Structured Data Collection and Knowledge-Based User Guidance for Abdominal Ultrasound Reporting

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ABSTRACT

This paper describes a system for structured data collection and report generation in abdominal ultrasonography. The system is based on a controlled vocabulary and hierarchies of concepts; it uses a graphical user interface. More than 17,000 reports have been generated by 43 physicians using this system, which is integrated into a departmental information system. Evaluations have shown that it is a well accepted tool for the fast generation of reports of comparatively high quality. The functionality is enhanced by two additional components: a hybrid knowledge-based module for "intelligent" user guidance and an interactive tutoring system to illustrate the terminology.

INTRODUCTION

The majority of medical records and medical reports is still paper-based, although clear advantages of computer-based medical records have been shown [13]. Problems of central importance are data entry into electronic systems and the extraction of structured information out of unstructured data. While analyses of free text documents [7] created by secretaries or by direct speech recognition systems represent a remarkable way of extracting information, several systems have been presented during the last few years that use structured or "predictive" data entry [1,2,3,16]. These systems are based on controlled vocabularies and use graphical user interfaces. Their objectives are to bridge the gap between paper-based and electronic patient records, to facilitate physician data entry, and to create reusable information of high quality.

This paper describes a system for structured data collection and report generation in abdominal ultrasonography which has been in routine use in an academic hospital for 2 years. The system has been based on analyses of large numbers of free-text reports. The design methods and results are transferable to other application domains like endoscopy or other radiological methods.

Two additional modules have been added to the main component for structured information entry: a knowledge-based system, and an interactive tutoring system.

The objectives of the knowledge-based component are to guide the user by displaying a ranking of possible diagnoses and of additional input-triggered questions as well as further suggestions. This module has been realized on the same platforms as the main component, and it is fully integrated.

The basic idea of the tutoring system is to illustrate the vocabulary by a significant number of images covering a broad clinical scope. A clear need was identified for two types of the tutoring system: an integrated component that presents reference images during routine work, and a separate teaching component where students can work without time pressure. This second type of system has been realized on a separate platform.

This paper presents technical aspects of the three system components. In addition, some results of the various evaluation steps are summarized.

METHODS

Structured data collection

Before the development of the system, 6,837 handwritten ultrasonography reports, 9,873 freely dictated gastroscopy reports, and 500 freely dictated medical discharge letters were analyzed. These analyses concentrated on contents and form, frequencies of words, and type-token-relations (number

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of different words divided by number of words). Using the results of these analyses, a controlled vocabulary was defined by domain experts of the German Society of Ultrasound in Medicine.

The screen layout is based on structured forms with input-triggered (dynamic) highlights of the next relevant screen objects. Depending on the nodes actually chosen, the system points out for which nodes input is expected next, thus reminding the user to enter important information and leaving out irrelevant alternatives. The user is guided through short sequences of screens.

A formal language has been developed which allows the description of a medical sublanguage. The semantics are based on concept hierarchies (anatomy / topography, morphology, function, characteristics of the examination); the concepts are represented as screen objects. The syntax includes a formalism for the description of hierarchies of concept nodes in (sub-)trees, constraints for the number of nodes eligible in a (sub-)tree, and constraints concerning the order of input in (sub-)trees. These mechanisms allow the characterization of input objects as alternative choices or as obligate input; furthermore they remind the user to enter medically necessary context information.

The generation of reports is realized by means of a second description language. As the analyses of free text reports have shown that the use of comparatively simple nominal phrases is adequate for report generation, the text generator is based on mechanisms for direct expansion of form texts and for the generation of textual lists. For the adaptation of flexions, conditional expressions are used.

The system has been implemented under UNIX in C by use of the tools "lex" and "yacc". Graphical frontends are realized under X-Windows and OSF/ Motif, in addition graphical MS-DOS frontends are used. Data are stored under the distributed relational database management system INGRES.

After the first 2,491 reports, a system evaluation has been performed [10] which included a questionnaire to determine user acceptance. After 14 months (and 8,827 reports generated), a second questionnaire was issued.

The integrated knowledge-based module

For the derivation of possible diagnoses based on given user input, two prototypes have been realized: a rule-based system and an artificial neural net [11]. Mainly because of advantages for the acquisition of knowledge, especially the possibility to use revised cases from the database [11], the neural net was chosen for the further development and integrated into a hybrid approach. A three-layer, fully connected, feed-forward network has been created for the diagnosis of liver diseases. It contains 76 neurons in the input layer, 30 hidden neurons and 27 output neurons. The system has been implemented in C and trained with the backpropagation algorithm [17]. The activation values of input neurons are interpreted as symptom manifestations (0/1 for absent/present) and the activations of output neurons as probabilities of diagnoses [cf. 14]. The vectors consisting of input and output activation values are used to train the net. Training vectors may be generated and checked by rules. Deviations from rule-generated vectors are possible.

