A DETAILED REPORT ON R&D AT INDIAN COMPUTER SCIENCE ESTABLISHMENTS

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A Detailed Report on R&D at Indian Computer Science Establishments *

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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

Government Sponsored Organizations:
BARC – Bhabha Atomic Research Center
CAIR – Center for AI and Robotics
CDAC – Center for the Develolpment 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? To address this question in the context of computer science, during the period Nov '94 – July '95, I conducted a study – by attending a number of conferences held in India and visiting research and educational institutions.

This document is a trip-report, summarizing the research conducted at each of the institutions I visited. The institutions are categorized as follows:

- Educational Institutions,
- Government Sponsored Research Organizations, and
- Private Research Organizations.

This report also has a description of the Education and Research Network and the Software Technology Parks that have been set up for software promotion.

In a companion report, I summarize the findings of my study. The summary report 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 nature of students and faculty at the educational institutions. Support for conducting research in the form of equipment, infrastructure, and publications is the next topic discussed. I then examine how Indian researchers publish their work. Finally, I report on the impact 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.

2 Educational Institutions

There are 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 do appear to be several less well-known universities where computer science research is being conducted. 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, on average, lacking in quality, and finally poorer infrastructure, namely library and computing facilities.

2.1 Indian Institute of Science (IISc), Bangalore

Computer science research is carried out across several departments at IISc: Computer sciencel and automation (which was previously called School of Automation; a majority of its senior faculty hence have background and interests in control systems but most of the younger faculty have CS interests), Electrical Engineering, Electrical Communication Engineering, and the Supercomputing Education and Research Center (SERC).

Veni Madhavan, a theoretical computer scientist, has been working for a number of years on the design and analysis of algorithms, graph theory, computational geometry and computational number theory. In the latter area, his interests lie in primality testing, factorization, and crypto systems. Recently, he has also been studying computational biology problems, especially, matching and gene sequencing.

Besides Veni Madhavan, the IISc theory group consists of Priti Shankar, Vijay Chandru, Vinay and Ashok Subramaniam. They are in the process of establishing a Center for Algorithms.

Chandru, with an operations research background, today works on several CS problems as well. He looks at the logical inference problem as a combinatorial optimization problem and has just co-authored a book on this topic, to be published by Wiley. He is also interested in graphs for architecture, investigating bounding diameters, polyhedral combinatorics, and set covering problems. Using integer and logic programming techniques, Chandru, in conjunction with CAIR, helped develop the expert system shell called nipuNa (which means "expert" in Sanskrit) as well as a prolog compiler – from scratch. The latter is to eventually incorporate constrained logic programming.

Manohar's area of research is application specific architectures, involving the development of parallel algorithms and architectures for graphics, visualization, and more generally, virtual reality. In collaboration with Chandru, Manohar is involved in CAD/CAM research. Together they use the notion of alpha shapes and voxels for 3D volume visualization. Their goal is to build a workbench for rapid prototyping, with voxel-based solid modeling tools. The hope is to give a "sculptor" the necessary interfaces to create a 3D object directly, instead of viewing and building it as something that is made up of multiple layers of 2D objects. Manohar is also interested in designing intelligent interfaces and evaluating the efficacy of interfaces. To this end, he is working on ways to instrument interface software to help in the evaluation.

Gopinath, Shankar, and Srikanth form the compilers group at IISc. While Srikanth's work covers retargetable code generation, incremental compilation methods and more recently, rapid prototyping, Gopinath has been looking at combining various phases of optimization for constant propagation and alias analysis. The performance degradation resulting from the inefficient use of resources, combined with the ever-increasing number of resources on a chip, makes their optimal exploitation very important. Gopinath has been studying this problem, focusing on multithreaded architectures with instruction level parallelism and low latency traps. Microstorage kernel architectures, file systems, and use of the World Wide

Web to construct a biodiversity information system are some of the other problems Gopinath is working on.

Manufacturing and business processes, and more specifically, reengineering them form Viswanadham's current research interests. More generally, his work involves fault-tolerant control system design and the modeling and control of flexible manufacturing systems. Four primitives form the basis for his approach to dealing with manufacturing processes: the core processes (which he believes will remain invariant even if there are changes in the technology), the interconnection technology used for material and information processing, the organization structure, and finally the people. In his model, the base layer consists of the basic processes, with customers (demanding the products) forming the top layer. The layers in between have to be configured in such a way as to reduce costs and delays in delivering the desired products. Thus, these layers basically determine which (intermediate) products go where and, hence, are communication-intensive.

The modeling and scheduling of flexible manufacturing systems form Narahari's research interests. He uses Petri nets and queueing theoretic approaches for modeling and performance analysis, a natural successor to his earlier work which focused on deadlock analysis in manufacturing systems. Today, Narahari is investigating performability as a general approach to achieve reliability and high performance, characterization of transient behavior, using concurrent engineering for product development, and the benchmarking and management aspects of manufacturing systems. He is also applying object-oriented design methodologies for manufacturing systems.

Narahari and Viswanadham have written a well-received book on the performance modeling of automated manufacturing systems, published by Prentice-Hall.

Ventatesh's research lies in feedback systems control and stability analysis, as well as remote sensing. His group, under sponsorship from ISRO, has built a highly successful image processing facility using AI and computer vision techniques. Tools developed here have been applied to detect diseases in citrus, sugarcane, and rice crops, as well as in banana, teakwood and sandalwood plantations. They have also built a local facility for color infrared processing incorporating techniques from neural networks and neurophysiology.

Thathachar characterizes his research broadly as machine learning, particularly stochastic learning automata. Based on his many years of working in the area, he has co-authored a book on the topic. He sees such automata as a "probabilistic teacher", one which maximizes the probability of giving a "yes" to a correct answer. The reinforcement for the automata's behavior comes from the environment. He has been investigating the interconnection of many automata to solve pattern recognition and control problems (such as backing up of a truck and the control of an inverted pendulum). He is also interested in fuzzy systems and in the stability problems of non-linear systems (modeling them as systems that switch from one linear system into another) seeking analytical models with reasonable approximations.

Patnaik currently pursues research on the modeling aspects of genetic and neural algorithms. One of the issues is related to convergence of a class of algorithms with binomially distributed populations. He has been developing adaptive genetic algorithms (GA), tuning the probabilities of crossover and mutation, to get to desired solutions faster. These algorithms have applications in VLSI testing, neural network weight optimization, partitioning problems in multichip modules, and VLSI placement and routing. For the problems looked

at, the results have been better than simulated annealing (SA). The adaptive algorithms take less time. The algorithms are being parallelized on the Param, the parallel processor from CDAC. The mathematical characterization of evolutionary algorithms is difficult, but, Srinivas has achieved this in his Ph.D. thesis. This work is continuing, with the modeling of other populations. Patnaik is also investigating combinations of SA and GA as well as others. The idea is to get intuitions from SA and move them to GA.

Patnaik's other current research involves VLSI/CAD testing and logic simulation and their parallelization and distribution. For instance, he has taken a medical imaging application and simulated and implemented it on a hypercube. The neural networks projects include object and speech recognition, signature verification, speaker identification, target identification. In the process, he and his colleagues have developed faster back propagation algorithms. VLSI chip design for genetic algorithms and neural networks, mobile computing and parallel architectures also fall within his current research interests.

Real-time systems, database systems and performance and management of computer networks are some of Haritsa's research interests. In the database area, he specializes in real-time databases, focusing on transaction processing issues. He has developed several high-performance concurrency control protocols, by appropriately extending the traditional database protocols. Recently, in collaboration with researchers at IITB, Haritsa has developed protocols to integrate real-time transactions and non real-time transactions in the same application in such a way that the performance of both is maximized. Other problems the group has looked at include the timely resolution of contentions in accessing database index structures and database compression. Haritsa has also been doing OODBMS design/implementation for different domains: network management, bio-diversity, manufacturing, and interconnection analysis in chip design. In the real-time arena, Haritsa has been interested in more fundamental questions related to how well a dynamic scheduling algorithm, needed for most practical applications, can perform relative to clairvoyant algorithms.

Jenkins's work spans the gamut from using Petri nets for analyzing power systems to multistaging fault-tolerant interconnection networks to user interfaces for cooperative work.

Modeling, analysis, and control are some of the topics that Anurag Kumar investigates in the context of communication networks. He is head of ERNET project at IISc. He is also setting up a center for telecommunication.

Keerthi has been working on learning systems, neural networks and control theory. Prasad (control systems, neural networks), Rangaswamy (theoretical computer science, software engineering), S.N. Rao (systems science), N.J. Rao (education), I.G. Sarma (optimal control, system simulation), Subramanian (multidisciplinary interests), Murthy (pattern recognition), Hansdah (databases), Mathew Jacob (computer architecture, parallel processing), and Sriram (computer architecture) are some of the other faculty in the department of computer science and automation.

Begun with a charter to provide a state-of-the-art computing facility, SERC today boasts of a computing environment that is one of the most well-endowed 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. It also houses researchers who work on multiprocessor architectures and their performance evaluation, databases, multimedia, computer networks, numerical algorithms and more gen-

erally scientific computing algorithms, for example, making use of sparcity of matrices and their physical interpretation (not calculating elements that are not needed), and scientific visualization. Balakrishnan is the current head of SERC.

Rajaraman, considered to be the father of Computer Science Education in India, has worked on many different areas of computer science. Stating that "generalization has served us well and narrow focus would have been a disservice", he feels that Indian researchers, in the past, had to be "a little bit more on the ground". His research, spanning several decades, covers a large territory. Indian language processing based on legal combination of Sanskrit phonemes, data retrieval systems, expert systems, computer aided learning systems, parallel processing, and programming languages and compilers are some of the topics covered. Prof. Rajaraman, who was the prime spirit behind the establishment of SERC (he was its head until recently), also set up a computer-aided design lab, a knowledge-based computing system lab, and the National Centre for Scientific Information (located at IISc).

One of SERC's researchers, Ghoshal, has been interested in all areas related to parallel systems, including operating systems for parallel file systems, microkernels for parallel systems, hypercube-based architectures, compiler and tool support, and numerical computations. He has experimented with several parallel architectures and developed validation suites.

It is important to mention that Profs. Patnaik, Thathachar, and Viswanadham are Fellows of the IEEE.

