Computer Science Research in India *

Krithi Ramamritham
Dept. of Computer Science
University of Massachusetts
Amherst, Mass. 01003
(krithi@cs.umass.edu)
(413) 545-0196
fax: (413) 545-1249

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Abstract

Has India realized its potential for high-caliber computer science research as indicated by (a) its having one of the largest technical manpower in the world, (b) its software industry's tremendous growth in the recent past, and (c) the demand in the West for students from its top science and technology educational institutions? This paper addresses this question, in the context of Computer Science. The observations and findings are based on visits to research and educational institutions and discussions with researchers – undertaken during a one-year sabbatical stay in India.

This paper begins with a discussion of the nature of computer science Research in India. The type of institutions in which computer science research is conducted is considered next followed by a discussion of the students and faculty at the educational institutions. Support for conducting research in the form of equipment, infrastructure, and publications, is the next topic discussed. We then examine how Indian researchers publish their work. Finally we study the influence on Indian computer science research of the phenomenal growth in exports by the Indian software industry and the arrival of multinationals since

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the recent liberalization and globalization of the Indian economy.

Keywords: Indian computer science, research and development, education and training, information technology, international science, problems of developing countries.

Contents

Glossary of Terms

Educational Institutions:
IISc – Indian Institute of Science
IIT – Indian Institute of Technology
REC – Regional Engineering College
UoH – University of Hyderabad
UoP – Pune University
VRCE – Visweswarayya College of Engineering, Nagpur

Government Sponsored Organizations:
BARC – Bhabha Atomic Research Center
CAIR – Center for AI and Robotics
CDAC – Center for the Development of Advanced Computation
CDOT – Center for the Development of Telematics
CMC – Computer Maintenance Corporation
ECIL – Electronics Corporation of India, Limited
ISI – Indian Statistical Institute
ISRO – Indian Space Research Organization
MatScience – Inst. for Mathematical Sciences, Madras
NAL – National Aerospace Laboratories
NCST – National Center for Software Technology
NIC – National Informatics Center
NRSA – National Remote Sensing Agency
TIFR – Tata Institute for Fundamental Research

Private Organizations:
SSF – SPIC Science Foundation, Madras
TCS – Tata Consultancy Services
TRDDC – Tata Research, Development, and Design Center
PSPL – Persistent Systems Private Limited, Pune

Professional Organizations:
CSI – Computer Society of India
NASSCOMM – National Association of Software and Service Companies
IMA – Indian Manufacturers Association

Infrastructure:
ERNET – Educational and Research Network
NICNET – National Informatics Center Network
STP – Software Technology Parks
VSAT – Very Small Aperture Terminal

Government (Funding) Agencies
AICTE – All India Council for Technical Education
DAE – Department of Atomic Energy
DoE – Department of Electronics
DoS – Department of Space
DST – Department of Science and Technology
MoD – Ministry of Defence

Conferences:
COMAD – Conference on the Management of Data
FSTTCS – Foundations of Software Technology and Theoretical Computer Science
IWPP – Intl. Workshop on Parallel Processing
CONSEG – Intl. Conference on Software Engineering Practices
Networks – Conference on Computer Communication Networks
CISMOD – Conference on Information Systems and Management of Data

1 Introduction

India prides itself in having one of the largest technical manpower in the world. Her software industry has seen tremendous growth – over 50% each year during the last 10 years – which is the envy of many software exporting countries throughout the world. The students from India's top science and technology educational institutions are highly sought after by research universities in the US and Europe. India is one of just half a dozen countries to have successfully built and deployed their own satellites and launch vehicles.

Given these much-publicized accomplishments, an obvious question is: Has the potential for high-caliber research, indicated by the above facts, been realized? This report addresses this question, in the context of Computer Science. The observations and findings are based on visits to research and educational institutions and discussions with researchers – undertaken during a one-year sabbatical stay in India.

This paper begins with a discussion of the nature of Computer Science Research in India. The type of institutions in which Computer Science research is conducted is considered next followed by a discussion of the students and faculty at the educational institutions. Support for conducting research in the form of equipment, infrastructure, and publications, is the next topic discussed. We then examine how Indian researchers publish their work. Finally we study the influence on Indian Computer Science research of the phenomenal growth in exports by the Indian software industry and the arrival of multinationals since the recent liberalization and globalization of the Indian economy.

Readers interested in knowing more about the research conducted at the Indian Computer Science R&D establishments mentioned in this report should refer to the detailed trip report [5] which complements this summary paper. Additional reading material on Indian Science in general can be found in some of the references listed at the end of this paper.

2 Nature of Computer Science Research in India

Computer Science (CS) research in India started in earnest only in the mid-80's triggered by the establishment of post-graduate programs in many institutions throughout the country at that time. Today, almost all areas of computer science research are covered by researchers in India, including topics that are "hot" elsewhere such as multi-media, workflow automation, virtual reality, and hardware-software co-design [5]. The territory covered by Indian researchers is impressive and most of the research problems tackled are of current interest globally. Some of the research has even attracted international attention including work on neuro-fuzzy systems, machine learning, genetic and neural algorithms, the modeling and control of flexible manufacturing systems, speech synthesis, databases, and complexity theory.

