

THE DIAGNOSTIC REPORTING SYSTEM: A REPORT ON THE DEVELOPMENT OF A SYSTEM

A generalized, personal-computer-based reporting system has been conceived, developed, and tested at APL. It improves report turnaround time by permitting users to select whole words, phrases, and paragraphs from a lexicon with a touch-activated display to produce a report that is printed immediately. The system was tested with a lexicon that was developed for use in radiological diagnosis reporting and was judged by radiologists to be adequate for reporting in large hospitals.

THE PROBLEM

Most, if not all, companies, institutions, and organizations create daily reports pertaining to the condition of "something." A few examples would include ship logs, trouble/failure reports on equipment, the disposition of court cases, and medical reports. The latter might consist of emergency-room action reports, patient monitoring reports, pathology reports, and radiological diagnostic reports, among others. Each report has the following characteristics:

1. Timeliness,
2. Similarity to previous reports,
3. A common, well-defined lexicon.

Many of the reports identified above are handwritten and then retyped once or twice. However, some are dictated rather than handwritten, particularly medical reports. Dictated reports must be transcribed, edited, and reviewed before being signed and distributed. This introduces the concept of turnaround.

THE NEED TO IMPROVE REPORT TURNAROUND

Report turnaround can be defined as the time required to receive a final complete and correct report after handwriting or transcribing the initial draft. Obviously, the time it takes for editing and review or (in the case of dictation) for transcription, editing, and review can affect turnaround time and adversely affect an institution's operation.

Although all reports that describe "the condition of something" are affected by turnaround, the effect of a long turnaround is perhaps felt most acutely in the medical profession. It has been reported that turnaround time for radiological diagnosis can be as long as 2 weeks.¹ Normally, turnaround for radiological diagnosis is 24 hours.

PREVIOUS WORKING SOLUTIONS

Radiologists in the Radiology Department at Johns Hopkins Hospital began to develop reporting systems to improve turnaround time in the late 1960s and early

1970s.² The first device, developed in 1967, used a specially built matrix keyboard for direct access to a computer. It allowed radiologists to select, via the matrix keyboard, complete words rather than letters as with a normal keyboard.

Between 1967 and 1972, a lexicon was developed that contained most of the terms required for adult radiology reporting. The effort caused the radiologists to re-evaluate the method of displaying the lexicon. The end result was a second-generation system, based on an IBM 2760 computer, that consisted of three units: the reporting terminal to display the lexicon, a CRT for proofing reports, and a communications typewriter. The heart of the system was the reporting terminal.

The reporting terminal was a large-screen device divided into left and right screens. The left screen was a backlit permanent display of terms applicable to all radiology examinations, including statements of normalcy, negation, degree of certainty, measurements, adjectives, advice for further study, access points to different body areas, differential diagnoses, and the pathology/anatomy lexicon. The right screen projected frames of 16-mm color film (selected by probe and under computer control). The frames contained graphics of the different body parts, the differential diagnoses, and the pathology/anatomy lexicon.

As expected, the mechanical movement of the 16-mm film, which was state of the art at the time, was a potential problem in that it had to move quickly and accurately from one frame to another. This was a major contributor to the development of the third-generation system.

The third-generation system consisted of a microprocessor-controlled slide projector that projected slide images onto a touch panel. The various slides were the result of major work on the lexicon. More than 6000 terms had been identified, categorized, and separated into slides or frames, and many new icons and graphic presentations had been developed. The transfer from 16-mm film to a set of slides or frames is particularly important because it established, at least for radiology, that many reports are similar (characteristic 2 of the identified problems listed above) and that all the reports use a common lexicon (characteristic 3) so that an infinite

variety of words and terms can be reduced to a manageable set.

The third-generation system was developed and used in various facilities in the United States between 1972 and the present. However, like the previous generations of reporting systems, advances in technology provided an opportunity to improve the concept while adding capabilities and functions that could not be implemented in 1972.