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The department is one of the leading research institutions in the country with internationally visible work in compiler technology, VLSI, and databases, to name a few areas. In addition, many of its faculty interact with industries and government-run organizations, transferring technology as well as helping in the computerization of their activities.

Dhamdhere and his colleagues, Biswas, and Sanyal, have been working in the area of parallelizing compilers and the theory of compiler optimizations for more than a decade. The group has been steadily pushing the state-of-the-art in compiler technology and is a (not-very-often-seen Indian example) project with long-term and focused goals. Recent results in the area of unified compiler optimization techniques deal with data flow analysis, especially bidirectional dataflows. Their theory has been able to explain existing results in dataflows and also offers insights into the process of dataflow, both unidirectional and bidirectional. Another result from this group is on the theory of incremental dataflow analysis. They have been able to formally characterize the changes that occur to compiled code due to changes

in the source code. Heuristics for register allocation, mapping task graphs onto parallel architectures, and language processing tools such as optimizer generators are some of the other problems the group is currently interested in.

Another research group with the critical mass needed to carry out state-of-the-art research is the database group consisting of Sarda, Phatak, and Seshadri. For a number of years, Sarda has been working with temporal databases, defining an extended relational model to capture time and history and proposing extensions to SQL to deal with such data. In addition, currently the group is investigating object-oriented databases, deductive databases, real-time databases, heterogeneous and multimedia databases, and parallel database platforms. Some of the issues being investigated include storage techniques, management of objects with evolving properties, identification of and parallel implementation for database operations on multimedia objects, query processing and optimization, query cost estimation through sampling, and media synchronization. The group has a highly practical orientation. To serve as an experimental testbed, a simulator, allowing the study of disk, index, and buffer management, transaction processing issues, and scheduling issues, has been developed and is continuously being upgraded to meet new experimental needs. Since most of the legacy applications are in COBOL (especially in India), the group has been working on developing many tools that aid in the conversion of such systems to work on relational and object-oriented database platforms. Another product of this group of import to industry has been the development of benchmark suites consisting of synthetic data as well as workloads to evaluate the performance of relational database management systems.

Two faculty members, Venkatesh and Sherlekar, have been working in the area of CAD for VLSI and have been very successful in transfering their technology through a company called Silicon Automation Systems – a company they are moving to shortly. The group has its roots in the Integrated Design Automation Project, a collaborative project (between the IITs at Bombay, Madras, Delhi, and Kharagpur as well as the Indian Institute for Science) funded by the Department of Electronics. The project produced tools for simulation and microcode synthesis, and more recently, testing and fault simulation. Some of the industry-oriented projects they have undertaken include the development of a synthesis tool for a Hardware Description Language, a fast functional Verilog simulator, and programming language tools, debuggers and cycle-level simulators for an embedded-application-oriented RISC processor. A more research oriented project involved the realization of large circuit given a set of reprogrammable devices (FPGAs) with programmable interconnectivity. This is motivated by the implementation needs of circuits whose specifications change with time.

Mehndiratta is interested in several areas including multi-media, real-time systems, and networks. He is the IITB coordinator for the ERNET project. He and his students have built several prototype systems. One is Yatharthu, a real-time system for routing audio (and potentially) video communication, based on a 386 PC. Another is Varthalaap, a network-based teleconferencing system. It is X-windows based, runs on Silicon Graphics workstations, and uses TCP/IP sockets for communication. The system rivals university prototypes I have seen in the US – both in its capabilities and its user friendliness. For instance, it comes with a whiteboard, audio and image communication facilities, dynamically constituted groups, and controlled group communication. Lack of resources stand in the way of its extended use and experimentation (for example, to study the scalability of the solutions). Because of

its current reliance on the ethernet, it only deals with image transmissions. The group is getting involved in mobile computing, with focus on routing algorithms.

Sharat Chandran has been working on problems related to computer graphics. He characterizes his interests as being in the "forward problem" of rendering graphics as well as in the "inverse problem" of image processing. He shares his interests with Kekre and Ramakrishna. This group is looking beyond the design and construction of rigid bodies, well studied in the literature, but only in its nascent stages as far as Computer Integrated Design and Manufacturing (CAD/CAM)in Indian Indian industry is concerned. Specifically, the goal is to model the impact, deformation, and collision detection properties of elastic bodies. Other topics being studied include visible surface determination when the viewpoint may be in motion, volumetric rendering from cross-section views, and fractal-based image recognition.

Ramesh's interests lie in formal aspects of concurrency. He is particularly interested in applying formal methods to large systems. He has been working with Harel's Statecharts, investigating the simulation of statechart-modeled systems as well as developing tools. With researchers working on VLSI, Ramesh is trying to marry Verilog and Statecharts. He has also been collaborating with Shyamsundar of TIFR and the Esterel group in France on the verification of reactive communicating processes.

Diwan works on graph algorithms with the display perspective. Thus, he works with graph theoretic characterization of the display properties of graphs. He has also worked on the state assignment problem, dealing with multi-logic minimization in VLSI circuits.

Other theory oriented researchers include Sohoni, who works on combinatorial optimization and algebraic algorithms; Viswanathan, who works on approximation algorithms, complexity theory; and combinatorics, and Khalid, who applies queueing theory for performance evaluation of computer networks.

SSSP Rao, with interests in VLSI design and advanced computer architecture, has been heavily involved with the industry and is well-known for his technology transfer mission. For instance, his work with CDOT resulted in the production of switches with 30% lower switching costs.

Arunkumar (systems modelling and simulation, architecture, AI), Sivakumar (automated reasoning, rewrite systems, distributed systems), Nagaraja (AI, pattern recognition, computational learning theory), and Bhattacharya (neural networks, machine learning, distributed AI) are some of the other faculty in the department involved in research.

The department is slated to move into a new roomy and well lighted (with natural light) building with an interesting design. It is a "product" of Project IMPACT, a project funded mainly by the World Bank, aimed at the development of manpower and education in CS and Electronics. With the faculty at IIT Bombay and Jadavpur University (in West Bengal) serving as the primary resources, the goal is to upgrade the curricula at selected colleges. Funds have also been provided for equipping the colleges with up-to-date computing and networking infrastructure.

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Jain is interested in several areas, including multi-media, networks, and real-time systems. In the multi-media area, he is interested in the retrieval of multi-media objects and context-based search. Also, he is investigating issues related to synchronization of multi-media streams, with focus on display and communication. In the networking area, Jain and his students are working on feedback-directed communication, specifically, on using of the bandwidth left after taking into account the needs of synchronous traffic in high-speed networks. Finally, he has begun work on dynamic real-time scheduling with periodic and non-periodic task arrivals.

After doing his Ph.D. involving the application of machine learning techniques to load balancing in distributed systems at the Univ. of Illinois, Urbana and subsequently spending two years with the parallel processing group at NASA, Ames Research Center, Pankaj Mehra recently joined the department. His area of interest is parallel computing, specifically, studying the performance and scalability of parallel and distributed programs with the goal of doing "performance debugging" as opposed to the debugging the functionality of programs. Towards this end, he is looking at techniques to build a high-level view of program behavior in order to infer message passing patterns of programs, and to determine the types of communication in the different phases of a program. Along with Shroff, Mehra plans to venture into computational chemistry and computational mechanics problems.

Gautam Shroff, a Ph.D. from RPI in the US, is interested in parallel algorithms and numerical analysis for large-scale problems. He is involved in the parallelization of several large scientific applications. Weather forecasting code is being parallelized as part of a project sponsored by CDAC. Another is an effort to parallelize Computational Fluid Dynamics (CFD) code in collaboration with the process modeling group of TRDDC, Pune. Shroff is also developing libraries that support high-level constructs for parallel programming on workstation networks and parallel machines. The routines also support parallel I/O and automatic data partitioning and distribution. In numerical analysis, he is investigating acceleration techniques to speed up iterative solvers.

Anshul Kumar's work deals with high-level synthesis, from behavioural specifications to functional blocks. A collaborative project between IITD, IITB and Semiconductors Complex Limited is building an integrated design automation system. Work deals with logic level synthesis, especially for the finite state machines. This involves scheduling, allocation of components, generation of control signals, and clock signal generation. Anshul Kumar is also interested in low-level synthesis using FPGAs as building blocks. He believes that these are good alternatives to ASICs. In this work, he collaborates with Balakrishnan, Sashi Kumar, and P.C.P. Bhatt.

Madan's interests are in single and multiprocessor architectures and networks, specifically, design of switches and the internetworking of LAN segments. He heads IITD's computer center.

Maheshwari's primary area of interest has been algorithms, but more recently, he has been working on databases, on both formal and practical aspects. Specifically, he has been studying recovery issues related to nested transactions, with focus on I/O automata based proof techniques. He is fascinated by La Fortune's state estimation techniques and their application to concurrency control and for optimizing join operations. Now he is applying these ideas for more complicated concurrency control paradigms and also distributed systems.

The five IITs were given funding to develop library information systems; but each has developed its own, without any coordination between them. IITD has based its system on files. The system does multi-dimensional search using kd-trees, and maintains primary and secondary indices in RAM, resulting in a reduction in search time. Using the experience and the tools developed in this project, Maheshwari is now moving in the direction of developing office automation applications.

The group working on algorithms is perhaps the strongest one at IITD. It consists of Maheshwari, Vijay Vazirani, Sanjeev Kapur, Huzur Saran, Sandeep Sen. Between them, they work on the design of parallel algorithms for combinatorial optimization, graph theory, and computational geometry. In particular, they are interested in algorithms for linear programming, matching, and hull finding as well as randomised and approximation algorithms.

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One of the main research projects at IITK is in natural language processing. Prof. Sangal is investigating the machine translation from one Indian language to another while Prof. Sinha's work involves English to Hindi translation.

With Vineet Chaitanya, Sangal applies the Paninian framework to modern Indian languages. This has allowed the development of computational grammars for Indian languages with the nice property that efficient parsing is feasible.

Sinha's work is based on the word expert model utilizing Karak theory, pattern-directed rule base and and a hybrid example base. Also, he supervised the initial work that eventually led to the GIST technology for multi-lingual processing.

In a multi-institution project funded by the UN's Development Program, Prof. Dhande is investigating computer graphics and CAD for mechanical engineering applications. His group also does industrial consultancy work for the Indian Railways and for the National

Aerospace Laboratories.