One area where solutions unique to Indian conditions have been developed is machine-assisted language processing. With a vast population conversing in a multitude of languages (there are over twenty officially-recognized regional languages!), many with their own scripts, the problem of translation and transliteration from English to these languages and from one Indian language to another is daunting, but one which has the potential for a huge pay-off, – socially, politically, and economically. It is not surprising that many computer science researchers are grappling with this problem. Some of the solutions are quite mature, and available as commercial software offerings. Many of these permit interactions with the computer in a local language, using keyboards designed explicitly for the language.

The results of the efforts mentioned above demonstrate that it is possible to carry out high-quality research in India, leading to publications in visible international journals; the potential exists and the resources can be garnered. However, most of the rest of the research is found wanting in quality. Incremental solutions – developed relative to an existing published result, and the lack of in-depth evaluations – are the norm. A senior faculty member at an IIT summarized the status of computer science research at India's leading basic research institutions thus: "The averages are there, but the peaks are not."

Several explanations can be offered for this gap between potential and reality. They relate to an ill-defined definition of the purpose of research in a developing country like India, absence of incentives as well as recognition, lack of critical mass in most research areas, paucity of resources – both in quality and quantity, suboptimal utilization of what is available, low funding levels and the missing of accountability.

There are many in Indian computer science who argue that the goals of research and development in India ought to be manpower development, increasing competence, and keeping faculty up-to-date with current techniques. Towards this end, it is said that "reinventing the wheel" is not only necessary but also important. This might be one of the reasons that even though it is said (repeatedly) that India has one of the world's largest technical manpower, the manpower needed to do state-of-the-art research is found to be wanting, both in quality and quantity. According to Prof. Mahabala of Indian Institute of Technology (IIT) Madras, this is because the "driving forces are not here." Since highly-trained, quality manpower is the key to the founding of new enterprises and for entering novel highly value-added arenas, many policy makers appear concerned with this issue. It is high time, since many echo Prof. Narasimhan, a doyen of Indian computer science, who feels that "there is no systematic effort to break new ground" even though information technology is more available now.

A stumbling block is the prevalent view that it is difficult to do "cutting-edge" research in India. A related view is that "creating new areas is very difficult, but contribution to an existing area is possible". A researcher who recently returned to India from the U.S. said that, because of this, one needs to come equipped with broad-based interests rather than a narrow focus. (As it turns out, whereas for almost twenty years research organizations had a difficult time attracting Indian researchers working abroad, the last few years have begun to see a reversal in this trend.)

Prof. Rajaraman, considered to be the father of Computer Science Education in India, feels that Indian researchers, in the past, had to be "a little bit more on the ground". He says "generalization has served India well and narrow focus would have been a disservice".

Because of the breadth of research coverage, in most areas of computer science research there is a subcritical research force as a result of which most Indian researchers work in isolation. They hence miss the much-needed opportunity to interact with peers and fellow workers in their area of specialization. Even when there are related efforts elsewhere within the country, as a researcher admitted, "Indians don't know what others are doing." With the current availability of e-mail, a few researchers have begun collaborative efforts, mainly with colleagues overseas. Many are of the opinion that cooperation among researchers within India will not pick-up substantially due to the limited monetary resources available and the severe internal competition that it implies. One of the fall-outs of the subcritical research mass has been the inability of the funding agencies to obtain quality peer reviews.

One area that does not suffer from this problem is computer science theory. Most research-oriented academic departments have a substantial theory group, often the only group with critical mass. These researchers do not have to contend with the lack of resources and many with mathematical background find it an easier area to (re)train themselves in.

Besides a few research groups, ones with the required critical mass, very few researchers work with long-term research goals – needed to have a coherent vision – and strive to achieve it. This, along with an apparent lack of recognition of "sparks", a problem mentioned by many junior faculty, are cited as two of the many reasons for lower visibility of Indian computer science research. Another reason given is the paucity of research funds and the manner in which it is administered.

CS research in India is funded primarily by All India Council for Technical Education (AICTE), Department of Science and Technology (DST), Department of Electronics (DoE), Department of Atomic Energy (DAE), Ministry of Defence (MoD), and Department of Space

(DoS). These are responsible for more than 80% of scientific R&D funding [7]. India has over 1100 R&D institutions but just a little over US$800 Million is spent on them annually. This is a meager 0.89% of its GDP (down from 1.1% of GDP just three years back). It is not surprising that research funds for computer science are also scarce. However, Dr. Vidyasagar, who is the director of the Center for AI and Robotics Research (CAIR) and is a member of virtually every apex funding body in the country, does not feel that substantially enhanced research funding is necessary. He says, "We have trouble finding even mediocre proposals to justify the level of funding that is already available."

