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Computer Science Research in India

The top Indian computer science research institutions have sufficient funding and an adequate infrastructure to conduct high-quality research. That is not always the case at the nation's other institutions.

Computer science research is an important issue in India, largely because the computer industry plays such an important role in the country's economy.

In India, which has one of the world's largest technical workforces, the information technology industry generated $2.2 billion in revenue in fiscal year 1994-95 and has been growing about 25 percent per year.

India's software industry is also growing rapidly, as shown in Figure 1. Between fiscal years 1989-90 and 1995-96, revenue from software exports increased from $100 million to $750 million, said Dewang Mehta, executive director of India's National Association of Software and Service Companies.[1]

During that same period, India's domestic software market has grown about 50 percent per year. According to a recent survey of India's software industry by London-based Marlin Partners Ltd., similar growth is expected until the end of the century, with the domestic market growing faster than the export market.[2]

It is thus important for India to nurture and strengthen its computer industry. In some cases, particularly at the top national research institutions, that has taken place. However, in many cases insufficient funding, an inadequate infrastructure, and other obstacles have hurt the ability of researchers to do high-quality work.

RESEARCH: PAST AND PRESENT

Computer science research in India started in earnest only in the mid-1980s, triggered by the establishment of postgraduate programs in many institutions. The Indian Institute of Science's V. Rajaraman, considered by many to be the father of Indian computer science education, said researchers initially conducted very general work.

Today, Indian researchers work in all computer science fields, including such hot areas as multimedia, workflow automation, virtual reality, and hardware-software codesign.[3] Some of the research has 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.

Major research projects

Because of the initial breadth of research coverage, there were not enough people working in many areas of computer science to conduct meaningful research on their own. So, during the past 10 years, funding agencies have sponsored special projects to stimulate focused and collaborative research, such as these:

- The KBCS (knowledge-based computer systems) and ERNet (Educational and Research Network) Projects, funded by the Indian Department of Electronics and the United Nations Development Program. Six research centers participated in the KBCS project, which has produced a number of prototype systems, including systems for pediatric health diagnoses, tutoring, speech synthesis, and machine-assisted language processing. The latter is particularly important in India,

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which has 426 languages, including 40 that are spoken by at least 1 million people.
- A project on computer-aided design (CAD) and microelectronics, funded by the Department of Electronics.
- A project on CAD and robotics, funded by the Ministry of Education.

Problems for researchers

The prevailing view in India is that it is possible to make advances in existing areas of research but difficult to do cutting-edge research. To correct this, many observers argue that India must develop a more highly qualified research workforce that uses up-to-date techniques.

Working in isolation. In India, many research-oriented academic departments have a substantial computer science theory group, which is frequently the only group with sufficient staff and resources. Researchers in most other areas work in relative isolation and don't benefit from interaction with fellow workers in their fields of specialization.

Indian researchers frequently don't know about related work done by researchers elsewhere in the country. A few researchers have begun using e-mail for collaborative efforts, primarily with colleagues in other countries. Some observers contend that Indian researchers won't work more cooperatively with each other in the near future because of concerns about helping people they may compete against in the future for funds and other resources.

Lack of long-term goals. Aside from members of a few major institutions, few researchers work with the long-term goals that are necessary to give research a coherent vision. This is because they receive little direction and don't collaborate enough to sustain the work necessary to achieve long-term goals.

Failure to break new ground. Many observers echo R. Narasimhan, a National Fellow in Information Technology at CMC Ltd., who said that in general, there is no systematic effort in India to break new ground in computer science research. Observers say the failure of universities, companies, and others to reward and recognize innovative ideas means there is inadequate incentive for most researchers to break new ground.

RESEARCH INSTITUTIONS

Three categories of institutions conduct computer science research in India.

Academic institutes

The seven major institutes, shown on the map in Figure 2 on the next page, are the Indian Institute of Science in Bangalore, and the six Indian Institute of Technology campuses, in Mumbai (previously called Bombay), Chennai (previously called Madras), Kanpur, Kharagpur, New Delhi, and Gauhati.

