A computer system for real-time monitoring and management of the critically ill

by DAVID H. STEWART, DAVID H. ERBECH and HERBERT SHUBIN

University of Southern California
Los Angeles, California

INTRODUCTION

During the past decade a number of specialized hospital units have been developed for monitoring and care of critically ill patients. These units, which include coronary and intensive care facilities, trauma, renal dialysis and post surgery recovery wards, now provide up to five percent of beds in acute community hospitals.1

Patients with acute circulatory or respiratory failure are often referred to these specialized units. An example is the patient in circulatory shock. This condition may result from the complications of a "coronary," from severe bleeding from a duodenal ulcer, or from a number of other disease processes. The patient in shock characteristically has low blood pressure and reduced blood flow. With inadequate circulation to his brain he may become stuporous or comatose. His respiration may fail and kidneys cease to put out urine.

Assessment of the circulatory and respiratory status of such a critically ill patient requires measuring a number of variables: hemodynamic (i.e., arterial and venous pressure, blood flow and volume), electrical (i.e., the electrocardiogram), blood gases (i.e., oxygen, carbon dioxide and pH) and blood constituents (i.e., potassium). Repeated assessment of these variables is required since the critically ill patient is not in a steady state, but is very labile, and undergoes rapid and often unpredictable changes in status.

Current problems

The organization and operation of critical care units require a major commitment of highly trained physicians, nurses and technicians, as well as substantial physical resources, in order to care for a relatively small number of patients who require numerous diagnostic and therapeutic services. Efficiency of operation is needed to reduce the work load on the professional personnel. Present manual methods of data collection and logging impose great demands on the staff, particularly during night hours and weekends when staffing is reduced.

Clinicians are concerned not only with the acquisition, but with the timely organization, analysis, and display of data to assure their immediate usefulness at the bedside. The availability of such information has been life saving, particularly in coronary care units where mortality has been reduced from 30 to less than 15 percent. Precise documentation of reduction in mortality rates in more generalized critical care units is as yet not as clearly established.

Experience

The Shock Research Unit, a specialized clinical research facility, has been developed for the triple purpose of rendering intensive care to seriously ill patients, studying underlying mechanisms of the disease process, and developing new techniques of evaluating seriously ill patients. In mid-1963, a computer was obtained and a system developed for monitoring patients.2,3,4 Algorithms were derived to convert electrical signals from transducers attached to patients into their cus-
With this system 11 primary measurements and 25 derived variables are recorded and displayed with a frequency which ranges from once a minute to once every twenty-four hours. These variables are summarized in Figure 1.

The present system operates on a 24-hour basis and is run exclusively by clinical personnel with minimal intervention by computer and engineering staff. Over 400 patients have been monitored and studied on a routine basis with the system. The feasibility and reasonableness of using computers to collect and analyze physiological data in a clinical environment has been demonstrated. An indication of its value is provided by the procedure for determining cardiac output. The time required for measurement of the indicator dilution curve and calculation of the cardiac output, which was approximately 45 minutes by manual methods, has been reduced to only 5 minutes with the computer. Experience with this system has shown that certain procedures with respect to treatment, which are currently performed manually, such as the administration of fluids and medications, are adaptable to computer control.

A shortcoming of the system has been the single channeled unbuffered data path. Dynamic variables, such as arterial and venous pressure and the electrocardiogram, do not require sampling at high rates, the maximum being below 1000 sp/s. However, the analysis process requires repeated readings of moderately complex wave forms. For example, arterial pressure, under some circumstances, may be sampled almost continuously for 30 seconds. When the volume of blood pumped by the heart (cardiac output) is calculated, it is necessary to sample the densitometer for as long as eighty seconds. In addition to these considerations, it has been necessary to monitor more than one patient concurrently. This period of processor dependence upon I/O may occur during the time when the process is critically real time and this may result in loss of medical information which is needed immediately by the physician at the bedside.

