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Computer Science Research in India: A Scientometric Analysis of Research Output During the Period 1994-2001

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Abstract

Computer science is of central importance to India for its impact on the national economy and society at large, and its role in shaping India as a technology superpower. This paper analyses the status of computer science research in India in terms of publication output, its areas of strength and weakness, and the leading institutions and individual scholars involved in computer science research in the country.

1. INTRODUCTION

Over the years, India has emerged as a major information technology (IT) force in the world. There is a strong national, political, and administrative commitment to IT as a priority sector. Realizing the special importance of IT, the Prime Minister of India gave a call to make India an IT superpower in the world within next ten years. As an initiating step in this regard, a high-powered National Task Force on Information Technology and Software Development was set up by the Prime Minister's Office on May 22, 1998, under the Chairmanship of the Deputy Chairman of Planning Commission. This taskforce formulated the draft National Informatics Policy. It addressed several different issues such as national information infrastructure, IT driven governance, IT education especially at college and secondary school level, information content on internet, laws and regulations for cyberspace, IT research & development, and IT manpower development, etc. The taskforce had set a vision of software export of around US$50 billion by 2008 from the level of US$1.75 billion during 1997-98.[1]

Computer revolution in India, which made modest beginnings with Homi Bhabha in TIFR in the 50's, took firm roots after the 60's with institutions like IIT Kanpur starting undergraduate and postgraduate programme in computer science.[2] Since then, India has come to establish a strong infrastructure both for teaching and research in computer science. The number of colleges and university departments teaching computer science at the graduate, post-graduate level and Ph.D. level is fast increasing. At present, India is producing 60,000 computer professionals through formal mode of computer education such as B.Tech/M.Tech/ MCA, etc. Over the years a massive system of non-formal education in computers has since emerged in the private sector, with institutions like NIIT, APTEC, taking the lead. India needs to considerably enhance the production of skilled manpower in the field of IT to develop capabilities to achieve the target of US$50 billion towards software exports. For this purpose, around one million professionals have to be produced in India in the next few years in this area.[1] The graduate and postgraduate students from India's educational institutions are fast getting

absorbed in the industrial sector on high salaries and are also sought after in US and Europe. A large number of Indian students are also going abroad for higher studies and to get absorbed in different countries after completing their studies in this area.[3]

A large number of institutes and firms from academic sector, R&D sector, government sector and private sector are involved in computer science research with support of government funds. These organisations are involved in a wide breadth of research problems under all major areas of computer science. These include topics such as: multi-media, workflow automation, virtual reality, and hardware-software co-design. Most of the research problems tackled are of current interest globally. Some of the research efforts have even attracted international attention, including work on neuro-fuzzy systems, machine learning, genetic and neural algorithms, the modeling and control of flexible systems, speech synthesis, databases and complex theory. [3-4]

Besides spending a considerable amount of money on infrastructure development and R&D activities on their own, these organisations are also getting enormous funds by way of extramural support from several government R&D agencies, including Ministry of Information Technology (MOIT), Department of Electronics (DoE), Defence Research & Development Organisation (DRDO), Department of Atomic Energy (DAE), Department of Space (DoS), All India Council of Technical Education (AICTE), Ministry of Human Resource Development and University Grants Commission (UGC).

Indian computer industry has seen a tremendous growth during the last 10 years. A large number of Indian firms have established IT services and have been involved in R&D work and are contributing substantially to national GDP. The three big IT companies in India, which started their businesses in the 60's and 70's, are Tata Consultancy Service, Infosys and Wipro. The exit of IBM in the 70's had indeed provided a challenge to the Indian IT industry and the industry did rise to the occasion. MNC's are also looking to India in a big way, and are making huge investments to set up R&D centres in the country. A lot of them are carrying out a significant proportion of their R&D work in India, and hence contributing to overall growth and success. The big global IT companies such as Oracle, IBM, SAP, Philips, Texas Instruments, etc., have already established their development centres in India. Some of them are even collaborating with academic institutions in India for education and research. [5]

Evidently, computer science is of central importance to India for its role and impact on the national economy and society at large, and in giving India a leading edge in emerging as a technology superpower. The national IT policy and funding support at governmental level in this area should help catalyze computer science manpower of high caliber for research in the country. This paper presents the status of computer science research in India in terms of publications output, its areas of strength and weakness, and the leading institutions and individual scholars involved in computer science research in the country. Amongst the earlier studies in this area, Das and Kranjai[6] conducted a study based on 1408 papers published by Indian scientists in international journals on computer sciences from 1991 to 2000, using *Science Citation Index (SCI)* as a base. This study was restricted to only developing a rank list of organisations conducting research and contributing research papers in this area.