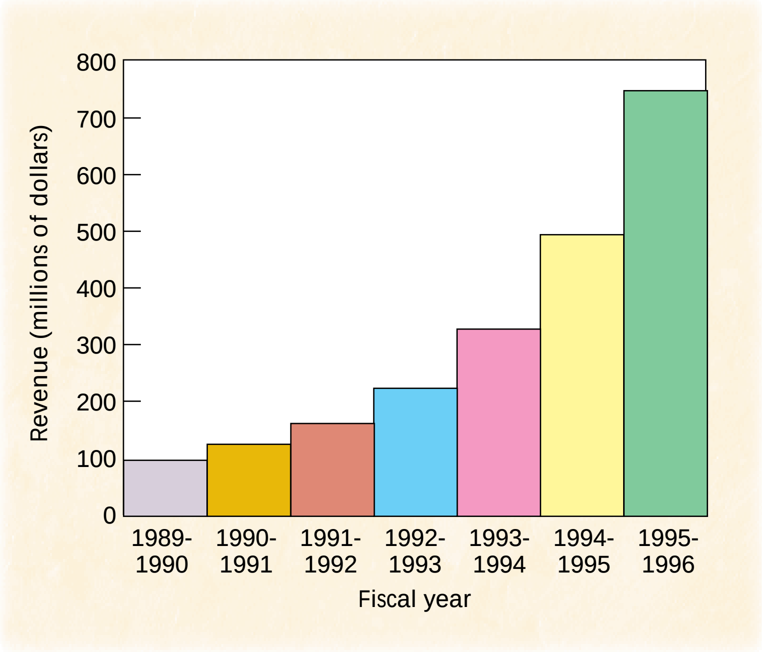

Figure 1. Software exports by Indian companies have increased steadily and substantially in recent years, rising from $100 million in fiscal year 1989-90 to $750 million in 1995-96. (Source: National Association of Software and Service Companies)

The next tier of institutions consists primarily of the state regional engineering colleges. Computer science research is also conducted at several other universities, including the federally administered University of Hyderabad and the Birla Institute for Technology and Science at Pilani.

At these schools, the faculty has a higher teaching load and students have a lower quality educational background than at major institutions, and the infrastructure (particularly the library and computing facilities) is inadequate. Thus, they generally do lower quality research than the major schools.

Government-sponsored institutions

A number of computer science research institutions are funded by government ministries and departments:

- India's Department of Atomic Energy funds the Tata Institute for Fundamental Research in Mumbai and the Institute for Mathematical Sciences in Chennai, which both conduct primarily theoretical research.
- Defense-related work takes place in a number of laboratories, many located in Bangalore and Hyderabad. For example, the Centre for Artificial Intelligence and Robotics Research in Bangalore serves as a think tank for the Ministry of Defense.

