The primary role of the radiologist is to examine patients, usually with the help of ionizing radiation, in order to provide information of use in patient care. The radiologist functions as a consultant that is, patients are referred to him by many other physicians, and he delivers information obtained from his special methods of examination back to each patient's referring physician. As a result the radiologist deals with greater numbers of patients than most physicians. Also, he needs to move a great deal of data quickly and accurately.

Radiology is a relatively young field of medicine, and the variety and complexity of examination techniques in the radiologist's armamentarium continue to multiply. Because of this and because he examines more patients each year, the annual increase in demand upon a radiologist's time has been estimated from 15 to 25 percent. Fortunately, however, radiologists are used to living with complicated electronic gear, and the specialty as a whole has shown considerable interest in employing data processing techniques to streamline patient care delivery.

Our own efforts began in 1965 as project RADIATE (Radiologic Diagnoses Instantaneously Accessed and Transmitted Electronically), continued as ODARS (On-line Diagnostic and Reporting System), and have finally been renamed MARS (Missouri Automated Radiology System). It was apparent initially that straightforward computer programs could carry out a variety of business functions such as patient billing or inventory control. However, the most important information flowing through a radiology department is the medical information, i.e., what the radiologist has to say about the patients he examined. The processing of this basic information was the problem we tackled.

Traditionally the radiologist has dictated his consultation after reviewing a patient's films. This dictation is then transcribed, proofread, and finally returned to the referring physician. The problem of capturing this data for a computer can be solved in a variety of ways ranging from keypunching the reports to utilizing typewriters which produce magnetic tape along with typed copy. Such approaches do provide the computer with data to process. Indeed, they provide a large amount of natural language data which requires very sophisticated processing to interpret. Although processing of dictated reports has the superficial advantage of not interfering with traditional methods, it tends to complicate the flow of information rather than facilitating it.

We have chosen a more radical approach for MARS. Instead of dictating his report, the radiologist interacts with the computer via an on-line terminal. He constructs his report by retrieving terms from several large lists, each containing a particular category of term, and stored in direct access files. The retrieval technique is a modified keyword in context approach. The radiologist types in one letter denoting the particular type of term followed by the first four letters of any word in the term. The computer displays a list of all terms associated with this keyword, and the radiologist selects one of these. Three categories of terms are available: examination types, anatomic sites, and diagnoses.

In addition to incorporating phrases retrieved by keyword, the radiologist has additional options in preparing his report. He may select any of a list of commonly employed phrases such as "there has been essentially no change in findings since the previous examination." This particular phrase being the fourth in the list, the radiologist may simply type "P4" to add it to the report. Or, if he does not remember the number, he may simply type "P" to request display of the entire list from which he then makes his selection. Another option available is the incorporation of a pre-coded sequence of statements which are retrieved by typing a three letter abbreviation, or mnemonic. For example, if the radiologist types "CAD," the computer will incorporate into the report a series of statements describing a geriatric chest with calcification in the aortic
arch, tortuosity of the descending aorta, and degenerative changes in the thoracic spine. These pre-coded statements frequently make it possible to complete an entire report by typing only a few letters. The approach is obviously quite similar to the use of “canned” reports generated by semi-automatic typewriters. However, the computer system does have the advantage that the radiologist reviews the report on his terminal immediately and, if he wishes, he may easily edit it. For example, if the changes in the spine are unusually marked, he might add an appropriate modifier to the report. Finally, if the radiologist is unable to express himself fully by the options provided, he may type as many additional remarks as he feels are needed.

This method was aimed at solving the basic problem of capturing the radiologist’s report in a form which the computer could comprehend. The technique met with criticism for two reasons. First, it altered the traditional form of the radiological consultation. Instead of paragraphs of prose, the referring physician would receive a somewhat terse list of observations and impressions. Second, it required that the radiologist operate a keyboard. Added to the very real problem which would arise if the radiologist were slowed down by using a terminal there is a largely emotional problem which stems from the idea that it is somehow “sissy” for an M.D. to type.

