PROGRESS, PROBLEMS and PROMISES

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The title of this symposium is "Computers in Health Care - Are they worth it?" For purposes of my discussion I would like to add to this question, "Are they worth it to me?" Like many of you, I discovered computers in the process of trying to solve a problem. Like some of you also, perhaps, I became fascinated by the machine and then went looking for new problems to solve with it. In this case the tool was not a microscope or a telescope that held out the promise of seeing more detail or further out into space. It was a tool to expand my intellectual power, my ability to gain insight into relationships more complex than I could grasp without it. Let me tell you a few of my experiences with computers over the last twenty-five years, in order to provide a basis for answering the question I have posed and perhaps stimulating you to pose the same question to yourself.

When I moved to Salt Lake City in 1953 after finishing my training in medicine and physiology here in Minnesota, I was given the opportunity to establish a cardiovascular laboratory for diagnostic heart catheterization at the LDS Hospital. This is a private 500 bed hospital manned by 300 private practitioners, mostly specialists and affiliated with the University of Utah. We were given a small room next to surgery to remodel and equip on a budget of $10,000. This included the fluoroscope. The next year the hospital was given a grant from the Ford Foundation, which we used to build a small research laboratory on the roof just above the catheterization lab. At this time I was taking a course on campus called "Advanced Engineering Math" in my spare time and one day we were introduced to the concept of representing a periodic time function in the frequency domain by the use of a technique called "Fourier analysis". The idea so intrigued me that I spent long hours deriving the Fourier components of arterial pressure waves using tedious manual measurements from the oscillographic recordings and a 30 inch slide rule with sine and cosine functions to perform the calculations. A few days later in that class we were introduced to the notion of a transfer function as a method of describing a circuit from the relationship of the output signal to the input. That night it occurred to me to analyze the behavior of an artery by the way it altered the pressure signal in the process of transmitting it. The next day I performed a Fourier analysis on a pressure wave recorded in the aortic arch and on another waveform recorded in the radial artery from the same heart beat. I obtained the transfer function by plotting for each harmonic the ratio of the output to the input. The resulting curve peaked at the fifth harmonic and then fell off rapidly resembling very closely the transfer function in my textbook obtained from a resonant circuit having a resistance, capitance, and inductance. I decided to build such a circuit in which each of these components could be easily varied to see if indeed I could simulate the behavior of the artery. With this circuit operating in the laboratory upstairs where lines were run from the pressure transducers in the cath lab, we began a series of experiments to test this idea. At a certain point in the diagnostic catheterization when one transducer was connected to a catheter whose tip lay in the aortic arch and the other transducer was sensing pressure through a needle in the radial artery, I would leave the patient with my assistant while I ran upstairs for a few moments to play with the circuit. Using a dual beam oscilloscope the downstream pressure wave from the transducer could be compared to the output waveform from the circuit. The input to the circuit was the electrical signal from the upstream transducer. The values for R, L, and C were empirically adjusted while I watched the waveforms until values were found which resulted in the two beams being superimposed throughout each heart cycle. At this point the circuit was altering the upstream electrical signal in the same way as the artery was altering the upstream pressure wave, and I could read off a resonant frequency and damping coefficient from the circuit parameters which also described for the first time the behavior of the artery in dynamic terms. I had indeed my first analog computer. As a result of this experience and a little reading I was off into the world of computers. With our first grant we bought some operational amplifiers, which grew into a roomful of analog computing equipment. We explored a variety of models of the circulation and its components and tested them against reality.

Although I had been intrigued with mathematics as a tool for gaining insight into functioning relationships in physiological systems, obtaining realistic solutions more often than not required simplifications that were difficult to justify. All of a sudden I had a tool that could solve large sets of differential equations and provide graphic solutions in realtime. In addition the actual circuitry represented by the computer provided another domain or frame of reference in which the physiological system could be understood.

as accurately as our best pediatric cardiologist from these pre-catheterization data and even better than the other physicians tested. Most importantly, we realized that the computer really could perform the diagnostic task.

Then began our fascination with signal processing using digital techniques, which led us into such things as ECG interpretation, automation of data acquisition and analysis in the cath lab, monitoring in the ICU and operating room and automated recognition of moving left ventricular borders from angiocardiographic data. These too were exciting times. We had the first A to D converter on an IBM 1620. With the computer we could estimate stroke volume and peripheral resistance from a pressure wave beat by beat in realtime. We had data coming at us from all directions and we devoted our efforts to new methods of data display and reduction. Based on the notion that the decision maker who uses all this data would like to have more detail about recent events and progressively less detail as events fade back into history a system for data compression was implemented which did just this. The amount of data represented by each bin displayed as a bar graph was proportional to the logarithm of the time measured back to the midpoint of that bar. The graphs produced by this clever algorithm failed to impress the clinicians. I don't think they ever really understood it, but I realized enough intellectual satisfaction from the months of effort on the project to override my disappointment at having to abandon it for reasons of disuse for some later generation who may find it useful.