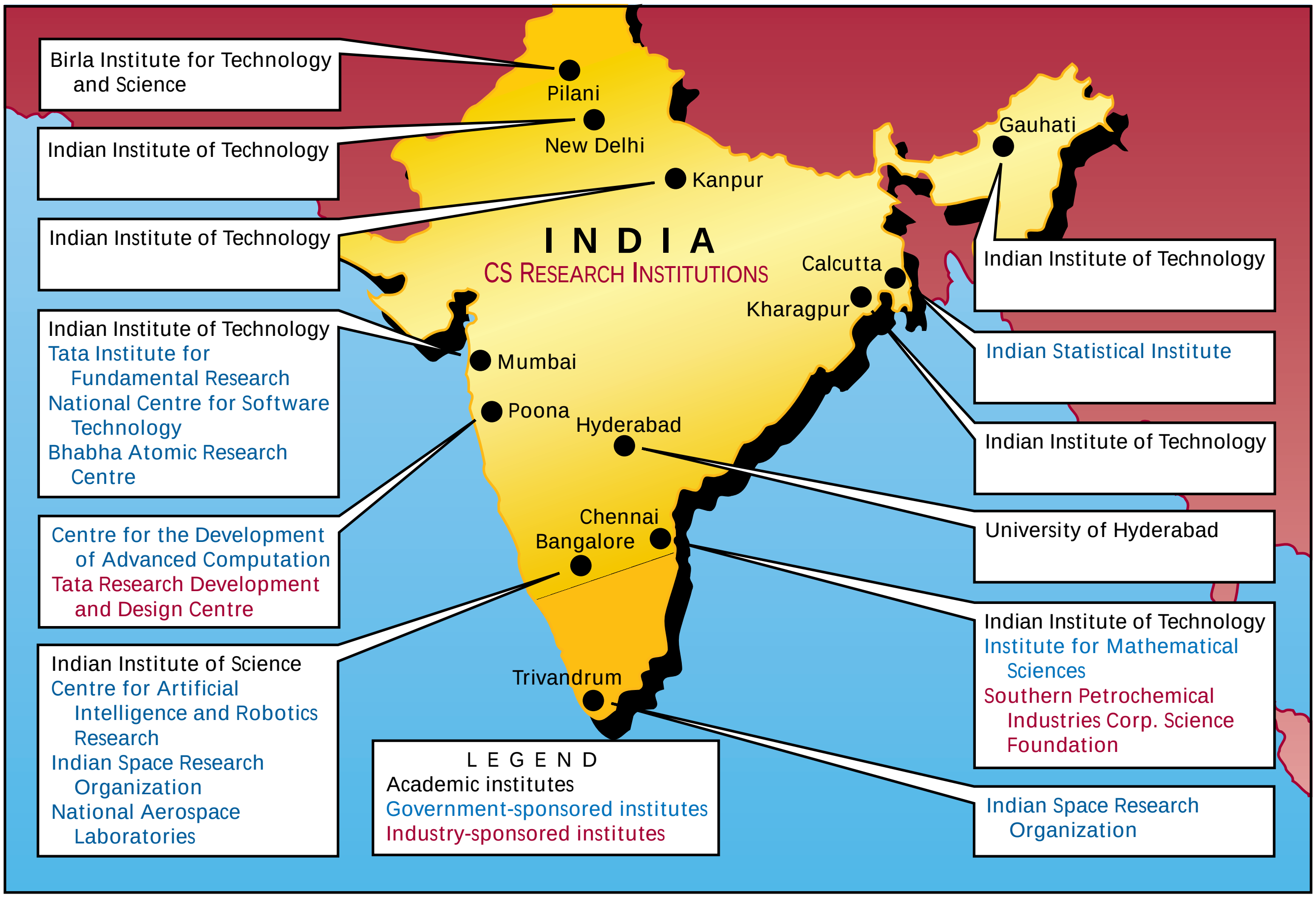

Figure 2. The locations of important universities and research institutions in India.

- The Ministry of Planning funds the Calcutta-based Indian Statistical Institute.
- The National Centre for Software Technology in Mumbai, which is partly self-funded and partly government-funded, conducts computer science research in several areas and provides education and training services.
- The Indian Space Research Organization, which has facilities in Bangalore and Trivandrum, is involved in computer science work, primarily of an applied nature for the nation's satellite program. The organization works on such projects as the development of launch vehicles.
- The National Aerospace Laboratories in Bangalore, Bhabha Atomic Research Centre in Mumbai, and Centre for the Development of Advanced Computation in Poona have focused on the development of parallel processing platforms for solving computational science problems. The Centre for the Development of Advanced Computation receives money from the national government and from the sale of its own products. The other two institutes are fully government-funded.