Barua's works is on operating systems, mainly on the development of indigenous versions of Unix and Mach. He is also interested in studying distributed systems issues, such as naming and architecture for file systems.

The department's two database researchers are Profs. Prabhakar and Karne, involved in a project for library automation. Prabhakar's other interests include hypertext, electronic publishing and application of multimedia, with focus on user interface design, file structures for large databases, and database performance tuning. Karne is interested in transaction processing, concurrency control and currently, long duration transactions.

Pankaj Jalote works in the areas of software engineering and software fault-tolerance. Specifically, in the former, he is interested in issues related to software quality, metrics, reliability, and process. Currently he is developing a real-time kernel for the control of chemical engineering processes.

Sanjeev Kumar Aggarwal's current interests lie in compilers for parallel programming. In particular, he is interested in developing customized tests to apply during loop optimization. This generalizes to the idea of reconfigurable compilers – based on an application's optimization needs. One of the goals of the work is to develop quantifiable measures for the selection of optimizations (during compile time and run-time) based on the ease of restructuring.

Ajay Jain works on fault-tolerance (through reconfigurability and testability) in VLSI systems.

Sanghi works in computer networks, having recently developed a high performance alternative to TCP.

Even though most of the faculty are in non-theory areas, most of the Ph.D. students are in theory. Out of the five theses submitted during 94-95 and six more in the pipe, only one, dealing with replacing software on line, was experimental in nature. "It is a struggle all the time", is a refrain heard too often in the context of attracting high caliber students to pursue Ph.Ds.

In the theory area, Somanath Biswas works in the structural complexity area, logics capturing complexity classes and constructive higher order logics. Mukhopadhyay's research is in computational geometry and its applications. Sanjeev Saxena, Ratan Ghosh, and Phalguni Gupta have interests in (parallel) algorithms. Ghosh also works on dependence tests for restructuring sequential loops for parallel execution and tools for parallel and genetic computing.

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One of the major research activities in the department relates to VLSI. It has "galvanized" the team consisting of Pal Chaudhuri, Basu, Sengupta, Chakravarthy, Mazumdar, Sarkar, and A. Pal. They are investigating a number of issues in the general area of design automation and designing for testability. Hardware/software co-design through proper hardware and software partitioning is being investigated based on microprocessor-based controllers. Heuristic search techniques and knowledge-based approaches are used for datapath and control optimization, for partitioning, as well as for circuit layout. Formal verification techniques, based on higher-order and temporal logics, are being used for design verification. An object-oriented database has been developed for managing the design objects as well as the design process.

The VLSI effort gets its funds from the Department of Electronics as well as several companies including TI, CDoT, Motorola, and Cadence (which offered its software gratis). The group has been quite successful in applying its research results in practice. For instance, CDoT has embraced the group's cellular automata based error correcting code and compression techniques for their VSATs (Very Small Aperture Terminals). A venture has also been started by Pal Chaudhuri to commercialize some of the research results.

As mentioned earlier, the database research group, headed by Mazumdar, has developed database support for VLSI design applications. In the context of object-oriented modeling of VLSI objects and the resulting encapsulation effects, they are trying to understand to what extent a circuit is visible to the outside so that it can be controlled effectively. The use of long transactions for such design purposes is also being studied. Rajiv Mall, whose interests also lie in databases, is working on active databases and information modeling. Using multimedia data and imaging, the group has been modeling the immuno-genetic aspects of leprosy in an attempt to develop knowledge-based diagnosis techniques and for monitoring prognosis of this endemic disease. Their use of cooperating multiple expert systems increases the efficiency of the system under changing disease states over time. An object oriented expert systems shell for target identification of aerial data has also been developed with funding from the defence department.

Chakrabarti has developed and applied modified and parallelized A*-based heuristic search techniques. Issues raised by bounded memory have been studied. The applications include constrained optimization problems such as VLSI circuit optimization, learning, and multi-objective search.

The image processing group integrates researches from many departments, with Bhattacharyya, Das, and Mukherjee involved from CS. The group investigates low-level image processing issues such as segmentation and edge detection. They have, in fact, designed VLSI chips to speed up such processing. Interestingly, the techniques have been applied to detect defects in rubber and in polymer structures – in addition to the traditional remote sensing applications.

T.K. Dey and S. Pal pursue interests in Computer Vision and Computational Geometry. One of the questions they are grappling with has to do with applying computational geometry results to topology. Solid modeling and triangulation (decomposition) of objects, visualization of molecules (with the ball and stick model), and the issue of considering re-

flecting surfaces during visibility determination are some of the topics under investigation.

Ramamoorthy studies distributed systems problems, especially the embedding of parallel problems in parallel architectures. He is attempting to build a distributed processing platform to help in his experimental efforts.

Ghose's current interests are in theoretical computer science, focusing on the design and analysis of parallel graph algorithms and their application to VLSI design.

The department started in 1984, with its first Ph.D. completing the thesis in 1986. Averaging about four each year, the department saw a bumper crop of 11 Ph.D's in 91-93. The department has a faculty of 19. However, the department, as with other institutions, expects that the number of students interested in pursuing their Ph.Ds is highly likely to go down in the coming years.

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2.6 Indian Institute of Technology (IIT), Madras

With his work spanning over thirty years, Yegnanarayana has had long-term interests in speech research. He has been trying to understand speech production and perception, attempting to make machines carry out what humans do naturally. Thus, he views speech as a natural mode of communication and investigates the machine-understanding of human speech as well the machine production of human-understandable speech. Over the years, he and his colleagues have refined the techniques based on current technology, starting from the use of digital signal processing techniques to the use of a variety of AI techniques today. The AI techniques combine aspects from symbol manipulation, heuristic search, expert systems, fuzzy logic and neural networks. Most of this work is algorithmic in nature. Yegnanarayana makes the interesting point that while basic computing involves "localized" computations, human speech and vision processing is "global" in nature. This global-local interaction appears difficult to implement efficiently with computers. Another point he makes is that while we should aim high, it is also important to know what cannot be done so that we can aim at the right level.

Given the similarities underlying speech processing on the one hand and image processing / computer vision on the other, Yegnanarayana and his colleagues, Raman, Murthy, Das, Sundar, and Ramana Rao have produced results applicable to these areas as well. For instance, they are studying inputs to machines in the form of hand-drawn figures and handwritten characters. Also, studies involving natural language processing, with focus on knowledge representation and reasoning, are being conducted for Indian languages.

Mahabala believes that AI was indeed oversold in its early years, but that it has delivered in one area, namely, expert systems, and in particular, in diagnosis. He believes that model-based diagnosis has to be qualitative and that a multi-model diagnostic system is essential

to deal with practical situations. Several prototype expert systems have been built by Mahabala and his colleague, Ravi Prakash based on this philosophy. These demonstrate the superiority of model-based approaches over rule-based systems, especially in domains where it is difficult to obtain precise knowledge in the form of rules. One provides advice to the range-safety officer just after the launch of a spacecraft. It helps the officer determine if the flight parameters are within safe limits so that it can be allowed to proceed. If this is not the case, the officer will be advised to safely detonate the launched vehicle. Another advising system, called Ekalavya, has been developed to help trained primary health workers to deal with illnesses in rural four-year olds. In addition, several other diagnosis and advising systems, for use in power and industrial applications, have been developed and field tested.

These systems were built as part of the Knowledge-Based Computing Systems (KBCS) project. IIT Madras was one of six nodal centers and its work dealt with expert systems for diagnosis. The other five centers were TIFR (speech processing), IISc (parallel processing), NCST (expert systems and natural language processing), ISI (image processing) and the central government's Department of Electronics (DoE). The funding for the project was provided by the United Nations Development Program and DoE. During the period 1986-95 each nodal center received a total of one and a half crore Rupees (half a million 1995 US Dollars). Approximately fifteen Ph.D's are said to have been produced by the various nodal centers during this period.

Khemani, whose Ph.D. was in the area of planning in an uncertain environment (the game of bridge being the specific domain) characterizes his research interests as being in "language and thought". In AI terms, his work lies in the intersection of problem solving and natural language understanding, and is concerned with the questions of representing knowledge and the use of knowledge. He feels that in the game of bridge one encounters real-world examples of all the problems studied in AI. His goal is to write a bridge-playing program in the next ten years! Believing that a system must be able to say what it is doing, he is interested in a system that can represent its own activity such that it can explain its activity. Towards this end, his recent work involves text planning and text generation.

Muthukrishnan is interested in various aspects of software and systems. His recent work relates to programming languages, operating systems, object-oriented and real-time databases, and distributed computing. Using mutual exclusion of access to system data structures as the basic building block, he has developed a suite of load sharing algorithms for distributed systems. RT-Genesis, a real-time database management system, has been developed by modifying an existing commercial DBMS, Genesis. RT-Genesis is a relational database management system that accommodates SQL queries and transactions having time constraints. It features time-cognizant algorithms for scheduling, concurrency control and buffer management. In another database project, an object-oriented veneer has been added to a relational database system. Thus, a database user sees and manipulates data encapsulated in objects which are transparently mapped to relations.

Janakiram has research interests that encompass operating systems, distributed computing, and databases. With a Ph.D. in mechanical engineering, he is driven by a desire to understand the practical issues in providing the necessary technology for applications, such as CAD/CAM, that have real-time constraints, that need database support, and have fault tolerance as a basic requirement. With this broad goal, his recent work has included the

study of reverse scalablility (how can we design the solution for a large distributed system to work on a system with a small number of nodes?) compile time partitioning of large objects for better parallelism and load balancing, constraint specification, propagation, and maintenance in large design applications, and the partitioning of messages for transmission to improve reliability.

Janakiram is also working towards a clear separation of programmer's concerns from systems' concerns in parallel programming on loosely coupled distributed systems. With this broad goal, he has developed a language construct for system independent parallel programming on distributed sytems, a scheme for object based subcontracting for loosely coupled distributed systems, a paradigm for replicating objects in distributed sytems, and an anonymous RPC based technique for parallel programming on loosely coupled distributed systems. With these components in hand, he is now working on a full fledged language for programming on distributed abstract machines (DAM).

