*DESIDOC Journal of Library & Information Technology*, Vol. 30, No. 6, November 2010, pp. 39-54


# Indian Computer Science Research Output during 1999-2008: Qualitative Analysis

B.M. Gupta, Avinash Kshitij, and Yogendra Singh*

*National Institute of Science, Technology and Development Studies*
*Dr K.S. Krishnan Marg, New Delhi-110 012*
*E-mail: bmgupta1@gmail.com*

**Indian Institute of Technology, Roorkee-247 667, Uttrarakhand*
*E-mail: yogi@iitr.ernet.in*

**ABSTRACT**

The paper analyses research output of computer science, in 11 sub-fields, in India during 1999-2008. The parameters studied include total research output, publications growth, citation impact, share of international collaborative publications, research communication in productive journals, characteristics of most productive institutions, authors, and high-cited papers.

**Keywords:** Quantitative analysis, indian publications, productive journals, computer science

## 1. INTRODUCTION

The Indian information industry is undoubtdly acknowledged as an important player in world. The availability of technical human capital, proficiency in English, cost competitiveness, quality-training institutes, and favourable government reforms have laid solid foundations of the information industry and well-sought destination of global companies to outsource their businesses. India's most priced resource is its readily available technical workforce. It is estimated that India has over 4 million technical workers and over 1832 educational institutes and polytechnics, which train more than 67,785 computer software professionals every year[1].

The Indian information technology (IT) industry has played a key role in putting India on the global map. Thanks to the success of the IT industry, India is now a power to reckon with. The IT industry may be sub-divided into: (i) IT services, (ii) ITES services (ITES-BPO services), and (iii) e-commerce. According to the Department of Information Technology, (DIT), Government of India (GoI), the overall revenue from Indian software and service industry is estimated to have grown from US$10.2 billion during 2001-02 to US$58.7 billion during 2008-09, translating to a CAGR of 26.9 per cent. The export intensity (the share of IT-ITES revenue) of Indian software and services industry has grown from 74.5 per cent during 2001-02 to 78.9 per cent in 2008-09.The total software and services exports are estimated to have grown from US$7.6 billion to US$46.3 billion during 2008-09, a CAGR of 28.6 per cent[2].

### 1.1 Government Initiatives

A number of infrastructures and other policy initiatives had been taken by the GoI to develop and promote IT as an important engine of economic growth. The National Informatics Centre (NIC) was established in 1975, followed by Computer Maintenance Corporation (CMC) Ltd in October 1976.

During 1986-1997, the GoI embarked upon the creation of the following wide-area networks schemes:

(i) INDONET (intended to serve IBM mainframes in India).

(ii) NICNET (the network for India's National Informatics Centre).

(iii) ERNET (the academic research oriented network education and research network).

Received on: 28 May 2010

In 1991, the Department of Electronics created a corporation called Software Technology Parks of India (STPI) to provide VSAT communication without breaching its monopoly. STPI set up software development parks in different cities to provide satellite links to firms. The Videsh Sanchar Nigam Ltd (VSNL) introduced Gateway Electronic Mail Services in 1991, 64 kbit/s leased line service and a commercial Internet access on a visible scale in 1992. A new ministry, namely, Ministry of Information Technology, was established in October 1999, which was re-christened as Ministry of Communication and Information Technology in September 2001 given the increasing convergence between communication technology and information technology[3].

The government under Shri Atal Bihari Vajpayee placed the development of information technology among its top five priorities, and formed the National Taskforce on Information Technology and Software Development, under the Deputy Chairman of Planning Commission in May 1998 with the objective of framing a long-term National IT Policy for the country. Within 90 days of its establishment, the taskforce produced an extensive report, in three parts, on the state of technology in India and its IT action plan with 108 recommendations. The reports finally become a solid base for the present policy development to built India's infotech industry to proliferate the use of IT in the country. The New Telecom Policy, 1999 (NTP, 1999) helped further liberalise India's telecommunication sector[3].

The GoI enacted the Information Technology Act in 2000, which provides a legal framework to facilitate e-commerce and electronic transactions. The government approved the National e-Governance Plan (NeGP) comprising 27 Mission Mode Projects (MMPs) and eight components on 18 May 2006, which played an important role in increasing Internet penetration in rural India. The State governments are also enunciating their IT policies. Many States are now vying with each other to develop their own brands of Silicon Valleys as hubs of IT activities.

### 1.2 R&D Efforts

The R&D in computer science is undertaken by academic institutions, government-sponsored R&D institutions, and industry-sponsored institutions[4]. Among the academic institutions, the major role has been played by Indian Institute of Science; Bengaluru; Indian Institute of Technology (IITs); Indian Statistical Institute, Kolkata; National Institute of Technology (NITs); Indian Institute of Information Technology (IIITs); engineering colleges with deemed university status; universities with engineering and technology faculty; and government and private engineering colleges. The R&D work is undertaken in several R&D institutions under various research departments and agencies of Ministry of Information and Communication Technology (MoICT), Department of Electronics (DoE), Department of Atomic Energy (DAE), Department of Space (DoS), Defence Research and Development Organisation (DRDO), Council of Scientific and Industrial Research (CSIR), Department of Science and Technology (DST), etc. In addition extra-mural funding has been provided to academic and research institutions in computer science by agencies such as Ministry of Human Resource Development (MHRD), All Indian Council of Technical Education (AICTE), University Grants Commission (UGC), MICT, DoE, DAE, DoS, DRDO, DST, CSIR, etc. from time to time. Among the industry-sponsored research, the major R&D work in computer science in India is undertaken by Indian companies such as Tata Consultancy Services (TCS), Tata Research Development Design Centre, Infosys Technologies, Wipro Technologies, HCL, etc., and foreign companies, such as Texas Instruments, IBM Research Centre, GE Research Centre, Motorla Inc., Oracle, Intell Corporation, Mocrosoft, Dell, and CISCO Systems Inc., etc.

### 1.3 Professional Bodies

Few professional associations and bodies such as National Association for Software and Service Companies (NASSCOM), Manufacturer's Association of Information Technology (MAIT), the Institution of Electronics and Telecommunication Engineers (IETE), Computer Society of India (CSI) and Indian Association for Research in Computing Science (IARCS) have come up in the country for promotion of education, research and business promotion activities in IT.

## 2. LITERATURE REVIEW

Among the few quantitative studies on computer science carried out in India, Das and Kranzai[5] analysed the major Indian institutions publications on computer science as covered in *Science Citation Index (SCI)* database during 1991-2000. Gupta and Dhawan[6] studied computer science publications authored by Indian scholars as covered in *INSPEC Database* during 1994-2001, with a focus on publication output and impact factor quality, areas of strength and weakness, and contribution of leading institutions and individual scholars. Suresh and Garg[7] analysed Indian computer science publications of Indian and Chinese scholars as covered in specialised bibliographies during 1971-2000, in terms of local and international journals, impact factor range and coverage in *SCI* versus non-*SCI* covered journals, the extent of collaboration, etc.

## 3. OBJECTIVES

The main objective of this study was to analyse the research performance of India in computer science research across 11 major sub-fields, as reflected in their publication output during 1999-2008. In particular, the study focuses on the publication growth, international collaboration share, publication productivity and impact of leading institutions and authors, the patterns of research communication and the characteristics of high-cited papers.

## 4. METHODOLOGIES AND SOURCE OF DATA

This study is based on the Indian publication data in computer science retrieved from the *Scopus Citation Database* for 10 years (1999-2008). Three-year citations window was used for counting the citations received and to access the impact of Indian research output, Indian institutions and authors, and international-collaborative publications.

The *Scopus* classified the entire S&T literature under four broad fields (physical, life, engineering and health sciences) and 20 narrow fields including computer science. The study is limited to the literature covered under computer science. There is an overlapping of journal coverage under the 20 narrow subject fields. The authors have identified 11 sub-fields using a keyword strategy (*Appendix 1*).

The process used for keywords selection was as follows. First a general query on Indian computer science research during 1999-2008 using the following search strategy was made: "affil (india) and pubyear aft 1998 and pubyear bef 2009 and [limit-to (subjarea, "comp")]". This query additionally generated a set of 160 leading keywords with the frequency of their occurrence varying from 133 to 2195.

Then the Indian computer science experts were consulted for choosing the most important keywords relevant to the 11 sub-fields defined. The list of keywords generated from the database was sent to 50 Indian experts with a request to relate these keywords to these 11 sub-fields and to suggest new keywords not existing in the list of keywords sent. On the basis of experts' advice, the keywords relevant to the 11 sub-fields were finalised.