Industry-sponsored laboratories

A number of institutions that conduct computer science research serve the needs of domestic and foreign private companies. There are many prominent examples:

- The Tata Research Development and Design Centre in Poona primarily conducts applied research for the Tata group of companies, which includes such businesses as Tata Consultancy Services, a software firm. Although the center receives some government funding, most of its money comes from the Tata Group, one of India's biggest conglomerates.
- The Southern Petrochemical Industries Corporation Science Foundation in Chennai is sponsored by but is not a part of Southern Petrochemical Industries. Researchers at the foundation's School of Mathematics conduct primarily theoretical research.
- Several labs are sponsored by and conduct product development research for multinational companies with facilities in India, such as Texas Instruments, Motorola, and Oracle.

ACADEMIC INSTITUTIONS: A CLOSER LOOK

Academic institutions play a crucial role in Indian computer science research because they conduct research and train researchers.

Students and faculty

Indian universities offer a variety of programs to their students.

Bachelor's programs. Students are admitted to the bachelor's of technology programs at the Indian

Institute of Technology campuses after taking the fiercely competitive Joint Entrance Examination. Of the 100,000 people who take the exam every year, the six campuses accept 2,000 students purely on the basis of their scores. The curriculum at these schools is at the same level as that at the top institutions in developed countries. Their bachelor's of technology program includes an ambitious final-year project. Many students publish the results of their projects in journals or present them at conferences.

Many of the well-trained Indian Institute of Technology and Indian Institute of Science students pursue further studies abroad, mainly in the US. Surveys done in the late 1980s indicated that the average yearly emigration of students from Indian Institute of Technology campuses ranged from 20 to 35 percent overall but exceeded 50 percent for computer science students.[4] By 1995, 20 of the 30 students who earned their bachelor's of technology in computer science from the Indian Institute of Technology, Chennai, pursued further studies in the US.

Competition to enter the bachelor's degree program in computer science at second-tier institutions is also rigorous, as it is one of the most popular majors. Students at these schools must complete final-year projects, frequently for companies at which they work as interns. After receiving their bachelor's degrees, some of these students enter graduate school, but many take jobs at India's large software houses.

Master's programs. Among the Indian Institute of Technology students who stay in India after earning their bachelor's degrees, many choose a career in management and pursue master's of business administration degrees at one of the four Indian Institutes of Management. Thus, few Indian Institute of Technology students pursue science or engineering careers in India.

Many Indian academic research institutions have a master's of technology program. Students are selected after taking the Graduate Aptitude Test in Engineering, which is not quite as competitive as the Joint Entrance Examination. A few institutions have master's of science programs. In these programs, students must perform research projects.

Doctoral programs. The Indian Institute of Science has more PhD students in computer science than any single university campus. In 1995-96, the Department of Computer Science and Automation produced eight PhD graduates.

Faculty

Some institutions hire new PhDs as assistant professors. Most, however, require a few years' experience as lecturers. Most schools do not clearly state how faculty members can earn promotions. In fact, the Indian Institute of Technology campuses don't offer promotions. Instead, faculty members generally must apply for higher ranking job openings along with other candidates, which can lower faculty morale and use staff resources ineffectively.

Need for fresh blood. Some research-oriented academic institutions need an infusion of new faculty members to generate new ideas and new ways of doing things. However, there are relatively few openings for new faculty members. In addition, the positions don't always attract the most highly qualified candidates because the pay for entry-level assistant professors is lower than that for computer scientists who enter the private sector, even those with only master's degrees.

Academic inbreeding. "Academic inbreeding," which is often associated with academic stagnation, has been a problem at India's top educational institutions. In some cases, almost half of the faculty members in computer science work at the school from which they received their PhDs. Although institutions try not to hire their own students immediately after they receive their PhDs, most will hire them after they have spent a year or two elsewhere.

EQUIPMENT, INFRASTRUCTURE, AND RESOURCES

The quality of computer science research done in a country depends largely on the equipment, infrastructure, and resources that its research institutions have available. Although a few top Indian institutions have what they need to do top-level work, widespread inadequacies at many other institutions have held back the overall quality of computer science research in India.