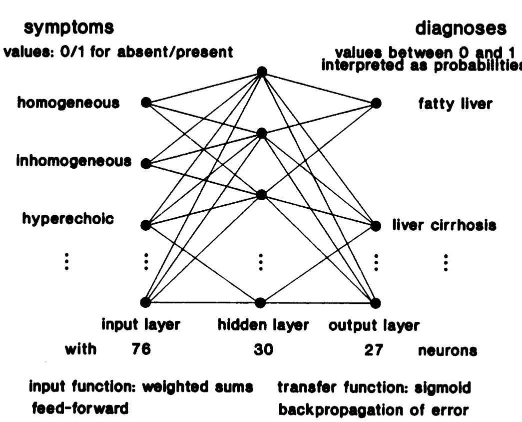

Fig. 1: Characteristics of the neural network.

The training data set consists of 1,030 profiles, which have been derived from the literature and from real cases in the database. No case was directly taken from the database without previous expert review.

For the second step, i.e. the derivation of questions and suggestions from the ranking of diagnoses, rules are used. They were implemented using a (pre-) compiler based on "lex" and "yacc". The knowledge-based component has been fully integrated into the system for UNIX and DOS-frontends.

A laboratory evaluation has been carried out. From the database 215 cases were chosen and diagnoses were ascertained from the corresponding medical records. In 77 cases, diagnoses had been histologically confirmed. These (clinically or histologically confirmed) diagnoses of the medical records were compared with the system's final proposals. In order to get equally distributed diagnoses, reports were chosen from the database system according to diagnosis categories: if more than 20 reports with a certain diagnosis were present, 20 of them were chosen randomly, otherwise all cases were used.

The interactive tutoring system

The tutoring system is based on the same terminology as the documentation system described. It contains an introduction into the method of ultrasound examination (including the meaning of technical parameters and images illustrating possible pitfalls), anatomical and corresponding ultrasound images, and a quiz component. The main part allows the illustration of findings and diagnoses by ultrasound images. Series of images can be displayed for each term (and combination of terms) of the vocabulary, and for each diagnosis. The browsing facilities of a hypermedia system are utilized to allow views from different perspectives. In addition to hierarchical links, cross links are extensively used.

The system has been implemented on Apple Quadra computers with SuperCard (Aldus Corp.), QuickTime (Apple) and db_Vista (Raima Corp.) by use of XCMDs. Images have been scanned from hardcopies or taken from the video-output of the ultrasound device via frame-grabbers.

RESULTS

Structured data collection

The analyses of handwritten and dictated reports and letters showed that ultrasonography reports are highly suitable for structured data collection. Compared to medical letters, texts are highly structured, the form is simple and shows a concentration on nominal phrases. Verbs are rare, and the type/token relation is low. Fig. 2 shows an example of the numerical analyses.

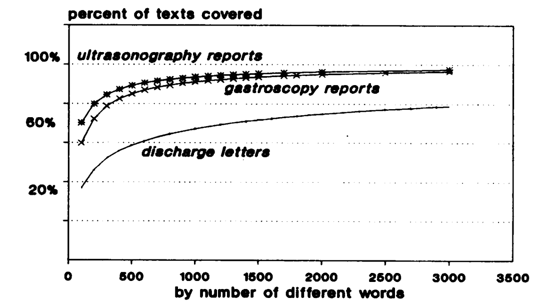

Fig. 2: As a complexity measure, the percentage of texts covered by different words was calculated.

The system for structured data collection has been in routine clinical use for 2 years, and more than 17,000 reports have been created by 43 physicians and stored in an INGRES database. Fig. 3 shows a screen of an MS-DOS frontend.

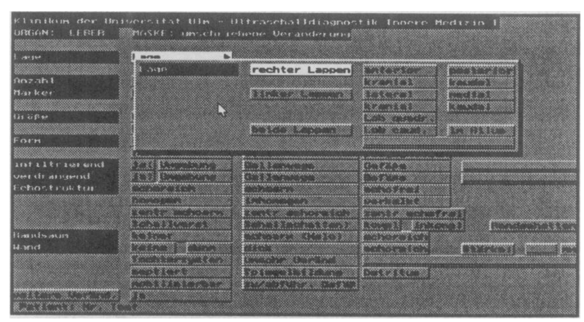

Fig. 3: Typical screen for data input on a PC.

After the first 21 weeks of routine use of the system, 2,491 reports had been generated by 14 physicians. An evaluation [10] showed a significant increase in report completeness, data correctness of almost 100%, kappa values [4] of well above 0.75 for objectivity and validity, and good user acceptance. The average data entry time was less than 2.5 minutes. Additional free text was used in about 30% of the reports. After 14 months, a second survey confirmed the high user acceptance.

The knowledge-based component
Suggestions generated by the knowledge-based module are continuously displayed in additional windows for the UNIX-version, and invoked by mouse click on the main screen for the DOS version. Response times on 80386/80486 frontend computers are negligible. Fig. 4 shows an example under UNIX.