## 5. ANALYSIS

### 5.1 India's Publication Output in Computer Science

India's total cumulative publications output in computer science comprised 15924 publications during 1999-08, with average number of publications per year as 1592. The cumulative publications output of India increased from 3315 publications to 12609 publications from 1999-03 to 2004-08 witnessing a growth of 280.36 per cent. India's annual average publication growth rate during 1999-2008 was 28.68 per cent. In terms of impact and quality, the average citations per paper registered by India's publications output during 1999-06 were 2.10. The average citations per paper for India's cumulative publications decreased from 2.31 during 1999-02 to 2.01 during 2003-06. The h-index registered by all Indian publications during 1999-08 was 60 (Table 1). Based on the publications data, the total cumulative collaborative publications output during 1999-08 comprised of 3173 publications, which constituted 19.92 per cent share in the cumulative output of India in computer science. India witnessed a substantial decrease in the share of international-collaborative publications from 24.95 per cent (827 publications) during 1999-03 to 18.60 per cent (2346 publications) during 2004-08.

**Table 1. Growth and impact of Indian publications in computer science during 1999-08**

| Year | TP | TC | ACPP | Year | TP | TC | ACPP |
|---|---|---|---|---|---|---|---|
| 1999 | 592 | 1159 | 1.96 | 2006 | 2302 | 2594 | - |
| 2000 | 681 | 1219 | 1.79 | 2007 | 3150 | - | - |
| 2001 | 541 | 1185 | 2.19 | 2008 | 4777 | - | - |
| 2002 | 622 | 2077 | 3.34 | 1999-03 | 3315 | - | - |
| 2003 | 879 | 2279 | 2.59 | 2004-08 | 12609 | - | - |
| 2004 | 1158 | 3080 | 2.66 | 1999-08 | 15924 | - | 1.13 |
| 2005 | 1322 | 3424 | 2.59 | - | - | - | - |

*TP=Total Papers; TC= Total Citations; ACPP=Average Citations per Paper*

### 5.2 Sub-fields of Research in Computer Science in India

The analysis of Indian research output in computer science under 11 sub-fields is discussed in the following paragraphs.

#### *5.2.1 Computer Theory*

The total Indian research output in computer theory comprised 504 publications, accounting for 3.17 per cent share in their national publications output in computer science. Of the total Indian publications on computer theory, 269 were published as conference publications, 229 as articles, 3 as reviews, and 1each as editorial, article in press, and letter. The number of Indian publications in computer theory increased from 108 in 2003 to 396 during 2004-08, showing a growth rate of 266.67 per cent. Of the total publications in computer theory, 19.84 per cent (100 Publications) were found to be internationally-collaborative.

The share of Indian international collaborative publications in computer theory has decreased from 27.78 per cent (30 Publications) during 1999-03 to 17.68

per cent (70 publications) during 2004-08. The h-index of the total Indian publications during 1999-08 was 17. The average citation per paper on a three-year citation window registered by the 504 Indian publications in computer theory was 1.45. The average citation per paper decreased from 1.89 during 1999-03 to 1.34 during 2004-08.

The major Indian institutions contributing in terms of publications output to computer theory research were:

*Institutes of National Importance:* ISI-Kolkata (57 publications), IISc-Bengaluru (44 publications), IIT-Kharagpur (37 publications), IIT-Bombay (28 publications), IIT-Delhi (24 publications), IIT-Madras (23 publications), IIT-Kanpur (18 publications) and IIT-Guwahati (13 publications).

*Universities/Deemed Universities*: Bengal Engineering and Science University (24 publications), Jadavpur University (18 publications), Annamalai University (9 publications), University of Mysore (6 publications), BITS-Pilani (5 publications), University of Hyderabad (5 publications), West Bengal University of Technology (4 publications), Banaras Hindu University (4 publications) Indian School of Mines, Danbad (4 publications) and University of Delhi (4 publications).

*NIT/RECs:* Motilal Nehru NIT, Allahabad (7 publications), NIT-Tiruchanapally (4 publications) and NIT-Jamshedpur (4 publications).

*Industry:* IBM-India (6 publications), Honeywell International India Ltd (6 publications), Satyam Computers (5 publications), TCS (5 publications), and Tata Research Development and Design Centre (4 publications).

*Indian Institute of Information Technologies:* IIIT-Hyderabad (6 publications).

*Research Institutes:* TIFR Bombay (13 publications), IMS Chennai (12 publications) and Chennai Mathematics Institute (7 publications).

*Colleges:* Madras Christian College (5 publications).

The most productive Indian authors participating in computer theory research were: B.K. Sikdar (Bengal Enginering and Science University.; 17 publications); P.P. Chaudhuri (N.S. Engineering College, Calcutta, 11 publications); S.C. Nandy (ISI-Kolkata, 10 publications); N. Ganguly (IIT-Kharagpur, 10 publications); B.B. Bhattacharya (ISI-Kolkata, 10 publications); S. Das, ISI-Kolkata, 9 publications); S.N. Krishna (IIT-Bombay, 9 publications); P. Maji (ISI-Kolkata, 8 publications); S. Chattopadhyay (IIT-Kharagpur, 7 publications); and K. Krithivasan (IIT-Chennai, 7 publications).

The major journals contributing to computer theory research were: *IETE Journal of Research* (13 publications); *Fundamental Informaticae* (11 publications); *Theoretical Computer Science* (9 publications); *Lecture Notes in Computer Science* (8 publications); *Information Processing Letters* (7 publications); *Pattern Recognition Letters* (7 publications); *Electronic Notes in Theoretical Computer Science* (6 publications); *Signal Processing* (6 publications); *Information Technology Journal* (5 publications); and *IEEE Transaction on Systems, Man and Cybernetics, Part B (*5 publications).

These 504 Indian publications in computer theory received 1216 citations (since their publication till February 2010) with an average citation of 2.41 per paper. Of these total 504 publications, 251 received, 1 and more citations: 217 publications in citations range of 1-9; 22 publications in citation range of 20 to 29; 8 publications in citations range of 20-29; 3 publications in citations range of 30-39; and 1 paper in citations range of 40-49.

The top 20 high-cited Indian publications on computer theory received 16 to 47 citations. Of these 20 high-cited publications, 17 were articles, 2 conference papers and 1 review paper. Among these 20 high-cited publications, 11 involved international collaboration (8 bilateral and 3 multilateral), 3 national collaborations while 6 have no collaboration). Fifteen Indian organisations involved in these 20 high-cited publications were: ISI-Kolkata (7 publications); IISc-Bengaluru (4 publications); IIT-Bombay (3 publications); IIT-Kharagpur (1 paper); IIT-Guwahati (1 paper); IIT-Delhi (1 paper); Jadavpur University (1 paper); University of Kalyani (1 paper); Bengal Engineering and Science University-Howrah (1 paper); IMC-Chennai (1 paper); Chennai Mathematical Institute (1 paper); Wipro Technologies (1 paper); Strand Genomics (1 paper); Price Waterhouse Coopers-Calcutta (1 paper) and Delsoft India Pvt Limited-Noida (1 paper). These 20 high-cited publications were published in 17 journals, including 2 publications in *IEEE Transactions on Systems, Man and Cybernetics, Part B,* and 1 paper each in 16 other journals.

### *5.2.2 Software Engineering*

The total Indian research output in software engineering comprised 516 publications during 1999-2008. Of the total publications, 310 were published as conference publications, 197 as articles, 7 as reviews, and 2 as editorials. The number of Indian publications in software engineering increased from 96 during 1999-03 to 420 during 2004-08, showing a growth rate of 337.5 per cent. Of the total Indian publications on software engineering, 18.80 per cent (97 publications) appeared

as internationally collaborative. The share of international-collaborative publications on software engineering increased from 16.67 per cent (16 publications) during 1999-03 to 19.28 per cent (81 publications) during 2004-08. The h-index of the total Indian publications on software engineering during 1999-08 was 16. The average citation per paper on a three-year citation window registered by the 516 publications was 1.24. The average citation per paper decreased from 2.04 during 1999-03 to 1.06 during 2004-08.

The major Indian institutions contributing to software engineering research were:

*Institutes of National Importance:* IIT-Kharagpur (25 publications), IISc–Bengaluru (24 publications), IIT-Delhi (19 publications), IIT-Bombay (18 publications), IIT-Kanpur (17 publications), IIT-Madras (11 publications) and IIT-Roorkee (11 publications);

*Universities/Deemed Universities*: University of Delhi (17 publications), Annamalai University (15 publications), GGS Indraprastha University (14 publications), Jadavpur University (11 publications), Guru Nanak Dev University (8 publications), BITS-Pilani (6 publications), and Thaper University (6 publications).

*NIT/RECs:* NIT-Jamshedpur (9 publications), Motilal Nehru NIT (7 publications) and NIT-Kurukshetra (5 publications).

*Industry:* Infosys Technologies (20 publications), IBM-India (13 publications), TCS (11 publications), Microsoft (9 publications) and Tata Research Development and Design Centre (8 publications).

*Select Engineering Colleges*-Dhirubhai Ambani Institute of Information and Communication Technology (7 publications) and Basaveshwar Engineering College (5 publications).