Kalyanakrishnan's work is aimed at developing an environment where many commonly used applications can be made to run in Indian languages. This goal has been achieved by developing a C-callable input/output library which allows one to take input and display the output in Indian languages. Instead of using multi-byte representations like other approaches, this system uses a fixed size 16 bit code to represent characters. A common generic representation has been used for all languages and hence, transliteration is inbuilt into the system. The characters are displayed by drawing them as combinations of bezier curves and hence storage requirements are reduced and different fonts and sizes can be achieved through transformations on the bezier curves. Since Postscript supports bezier curves, printing is facilitated. The work that has been done till now includes development of various applications like a shell, an editor, utilities that can query large archives of data, and programs that can act as tutors for Indian languages. The library and these applications are now available in many platforms, MS-DOS, BSD, SunOS, MS-Windows and X-Windows. Networking applications like e-mail and talk have also been developed. Future plans include making the system available on other platforms like the Mac. More sophisticated networking applications could be built. Hypertext is also being considered.

Raghavan is one of the founders of the ERNET project in India, but, his research at IIT, Madras has been quite broad in its scope, covering many areas related to computer networks, especially protocol software engineering. His work spans the spectrum from protocol specification to implementation, covering development, conformance testing, and performance along the way. He has developed and implemented a subset of the ISO-OSI model called OSInet, designed for Local Area Networks. Many experimental studies have been carried out in the context of this network. These relate to the use of the OSI directory structure for maintaining network-wide information, developing secure versions of the file servers, buffering for the OSI stack and fault diagnosis and management. OSInet with its fault-management software has been packaged and given to colleges as well as to the Department of Telematics for fault reporting, diagnosis, and fixing.

More recently, he has also begun work on multimedia systems, focussing on design and networking issues. This work, with Prabhakar and Satish Tripathi as collaborators, has produced several results including formal techniques for modeling synchronization aspects of multimedia presentations and for QoS negotiations. Dynamic Timed Petri Nets, in con-

junction with Context Free Grammars, are used to provide the needed formalism. All of this work is motivated by a need to understand the implications of user-level requirements on the network bandwidth needed. He is also examining the issue of traffic shaping in multimedia applications based on prior observations.

The Wireless Local Loop (WLL) project is a high-profile multi-PI project involving Gonzalves from the CS department and Jhunjhunwala and Ramamoorthy from the Electrical Engineering Department. The physical wires connecting a local telephone exchange and the telephone equipment being the biggest cause of unreliability, the WLL project, as the name implies, will eliminate these wires. Instead, tens of subscribers will be connected to a base station, several of which are reliablly connected to the local exchange. This goal is itself not unique, but what differentiates this work from others in progress around the world is the development of telecom systems fitting Indian conditions, providing the same voice quality as with wires but at much lower cost. Several Indian manufacturers and R&D companies are involved in the development work funded to a large extent by Analog Devices of the US. This group of researchers has also developed a commercialized digital telephone answering machine which is tapeless (it uses solid state memory) and utilizes a low bit-rate speech compression technique.

The design and analysis of parallel algorithms and architectures form the theme of Siva Ram Murthy's research. He has been studying parallell algorithms for matrix manipulations and computational Fluid Dynamics problems on reconfigurable meshes, hypercubes and other architectures. His recent work has taken him to the domain of real-time, again, studying allocation, scheduling, and partitioning problems, but now, in the context of time-constrained computations. Without access to a parallel programming environment or platform, Siva Ram Murthy depends extensively on simulations to validate his ideas.

Pandurangan and Kamala Krithivasan have research interests in various areas of theoretical foundations of computer science. Kamala Krithivasan's primary research area has been formal languages and graph grammars even though more recently she has been concerned with computational geometry problems. Specifically, she has been investigating dynamic path planning problems involving stationery, moving, as well as movable obstacles. She has also been studying closure properties of cellular automata, in particular, of time-varying automata where the route of a computation, as well as the functions computed by an automaton changes with time. The complexity of these computations is also of interest to Krithivasan and her colleagues. Pandurangan's work covers complexity theory, graph grammars and algorithms, and computational geometry. The history of his research is consistent with his motto of "keeping with the current trends". So it is not surprising that his current interests include randomized algorithms and theoretical aspects of VLSI and systolic arrays.

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2.7 Pune University

The computer science department at the University of Pune is an example of the smaller research-oriented CS departments in India (the first tier being the IITs and IISc).

The head of the department is Prof. Sahasrabuddhe, former head of the CS department at IIT, Kanpur. The department offers three types of Masters' programs: (1) Master of Computer Applications (MCA) – with emphasis on practice, as reflected by a need to spend one semester at an industrial establishment, (2) Master of Science (M.Sc.) – preparing students for higher studies and research, and (3) Master of Technology (M. Tech) – for students with non-CS backgrounds. The department also has a Ph.D program and a small number of external candidates (for example, from CDAC, Pune which is "next door") have signed up with the department.

Four of the department's ten or so permanent faculty hold Ph.D's. The M.Sc. and M.Tech projects range from the mundane, e.g., building a Prolog interpreter, to the esoteric, e.g., synthesis and analysis of (North Indian Musical Notes). The individual faculty members themselves have several interesting research interests. These include limitations of formalizing the pragmatics of programming languages, measure of concurrency (in logic programs), compilers and their efficiency, remedial (time-shared) tutoring, concurrency control for mobile, federated and real-time databases, computational geometry, rewrite systems, and search for a common language underlying ragas.

The computing facilities of the department do not lend themselves to computationally intensive research. The main computing facility is a twin CPU (M88110) Aviion 8500 computer system with 64MB memory, which is connected with about 30 PC/XT/AT/386/486 systems and 16 Ascii terminals. Some 486-based machines have Linux and SCO Unix. The departmental lab is connected via a fibre optic link with the other university departments and CDAC, which is located close by.

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2.8 Regional Engineering College (REC), Trichy

The computer science program at REC, Tiruchirapalli, is considered by many to be one of the best among the RECs. It has eleven faculty members, with its current head, Gopalan, being the only one with a Ph.D. However, four of the faculty members are pursuing Ph.D.'s under the Quality Improvement Program (QIP) of the government of India. REC has given them up to three years to finish their Ph.Ds and those selected have committed to teaching for five years after completing their thesis.

Bachelors (B.E.) and masters (M.E. as well as Master of Computer Application (MCA)) programs are offered. An examination of the curriculum shows that the courses offered are intended to keep pace with emerging technologies.

This REC takes pride in its state-of-the-art computing center, called the Octagon. Serving as a repository for all computing and telecom infrastructure, this centralized facility is aimed at maximimizing the availability and utilization of hardware and software resources. All maintenance activities are also carried out by engineers at the center. Balamurugan is credited with the ideas underlying the concept and implementations of this facility. It serves the needs of all the academic departments and is also involved in satisfying the administration's computing requirements. Its staff of twelve are said to spend fifty percent of their time towards industrial consultancy projects. Its clientele includes the Department of Defense as well as small IT companies. The training programs offered by the computing center are said to be much sought after.

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2.9 University of Hyderabad

Visit to the University of Hyderabad's CS department was a pleasant surprise. The department is housed in a building called the AI lab, and true to its name, a large fraction of the department's faculty are very active in (collaborative) AI research. In fact, the department offers an M.Tech program in AI in addition to its regular M.Tech in CS.

My host, Uma, is one of only a handful of women CS researchers country-wide. Her research interests lie in multi-agent real-time AI systems. In a recently published work that just appeared in IEEE Expert, she and her colleagues, including Prof. BE Prasad, describe an expert system shell. The execution semantics and the knowledge base are captured using timed Petri nets, and using this the group, has been able to analyze interference freedom during multiple rule executions. The system is applied to a aerospace vehicle checkout application where it can advise operators with processed data.

P.S. Rao, whose interests lie in parallel architectures, is collaborating on the above project, specifically attempting to understand the issues related to mapping of the rules and the partitioning of the knowledge across multiple nodes. He is also studying communication along regular interconnection topologies.

Collaborating with Narayana Murthy, A.S. Reddy hypothesizes the use of a universal language with a universal class structured grammar to handle the problem of natural language processing. He has tried out some of his ideas, applying them to do English language processing, building a lexicon and a morphological analyzer. He envisages a natural language processing paradigm starting initially with processing based on syntax, then doing further localized analysis based on semantics, and finally involving pragmatics.

Agarwal's interests lie in computer vision and image processing. In particular, he has been using neural networks for recognizing cursor scripts, understanding the dollar amount in checks being a specific application domain.

K.C. Reddy's work has led to the development of an integrated computer architecture for intelligent actions. As part of this, he has developed a unified knowledge representation scheme with shallow, deep and solution knowledge bases. He has tried out his ideas on three domains: agriculture, trigonometry, and games.

Pujari has been involved for a number of years with computation vision problems, especially active view construction. He has shown how a perspective view can be constructed from multiple orthogonal views. His other interests lie in GIS and combinatorial algorithms.

This group of researchers keeps very close contacts with overseas colleagues. For instance, many have spent a year or two overseas with one faculty member currently abroad. Two, Uma and K.C. Reddy, are about to begin visits to France and Germany, respectively. While a majority of the interactions are with colleagues abroad, A.S. Reddy expects to host researchers from IIT Kanpur working on NLP. Overall, a very active and productive group and matching (and even surpassing) some of the first-tier research institutions, executing projects sponsored by many prestigious R&D organizations around the country.

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2.10 Anna University, Madras

The Guindy Engineering College goes back more than two hundred years, but its computer science program is only eight years old. Its Ph.D. production is just picking up, with five having completed and about a dozen currently enrolled.

Of special significance is that a large proportion of the faculty have interests in various aspects of neural networks. Not surprisingly, the school hosts the bi-annual Conference on Neural Networks. The recent one was held in March 1995. The department has two research grants, one from AICTE and another from the University Grants Commission (UGC), towards work on the applications of neural networks. With help from NRSA, a Ph.D. student is involved in the use of remote sensing data for rainfall prediction. NRSA helped in the collection of data and the subsequent validation of the prediction algorithms.

The director of the School of Computer Science, Prof. Ganapathym is one of the researchers devoted to neural nets and their applications for pattern recognition, computer vision, as well as image and speech processing. His other interests lie in fault tolerance and the algorithmic aspects of parallel processing. Prof. Mehta is another faculty member interested in neural networks, with additional interests in simulation and modeling.