The record keeping responsibilities of the physician, nurse and technician have posed a major problem. Numerous forms have been required for the history, findings on physical examination, progress reports, routine and special laboratory studies. This has created reams of poorly organized, non-cross-referenced data. The initial system has been incapable of prolonged dialogue for such manually entered data.

Based on our experience with the initial system over a 5-year period, we have developed a new system for use in the environment of the critically ill patient. A major goal of this system is to automate the critical care environment, with specific attention to the following tasks:

**Monitoring and measurement**
1. Monitoring of cardiovascular, respiratory and metabolic variables.

**Control**
1. Infusion of fluids and medications under computer control.
2. Regulation of ventilators with respect to the pressure and volume settings and the relative concentration of gases they deliver.
3. Control of body heating and cooling devices.
4. Control of cardiac pacemakers.

---

**FIGURE 1—Primary and displayed variables**

<table>
<thead>
<tr>
<th>Primary Signal</th>
<th>Sensor</th>
<th>Displayed Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrocardiogram</td>
<td>Surface electrodes (Sanborn)</td>
<td>a. heart rate</td>
</tr>
<tr>
<td>Arterial pressure</td>
<td>Strain gauge transducer (Statham)</td>
<td>a. systolic pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. diastolic pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. mean pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. variation between highest and lowest systolic pressures in read interval</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. pulse rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. pulse deficit</td>
</tr>
<tr>
<td>Venous pressure</td>
<td>Strain gauge transducer (Statham)</td>
<td>a. mean pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. respiration rate</td>
</tr>
<tr>
<td>Optical density of arterial blood</td>
<td>Densitometer (Gilford)</td>
<td>a. cardiac output</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. cardiac index</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. work done by heart</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. stroke work</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. vascular resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. central blood volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>g. mean circulation time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>h. appearance time</td>
</tr>
<tr>
<td>Temperatures</td>
<td>Thermistor (Yellow Springs Instrument Co.)</td>
<td>a. rectal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. skin, finger</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. skin, toe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. skin, thigh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. skin, arm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. ambient air</td>
</tr>
<tr>
<td>Urine output</td>
<td>Shock Research Unit design</td>
<td>a. urine output/hour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. urine output last 5 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. cumulative volume</td>
</tr>
<tr>
<td>Manual input</td>
<td>Manual entry unit</td>
<td>a. PO2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. PCO2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. pH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. oxygen saturation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. plasma volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. red cell volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>g. medications and fluid administered</td>
</tr>
<tr>
<td></td>
<td></td>
<td>h. height, weight, age</td>
</tr>
</tbody>
</table>
5. Control of the flushing procedures for intra-vascular and urinary catheters.

**Records**

1. Comprehensive record keeping, including entry, organization, storage, return and display of non-sensed data which must be available for a well organized clinical facility.

**Functional requirements of the system**

The requirement for multi-usage systems design is apparent in the critical care environment. The computer needs to simultaneously acquire data, control many processes in the ward and manage the retrieval and display of information on both the current and previous status of the patient.

**Real time acquisition and display**

To provide input to the computer, analog devices are attached to the patient to sense physiological activity. These signals are continuously presented on a bedside oscilloscope by signal conditioning hardware as shown in Figure 2. The signal conditioners amplify the signals and perform a preliminary analysis of wave forms. The output of these conditioners is attached to the multiplexer, then to the A/D convertor interfaced to a computer channel. The computer must also be capable of real time analysis of these signals. As an example, the computer must be capable of recognizing individual components of the EKG signal (i.e., the QRS wave), find the pulse wave in the arterial pressure signal, calculate maximum, minimum, and mean arterial pressure, before the next heart beat occurs. Although the heart rate is normally about 80 per minute, rates in excess of 160 per minute are often encountered in the critically ill patient.

An on-line blood chemistry unit is being developed for use at the bedside. This will enable the computer to monitor $\text{PO}_2$, $\text{PCO}_2$, pH and electrolytes as well as blood volume measurements. The timing requirements for this type of monitoring are not based upon the real time correspondence with the body but rather upon the techniques of measurement. Measurement can be as simple as the sampling of the output of an electrometer connected to an electrode or as complex as spectral analysis.