Effects of funding

Funding levels vary considerably between the major computer science institutions and the other facilities. (See the "Funding for Computer Science Research" sidebar.) This profoundly affects the type of equip-

Funding for Computer Science Research

Computer science research in India is funded primarily by the All India Council for Technical Education, the Department of Science and Technology, the Department of Electronics, the Department of Atomic Energy, the Ministry of Defense, and the Department of Space.

India has more than 1,100 research and development institutions. However, according to Department of Science and Technology statistics, federal, state, and private institutions spent about $2 billion during fiscal year 1995-96 on all research and development, which is less than 1 percent of India's gross domestic product. This level of research funding is low compared to most developed countries but is higher than many developing nations.

M. Vidyasagar, director of the Centre for Artificial Intelligence and Robotics Research and a member of virtually every important Indian funding body, does not feel that greater research funding is necessary. "We have trouble finding even mediocre proposals to justify the level of funding that is already available," he said.

As in developed countries, Indian funding agencies are demanding that research institutions work on more product-oriented and industry-oriented projects in order to receive additional money. However, C.R. Muthukrishnan of the Indian Institute of Technology, Chennai, said many institutions suffer from inertia and may not be able to meet these demands.

Even though India's communications facilities have developed considerably, the infrastructure still doesn't meet the needs of research and development institutions.

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Major institutions. Begun in 1970 as the Computer Centre with a charter to provide a state-of-the-art computing facility, the Indian Institute of Science's Supercomputer Education and Research Centre today boasts one of the world's best computing environments. The center consists of the most modern workstations, parallel processors, and supporting infrastructure. It serves the needs of the institute and, in many cases, the entire nation. The Indian Institute of Technology campuses and such major research laboratories as the Centre for Artificial Intelligence and Robotics Research and the Tata Institute for Fundamental Research are also well equipped.

Other institutions. A number of problems plague the remaining institutions, which are not well funded. For example, there is not enough money to keep machines up-to-date. In addition, air conditioning is frequently inadequate and the uninterruptible power supply is limited. Thus, people cannot use their machines optimally, which frequently limits experimentally intensive research.

Changing circumstances. The Indian Institute of Technology campuses used to get modernization money regularly. However, this is changing because the funding is currently controlled by the All India Council for Technical Education, which is spreading the available money across a greater number of institutions. This has allowed smaller institutions to acquire better computing and communications equipment.

Communications infrastructure

Even though India's communications facilities have developed considerably during the past five years, the infrastructure is still inadequate to meet the needs of Indian research and development institutions. (See the "Communications Facilities for Research" sidebar.) However, the Department of Telecommunications' decision to let private companies provide Internet services[5] should improve communications quality and accessibility.

Educational resources

Many researchers complain about the lack of access to journals and conference publications. For Indian researchers, journals and conference proceedings are very expensive, particularly if they must be sent by air mail. This leaves many researchers unaware of new work in their fields.

This is not the case for the relatively few researchers who have Internet and World Wide Web access. However, many of these researchers don't have sufficient computer storage capacity or funding to take full advantage of these resources.

Communications Facilities for Research

India's Educational and Research Network (ERNet) project began in 1986 as an experimental project by the United Nations Development Program and the Department of Electronics. It is now an integral part of the science and engineering research infrastructure. Thanks to the network, some Indian researchers have access to the World Wide Web, e-mail, Usenet bulletin boards, and software that is in the public domain.

The United Nations Development Program has spent $7 million and the Department of Electronics has spent $8 million on ERNet since 1986. The eight nodes on the backbone star network—five Indian Institute of Technology campuses, the Indian Institute of Science, the National Centre for Software Technology, and the Department of Electronics—receive all ERNet services. Most of the remaining nodes have only e-mail. According to S. Ramani, director of the National Centre for Software Technology, ERNet has connected about 400 research and educational institutions, which have about 50,000 users.