2. DATA SOURCE

Data on publications in computer science from India pertaining to the period 1994-2001 were downloaded from the INSPEC database. It is the most comprehensive and leading bibliographic database providing access to the world's scientific and technical literature in physics, electrical engineering, electronics, communications, control engineering, computers and computing, and information technology. The Institute of Electrical & Electronics Engineers (IEE) scans over 3500 national and international S&T journals and some 1500 conference proceedings/seminars, and numerous other

publications each year for inclusion in its database. This database now contains over seven million bibliographic records and is growing at the rate of 350,000 records per year.

The 'Computer and Control' Section under the INSPEC database has seven main fields and 23 subfields. The main fields (along with the subfields) are:

(a) General and management topics (General control topics, general computer topics, and management topics)

(b) Systems and control theory (Mathematical techniques, systems theory and cybernetics, and control theory)

(c) Control technology (Control and measurement of specific variables, control equipment and instrumentation, and control applications)

(d) Numerical analysis & theoretical computer topics (Numerical analysis and computer theory)

(e) Computer hardware (Circuits and devices, logic design and digital techniques, computer storage equipment and techniques, analogue and digital computers & systems, Computer peripheral equipment, and data communication equipment & techniques)

(f) Computer software (Software techniques and systems)

(g) Computer applications (Business & administration, information science & documentation, natural sciences computing, engineering computing, and other computer applications).

The study quantified the impact of research in computer science in terms of three indices:

(i) Percentage share of country output in SCI-covered journals,

(ii) Percentage share of papers in high impact journals (IF = 1.5 or more) and low impact journals (IF = 0.5 or less), and

(iii) The average impact per paper.

3. RESULTS

3.1 Publication Dynamics and Communication Pattern

The research output, as reflected in INSPEC-database, revealed that Indian scholars published 4690 papers in computer science during 1994 to 2001. Of these, 3143 papers (67%) had appeared in journals and the rest 1547 (33%) in conference/seminar proceedings. Of the journal papers, 2028 (64.5%) were published in Journal Citation Report (JCR)-covered journals, and the remaining 1115 (35.5%), a significantly high share, in non-JCR covered journals. Given the high level of investment in the R & D in the IT sector in India over the years, a high rise in research publications in this area is natural expectation. But the increase registered was only marginal from 2299 papers during 1993-97 to 2391 publications during 1998-2001.

The 3143 papers in computer science had appeared in 575 scholarly journals originating from 24 countries. Of these, 2311 papers (73.5%) were in 524 foreign journals and the rest 832 papers (26.5%) in 51 Indian journals. Amongst papers in foreign journals, the largest share (808 papers) had appeared in 155 UK journals, followed by 676 papers in 187 US journals, 463 papers in 89 Netherlands journals, 63 papers in 17 Singapore journals, 58 papers in 17 German journals, 38 papers in 11 Switzerland journals, 27 papers in 12 French journals, 24 papers in 9 Polish journals, etc.

The significant foreign journals, wherein the Indian scholars had published, in order of ranking were:

- *Fuzzy Sets & Systems*, The Netherlands (93 papers)
- *Microelectronics & Reliability,* UK (69 papers)
- *Computers & Structures*, UK (64 papers)
- *International Journal of Systems Science*, UK (45 papers)
- *European Journal of Operational Research*, The Netherlands (38 papers)

