Computer science research: the top 100 institutions in India and in the world

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Computer Science Research: The Top 100 Institutions in India and in the World

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Abstract: This paper aims to perform a detailed scientometric and text-based analysis of Computer Science research output of the 100 most productive institutions in India and in the world. The analytical characterization is based on research output data indexed in Scopus during the last 25 year period (1989-2013). Our computational analysis involves a two-dimensional approach involving the standard scientometric methodology and text-based analysis. The scientometric characterization aims to assess Indian research in CS domain vis-à-vis the world top and to bring out the similarities and differences among them. It involves analysis along traditional scientometric indicators such as total output, citation-based impact assessment, co-authorship patterns, international collaboration levels etc. The text-based characterization aims to identify the key research themes and their temporal trends for the two institution sets. The experimental work is one of its kinds and perhaps the only such work that identify characteristic similarities and differences in CS research landscape of Indian institutions vis-à-vis world institutions. The paper presents useful analytical results and relevant inferences.

Keywords: Computer Science Research, India, Information Technology, Informetrics, Scientometrics.

JEL Classification I23

1. Introduction

The Information Technology (IT) plays a very vital role in progress of any nation in the modern era. The Information and Communication Technologies (ICT), to a large extent, are based on research and development in Computer Science (CS). The present century has witnessed rise of knowledge economies and nations across the world are investing more and more on the development of science and technology, particularly ICT. Though, a late starter in CS domain research, India has got more and focuses on it during last two decades and has attained a respectable presence in the IT development sector. However, Indian institutions are yet to attain the stage of being at forefront of knowledge creation in CS domain. In this context, it is important to measure and assess research competence of most productive Indian institutions vis-à-vis the most productive world institutions. This paper presents our research work with this broader motivation and presents outcomes and inferences obtained using standard scientometric and a novel text-based analytical methodology. Our analysis involves a fairly large set of 100 most productive institutions in India as well as in the world. The data for analysis is the CS domain research output for last 25 year period (1989-2013) indexed in Scopus[1].

We have tried to do a systematic computational analysis to characterize similarities and differences in the research output of most productive institutions of India and the world. Our effort has been to present a detailed analytical characterization of CS research from most productive Indian institutions vis-à-vis the most productive institutions worldwide. More precisely, we aim to answer following research questions:

- What are characteristic similarities and differences in CS domain research of most productive Indian institutions and the most productive world institutions?
- What is India's contribution to the total CS research worldwide and what is its relative impact?
- What major research themes are pursued by most productive Indian institutions and how does it relate to the research themes pursued in most productive world institutions?
- What inferences such a characterization may have for Indian institutions in CS domain research?

We believe that the results and discussion in the paper help in answering the research questions stated above and few other related ones.

The rest of the paper is organized as follows: Section 2 briefly describes some related work. The section 3 presents a brief overview of CS domain research in India. Section 4 describes the data collection and the section 5 explains the methodology followed. The section 6 presents results of scientometric indicator computations for both Indian and world institutions. Section 7 presents analysis of Indian and world CS research institutions using Exergy-based trajectory analysis. Section 8 describes the identification of

[1] http://www.scopus.com/

research themes in the data and their trends. The section 9 presents a summary of the work and the major inferences obtained.

2. Related Work

Though, no previous work have done the kind of analytical characterization we attempted to do, we still list some past research work focused on scientometric profiling for a country/ region and/ or a particular subject. Most of these related research publications are, however, limited to performing standard scientometric analysis. Nevertheless, we list some of the research works that helped us in identifying our research questions and the comparative analysis methodology. A recent work (Fu, 2013) studied the independent research of China and compared the results with the publication outputs of seven major industrialized countries. Another work (Kao, 2012) studied the improvement in management research in Taiwan for a specific domain. Another related work (Gupta, 2011) accessed several parameters such as total research output, its growth, rank and global publication share, citation impact, share of international collaborative papers of Indian CS research output during 1999-2008. One more recent study (Matthews, 2013) tried to find typical ranges of two measures of individual productivity: number of papers and sum of author share for physics publications in South African universities. Another work (De Souza, 2012) aimed to present the profile of the researchers, the pattern of scientific collaboration and the knowledge organization in the area of information science in Brazil. In one of our recently published work (Uddin, 2014a), we tried to map the academic research landscape of South Asian countries involving all disciplines. Another recent work (Uddin, 2014b) did a similar analysis for the CS domain research in the SAARC region. Some researchers also dedicated their researches solely to explore the collaboration in different scientific domains discovering collaboration patterns and its impact on research activities. One of such works (Tang, 2011) analyzes the rapid growth of China in the field of nanotechnology and the rise of collaboration between China and the US in this emerging domain. Similarly, some other recent papers (Ozel, 2012; Onyancha, 2011; Costa, 2013; Prathap, 2013; Teodorescu, 2011; Abramo, 2013; Viana, 2013; Ortega, 2013; and Liu, 2013) reported different aspects of collaboration, growth and quantitative/ qualitative measurements. In most of these works, the techniques of presenting and analyzing research output vary over researchers' need and similarly, the covered datasets are time and source dependent. Though, we learned lessons from the previous works listed here, we aimed to do a different kind of analytical characterization using both, the standard scientometric and a text-based computational analysis.

