Men, machines, and ideas: An autobiographical essay*

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In this autobiographical essay I describe the manner in which my professional career was shaped by men, machines, and ideas. Pre-eminent among the men was Homi Bhabha. My colleagues with whom I was fortunate to be able to work during my long stay at TIFR, the institute founded by Bhabha, provided indispensable support to whatever I was able to achieve. My entire professional life has been very intimately intertwined with computers – their theory, design, and use. Computational modelling as a methodological tool to come to grips with all aspects of agentive behaviour has been a unifying theme in all my thinking and research activities.

'Ah, but a man's reach should exceed his grasp,
Or what's a heaven for?...'

R. Browning
Andrea del Sarto (97–98)

Men

Time, place, and effort

THE contribution one is able to make in any field is actually a function of three independent variables: time, place, and effort. However great the effort is, in other words, however great one's intrinsic worth is, or one's intrinsic capabilities are, if time and place are not supportive, the end result will not amount to very much. Whatever my intrinsic capabilities, I must acknowledge it has been my good fortune to have had significant support of time and place.

My entire professional life has been very intimately intertwined with computers: their theory, their design, and their use. More significantly, computational modelling as a methodological tool to come to grips with agentive behaviour in all its aspects has been a continuous and unifying theme in all my professional thinking and research activity. (This is discussed in greater detail later in this article.)

I got involved in computing right from the start of the field. My professional life coincides exactly with the life of computers as autonomous information processing machines and computing as an independent academic discipline. One gains major advantages by growing up with a field from time T_0, because one is able to be a trendsetter rather than be a mere trendfollower. Anything one attempts at all, being new, is pathbreaking. I have benefited from these advantages – especially in the Indian context. However, I cannot claim that I have made pathbreaking contributions to computing as an academic discipline except to a very limited extent. The computing field has grown and diversified much too rapidly for any single person to dominate it. My contributions to research in computational modelling of agentive behaviour have, perhaps, been somewhat more significant.

But more than the support of time, the support of place has been far more significant in my case. I mean by 'place', the 'contexts' of one's professional life in all its aspects. For the world to get to know and accept one, *godfathers* are essential and, more importantly, *godfathers* of the right sort and right intrinsic worth themselves. I must acknowledge here the total and informed support I was fortunate to receive from three individuals during my 36-year long stay (1954–1990) at the Tata Institute of Fundamental Research (TIFR) in Mumbai.

The first, of course, was Homi Bhabha. Without his acceptance and active support of the project, TIFRAC (TIFR Automatic Computer, the first fullscale electronic digital computer designed, built, and operated in India) could not have been built leading to all the fallout that stemmed from it. (This project is discussed in greater detail later in this article.) After Bhabha's tragic death in an air-crash, Vikram Sarabhai took his place and was equally understanding and supportive, and encouraged my efforts at the policy formulation levels for the promotion of Information Technology (IT) in India. (This aspect is not discussed further in this essay.) M. G. K. Menon was my third professional benefactor within TIFR, but very much more so outside, especially in the formative years of the Electronics Commission, of which he was the founder-Chairman, and its executive organ, the Department of Electronics, of which he was the founder-Secretary. It was at Menon's initiative that the National Centre for Software Development and Computing Techniques (NCSDCT) was set up at TIFR with the assistance of the United Nations Development Programme (UNDP). I shall describe below the significant role played by NCSDCT in the development and use of information technology in India.

Bhabha and Sarabhai

It may be worthwhile to digress a little at this stage to describe in somewhat greater detail the personalities of Bhabha and Sarabhai because of the unique roles they played in the Indian Science and Technology (S&T) scene. These two, perhaps more than anyone else, have contributed seminally to the technological transformation of India since its independence in 1947. Most of the individuals who are currently heading the S&T agencies, or giving shape to S&T policies in the country, have been nurtured by these two.

In their background, upbringing, education and training, outlook on life, cultural interests, and styles of functioning, there was a remarkable similarity between these two men. Both were great innovators and organization builders deeply concerned with the methodological issues relating to organization building. It is my belief that both Bhabha and Sarabhai were able to achieve as much as they did in their rather restricted life-span only because, apart from being highly compe-

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tent pure-scientists, they were very practical-minded, and were imbued thoroughly with the spirit of entrepreneurship.