Dr. Balasubramaniam applies knowledge-based approaches for pattern clustering. He works with both rule bases and Dempster-Shaffer techniques. He also uses neural networks for pattern classification and stereo motion analysis.

Dr. Krishnamoorthy uses graphics for visualizing Tamil characters and also to make it easier for introducing Tamil through games. He has come up with a keyboard – based on the analysis of compound characters in Tamil – with the goal of reducing the number of keystrokes needed for typing in Tamil. He feels that one has to approach the computerization in Tamil from first principles, that is, by examining the unique characteristics of Tamil, rather than view the problem as one of tailoring techniques developed for Hindi or English to suit the needs of Tamil.

Mr. Gopal, a lecturer in the department and also pursuing his Ph.D. under the guidance of Prof. Muthukrishnan of IIT Madras, has interests in operating systems for distributed computing environments. For his Ph.D. he has been working on a monitor-based model for designing servers in operating systems.

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2.11 Visweswarayya College Engineering (VRCE), Nagpur

VRCE is one of the Regional Engineering Colleges (RECs), located in Maharashtra state. The Department of Electronics and Computer Science and Engineering offers the Bachelor of Engineering (BE) degree in Electronics and in Computer Science. The BE program started only in 1987. An M.Tech program exists only in Electronics, with some CS courses offered as part of the curriculum.

M.Tech students do a six-month practical project. Most students spend the six months at industrial establishments and R&D organizations. Tata Institute for Fundamental Research (TIFR) and Bhabha Atomic Research Center (BARC) are two of the major research organizations frequently involved in such projects. This affords the students an opportunity to get practical experience and the host institutions also benefit since they get work done by enthusiastic students who quite often join the same companies where they did the project. Some of the projects were quite ambitious. I was given a report on a project involving novel uses of digital signal processing chips and another on natural language processing.

There are only four CS faculty members, just one of whom (my host) has a Ph.D. in CS (from IIT Madras). The department's computing facility includes a 68030-based machine (being replaced by an RS4000 machine), several PCs, and a 16-processor PARAM multiprocessor (from CDAC), a machine just being installed. Fortunately, VRCE is one of many second-tier institutions each of which has been given 1.4 crore rupees (almost half a million US dollars) to completely overhaul the computing and communication facilities. With these

funds, VRCE plans to install several workstation-based servers, PCs, network facilities, and a VSAT terminal for satellite hookup with ERNET.

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3 Government Sponsored Organizations

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 the Center for AI and Robotics Research (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. NCST carries out research in several areas of computer science and also has 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 Laboratory (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. Recent overhaul in the Indial telephony is due to Center for the Development of Telematics, (CDOT). Development activities take place at the Computer Maintenance Corporation (CMC) and Electronics Corporation of India Limited (ECIL).

3.1 Center for AI and Robotics (CAIR), Bangalore

CAIR 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 center offers its researchers time to pursue pure research in addition to working on specific project-related work.

Currently, basic and applied research at CAIR covers the following areas: Logic pro-

gramming, knowledge-based systems, neural networks, robotics, vision, control systems and learning theory.

Some of the projects being executed at CAIR are:

An expert system shell called nipuNa (meaning expert in Sanskrit), a hypertext-based system with an (X)windows interface for PCs and Sun workstations. It has been used for several applications including one for part identification for robotic applications.

The control systems group has been working on the multi-institution Light Combat Aircraft (LCA) Project. CAIR's focus is on the control laws governing the LCA's flight.

The robotics group has developed a gantry robot and supplied it to Hindustan Aeronautics Limited (HAL) for LCA's wing inspection. The group is also working on force control of robots, robot handwriting, and force sensors. Besides this, they have started work on virtual reality for teleoperation and mobile robotics, with vision and ultra-sonic integrated sensing and AI based path planning.

In addition to several theoretical studies of neural networks, a cellular neural network simulator is being developed for target recognition (recognition of smaller images in larger ones), and the correlation and matching of images with modal objects.

Another project seeks to use machine vision technology for object identification based on depth information. Towards this end, a parallel stereo algorithm has been developed and implemented.

Several efforts are in progress in the area of image analysis and rendering. One such project, in collaboration with NRSA, colors images based on their characteristics. The goal of another is to generate 3-D reference images from several 2-D scenes. A third deals with texture analysis.

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3.2 Center for the Development of Advanced Computation (CDAC), Pune

CDAC was launched in the late 80's to build GigaFlop range parallel computers in India. This was partly in response to the difficulties faced by India in procuring Cray-class computers for applications such as weather prediction. CDAC's first generation parallel machines used INMOS Transputer processors (T805's each claiming 4.25 MFlops). The top-end in this class used 256 processors and produced a sustained performances of up to 200 MFlops. It was used in a variety of scientific applications, including Computational fluid dynamics and simulation.

The task that CDAC has undertaken today involves the delivery of GigaFlop range paral-

lel computers built out of SUN's Sparc processors. The major focus is on the interconnection network. The ultimate goal is to build a network scalable to 2000 nodes using INMOS DS links. The resulting system would be driven by a home-grown operating system that is in conformance with OSF/Unix. A small version of the CDAC machine (called PARAM/9000) was unveiled at the First Workshop on Parallel Processing, held in Bangalore, in Dec 1994.

Several research projects within CDAC are in progress to capitalize on PARAM's power. One is a collaborative project with IIT Delhi on parallelizing the T80 weather code. Another is on parallel databases, attempting to provide support for storage management, caching, concurrency control, and recovery. One of the initial products of this latter effort is a replicated storage manager based on ISAM.

Based on discussions with (potential) users of the first generation PARAM machines, indicates that while CDAC may have gained considerable experience building parallel machines, customers have not been satisfied with the software that was packaged with the machine, both in terms of the range of support provided by them to develop parallel applications as well as in terms of the stability and reliability of the software. CDAC's switch to more general purpose processors (namely the SPARCs compared to Transputers) may have been prompted by such feedback.

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3.3 Center for the Development of Telematics, (CDOT), Delhi

CDOT started in 1984 as a research project aimed at the indigenous development of digital switching systems (telephone hardware and software). A brainchild of Dr. 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.

Starting with the development of 128-line PABX in 1985, CDOT has been able to produce 40K-line switches. The smaller switches, with up to 256 ports have been "ruggedized" to work reliably even in dusty rural areas where wide temperature fluctuations are the norm but no airconditioning is available. These small switches cater to more than 90% of Indian rural connectivity today. CDOT's rural switches have built-in diagnostics and redundancies and are remotely monitorable with no need for on-line operators. A recent addition to such a rural switch is a 10-channel UHF radio system that allows it to link with a public network, obviating the need for overhead lines or (the more expensive) underground cables. The cost-effectiveness is particularly prominent in hostile terrains such as in hilly areas and in calamitic situations such as earthquakes. Given these skills, CDOT's focus will continue to be to fill the rural telecom market needs (where it currently has a monopoly). In urban areas

its share is small, and is likely to remain small because of the entry of multinationals.

According to Dr. Bishnu D. Pradhan, today CDOT is embarking upon research and development efforts to provide ISDN, ATM, satellite communication, and Intelligent network capabilities. Another ambitious goal is to exploit its software engineering skills in the telecom area to start a "telecom software house".

According to Hiranmay Ghosh who heads the software engineering and quality assurance department, the challenges faced by software engineers arise from the fact that today the turnaround time for software is too long, the requirements are quite volatile, and finally, configuration management and testing as well as system integration are formidable tasks. His group has begun to use software automation to reduce human errors, and to adopt the process notion along with CASE tools to reduce lifecycle costs.

In order to solve some of its more research-oriented problems, CDOT already has 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 theoretical areas related to telecom. Of course, when all is said and done, the total telecom-related research budget will be miniscule compared to CDOT's overseas competitors.

India has a telephone density of about 0.78 per 100 people, one of the lowest in the world. However, in the metropolitan areas, the density is closer to 10 per 100 people. In view of this wide disparity, the government plans to connect all of India's more than half a million villages by the end of this century. This should give CDOT a large market. Of course, the present lenient policy towards privatization will allow others to enter the fray.

One of the key issues that Indian telematics researchers are dealing with is how to position themselves in the context of the onslaught of multinationals such as AT&T, Ericsson, and Alcatel. CDOT's view is that its switches are geared specifically for Indian conditions, CDOT's technology costs a lot less than imported technology, and that while equipment from overseas has more features than CDOT's, most of those features are irrelevant or unnecessary for India. Whether CDOT's view will prevail at the end is a big question mark. Also, how well CDOT is capable of gearing up to keep its equipment up-to-date and meet new needs in a timely fashion given the competitions' experience and size is unclear.

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3.4 Computer Maintenance Corporation (CMC), Hyderabad

CMC is a Department of Electronics controlled, self-sustaining, public sector undertaking. Conceived in 1976 as an organization designed to take over the maintenance of IBM machines upon the forced departure of IBM, today maintenance produces just 50% of CMC's revenues.

During its initial years, given the unavailability of IBM components needed to upgrade the machines CMC developed the necessary technologies to reengineer existing systems – enhancing the memory on the 1401s and the 360s, rewriting COBOL compilers to make use of this additional memory, and rewriting device drivers to marry peripherals and CPUs from a variety of sources, both in the east and in the west.

After this initial start, CMC ventured into less anachronistic areas. Most of CMC's expertise used to execute today's projects was gained from the UNDP-funded project Interact. Its goals were to promote technical education and develop know-how in emerging application areas such as meteorological image processing, real-time data acquisition, and railway freight management. Specific technologies included image processing and pattern recognition, real-time, and transaction processing,

All of these technologies came in handy when CMC started executing its two major projects in the 80's: the railway reservation system and the power distribution automation system. The former is highly appreciated by the common man, now having to wait in line for a very small fraction of what he had to endure prior to the automation of train reservation. Today, one can buy reserved train tickets between any two points connected by train at almost all train stations. The latter has allowed better utilization of the power available, the minimum capability needed to solve India's chronic power shortage.

Among the many varied projects CMC has worked on, notables include fingerprint identification systems, used today by the National Crime Record Bureau, New Delhi and the systems for marine container handling and ship-operating planning.

All offices of CMC in India are connected via INDONET, India's first commercial computer network.

The software group at CMC, as in other R&D institutions, is getting involved in the applications of multi-media, object orientation, visualization and user-friendly graphical user interfaces. Their initial effort in these areas has produced an office automation product called Officemate which provides support for document management and networking.