- *International Journal of Production Research*, UK (38 Paper)
- *Proceedings of the SPIE*, USA (38 papers)
- *Computers & Mathematics with Applications*, UK (36 papers)
- *Pattern Recognition Letters*, The Netherlands (35 papers)
- *Pattern Recognition*, UK (30 papers),
- *Computer Communications*, UK (30 papers)
- *Optimization,* UK (23 papers)
- *International Journal on Information & Management Sciences*, Taiwan (23 papers)
- *Computers & Geosciences*, UK (22 papers)
- *IEEE Transactions in Signal Processing*, USA (21 papers)
- *Information Processing Letters, The Netherlands* (21 papers)
- *Information Sciences* , USA (21 papers)
- *Journal of Parallel & Distributive Computing,* USA (18 papers)
- *Production Planning & Control*, UK (18 papers)
- *IEEE Transactions on Systems, Man and Cybernetics*, Part B, USA (16 papers)
- *Computers & Chemical Engineering*, UK (16 papers)
- *Journal of Computational & Applied Mathematics*, The Netherlands (16 papers)
- *Journal of Systems Architecture*, The Netherlands (16 papers)
- *IEEE Transactions on Aerospace & Electronics Systems*, USA (15 papers).

The significant Indian journals, wherein the Indian scholars had published, in order of ranking were:

- *Journal of the Institution of Electronics & Telecommunication Engineers* (79 papers)
- *Opsearch* (63 papers)
- *IETE Technical Review* (51 papers)
- *Journal of the Institution of Engineers (India)-Electrical Engineering Division* (48 papers)
- *Sadhana* (47 papers)
- *CSI Communications* (44 papers)
- *Telecommunications* (36 papers)
- *Vivek* (27 papers)
- *IASLIC Bulletin* (20 papers)
- *Journal of the Institution of Engineers (India), Electronics & Engineering Division* (17 papers)
- *Computer Science & Informatics* (15 papers), and
- *DESIDOC Bulletin of Information Technology* (15 papers), etc.

3.2 Analysis by Main & Sub-fields

The seven broad subject fields under computer science were categorized into three groups based on the level of publications productivity under each:

- High productive fields: Systems & control theory (1530 papers) and computer applications (1082 papers)
- Medium productive fields: Computer software (716 papers) and numerical analysis & theoretical computers topic (555 papers)
- Low productivity fields: Control technology (368 papers), computer hardware (324 papers), and general & management topics (115 papers).

The publications output during 1993-97 to 1998-2001 had gone up in the following subject areas: computer hardware from (159 to 165 publication), computer software (from 311 to 405 publications), computer applications (from 453 to 629 publications), and general & management topics (from 41 to 74 publications). In other three subject fields, publications outputs during the period under study depicted a declining trend.

The impact of Indian contributions in computer science research across main seven subject fields varied between 0.409 and 0.606, whereas the country's average impact was determined as 0.451. In terms of impact factor per paper three subject fields stand out better than others. These are: Numerical analysis & theoretical computer topics, computer hardware and control technology.

- NATCT, Numerical analysis & theoretical computer topics, a medium productivity

level subject field, registering the highest (0.494) average impact per paper vis-à-vis other six fields. Nearly 50% of papers under this field were published in the JCR-covered journals. However, its 64.1% (175 papers) were published in low impact journals, 33.7% (92 papers) in medium impact journals, and 2.2% (6 papers) in high impact journals.

- The computer hardware, is also a medium productivity level field, it registered average impact (0.457) per paper. It had contributed 125 papers (38.58%) in JCR-covered journals. Its share in low impact journals was 62.4% (78 papers), in medium impact journals it was 35.2% (44 papers), and in high impact journals it was 2.4% (3 papers).
- The control technology is a low productivity level field. It registered average impact (0.457) per paper. It contributed 145 papers (39.4%) in JCR-covered journals. Its contribution in low impact journals was 62.07% (90 papers), 37.24% (54 papers) in medium impact journals, and 0.69% (1 paper) in high impact journal.

The distribution papers at sub-field level indicated that the publications output varied from 3 to 1056 papers. These sub-fields were also categorized into three broad subject groups based on productivity under each:

- High productive fields: Systems theory & cybernetics (1056 papers), software techniques & systems (716 papers), and computer applications in engineering (425 papers)
- Medium productive fields: Information science & documentation (282 papers), control theory (264 papers), control applications (337), logic design & digital techniques (219 papers), computer applications in business & administration (212 papers) and mathematical techniques (210 papers)
- Low productive fields: Computer applications in natural sciences (87 papers), other computer applications (76 papers), general computer topics (71 papers), analogue and digital computers systems (58 papers), management topics (41 papers), numerical analysis (41 papers), data communication equipment & techniques (20 papers), control equipment & instrumentation (17 papers), control & measurement of specific variables (14 papers), computer storage equipment & techniques (14 papers), computer peripheral equipment (8 papers), circuits & devices (5 papers), and general control topics (3 papers).