There is a passage in David McClelland's book, *The Achieving Society*, which I think sums up the personalities of these two men extremely aptly. McClelland writes: 'In many ways the *Homeric Hymn to Hermes* sums up the characteristics of the entrepreneur and his relation to the traditional social order.... What is his essential spirit? He is in effect a little dynamo of energy – always on the move, in a hurry. He doesn't waste a moment's time, but starts out into the world to get ahead the moment he is born. He makes his technical innovations and pursues his career in a spirit of restless energy in which there is much motion and little waste of time[1].'

A very important aspect of the personalities of Bhabha and Sarabhai (that has not been discussed very much in accounts of them), was their high technological literacy, which was wide and deep. The need for technological intervention in converting ideas to action was realized by them, (which is the essence of technological literacy), not merely in doing science but in a variety of other areas, for example, in management and administration, in organizing space in architecture, and so on.

Bhabha's appreciation of the crucial importance of technological literacy and technological culture in doing highly creative work in an institution devoted to fundamental research may be seen reflected in all aspects of functioning of TIFR. TIFR is a technology-rich place. Productivity of average individuals goes up in a technology-rich environment. According to Blackett: 'A good laboratory is one in which even mediocre scientists can do good work'.

As we shall see in the sequel, the technologically literate environment of TIFR was an essential facilitating factor in undertaking cutting-edge work in computer science, particularly in software technology development and dissemination. The culture of TIFR was also an indispensable factor in promoting cross-disciplinary thinking and research in the computational modelling of agentive behaviour.

Support from other individuals

In addition to the three specific individuals mentioned, during my long stay at TIFR it was my good-fortune to have had as colleagues and students a very large number of creative, enthusiastic, and professionally high-calibre individuals from whom one could learn. If one starts enumerating their names, it could be a very long list indeed. But, outside of TIFR, I should mention two individuals for the part they played in significantly shaping my professional career.

The first was K. Sreenivasan, Head of the Telecommunication Engineering Department at the College of Engineering, Guindy, Chennai, where I received my first degree (B.E.(Hons), 1947). But for his advice and assistance, I would not have applied for and obtained a part-loan scholarship from the J.N. Tata Endowment enabling me to take up post-graduate studies in the USA. The six years (1948–1954) I spent in the United States at a critical, formative period of my professional life were significant determiners of my subsequent professional work.

The second person is P. P. Gupta who was the founder Managing Director (CEO) of the Computer Maintenance Corporation – as CMC Ltd. was known at the time it was started as a public sector corporation in 1976. In the very first years of the corporation, interaction with him at the working-level (in my capacity as the founder-Chairman (1976–1979)) was a creative experience. His totally unconditional support (in all my professional activities, inside and outside the Corporation) has been a significant facilitator of what I have been able to contribute to the computer industry in India, and to the IT field in general.

Machines

The TIFRAC project

Designing and building TIFRAC: Activity in the area of computer science and technology started in 1954 in TIFR as one aspect of development work in the Instrumentation Group. After some preliminary efforts at building digital logic subassemblies, a decision was taken, towards the end of 1954, to design and build a fullscale, general purpose, electronic digital computer using contemporary technology. At the initial stages, the total number of persons working on this project was about six, most of whom had a M.S. degree in physics with specialization in electronics. Except for one member (namely, myself), none had been outside India, and none of the participants in the project, including myself, had any experience in either using a computer or operating one, let alone building one.

In these circumstances, it seemed prudent to go about the task in two phases. The first phase would involve the design and construction of a pilot machine which would serve as a proving ground for ideas in circuit and logic system design. Engineering design and fabrication techniques could be tried out in putting together the pilot model. Based on this experience and making use of the personnel recruited and trained on the job during the first phase, a fullscale computer could be designed and built in the second phase.

The design work on the pilot machine was started early in 1955 and by October 1956 it was operational. Design on the fullscale machine was started early in 1957 and its fabrication was completed early in 1959. But owing to the non-availability of a suitable airconditioned area, the computer could be commissioned after complete testing only in February 1960. This computer was named TIFRAC subsequently in 1962, when the new TIFR building was inaugurated by Prime Minister Jawaharlal Nehru.

The TIFRAC project: Technical comparisons: To evaluate properly the significance of what was accomplished by the TIFRAC project in terms of know-how generation in computer technology, it is necessary to compare the design and engineering aspects of TIFRAC in terms of the state of the art at that time in the rest of the world[2].