The computer's ability to analyze signals at beat-to-beat rates is an asset during moments of crisis and during procedures such as drug administration. However, if such detailed information were accumulated continuously, the physician would be overwhelmed by a flood of data. There is a need, therefore, to provide a schedule of monitoring and reporting which will insure that patients are under constant surveillance, but the physician and computer are relieved of an overwhelming data management problem. The monitoring schedule under development at the Shock Research Unit allows for two modes of operation. The physician is able to request beat-by-beat measurements. The routine mode of monitoring, however, is based upon the ability to define or predict the amount and rate of change to be expected in any given variable. Heart rate and rhythm are monitored almost continuously because abrupt changes in these variables may be followed by rapid deterioration in patient status. However, skin and rectal temperature are monitored at 15-minute intervals because significant changes in these signals are generally of longer duration. After the data are converted into physiological units, they are analyzed to determine its significance. Is the change measured in a particular variable to be expected statistically and does it correspond to changes in other variables? If the variations are statistically non-significant then the data are discarded. However, if there has been a significant change this is logged in the computer records. The ward staff is immediately alerted and informed as to which variable has changed.
Digital control

Figure 3 shows diagrammatically a number of new concepts which in part have their rationale in the advances in process control engineering in critical processes. The time has come, technologically, when computers can be programmed to assist and control medical procedures under the direction of the physician and nurse. Computers can control the rate of fluid and medication administration through actuation of pumps and injectors. Such a pump is now in engineering phases at the Shock Research Unit. This pump is intended for long term administration of fluids or medications from a bottle. The nurse will be able to request the computer to administer the fluid or medication at specified rates. The computer will then check a rate table to see if the rate is unusual. If so, it will ask the nurse to confirm this rate. If not, it will adjust the pump speed much more accurately than is done by the drops per minute method currently in general use. It will make entries to the fluid intake log and then monitor the bottle for low level. An increase in central venous pressure may indicate over-administration of fluids. If central venous pressure (which is computer monitored) should rise above a predetermined level, the pump can be either shut off or slowed down and the medical staff notified. It is a similar technological problem to have the computer adjust and monitor specialized equipment for assisting the patient's respiration. The interaction of the nurse, computer and ventilating device would be similar to that of the pump and would include safety mechanisms and confirmation of orders before adjustments are made.

Some control devices, such as cardiac pacemakers, are already in use in many coronary care units. Control and monitoring of these devices, if given to the computer, can insure a level of reliability previously unobtainable.

The chemical analysis subsystem now under design at the Shock Research Unit is called the “On-Line Analyzer” (OLA). With the OLA system the computer will be able to control withdrawal of blood samples, reinfusion of blood samples, and mixing of samples with chemicals where necessary. Results of these chemical tests will be input directly to the computer. This will permit moderately complicated procedures to be done at intervals related to their clinical usefulness rather than their complexity.

Another advantage of digital control is the ability to adapt signal conditioning units to the course of the patient. An example of this adaptability would be the control of amplifiers and filters such that obscured regions of a signal may be highlighted for computer analysis. Another feature is the ability of the computer to perform sensor calibration checks automatically, thus freeing nurses and paramedical personnel from time consuming chores which remove them from the patient.

Data management

The data management system must be versatile in structure and in its ability to meet the needs of the clinically and the statistically oriented staff (Figure 4.) Numerical and textual data are stored in a form easily retrievable for ward display and for later statistical analysis. It has been noted that the ability to retrieve textual as well as numerical information in a neat format will greatly help the physician in the care of the patient.

Displays. Included in the system are displays located at each bedside and in the physician's study. Display requirements for an intensive care ward present a multifaceted problem. The solution is found in providing two types of displays.

