COMPUTERS IN MEDICINE

Mathematics, Computers, and the Doctor

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There is at present an increasing awareness among doctors that new developments in mathematics and computing are of direct interest to medicine. At the same time there is a certain feeling of helplessness in the face of these same developments. In general, people who take up medicine are often not very enthusiastic about mathematics and most doctors are busy enough keeping up with developments in their own profession without having time to extend their reading into new areas of science and technology. The result is a lack of knowledge often exaggerated by the inferiority complex most people possess with respect to mathematics. This article aims to survey the relationship between medicine, mathematics, and computer science and to suggest one or two ways in which this relationship could be fostered.

Two important distinctions must first be made. The first of these is between medical practice in the widest sense and medical research. Much of the research done by doctors takes place in hospitals, particularly the large teaching hospitals, and the structure of the profession makes it rather easy to stress the importance of research activities as against the problems of everyday medicine, whether in the hospital, in general practice, or in the local authority service. Moreover, there is more to research in medicine than is sometimes considered under the heading "medical research." Operational studies of queueing in x-ray departments, or work study in operating-theatres, may have as much to offer in the short term towards the patients' welfare as a good deal of the laboratory and clinical research currently in progress.

The second distinction is that between mathematics and computer science. The first computers in the modern sense were thought of explicitly as calculating engines, and it took some time for their far wider capabilities to be appreciated and exploited. Even today it is often difficult to use a computer to its full non-arithmetic capability because its design and configuration have been framed with straight computation in mind. Yet it is clear that it is just this capability whose exploitation is going to have the most far-reaching consequences.

Our subject thus splits into four segments—(medical practice *v.* medical research) $\times$ (mathematics *v.* computer science). In medical research, at least, the role of mathematics is fairly straightforward. Mathematics has obvious applications in the more laboratory-based disciplines such as biophysics and physiology, but in fact almost any experimental or observational study involves, whether implicitly or explicitly, a model of the true situation, and such a model is usually best described in mathematical terms. Such a description may in fact throw new light on an apparently tricky subject. For example, the oral glucose tolerance test is very well known, and yet there is considerable argument regarding the best means of using data from the test to study disease states and the effects of drugs; the introduction of some of the concepts of control system engineering suggests a number of ways in which the problem could be approached with advantage.

Mathematics and Statistics

When the role of mathematics in research is being discussed, it has become fashionable to play down the importance of statistics as against some of the less familiar branches of the

subject. It would be possible to make yet another distinction, this time between mathematics and statistics as quite distinct disciplines, and clearly I have a personal interest to declare. Nevertheless, any mathematical model must at some point be confronted with the real world, and in this confrontation statistics has inevitably to be employed, of a greater or less degree of sophistication. As one example, compartmental models of metabolic and other systems are popular in many fields of medical research, but it does not take any great statistical finesse to show that very many bodies of data are simply far too flimsy to support the tower of negative exponentials that is confidently erected upon them.

G. Barnard has defined statistics as "the interesting parts of applied mathematics." Be this as it may, medical research can use a good many mathematical techniques and concepts that are not commonly found in the statistics textbooks. There is, moreover, a real difficulty here. A famous mathematical text is entitled *Elementary Mathematics from an Advanced Standpoint*, but medical research is apt to need the exact reverse of this—the relatively elementary parts of mathematical topics usually thought of as extremely advanced. Boolean logic is one of these; matrix algebra is another; control system theory has already been mentioned. With the current overhaul of the school mathematics curriculum these topics will eventually become less unimaginably foreign to the average medical research worker, but in the short term the difficulty remains. It must be emphasized that large parts of them, and these often the most useful, are truly elementary, less *complicated* than the mixed radix arithmetic that a non-decimal currency imposes on most British shop-assistants. It may or may not be true that spectrum analysis cannot be understood to its ultimate depths without the concepts of Hilbert space; but to prohibit its widespread teaching and use on these grounds is as much as to demand a competence in advanced quantum theory from every radiologist.

The prospect of more mathematics in medical research, coupled with the axiom that medical research is aimed at influencing medical practice, raises the question of the amount of mathematics needed by the medical practitioner. A rough answer seems to be "the same as the amount of engineering knowledge needed to drive a car." It should be possible to use the results of medical research with almost no appreciation of the techniques that have produced them—if it is not, the research is to that extent incomplete—but the doctor who understands the researcher's methods may well be able to use his results more expeditiously.