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Dr. Narasimhan is a doyen of Indian Computer Science Research, having been connected with it in various capacities since its formative years. After spending a large fraction of his career with the TIFR's National Center for Software Development and Computer Technolgy, he is currently a CMC fellow.

He continues to pursue his interests in natural language behavioural modeling and the evolutionary history of languages. He is one of the many researchers who expressed the problem of Indian researchers being unable to keep abreast of current literature.

Another long-term interest of Prof. Narasimhan has been IT policy issues vis a vis

developing countries. He phrases the question as "How IT can be deployed to serve the bulk of the population"? He remarks that "there is no systematic effort to break new ground" even though IT is more available now. In support of the increased access and use of IT he cites the use of graphics in Indian advertising and Computer-based design centers at the National Institute of Design, Ahmedabad, the National Institute of Fashion, Delhi, and the Central Leather Research Institute, Madras.

With regard to the current software boom in India, Dr. Narasimhan feels that very few software houses have the necessary capability "to do design and quality assurance". In his opinion, shared by many academic researchers, the country needs "technically-oriented leadership" in the ministries to harness the current potential in the IT area.

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3.5 Electronics Corporation of India Limited (ECIL), Hyderabad

ECIL's activities are partitioned across three groups: controls systems, computers and communication. The communication group is made up of switching and transmission groups.

The mainstay of the computer group today are 68030 and VME-bus based Unix boxes. Its customers include the Department of Atomic Energy, and Dept. of Space's SHAR center where it is used in telemetry applications. Boxes fitted with the Versados Real-Time Operating System are being used by BHEL in the power industry.

In the communication area, ECIL is one of the licencees of CDOT technologies and so its staff is always looking to see how the latest technologies can be used to build functional units for communication. One of the products of the communications group is an operators maintenance computer to obtain data about calls, etc.

If ECIL's experience 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.

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3.6 Indian Statistical Institute (ISI), Calcutta

A computer scientist would easily be misled, from ISI's name, into believing that little, if any, CS research is likely to be in progress at ISI. On the contrary, research of a high caliber goes on at the ISI premises in Calcutta. In fact, the first indigenous digital computer – fabricated using discrete transistor units – was commissioned in 1966 in collaboration with Jadavpur University. In the mid-70's ISI's staff had developed microprogrammed chips for FFTs with fault diagnosis capabilities. They experimented with graph-theoretic algorithms, system level diagnosis, and fault-tolerant computing.

Researchers in the Electronics Unit have been working in the areas of logic synthesis, testing and design for testability of VLSI circuits, physical design, applied graph theory, computational geometry, parallel algorithms and architectures, and network topology. The VLSI design group is well-known for its work on floorplan optimization, inherent nonslicibility and canonical embedding of rectangular duals, parity and syndrome testing, studies in redundancy and testable designs of sequential circuits, circuit partitioning and routing. A significant amount of research has also been done in designing new network topologies (e.g., multi-mesh and fractal graphs), and implementing parallel algorithms. In the area of multistage interconnection networks, the group has developed a new concept called bit-permute closure sets that characterizes conflict graphs and has applications to routing. The VLSI design group is led by B. B. Bhattacharya and the parallel processing group by B. P. Sinha. The other members are J. Dattagupta, N. Das, K. Mukhopadhyaya, S. Sur-Kolay, R. K. Das, D. Das, S. C. Nandy, S. Sengupta, M. Ghosh, D. K. Das and M. K. Chakraborti.

Aditya Bagchi, the head of the computer and statistical service center, works on database related problems, including dynamic federated databases and statistical database models. An interesting practical problem, posed by the department of archeology, requires the development of an object base to store objects with a large number of features, not all of which can be specified at design time. Also, the objects are difficult to classify a priori. Bagchi is trying to connect this problem with fuzzy logic in order to come up with a solution.

The Machine Intelligence Unit, designated as a center of Excellence, started its work with statistical techniques for pattern recognition and image processing then approached the problem by applying fuzzy logic. In the process, work began on neuro-fuzzy systems which combines fuzzy logics with neural networks. Sankar K. Pal, a senior member of this group, currently working as a Jawaharlal Nehru Fellow, is considered to be a pioneer in this area, internationally. The other members of the group are N. R. Pal, S. Mitra, J. Basak, C. A. Murthy, S. N. Biswas, A. Ghosh, D. P. Mandal and M. K. Kundu. New connectionist models and systems are developed for object recognition problems. The power of genetic algorithms is also being combined for solving many of the application driven problems in

computer vision, pattern recognition, and image processing. More recently, fractals have been put to work to segment and code images. A substantial portion of this group's funds comes from external sources, such as the Ministry of Defense – for satellite image processing, the Council for Scientific and Industrial Research – for forensic applications, and the Nehru Memorial Fund – for projects demonstrating the need to combine the three techniques.

The Electronics and Communication sciences group does research on the synthesis and recognition of speech and music. An interesting problem they are attempting to solve involves "visual speech" – from the lip movements of a speaker, how can we determine what is being spoken? Also, with funding from NRSA, the group is looking at ground and satellite based remote sensing to understand wave propagation and atmospheric dynamics in altitudes of up to one kilometer.

Finally, in conjunction with the statistical and mathematical division, CS researchers also work on applied statistical research involving cryptology and the applications of cellular automata.

Funding for ISI comes mostly from the department of statistics of the Ministry of Planning.

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3.7 Indian Space Research Organization (ISRO)

The corporate headquarters of the Indian Space Research Organization (ISRO) is located in Bangalore, but, activities related to satellites, launch vehicles, and applications are carried out at numerous centers throughout the country. The development of the sensors and payloads is the responsibility of ISRO's Satellite Application Center (SAC) in Ahmedabad. ISRO Satellite Center (ISAC) in Bangalore is responsible for the design, development, assembly, and testing of satellites. Vikram Sarabhai Space Center (VSSC), at Tiruvananthapuram, is responsible for launch vehicles. Liquid propulsion modules, including cryogenic engines, are developed at the Liquid Propulsion Systems Center located near Tiruvananthapuram. Satellite launching takes place from Sriharikota, north of Madras, referred to as SHAR. Hassan, near Bangalore, is where the Master Control facilities for satellite station keeping are located. The reception and processing facilities for remote sensing data are available at National Remote Sensing Agency (NRSA), in Hyderabad.

On my trips, I visited ISAC, VSSC, and NRSA.

ISRO Satellite Center (ISAC), Bangalore

The reliability and successful operations of many indigenous satellites have placed India in a strong position to achieve her communication, remote sensing, meteorological, and

television broadcast needs using her own satellites.

ISAC's first satellite, Aryabhata, proved India's satellite building capabilities. Simple in global terms, it contained a small scientific payload for conducting X-ray astronomy, solar physics and aeronomy. In April 1975, it was placed in near-earth orbit by a Soviet rocket. Showing continued success, ISAC built Bhaskara, Apple and Rohini series of satellites. These were experimental earth observation and communication satellites, to serve as proofs of concepts.

India's entry into operational era began in 1983 with the INSAT satellites built overseas. However, the second generation multipurpose geostationary satellites (for telecom, TV broadcast, and meteorological applications) have been developed by ISAC. While for now these are being launched by Ariane, the European launch vehicle, with India's own GSLV class launch vehicles – capable of placing these satellites in the required geo-stationary orbit – on the anvil, India expects to be self-sufficient not only in its satellite building capabilities but also in its launch capabilities.

Parallel with the INSAT activity, the Indian Space effort has achieved self-reliance in remote sensing, having built a series of operational Remote Sensing satellites, starting with the IRS-1 class satellites, launched by the Soviet Union in March 1988. With the most recent launch of the PSLV which placed the latest IRS satellite in polar sun-synchronous orbit on October 15 1994, India has rounded off its satellite building with launching capabilities.

Vikram Sarabhai Space Center (VSSC), Tiruvananthapuram

VSSC is responsible for the whole gamut of issues involved in launch vehicle development. Its scientists and engineers have several success stories of which to boast. From humble beginnings, starting with the early days of sounding rockets, its most recent success story is the Polar Satellite Launch Vehicle (PSLV) which placed the indigenous 1000 KG class Indian Remote Sensing satellite IRS-P2 in orbit on October 15, 1994. PSLV's successor is the GSLV, with the G standing for Geosynchronous. It will be capable of launching 2500 KG class communication satellites in geosynchronous orbit.

Located on the magnetic equator and hence strategically poised for scientists to conduct atmospheric research, the Thumba Equatorial Rocket Launch Station at the VSSC Complex has been dedicated to the UN for research on atmospheric sciences.

My host, Narayanan, heads the software quality assurance group. It was established when it was determined that the failure of the first launch of the PSLV in September 1993, during its transition from the second to the third stage, was due to a software error. His group uses a combination of formal methods, methodical documentation, testing, and simulation to ensure the quality of the code produced. They have been able to use formal methods, especially VDM (Vienna Development Method), for the specification of certain key subsystems. Formal verification is yet to be tried; but, according to Narayanan, even the attempt to carefully specify important behavioral properties has produced useful dividends. In one case, it revealed that the software had not accounted for the occurrence of a particular state of the system.

The flight computer group, headed by D. Basu, is responsible for the design and development of the hardware and software for all the subsystems on board the launch vehicle. This consists of the guidance, navigation and control computers. Navigation related activities are

executed on a single 68000 processor, while guidance and control activities are executed on another. A duplicate pair of 68000's execute in active redundant mode where the machines are cross-connected for maximum reliability. Thus, as long as one of the navigation processors and one of the guidance/control processors is alive, the mission will be successful. Within the navigation computer, attidute (angular) inputs and processing are carried out at 20 msec frequency while acceleration, velocity and position related processing takes place every 500 msecs. Within the guidance/control processor, guidance related activities take place every 500 msecs while control is exercised every 20 msecs. Because of these simple temporal relationships, a static table-driven scheduling approach is used for these computations.

The 68000s are being stressed to their limits by the current computations, and hence, there is a move to build the next generation avionics based on faster processors that have since entered the market.

Real-time computations also occur during pre-launch integration and check-out. Each of the four stages of the vehicle can be checked out independently by an automated time-driven launch sequence program. Mechanical and electrical interfaces are checked out against expected chain of signals and states. This is done via stimulus-response checks as well as surveillance. At T-30 seconds, the four on-board computers move to flight mode at which point they themselves begin to poll for sensor data.