Early in 1985, funds were requested from the APL Development Fund to prepare a program plan for the development of a prototype system that eliminated many of the identified problems of the previous system while adding new capabilities and functions to the concept. A program plan was prepared that called for the development of a prototype fourth-generation system that would be generic in nature and that would use current technology, retain or improve the functional capabilities of the current systems, and be easily adaptable for a variety of reporting areas.

The program plan for the Diagnostic Reporting System (DRS) was presented to and accepted for funding by the Center for Devices and Radiological Health of the Food and Drug Administration of the Department of Health and Human Services.

DEFINED NEEDS OF THE DRS

The goal of the program plan was the development of a unique prototype reporting system. The working objectives are listed in Table 1; the functional requirements of the system are shown in Table 2.

Table 1—Objectives of DRS development.

1. The device will be capable of displaying any developed lexicon quickly and easily.
2. It will be semiautonomous with regard to any other information system and be independent of any central computer system.
3. It will interface with and be capable of using voice-recognition devices where applicable.
4. It will be easy to maintain and be as reliable as commercially available personal computers.
5. New lexicons will be easy to develop and implement.

Table 2—Functional requirements of the DRS.

1. Generate a report.
2. Communicate with other systems.
3. Modify the resident lexicon.
4. Correlate externally introduced information with its internal information.

One of the first tasks was to refine the system concept of the DRS. A survey of a number of third-generation system users was conducted to obtain information about the advantages and disadvantages of the current system. The study included the resolution of certain issues involving both hardware and software, such as the use of a monochromatic versus color lexicon display, the use of ethernet as a local area network interface, and the desirability of a flat-screen device versus a CRT system. It also included final development of the complete system architecture. A summary of the findings of the study³ is shown in Table 3.

ENGINEERING ISSUES

There were three major engineering issues in the development of the prototype DRS: touch-screen development, lexicon capture, and touch-screen graphics.

Touch-Screen Development

Touch-screen development was a major concern from the beginning of the program. It was believed that the

Table 3—Results of the concept refinement study.

The DRS should be able to

1. Store patient information for up to 6 weeks.
2. Operate in a stand-alone fashion with an optional mainframe interface.
3. Retrieve patient data from active storage by using the last name and the last four digits of the patient's social security number as well as the accession code.
4. Show a full-screen patient demographic display to enter, edit, or display patient information.
5. Customize touch-panel screens for a physician's own use at the discretion of the DRS administrator.
6. Use standard report formats in particular facilities through administrator interaction.
7. Retrieve the results of previous examinations.
8. Allow for multiple signatories of any given report.
9. Provide notification of unfinished or preliminary reports when a physician logs onto the unit.
10. Provide the capability for a physician to initiate, with one touch, an individualized report for a normal examination.
11. Accept externally prepared reports (in ASCII text) for internal storage and retrieval.
12. Support a log-on password sequence for security.
13. Summarize all reports for research functions.

printed for the graphic area touched), whether or not a touch point exists in that space, the touch point's shape, the touch point's color, and the existence of any portion of a graphic in that area. This information was stored on a floppy disk and was used later to create electronically new frames for use in the DRS.

Touch-Screen Graphics

Approximately 32 frames contained stylized line drawings of various portions of the human anatomy, primarily bone structure (Fig. 1 shows the hand). Some frames contained icons, which are smaller representations of major muscles such as the heart and its arteries and veins. To capture these graphics and icons, special software routines were written or were used to transfer the data from the 35-mm slide to an electronic medium. For the graphics, a black and white photograph was printed, from which a line drawing was prepared. The line drawing was scanned by a facsimile transmitter and digitized, and the electronic representation of the graphic was then scaled and stored for later use in the construction of a frame. Icons were somewhat easier to transfer because it was possible to draw them directly using a commercially available program, Dr. Halo.