The only way we could see to answer these objections was to put the System to work. Our immediate goal was not to automate all the functions of the department, but to test the hypothesis that the medical information flow could be handled by an on-line system as described. Accordingly we wrote, tested, and rewrote programs. Finally, on April 1, 1970, we locked up the radiologists’ dictaphones and began using MARS to process all consultation in our department. Clinical use required not only that the radiologist be able to interact with the computer to define individual reports but also that there be a system for handling the flow of patients through the department. The system we have used can best be described by following the progress of a typical consultation through the department.

A patient presents for examination in the department at a reception area accompanied by a request form filled out and signed by the referring physician. The receptionist informs the computer of the patient’s arrival by entering the patient’s unit number via a terminal. The computer searches the hospital master disk file for this number and responds by displaying information found there, including the patient’s name, date of birth, sex, race and hospital ward or outpatient clinic code. If the information is not on file (as, for example, in the case of a patient not previously seen at the hospital who requires emergency care), it is entered by the receptionist manually. The receptionist then types in the clinical history provided by the referring physician, along with his name. Finally, the examination requested is entered, and the computer stores all of this information in a temporary holding file. A three digit number indicating the location of the record within this file is displayed to the receptionist who writes it on the request form.

The patient is examined and the roentgenograms, along with the patient’s previous X-rays and reports and the request form are brought to a radiologist at one of several terminals for interpretation. The radiologist begins by entering the three digit address of the information entered by the receptionist. The computer retrieves the preprocessed patient identification data and displays it on the screen. The radiologist corrects any errors in this data and then completes the report by the method outlined above. Finally the radiologist proofreads the entire report, makes any corrections and then signals the computer that the report is complete. The computer immediately types out a copy of the report on an output terminal located on the patient’s ward and, simultaneously, three copies are produced in the department of radiology. One of these copies is affixed to the jacket containing the patient’s radiographs; the second is mailed to the referring physician for his convenience; and the third is attached to the request form, presented to the radiologist for signature and returned to the patient’s medical record.

All the reports transmitted during the day are kept on a random access disk file and any of them can be reviewed instantly by entering any patient’s unit number on a terminal. At night, each report transmitted is permanently stored in a numerically coded form on a large direct access file. From this file any report for any patient can be retrieved for review within a matter of seconds. Also categorical searches can be performed on-line.

In our two years of experience with this system we have learned many things. Primarily we have shown that it is possible to operate a department with an on-line information system. In evaluating MARS we did measure some parameters such as the time spent by patients in the department and the time a radiologist spends reporting a case. We found these to be essentially unchanged from data accumulated before the System went into operation. MARS did, however make a great reduction in the delay between arrival of a patient in the department for examination and delivery of a written consultation. Before MARS this delay averaged 23 hours with about 75 percent of all reports being sent out on the day following the examination. With MARS this delay has been reduced to an average of 10 hours, and 75 percent of all reports are transmitted on the day.
of the examination. We regard this as a significant improvement in patient care.

Our experience operating MARS has not been uniformly pleasant, however. We have been plagued by unreliable computer services. We have been operating on an IBM 360-50 under O.S. using the Baylor Message Handler for terminal I/O. The system is a busy one with two million bytes of "slow" core, multiple tapes, disks, and a data cell. In addition to a couple of batch partitions, the system handles a variety of on-line applications for other departments in the Medical Center, as well as a good deal of developmental work. With all of this, the time during which MARS has not been available to radiology has averaged slightly over 10 percent of our working day. For the most part, failures are due to system software. The system simply dissolves. Generally it can be restarted in from fifteen to twenty minutes providing our radiologists with an unscheduled coffee break. More serious failures of hardware or software have not been uncommon, however, and when the system is down for an hour or longer we revert to dictation of reports.

We should emphasize that our computer center has a staff of good systems programmers and is headed by an able Director. However, we see certain disadvantages in the very concept of a large central computer. If a radiologist is going to build his practice around an information system, then he will be responsible for the effect that system has on patient care. This responsibility is very difficult to assume unless it is coupled with clearly defined administrative control over the operation of that system. It is difficult to see how this is possible if the radiologist is only one user of a large time sharing computer.