1. Large screen TV

Currently available devices used for interaction with the computer system (keyboard CRT displays) are not sufficient for all requirements, in that they fail to provide a sufficiently large display, having been de-
signed for desk top usage. Personnel in the ward are usually on the move and must be able to read displays accurately from varying distances. If emergency information must be projected on a keyboard display, competition between the user and the computer system obviously must be avoided. The solution has been to acquire computer-controlled character generators for driving large screen closed circuit television monitors which are strategically located to provide a display visible throughout the room. This device is only available to the computer and displays only the most current significant information concerning the patient.

2. **Keyboard displays**

Physician’s and nurse’s records are entered into the computer system through the use of a keyboard device providing 2,048 characters of display for selection of options and message formation. From this bedside terminal, the physician reviews the entire patient file and enters comments and impressions. Nurses enter information which include drugs administered, procedures performed and non-sensed data regarding the patient’s condition. The information is entered in a multiple choice format. This is necessary because few ward personnel can type competently. While free text would function as narrative, experience in our own unit shows that information is gathered more dependably when a detailed format is followed than when users have a free choice as to which information is recorded. Another approach which has been considered is the use of a clerk to enter the notes of the physician, nurse and technician into the computer. The use of multiple forms, even in this manner, is inconsistent with the principle of having all information available at one source. Since the use of such a system is subject to the adequacy of staffing, delays in entry of information may also be interposed.

In addition to the alphanumerical display, a storage CRT for graphical display of all data available at the keyboard is provided. From this CRT terminal the physician requests the computer to locate wave form data on an analog tape recorder and display it on the oscilloscope associated with the terminal. Hard copy of all information in the system is also logged on off ward teletypes for the purpose of back up, a critical requirement in the event of machine failure. A high speed line printer develops the entire hard copy patient file at the time of discharge for inclusion in the general hospital records.

**Plotter.** There are several reasons for hard copy graphical display. Foremost is the fail safe problem. Physicians make extensive use of trend plots and these are available at the bedside on the CRT displays. However, in order to insure that graphical display describing the patient’s course is available in the event of machine failure it is necessary to generate hard copy on a continuing basis. Second, hard copy display is required for the hospital record. Traditionally nurses have kept some form of trend recordings on the patient’s vital signs. Trend plotting of major parameters for fail safe, proceeds automatically without need of request. In this system the physician or nurse can develop graphical presentation on the CRT not only of the vital signs but also of a number of other variables of interest. They can then request that this be prepared on hard copy for the hospital record, or for study at areas remote from these facilities.

**Analog Tape.** During monitoring, the physician can remotely engage an analog tape recorder to record wave forms as they are sensed from the
patient. However, the amount of information which the physician finds useful from such extensive recording requires a substantial editing effort. The computer is also programmed to switch on the tape recorder when a major change occurs in a variable and switch it off when the values for the variable return to specified limits. Under both options, the point on the analog tape where items of interest are stored, is automatically recorded, thus facilitating tape editing under computer control.

**Software**

In solving the functional requirements, the following philosophies have arisen. Some special programs may have their own hardware interrupt priority level, but programs executed by the program scheduler do not have a priority until they are initiated. These priorities are determined by the need to minimize fluctuations in the actual initiation frequencies and insure the regularity of acquisition of time sequenced data (Figure 5). Within classes of priorities, the actual activation position in the queues is determined by the requested execution frequency, with items of highest frequency coming first.

The problem in many real time systems is that the total execution time of the programs to be scheduled is greater than the recycling time of the program executing with the highest frequency and, therefore, programs of a lesser priority are periodically interrupted and displaced from their cycling interval. However, this is not a problem here since the total execution time easily fits into a scheduler frequency determined by the program of highest frequency. The problem is that the processing in each program must wait for a series of timed analog inputs and the need is thereby created for two types of scheduling so that these waits may be interleaved with other processing.