In the original 35-mm slides, both the graphics and icons were colored, with the interior a different color from the background surrounding it. A problem was encountered after digitizing the graphics: it was not possible to color the interior of the graphic, because the digitized line drawing was not continuous. Colors "painted" in the interior of the graphics bled through the discontinuities, and the background became the same color as the interior, causing the lines to be lost. That problem has not been resolved. Icon drawings were not affected by this phenomenon, because the lines could be closed with Dr. Halo; the interior color was contained and did not bleed into the background.

THE PROTOTYPE DRS

The DRS (Fig. 2) was assembled by Index Industrial Design and Development, Cold Spring, N.Y., in 1986. The design was chosen from five initial designs that were prepared by Index during the summer of 1986. Index then constructed a foam board mock-up of the unit, which was taken to three hospitals for evaluation: Johns Hopkins Hospital, Walter Reed Army Medical Center, and the National Naval Medical Command Hospital. The mock-up was approved with minor modifications, and the prototype unit was assembled.

Hardware

The basic hardware of the system, in addition to the outer covering shown in Fig. 2, consisted of a minicomputer, the flat-faced lexicon display, infrared touch detector circuitry, the reporting display monitor, and a lift actuator to raise and lower the entire unit (lexicon display). The computer chosen was a Texas Instruments Business-Pro minicomputer, which is configured with a standard 1.2-Mbyte floppy disk, two 20-Mbyte hard disks, 10 Mbytes of random access memory (RAM), and



Figure 2—Front view of the DRS.

the appropriate drivers. It also includes a PC-AT color/graphics adapter and a video board from Number Nine Computer Corp. Additional slots are available for insertion of other boards, such as the Texas Instruments Speech System.

The lexicon display monitor is a 14-in. (diagonal) Zenith "flat tension mask" high-resolution monitor (Model cdl-3hx-nc) with a faceplate that is perfectly flat and nearly reflection-free. It surpasses conventional CRTs by as much as 80% in brightness and 70% in contrast ratio.⁴ The monitor did not require any modification for use in the DRS but is being driven at twice the normal horizontal oscillator frequency by the Number Nine board.

The infrared touch-activation device was built by Electro Mechanic Systems (EMS) of Champaign, Ill., to meet the geometric specifications of the lexicon display monitor. The lexicon (including the outer bezel) is displayed in 20 rows and 19 columns, or 380 touch areas. The design required that two horizontal and two vertical infrared paths intersect over each touch area. This allows the touch-activated device to majority vote when it translates the touched point into a location. The scanning of the 38 horizontal and 40 vertical infrared receivers and the translation of detected blocked paths into a location are controlled by circuitry in the EMS system. The row and column location is then transmitted by means of a serial RS-232 port to the computer.

The report monitor is a 9-in., high-resolution color monitor (Model HX-9) built by Princeton Graphics Systems of Princeton, N.J. It is driven by the PC-AT color/graphics board and displays all system operations as well as the diagnostic report as it is being composed.

The lift actuator is an electrically driven scissor jack that can raise or lower the lexicon display to a comfortable working height for the physician or radiologist. The system has a vertical travel of approximately 12 in., the need for which was established during the evaluation of the mock-up before prototype construction. Since then, as a result of clinical evaluation, the need to provide this feature has been questioned because all the evaluators sat at the system when using it.

Software

The DRS is a lexicon-driven, personal-computer-based, automated reporting system. The software system is a generic modular system for preparing certain types of routine reports. By defining a lexicon for a specialty and organizing it in display frames for use with the touch-screen (or lexicon) display, the system can be adapted for any discipline.

The software system was primarily written in Turbo Pascal. Some elements of the program have been coded in machine language in order to speed up operation. The device driver that interfaces with the touch-activated device was written in Assembly language. Extensive use was made of commercially available routines and subroutines throughout the program to minimize repeat development. Table 4 shows the commercially available programs from which certain routines were extracted.