During the ten years 1945–1955, the first generation computers built out of vacuum tubes, semiconductor diodes and ferrite-core memories were evolved and essentially brought to perfection. The basic logical scheme of this generation of computers was described by John von Neumann in a now classical report in 1946. He himself started a project at the Institute of Advanced Study (IAS), Princeton, in 1946, to build a computer based on the ideas he had described. This machine was completed in 1952. Simultaneously with the IAS project, several universities and Atomic Energy groups started building copies of the IAS machine. Notable among them was ILLIAC I built by the University of

Illinois, Urbana. The TIFRAC control logic design benefited crucially through design details kindly made available by the ILLIAC team. The first IBM commercial machines, based on a very similar logical scheme, the IBM 701, were beginning to be installed in early 1953.

Starting from the end of 1953, events started to occur rather rapidly in the computer field. IBM started in 1954 its FORTRAN (FORmula TRANslation) project (to develop a high-level programming language) which was completed in 1957. Simultaneously it started developing the IBM 704, and the first systems were delivered early in 1956. IBM 7090, a fully transistorized computer system, using 3-microsecond ferrite-core memory was operational in 1959. With time-shared peripherals, the 7090 was among the first systems to belong to the second generation of computers.

In Table 1 are summarized the principal features of the IAS computer built by von Neumann, the IBM 701, the TIFR pilot machine, and TIFRAC. Some interesting comparisons emerge from this table. The TIFR pilot machine, it will be seen, except for its size, was quite in pace with the state of the art in 1954. The design of TIFRAC in 1957 was still not very much behind what was being attempted at that time elsewhere. But by the time TIFRAC was commissioned early in 1960, computer technology had surged ahead leaving TIFRAC behind as an obsolete first generation machine. This, of course, was true of all the other Princeton-type machines which, however, by 1960 had had a useful life of about 5 years. None of these machines could have been converted to a second generation system by its original builders using the fabrication techniques they were accustomed to. Second generation computers required for their construction, in an essential way, production know-how which only large scale computer manufacturers had or could command. In view of this, TIFR, having decided in 1962–63 to upgrade the computing potential available in the Institute, was wise to investigate in the world market for the best available commercially-manufactured system.

The TIFRAC project: Principal gains: TIFRAC was in operation from 1960 to early 1964. Towards the end of this period it was being operated for 2 shifts daily to cope with the computational demand on it. It would not be far wrong to say that many of the computer users in India, handling sophisticated and advanced computational techniques, had their first introduction to programming through the use of TIFRAC. An important outcome of the TIFRAC project was the spread of computer consciousness among research scientists, primarily in TIFR and the Atomic Energy Establishment, and some of the universities (notably the crystallography group in Chennai). Data analysis of the early extensive airshower experiments of the Cosmic Ray Group in TIFR would not have been feasible but for the availability of TIFRAC.

Within the Computer section of TIFR, which now consisted of some two dozen persons (academic, scientific, and technical), as against the original half-a-dozen or so, the designing, building, commissioning, and operation of TIFRAC resulted in a variety of benefits. A hard core of specialists had grown to maturity who could tackle with confidence the logical, circuit, system, and engineering design of a variety of digital equipment. Once the construction of the main computer was completed, more time was devoted to the development of peripheral hardware. A cathode-ray tube (CRT) display, with novel character generation capability, was designed and built using a Memotran tube. There was considerable amount of academic activity in the study of automata, coding theory, and formal aspects of computation theory. Circuit design was shifted increasingly to the use of transistors. A magnetic tape back-up storage for TIFRAC was designed and built.

Table 1. A comparison between 4 first generation computers

	Institute for Advanced Study, Princeton	IBM 701	TIFR pilot machine	TIFRAC
Date started	1946	1950	1955	1957
Date commissioned	1952 (June)	1952 (production delivery)	1956 (Nov.)	1959 (Feb.) completed 1960 (Feb.) commissioned
Hardware in central processor	2300 vac. tubes	4000 vac. tubes 13,000 germanium diodes	–	2700 vac. tubes 1700 germanium diodes 12,500 resistors
Memory type and capacity	CRT (Williams memory); 1024 words	CRT (Williams memory); 2048 words	Ferrite core memory; 256 words	Ferrite core memory; 2048 words
Memory cycle time	–	12 μsec	–	15 μsec
Word length	40 bits	36 bits	12 bits	40 bits
Logic scheme	Parallel, asynchronous, fixed point, single address	Parallel, synchronous, fixed point, single address	Parallel, asynchronous, fixed point, single address	Parallel, asynchronous, fixed point, single address
Add/Subt. time	60 μsec	60 μsec	–	45 μsec
Multiply/Div. time	800 (1100) μsec	456 μsec	–	500 μsec
Input/Output	Punched cards, paper tape. A magnetic drum was added later	Punched cards, 150 lpm printer	Paper tape, teleprinter (page printer)	Paper tape, teleprinter (page printer), CRT character display. A magnetic tape drive was added later
Total power	–	88 kVa	10 kW	20 kW