Expect for three sub-fields which fall under general and management topics, the ranking of sub-fields by impact is as follows. computer storage equipment & techniques (1.181), computer applications in information science & documentation (0.666), control equipment & instrumentation (0.644), computer applications in natural sciences (0.521), control & measurement of specific variables (0.542), mathematical technique (0.504), and computer theory (0.502), and logic design & digital techniques (0.469). All other sub-fields had registered average impact less than 0.451.

3.3 Sector-Wise Analysis

The academic sector institutions made the highest contribution to computer science research, contributing 74.44% (3492 papers), followed by R&D sector (598 papers, 12.75%), industrial sector (406 papers, 8.66%), government sector (62 papers, 3.28%) and others (40 papers, 0.85%). Nearly 46% papers under the academic sector were in JCR-covered journals, followed by 38.29% in R&D sector, 33% in industrial sector and 31.17% in government sector. Impact-wise, the average impact per paper was highest, 0.519 by R&D sector, followed by industrial sector (0.505), academic sector (0.440), government sector (0.389), and others (0.363). Similarly, the largest percent share of papers of R&D sector was in high impact journals (8.73%), followed by academic sector (3.18%), government sector (2.08), and industrial sector (0.74%).

3.3.1 Academic Sector

The academic sector institutions, which contributed a total of 3492 papers, had published 1603 papers (45.90%) in JCR-covered journals. The university segment made the largest contribution (1603 papers, 64.37%), followed by institutions of national importance (676 papers), colleges (521 papers), deemed universities (43 papers) and inter-university institutions (4 papers). Amongst colleges, the largest contribution (420 papers) came from engineering colleges.

The publications output from academic sector was highest in systems & control theory (1311 papers, 37.54%), followed by computer applications (702 papers, 20.10%), computer software (489 papers, 14.00%) and numerical analysis & theoretical computer topics (410 papers, 11.74%). In rest of the subject fields, the output was less than 10% of the total output. A large number of institutions form academic sector participated in research activities in computer science. Among the productive institutions, there were 17 institutions, which have contributed papers from 10 to 19 papers, 9 institutions from 20 to 49 papers each, 4 institutions contributed from 50 to 99 papers each and 6 institutions contributed from 223 to 396 papers each. These 36 institutions together have contributed 68.73% (2400 papers) of the total papers under the academic sector.

The institutions under academic sector contributing papers 200 or more were:

- Indian Institute of Technology (IIT), Madras (396 papers)
- Indian Institute of Science (IIS), Bangalore (348 papers)
- Indian Institute of Technology (IIT), Bombay (267 papers)
- Indian Institute of Technology (IIT), Kharagpur (234 papers)
- Indian Institute of Technology (IIT), Delhi (227 papers); and
- Indian Institute of Technology (IIT), Kanpur (223 papers).

These six institutes are institutions of national importance and together they had contributed around 48% papers in JCR-covered journals. Of the papers in JCR-covered journals, 28 were in high impact journals, 278 in medium productive journals, and 544 papers in low impact journals (IF<0.5). Impact-wise, the largest impact (0.623) per paper was made by Indian Institute of Science, Bangalore followed by IIT, Bombay (0.493)), IIT, Kanpur (0.483), IIT, Kharagpur (0.456), IIT, Delhi (0.413) and IIT, Madras (0.400).

The output by these six institutions were widely scattered across all seven subject fields: systems & control theory (514 papers), computer applications (330 papers), computer software (273 papers), numerical analysis (259 papers), control technology (167 papers), computer hardware (134 papers), and general & management topics (18 papers).