The administration of research funds is highly bureaucratized, with the funding distributed in opaque ways, with many big players receiving large sums of research funds, and with junior researchers getting little support. This, in addition to the lack of accountability, have been detrimental to the conduct of computer science research. There are, of course, exceptions, with some shining examples towering over what could be otherwise termed as "trodden-path-research".

These exceptions have been in research and development organizations funded or sponsored by MoD, DAE, and the DoS – which typically do more applied and target-specific work. In order to stimulate similar result-oriented thinking in other research organizations, during the last ten years, many "thrust-area" projects have been sponsored by the funding agencies. They include the Knowledge-based Computer Systems (KBCS) project and the Educational and Research Network (ERNET) project – both funded by a DoE and UNDP consortium, a project on Computer-Aided Design and microelectronics, funded by DoE, and a project on CAD and robotics, funded by the ministry of education.

The KBCS project had six "nodal centers": IIT Madras – expert systems for diagnosis, Tata Institute for Fundamental Research (TIFR) – speech processing, Indian Institute of Science (IISc) – parallel processing, National Center for Software Technology (NCST) – expert systems and natural language processing, Indian Statistical Institute (ISI) – image processing, and DoE. During the period 1986-95 each nodal center received a total of around one and a half crore Rupees (half a million 1995 US Dollars). Around fifteen Ph.D's are said to have been produced by the various nodal centers during this period. Many prototype systems have been produced including:

- a health advising system, called Ekalavya, developed at IIT Madras – to help trained primary health workers to deal with illnesses in rural four-year olds.
- an intelligent tutoring system developed by NCST for Hindi, called Vidya ("education", in Sanskrit) – it comes with a gener-

ative testing system called Veda ("knowledge") whose front-end is called Vyasa (believed to be the author of the Hindu epic Mahabharatha).

- a speech synthesis system developed by TIFR, and demonstrated in the context of a railway reservation inquiry application – it can generate arbitrary utterances where an utterance consists of an arbitrary sequence of phonemes (from a repertoire of 58).

The ERNET project which began as an experimental project has now become an integral part of the research infrastructure for researchers in sciences and engineering. The experience gained by NCST, ERNET's gateway to the Internet, from the design, development and implementation of ERNET has been used to develop an internet-style network for the oil industry. A network for agricultural research connecting over one hundred on-line stations has also been set up along similar lines.

However, until now, researchers involved in basic research have experienced very little pressure to be accountable to funding agencies. This lack of accountability is also cited as a reason for the low level of technology transfer from these research establishments. Now funding levels appear lower, with almost no major focused projects on the anvil. Funding agencies are, however, demanding more product and industry oriented practical results. Prof. Muthukrishnan of IIT Madras, opines that because of "the inertia of academic institutions, they may not gear themselves up to meet industrial needs". At the same time, junior researchers, in addition to complaining about inaccessible research funds, charge that this change in expectations is being pursued with such zeal and without adequate preparation that it could be more hurtful than helpful.

3 Computer Science Research Institutions

Three categories of institutions conduct CS research in India: the major teaching and research institutes devoted to science and technology, government-sponsored laboratories and industry-sponsored laboratories.

1. The six major research and teaching institutes devoted to science and Technology.

These six institutes are the IITs (of which there are five, with one more coming up in Assam) and IISc, located in Bangalore. These institutions form a select group in the minds of the government as well as the citizens.

The next tier of institutions is made up primarily of the Regional Engineering Colleges (RECs), with one located in each state. Also, there are several other universities where computer science research is being conducted quietly. (One such is the University of Hyderabad; researchers here are very active in (collaborative) AI research, keeping close contacts with overseas colleagues.) But a considerable gap does exist between the six top tier institutions and the next because of high teaching load imposed on the faculty, students being, on average, of a lower quality, and finally poorer infrastructure, namely library and computing facilities.

2. Government-sponsored Institutions.

These institutions are funded by different government ministries and departments.

TIFR and the Institute for Mathematical Sciences (MatScience) perform research which is predominantly of a theoretical nature. These are funded by DAE.

Defence-related work takes place in a number of labs around the country, many located in Bangalore and Hyderabad, both in Southern India. A good example is CAIR which can be described as a "think-tank" serving the AI and robotics needs of Indian Ministry of Defense. It is a component of the Defense Research and Development Organization (DRDO).

The Ministry of Planning funds ISI, with its primary location in Calcutta. (It is worth noting that the first indigenous digital computer – fabricated using discrete transistor units – was commissioned by ISI in 1966 in collaboration with Jadavpur University.)

NCST also carries out research in several areas of computer science besides having education and training among its functions. NCST is a successor of the erstwhile National Center for Software Development and Computer Technology (NCSDCT) which was a component of TIFR.