On the programming side, the availability of a functioning computer made it possible to recruit and train additional programming staff members. A 3-address interpretive routine for floating-point arithmetic incorporating several features especially useful in matrix computations was designed and implemented and proved to be very popular among the users. The main and auxiliary storages were too inadequate to attempt the design of compilers of any sort.

The experience gained in maintaining and operating TIFRAC provided an invaluable opportunity to train and grow a group of technical personnel thoroughly conversant with the preventive maintenance aspects of a complex electronic system made up of hundreds of interconnected sub-assemblies. The availability of all these trained personnel, with hardware and software development and maintenance capabilities, proved to be of critical value subsequently when a decision was taken to go in for a commercially manufactured large scale second generation computer system.

Computer group and the National Computation Centre: Between 1959 and 1962 some half-a-dozen of the scientists who had been actively concerned with the design and construction of TIFRAC had gone to various universities in the USA on a variety of visiting appointments. Three of these decided to settle down permanently in the US; one returned in 1962 after working for two years on a second-generation computer system project at the University of Illinois. The others continued for longer periods in the US and returned subsequently. I spent 3 years (1961–1964) as a Visiting Scientist at the Digital Computer Laboratory in the University of Illinois, Urbana; (further details of work done are given later in this article).

The availability in the US of staff members of TIFR with specialized working knowledge of computers enabled TIFR to set up an Expert Technical Committee to make an assessment of commercially available large scale computer systems of contemporary technology and recommend the purchase by TIFR of a system with a suitable configuration of peripherals keeping in mind the current and near-future computing requirements of TIFR in particular and the country in general. I was nominated to chair this committee.

After analysing in detail the technical characteristics and cost structure of 4 computer systems, viz. IBM 7094, CDC 3600, Philco 211, and Univac 1107, the committee recommended the purchase of the CDC 3600 system (although only the first such system was in actual operation in the manufacturer's plant in Minneapolis at that time). TIFR accepted the recommendation. With the help of a US Aid Loan, a CDC-3600-160A System – as recommended by the committee – was purchased and commissioned at TIFR in mid-June, 1964. From October, 1964, the National Computation Centre based on this system started functioning as a regular national facility. The system was maintained and operated entirely by TIFR staff. The original Computer Section was upgraded to a full-fledged Computer Group with a wide range of R&D activities in hardware and software, apart from managing the National Computation Centre[3]. I was appointed the head of the Computer group.

The National Centre for Software Development and Computing Techniques (NCSDCT)[4]

The NCSDCT project: Concept and history: Soon after the establishment of the Electronics Commission and the Department of Electronics early in the 1970s, the Government of India took two major decisions to achieve self-reliance in computer technology development and usage. The first was to work towards the development and manufacture of small and medium-sized computer systems with associated software within the country so that, within a delimited time period, the bulk of the computer systems needed in this range could be met from indigenous production. The second decision was to centralize all computer procurement based on global tenders. With a view to ensuring the availability of adequate maintenance and other customer services to users of imported computer systems, a public-sector corporation called 'The Computer Maintenance Corporation' was set up in 1976.

To assist in the development of adequate manpower with software engineering skills and computer-application know-how, the Government of India, through the Department of Electronics, planned the establishment and support of major regional computer centres in various parts of India. The Department of Electronics sought the assistance of the UNDP in growing such regional computer centres.

A UNDP Mission visiting India in May 1973 was impressed by the government plans but felt that an undertaking with such ambitious scope could succeed only if it was actively supported by significant and high-level R&D activities in the relevant areas and disciplines. The Mission, after a detailed survey of the activities in computer science and technology in the various institutions in the country, strongly recommended the creation of the NCSDCT at TIFR. The Mission suggested that this Centre should take a leading role among the planned computer facilities suggested for UNDP support, as well as serve as a support centre for other large regional computer installations.