Monitor type functions are usually executed at the same priority level as the program requesting them. All non-analog I/O for any one device is run at one level to relieve the re-entrancy problems. Each actively monitored bed has its own core buffer to insure patient file updating speed as well as safety. This buffer is written onto the disk after each data update group as well as other control information has been calculated to insure that there is no loss of valuable data in case of system failure. This output is of course overlapped with processing, but input is not overlapped except by higher level routines.

The various tables and queues throughout the system are list structured and utilized so that no garbage collection is needed. As items are deleted their positions are set to “unused,” and new assignments are always made from the physical head of the list.

Core memory has been divided into three sections. The monitor functions and I/O handlers reside in the first section. The second section contains the schedulers, the resident foreground programs, and the necessary modules from the Fortran systems library. The third section is for non-resident foreground, or background since the area is large enough for the Fortran compiler to run. Some of the applications programs are described in the references.

**FIGURE 5—Relative hardware priorities**

- Analog scheduler clock
- Program scheduler clock
- Monitor time clock
- I/O interrupt
- Special external interrupts
- Analog scheduler
- Highest program priority
- Keyboard display handler
- Intermediate program priority
- Program scheduler and loader
- Lowest program priority
Schedulers

The multiprogramming philosophy adopted requires simultaneous processing of programs and the reading of many analog lines for several patients at data rates up to 1000 times per second. Analog pre-processing is being used, but moderate rate digital sampling and analysis cannot be entirely replaced. To facilitate a versatile selection of both channels and frequencies and allow for the timed reinitiation of various monitoring programs, a program scheduler and an analog scheduler have been incorporated into the system.

Cycling of the initiation phase of the program scheduler is determined by its private hardware clock. It picks information from the program queue to determine the proper sequence for program executions. Servicing programs for the keyboard displays allow the clinical staff to insert or remove programs from this queue. When executing programs request analog I/O, they enter requisite information into a table known as the analog table, and return control to the program scheduler which searches the program queue for the next program awaiting execution (Figure 6A, 6B). The analog scheduler, running on a separate hardware clock and at a higher hardware priority, continually scans the analog table at a high rate for I/O requests at varied frequencies and channels, interleaving these requests. No attempt is made to time slice among applications programs of an equal priority except at these analog I/O request points. The overhead and complexity of going any further with time sharing far outweigh any value which might be realized. The execution speed of the processor used allows for the completion of the computations involved in far less time than significant change can occur in variables being monitored. However, as some of the

From the collection of the Computer History Museum (www.computerhistory.org)
analog I/O requires sampling to run many seconds at low rates (e.g., 80 seconds for cardiac output at 20 samples per second), processing must continue during these long waits.

An initialization procedure is used to insert programs into the program initiation queue (PTAB). This initialization routine uses four parameters—an active file number, a program name, a program reinitiation interval, and the keyboard display unit associated with this copy of the program. Programs are assigned to the first "unused" entry in PTAB. Using the reinitiation interval, the program is given an activation sequence number determined by placing it into the list structured queue with the re-establishment of pointers such that the program having the short reinitiation (or highest frequency) interval is at the head of the list. The scheduler reinitiation rate is an integral divisor of all the possible applications program rates. Also placed in the PTAB is a pointer to a list of analog channels to be read. Since there are inevitably times when one channel or piece of equipment is not functioning properly, these channel numbers are stored in a list which can be modified without recompilation of the applications programs. There is a library table which contains the names of all available applications programs and their location on the disk. This table is searched by program name and an index or program number is determined and placed into the program table. This is used by the relocating loader when the program is to be initiated.

Programs are picked from PTAB, loaded, and execution is started. Execution continues until either the analog scheduler or higher level programs interrupt, or until this program requests analog I/O, keyboard display I/O or change in execution priority. These requests are made through Fortran calls to assembly language subroutines which use hardware trapping to access servicing routines. When analog I/O is requested the servicing routine places into the execution pending queue (ETAB) a reset interval frequency (INT), the number of separate read requests (RN), and a pointer to the channel numbers for each read (CHPTR), as shown in Figure 6A. A structure similar to that proposed by Fitzwater and Schweppe has been implemented to allow applications programs dynamic control of the amount of I/O overlap and execution priority. One parameter supplied to the analog scheduler is an index (I) which is updated by the scheduler after each read. If the applications program informs the scheduler that it desires to have control returned to it before the completion of all I/O (wt = false), an IF statement is positioned after the analog call in the program to compare this I/O index with a processing index. If the processing index is equal to the read index, the program calls the WAIT function. Priority of execution (PRTY) may be higher or lower than the program scheduler and may vary from one analog request to another within one program.