The basic software concept (Fig. 3) shows that the system has four major modules: the System Initiator, the Clerk Function module, the Physician Function module, and the System Administrator Function module. Details of these modules are beyond the scope of this article, but the sense of the software can be conveyed by reviewing the operational function of each major module (or routine) and the submodules called by the major modules.

Table 4—Commercially available software programs used in the development of DRS software.

1. MS-DOS, Version 3.10, operating system, Microsoft Corp.
2. Dr. Halo, Version 2.26, graphics subroutine library, Media Cybernetics
3. Dr. Halo DPE, desktop publishing editor, Media Cybernetics
4. Turbo Pascal, Version 3.0, general-purpose high-level language, Borland International, Inc.
5. Turbo Pascal Tool Box, Version 1.0, selected Turbo Pascal development programs, Borland International, Inc.

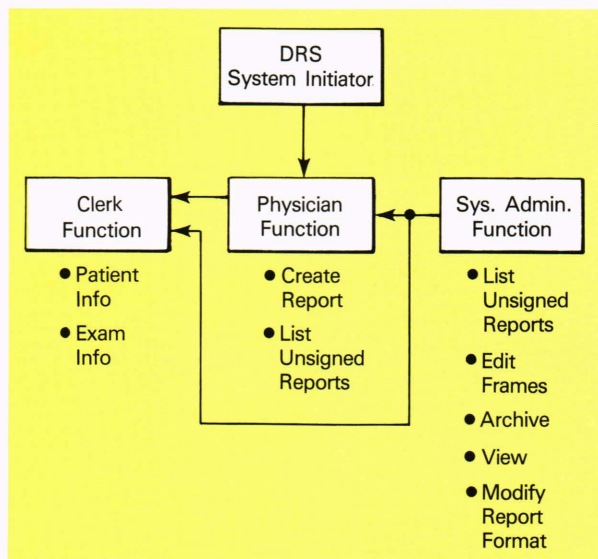


Figure 3—The basic software concept.

System Initiator

The System Initiator module prepares the DRS system for operation. When the system is turned on, the System Initiator clears temporary storage, loads certain files, and transfers selected frames from the hard disk to the RAM disk. It pauses after displaying the sign-in frame on the lexicon monitor and the user ID entry screen on the report monitor display. When a user enters an ID, the System Initiator verifies that the user has been authorized to use the system and transfers control to the appropriate major module (Clerk, Physician, or System Administrator module).

Clerk Module

If the user has been identified as a clerk, the Patient Information submodule within the Clerk Function causes a blank patient demographic template containing various patient field labels to be displayed on the report monitor. The clerk can use the fields to locate patient records that already exist in the system or to add new patient records. The data entry for both old and new patients has been designed to be user friendly. After using this portion of the Clerk Function, the clerk can choose to enter examination information for that patient (or any other patient in the system). In this case, the Clerk Function Exam Information submodule causes a template containing various examination field labels to be displayed on the report monitor. The clerk enters the necessary data and proceeds to a new patient. The system automatically saves the patient information and the examination information so that both sets of information can be integrated and recalled by the Physician module.

The Clerk module is a major improvement over the existing system. It can store patient information for 6 months or longer and can hold up to 30 examination records per patient.

Physician Module

If the user has been identified as a physician, the System Initiator module verifies that the physician is authorized to use the system. If that is the case, the List Unsigned Reports submodule locates all patients who have examinations to be read or diagnosed by that physician, including any unfinished reports (unsigned reports). The physician selects those examinations for which a report is required; next, the Create Report submodule locates the patient and the examination information and displays this information along with the report template on the report monitor. The Create Report submodule, using the examination information, also causes the main diagnostic frame associated with the examination to be displayed on the lexicon monitor.