The most productive Indian authors participating in software engineering research were: P. Jalote (IIT-Delhi, 13 publications); R. Mall (IIT-Kharagpur, 11 publications); Y. Singh (GGS Indraprastha University, 7 publications); S.S. Manvi (IISc-Bengaluru, 7 publications); A. Konar (Jadavpur University, 7 publications); S. Ramesh (General Motors, 6 publications); S.K. Rajamani (Microsoft, 6 publications); S.K. Aggarwal (IIT-Kanpur, 6 publications); S. Bhattacharya (NIT-Durgapur, 5 publications); and G.V. Uma (Annamalai University, 5 publications).

The major journals contributing to software engineering research by Indian scholars were: *Lecture Notes in Computer Science including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatic*s (34 publications, *IEEE Software* (15 publications), *IETE Journal of Research* (10 publications), *Information Technology Journal* (8 publications), *Information and Software Technology* (8 publications), *Advances in Software Engineering* (7 publications), *Electronic Notes in Theoretical Computer Science* (6 publications), *Journal of Object Technology* (6 publications), *Wwseas Transaction on Computers* (6 publications), and *International Journal of Automation and Computing* (5 publications).

These 516 Indian publications on software engineering received 1172 citations (since their publication till February 2010) with an average citation per paper of 2.27. Of these 516 publications, 180 received one or more citations: 159 in citations range of 1-9; 19 in citation range of 20-29; 5 in citations range of 20-29; 2 in citations range 30-39; 3 in citations range 651-100, and 1 in citation range of 100-199.

The top 20 high-cited publications on software engineering received citations from 13 to 106. Of these 20 high-cited publications, 17 were articles, 2 conference publications, and 1 a review paper. Among these 20 high-cited publications, 9 involved international collaborations (8 bilateral and 1 multilateral), 1 national collaboration, while 11 have no collaboration. Seventeen Indian organisations were involved in these 20 high-cited publications including 3 publications from IIM-Bengaluru, and 2 publications each from IISc-Bengaluru, Infosis Technologies Limited, and Tata Research Development and Design Centre, Pune. These 20 high-cited publications were published in 18 journals including 8 publications in *IEEE Software* and 2 publications each in *Information and Software Technology,* and *IEEE Transactions on Software Engineering.*

### *5.2.3 Database Management System*

The total Indian research output in database management system comprised 543 publications during 1999-08. Of the 543 publications, 288 were published as conference publications, 250 as articles, 3 as reviews, and 1 each as editorial and a letter. The number of Indian publications on database management system increased from 133 in 1999-03 to 410 in 2004-08, showing a growth rate of 208.27 per cent. Of these publications, 23.02 per cent (125 publications) appeared as internationally collaborative. The share of international-collaborative publications decreased from 30.82 per cent (41 publications) in 1999-03 to 20.49 per cent (84 publications) in 2004-08. The h-index of the total Indian publications during 1999-08 was 23. The average citation per paper registered by the 543 publications in database management system was 1.90. The average citation per paper on software engineering on a three-year citation window decreased from 2.86 during 1999-03 to 1.59 during 2004-08. The major

institutions contributing to database management system research were:

*Institutes of National Importance:* IISc-Bengaluru (55 publications), ISI-Kolkata (49 publications), IIT-Delhi (44 publications), IIT-Bombay (23 publications), IIT-Kharagpur (22 publications), IIT-Roorkee (21 publications), IIT-Madras (15 publications), IIT-Guwahati (6 publications), and IIM-Calcutta (4 publications).

*Universities/Deemed Universities*: Annamalai University (16 publications), Jadavpur University (10 publications), University of Calcutta (7 publications), University of Hyderabad (7 publications), Jamia Millia Islamia (6 publications), University of Mysore (5 publications), University of Delhi (5 publications), Bengal Engineering and Science University (3 publications), and Thaper University (3 publications).

*NIT/RECs:* NIT-Surathkal (7 publications) and NIT-Jamshedpur (4 publications) (5 publications).

*Industry:* IBM-India (16 publications), Microsoft (11 publications), Alcatel-Lucent-Bell Lab (6 publications), and Infosys Technologies (4 publications).

*IIndian Institutes of Information Technologies*: IIIT-Hyderabad (14 publications) and IIIT-Allahabad (4 publications).

*Research Institutes*: TIFR-Bombay (7 publications) and MIS-Chennai (7 publications).

*Select Engineering Colleges*: PSG College of Technology (5 publications).

The most productive Indian authors participating in database management system research were: P. Jalote (IIT-Delhi, 13 publications); R. Mall (IIT-Khar, 11 publications); Y. Singh, (Guru Gobind Singh Indraprastha University, 7 publications); S.S. Manvi (IISc-Bengaluru, 7 publications); A. Konar (Jadavpur University, 7 publications); S. Ramesh (General Motors, 6 publications); S.K. Rajamani (Microsoft, 6 publications); S.K. Aggarwal (IIT-Kanpur, 6 publications); S. Bhattacharya (NIT-Durgapur, 5 publications); and G.V. Uma (Annamalai University, 5 publications).

The major journals contributing to database management system research by Indian scholars were: *Lecture Notes in Computer Science including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics* (80 publications, *Bioinformatics* (14 publications), *IETE Journal of Research* (10 publications), *Pattern Recognition* (8 publications), *IEEE Transaction on Knowledge and Data Engineering* (6 publications), *Information Technology Journal* (6 publications), *Information Sciences* (5 publications), *ACM Transaction on Database Systems* (5 publications), *Data and Knowledge Engineering* (5 publications), and *SIAM Journal of Computing* (5 publications).

These 543 Indian publications on database management system received 2510 citations (since their publication till February 2010) with an average citation per paper of 4.62. Of these 543 publications, 278 received one or more citations: 218 in citations range of 1-9; 36 in citation range of 10-19; 7 in citations range of 20-29; 4 in citations range 30-39; 2 in citations range 40-49; 8 in citation range of 50-99; and 3 in citation range of 100-199.

The top 20 high-cited publications in database management system have received citations from 28 to 177. Of these 20 high-cited publications, 17 publications are published as articles and 3 as conference publications. Among these 20 high cited publications, 9 involve international collaboration (7 bilateral and 2 multilateral), 2 national collaboration while 9 involve zero collaboration). Thirteen Indian organisations are involved in these 20 high-cited publications including 5 from ISI-Kolkata, 3 publications from IIT-Bombay and 2 publications each from Annamalai University, IISc-Bengaluru, IIT-Delhi, and IIT-Kharagpur. These 20 high-cited publications were published in 14 journals, including 4 in *Bioinformatics* and 2 in *IEEE Transactions on Neural Networks.*

### *5.2.4 Internet and Multimedia*

The total Indian research output in Internet and multimedia comprised 1499 publications during 1999-2008. Of these 1499 publications, 1002 were published as conference publications, 464 as articles, 25 as reviews, and 18 as editorials. The number of publications on Internet and multimedia increased from 198 during 1999-03 to 1301 during 2004-08, showing a growth rate of 557.07 per cent. Of the total publications, 20.15 per cent (302 publications) appeared as internationally collaborative. The share of international collaborative publications in Internet and multimedia decreased from 36.87 per cent (73 publications) during 1999-03 to 17.60 per cent (229 publications) in 2004-08. The h-index of the total publications in Internet and multimedia during 1999-08 was 31. The average citation per paper on Internet and multimedia on a three-year citation window registered by the 1499 publications was 4.41. The average citation per paper increased from 3.99 during 1999-03 to 4.68 during 2004-08. The major Indian institutions contributing to Internet and multimedia research were:

*Institutes of National Importance:* IISc-Bengaluru (88 publications), IIT-Delhi (66 publications), IIT-Madras (64 publications), IIT-Bombay (58 publications), IIT-Kharagpur (51 publications), IIT-Kanpur (31 publications),

ISI-Kolkata (29 publications), IIT-Roorkee (25 publications), IIM-Calcutta (15 publications) and IIT-Guwahati (11 publications).

*Universities/Deemed Universities*: Annamalai University (96 publications), Jadavpur University (25 publications), Aligarh Muslim University (15 publications), University of Hyderabad (13 publications), University of Delhi (11 publications), West Bengal University of Technology (9 publications) and BITS-Pilani (8 publications).

*NIT/RECs*: NIT-Tiruchanapally (22 publications), NIT-Jamshedpur (20 publications) and NIT-Rourkela (9 publications).

*Industry:* IBM-India (38 publications), Infosys Technologies (29 publications), Motorola (20 publications), Bell Lab Res (18 publications), TCS (17 publications), Samsung Electronics (14 publications) and Alcatel-Lucent-Bell Lab (10 publications).

*Indian Institute of Information Technologies:* IIIT-Hyderabad (19 publications).

*Research Institutes:* TIFR-Bombay (9 publications).