Requests in the ETAB are entered by reinitiation interval (frequency) just as they are in the program queue. There is a multi-priority structure as shown in Figure 6B for determining the return of control, after completion of pending analog input. When each application program requested analog I/O, its restart priority level was inserted into ETAB. Three sections of the analog scheduler at three lower priority levels search this queue to determine if there are any programs requesting execution. The highest priority of execution that can be requested is for programs that must execute a section of code between each read. The next priority of execution available is at a lower interrupt level for programs which have a higher priority than the program scheduler, but do not need to execute between analog reads. The lowest execution priority level is below the program scheduler. When all analog I/O pending for a program has been completed, the program is assigned to the hardware priority level it requested, its entry in ETAB is deleted, and control is returned to this level if no higher level is waiting. Further analog requests by this program create a new entry in ETAB. When control is returned to each applications program, execution is continued until either the program requests more analog I/O via the analog initialization routine, or until the program calls the program deletion routine.

**Data file system**

One of the most important indices of medical data is time. As physicians review patients' records, they group information into "time lines" and then compare these against each other. (E.g., Given a patient's mean arterial pressure and blood volume at time 1, and the fact that the patient was administered a drug, is it significant that at time 2 he now has a higher blood pressure and
Groups of variables (e.g., hemodynamic variables) are usually considered together and called "summaries." One group recorded at the same time may be called an instance in a summary.

In the data management system there are two types of summaries. Type I is numeric information derived either directly or indirectly from the analog monitoring, and Type II is textual information which is inserted through the keyboard display devices. Type I information is stored as half word (16 bit) integers, and Type II as standard hexadecimal alphanumerics. Each instance of a summary contains a time, and a forward and a backward pointer to other instances of that summary. Instances are stored sequentially as they occur in time and are interleaved with instances of other summaries (Figure 7).

To facilitate the storage and retrieval of data, there is an outline for each patient file (Figure 8). This outline is the first record in each file and indicates which summaries are included in the file, and explicitly which parameters are being monitored for Type I summaries. Type II summaries have only their names in the outline and all structure exists in the data records. Information in the Type II summaries consists of pointers, names and values (Figure 8). Names (or qualifying names) are like indentation levels in an outline, and have a length of 8 hexadecimal characters. The values contain the actual textual information of interest and are of variable length. The first byte of the value is the character length of that value. There is a pointer with each name at each level, and this permits searching through the qualifying names at each level without searching through all of the text. Qualifying names can be appended to the beginning of the value and at any level the set of all subordinate names and values is a value. This allows the user to know as little about the outline structure as the main heading, or as much as the entire structure.

Each patient file can consist of many physical records where each physical record, for the purposes of buffering, is of a fixed length of 360 words of 32 bits. Each bed in the ward has its own buffer, but all other active files alternate the
use of a common disk I/O buffer. Instances of summaries of the patient file are stored into a buffer until it is approximately 95 percent full. Although the alphanumeric summaries were designed, because of their length, to allow for continuation in subsequent records, numeric summaries were not. Therefore, 100 percent buffer usage is uncertain. It is also desirable to allow space for record modification. There is a list of first and last instance pointers at the beginning of each data record where these pointers are in the same order as their respective summaries in the outline.