The Indian Space Research Organization (ISRO), is also involved in computer science work, but most of its work is of an applied nature, in the context of satellites and launch vehicles. ISRO has been building satellites for remote sensing as well as for communication. Its most recent success involved the launch of the Polar Synchronous Launch Vehicle capable of launching 1000-Kg class satellites into sun-synchronous orbits.

National Aerospace Laboratories (NAL), Bhabha Atomic Research Center (BARC), and Center for the Development of Advanced Computation (CDAC) have had the development of parallel processing platforms for solving computational science problems as the main focus of their computer science research.

3. Industrial Labs:

Tata Research Development and Design Center (TRDDC), supported by the Tata group of companies, and the SPIC science foundation (SSF), sponsored by SPIC, a petrochemical corporation, are good examples. While the latter is primarily involved in theoretical computer science research, TRDDC is geared up to "result-oriented research" to meet the needs of Tata Consultancy Services (TCS) and its clients, and more generally, the Tata group of companies. The uniqueness of TRDDC comes from its self-supporting R&D effort. Even though most of the projects are done for TCS, TRDDC also has funds from DST, MoD, and other government organizations.

In addition, there are several labs that are sponsored by many multinationals in India, such as Texas Instruments (which led the way, as early as in 1987), Motorola, and Oracle. But, at this point, these labs are mostly involved in developmental activities defined and subcontracted by their parent organizations.

4 Students and Faculty at the Educational Institutions

It is not an exaggeration to say that computer science researchers in the US and Europe have a very high regard for graduate students trained at the IITs and in IISc. The reasons are easy to find. Admission to the Bachelors' program (called B.Tech) at the IITs is through a fiercely competitive entrance examination called the Joint Entrance Examination (JEE). It is written by over 100,000 students every year, with less than 1500 selected – based purely on their ranking in the JEE. The curriculum at the IITs is on par with top institutions in developed countries. A laudable feature of the B.Tech program is that during the final year, students are required to do a project, which in many instances are quite ambitious with students going on to publish their work in conferences and journals.

All the academic research institutions have a Masters' program (called M.Tech), students selected once again after a competitive examination called GATE, perhaps not quite as competitive as JEE. M.Tech's come (more often than not) from a non-IIT background and their preparedness in computer science is also considered to be lacking, but they make up for it through their hard work. While some of the IITs require computer science background (for example, IIT Bombay does not admit students who are not among the top 7% in computer science GATE), others do not. M.Tech's also do a project, but since the program itself is only three semesters long and the project is done during the third, there is less time to execute a project of an involved nature. Also, if a student arrives with no computer science background, it does not allow him or her to do a substantial project.

Some institutions have a program called Master of Science, which is purely research project oriented. The number in this category is quite small and not all academic institutions have an M.S. program.

As part of the Quality Improvement Program (QIP), an effort to modernize the faculty at teaching institutions, faculty from smaller colleges and universities are encouraged to apply to do their Ph.Ds at IITs and other institutions. For instance, four of the computer science faculty at the Regional Engineering College (REC) in Trichy (out of just about a dozen) are currently doing their Ph.D.'s under this program. Since most of the faculty at smaller educational institutions offering programs in CS do not have Ph.Ds, the QIP is a worthy enterprise.

All graduate students are supported by the Ministry of Human Resource Development (MHRD) (even though there is a move, especially for Ph.D. students to be paid from research grants). If one enters the Ph.D. program after a Bachelors' degree, assistantship is guaranteed for five years; for those joining after a Masters degree, four and a half years. Because of this and the fact that all faculty salaries are on a 12-month basis, there is very little compulsion for an academic researcher to seek external funding for his or her research, except perhaps to support travel and for books and equipment.

IISc has the largest contingent of Ph.D. students, having produced 20 Ph.Ds during 94-95 with over 40 in the pipeline. Each IIT has between 10 and 15 students pursuing their Ph.Ds., a number smaller on average compared to the recent past. I often heard the remark that the number of students interested in a Ph.D degree and of Ph.D. caliber has been decreasing. This does not augur well for the future of Indian computer science. It is hence important to understand the reasons for this trend. We will discuss some of these here.

Faculty at the top educational institutions belong to three ranks, Assistant Professor, Associate Professor and Professor. The nomenclature varies in other institutions. While fresh Ph.Ds have joined as Assistant Professors in some of the institutions, most places insist on a few years' experience. Even though Assistant Professorship is tenured, the requirements to move into a higher rank are not very transparent. In fact, IITs don't appear to have the notion of promotions. If one desires a higher rank, he or she must respond to an advertisement for that rank. The lack of transparency as well as norms for such promotions, causes, as a junior faculty put it, "the dilemma of whether to focus on "local developmental work" or "international publishable work"."

With the "graying" of the research-oriented academic institutions, there is a need to infuse fresh blood. But with very few retirements in the offing, the number of openings in established institutions is small. Even if one finds a position, a fresh Assistant Professor should be content with a take-home-pay that could be substantially less than the earnings of a fresh Master's student entering the private sector.

