIOWA; University of Iowa Telemedicine Web Page; URL: http://www.lib.uiowa.edu/hw/telemed, 1997.

[19] Verplank W.L.; "Graphics in Human-Computer Communication: Principles of Graphical User-Interface Design"; Proceedings of the IFIP-IMIA Second Stockholm Conference on Communication in Health Care, Stockholm, Sweden, Peterson H.E. & Schneider W. ed, pp. 113-130, 1985.

[20] Wells R.S. and Lemak C.H.; "Beyond adoption to sustained use: Telemedicine for rural communities"; Telemedicine Journal 2(4): 285-293. 1996.

[21] Williams B.T.; Computer Aids to Clinical Decisions; CRC Press, Inc., Boca Raton, Florida, Vol 1 1982.

[22] Williams B.T., Johnson R. & Chen T.T.; "PLATO-Based Medical Information Systems-Overview"; Proceedings of the 1st Conference on Medical Info. Systems, Urbana, Illinois, pp. 145-149, October 17-18, 1974.

[23] Williams B.T., Chen T.T., Schultz D.F., & Johnson R.; "A Terminal-Oriented Clinical Record System"; Computer Graphics, **9**(1):115-135, 1975.

[24] Williams B.T., Chen T.T., Schultz D.F., Moll J.D., Flood J.R. & Elston J.; "PLATO-Based Medical Information System--Variable Keyboards"; Proceedings of the 2nd Conference on Medical Info. Systems, Urbana, Illinois, pp. 56-61, September 24-25, 1975.

[25] Williams B.T., Chen T.T., Johnson R., & Schultz D.F.; "A Terminal-Orientated Clinical Record System" in Perkins W.J., (ed), Biomedical Computing; University Park Press, Chpt 36, pp. 311-321, 1976.

[26] Williams B.T., Foote C.F., Galassie C., Schaeffer R.C.; "Augmented Physician Interactive Medical Record"; Medinfo 89: Proceedings of the 6th Conference on Medical Informatics, Beijing-Singapore, Barber B, Cao D, Qin D, Wagner G ed, North-Holland, Amsterdam, pp. 779-783, 1989.

[27] Williams B.T., Yoder J.W. & Schultz D.F.; "The MEDIGATE System for Direct Entry of Physical Findings by the Examiner: User Interface Issues"; Proceedings of The International Health Evaluation Association Annual Symposium on The Art and Science of Preventive Medicine, La Jolla, California USA, Felitti, V.J. ed, pp. 106-114, 1990.

[28] Winston P.H.; Artificial Intelligence; Second Edition by Addison-Wesley Publishing Company, Inc., MA 1984.

[29] Yoder R.D., Evan M.R. & Sweeney J.W.; "Processing Pictures With Computers"; JAMA, 200(13): 119:123, June 26, 1967.

[30] Yoder J.W.; The Role of Human-Computer Interaction In Medical Information Systems: Principles And Implementation of MEDIGATE"; Unpublished Master Thesis, University of Illinois at Urana-Champaign, 1992.