Our experience with MARS on the 360 has convinced us that the concept of on-line management of information flow is valid for a department of radiology. We have been reluctant, however, to fully exploit the possibilities for a more completely automated department on a computer system with the disadvantages outlined above. Finally, we have become quite interested in building a system which can be exported easily to other departments. For these reasons we are in the process of implementing a stand-alone version of MARS on a smaller computer, the PDP-15, using MUMPS, the Massachusetts General Hospital Multi-Programming System.

The basic reporting function of MARS on the PDP-15 is still quite similar to that discussed previously and consists of retrieving from standardized tables those terms to be incorporated into the reports. We have been able to make the retrieval of terms a bit more sophisticated, however. After examining the frequency with which terms were used in some 50,000 reports we found that a relatively small number of terms were used quite frequently. These terms have been assigned unique three-letter mnemonics so that they can be retrieved without bothering to look at other terms which would be retrieved under the keyword search. In addition, the keywords are no longer restricted to four letters. The modifying terms have been expanded, separated into exam, site, and diagnosis categories, and assigned mnemonic codes for retrieval. Also, the definition of "canned" reports has been left to the discretion of the individual radiologist, so that these can be tailored to suit his needs. Finally, the program has been altered so that the radiologist can specify multiple terms with one input string. This frequently makes it possible for him to define an entire report with one turn-around at his terminal.

In addition to these relatively minor changes at the radiologist-computer interface, we are expanding MARS to automate several other departmental functions. For the most part these are the fairly straightforward business-like applications which we ignored previously, and they come as rather natural spin-offs from the medical information system. These applications are, however, extremely important from a cost-effectiveness viewpoint. One application is patient billing. Since the MARS report contains the name of the patient, the examination performed, and the consulting radiologist's name all the information needed to specify the charge is available to the System. It is only necessary to associate with each examination in the table the appropriate fee. The System displays these charges to the radiologist who verifies and/or corrects them just prior to transmitting his report.

In many departments patient billing is handled by another agency, usually a hospital. Under those circumstances the department's responsibility ends at correctly specifying the charge for each patient. If billing is done by hand, a daily listing of charge should suffice. At our hospital, patient billing is done by computer, so that we will provide the charges on magnetic tape. We do expect to develop a more complete billing and accounting system for those departments which elect to handle this function. Our basic concept is to keep computerized ledger sheets on direct access files. For active accounts, this record will contain both itemized charges and a record of payments made. Inactive accounts will be transferred to tape and/or paper files. The goal is to provide a billing system which is responsive to human direction and can make any patient's bill accessible for review and, if necessary, correction on-line.

Another type of information which MARS can provide automatically is a statistical analysis of the department's work load. The rapid growth of services
delivered by radiologists means that additional equipment and personnel must be acquired almost continuously. In deciding just what piece of equipment should be purchased next it is obviously valuable to know what types of examinations are being performed most often. We assign a statistical code to each entry in the examination table which defines for the System how we want our utilization counts broken down. When a report is transmitted the appropriate counts are incremented. These figures are stored by the day during any month. At the end of the month totals are printed out, and at the end of the year a monthly breakdown is produced.

Another operation in the department which is amenable to automation is management of the X-ray files. Currently roentgenographic images are stored on large films. All films for a patient are usually stored together in one or more large jackets which in turn are filed according to patient number. Films are pulled from the files either for use within the department or to be loaned to referring physicians for use outside the department, for use in conferences, clinics or in the operating suite. Since the X-rays themselves form a part of the medical record, the radiologist being legally responsible for them, it is obviously essential to have a system for keeping track of who has checked out what films. It is also necessary at times, to send out "overdue" notices. Current films are also pulled for review by referring physicians within the department viewing area. Since these films do not leave the department, it is not necessary to check them out. However, it is not uncommon for a doctor to request films which have been checked out. Under any of these circumstances a harried search through the department, and through multiple scraps of paper ensues. Some tracking of the films within the department is accomplished by logging the patient in and reporting the case. It would be possible to create additional check points to further ameliorate this problem.

Finally, any time a patient is examined in radiology, all of the patient's previous X-rays are pulled for review so that the radiologist may detect for changes in the area examined, or so that he may correlate the findings from examinations of other areas. In order to reduce the delay caused by pulling the old films, MARS transmits a request to the file area as soon as the patient is logged in at the reception area.