A large proportion of the well-trained IIT and IISc students go abroad, mainly to the US, for their further studies. So India does not reap the benefits of having trained them. Among the IIT students who stay in India after their B.Tech's, a sizable number opt for a career in management, and hence join the MBA program in one of the four prestigious Indian Institutes of Management (IIM). As a result, the number of IIT students who pursue a career in science or engineering within India is dishearteningly small.

Whereas in the pure sciences, the percentage of women in India (both among students and faculty) is much higher than in the U.S., in engineering disciplines, the situation is the opposite. Being associated with engineering, the computer science research roster in India has a very small number of women. To its credit, IIT Madras has two women faculty in the computer science department, with one serving as its current head. IISc and IIT Bombay have one each in their faculty.

Inbreeding, often associated with stagnation, is a common phemonenon at the top educational institutions, with the ratio – of those with a Ph.D. from the same institution – sometimes approaching one-half. Even though an institution tries not to hire one of its own immediately after his or her Ph.D., most have no hesitation if the person has spent a year or two elsewhere before returning to his or her Ph.D. institution.

Among the educational institutions, according to many computer science researchers around the country, IISc has a greater appreciation for research in pure sciences and this is true for computer science as well. Many of the IIT faculty I talked to feel that training and educating students is their foremost task, in contrast, for example, with IISc, ISI, and TIFR, where research is. There is also a general feeling that the IITs can do a better job if they set their performance thresholds higher. The directors of the IITs have a bigger say in setting the directions of their respective institutions than the heads of the above mentioned research-oriented institutions. Hence, any changes or redirections, giving more emphasis and recognition for research and thereby tapping the available research potential, awaits their directives and blessings.

5 Research Equipment and Infrastructure

Begun with a charter to provide a state of the art computing facility, the Supercomputing Education and Research Center (SERC) at IISc today boasts of a computing environment that is one of the best in the world. This environment consists of several latest types of workstations, parallel processors, and supporting infrastructure, and serves the needs of researchers at IISc as well as the country at large. To a large extent, even the IITs, and the major research laboratories, such as CAIR and TIFR, are well endowed in terms of number and type of equipment.

But two problems plague the computing infrastructure in educational institutions in general. One is the lack of funds to keep the machines up-to-date, another is the presence of fairly rigid firewalls between the facilities belonging to projects. Combined with the fact that funding does not trickle down from the well-funded, these factors exacerbate the (lack of) equipment problem. Also, because of inadequate conditioning and limited capabilities of UPS, most machines are utilized suboptimally. Experimentally-intensive research is greatly affected and sometimes made impossible by these problems.

Whereas IITs used to get modernization money regularly, this purse is currently controlled by the All India Council for Technical Education (AICTE) which is spreading the available funds across more campuses. This has resulted in a net fall in the funds available to IITs for upgrading their equipment even though smaller institutions have been able to acquire better and more up-to-date computing and communication equipment.

Thanks to ERNET, India's researchers have access to Usenet bulletin boards and to public domain software, in addition to being able to communicate with their colleagues through e-mail. Eight nodes form its backbone – the five IITs, the IISc, NCST, and DoE. Funding for ERNET was provided by the United Nations Development Program (UNDP) with matching funds from DoE. The eight nodes on the backbone star network have e-mail, ftp, and telnet facilities. The remaining nodes currently have e-mail only. According to Dr. Ramani of NCST, Bombay, ERNET has been able to connect approximately 300 research and educational institutions throughout India, with an estimated 30000 users.

The current ERNET is made up mostly of 9600 BPS lines and dial-up links. It is soon to be expanded to consist essentially of a satellite-based communication network with nodes using VSATs (Very Small Aperture Terminals) for communicating with Bombay.

Another network, NICNET, is satellite-based and spans the country but has been designed to cater to the needs of the government. NICNET connects the nation's capital with the capitals of the states and the headquarters of the over 500 districts (each state in India is subdivided into many districts for administrative purposes). NICNET was developed by National Informatics Center (NIC), a government organization set up in 1975 to bring the benefits of information technology and networking to help this nation, most of whose people live in the villages. NICNET's nodes are linked to the master node in Delhi through VSATs connected via India's geostationary INSAT-2B communication satellite. Using NICNET, NIC helps the government collect information of various types, from weather to crop yields. These assist the more than fifty ministries in the central as well as state governments in planning and forecasting, for example. (Unfortunately, there is no direct link between NICNET and ERNET. Hence, much of this data is inaccessible to researchers on the ERNET.)

One of the reasons these networks are satellite-based is the dependability problems present in India's telephone system. It must, however, be said that the telephone system has come a long way since the early 80s. Much of the credit for this belongs to the Center for the Development of Telematics (CDOT) which started in 1984 as a research project aimed at the indigenous development of digital switching systems (telephone hardware and software). A brainchild of Mr. Sam Pitroda, what began as a telecom research center became CDOT with a mandate to produce (initially) switching and (later) transmission systems suitable for Indian conditions.