The reasons for the choice of TIFR as the host institute for NCSDCT must be self-evident from our earlier discussions of the wide-spectrum computer activities TIFR had been engaged in for over 20 years starting from the TIFRAC project initiated in 1954. The National Computation Centre based on CDC 3600-160A was being managed by TIFR from October, 1964 with no external technical assistance. This facility was in very wide use by practically every sector connected with national development. Optimization and other packages available at the National Computation Centre were being extensively used by petroleum companies, dockyards, power and space agencies, state governments, and town-planning organizations.

NCSDCT started functioning informally from late 1974. In 1975, with the signing of a contract by UNDP to purchase a large computer system with sophisticated time-sharing and graphics capabilities, the project was formally launched. A dual-processor DEC system 1077 and PDP-11/40 based Vector General Graphics System was installed at TIFR in mid-1975 and formed the base for the operation of NCSDCT. The NCSDCT project, which was initially approved for 3 years, was subsequently extended for another 2 years. Based on the successful completion of the first 5 years of the project, a Phase II lasting for an additional 3 years was approved with a limited UNDP funding.

NCSDCT was spun off from TIFR in 1985 and set up as an autonomous technology development and research centre in Juhu, Mumbai, under the administrative jurisdiction of the Department of Electronics. To reflect more appropriately the nature of its activities, its name was changed to 'National Centre for Software Technology (NCST)'. I was the Director of NCSDCT during its 10 year life (1975-1985) at TIFR. S. Ramani, one of the core staff members of NCSDCT, has been heading NCST since its establishment.

I have already mentioned that the decision to locate NCSDCT at TIFR was taken to ensure that NCSDCT could go into effective operation with minimum delay and from as high a take-off level as possible. The decade-long functioning of NCSDCT fully validated the reasoning behind this decision. Without the infrastructural support provided by TIFR, and without its academic and professional culture, NCSDCT could not have functioned at the level of efficiency at which it did. The high quality leadership provided by the core staff of NCSDCT, all of whom held tenure staff positions at TIFR, contributed in an indispensable measure to the achievements of NCSDCT. When fully operational, NCSDCT had a R&D staff strength of about 30 (including visitors) – roughly a third of them had Ph D degrees, and all the rest MS or M Tech degrees. Including operational and administrative staff, the total staff strength of NCSDCT was about 50 (roughly a fourth holding tenure positions in TIFR).

The NCSDCT project: Achievements and lessons

Technology development: Content and method: NCSDCT played a seminal role as an innovating and catalysing change-agent in the areas of software engineering and software technology in India. Because of the initiative taken by NCSDCT, contemporary computing facilities and computing practices were introduced to software practitioners in India for the first time. Also, for the first time, significantly new areas of work were started in India in software technology, such as the design and implementation of operating systems and language processors using high-level implementation languages; computer graphics and computer-assisted text-processing and composition not only in English but in Indian languages and scripts; digital data-transmission and computer networking; design and use of database management systems; development of sophisticated mathematical programming software systems; and so on.

The rapid growth of computer science and technology in the Western countries makes it essential for every computer-related activity (that aspires to compete in the world market) in countries like India to be based on the best available techniques and methodology if it is to be economically viable. Also computing science is one of the few fields where several of the theoretical advances have had an immediate effect on practice. Keeping these aspects in mind, NCSDCT consciously involved itself in a range of activities from theoretical work on design techniques to practical work on implementation. NCST – as NCSDCT's successor – has continued to follow this philosophy, considerably widening and deepening its involvement in the development of implementation methodologies and practices based on well-understood and sound theoretical concepts.

Technology development in any area can be approached in three ways: by providing new products, by offering new services, or by trying to change professional practices and attitudes. In the area of software engineering and software development, NCSDCT tried to approach the problem of upgrading the indigenous level of technology in all these three ways. But the emphasis was in the last mode, namely, changing software practices and methodology of programming. This objective, in general, is not very easy to achieve.

The real solutions to the problems of large-scale software production lie in the choice of (or development of, where not initially available) design techniques and software production tools. It is, therefore, of great importance that efforts be directed to the study and development of: (1) new techniques for the specification and design of programs; (2) new tools with which design can be efficiently converted to working programs; and (3) formal tools and methods for establishing the correctness and reliability of programs.

Some software development activities at NCSDCT were directly concerned with design and specification issues (as in the Program Manipulation Laboratory); others developed and used contemporary program design methodologies. In many ways, the use of such techniques (and the computing environment available at the NCSDCT computing centre) made it possible for small groups to attempt and accomplish ambitious tasks. It is the successful implementation of large software products exploiting the power of theoretically sound design methodologies and implementation tools that enabled NCSDCT to convince professionals, working in the field, of the practical value of these methodologies and tools. Dissemination of these ideas formed an integral part of the training programmes run by NCSDCT: (see next section for details).