The most productive authors participating in Internet and multimedia research were: R. Rastogi (Yahoo Labs-Bengaluru, 18 publications); K. Ramamritham (IIT-Bombay, 16 publications); S.S. Manvi (Reva Institute of Technology and Management-Bengaluru, 13 publications); P. Venkataram (IISc-Bengaluru, 13 publications); A. Kumar (IBM Research Laboratory-New Delhi University, 13 publications); V. Vaidehi (Madras Institute of Technology-Chennai, 13 publications); D. Mukhopadhyay (Calcutta Business School-Bishnupur, 12 publications); C. Siva Ram Murthy (IIT-Madras, 11 publications); A. Nanavati (IBM India Research Laboratory-New Delhi, 11 publications); and K.R.Venugopal (Visvesvaraya College of Engineering–Bengaluru, 11 publications).

The major journals contributing to research in Internet and multimedia were: *Lecture Notes in Computer Science including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics* (138 publications), *IETE Journal of Research* (25 publications), *Bioinformatics* (24 publications), *Information Technology Journal* (17 publications), *Computer Communications* (15 publications), *Computer Networks* (10 publications), *Bell Laboratory Technical Journal* (9 publications), *Multimedia Tools and Applications* (8 publications), *IEEE Journal on Selected Areas of Communication* (8 publications), and *Wseas Transaction on Computers* (8 publications). These 1499 publications on Internet and multimedia received 4004 citations (since their publication till February 2010) with an average citation per paper of 2.67. Of these 1499 publications, 504 received one or more citations: 409 publications in citations range of 1-9; 50 publications in citation range of 10-19; 13 publications in citations range of 20-29; 8 publications in citations range 30-39; 7 publications in citations range 40-49; 14 publications in citation range of 50-99; and 3 papers on citation range of 100-199.

The top 20 high-cited publications on Internet and multimedia received citations from 49 to 176. Of these 20 high-cited publications, 15 were published as articles, 2 as reviews and 3 as conference papers. Among these 20 high-cited publications, 12 were international collaborations (8 bilateral and 4 multilateral), 2 national collaborations, while 7 as no collaboration). Eighteen Indian organisations were involved in these 20 high-cited publications including 3 publications each from Indian Institute of Science, Bengaluru and IMTECH-Chandigarh, and 2 publications each from IIT-Bombay, IIT-Delhi, and ISI-Kolkata. These 20 high-cited publications were published in 13 journals including 6 publications in *Bioinformatics*.

### *5.2.5 Artificial Intelligence*

The total research output in artificial intelligence comprised 2394 publications during 1999-08. Of these 2394 publications, 1140 were published as conference publications, 1205 as articles, 33 as reviews, 6 as editorials, 4 as articles in press, 3 each as letters and erratums. The number of publications in artificial intelligence increased from 508 in 1999-03 to 1806 in 2004-08, showing a growth rate of 223.79 per cent. Of these 2394 publications on artificial intelligence, 23.94 per cent (342 publications) appeared as internationally collaborative. The share of international-collaborative publications in artificial intelligence decreased from 16.14 per cent (82 publications) during 1999-03 to 14.40 per cent (260 publications) during 2004-08. The h-index of the total publications in artificial intelligence during 1999-08 was 40.5. The average citation per paper registered by the 2394 publications on a three-year citation window was 2.07. The average citation per paper on a three-year citation window decreased from 3.09 during 1999-03 to 1.79 during 2004-08. The major Indian institutions contributing to artificial intelligence research were:

*Institutes of National Importance:* ISI-Kolkata (236 publications), IIT-Kharagpur (137 publications), IIT-Delhi (131 publications), IISc-Bengaluru (125 publications), IIT-Kanpur (98 publications), IIT-Madras (90 publications), IIT-Bombay (58 publications), IIT-Roorkee (52 publications), and IIT-Guwahati (21 publications).

*Universities/Deemed Universities*: Jadavpur University (101 publications), Annamalai University

(99 publications), DEI-Agra (32 publications), University of Hyderabad (23 publications), BITS-Pilani (22 publications), Bengal Engineering and Science University (20 publications), Banaras Hindu University (17 publications), J.N.Technological University (17 publications), BITS-Mesra (17 publications), University of Madras (14 publications), Guru Gobind Singh Indraprastha University (15 publications) Aligarh Muslim University (15 publications) and Thaper University (14 publications).

*NIT/RECs:* NIT-Rourkela (39 publications), NIT-Tirchnapally (35 publications), NIT-Jamshedpur (28 publications) and Motilal Nehru NIT-Allahabad (17 publications).

*Industry:* IBM India Research Laboratory (20 publications) and TCS (18 publications).

*Indian Institute of Information Technologies:* IIIT-Hyderabad (27 publications).

*Select Engineering Colleges:* PSG College of Technology (38 publications), Thiagarajan College of Engineering (31 publications), Rashtreeya Vidaylaya College of Engineering (21 publications), Pondicherry Engineering College (20 publications), and Sri Venkateshwara College of Engineering (20 publications).

The most productive authors participating in in artificial intelligence research were: S.K. Pal (ISI-Kolkata, 40 publications); S. Bandyopadhyay (ISI-Kolkata, 37 publications); K. Deb (IIT-Kanpur, 36 publications); B.Yegnanaryana (IIIT-Hyderabad, 35 publications); G. Panda (NIT-Rourkela, 24 publications); S. Mitra (ISI-Kolkata, 21 publications); U. Maulik (University of Kalyani, 20 publications); P.K. Kalra (IIT-Kanpur, 20 publications); A. Ghosh (ISI-Kolkata, 19 publications); and D.K. Pratihar (IIT-Kharagpur, 18 publications).

The major journals contributing in artificial intelligence research were: *Lecture Notes in Computer Science including subseries, Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics* (185 publications), *IETE Journal of Research* (72 publications), *Applied Software Computing Journal* (63 publications), *Neurocomputing* (40 publications), *IEEE Transactions on Neural Networks* (34 publications), *IEEE Transaction on Systems, Man and Cybernetics, Part B* (31 publications), Advances in Modeling and Analysis (27 publications), *Studies in Computational Intelligence* (26 publications), *Pattern Recognition* (25 publications) and *Journal of Institution of Engineers, Part CP: Computer Engineering Division* (23 publications). These 2394 publications in artificial intelligence received 12056 citations (since their publication till February 2010) with an average citation per paper of 5.03. Of the total publications on artificial intelligence, 1054 received one or more citations: 806 in citations range of 1-9; 149 in citation range of 10-19; 45 in citations range of 20-29; 21 in citations range 30-39; 10 in citations range 40-49; 20 in citation range of 50-99; 8 in citation range of 100-199; 3 in citation range of 200-299; 1 in citation range of 401-499; and 1 above 2000 citations.

The top 20 high-cited publications on artificial intelligence received citations from 68 to 2245. Of these 20 high-cited publications, 19 were articles and 1 review. Among these 20 high-cited publications, 5 involved international collaborations (4 bilateral and 1 multilateral), 6 national collaborations, while 9 no collaboration). Eleven Indian organisations were involved in these 20 high-cited publications including 8 publications from ISI-Kolkata; 5 publications from IIT-Kanpur; 3 publications from Kalyani Government Engineering College; and 2 publications from Indian Institute of Science, Bengaluru. These 20 high-cited publications were published in 14 journals including 4 publications in *IEEE Transactions on Neural Networks*, 2 publications in *Pattern Recognition*, 2 publications in *IEEE Transaction of Systems, Man and Cybernetics, Part B,* and 2 publications in *Evolutionary Computation*.

### *5.2.6 Computer Networks*

The total output in computer networks comprised 3976 publications during 1999-08. Of these publications, 2476 were published as conference publications, 1432 as articles, 43 as reviews, 13 as editorials and 3 as letters. The number of publications on computer networks increased from 600 during 1999-03 to 3367 in 2004-08, showing a growth rate of 461.17 per cent. Of the total publications on computer networks, 20.19 per cent (801 publications) appeared as internationally collaborative. The share of international-collaborative publications on computer networks decreased from 32.50 per cent (195 publications) during 1999-03 to 17.99 per cent (606 publications) during 2004-08. The h-index of the total publications in computer networks during 1999-08 was 43. The average citation per paper registered by the 3976 publications on a three-year citation window was 1.39. The average citation per paper decreased from 3.12 during 1999-03 to 1.08 during 2004-08. The major institutions contributing to computer networks research were:

*Institutes of National Importance:* IISc-Bengaluru (291 publications), IIT-Kharagpur (238 publications), IIT-Madras (227 publications), IIT-Delhi (194 publications), IIT-Bombay (173 publications)< IIT-Roorkee (101 publications), IIT-Kanpur (92 publications), ISI-Kolkata

(39 publications), IIT-Guwahati (62 publications), and IIM-Kolkata (39 publications).