Today CDOT is embarking upon research and development efforts to provide ISDN, ATM, satellite communication, and Intelligent Network capabilities. In order to solve some of its more research-oriented problems, CDOT has already formed alliances with academia. Whereas so far these have been related to streamlining product development, the aim is to attract academic researchers to work in more technical areas related to telecom. Of course, all said and done, the total telecom-related research budget will be relatively small compared to CDOT's overseas competitors.

With respect to other resources needed to conduct research, the lack of access to journals and conference publications is a complaint most often aired by active researchers. Whereas even researchers in the West are worried by the number of journals one has to contend with (as well as their price), by Indian standards, journals are very expensive and more so when they have to be sent by airmail. Obtaining conference proceedings is even more problematic. The proliferation of journals and conferences, often with narrow focus, has only made the problem too difficult to tackle, especially in an age of diminishing research funds. Thus, researchers face the prospect of not being aware of new and related work, and for the lucky ones, becoming aware after a few months' delay.

It should be said that the access to the Internet has helped solve this problem for some. But, in general, it has not helped. This is because a very large percentage do not have telnet and FTP facilities. Even if they did, the necessary hard disk storage capabilities are lacking and printing the postscript version of a paper is itself a time-consuming and expensive proposition.

6 Research Publications

While many researchers do publish in journals and conferences, the chosen fora are usually not the ones with high profile. For instance, very few Indian researchers (even attempt to) publish in "transaction journals". ISI's Dr. Shankar Pal, internationally known for his work on neuro-fuzzy systems and who serves on the editorial board of many journals, including transactions, attributes this phenomenon to the lack of confidence and shyness. He believes that university researchers are especially prone to this problem. Given the lack of critical mass in most research areas, and therefore the absence of able guidance and useful comments from within, it is important for researchers in India to try to publish their work in mainstream, visible journals and conferences. There is a tension between this need and the need to increase the quality of Indian computer science journals. This conundrum is not unique to India (see for example, [1]).

Several Indian journals are available for computer scientists to publish their work. The Journal of Computer Science and Informatics is published by the Computer Society of India. Another journal, Sadhana, is published by the Indian Academy of Sciences. The IISc publishes its own journal. Both Sadhana and the IISc Journal cater to a wide variety of engineering disciplines, not to computer science alone. There are also other journals, such as the one published by the Institution of Engineers, which cater to a multitude of engineering disciplines including computer science.

Many senior researchers who have tried to publish in high profile international journals have, however, commented on the poor quality of the reviews their papers have received from such journals. They are of the opinion that some of the reviewers may dismiss a paper purely on subjective biases seeing that the authors are from a developing country. Given the number of times I have heard this remark, one has to believe that there is some truth to this. It is also said that papers written by Indians, written with foreign affiliations when on trips abroad, seem to receive faster and better response. Nevertheless, those that have established a name for themselves either through sheer good work combined with perseverance or through collaboration with researchers in the West believe that these are not insurmountable problems, at least not anymore.

Additionally, it can cost close to Rs 1000 (about US$30) just for the production of a laser-printer quality original along with the cost of copying a paper to send to a conference or a journal. Many good researchers in smaller, less-endowed colleges are hence forced to seek journals and conferences for their publication based on "safety" considerations rather than quality. Because of their smaller research budgets, they have less leeway in the way in which their funds can be spent.

For a researcher in India, the cost of attending a conference in Europe and the U.S. can be as much as one year's gross salary; to attend a conference in India is about two months' salary. Research institutions and funding agencies do allow foreign travel, but given the costs, these are rare occurrences. This is cited as yet another reason for the poor visibility of Indian research.

Fortunately, an Indian researcher today can find several conferences in India to choose from to present their work. If one were to measure research productivity and interest purely by the number of conferences held in India, it is quite impressive. Many of these are sponsored by international organizations such as the IEEE and IFAC. These are devoted to VLSI design, parallel processing (IWPP), theory (FSTTCS), software engineering CONSEG), databases (COMAD, CISMOD), and communication networks (Networks). In the recent past, these conferences have had between one-fourth to one-third of the accepted papers from authors residing in India. While these international conferences do attract a number of researchers from abroad, most of them are non-resident Indians. One exception is the theory-oriented FSTTCS, an Indian conference with perhaps the longest history. It is attended by many from outside India, especially, Europe. Its proceedings are published by Springer-Verlag.

Many international conferences are also coming to India: the 1996 edition of the Very Large Databases (VLDB) conference, the Fourth Asian Test Conference and the Third Asia-Pacific Conference on Hardware Description Languages, to name a few.