To the best of our knowledge, no previous work aimed to do the kind of analytical characterization, we report here for the CS domain research in India (vis-a-vis the world).

3. Overview of CS Research in India

CS as an academic discipline in the world began in a systematic manner in 1950s. The world's first computer science degree program, the Cambridge Diploma in Computer Science, began at the University of Cambridge Computer Laboratory in 1953. The first computer science degree program in the United States was initiated at Purdue University in 1962[2]. The now well-known department of Computer Science in Stanford University was founded in 1965[3]. Thereafter, a large number of universities in developed countries started CS education in the period of 1960's. In India, CS as an academic discipline was first introduced in 1963 by Indian Institute of Technology (IIT) Kanpur, with the start of "Computer-related" courses and the first "CS classroom", though an independent academic program in CS started in 1971[4]. The IIT Madras CS department started in 1973[5], though initially as Computer center. Similarly, formal CS department started in IIT Kharagpur in 1980[6] and IIT Bombay in 1982[7], in continuation to their initial efforts at teaching computing courses. The department of Computer Science and Automation (CSA)[8] at Indian Institute of Science (IISc) Bangalore started in 1969. It was originally called the "School of Automation" and continued to be known with this name till the mid-eighties. In the university system, Jadavpur University started a postgraduate diploma in CS in 1968, a first of its kind. A formal department of CS was carved out of trifurcation of the ECTE department in 1988[9]. The (Indian Statistical Institute) ISI Calcutta started a two year M. Tech. program in CS in 1981, perhaps first such postgraduate program of its kind[10]. By the end of 1980s, many prominent institutions started academic programs/ departments in CS. However, in the early period, the major focus was on education, training and manpower development. Research activity in CS started to grow only in 1990s. The last two decades have seen CS research gaining momentum, with establishment of CS departments in all major universities/ institutions and establishment of specialized institutions for Information Technology (IT) teaching and research. Some of these new specialized IT

[2] http://en.wikipedia.org/wiki/Computer_science
[3] http://cs.stanford.edu/
[4] http://www.cse.iitk.ac.in/dept/index.html
[5] http://www.cse.iitm.ac.in/
[6] http://cse.iitkgp.ac.in/
[7] http://www.cse.iitb.ac.in/page17
[8] http://www.csa.iisc.ernet.in/aboutus/aboutus.php
[9] http://www.jaduniv.edu.in/htdocs/view_department.php?deptid=59
[10] http://www.isical.ac.in/~mtechcs/

institutions have gained a very respectable presence in CS research in a very short span of time. Some of the major IT companies have also started their research laboratories in India during the last 2-3 decades, such as IBM Research in 1988 and Microsoft Research in 2005. Some applied research in CS domain is now also carried out at various government laboratories/ organizations, such as CSIR[11], DRDO[12], ISRO[13] etc.

In order to have a more informed picture of the current status of CS research in India, we have collected data for CS domain research output of all institutions in India, for the 25 year period from 1989 to 2013, from the Scopus database. This period happens to be the period of actual growth in CS research in India. We plot the year-wise proportionate contribution of India to the total CS domain research worldwide in Figure 1. We see that India's share to the total CS research output of the world is increasing in general, except in few years. In terms of percentage contribution, it increased from 1.88% in 1989 to 4.95% in 2013. The rate of growth is more clearly visible from 2000-01. Also, computing the rates of growth of CS research in India and the total world tells us that India's average rate of growth is higher than the world.