The next four academic institutions, contributing papers from 54 to 84, were: Jadavpur University, Indian Institute of Management, Anna University, and University of Delhi. Together, these four academic institutions contributed 270 papers, of which 129 papers were in JCR-covered journals. Of the papers in JCR-covered journals, 2 appeared in high impact, 12 papers in medium impact and 115 papers in low impact journals. The average impact per papers of these four institutions varied from 0.255 to 0.386.

3.3.2 R&D Sector

The R&D sector contributed 598 papers. The publication output under this sector was highest in computer applications (192 papers, 32.11%), followed by systems & control theory (129 papers, 21.57%), numerical analysis & theoretical computer topics (107 papers, 17.89%), computer software (69 papers, 11.89%), etc. In rest of the fields it was less than 10% to the total output.

In terms of total publication and their percentage share of their publication output, the major research agencies under the R&D sector, were:

- Department of Atomic Energy (DAE) (127 papers, 21.24%)
- Defence Research & Development Organization (DRDO) (119 papers, 19.90%)
- Council of Scientific & Industrial Research (CSIR) (114 papers, 19.06%)
- Department of Electronics (DoE) (81 papers, 13.54%), and
- Department of Space (DoS) (49 papers, 8.19%).

The major emphasis of CSIR and DRDO was in: Computer applications (65 and 46 papers), systems & control theory (17 and 35 papers) and control technology (10 and 16 papers). The emphasis of DAE and DOE were on numerical analysis & theoretical computer topics (44 and 57 papers), computer software (36 and 5 papers) and systems & control theory (18 and 11 papers). The emphasis of DoS was primarily on computer applications (22 papers) and control technology (10 papers).

The leading institutions under the R&D sector, in terms of total papers and percentage share of their publication in total output, were:

- Indian Statistical Institute (ISI) (258 papers, 43.14%)
- Institute of Mathematical Sciences, Chennai (IMS) (73 papers, 12.21%)
- Tata Institute of Fundamental Research (TIFR) (72 papers, 12.04%)
- Bhabha Atomic Energy Research Center (BARC) (35 papers, 5.85%), and
- Center for Artificial Intelligence and Robotics (CAIR) (31 papers).

These five research institutions together contributed 78.43% (469 papers) to the total papers in R&D sector. In 469 papers, 285 papers were in JCR-covered journals. Of the JCR-covered papers, 13 papers were in high impact, 67 papers in medium impact, and 125 papers in low impact journals. Impact-wise, the largest impact per paper (0.629) was made by Institute of Mathematical Sciences, Chennai, followed by 0.604 by CAIR, 0.603 by Tata Institute of Fundamental Sciences, 0.600 by Indian Statistical Institute and 0.529 by Bhabha Atomic Energy Research Center.

3.3.3 Industrial Sector

This sector contributed 406 papers, with major focus in computer software (116 papers), followed by computer applications (105 papers), systems & control theory (64 papers), general & management topics (38 papers), control technology (34 papers), computer hardware (25 papers), and numerical analysis & theoretical computer topics (24 papers). The private sector industries contributed a larger share (84.2%) of papers in the total publications output of this sector, and the remaining 25.8% was from public sector industrial enterprises. The average impact of private sector industrial enterprises was 0.505, higher than the private sector enterprises impact of 0.485.

Among the industrial sector the major contributors were from:

- Infosys, Bangalore (49 papers)
- Tata Consultancy Services (29 papers)
- Tata Research Development & Design Center, Pune (24 papers)
- Motorola India (10 papers)
- Wipro (10 papers)
- Tata Inf. Syst. Ltd., Bangalore (8 papers)
- Lucent Technol. India Private Limited, Pune (7 papers)
- GE India Technol. Centre. Pvt. Ltd., Bangalore (6 papers)
- IBM India Research Lab., New Delhi (4 papers), etc.

Among public sector companies, the major contributions were from:

- Computer Maintenance Corporation Ltd. (CMC Ltd) (23 papers)
- Bharat Heavy Electricals Ltd. (BHEL) (17 papers)
- Indian Telephone Industries Limited, Bangalore (6 papers), etc.