Soon after liftoff, telemetry data, including those emanating from each of the on-board computers, is displayed in real-time on experts' consoles. Range safety checks are carried out to ensure that the health and trajectory of the launch vehicle are within the safe operating range. In the most recent launch, advice from an AI expert system developed at IIT Madras was also available during this checking.

I was truly impressed by the number of highly interrelated disciplines, subsystems, engineers, and scientists that must come together to ensure the successfull launch of a 1000 KG satellite – with the satellite being launched at the end of a mere 1200 sec journey. While many more successful launches are needed to have unswerving confidence in VSSC's launch capabilities, all leading indicators are pointing in the right direction. I believe that the recent textbook-perfect PSLV launch and the enterprising team of VSSC scientists and engineers involved in this effort are two such indicators.

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3.8 National Remote Sensing Agency (NRSA), Hyderabad

NRSA is a Department of Space sponsored organization devoted to the acquisition, processing, and dissemination of remote sensing data. Data is acquired primarily via India's own IRS 1-A and 1B, as well as satellites belonging to other countries, such as USA's Landsat. Whereas the reception and processing facilities are available at NRSA, the development of

the sensors and the payloads are developed at ISRO's Satellite Application Center (SAC).

NRSA's scientists are responsible for the corrections to raw data, for example compensating for geometric errors and for errors due to earth's rotation. Further processing is then done to classify and enhance the quality of the data. Some of the work done in image processing, edge and contour detection, surface construction, and compression utilize sophisticated technologies, most of which have been developed in-house.

NRSA's data is used by a number of agencies of the Government of India in the areas of ground water targeting, flood mapping and damage assessment, soil mapping, watershed management, crop estimation, ocean studies, etc., to name just a few. The utility of remote sensing data to a developing country like India has been highly appreciated by policy planners. Many agencies, public as well as private, seek NRSA's help for the acquisition and processing of needed data. An integrated mission for sustainable development has begun to chart out all the details pertaining (to start with) to 136 districts, with the help of NRSA data. The goal is to develop a comprehensive Geographical Information System (GIS) about these districts and subsequently increase the coverage to the rest of India. While most of the data is acquired from satellites, aerial cameras aboard aircrafts are also deployed. Given these multidisciplinary activities, NRSA boasts of application specialists in a wide variety of areas under one roof.

Another activity of NRSA involves the training of a variety of people, from scientists to decision makers, on the use and interpretation of remote sensing. Training is imparted at the Indian Institute for Remote Sensing at Dehradun as well as at various ISRO establishments and educational institutions. The success of the training program is evident from the fact that the syllabus developed by NRSA is being adopted globally.

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3.9 National Aerospace Laboratories (NAL), Bangalore

NAL is one of the government Laboratories which is deeply involved in the Light Combat Aircraft (LCA) project of India's Department of Defense.

Dr. Pedar and his colleagues are involved in safety and reliability analysis, through both mathematical analysis and simulation. They work on detailed subsystems-level analysis as well as complete system-level analysis.

One of the issues they are grappling with has to do with hardware/software interaction and system level software reliability models. To date, even though many software recovery techniques have been developed and their reliability properties are known at the level of individual techniques, models for determining software reliability at the system level are not known.

Worthy of mention here is that the LCA project uses a "safe subset" of Ada to develop

its software. Because of this, Pedar's group is also studying the "stress" testing of software.

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3.10 National Center for Software Technology, NCST

NCST can be described as a successor of the erstwhile National Center for Software Development and Computer Technology (NCSDCT) which was a component of TIFR. In fact, many of the senior staff including the current Director of NCST Dr. Ramani, were associated with NCSDCT. NCSDCT was one of the first labs in the world to have developed and used a CSP compiler.

NCST was set up in 1985-86 in Bombay. In 1992, another center was started in Bangalore. NCST devotes 25% of its efforts towards education and training and 50% towards applied research. The remaining 25% goes towards technology transfer which is accomplished through an industrial affiliates program in which there are currently 75 members. Close to two-thirds of its funds come out of its education and technology transfer activities, the remaining funds being provided by the government.

NCST is the international gateway to the rest of the world for India's ERNET. The experience gained from the design, development and implementation of the 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 is also being set up along similar lines, with technical support from NCST.

Major applied research efforts are on in Graphics/CAD systems and knowledge based systems.

According to Gopalaswamy, the graphics group's activities can be placed in three categories. The first involves the design, development and integration of tools for computer aided design (CAD). X/motif is used to achieve the integration between tools to produce a system for modeling and rendering 3D surface geometry. It has been put to use for 3D volume-grid generation in the context of an aircraft design project. The second activity is in the area of electronic publishing - for Indian languages. This activity involves (1) font design with Bezier curves - in conjunction with IIT Bombay and the Indira Gandhi National Centre for the Arts and (2) development of document preparation systems. In other related work, NCST researchers are also investigating issues in image processing and computational geometry with the goal of developing an image processing platform. They are also developing a multimedia "talk" facility over a network of workstations.

NCST is one of the nodal centers for the KBCS project. Sasikumar, a member of this project, explained that Intelligent Tutoring Systems, Expert System Shell development, and

Natural Language Understanding are the center's main activities.

1) The Intelligent Tutoring System for Hindi is called Vidya (meaning "education", in Sanskrit). It comes with a generative testing system called Veda ("knowledge") whose front-end is called Vyasa (believed to be the author of the Hindu epic Mahabharatha). The tutoring system is a remedial system, aimed at enhancing a student's performance. A tutoring system for mathematics has also been developed.

2) More than 300 copies of Vidwan, NCST's expert system shell product, are in use all over India.

3) The natural language understanding effort combines information retrieval techniques with machine-assisted English to Hindi translation. The domain chosen for this work is automatic news categorization, archival, and retrieval. Context-based search is provided rather than keyword-based search. Learning-based approaches are used for this categorization. A product from this group, called ReQuest, is targeted at journal abstract search. A Marathi (the lingua franca of the state of Maharashtra whose capital is Bombay) version of this product is being used in the state for locating documents. NCST is developing a machine translation prototype for translating English news stories into Hindi. Machine-assisted translation is carried out in four stages: The text is automatically simplified by a process which breaks up long sentences using heuristics. Then a bottom-up morphological and syntactic analysis is carried out. The content is then captured in a knowledge-representation scheme. Finally, a synthesis phase expresses the content in Hindi sentences in the Devanagari script.

Heuristic scheduling systems created by NCST have also been used for resource scheduling in the transportation arena. Oil tanker scheduling, airline scheduling and pipeline scheduling are some of the applications created by the Knowledge Based Systems Group.

In the database area, NCST has been working with object-oriented database systems and developing office information systems.

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3.11 National Informatics Center (NIC)

National Informatics Center (NIC), New Delhi

National Informatics Center is a government organization set up in 1975 to bring the benefits of information technology and networking to help a nation, most of whose people live in the villages. Towards this end, NIC developed the NICNET, a satellite-based computer communication network with over 650 nodes connecting the nation's capital, the capitals of the states and the headquarters of the over 500 districts. These nodes are linked to the master node in Delhi through VSAT (Very Small Aperture Terminals) antennas 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. During natural calamities, such as India's notorious cyclones, NICNET has helped connect affected areas. Using information collected through its network, NIC has developed large databases containing data on argriculture, transportation, manpower, and health, to name a few. Thus, NIC serves as an information provider to more than fifty ministries in the central as well as state governments for planning and forcasting, just to name a few uses. NIC is also charged with the collection and analysis India's population census and (more recently) in handling the complex task of managing India's general elections. Through these activities, NIC's staff have built up considerable expertise in the areas of databases, networking, modeling and analysis, as well as expert systems. The staff is also entrusted with the job of training central government staff about the capabilities of computers.

NICNET is also used by several public enterprises such as Steel Authority of India, Fertilizer Corporation of India, and Food Coorporation of India, to network their sites.

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National Informatics Center, Hyderabad

The Hyderabad center of NIC oversees NIC's operations in the southern region. GISTNIC, a large public database providing information of general interest to the "common man" was designed and developed at this center. Whereas NICnet allowed for two-way communication between two government bodies, GISTNIC extends its scope so as to benefit the general public. It is a (currently) centralized repository of information on a variety of subjects including tourism, the economy, and education. GISTNIC contains only static and quasi-static information (covering changes occurring at most once in a month, for example in economics-related data). Thus, highly dynamic data, such as stock prices, are not included. The database is accessible from GISTNIC terminals provided in many central locations, including tourism bureaus in most cities. These terminals are connected through NICnet to the central database.

Out of his own personal interest, Prabhu has also been working on gathering information from various sources on indigenous medicines, trades, sciences, and technologies and this information is also available over GISTNIC.

Using the sutras (rules) defining Sanskrit grammar, Prabhu has also been involved in developing translators from Hindi to Telugu, the language spoken in Andhra Pradesh. Another project is to use a restricted form of natural language for modeling frame-based knowledge implementations. Some of the details underlying these ideas are worked out by Masters' students working on their projects at local CS departments.

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3.12 Tata Institute for Fundamental Research (TIFR), Bombay

TIFR is an autonomous institute devoted to the pursuit of basic and applied research. It is a research and development organization under the Department of Atomic Energy.

CS research at TIFR is conducted by the theoretical computer science group and the Computer Systems and Communications Group.

The research interests of Shyamsundar, a member of the theory group, lie in the design, programming, and verification of hybrid real-time systems. To this end, he has developed the language called Communicating Reactive Processes (CRP), an extension of Esterel and CSP designed to capture reactive behaviors in systems which have both synchronous and asynchronous components. It can be used to program dynamic real-time systems. An implementation of CRP is in progress. He is also studying the properties of an input-buffered version of CSP. In the area of logic programming, he has been investigating the termination of parallel logic programs using term rewriting techniques.

The rest of the theory group at TIFR, whose regular members, besides Shyamsundar, are Subramanian, Ghosh, Pandya, Radhakrishnan and Pradhan, is seeking solutions for problems involving computational geometry, combinatorial optimization, wait-free synchronization of read/write variables, semantics of concurrency, variations of Temporal Logic, such as interval temporal logic, and category theory.