Role of Computers

Mathematics, then, is primarily the tool of the medical research worker, and in so far as computers are used for mathematical work they will also be important in this area. When we turn to the non-arithmetic applications of computers, however, the possible applications in everyday medical practice may well overshadow those in research. These applications are, broadly speaking, of three kinds. In the first, the computer is used as a controller of some physical or biological system.

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At present the systems actually being controlled by computers are of small or moderate complexity, ranging up to a fair-sized steel works, chemical plant, or power station. A human body is a system both more complex and less well understood than these, but there is a real possibility that the near future may see the computer as a working tool of the anaesthetist, sensing the patient's respiration, blood chemistry, heart beat, and electroencephalogram, and controlling the input rate of anaesthetic agents and inspired gases so as to maintain the required level of anaesthesia. As "brains," computers are unbelievably stupid, but at least they do not suffer from fatigue during the lengthy sessions that spare-part surgery and other modern techniques seem likely to demand.

Information Stores

In the second main type of application the computer is used as an information store. Under favourable circumstances computers can store (on magnetic tapes or discs) very large amounts of information in a very compact form, and can get the information back in a time ranging between minutes and milliseconds—the former if a human operator has to go and find the right reel or disc and mount it on the reader. We still do not know nearly enough about ways of exploiting this power, the problems of which spread in all directions. Recording numerical information is quite easy, and it is perfectly possible to store verbatim text, but we probably do not need to burden the tapes with the string of 40 characters "No pulmonary lesion—heart size normal," which is the outcome of a large proportion of chest x-ray films. How far are doctors prepared to use standard phrases for the computer's convenience, and will they be satisfied when their own text is encoded and later recoverable only in "standardized" form? What devices are appropriate for capturing and later displaying the stored information? Most of those available today are expensive, noisy, or both. How are we to phrase requests for retrieved information? Users of the Medlars system, where the information stored relates to the current medical literature, will know that this is not at all an easy question.

For all this caution, the use of computers as information stores is already producing results. The best known of these are probably those from Dr. E. D. Acheson's group at Oxford. By record linkage—storing information taken from birth and death certificates, hospital discharges, and other sources and by retrieving *all* the data available on a particular set of individuals—Acheson has already shown that new knowledge is lying hidden in existing routine records, concealed only by the haphazard way in which the records are collected. As impressive are the achievements of Dr. T. M. Galloway and his colleagues of the West Sussex County Council, who record birth records on a computer file and in due course use the computer to prepare immunization schedules, to send reminders to parents, and to make appropriate payments to the doctors concerned. The results of this exercise (which leads to less work by the administrative staff at county headquarters) are abundantly apparent in the West Sussex immunization rates. It is encouraging that Dr. Galloway's initiative is being followed up by other local authorities in an organized way, and interesting to note that it could quite readily be combined with Dr. Acheson's scheme.

Output Analysis

The third type of computer use, somewhat closer to orthodox arithmetic, involves the analysis of the outputs of recording devices. An example is the system devised by Elliott Medical Automation Ltd. for Dr. F. V. Flynn at University College Hospital in London. Here the outputs from a 5-channel autoanalyser are captured on paper tape and subsequently analysed by a computer to give printed lists of blood electrolyte

levels annotated with patients' names, numbers, and wards, together with a number of visual indicators of abnormal findings. The U.C.H. system is experimental and relatively primitive, but it has laid a vital foundation on which several more ambitious systems are being built. Computer analysis of electrocardiographic tracings has so far not proved very popular in this country, though several American centres are active in the field, but there may well be more to gain from computer analysis of the electroencephalographic record, which is at once far more complex and much less suitable for "eyeball analysis." Dr. H. Townsend in Edinburgh is working in this field at present.

It will be apparent that these three kinds of computer application are all linked together. The computer-calculated results of chemical analyses are themselves placed in the computer-operated information store; combined there with other information, they form inputs to the control system for the patient that is constituted by the computer-assisted clinician and his supporting staff. It is important to realize that a single machine can if necessary play all three roles; some modern developments, whereby the expensive central core and processor are shared by a number of peripheral units, make this more feasible, while others, such as the marketing of small but reliable and powerful machines at prices below £5,000, tend to lead in the opposite direction.