*Universities/Deemed Universities*: Annamalai University (204 publications), Jadavpur University (91 publications), BITS-Pilani (38 publications), Jawaharlal Nehru University-New Delhi (35 publications), University of Delhi (31 publications), Aligarh Muslim University (31 publications), University of Hyderabad (28 publications), Bengal Engineering and Science University (21 publications), and Jayee University of Information Technology (20 publications).

*NIT/RECs:* NIT-Jamshedpur (51 publications), NIT-Tirchanapally (48 publications), NIT-Rourkela (37 publications) and Motilal Nehru NIT-Allahabad (19 publications).

*Industry:* IBM-India (82 publications), IBM India Research Laboratory (74 publications), Infosys Technologies Ltd (40 publications), TCS (34 publications), Motorola (32 publications), Bell Lab Research Centre (32 publications), Alcatel0Lucent-Bell Lab (26 publications), Honewell International India (26 publications) and Samsung Electronics (20 publications). *IIITs:* IIIT-Hyderabad (42 publications), IIIT-Allahabad (32 publications) and IIIT-Bengaluru (21 publications).

*Select Engineering Colleges:* Pondicherry Engineering College (41 publications), Sri Venkateswar College of Engineering (32 publications), PSG College of Technology (29 publications), Dhirubhai Ambani Institute of Communication and Technology (28 publications), NSIT-Delhi (23 publications), Rashtreeya Vidayalaya College of Engineering (23 publications), and Thiagarajan College of Engineering (20 publications).

*Research Institutes:* TIFR-Mumbai (38 publications) and C-DAC-Pune (19 publications).

The most productive authors participating in computer networks research were: C.S.R. Murthy (IIT-Madras, 76 publications); A. Kumar (IISc-Bengaluru, 33 publications); M. Misra (IIT-Roorkee, 28 publications); B.S. Manoj (IIT-Madras, 26 publications); S. Nandi (IIT-Guwahati, 25 publications); S. Shanmugavel (Annamalai University, 24 publications); K. Ramamritham (IIT-Bombay, 24 publications); R. Rastogi (Bell Lab Research Centre, 23 publications); V. Vaidehi (Annamalai University, 21 publications); and A.K. Sarje (IIT-Roorkee, 20 publications).

The major journals contributing in computer networks research are: *Lecture Notes in Computer Science including subseries, Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics* (296 publications), *IETE Journal of Research* (110 publications), *Information Technology Journal* (76 publications), *Computer Communication* (66 publications), *Computer Networks* (29 publications), *Wireless Networks* (24 publications), *IEEE/ACM Transaction on Networks* (24 publications), *IEEE Journal on Selected Areas in Communication* (20 publications), *Wireless Personal Communication* (20 publications) and *Photonic Network Communication* (19 publications).

These 3967 publications on computer networks received 10306 citations (since their publication till February 2010) with an average citation per paper of 2.60. Of the total publications in computer networks, 1403 have received one or more citations: 1142 in citations range of 1-9; 143 in citation range of 10-19; 52 in citations range of 20-29; 20 in citations range 30-39; 12 in citations range 40-49; 24 in citation range of 50-99; 8 in citation range of 100-199; and 2 in citation range of 200-299.

The top 20 high-cited publications received citations from 70 to 285. Of these 20 publications, 17 were published as articles and 3 as reviews. Among these 20 high-cited publications, 17 involved international collaborations (15 bilateral and 2 multilateral) and 4 national collaborations). Nineteen Indian organisations were involved in these 20 high-cited publications including 5 publications each from ISI-Kolkata and IIT-Delhi, 3 publications from from IIT-Madras, and 2 publications each from BITS-Pilani and Tajas Networks, Bengaluru. These publications were published in 13 journals, including 3 in *Wireless Networks* and 2 in *IEEE/ACM Transactions on Networking, IEEE Transaction in Communication*, *IEEE Networks*, and *IEEE Journal on Selected Areas in Communication* and *Computers.*

### *5.2.7 Computer Software*

The total research output in computer software comprised 4846 publications during 1999-08. Of these publications, 2373 were published as conference publications, 2389 as articles, 60 as reviews, 15 as editorials and 6 as letters. The number of publications on computer software increased from 1074 during 1999-03 to 3772 during 2004-08, showing a growth rate of 251.21 per cent. Of the total publications in computer software, 19.33 per cent (937 publications) appeared as internationally collaborative. The share of international-collaborative publications on computer software decreased from 24.95 per cent (268 publications) during 1999-03 to 19.33 per cent (669 publications) during 2004-08. The h-index of the total publications in computer software during 1999-08 was 52. The average

citation per paper registered by the 4846 publications on a three-year citation window was 2.06. The average citation per paper registered by total publications decreased from 3.08 during 1999-03 to 1.77 during 2004-08. The major institutions contributing to computer software research are:

*Institutes of National Importance:* IISc-Bengaluru (337 publications), ISI-Kolkata (297 publications), IIT-Delhi (289 publications), IIT-Kharagpur (278 publications), IIT-Madras (229 publications), IIT-Bombay (195 publications), IIT-Kanpur (176 publications), IIT-Roorkee (89 publications), IIT-Guwahati (55 publications) and IIM-Kolkata (24 publications).

*Universities/Deemed Universities*: Annamalai University (166 publications), Jadavpur University (129 publications), University of Delhi (51 publications), Bengal Engineering and Science University (48 publications), University of Mysore (43 publications), University of Hyderabad (41 publications), BITS-Pilani (39 publications), University of Calcutta (30 publications), GGS Indraprastha University (27 publications), Osmania University (24 publications), Aligarh Muslim University (24 publications) and Dayalbagh Education Institute-Agra (26 publications).

*NIT/RECs:* NIT-Jamshedpur (41 publications), NIT-Rourkela (39 publications), NIT-Tiruchiarappali (38 publications) and Motilal Nehru NIT-Allahabad (34 publications).

*Industry:* IBM-India (82 publications), IBM India Research Lab (77 publications), Infosys Technologies Ltd (57 publications), TCS (35 publications), Microsoft (34 publications), IBM Thomas J Watson Research Centre (28 publications), Tata Research Development and Design Centre-Pune (25 publications), Microsoft (23 publications) and Alcatel-Lucent Bell Lab (20 publications).

*Indian Institute of Information Technologies:* IIIT-Hyderabad (60 publications).

*Select Engineering Colleges:* PSG College of Technology (51 publications), Pondicherry Engineering College (28 publications), NSIT-Delhi (28 publications), Rashtreeya Vidayalaya College of Engineering (27 publications), Sri Venkateswar College of Engineering (25 publications), Thiagarajan College of Engineering (22 publications); and Dhirubhai Ambani Institute of Communication and Technology (20 publications).

*Research Institutes:* IMS-Chennai (34 publications) and TIFR-Mumbai (33 publications).

The most productive Indian authors participating in computer software research were: S.K. Pal (ISI-Kolkata, 41 publications); S.N. Sivanandam (PSG College of Technology, 32 publications); S. Bandyopadhyay (ISI-Kolkata, 29 publications); R. Kumar (IIT-Kharagpur, 26 publications); B.B. Chaudhuri (ISI-Kolkata, 25 publications); S. Sumathi (PSG College of Technology, 25 publications); P. Jalote (IIT-Kanpur, 23 publications); C.S.R. Murthy (IIT-Madras, 42 publications); R. Mall (IIT-Kharagpur, 22 publications); C.V. Jawahar (IIIT-Hyderabad, 22 publications).

The major journals contributing to computer software research were: *IETE Journal of Research* (140 publications), *Pattern Recognition* (88 publications), *Pattern Recognition Letters* (84 publications), *Information Technology Letters* (54 publications), *Bioinformatics* (41 publications), *Lecture Notes in Computer Science including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics* (38 publications), *IEEE Transaction on Systems, Man and Cybernetics, Part B* (33 publications), *Signal Processing* (32 publications), *Studies in Communication Intelligence* (29 publications), *Advances in Modelling and Analysis, Part B* (27 publications) and *Computer Communication* (25 publications). These 4846 publications on computer software received 22579 citations (since their publication till February 2010) with an average citation per paper of 4.66. Of these, 2199 received one or more citations; 1709 in citations range of 1-9; 293 in citation range of 10-19; 83 in citations range of 20-29; 36 in citations range 30-39; 21 in citations range of 40-49; 41 in citation range of 50-99; 11 in citation range of 100-199; 2 in citation range of 200-299; 1 in citation range of 401-499; and 2 above 2000 citations**.**

The top 20 high-cited publications on computer software received citations from 89 to 2245. Of these 20 high-cited publications, 16 were published as articles, 3 as reviews, and 1 as conference paper. Among these 20 high-cited publications, 7 involved international collaborations (4 bilateral and 3 multilateral), 7 national collaborations, while 6 have no collaboration. Fifteen Indian organisations involved in these 20 high-cited publications were: ISI-Kolkata (6 publications), IISc-Bengaluru (3 publications), IIT-Kanpur (3 publications), IIT-Madras (2 publications) and IMTECH-Chandigarh (2 publications). These 17 high cited publications were published in 14 journals including 3 in *IEEE Transactions on neural Network* and 2 publications each in *IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE transaction on Evolutionary Computation,* and *Bioinformatics.*