Many local conferences are organized by the 15000-member Computer Society of India (CSI), Institution of Electronic and Telecommunication Engineers as well as the government research laboratories. These are in emerging areas such as neural networks, software quality, and object-oriented systems. Another conference, on Intelligent Systems, held in Bangalore, is also dominated by neural networks researchers. The interest in neural networks is growing among Indian computer science researchers, perhaps because it has a sounder mathematical basis compared to other AI techniques. Several vendor-based meetings are also held regularly, these being sponsored by National Association of Software and Service Companies (NASSCOMM) and the Indian Manufacturers Association (IMA). It is said that these two have eroded the monopoly that CSI has had as the primary organization for Indian computer science.

7 Influence of Industry on Research and Education

During 1992-93, production by Indian computer industry was of the order of one billion US dollars, hardware contributing to two-thirds of this figure. This represents less than 0.5 percent of India's gross national product. The highly celebrated computer software exports was estimated at US$330 Million in 1993-94, growing to US$450 Million in 1994-95, and expected to reach the one billion US dollar level by 1998.

This is considerable by Indian standards but not on the international scale, accounting for less than one percent of the world market. But it is growing at a compounded rate of 54% over the last 10 years.

India is now home to some of the world's best software consultants, providing off-shore support to organizations abroad, in areas such as operating systems, database management systems, and graphical user interfaces. An often-cited example of such consultancy operations is Bangalore-based Wipro, which has set up its "laboratories for hire". But, when it comes to software development, much of what is produced in India is one-of-a-kind, for a particular customer. That is, little, if any, is replicated and marketed. This contributes to the low profit margins of these products. However, with the emphasis switching noticeably from on-site to off-shore software development, the value added to software produced within India has been on the rise. Today the US is the largest client, with close to 60% of India's software exports. Europe imports a little over 20%. But it is expected that exports to Japan and the rest of Asia will claim a larger share in the coming years.

The increase in off-shore development is facilitated by Software Technology Parks (STPs) that have become ubiquitous in India and are located in most states. These are DoE-sponsored schemes to promote software exports. Though called parks, they are housed in multi-storied buildings which provide space for not only the park's administrative offices but also for the companies involved in the software development activities under the auspices of the STP. All the companies are oriented towards 100% software export. What makes the Parks attractive for entrepreuners and start-ups is that a park provides facilities essential to establish an office and communication facilities starting from telephones and faxes to 64Kbps links to the Internet. Given the power brownouts and blackouts common to many parts of India, the Park also provides backup power sources. The Park helps with the handling of bureaucratic details concerning licenses, and import/export certification (which have been highly simplified under the new liberalized regime). All of these contribute to a much reduced gestation period. The STPs at Noida, near Bombay, Bangalore, and in Hyderabad are among the most successful to date.

As an example, the STP building in Hyderabad has thirty small concerns within its premises. Because of the unavailability of space, an additional twenty-five are located in other parts of Hyderabad, but with links to STP. The companies are involved in developing a large spectrum of products and services, including the traditional services such as data conversion and system reengineering to more high-tech areas such as CAD services and VLSI chip design.

While special programs such as the STPs for promoting software exports exist, no concerted effort has been expended on increasing the awareness and use of information technology within the country. India's per capita use of computers is one of the lowest in the world [3]. Very little of the software produced in India, especially by the big software houses, is developed for local consumption. Only about one-third of Indian software industry's turnover is attributable to the domestic sector. Even though a high level of computerization has been achieved in the financial, transportation, communication, as well as high-scale retail sectors, and to a lesser level in multi-lingual word processing (with CDAC leading the way), vast opportunities remain untapped elsewhere. Exploiting the potential in the domestic market is essential for Indian computer industry to maintain its growth pattern and for the fruits of information technology to reach the masses. Many big software houses have been reluctant to produce software for the domestic market because of the piracy problems.

The current climate of liberalization in India, much heralded in the West, has had a profound effect on organizations involved in research and technology. This effect is felt on several fronts. If the experience of the Electronics Corporation of India, Limited (ECIL) is any indication, it is clear that with globalization one of the biggest losers are the R&D groups internal to an organization. Many erstwhile development and manufacturing entities have instead become distributors of foreign-made products, finding that route to be more cost-effective, at least in the short term.

This, along with the arrival of high-paying multinationals, has changed the employment picture substantially. Heretofore, the challenging opportunities existed in government-run labs and so the bright minds did not hesitate working there even though the salaries were lower than in private organizations. The new arrivals have had an easy job recruiting highly trained scientists and engineers *and* paying them handsome salaries. This loss of manpower in government organizations (and to a lesser extent in privately owned Indian organizations) has led to several adverse effects. The morale of those that still remain in indigenous R&D organizations has suffered a huge setback. The idealism and euphoria that was the hallmark in the mid-80's has evaporated. Setbacks have also occurred in meeting project deadlines.