Urgent Problem

So much, then, for the impact on medicine of mathematics and computers. What of the responsibilities of the people concerned on either side of the fence? The demands on the mathematicians are perhaps the easier to meet, since they represent in some respects an extension of an already existing movement in mathematical teaching and exposition; they add up to the willingness and ability to communicate their findings to groups of non-mathematicians. This involves a fresh look at the corpus of mathematical knowledge, stressing the logical sequences that exist there rather than those based more on the history of the subject. Many mathematical syllabuses are in fact historically based; much of the rigorous analysis included in school and undergraduate mathematical teaching stems directly from the revolution headed by G. H. Hardy half a century ago. But Hardy openly despised applied mathematics, and a different outlook is essential if medical workers are not to be completely alienated. Teaching applied mathematics to non-mathematicians is *difficult*; it needs, among other things, the enthusiasm and the maturity necessary to gain a real understanding of the non-mathematician's own field of special knowledge.

For the practising doctor the situation may well be more difficult because the demands will be on his scarcest commodity, time. In the broadest outlines the developments in mathematics and computing that medicine require can be specified by non-medical men, but the complexity of medical life is such that detailed specifications are apt to be disastrously unsatisfactory unless they are drafted with the fullest medical collaboration. This in turn means that a fair number of doctors must devote their time to acquiring a real understanding of the capabilities of mathematics and computers. This may not be a full-time task, but it is certainly more than a spare-time one. So far almost all the major advances have stemmed from individual initiative, but we shall probably not get much further without a more organized attack. The recent conference sponsored jointly by the British Medical Association and the Institute for Mathematics and its Applications (see *B.M.J.*, 23 December 1967, p. 737) suggests that combined action by those two bodies may be the most urgent requirement.

For urgency there certainly is. Whatever the views of doctors and research workers, those concerned with administering the National Health Service have already seen the potential gains in efficiency and economy that computers are capable of bringing

to the payment of salaries and wages, the maintenance of stocks, and other expensive activities. Several computers have already been installed by regional hospital boards and it will not be long before they turn up inside hospitals.

Administrative tasks will not load a hospital computer fully, and hence there will rightly be pressure to use the equipment directly for problems of patient care, the medical record providing the interface between the two types of activity. By the time this point is reached decisions will have to be made concerning the form of medical records, their accessibility, and

the techniques of recording and reproducing them, and these decisions will impinge directly on the daily work of the medical and nursing staff. It will be well if the decisions are made in full collaboration with doctors who are adequately acquainted with the problems involved, for made they will be, whether such collaboration is forthcoming or not. Rightly used, computers and mathematics have much to offer to the medical profession. Only if the profession is willing to involve itself to the full in their development will the most effective applications be pursued.

TOMORROW'S BUILDINGS

New General Teaching Hospital at Liverpool

Work is about to start on Phase 2 of the new general teaching hospital at Liverpool. In a booklet describing the hospital,¹ Mr. A. V. J. Hinds, the Secretary of the United Liverpool Hospitals, explains that this is intended to replace four relatively small and geographically separated hospitals (the Royal Infirmary, the Stanley Hospital, David Lewis Northern Hospital, and the Royal Southern Hospital). Work on Phase 1 of the new hospital started in 1965, and includes a training college for nurses, physiotherapists, and other ancillary workers; a residential block; and a boiler house and laundry. Phase 2 of the project includes the main ward block, outpatients department, university clinical departments, and the clinical sciences building. The main block is fourteen storeys high, and contains about 800 beds made up of sixteen

50-bed units (two on each floor) designed on a basically standard pattern. The ward design is based on the "race-track" principle with areas for patients sited on the periphery of the block and services and corridors forming a central core; most floors contain a six-bedded intensive care unit.

Operating Theatres

Ten operating theatres will be provided linked with sterile nursing unit and intensive therapy unit. The theatres will be connected by television to the viewing galleries above and also to the lecture theatres in the clinical sciences building. The outpatient unit is at ground-floor level and contains 11 clinic suites, each of which will be grouped round landscaped courtyards. This unit will also include a major accident department, two operating theatres for day cases, and departments of physical medicine, radiology, and pharmacy.

The four-storey block containing the university clinical departments will be linked with the wards, each department having direct access to its own ward. In their turn the university clinical departments will be linked to the clinical sciences building. The latter, which will have varying storey heights, will contain the departments of bacteriology and pathology, the medical library, the animal house, and three lecture theatres.

The Medical Teaching Centre will also include a dental hospital and University School of Dental Surgery. These new buildings, the booklet says, will enable the present annual intake of dental students of 35 to be raised to 60 from 1972 onwards and the number of patients treated annually to be raised from 81,500 to 140,000 respectively.

The architects for the new general teaching hospital are William Holford and Associates, Liverpool, and the main contractors for Phase 2 will be Tersons, London.

¹ *The New Medical Teaching Centre for Liverpool*. Reprinted from *Architecture North West*, 1967.