### 5.2.8 Computer Architecture

The total research output in computer architecture comprised 284 publications during 1999-08. Of these, 154 were published as conference publications, 126 as articles, 3 as reviews, and 1 as editorial. The number of publications on computer architecture increased from 76 during 1999-03 to 208 during 2004-08, showing a growth rate of 173.68 per cent. Of the total publications on computer architecture, 29.22 per cent (83 publications) appeared as internationally collaborative. The share of international-collaborative publications in computer architecture decreased from 34.21 per cent (26 publications) during 1999-03 to 27.40 per cent (57 publications) during 2004-08. The h-index of the total publications during 1999-08 was 15. The average citation per paper in computer architecture registered by the 284 publications on a three-year citation window was 1.76. The average citation per paper increased from 1.70 during 1999-03 to 1.83 during 2004-08. The major Indian institutions contributing on computer architecture research were:

*Institutes of National Importance:* IISc-Bengaluru (30 publications), IIT-Bombay (17 publications), IIT-Delhi (17 publications), IIT-Madras (14 publications), IIT-Kharagpur (12 publications), IIT-Kanpur (12 publications), ISI-Kolkata (6 publications) and IIT-Roorkee (4 publications).

*Universities/Deemed Universities:* Annamalai University (10 publications), BITS-Pilani (8 publications), Jadavpur University (5 publications), Bengal Engn and Science University (3 publications), Vellore Institute of Technology (3 publications), Behampur University (3 publications) and West Bengal University of Technology (2 publications).

*NIT/RECs:* NIT-Tiruchiarapalli (5 publications); *Industry:* IBM-India (9 publications), Infosys Technologies Ltd (9 publications), IBM India Research Lab (9 publications), IBM Research (5 publications), Intel Corporation (4 publications), Alcatel-Lucent-Bell Lab (3 publications), Texas Instruments (3 publications), Tata Res Dev and Design Centre,-Pune (3 publications), Samsung Electronics (3 publications), Emuzed India Pvt Ltd (2 publications) and Avisere Inc (2 publications),

*Indian Institute of Information Technologies:* IIIT-Hyderabad (4 publications).

*Select Engineering Colleges:* Dhirubhai Ambani Institute of Communication and Technology (6 publications) and Sri Venkateswar College of Engineering (4 publications) and Research Institutes: TIFR-Mumbai (3 publications).

The most productive Indian authors participating in computer architecture research were: R. Govindarajan (IISc-Bengaluru, 10 publications), K. Ramamritham (IIT-Bombay, 5 publications), T.S.B. Sudarshan (BITS-Pilani, 5 publications), M. Balakrishnan (IIT-Delhi, 5 publications), M. Chaudhuri (IIT-Kanpur, 4 publications), P. Jalote (IIT-Kanpur, 3 publications), S. Reddy (Tata Research Development and Design Center, 3 publications), S. Gurunarayanan (BITS-Pilani, 3 publications), P. Goyal (IIT-Bombay, 3 publications) and A. Sarje (III-Roorkee, 3 publications).

The major journals contributing to computer architecture research were: *Information Technology Journal* (6 publications), *Journal of Systems Architecture* (5 publications), *Microprocessors and Microsystems* (4 publications), *IBM Journal of Research and Development* (4 publications), *IEEE Transaction on Very Large Scale Integration VLSI Systems* (4 publications), *International Journal of Computing and Applications* (4 publications), *IEEE Internet Computing* (3 publications), *IEEE Micro* (3 publications), *IEEE Software* (3 publications), *Journal of Parallel and Distributed Computing* (3 publications) and *IEEE Transactions on Computers (*3 publications).

These 284 publications on computer architecture received 946 citations (since their publication till February 2010) with an average citation per paper of 3.33136. Of these publications on computer architecture, 136 received one or more citations: 104 in citations range of 1-9; 24 in citation range of 10-19; 3 in citations range of 20-29; 1 in citations range 30-39; 1 in citations range 40-49; and 3 in citation range of 50-99.

The top 20 high-cited publications on computer architecture received citations from 12 to 78. Of these publications, 16 were published as articles and 4 as conference publications. Among these 20 high-cited publications, 14 involved international collaborations (12 bilateral and 2 multilateral), 2 national collaborations and 5 have no collaborations). Sixteen Indian organisations were involved in these 20 high-cited publications including 3 publications from IBM India Research Lab, New Delhi, and 2 publications each from IBM Engineering and Technology Services, Bengaluru, IIT-Bombay, IIT-Delhi and IIT-Kharagpur. These 20 high-cited publications were published in 15 journals; including 3 in *IBM Journal of Research* and *Development* and 2 publications each in *Journal of VLSI Signal Processing Systems for Signal, Image* and *Video Technology* and *IEEE Micro*.

### 5.2.9 Operating Systems

The total research output in operating systems comprised 169 publications during 1999-08. Of these publications, 99 were published as conference

publications, 69 as articles and 1 as a review. The number of publications on operating systems increased from 33 during 1999-03 to 136 during 2004-08, showing a growth rate of 312.12 per cent.

Of the total publications, 23.08 per cent (39 publications) appeared as internationally collaborative. The share of international-collaborative publications in operating systems decreased from 30.30 per cent (10 publications) during 1999-03 to 21.32 per cent (29 publications) during 2004-08. The h-index of the total publications in operating systems during 1999-08 was 10. The average citation per paper registered by the 169 publications on a three-year citation window was 1.08. The average citation per paper has decreased from 2.00 during 1999-03 to 0.85 during 2004-08. The major Indian institutions contributing to operating systems research are:

*Institutes of National Importance:* IIT-Bombay (10 publications), IISc-Bengaluru (9 publications), IIT-Kanpur (8 publications), IIT-Delhi (8 publications), IIT-Madras (7 publications), IIT-Roorkee (6 publications), IIT-Kharagpur (5 publications), ISI-Kolkata (4 publications) and IIM-Bengaluru (2 publications).

*Universities/Deemed Universities*: Annamalai University (8 publications), University of Hyderabad (3 publications), Sardar Patel University (2 publications), Jadavpur University (2 publications) and University of Delhi (2 publications); *Industry:* BM-India (8 publications), IBM India Res Lab (5 publications), IBM Thomas J Watson Research Center (4 publications), Microdoft Research (4 publications), IBM Research (3 publications), Samsung Electronics (3 publications), Grid Logistics Technologies (2 publications), Sun Microsystems (2 publications), Hewlett-Packard (2 publications), Tata Res Dev and Design Centre,-Pune (2 publications), Intel Corporation (2 publications), Texas Instruments (2 publications), Satyam Computers (2 publications) and Philips Electronics (2 publications),

*Select Engineering Colleges:*Dhirubhai Ambani Institute of Communication and Technology (2 publications) and University College of Engineering, Burla (2 publications), GZS College of Engn and Technology (2 publications) and Pune Institute of Computer Technology (2 publications).

*Research Institutes:* C-DAC-Pune (2 publications) and BARC-Mumbai (2 publications).

The most productive Indian authors participating on operating systems research were: M. Chaudhuri (IIT-Kanpur, 4 publications), S.K. Nandy (IISc-Bengaluru, 4 publications), A. Chaudhuri (Microsoft, 3 publications), P.P. Chakrabarti (IIT-Kharagpur, 3 publications), D. Janakiram (IIT-Madras, 3 publications), P. Naldurg (Microsoft, 3 publications), S. Rajamani (Microsoft) (3 publications), R. Kumar (IIT-Kharagpur, 2 publications), M. Balakrishnan (IIT-Delhi, 2 publications) and S. Hangal (Sun Microsystem, 2 publications).

The major journals contributing to operating systems research are: *IEEE Transaction on Parallel* and *Distributed Systems* (5 publications), *Operating Systems Review* (3 publications), *Lecture Notes in Computer Science including Subseries Lecture Notes in Artificial Intelligence* and *Lecture Notes in Bioinformatics* (3 publications), *IETE Journal of Research* (3 publications), *Wseas Transaction on Computers* (2 publications), *Software Practice and Experiment* (2 publications), *Journal of Systems Architecture* (2 publications), *Journal of Parallel and Distributed Computing* (2 publications), *International Journal of Parallel Programming* (2 publications), *IEEE Software* (2 publications), and *IBM Journal of Research* and *Development* (2 publications).

These 169 publications on operating systems received 231 citations (since their publication till February 2010) with an average citation per paper of 1.37. Of the total publications on operating systems, 38 received one or more citations; 28 in citations range of 1-9; 7 in citation range of 10-19; 2 in citations range of 20-29; and 1 in citations range 30-39.