Unfortunately, at least until now, the labs established by multinationals have by far not given their scientists the same level of challenge at work, as the government labs. The result is that after a period of time, many begin looking for better opportunities abroad and in rare cases, within the country. (One of the faculty members I met had just moved from such a lab in spite of the enormous salary differential.) These trends will change only if (1) corporate R&D picks up from the current level, which is miniscule, and (2) salary disparity between public and private labs is reduced. Private institutions, including multinationals, must recognize that the Indian computer scientists are capable and deserving of their trust for building total systems. This attitude must replace one of serving as distribution centers or as small subcontracting houses. They can be the "driving force" to tap the hidden potential.

Many researchers had hoped and believed the boom in the computer industry – its eyes primarily aimed at overseas markets – and the resulting need for efficient solutions to new problems based on emerging techniques and tools would bring the practitioners thronging to the doors of the research institutions. Another phenomenon fueled this expectation. This was the elimination of the license Raj and, hence, of the protection offered by goverment's policies. Unfortunately, the expected industry-academy cooperation has not come to be. There are three probable explanations for this phenomenon.

1. Because of liberalization, as mentioned earlier, industry has found it expedient to license existing technologies from abroad as opposed to developing them locally, as was the case prior to liberalized import policies.

2. Industry so far has not found it necessary to seek the assistance of the scientific community except for human resources. If any help is needed (to improve on an imported product), it is sought from the original overseas developer.

3. There is a dichotomy between what industry expects the educational institutions' role to be – the imparter of immediately applicable technology – and what the institution thinks its role is – the imparter of basic skills and knowledge with which one can master any emerging technology.

While the third reason is not unique to India, its effect on computer science education perhaps is.

Educational institutions are under constant pressure to tread the fine line between the basics and the applications, between the skills and the tools. There is an increasing awareness that educators and researchers must teach state-of-the-art material and must themselves be aware of the available and emerging technologies. Given the inertia of traditional academic institutions, researchers are bound to find it difficult to gear themselves up to meet the needs of industry. Industry, with its usual preoccupations with short-term goals and results, quite often fails to see the immediate merits of what is imparted in academia. There is also the tension within the minds of the researchers in a developing country like India: between doing something for the development of India vs. doing something publishable.

Software houses lament that more often than not, a student coming out of a Bachelor's program is woefully unprepared to meet the practical challenges of the day, too deeply trained in the abstract, with little, if any, knowledge of the tools available or needed to pursue the software trade. So it is not surprising that today there are literally hundreds of training schools and institutes which offer courses on computer packages, databases, and tools. Even though they charge a hefty fee, running into several thousand rupees for a course that lasts for just a few weeks, they are highly sought-after. Several such establishments have branches (franchises) throughout the country. Many guarantee a job upon completion. Unfortunately, students who have experienced the teaching in such institutions have found themselves being taught by someone who himself/herself took the same course recently, and the facilities not being commensurate with the fees charged. There is, fortunately, a move to introduce accreditation for these institutions, which will hopefully improve the quality of the offered training.

Such efforts are long overdue since there is a general feeling among software educators and professionals alike that currently high-quality software professionals are not being produced. This is corroborated by the results of the nation-wide examination conducted by the NCST to test competence in software technology [6]. The immediate need for facilitating the continuing education of computer professionals has been expressed time and again to meet the current crisis in manpower, both in quality and quantity. Also, given that reengineering projects form the bread and butter of most, especially well-established, software houses, a strong feeling exists that these houses must move from being "programming centers" to "software engineering centers", keeping end-to-end project design, management and execution and the production of high-quality software in the forefront. Dr. Narasimhan feels that very few software houses have the necessary capability "to do design and quality assurance". Spurred by such comments, many of the larger software houses, such as TCS, a pioneer in the field of software exports, currently its leader by a wide margin, and employing around 4000 people, have an in-house training plus continuing education program. Several have already received or are striving for certification under ISO 9001. (Motorola (India) was in the news recently for achieving software engineering level 5 (SEL5) which recognizes maturity in managing the software process. It is one of the very few in the world to achieve this level.) Another idea mooted is to establish a consortium to form an institute of learning and training in computer science, an institute which would enable and promote interactions between industry and academics.

8 Conclusions

Many computer science researchers in India have endeavoured to carry out high caliber research in spite of limited infrastructure and resources to conduct and communicate their research. However, a majority have so far satisfied themselves with "thinking in the small", with short-term goals, and with the development of incremental ideas and solutions.

It is time to obtain a self-appreciation for what the research community – as a whole – is capable of, develop a shared long-term vision, harness the potential of the community, and embark upon systematic efforts to break new ground.

Indian computing industry must play its part, providing challenging opportunities that will bring out the potential in its employees. It cannot afford to sit on its current laurels for too long.

The country needs technically-oriented leadership in the government to make this possible. Areas requiring attention include better incentives and appreciation for good research productivity, prudent management and use of research funding, enhanced salary levels for researchers at all ranks, appropriate means to set and demand accountability, and improved opportunities for peer interactions within India as well as for interactions between industry and academics.

It is time for the research community to be awakened. It is time for the community to decide to wake up.

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