In the summer of 1966 my colleague Allan Pryor was in the process of evaluating his ECG interpretation program and asked me if I would continue this evaluation for him while he spent the summer on an assignment in Germany. The first month I read each electrocardiogram before comparing my reading with the computer's interpretation. The next month I reversed the process and first looked at the computer reading before checking the tracing to see if I agreed. Only those of you who have compared these two approaches will appreciate the difference in intellectual effort required. On a number of occasions that same summer I found myself in the ICU involved with nurses and housestaff in trying to understand the meaning of a trend in some physiological variable which the computer had brought to their attention. More often than not, some clinical data were required along with the hemodynamic findings to arrive at a management decision. After one such experience it occurred to me that we might preserve the intellectual process used to make such a decision in a form that the computer might use later to recognize the events that led to this decision should the combination occur again. The development of such a system for medical decision-making sprang from these experiences and has dominated our efforts for the last ten years.

This system, which we call HELP, has led us not only into data interpretation and diagnosis but into the development of many other applications including suggestions of follow-up studies and treatment, an on-line realtime quality control system for the whole hospital based on alerts provided by HELP decision criteria, development of a large data base and systems for accessing that data base to improve future decisions, and the development of tools for teaching decision-making to students and for the creation of decision criteria. Working with this system provided me with exciting challenges across the spectrum of computer activity, including the design of a data base to meet the needs for the decision-making system reliably and efficiently, the provision of computer-based tools to match the intellectual processes of the decision maker and the implementation of mechanisms for initiating a decision and reporting it under the appropriate circumstances. In addition, it has led me into areas of application outside my earlier medical interests which have proved most rewarding.

The HELP system is a tool to facilitate optimal medical decision-making thru the interfacing of three components:

1) A data gathering facility

2) A patient data file

and 3) A medical knowledge file structured in such a way that this knowledge will be appropriately used.

To accomplish this, the knowledge base is composed of modules, each of which is called a HELP sector and contains the logic for making a single decision. A list is created by the system for each data item of the decisions which use that data item. Thus each new item of data added to any patient's record will call into the CPU for execution any HELP sectors which use that data. This is done automatically - no one has to request a HELP consultation. If a decision is made, it too is treated as an item of data, and is stored in the record, and, in turn, will cause any sectors which use it to be processed. Thus the system is designed to go as far as it can with the decision process with each new observation recorded.

To me, however, the most exciting aspect of HELP is the fact that the system itself provides the basis for improvement of its future performance.

Since the HELP decisions are largely based on discriminant functions and probability estimations, the quality of these decisions is dependent on the validity of these statistical relationships. As the data base becomes larger, these statistics become more accurate. Already we have gone thru several improvements not only by getting better parameters for the functions used in certain HELP sectors, but have actually found from analysis of this data new variables and algorithms not previously known.

A system called STRATO has been developed to accomplish this task. This program permits the user to write a HELP sector to specify the criteria defining a population to be used for analysis.

For instance - all patients operated for appendicitis on whom the pathological diagnosis was appendicitis are defined as test population.

Control population - same except pathological diagnosis not appendicitis.

Now HELP can be used to define a variable in each of these two populations--i.e., first white blood count after admission.

The distribution of this variable can then be compared by plotting the distribution in one population over the other. If they are different, white blood count may be a good variable which can be incorporated directly in a HELP sector for diagnosing future patients suspected of appendicitis.

The need for this kind of research becomes very apparent as we examine the real basis for much of our decision-making in medicine. Expressing the decision criteria explicitly as required for computer execution puts the problem in perspective in the same way that developing a model of a physiological system - even in the block diagram stage - often shows us very clearly what we don't yet know about that system. What is needed, I believe, is a refereed journal in which medical decision algorithms can be published along with a description of the experiences or experiments that support them. This will attract researchers into this important activity. We must not fall into the practice of developing decision algorithms that are divorced from reality as were some of the physiological models developed by engineers who had no contact with real data. To avoid this, capable medical scientists must be attracted to work in this field who have at least one foot in the appropriate clinical environment. Our bottleneck will not be hardware or even software, but will be the development of the medical decision algorithms - the medical ware.

The computer has provided me with many of the intellectual satisfactions usually reserved for the theorist and at the same time with the excitement of testing these theories by implementation in a real environment. Has the computer been worth it to me? Has it been worth all the frustrations associated with finding that last bug, of getting this program to really work before I start on the next one, which I am sure will be the answer to everybody's problem? How can I get enthused about cost/benefit analysis of the current system when, compared to the one I have in mind, it is already obsolete? Yet, I must learn from the real world where my current system fails and design the new one to overcome those failures. I must test how well it does the job it is intended to do.

Where are we going from here? How much of our time are we going to spend analyzing what we have and basing our decisions as to whether computers are worth it on today's technology? The one thing quite apparent from even a cursory look at the advances in computers over the past twenty years is that today's technology provides but a hazy picture of what even the near future will provide. Let's not spend all our time and resources measuring how long it takes or how much it costs to get there with today's buggy, but let's get on with the job of building tomorrow's automobile and planning where to go with it.