4. Data Collection

We have collected data of CS research output for a period of 25 years (1989-2013) from Scopus, a well-known bibliometric database. A total of 2,876,512 publication records ~~are~~ (were) found for the period 1989-2013 for the whole world, where India contributes 84,385 (about 2.93%) research papers, as on March 2014. We collected data institution-wise for 100 most productive institutions from India (referred to as I100) and the world (referred to as W100). Our collection, though not exhaustive, is a good representative of research output data. The collected representative data covers ~~846,527~~ 846,526 records (about ~~29.43%~~ 29.6%) of the world CS research output and ~~59,682~~ 59,619 records (~~70.73%~~ 71%) of the total Indian CS research output~~. Out of a total of 61,502 records in Scopus for Indian CS research output (I100), 1,314 entries have missing year value and about 506 duplicate entries, which leave unique records as 59,682.~~ Out of a total 60,119 records in Scopus for Indian CS research output (I100), duplicate records were removed, which leave 59,619 unique records. Similarly, for world universities in CS research (W100), ~~846,527~~ 846,526 are unique records as against 924,575 records originally found in data. In addition to CS domain research output of I100 and W100, we also collected some related statistics for India and world, such as

[11] http://www.csir.res.in/
[12] www.drdo.gov.in
[13] http://www.isro.org/

Gross Expenditure on Research and Development (GERD), Researchers per million people etc. The table 1 shows these values to establish a broader background perspective for our analytical characterization.

5. Methodology

Our analytical characterization methodology is primarily a two-dimensional approach, comprising of a standard scientometric analysis and a computational text analysis. First, we perform a scientometric characterization along the six main indicators, namely Total Publication (TP), Total Citations (TC), Average Citation Per Paper (ACPP), HiCP (Highly Cited Papers), Internationally Collaborated Papers (ICP) and the cited percentage. Out of these, only TP is a primary indicator, and all other secondary indicators are computed programmatically from the data. We have computed these indicators for all the institutions in both the sets. Second major part of our analysis is to characterize the major research themes pursued and advanced by the institutions in the set. For this task, we have processed the entire data to classify every research output in one (or more) of the 11 major thematic areas in CS research, as illustrated in Appendix. This thematic mapping is more informative than the subcategory labels used by the Scopus database and is extended from a recent previous work (Uddin & Singh, 2015). For classifying a paper to belong to a thematic area, its 'author keyword', 'paper title' and 'abstract' fields are analyzed. A paper is assigned a thematic class which has substantial match of keywords with the predefined thematic classes. After attributing thematic areas to each paper, we measured the thematic area strength of all the institutions and identified leading institutions in a particular thematic area (Thematic trend, we have done for I100 & W100 as a whole but not institution-wise). This has been done for the two sets, I100 and W100. While, the scientometric analysis helps us in analytical and comparative characterization of research competitiveness of I100 and W100 sets, the text-based computational analysis helps us in identifying leading research themes pursued by institutions in the two sets and the similarities and differences among them.

6. Scientometric Indicator Computations

We would first present the computational results of analytical characterization using scientometric indicators. The results compare and characterize the two sets, I100 and W100, along different indicators as summarized in the four subsections below.

6.1 Research Output

We first tried to do a detailed indicator-based comparison of institutions in I100 and W100. Before, we present the results; it would be relevant to mention here that no Indian institution figures in the W100 set of 100 most productive institutions worldwide. The relative rank on productivity of Indian institutions can be understood from the fact that total 25 year period CS research output of 100th institution (University College London) in W100 is 5,747 whereas, the output of the two top ranking Indian institutions, namely Indian Institute of Technology, Kharagpur and Indian Institute of Science, Bangalore are 3,514 and 3,506, respectively. The most productive Indian institution has output levels below 150th rank institution in W100. It may also be worth mentioning that in a recently published ranking by ARWU[14], only two Indian institutions, "Indian Statistical Institute" and "Indian Institute of Science", are placed in the top 200 list, under CS subject category. We present the detailed statistics of scientometric indicator-based comparative assessment in tables 2 and 3. The table 2 presents comparative figures for the sets, I100 and W100, as a whole. Form the tables; we observe that there is a significant difference among indicators like ACPP (I100 average being 2.66 and W100 average 9.37), HiCP (average value of 60 for I100 and 855 for W100), ICP (110 for I100 as against 2419 for W100) and cited percentage (39.33% for I100 and 58.91% for W100). The table 3 presents values of various scientometric indicators for 20 most productive institutions in I100 and W100, for a more detailed comparison.