Education and training: The demand for software engineers in India capable of productive participation in sophisticated software development projects has been rising steeply in the recent past. Software development, as a well-defined industry, has taken root in this country. Adequate manpower development to meet this growing demand has become a major challenge to educational and training institutions. Formal educational channels are wholly inadequate to cope with a demand of this magnitude. What are really needed are facilities for extension training, part-time classes, and continuing education, satisfying the highest technical and professional standards.

To face this challenge, NCSDCT started its one-year, modularly designed, evening course in computer science and application. The classes were held at Victoria Jubilee Technical Institute (VJTI) in Central Mumbai, with a remote data-link (using telephone lines) to the PDP-10 computer system at NCSDCT in TIFR. The course started with the explicit stipulation that academic rigour would be maintained at the same level as in a full-time post-graduate course. Preference was given to candidates already employed in software development activities. Employers were persuaded to pay for the training of those employed by them. Entry was controlled through a fairly rigorous entrance test.

In order to teach large groups of students (60 to 80 at a time) effectively, a teaching methodology was adopted incorporating many unconventional aspects: for example, self-study, liberal availability of consultants and computer access, many assignments and tests interleaved with a small number of formal lectures, distribution of high-quality text-books (often obtained from outside India) to each student, and so on. This teaching programme very soon became one of the most sought after training programmes in Mumbai. It is worth noting that NCST, building on this experience, has made conducting post-graduate, and advanced-level training courses as one of its core activities.

Aside from conducting training courses for outsiders, NCSDCT consciously based its functioning on the philosophy that its own staff members *in every category* must be involved in technologically and intellectually creative and challenging activities in some measure, however limited. Thus everyone, from computer operators, hardware and software systems staff, to project and research staff, devoted some percentage of their time to developmental and/or teaching/training/consultancy activities. This approach proved to be extremely successful in the professional development of the staff and in maintaining a high level of motivation among them. This approach also contributed in maintaining the staff-size small and in stretching their responsibilities to meet new commitments to the extent possible.

Need for professional contacts: Computer technology is a fast moving field and, because of the size of involvement in this technology, much of the development takes place in Western countries. Practically all the technical conferences where exchange of ideas and information take place, and professional contacts are established, are held in the West. Cost of travel prohibit participation in such conferences by Indians in significant numbers. A logical alternative is to have world-class, high-level, conferences organized in India which would attract foreign participants active in R&D.

With this in view, NCSDCT started a conference series titled: 'Foundations of Software Technology and Theoretical Computer Science (FST-TCS)'. This conference, an annual event, has been held without interruption since 1981, and is undoubtedly the most highly valued conference in India in its fields of coverage both in terms of its technical content and its organizational efficiency. Papers accepted for presentation are rigorously refereed by a panel of specialists (both Indian and foreign) and the proceedings are printed and published by a commercial publisher of high repute from outside India. From 1985, this conference has been organized and managed autonomously by Programme and Organization Committees specifically elected for this purpose every year by the participants. The participants also decide on the venue of the conference in India for the following year.

Management structure: Taking into consideration the highly innovative and creative nature of the work envisaged for NCSDCT, it was felt from the very beginning of the project that the Centre should be autonomous and the direction of its activities should be determined by its own staff keeping in view the overall objectives and responsibilities outlined for the Centre in the Project Report. The Government of India (GoI) decided that TIFR should manage NCSDCT according to its administrative norms. The Management Council of TIFR, in its turn, agreed that the powers of management should rest with the Director of the Centre and he should be given complete freedom to operate within the broad limits defined for NCSDCT.

A Policy Committee consisting of representatives of GoI, UNDP, NCSDCT, and two external experts, was constituted to review annually the on-going activities at NCSDCT and approve future activities, budgetary support for these, and related matters. During phase I, M. V. Wilkes, Head of Department, Computer Laboratory, Cambridge University, England and W. A. Wulf, Department of Computer Science, Carnegie-Mellon University, Pittsburgh, USA acted as external experts in the Policy Committee.

This arrangement worked extremely smoothly, and during the 10-year period that NCSDCT was in TIFR, except for the UNDP budgetary input, NCSDCT was completely self-sufficient (earning its keep through services rendered) so far as its operational budget was concerned.