TIFR is one of the nodal centers of the KBCS project. The focus of the TIFR work has been on natural language processing, in particular, speech synthesis and recognition. The speech synthesis system, can generate arbitrary utterances where an utterance consists of an arbitrary sequence of phonemes (from a repertoire of 58). The system has been demonstrated in the context of a railway reservation inquiry application. A 200-word vocabulary from the same domain has been used to evaluate the solutions developed for speech recognition. The speech recognition work uses higher level language properties to improve performance. Two different design philosophies have been tested. One integrates speech knowledge with statistical techniques. Another is based on the statistical method of Hidden Markov Modeling. The group has also been investigating the use of connectionist architectures for the classification of spoken sounds.

In addition to the major efforts mentioned above, TIFR's CS researchers are also working on parallel processing and high-speed networking.

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4 Private Organizations

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.

4.1 SPIC Science Foundation (SSF), Madras

Computer scientists at the SPIC Science Foundation are part of the Foundation's School of Mathematics whose goal is to conduct research in pure mathematics and theoretical computer science. The school, which was created in 1989, has a small Ph.D. program, joint with the Birla Institute of Technology and Science (BITS), Pilani. A total of nine Ph.Ds are currently enrolled with the school.

The Computer scientists pursue research in the areas of theory of distributed computing, complexity theory and combinatorial optimization. Thiagarajan, who received his Ph.D. from Rice University, Houston and had spent several years at GMD, St.Augustin, Germany working in C.A.Petri's group and subsequently taught at Aarhus University, Denmark, is the senior-most researcher in computer science. He works on models and logics for distributed computing. Madhavan Mukund, who obtained his Ph.D. from Aarhus, has interests in the use of logics for specifying and verifying concurrent systems. He also works on partial order based models for concurrent systems. Another member of the CS research group is Manindra Agrawal whose research is in complexity theory. He got his Ph.D. from IIT Kanpur. The fourth member of the group is K.V. Subramaniam whose research interests are Complexity theory and Combinatorial Optimization. He did his Ph.D. work at the Tata Institute of Fundamental Research, Bombay.

Recent results of this group include (1) an extension of linear time temporal logic to Mazurkiewicz traces, (2) the formulation and solving of a gossip problem in an asynchronous framework with a number of logical applications in an automata-theoretic setting, (3) a syntactic characterization of a subset of propositional temporal logic formulas that can be verified efficiently using partial order based techniques, and (4) a protocol for the dynamic maintenance of information about the state of a message-passing system.

These researchers at SSF have close collaboration with CS researchers at the Institute for Mathematical Sciences (MatScience) which is also located in Madras.

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4.2 Tata Consultancy Services (TCS), Madras

TCS is the largest software house in India with most of its customers being overseas. It has offices in all major metropolitan areas with Bombay and Madras having offices with over one thousand employees.

While almost all its activities have tight deadlines and hence there is little scope for seeking optimality in performance or functionality, and hence little scope for research, it prides itself in keeping its personnel up-to-date though a highly regarded continuous education program. This is also aimed at familiarizing its staff with emerging technologies. Because of this, even though re-engineering projects – migrating existing software from one linguistic/hardware platform to another – continue to be the bread and butter of TCS, current projects involve the latest in multi-media to advanced transaction processing. The payoffs from TCS's approach became clear when one of its software reengineering efforts, executed for a British client, Sun Life Assurance Society in Bristol, recently won the "top-nine software" award from the British Computer Society.

The philosophy in the mid 80's was to have each center specialize in software for a particular platform. The current thinking, in light of the proliferation of vendors and the prevalence of heterogeneity and distribution, is to allow each location to be more diversified according to the needs of the clients of each center.

Most of the TCS locations are connected via leased 64K lines. Some of the locations are also directly connected with clients. For example, the TCS office in Madras is involved in the on-line maintenance of Shell Oil's systems in Houston. To achieve this, TCS has staff in Madras interacting with Houston through direct lines.

Mukherjee and Padmanabhan are among a small number of TCS personnel who have research within their charter. Both are interested in databases, a component of a large proportion of TCS's software. Client-server architectures, application of object-oriented databases, distribution and heterogeneous databases, and database reconfiguration and data fragmenta-

tion are some of the issues for which high-performance solutions are sought by their research.

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4.3 Tata Research, Development, and Design Center (TRDDC), Pune

Tata Research, Design and Development Center (TRDDC) started in 1981 as an experiment to show that "research pays back", and time and again one hears or reads about its motto as described by J.R.D. Tata's vision: to bring "the benefits of existing knowledge to our industry and our people". It was founded by Dr. Subba Rao who is its current Executive Director. Today, TRDDC is geared up to "result-oriented research" to meet the needs of 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, DoD, and other government organizations.

Two groups at TRDDC are involved in CS related research: software technology and process modeling and simulation.

Prof. Kesahav Nori (who used to be at TIFR, Bombay, had a brief stint at ETH, Zurich, and also spent two years at CMU) heads the Software Technology group. His group's mandate is to conduct in-house R&D relevant to TCS and its clients.

Nori's research lies in developing "generative approaches to programming". Compiler compilers, and parameterized compilers are some of the forms this approach takes. Given that in the 80's TCS's clientele was mainly involved in banking, the original goal was to develop banking applications generators. But this did not take off. Fortuitously, since many of the software projects of TCS involved re-engineering and retargeting existing applications, Nori's group has produced tools for automated translators from one platform or programming language to another. Since 1985, the tools produced have helped achieve almost 100% automated translation. Given that even today, re-targeting and re-engineering earns a substantial portion of TCS's revenues, this is an important success story for Nori's early efforts. Equally important, such projects are not intellectually stimulating because of their routine and dull nature and so the tools' help in such projects is especially appreciated.

Nori's group is currently involved in a whole gamut of issues related to the software development process, with focus on software quality and correctness, and their relation to human effort. Towards this end, they are attempting to understand the principles underlying the architecture, design, construction and maintenance of software, by viewing system design along the lines of computer hardware engineering principles. Based on the belief that "doing engineering in no way forsakes (the use of) formal methods" he and his colleagues are persuing

ways by which to assert-by-design the correctness, performance, and reliability profiles of software.

Within this global viewpoint, the software group's projects are designed relative to the roles played for TCS by TRDDC. Thus, the collaboration between TCS and TRDDC spans the spectrum from strategic planning to joint execution efforts. Mostly, as in the past, the interactions involve the identification as well as development of tools and techniques that can have an impact on the productivity of TCS's software engineering operations in the large. Because of this, the results of TRDDC's research efforts have by far been much more visible on a practical scale but much less on a research scale.

A group that derives substantial support from the software group is the process modelling group headed by Dr. Biswajit Basu. It has been involved in process modeling and simulation since 1984.

The use of modeling in Indian industry is not significant. TRDDC's process modeling group has been trying to educate the industries, especially, metallurgy and materials processing industries, about the efficacy and importance of modeling in tackling problems related to energy consumption, quality, reliability and productivity. It helps identify processes and approaches through visits to plants, and then offers solutions. One of the biggest customers of this group is the Tata Steel Company.

This group's activities are multidisciplinary, involving people with a variety of backgrounds, including computer science. Academics are also used in the projects, especially to critique solutions developed at TRDDC. They are also involved in developing tailored and packaged courses for industry with the help of academics. For example, Prof. Gautam Shroff of IIT Delhi has been interacting with TRDDC to develop and teach courses on distributed computing. One of the ongoing collaborative projects is on the distribution and parallelization of simulation.

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4.4 Persistent Systems Private Limited (PSPL), Pune

Persistent Systems Private Limited (PSPL) is a relatively small (employing twenty-five professionals) software development company located in Poona, an emerging center for high-tech establishments. PSPL is an exemplar of an opportunistic enterprise, one which capitalizes on the high-caliber manpower available in India for sophisticated software development, and one which utilizes the facilities provided by the Software Technology Park (STP) in Pune. Because of its operations under the STP, PSPL has access to high-speed data communication links as well as streamlined export/import procedures.

PSPL was established just a few years ago by Anand Deshpande after his brief stint with

HP following his graduate studies at Indiana University. Since then, he has managed to set up a company with broad-based expertise covering the overlapping areas of databases, communication, operating system, compilers, and graphical interfaces. The array of computing and operating system platforms that his staff works with is impressive. So is his multinational clientele, which in early 1995 included Microsoft and HP Labs, as well as database companies such as Illustra Information Technologies, Versant, and O2 Technology (France). The projects range from porting and re-engineering to the complete development of software.

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5 Infrastructure

This section provides a summary of (1) ERNET that has come to be the mainstay of communication for researchers in computer science as well as other fields and (2) Software Technology Parks that small and emerging enterprises involved in software and hardware development, mainly targeted at exports, have come to rely upon.

5.1 Educational and Research Network (ERNET)

ERNET is a national network spanning research and educational institutions throughout India. Eight nodes form its backbone – the five IITs, the Indian Institute of Science, NCST (Bombay), and the Department of Electronics. Funding for establishing the ERNET was provided by the United Nations Development Program (UNDP) with matching funds from the Indian Government's Department of Electronics. What began as an experimental project has now become an integral part of the research process for researchers in sciences and engineering.

ERNET supports ISO and TCP protocols with IP level routers. Both SMTP and X.400 architectures are supported. The eight nodes on the backbone star network have email, ftp, and telnet facilities. The remaining nodes currently have email facility only. According to Dr. Ramani of NCST, Bombay, ERNET today has been able to connect approximately 300 campuses and an estimated 30000 users. 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.

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 for communicating with Bombay.

Ernet is attempting to form a society made up of user communities with DST, CSIR and other major consumers making significant contributions.

NICnet holds all the government-related data. Unfortunately, there is no direct link between NICnet and ERNET. Hence, much of this data is inaccessible to ERNET users.

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5.2 Software Technology Parks (STP)

Software Technology Parks have become ubiquitous in India and are located throughout the country, in most states. These are government (more precisely, Department of Electronics) sponsored schemes to promote software exports, perhaps the fastest growing exports from India. Though called parks, they are housed in multi-storied buildings which provides 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 Park attractive for entrepreuners and start-ups is that the Park itself provides facilities essential to establish an office, 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 beaureucratic 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. 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. Information about the STPs is available on the World Wide Web at URL: http://www.stph.net/

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