The top 20 high-cited publications on operating systems received citations from 3 to 34. Of these, 15 were published as articles and 5 were conference publications. Among these 20 high-cited publications, 15 involved international collaborations (14 bilateral and 1 multilateral), 2 national collaborations while 5 have no collaboration). Eighteen Indian organisations were involved in these 20 high-cited publications including 3 publications by IIT-Delhi, and 2 publications each by IIT-Bombay and Tata Research Development and Design Centre, Pune. These 20 high-cited publications were published in 14 journals, including 2 publications each in *IEEE Transactions on Parallel and Distributed Systems* and *IEEE Software.*

### *5.2.10 Cryptology*

The Indian research output in cryptology comprised 177 publications during 1999-08. Of the total publications on cryptology, 130 were published as conference publications, 45 as articles, and 2 as reviews. The number of publications in cryptology has increased from 18 during 1999-03 to 159 during 2004-08, showing a growth rate of 783.33 per cent. Of the total publications, 14.12 per cent (25) appeared as internationally collaborative. The share of international-collaborative publications decreased from 16.67 per cent (3 publications) during 1999-03 to 13.84 per cent (22 publications) during 2004-08. The h-index of the total

publications on cryptology during 1999-08 was 9.5. The average citation per paper registered by the 177 publications on a three-year citation window was 1.33. The average citation per paper decreased from 2.11 during 1999-03 to 1.24 during 2004-08. The major Indian institutions contributing to cryptology research were:

*Institutes of National Importance:* ISI-Kolkata (43 publications), IIT-Kharagpur (12 publications), IIT-Madras (7 publications), IIT-Delhi (5 publications), IISc-Bengaluru (3 publications) and IIT-Guwahati (2 publications),

*Universities/Deemed Universities*: Annamalai University (10 publications), Jadavpur University (6 publications), Vellore Institute of Technology (2 publications) and Osmania University (2 publications);

*Industry:* Infosysis Technologies Limited (5 publications), TCS (4 publications), IBM-India (2 publications) and Microsoft Research (2 publications).

*Select Engineering Colleges:* Sidganga Institute of Technology–Tumkar (14 publications), National Institute of Engineering, Mysore (4 publications) and M.S.Ramaiah Institute of Technology (2 publications).

*Research Institutes:* TIFR-Mumbai (3 publications) and C-MMACS-Bengaluru (2 publications).

*NITS/RECS:* NIT-Warangal (13 publications) and NIT-Calicut (2 publications).

The most productive Indian authors participating in in cryptology research were: A. Maitra (ISI-Kolkata, 23 publications); P. Sarkar (ISI-Kolkata, 20 publications); B.B. Amberker (NIT-Warangal, 13 publications); N.R. Sunitha (Sidganga Institute of Technology-Tumkar, 10 publications); K.C. Gupta (ISI-Kolkata, 8 publications); G. Paul (Jadavpur University, 6 publications); D. Mukhopadhyay (IIT-Kharagpur, 5 publications); T.K. Das (ISI-Kolkata, 3 publications); N. Nalini (Sidganga Institute of Technology, 4 publications); and G. Raghavendra (National Institute of Engineering-Mysore, 4 publications).

The major journals contributing to cryptology research were: *Lecture Notes in Computer Science including Sub-series Lecture Notes in Artificial Intelligence* and *Lecture Notes in Bio-informatics* (44 publications), *IEEE Transactions on Information Theory* (5 publications), *Lecture Notes in Computer Science* (4 publications), *Wseas Transaction on Computers* (3 publications), *IEICE Transaction on Fundamentals of Electronics Communication and Computer Science* (2 publications), *Information Technology Journal* (2 publications), *Computer Communications* (2 publications), *Journal of Institution of Engineers. Part CP: Computer Engineering Division* (2 publications), *Theoretical Computer Science (*2 publications), and *Wseas Transaction in Information Science and Applications* (1 paper)

These 177 publications on cryptology received 315 citations (since their publication till February 2010) with an average citation per paper of 1.78. Of the total publications on cryptology, 58 publications received one or more citations: 49 in citations range of 1-9; 6 in citation range of 10-19; 1 in citations range of 20-29; 1 in citations range of 30-39; and 1 in citations range 50-99.

The top 20 high-cited publications on cryptology received citations from 4 to 58. Of these 20 high-cited publications, 14 were published as articles, 5 as conference publications, and 1 as a review paper. Among these 20 high-cited publications, 4 involved international collaboration (4 bilateral), 1 national collaboration, while 13 have no collaboration). Ten Indian organisations were involved in these 20 high-cited publications including 14 publications from ISI-Kolkata. These 20 high-cited publications were published in 13 journals including 4 publications each in *Lecture Notes in Computer Science* and *IEEE Transaction in Information Theory,* and 2 publications in *Lecture Notes in Computer Science* including *Sub-series Lecture Notes in Artificial Intelligence* and *Lecture Notes in Bio-informatics.*

### *5.2.11 Computer Hardware*

The research output in computer hardware comprised 721 publications during 1999-08. Of these publications, 409 were published as conference publications, 304 as articles, 6 as reviews, and 1 each as editorial and article in press. The number of publications on computer hardware increased from 181 publications during 1999-03 to 540 publications during 2004-08, showing a growth rate of 190.34 per cent. Of these, 22.75 per cent (164 publications) appeared as internationally collaborative. The share of international collaborative publications in computer hardware decreased from 27.62 per cent (50 publications) duing 1999-03 to 21.11 per cent (114 publications) during 2004-08. The h-index of the total publications on computer hardware during 1999-08 was 18. The average citation per paper registered by the 721 publications on a three-year citation window was 2.54. The average citation per paper decreased from 3.35 during 1999-03 to 2.27 during 2004-08. The major Indian institutions contributing to computer hardware research were:

*Institutes of National Importance:* IIT-Bombay (10 publications), IISc-Bengaluru (54 publications), IIT-Kharagpur (51 publications), IIT-Delhi (41 publications), IIT-Madras (34 publications), IIT-Bombay (31 publications), IIT-Kanpur (18 publications), IIT-Guwahati

(14 publications), ISI-Kolkata (13 publications) and IIT-Roorkee (8 publications)

*Universities/Deemed Universities*: Annamalai University (34 publications), Jadavpur University (17 publications), BITS-Pilani (13 publications), Aligarh Muslim University (11 publications), Bengal Engn and Science University (10 publications), Cochin University of Science and Technology (8 publications), Vellore Institute of Technology (6 publications), University of Delhi (5 publications), Osmania University (6 publications), Guru Nanak Dev University (5 publications) and Amravati University (4 publications);

*Industry:* IBM-India (16 publications), Texas Instruments (15 publications), Intel Corporation (12 publications), IBM Thomas J Watson Research Center (10 publications), Infosysis Technologies Limited (10 publications), IBM India Research Lab-New Delhi (9 publications), Tata Res Dev and Design Centre-Pune (7 publications) and IBM Research (6 publications).

*Select Engineering Colleges:* NSIT-Delhi (9 publications), Dhirubhai Ambani Institute of Communication and Technology (6 publications), G H. Raisoni College of Engineering (6 publications) and Sree Venkateswara College of Engineering (5 publications).

*Research Institutes:* TIFR-Mumbai (6 publications), CEERI-Pilani (5 publications), NPL-Delhi (4 publications) and DRDO (4 publications).

*NIT/RECs:* NIT–Tiruchirapally (6 publications) and NIT-Rourkela (4 publications).

*Indian Institute of Information Technologies:* IIIT-Hyderabad (13 publications).

The most productive authors participating in computer hardware research were: R. Govindarajan (IISc-Bengaluru, 12 publications); M.B. Srinivas (IIIT-Hyderabad, 8 publications); S.K. Nandy (IISC-Bengaluru, 5 publications); S.S. Rajput (ABV Indian Institute of Information Technology and Management-Gwalior, 7 publications); I. Chakrabarti (IIT-Kharagpur, 7 publications); B.B. Bhattacharya (ISI-Kolkata, 7 publications); S. Banerjee (IIT-Kharagpur, 6 publications); P.P. Chakrabarti (IIT-Kharapur, 6 publications); R. Senani (NSIT-Delhi, 6 publications); and M.Balakrishnan (IIT-Delhi, 6 publications).

The major journals contributing to computer hardware research were: *IETE Journal of Research* (27 publications), *IEEE Transaction on Computer Aided Design of Integrated Circuits* and *Systems* (11 publications), *Microprocessors* and *Microsystem*s (11 publications), *Information Technology Journal* (11 publications), *Signal Processing* (10 publications), *IEEE Transactions on Very Large Scale Integration VLSI System* (9 publications), *Analog Integrated Circuits* and *Signal Processing* (8 publications), *Journal of System Architecture* (8 publications), *Journal of VLSI Signal Processing System for Signal, Image* and *Video Technology* (8 publications) and *Journal of Circuits System* and *Communication* (7 publications).