Ideas

The need for an integrated framework: Physical and behavioural sciences

A polarized view: It has been the practice in India to interpret 'science' narrowly as referring exclusively to the physical sciences (including biology and mathematics) and to the technology disciplines immediately related to these. The scientific leadership at the national level is overwhelmingly drawn from these disciplines. However, India's immediate and pervasive national problems are related to society and social institutions, and to individuals, their attitudes, motivations, and behaviour. There is – among the general public, including many of the physical scientists – very little recognition that these socio-psychological problems ought to be, and can be, studied and understood by the use of scientific methodology. The general unwillingness to grant that individual and social behavioural phenomena are amenable to scientific study and theorising has given rise to a national ethos where science does not guide the life, attitude, and thinking of scientists, but is merely a technical profession that one practices during office hours.

How can one account for this state of affairs? I think there are two reasons for this. Firstly, there is a received view of what science is all about. The essence of scientific activity according to this view consists in the capability to formulate scientific laws and to use these to make predictions. But we can neither formulate general laws nor can we make predictions about social and individual behaviour. Hence, there cannot be a science of such behavioural phenomena.

The second reason follows directly from the scepticism outlined above. What are of central importance in the study of individual and social behaviour are concepts like 'value', 'meaning', and 'purpose'. These are precisely the concepts that science (i.e. the physical sciences) explicitly avoids. Hence, behavioural phenomena can only be apprehended through non-physical, non-materialistic means. Thus, one tends to set up two polarized frames of reference – an outer-directed, physical, materialistic one, and an inner-directed, non-physical, mystical one. And Indian philosophy is considered to be pre-eminently concerned with providing the second frame of reference.

Objects versus agents: How would one proceed, then, to evolve an integrated framework for science that would enable the objective study of both the physical world and the behavioural world relating to individual organisms and social systems? The award of a Jawaharlal Nehru Fellowship for 2 years (1971–1973) gave me the time and opportunity to tackle this problem by analysing and trying to understand scientific methodology from first principles. The outcome has been discussed in detail in several reports and publications[6,7]. In summary, the thesis is as follows.

The physical sciences are concerned with physical phenomena: that is, the occurrences and properties of physical objects (i.e. matter) and physical processes involving such objects (i.e. physical events). The methodology of the physical sciences centrally involves the construction of mathematical models (or mathematical theories) to account for physical phenomena. Mathematics (i.e. pure and applied mathematics formalisms) provides the theoretical framework for constructing such models or theories.

Opposed to physical objects are agents. An agent is characterized by an action repertoire which it can deploy intentionally (i.e. in a goal-directed manner) to bring about desired-for changes in the world (including itself). In other words, an agent, instead of being merely reactive, can be pro-active. The notion 'desired-for change' necessarily involves a value dimension characterizing the behaviour of agents. The study of agentive behaviour is concerned with articulating computational (i.e. information-processing) models for the action capabilities of specific agents or classes of agents. Computational formalisms underpin this model-construction activity.

The behavioural sciences are concerned with the explication of phenomena of which agentive aspects of agents form an essential part. The situations that the physical sciences study, on the other hand, do not involve agentive aspects in any sense. The difference between the physical and behavioural sciences arises not because of some presumed difference between the physical and the 'mental' (or, because of some inexplicable difference between 'matter' and 'spirit'), but precisely because of the difference in the characterization of phenomena that do not and do involve agentives aspects, respectively. To develop this thesis in greater detail here would take us too far outside the scope of this essay[8].

Research issues

Modelling visual behaviour: In the 60s and early 70s, my primary research interest was in the computational modelling of visual behaviour. My interest in the computer-processing of pictures began during my 3-year stay (1961–1964) at the Digital Computer Laboratory, University of Illinois, Urbana. I was one of the early workers in this area to advocate structural models to analyse and describe what is in the visually-given image[9,10].

Interpretation of any complex situation necessarily requires the articulation of aspects of this situation. We have to isolate the component parts of the situation and exhibit the inter-relationships between these parts. In this sense, any interpretation of non-trivial situations calls for the use of some kind of segmentation procedure. Subsequently these segmented components would have to be related to aspects of the external situations which these components describe or represent. Syntactic (i.e. structural) analysis and semantic considerations, thus, tend to play fundamental roles in assigning interpretations to both speech and pictorial inputs[11,12].