6.2 Co-authorship Patterns

The second important aspect we addressed is about the co-authorship and collaboration patterns seen in the CS research in top Indian institutions and the top institutions worldwide. The authorship pattern for research papers has known to have effect on their overall impact. A paper with multiple (more than one) authors is the joint contribution of two or more authors and has inputs from different people/ groups. Higher multi-authored papers are an indicator for higher interdisciplinary research and/ or higher level of collaboration between researchers at national or international level. Research projects involving bigger groups also result in higher multi-authored papers. From the data, we observed the co-authorship patterns for India, and found that about 39.4% of the total CS research outputs of I100 involve two authors and about 32% with three authors. Only about 5% of the output is by a single author, indicating that about 95% of the total CS output involves some form of collaboration. The co-authorship pattern for the W100, however, shows different scenario where the co-authorship distribution is less skewed (0.91) than that of Indian CS co-authorship

[14] http://www.shanghairanking.com/SubjectCS2014.html

distribution (1.51). The Figures 2(a) and 2(b) show year-wise trends of co-authorship patterns for the collected data. There is a clear trend towards higher collaboration between researchers, as measured by multiple authors in more and more research papers. In the most recent year, about 50% of the total CS research for W100 is with three or more authors, while it is about 30% for the I100.

6.3 International Collaboration Patterns

After observing a higher proportion of multi-authored papers, we aimed to measure the types of collaboration patterns as national or international. Higher international collaboration is not only an indicator of multi-national collaboration but also shows maturity and international nature of a discipline. A study (Smith 1958) was perhaps the first work on collaboration and it proposed that collaborative papers can be used as a proxy measure of collaboration among researchers. In another work, Glanzel (2001) showed that international co-authorship, on average, results in publications with higher citation rates than purely domestic papers. Through computational analysis, we found that 95.5% of the I100 are co-authored (with average co-authorship value as 2.92), whereas 93.5% of the W100 are co-authored (but average co-authorship value as 3.41). The average co-authorship for W100 is higher, an indicator of higher level of collaboration. The Figure 3 shows collaboration patterns for outputs of I100 and W100. We observe that I100 has 25% of the collaborated papers involving international collaboration as against 30% value for W100. We also identified the top collaborating countries by Indian authors. The Table 2 shows the list of top 20 countries having highest collaboration in I100 output during the 25 year period. The United States of America contributes largest share of I100’s international collaboration (with 4316 research papers) followed by Singapore (849 research papers) and Canada (801 research papers). The W100 data shows higher international collaborative research papers, including multi-country collaboration outputs.

6.4 Citation-based Impact Assessment

An independent report by Thompson Reuters showed that India had about 0.52% of its national output (all disciplines) in the worldwide HiCP list in 2011 (Thompson Reuters Report on The Research and Innovation Performance of G20, March 2014). It is well accepted that solely counting number of research publications may not be the best method to measure the scientific research productivity and usefulness. It focuses primarily on the output quantity and not on the quality as measured through impact/ productivity. It would naturally be unfair to treat two research papers, one with very high citation count and the other with low or no citation, as equally useful. On the other hand, a research paper with higher citation is considered more effective, useful and productive. Citation count is considered an effective measure of productivity and influence of a research paper. We have extracted total citations of each research paper in the I100 and W100 data and also identified the top cited papers (top 10% most cited papers) in each group for each of the 25 years. We track the institution information for all such records and look for top contributing institutions to the set of highly cited (top 10%) publications. The figure 4(a) shows the number of collaborated papers among the top 10% highly cited papers in I100. We find that total of 1797 papers (approximately 30% among the top 10% cited papers) are collaborated internationally. After an assessment of relationship between collaboration and citation-impact, we moved to identify the top institutions in I100 with highest proportions of top 10% highly cited papers in I100. The figure 4(b) shows top five institutions for each year chronologically. The vertical axis represents the contribution in percentage to the top10% cited papers in the particular year. The figure clearly shows that initially only certain selected institutions contributed to the elite set of papers and grabbed maximum of the set. However, over the period of time other institutions also contributed to the top 10% highly cited papers, an indicator of quality research output being generated from more and more institutions. On an average, 12 institutions from India are the most frequent contributors to the top cited papers in I100 set. The Indian Institute of Science (IIS) showed almost omnipresence in all the years, except 1989, indicating most consistent qualitative output. The Indian Institute of Technology, Kharagpur (IITK), Indian Institute of Technology, Delhi (IITD) and Indian Statistical Institute, Kolkata (ISIK) are few other frequent names in the list. We also measured the proportion of CS research output in I100 and W100 that remains un-cited. The figure 4(c) shows the percentage of cited and un-cited papers for both I100 and W100, shown over five consecutive chronological blocks of five years each. The problematic indication observed is that the percentage of papers that are cited is decreasing over the time. This may be due to smaller citation window availability or possibly with higher amount research output, a large part of which is not that useful/ productive. On a comparison between I100 and W100 data, we observe that the corresponding cited figures (in percentage) for first two blocks are almost same but the values for W100 in recent three blocks are higher, implying low immediacy index for CS research output from India.