3.3.4 Government Sector

The government sector contributed 154 papers, with largest in computer applications (62 papers), followed by computer software (41 papers), systems & control theory (22

Table 1. Contribution of Indian Scholars

S. No.	Institution	Authors along with their quantum of contribution
1	Indian Statistical Institute	S K Pal (52 papers), N R Pal (41 papers), B B Chaudhuri (38 papers), S Mitra (25 papers), and S Bandyopadhyay (21 papers)
2	IIT, Delhi	C P Ravikumar (23 papers), V Kumar (20 papers), S Sen (20 papers), and Y Singh (20 papers)
3	IIT, Kharagpur	S Pal (66 papers), PP Chakrabarti (25 papers), K Dutta (24 papers) and K B Datta (21 papers)
4	IIT, Madras	C Siva Ram Murthy (45 papers), and C Rajendran (38 papers)
5	IIT, Bombay	B Bandyopadhyay (25 papers) and A Mukherjee (20 papers)
6	IIT, Kanpur	M Agrawal (23 papers) and K Deb (22 papers)
7	IIS, Banglore	A Kumar (23 papers) and J Haritsa (20 papers)
8	TIFR, Mumbai	R K Shyamasundar (35 papers) and K Kumar (22 papers)

papers), general & management topics (9 papers), computer hardware (8 papers), numerical analysis & theoretical computer topics (7 papers) and control technology (5 papers). The maximum contribution under government sector was from National Center for Software Technology, (NCST), Mumbai (33 papers), Center for Development of Advanced Computing (C-DAC)(21 papers), National Informatics Center (NIC) (13 papers), etc.

3.4 Contribution of Individual Scholars

2889 Indian scholars contributed the 4690 research papers in computer science. The range of the contribution of these scholars varied from 2 to 66 papers. In this sample, 2219 Indian scholars contributed 1 to 3 papers in contrast to only 37 scholars contributing 20 to 66 papers. These 37 most productive scholars belong to 21 organisations. The maximum number of scholars (6) belonged to Indian Statistical Institute, followed by 4 each from IIT, Delhi and IIT, Kharagpur, 2 each from IIT, Bombay, IIT, Kanpur, IIT, Madras, IIS, Bangalore and Tata Institute of Fundamental Research, Mumbai and 1 each from 13 other organisations (Table 1). Impact wise, the largest impact per paper (1.154) was made by J Haritsa, followed by 1.091 by P Dasgupta, 0.961 by P P Chakrabarti, and 0.882 by M Vidyasagar, etc.

4. DISCUSSION

There is a wide gap between the quantitative and qualitative performance of research in computer and control science research in India and this gap also persists even at the subfields level. This is more so because a significant proportion of country's publications output is reported in non-SCI-covered journals. Its publications share in SCI-covered journals is low and confined to low and medium range impact factor journals. It is a matter of concern that its share in high impact factor journals is only marginal. The high productivity fields and the high impact fields are not the same. This disparity once again highlights the gap between the quantitative and qualitative performance of research in computer science.

The reasons for the gap could be attributed to the need for protecting IPR interests or it may be due to lack of focus in research, lack of practical applications of research, or lack of accountability. It could also be that research efforts are directed at reinventing the wheel, the purpose being manpower development, increasing competence, and keeping the faculty up-to-date with current techniques.

Although software industry in the country seems to be going stronger and also growing fast, it is surprising that R&D activity in computer software is neither high in the academic sector nor in the R&D sector. The low impact of this field (computer software)

vis-à-vis other computer science fields is a matter of concern. The leading areas of research across various sectors are not similar. In the academic sector the leading areas of research are systems & control theory and computer applications. In R&D sector, these are computer applications, and systems & control theory. In government sector, it is computer applications and in industrial sector it is computer software. Interestingly, R&D activity in computer hardware is also not a priority area of research of any sector.

Currently, computer science research is driven mainly by academic sector. This is more so because three-fourth of country's output in computer & control science is contributed by academic sector, and the remaining one fourth by institutions from many other sectors such as R&D sector, government sector, industrial sector. The leading institutions in computer and control science in the country are: Indian Institute of Technology, Chennai; Indian Institute of Science, Bangalore; Indian Institute of Technology, Kharagpur, Indian Institute of Technology, Mumbai, Indian Statistical Institute, Kolkata; Indian Institute of Technology, Delhi; and Indian Institute of Technology, Kanpur.

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