ERNet used to be primarily made up of 9.6-Kbps lines and dial-up links. It is now being upgraded to a satellite-based communication network with nodes that use very-small-aperture terminals (small satellite dishes) to communicate with the National Centre for Software Technology, ERNet's gateway to the Internet. For communication with the US, ERNet now has 128-Kbps links from Bangalore and 64-Kbps links from Mumbai, and it is scheduled to have 2-Mbps links from seven cities soon. There are already a number of 64-Kbps links within India.

If attempts to link ERNet to the National Information Centre Network (NICNet) are successful, a huge resource would become available to researchers. The National Information Centre developed NICNet as a satellite-based network that serves the government's statistical and planning needs. NICNet connects the nation's capital, New Delhi, with the state capitals and state administrative districts. NICNet's nodes are linked to the master node in Delhi via very-small-aperture terminals connected by India's Insat-2B geostationary communication satellite. There currently is no direct link with ERNet.

These networks are using satellites because India's telephone system has been undependable, although there have been many improvements during the past 15 years.

ARTICLES AND CONFERENCES

Publishing articles in journals and attending conferences are important to the development of research science in any country. Doing the work necessary to produce articles for leading international journals and conference proceedings, and receiving the resulting feedback would help Indian researchers. Quite a few researchers currently don't receive much feedback because there aren't many Indians working in their fields.

However, many researchers are limited in their ability to publish articles and attend international conferences, and this has hurt the development of computer science research in India.

Publishing articles

Many Indian researchers publish in journals and conference proceedings, but usually not those that are important or well known. Shankar Pal of the Indian Statistical Institute in Calcutta, a member of many journal editorial boards, said many Indian researchers don't submit articles to the well-known journals or proceedings because they are not confident that they will be accepted.

In addition, Indians are frequently torn between the desire to publish in major international publications and the need to improve the quality of Indian computer science journals, a problem common to many developing countries.[6]

Indian journals. There are several Indian computer science journals. The Computer Society of India publishes *The Journal of Computer Science and Informatics*. The Indian Academy of Sciences publishes *Sadhana*. There is also the *Indian Institute of Science Journal*. This journal, *Sadhana*, and several other publications address general engineering issues. India also has many magazines devoted to information technology.

Potential reviewer bias. Many Indian senior researchers whose submittals to high-profile international journals have received bad reviews express concern that reviewers tend to dismiss papers by authors from developing countries. They say that papers written by Indians working abroad seem to receive better responses from such journals. Nevertheless, many Indians who have published regularly in international journals say bias is no longer an insurmountable problem.

Limited by cost. The costs of preparing a paper for publication can be daunting for Indian researchers. Just producing copies of a paper on a laser printer for submission to a journal or conference proceedings can cost about $30. This is particularly burdensome for good researchers at smaller schools that have less money. Such researchers frequently choose not to spend their money submitting a paper to a well-known journal that might reject their work. Instead, they send their work to lesser known publications that are more likely to accept their articles.

Attending conferences

For an Indian researcher, the cost of attending a conference in the US or Europe can be as much as one year's gross salary. The cost of attending a conference in India is about two months' salary. Thus, Indian researchers do not frequently attend foreign conferences.

Fortunately, they can find a number of conferences in India devoted to such subjects as VLSI design, high-performance computing, software engineering, databases, communications networks, and such emerging areas as neural networks and object-oriented systems.

Some are attended primarily by resident and nonresident Indians. Others are international conferences, such as the Fourth Asian Test Conference, the Third Asia-Pacific Conference on Hardware Description Languages, and last year's 22nd Very Large Data Bases Conference.

Many are organized by the 15,000-member Computer Society of India, the Institution of Electronic and Telecommunication Engineers, or government research laboratories. Some are sponsored by vendor organizations, such as the National Association of Software and Service Companies. Many are sponsored by international organizations, such as the IEEE Computer Society and the International Federation of Automatic Control.