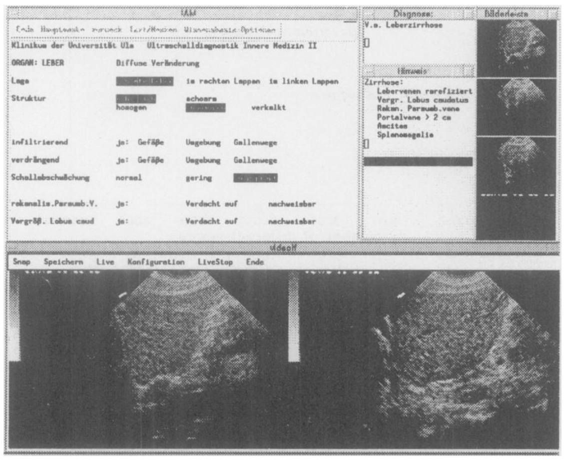

Fig. 4: Integration of the knowledge-based component. To the right of the form for structured data input, windows of the knowledge-based system are shown, here displaying one suspected diagnosis and several suggestions. In this UNIX-version, the live video window and several snapshots are displayed.

The system is in the prototype stage for diseases of the liver and has undergone a laboratory evaluation. The agreement between the clinical (in part histologically confirmed) diagnoses of the 215 cases and the system's proposals has been strong. As two of the evaluation parameters, a kappa coefficient [4] of 0.85 and an area under the ROC curve [6] of 0.91 were calculated.

The tutoring system
The tutoring system has been realized as a standalone prototype for the organ liver. To date, 400 images have been acquired. Live sequences will be added in a later stage.

The system combines elements of a conventional textbook of ultrasonography, a textbook of differential diagnosis, an atlas of ultrasonography and an atlas of anatomy. Fig. 5 shows an example.

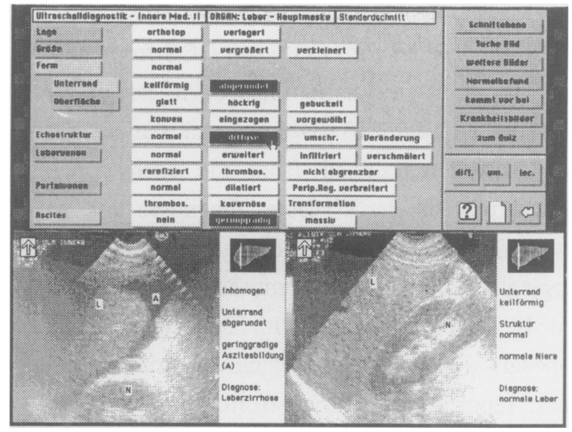

Fig. 5: Screen of the tutoring system. Structured forms are used for the selection of items to be illustrated by images and for the description of selected images. Browsing from findings to diagnoses and from diagnoses to findings is possible. The ultrasound scan planes can be changed.

DISCUSSION

Several systems for structured data input have been presented recently [1,2,3,16] which have one goal in common: to offer relevant choices by reacting adequately on given input. The interface described here is comparable, but somewhat closer to paper-based forms with which physicians are acquainted. The positive results of the evaluation steps confirm results of other groups [e.g. 5] and can be interpreted as arguments for a systematic data collection and precise definition of medical terms. It remains to be seen, if the chosen form of the user interface or somewhat differing approaches will prove useful in future applications, while new technologies like handwriting recognition [12] must show if they are sufficiently stable. On the other hand, the promising approach of extracting information out of free text [7] has to overcome problems of high interobserver variation and low completeness in free text documents [9,10]. More evaluations are needed.

Among the important ideas realized in the described approach are full integration of a knowledge-based system into the routine data-management environment [18] and the realization of reminder effects [13]. While structured forms already help in not overlooking important items [5], user guidance is enhanced here by dynamic highlighting of screen attributes, and by displaying additional screen windows with suggestions derived from the knowledge-base. Normal routine data input is not negatively affected by this knowledge-based module. Considering the number of different diagnostic methods in medicine and the rapid progress of medical science, knowledge acquisition and knowledge maintenance becomes an extremely important issue for such a highly specialized system. We therefore have chosen a hybrid technology that facilitates knowledge acquisition; this approach has shown good results in our first evaluation.

The third component, the interactive tutoring system, introduces images and is an important factor in the complex perceptive/cognitive process of interpreting diagnostic images. It illustrates the standard terminology and helps to display more images than can be shown in a book. The videodisk echocardiography encyclopedia [8] is an example of the successful realization of such a system.

Under the aspect of system integration, our approach shows parallels to the IMAGE/ICON [19] and the Intellipath [15] project. In conclusion, we consider a combination of the precise definition of medical terms, interactive use of medical knowledge and an interactive display of medical images an important perspective for the future.

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