One of the ways in which radiologists attempt to meet increasing patient loads is by keeping existing facilities busy through scheduling of examinations. In our department only those examinations which require the participation of a radiologist have been scheduled. In particular, nearly all patients have been simply sent from the clinics to the department without any prior warning. To alleviate this problem we have developed an on-line appointment book. A referring physician, or his secretary, may call the radiology reception area and request that a given exam be scheduled for his patient at a particular time. The System opens the appointment book to the appropriate day, and checks to see what has already been scheduled. If the schedule is tight, the System warns the receptionist who can then attempt to get another time which is more convenient for the patient, his physician, and the department. Each morning the schedule is printed out allowing our personnel to plan how they will meet the projected patient load. A longer range goal for this MARS module is to provide for a constant on-line reevaluation of the work load by the System, which might then make specific recommendations such as assigning individual patients to specific examination rooms.

A potentially great advantage of having a radiologist interacting with a computer is that the machine may be able to assist them interpret the films. There are several possible techniques for this. Perhaps the simplest of these is retrieval of useful medical data. We have a growing file of radiological information arranged hierarchically by organ system, and subdivided by diseases or roentgen findings. This film may be examined on-line by the radiologist while he is reporting. A slightly more complicated method of assisting the radiologist is to provide him with a logical tree for the analysis of certain diagnostic problems. The radiologist is asked a series of questions about the findings on the films and depending upon his answer to each question another appropriate question is asked until he reaches a leaf on the tree. Typically this will be a list of diagnostic possibilities. Another technique which may be employed is that of Bayesian analysis. The radiologist is asked to specify whether certain findings are present on the films, and the System then uses estimates of the frequencies with which these findings occur in various diseases to estimate probabilities for the diagnoses. Such programs are available for the diagnosis of pulmonary nodules, heart disease, and thyroid dysfunctions. The tree branching and Bayes techniques have been combined into a program for the analysis of solitary bone tumors. Many investigators are becoming interested in collecting the type of data required to attack diagnostic problems by means of these techniques.

There is great pressure on the medical profession to produce more patient care with no loss in quality and without further increasing the cost to society. Computer technology holds the promise of helping us to reach that goal. Our efforts in developing MARS have been to automate the practice of radiology. In doing this we have made changes from the traditional practice of our specialty; we feel that we have improved it.
Certainly there is need for further work. The use of computers for training radiologists and radiological technologists has not been thoroughly investigated. Technological advances on the horizon such as high quality microfilm systems for storage of roentgenograms, or electronic equipment to transmit images will both augment the possibilities for automation, and may well require sophisticated data processing systems to have their full impact. Finally, we are beginning to see some practical possibilities for direct computer analysis of the X-rays themselves. The task of demonstrating the feasibility of automated systems, of developing cost-effective systems, and of educating the medical profession to use them effectively should provide a challenge for many years to come.

BIBLIOGRAPHY

W J WILSON A W TEMPLETON A H TURNER
G S LODWICK
The computer analysis and diagnosis of gastric ulcers

G S LODWICK P L REICHERTZ
Computer assisted diagnosis of tumors and tumor-like lesions of bone
The Limited Bayes’ Concept Proceedings of Symposium Osseum London April 1968

A W TEMPLETON G S LODWICK S D SIDES
J L LEHR
RADIATE: A project for the synthesis, storage and retrieval of radiological consultations
Digest of the 7th International Conference on Medical and Biological Engineering 1967 Stockholm, Sweden

A W TEMPLETON P L REICHERTZ
E PAQUET J L LEHR G S LODWICK
F I SCOTT
RADIATE-UPDATED and redesigned for multiple cathode-ray tube terminals
Radiology Vol 92 No 1 pp 30–36 January 1969

P L REICHERTZ A W TEMPLETON J L LEHR
E PAQUET F B BIRZNIEMS
Design and implementation of ODARS, an on-line diagnosis and reporting system
Presented by Dr Peter Reichertz at the 12th International Congress of Radiology Tokyo Japan October 1969

J L LEHR R W PARKEY L J GARROTTO
C A HARLOW G S LODWICK
computer algorithms for the detection of brain scintigrams abnormalities
RADIOLOGY November 1970

From the collection of the Computer History Museum (www.computerhistory.org)