All active patient files are kept on the disk. There is a table in core and on the disk identifying physical records on the disk as patients' or unused records. Files of discharged patients are kept on magnetic tape, and there is a dictionary indicating where patient files are found on tape. Therefore, when a study is to be done on an old file, the file dictionary is scanned by patient number, and the system requests the pertinent tape to be mounted if it is not already mounted. The system then determines which disk records are available, and buffers from tape to disk. Oldest or least used files are automatically deleted from disk to make room if necessary. An active patient file table is maintained and is updated to include the patient number, active file number, present status of the file, and pointers into the patient's record. The first entries in the active patient file table are reserved for the active beds in the ward. The rest of the entries are shared by the terminals for any patient file of interest to the user of the terminal.

The rationale behind this structure is that no external dictionary is needed to retrieve any information. All structure is internal, and the user language is constructed such that the structure can be readily available to the inquirer. No two patients have identical files, and to force all files into one format would be time and space consuming. Even if two patients have the same monitored parameters, they will certainly have different lab tests, histories, physicals, etc., and they certainly will be stored at different time intervals.

Hardware

This description of computer and associated hardware (Figure 9) is included, but is not necessarily intended as a suggestion of the size of system required for intensive care monitoring.

In fact, the computer system described is part of a larger systems study of the entire intensive care facility. System studies are being conducted to quantify the hardware and software needs as functions of both degrees of illness and number of patients. Attempts to simulate are fruitless at the present time, since the interface between clinical medicine and computer has not been sufficiently explored.

The SDS process control computer system consists of:

A. A Sigma 5 central processing unit:
   1. 24,000 words of core storage
   2. 850-nanosecond cycle time
   3. memory protection
   4. 4 interval timers
   5. 40 levels of hardware interrupt
   6. additional register block (total 32 general purpose registers)

B. Peripheral I/O equipment:
   1. rapid access data (RAD) storage system (17 m. sec. average access)
   2. 2 magnetic tapes
   3. 1 card reader 400 cpm
   4. line printer 600 lpm
   5. 2 teletypes

C. Data acquisition equipment:
   1. multiplexers and their controls for switching input lines
   2. data channels for buffering input and output
   3. analog-to-digital converter (24kc with random addressing)
   4. digital-to-analog converters
   5. direct digital I/O for sensing and closing switches
D. Display equipment:
1. keyboard display
2. closed circuit display with character generator
   (Computer Communication Inc. CC301)
3. storage CRT (Tektronix 611)
4. digital plotter (CalComp)

ACKNOWLEDGMENTS

We would like to express our appreciation to M. H. Weil, Director of the Shock Research Unit and to J. A. Trotter, H. R. Joly and L. D. Cady, Jr., with whom various aspects of this subject were discussed.

The contributions of Mrs. Edith O'Neill, Mrs. Bess Strauss, and Mrs. Helene Wheeler in preparation of this manuscript are also gratefully acknowledged.

REFERENCES

1 Commission for Administrative Services in Hospitals (C A S H) 4777 Sunset Boulevard Los Angeles California 90027 Internal Report 1966
2 M A ROCKWELL H SHUBIN M H WEIL
   Shock III a computer system as an aid in the management of critically ill patients
   Comm of the ACM Vol 9 no 5 May 1966
3 R L PATRICK M A ROCKWELL
   Patients on-line
   Datamation Vol II no 9 Sept 1965
4 R E JENSEN H SHUBIN P F MEAGHER M H WEIL
   On-line computer monitoring of the seriously ill patient
5 H SHUBIN M H WEIL M A ROCKWELL
   Automated measurement of arterial pressure in patients by use of a digital computer
6 H SHUBIN M H WEIL M A ROCKWELL
   Automated measurement of cardiac output in patients by use of a digital computer
7 H SHUBIN M H WEIL
   Efficient monitoring with a digital computer of cardiovascular function in seriously ill patients
   Annals of Internal Medicine Vol 65 no 3 Sept 1966
8 H WYLE G J BURNETT
   Management of periodic operations in a real-time computation system
   Proc FJCC 1967
9 D R FITZWATER J SCHWEPPE
   Consequent procedures in conventional computers
   Proc FJCC 1964