These 721 publications on computer hardware received 1491 citations (since their publication till February 2010) with an average citation per paper of 2.07. Of the total publications on computer hardware, 189 publications received one or more citations: 146 in citations range of 1-9; 29 in citation range of 10-19; 4 in citations range of 20-29; 2 in citations range 30-39; 4 in citations range 40-49; and 4 in citations range 50-99. The top 20 high-cited publications on computer hardware received citations from 28 to 208. Of these 20 high-cited publications, 19 are published as articles, and 1 as a review. Among these 20 high-cited publications, 16 involved international collaboration (11 bilateral and 5 multilateral), 1 national collaboration, while 3 have no collaboration). Fifteen Indian organisations were involved in these 20 high-cited publications including 5 publications from IIT-Delhi, 2 publications each from BITS-Pilani, IIT-Bombay, and IIT-Kharagpur. These 20 high-cited publications were published in 67 journals, including 3 publications in *IEEE Micro* and 2 publications each in *IEEE Software,* and *IEEE Journal on Selected Areas of Communication.*

## 6. SUMMARY AND CONCLUSION

The cumulative publications output of India in computer science comprised 15924 publications during 1999-08, with average number of publications per year as 1592. It increased from 3315 publications during 1999-03 to 12609 publications during 2004-08, witnessing a growth of 280.36 per cent. India's annual average publication growth rate during 1999-2008 was 28.68 per cent. In terms of impact and quality, the average citations per paper registered by India's publications output were 2.10 during 1999-06. The h-index registered by all Indian publications during 1999-08 was 60. The cumulative collaborative publications output accounted for 19.92 per cent in the cumulative output of India in computer science. For the sub-fields cumulative output in Indian computer science research during 1999-08, the maximum research priority (4846 publications, 30.43 per cent share) is assigned to computer software in India during 1999-08, followed by computer networks (3967 publications, 24.91 per cent share), artificial intelligence (2394 publications, 15.03 per cent share), cryptology and computer hardware (721 publications, 4.53 per cent share, each), database management system (543 publications, 3.41 per cent share), software engineering (516 publications, 3.24 per

cent share), computer theory (504 publications, 3.17 per cent share), Internet and multi-media (499 publications, 3.13 per cent share), computer architecture (284 publications, 1.78 per cent share), and operating systems (169 publications, 1.06 per cent share). Out of 11 sub-fields identified above, only 3 sub-fields witnessed increase in their activities from 1999-03 to 2004-08 as reflected in their activity index: computer networks (from 72.65 to 107.19), software engineering (from 89.37 to 102.79), and operating systems (93.80 to 101.63). While in the remaining, there is a relative decline in publication activity.

In terms of growth from 1999-03 to 2004-08, the maximum growth rate (783.33 per cent) was registered by cryptology, followed by Internet and multimedia (557.07 per cent), computer networks (461.17 per cent), software engineering (337.5 per cent), operating systems (312.12 per cent), computer theory (266.67 per cent), computer software (251.21 per cent), artificial intelligence (223.79 per cent), database management system (208.27 per cent), computer hardware (190.34 per cent), computer architecture (173.68 per cent), computer networks (20.19 per cent), and Internet and multimedia (20.15 per cent). In terms of h-index value during 1999-08, the maximum (52) was registered by computer software, followed by computer networks (43), artificial intelligence (40.5), Internet and multimedia (31), database management system (23), computer hardware (18), computer theory (17), software engineering (16), computer architecture (15), operating systems (10), and cryptology (9.5). In terms of share of international collaborative publications during 1999-08, the maximum (29.22 per cent) wasregistered by computer architecture, followed by artificial intelligence (23.94 per cent), operating systems (23.08 per cent), database management system (23.08 per cent), computer hardware (22.75 per cent), computer theory (19.84 per cent), computer software (19.33 per cent), software engineering (18.80 per cent), and cryptology (14.12 per cent).

The impact and quality of research output under various sub-fields was also studied in terms of citations received on the three-year citations window during 1999-08. The maximum impact (4.41) was made by Internet and multimedia, followed by computer hardware (2.54), artificial intelligence (2.07), computer software (2.06), database management system (1.90), computer architecture (1.76), computer theory (1.45), computer networks (1.39), cryptology (1.33), software engineering (1.24), and operating systems (1.08). In terms of change in citation impact from 1999-03 to 2004-08, the sub-fields, which have improved their impact were: Internet and multimedia (from 3.99 to 4.68) and computer architecture (from 1.70 to 1.83). In all other fields, the impact has gone down from 1999-03 to 2004-08: computer theory (from 1.89 to 1.34), software engineering (from 2.04 to 1.06), database management (from 2.86 to 1.59), artificial intelligence (from 3.09 to 1.79), computer networks (from 3.12 to 1.08), computer software (from 3.08 to 1.77), operating system (from 2.0 to 0.85), computer hardware (from 3.35 to 2.27), and cryptology (from 2.11 to 1.24). India's strength and weakness as reflected in the analysis of 11 sub-fields of computer science gives valuable clues to Indian policy makers to plan for future research strategies, and to funding agencies to plan resource allocation in specific areas of national and global interests, which may be more crucial for future development of IT industry in India.

## REFERENCES


1. http://www.gatewayforIndia.com/technology/informa tionper cent20technology.htmlspx.

2. http://www.ibef.org/industry/informationtechnology.a spx.

3. http://en.wikpedia.org/information_Technology_in_ India.

4. Ramamritham, Krithi. Computer science research in India.http://www.fas.org/nuke/quide/india/agency/ kriti2.html.

5. Das, A.K. & Karanjai, A. Institutional distribution in computer science research in India: A study. *Annamalails Lib. Inf. Stud.,* 2002, **49**(1), 23-27.

6. Gupta, B.M. & Dhawan, S.M. Computer science research in India: A scientometric analysis of research output during the period 1994-2001. *DESIDOC Bull. Inf. Technol.,* 2005, **25**(1), 3-11.

7. Suresh Kumar & Garg, K.C. Scientometrics of computer science research in India and China. *Scientometrics,* 2005, **64**(2), 121-32.

## Keywords used for Searching Publication Data for the following Sub-fields

### Computation Theory

Finite automata, regular and language or expression, context-free) and (grammar or language), recursive function, turing machine, time complexity, automata theory, computation theory

### Software Engineering

Software and engineering, object-oriented design, black box and white box and testing), incremental testing, software metrics, software reliability, software standard, cocomo, capability maturity model, petri net, srs or uml

### Database Management Systems

Database management system, data abstraction, data definition language" or "ddl, data dictionary, e-r diagram, relational database management system" or rdbms, query language, sql" or odl or oql, relational calculus, bi-relation or multi relation, join algorithm, shadow paging, data ware house, data structure, data manupulation language or dml, database task group or dbtg

### Internet and Multimedia

Internet programming, html, xml, applete programming, http*, web server, search engine, crawler technology, Internet robot, web mining, e-commerce, web security, user interface style, visual design, multimedia, ip address, firewall, Internet

### Artificial Intelligence

Artificial intelligence, production system and matching, problem reduction, search space, heuristic search, knowledge representation, semantic net, fuzzy and (reasoning or logic), neural and (network or language), pattern directed search, propositional and predicate logic, natural language understanding, vision understanding, speech understanding, genetic algorithm

### Computer Networks

Network and protocol, wireless and (comm* or network), bandwidth and data, local area network or LAN, router, congestion and control, inter and connection and network, computer and network), Asynchronous and transfer and (mode or switch), client and server and (system or comput*), wide area network" or WAN, broadband), packet and switch*, socket and switch*, optical and connection, gateway* and computer and network), data transfer, distributed computing, world wide web" or WWW, packet OR circuit) and switch*, Internet and protocol, proxy and server, TCP-IP

### Computer Software

Computer AND software, computer simulation, computer aided" AND (software OR design), compiler design, object oriented program*, real time system, data mining, data acquisition, pattern and (matching OR recognition), image processing, java programming, programming language, software and architecture, software and (design or engineering or testing), user computer interface, computer graphic, graph theory

### Computer Architecture

Computer architecture, (cisc or risc) and architecture, sisd, simd, misd, mimd, instruction pipelining, cache memory, virtual memory, interleaved memory, shared-memory and architecture, computer organi*, instruction format, addressing mode

### Operating System

Operating system, interrupt handling, batch-processing, multiprogramming, demand paging, cpu scheduling, concurrent process, deadlock and (prevention or avoidance or detection or recovery), spool management, directory structure, file system, multiprocessing

### Cryptology

Cryptography and cryptanalysis, (private or public) and cryptography, linear cryptanalysis, rsa system, digital signature, stream ciphers

### Computer Hardware

Computer and hardware, digital signal processing, computer architecture, cmos