INDUSTRY'S INFLUENCE ON RESEARCH AND EDUCATION

Developments in India's computer industry have had a variety of effects on domestic computer science research and education.

Effects on the research community

As India's computer industry grew, researchers hoped this would lead to more and better opportunities for them. This did not occur to the extent researchers had hoped. And some of the opportunities that were created caused unexpected problems.

Imports and unmet expectations. Many researchers hoped the boom in India's computer industry would create challenging work for researchers. This did not happen for several reasons. For example, because of import liberalization, Indian companies have found it easier to license existing technologies from abroad than to develop them locally, as they did before liberalization. This has reduced job opportunities for Indian researchers.

In addition, industry has not asked the Indian research community to help improve imported products. Instead, industry has turned to the products' overseas developers.

Many Indian researchers publish in journals and conference proceedings, but usually not those that are important or well known.

Researchers have been disappointed that India's growing computer industry has not created more opportunities for them.

Changes in the software industry. India's domestic software market will grow faster than its export market. Although there has been a great deal of computerization in India, there are still many businesses, government agencies, and other organizations that have not been extensively computerized.

Meanwhile, the value of software produced in India for export is increasing because more work is being done on software for operating systems, database management systems, and graphical user interfaces. The Department of Electronics has facilitated this work by sponsoring software technology parks all over India.

This growth in India's software industry, along with the arrival of high-paying multinational corporations, has changed India's computer science research employment picture substantially. Previously, government-run labs offered the most challenging opportunities and attracted highly skilled researchers, even though the pay was substantially lower than in the private sector.

However, the multinational corporations and the software technology parks offer sufficiently high salaries to recruit highly trained scientists and engineers. This loss of personnel in government organizations and in some older private Indian companies has caused them to miss some project deadlines and has hurt the morale of the remaining employees.

These trends are likely to change only if

- corporate research and development in India increases from current levels,
- salaries at government laboratories rise, and
- private institutions, including those belonging to multinational corporations, create a greater number of challenging jobs by using Indian computer scientists to build entire systems rather than just components or subsystems.

Effects on education

Educational institutions contend their role is to teach basic skills and knowledge, and they have been slow to consider industry's needs. Industry, with its focus on goals and results, wants educational institutions to teach state-of-the-art technology that students can use immediately in a new job. Many software houses, for example, lament that many recent recipients of bachelor's degrees have received training that has been very abstract and have little if any specific knowledge of the tools needed to work for the companies.

Many educators and professionals say that India is not producing the number of high-quality software professionals that the country's growing software industry needs. A nationwide examination conducted by the National Centre for Software Technology indicated that this is the case.[7]

Many large software houses have thus started in-house training and continuing education programs. Several have applied for or received ISO (International Organization for Standardization) 9000 certification, which shows that recipients have standardized procedures for quality software development. And a number of companies have suggested establishing a consortium to form a computer science education and training institute, which would promote interaction between industry and academia.

Meanwhile, with increasing demand by industry for skilled computer science professionals, hundreds of training schools that offer expensive, short courses on computer packages, databases, tools, and so on have opened their doors. In response to complaints that these courses are ineffective, the national government is considering accreditation for these schools.

Many Indian computer science researchers have tried to carry out high-caliber research in spite of limited infrastructure and resources. However, the research community must now try to reach its potential by assessing its capabilities, developing a shared long-term vision, and embarking on systematic efforts to conduct cutting-edge research.

The Indian computing industry must play its part by providing challenging opportunities that will bring out its employees' potential.

Meanwhile, India needs technically oriented leadership in the government to make this possible. The government should develop programs to provide

- incentives for research productivity, prudent management, and the effective use of research funding;
- enhanced salary levels for researchers at all ranks;
- appropriate accountability systems; and
- improved opportunities for interaction between peers, between industry and academia, and with researchers abroad. ❖

For More Information

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