The physician then prepares a diagnosis, touching those areas on the lexicon monitor that best state the diagnosis. Various levels of frames exist in a hierarchical arrangement within the lexicon. The types of frames available are shown in Table 5. When the report is completed, the physician prints it. If other examinations have been selected, the system reenters the Create Report submodule; if there are no reports remaining, the system returns to the sign-in frame.

The Physician module closely emulates the previous system function, but other features have been added. One feature is the ability to respond differently to physicians with and without signature authority. Reports prepared by physicians without signature authority are held as unsigned reports until they are reviewed by a physician with signature authority.

System Administrator Module

If the user is the System Administrator, a menu of administrative options is presented after an ID has been entered, including Add/Change/Delete, List Unsigned Reports, Frame and Lexicon Edit, Archive Reports, and View Archived Reports. The System Administrator also can use either of the two previous modules.

If Add/Change/Delete is selected, a submodule is activated that allows the System Administrator to grant access to the system by means of the ID code security system. The administrator can also change levels of

authority and deny physicians and clerks access to the system.

If List Unsigned Reports is selected, a list of all reports that are unsigned is generated for review, including those that have been started by physicians and not finished as well as those that have been entered by the clerk but have not been started at all.

If Archive Reports is chosen, the System Administrator can transfer finished reports to floppy disks (or to a radiological information system, if the overall system is so configured). In its current configuration, the DRS can store approximately seven days' worth of reports (1000) in its available disk space.

If View Archived Reports is selected, the administrator can recall previously stored reports from floppy disks and display them on the display monitor. It should be noted that such reports cannot be changed. A modified report can be written from an archived report, but the security system precludes removing a signed report from the system except to archive it.

If the System Administrator selects Frame and Lexicon Edit, he can change any term of the 6000-word lexicon, the background color of the touch area, the touch symbol, the color of the touch symbol, and the term that is displayed (and printed) on the report monitor. Graphics and icons can also be imported into a touch area if required. The Frame and Lexicon Editing submodule is the most powerful innovation in the system and provides much flexibility.

TEST AND EVALUATION

The clinical test and evaluation of the DRS began in March 1987 and continued for 26 weeks. The clinical evaluation was conducted in two parts. The first was conducted at APL for one week in March 1987, during which clinical radiologists were exposed to and operated the DRS for the first time. Their comments about the operation of the system were recorded, resulting in 65 recommendations.

The second part of the clinical evaluation was conducted at Johns Hopkins Hospital during August and September 1987. Twelve radiologists were trained in the use of the system and operated it, independently of APL staff, during this period. Their comments about the system were recorded on evaluation sheets. After the clinical evaluation, these data were reviewed, evaluated, and summarized.⁵

The radiologists using the system concluded that the DRS (and, in particular, the Physician module) was "more than adequate" for reporting the results of radiological diagnoses. It should be noted that the two major new modules (the Clerk and the System Administrator) were not tested as rigorously as the Physician module. The adequacy of those two modules in performing their desired functions, although demonstrated in individual trials, has yet to be fully tested in a clinical environment.

CONCLUSION

The DRS is an effective generic reporting system that has great potential for decreasing the turnaround time

Table 5—Lexicon frames available in the DRS system.

1 sign-in frame
4 examination-type frames
44 main diagnostic frames
58 differential diagnostic frames
19 lexicon frames with anatomy terms
41 lexicon frames with pathology terms
1 standard report frame

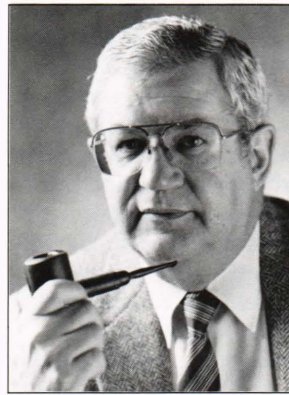
generally associated with certain kinds of standard reports. The device has been demonstrated and tested using a radiological lexicon and has been judged to provide all the necessary reporting functions needed for a reporting system. Further testing of the system with other lexicons is warranted.

REFERENCES

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