However, such interpretation assignment or description generation cannot be carried out meaningfully in a completely de-contextualized fashion. Analysing and assigning meanings to sensory inputs (especially auditory and visual inputs) necessarily have to be attempted keeping in mind all the time the end-use of the processed outputs. When vision is approached in this active (i.e. goal-directed/action-oriented) manner, our current understanding of how vision mediates behaviour in our day-to-day living turns out to be very poor. This problem becomes even more acute when one tries to come to grips with the mediating role of language behaviour.

Modelling language behaviour: During the last 3 decades I have been trying to work out and promote an approach to the study of language behaviour that takes pragmatics as a point of departure rather than syntax or semantics. The argument is that, from an evolutionary perspective, behaviour must have evolved to be put to specific uses. Use must, therefore, define structure and mechanism and not the other way around. This approach is motivated and discussed in several papers and two books[13,14]. Ethological studies of first language acquisition by children using this approach provide positive support to such a pragmatically-oriented approach to language behaviour[15].

Such an approach to first language acquisition by children has very close links to the orality–literacy contrast that has been extensively studied by a large number of specialists from various disciplinary viewpoints. Essentially, the claim is this. Oral (i.e. pre-literate) language behaviour differs in definite ways from literate language behaviour. Therefore, the behaviour mechanisms underpinning these two modes must be different. It is the mechanism underpinning the oral mode that must be genetically prewired, because it is this mode that all children normally acquire as a matter of course. Literacy – i.e. writing and reading – is not native to human beings, but is something that requires formal tuition (or self-tuition) for acquisition.

Literacy studies: Cognitive characterization of literacy from a fundamental and general viewpoint has been of interest to me. I have argued that it is wrong to view literacy narrowly in terms of only script-literacy (i.e. reading/writing using scripts). There are other aspects to literacy, for instance, visual literacy (i.e. thinking in terms of charts, diagrams, pictures, images, etc.), which are equally important and basic in developing cognitive and meta-cognitive skills[16].

It should be of particular interest to study contexts of visual literacy development (especially, in computer-oriented environments) among children and adult non-literates. Could pictorial literacy be made to act as a bridge between orality and full-fledged script literacy?[17]

Relevance to India

The present: The relevance to India of studies of the kind discussed above can be argued from two viewpoints: the present and the historical past. In terms of the present, eradication of illiteracy has been identified as a 'mission'. Much resource and many technologies are being deployed at the field-level to serve this mission. However, there are no commensurate efforts to study and understand at a cognitive/theoretical level what being 'literate' is all about. Clearly, there is an urgent need to structure and promote such studies[17].

Exploratory field-work carried out with children from elite schools in Mumbai show that schooling – even in these elite contexts – does not result in children becoming truly literate, i.e. in becoming competent to reflect and think for oneself. We must note that the foundation of scientific temper is reflective thinking. We cannot hope to promote the former without the latter[17].

The historical past: From the viewpoint of the historical past, the orality–literacy contrast in India presents many anomalous features. Although the Indian tradition has been an oral one – writing has been systematically undervalued in the tradition – it has been underpinned by pervasive literacy of great conceptual complexity. Forms of articulation, normally available only in the literate mode through the use of writing, were worked out and perfected using purely oral techniques. These led to the development of performing art forms – especially music and dance – of considerable formal sophistication. These literate underpinnings of the Indian oral tradition have not been systematically studied[16,18]. On the other hand, all this pervasive literacy notwithstanding, the Indian tradition has continued to remain an oral one in its intellectual and psycho–social aspects. For instance, the intellectual milieu has always been, and continues to be, disputatious, polemical, and didactic, and not comparative, critical, and reflective. How would one account for this?[16]

Coda

Consider the sociological problem of modernization of a traditional culture through innovative behaviour. What are necessary pre-conditions, and sufficient supportive structures and processes, for innovation to start, sustain itself and grow? Modernization must ultimately become effective in the day-to-day living of individuals and in their routine interpersonal interactions. Clearly, aspects of behaviour such as knowledge, belief, judgment, and value are of basic relevance here. A scientific outlook has a positive correlation with modernization. Nevertheless, as I pointed out at the start of this section, 'science' as a professional role seems to have little bearing on the several social roles of a 'scientist' in India. Why is this so?

The role of language behaviour in the control and shaping of behaviour in circumstances encountered in normal day-to-day living does not seem to have been studied seriously by sociologists. The role of literacy in changing social attitudes, social perception, and so on has not been seriously and systematically analysed. The relevance of literacy to behaviour change may be of much greater basic importance in modernizing a traditional society than its relevance to facilitating access to factual knowledge, i.e. to facts[17].

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