7. Performance based on Trajectory Analysis

A recent paper (Nishy 2012) proposed an exergy rank based on a thermodynamic analogy. The exergy indicator (referred as *X*) is a multiplicative product of quality and quantity of a scientist's or research group's performance. The measure is derived from primary/ secondary indicators like impact, citations and number of papers. The proposed system tries to define a single meaningful indicator that combines both, the quantity (number of papers published, *P*) and the quality (measured as impact, i=C/P, where C is citation count) aspects. A quality proxy, called exergy is defined as $X=(C/P)*C$. The values of *i* and *P* or *i* and *C* can be shown as trajectories on two-dimensional plot with respect to time (known as *iPX* and *iCX* approaches, respectively). Both the *iCX* (the contour lines for $X=iC$) and *iPX* (the contour lines for $X=i^2P$) can be chosen for two dimensional mapping of the information. The *iPX* approach is more intuitive as it shows the direct relation between quantity (*P*) and quality (*i*) which is of our interest but in *iCX* approach output *P* is hidden and does not directly reflect the quantity (*P*). We have used the exergy measure to compute quantity-quality composite rank for some selected institutions in I100 and W100.

We have measured the research performance of the top 5 Indian institutions in I100 and plotted them with the top 5 institutions in W100 list based on their TP value. This is done primarily to compare the relative performance of Indian institutions vis-à-vis the institutions in world top 100. Unfortunately, no Indian institution appears in the W100 list. The figure 8(a) displays the exergy values for the selected institutions. Here, the X-axis represents the time in year and Y-axis denotes the obtained exergy score in that particular year. Similarly, two sets of institutions were selected based on ACPP and on HiCP values. Selecting institutions on the values of different indicators help us to see the performance variability of institutions leading on different indicators' scale. Figures 8(b) and 8(c) shows the performance in exergy for institutions selected based on ACPP and HiCP, respectively. All the plots are made for eight 5 year rolling windows, from 2001-2005 to 2008-2012 to see the performance in the following 6th year (2006-2013). We see that all selected Indian institutions' performances are below all selected W100 institutions' performances, a result that needs serious thought. Among the top Indian institutions in I100, most of them are IITs. All the exergy graphs show that in terms of performance (quantity-quality) measure Indian institutions are far behind than that of W100 institutions. The important thing here to mention is that we did not consider the academic infrastructure such as number of faculties, active researchers etc in the context. The data and computed values are shown in supplementary table 5(a-c). The supplementary tables show the paper published (*P*) by the leading institutions over a five year publication window and citations (*C*) obtained in the next year for each publication window. These values are used to compute the impact ($i=C/P$) and the exergy ($X=C^2/P$).

8. Identifying Research Themes in Output

In addition to the scientometric analysis, we also performed a text-based analysis of the data to identify major research topics/ themes and their variations with respect to time. We used the burst detection algorithm (Kleinberg 2003) for this task. We applied the algorithm on the "indexed keyword" field of our data set for the entire 25 year period. The burst detection measures the keyword weights which is a function of the occurrence frequency and the time span of the keyword. The Science of Science (Sci2)[15] was used for temporal analysis (Burst Detection). A keyword with a heavy weight indicates that the topic was researched frequently for a significant period of time. The figures 6(a) and 6(b) show keyword density plots, based on their corresponding weights, for I100 and W100 data, respectively. For the visualization part, we used VOSviewer[16] reflecting the weights of corresponding keywords. We can see that "Computer Simulation" and "Mathematical Models" are present in leading positions in both figures. Similarly "Problem Solving" appears in both plots. However, the W100 plot shows a significance of topics like "Algorithms", "Approximation Theory", "Network Protocols" and "Computational Complexity"; where the I100 plots show significance of topics like "Computer Networks", "Information Technology", "Communication" and "Computational Methods", for the entire 25 year period considered. In supplementary figures 6 (c) to 6(g), we show the tag cloud plot visualization of the major research themes for the I-Top10 in the left and W100 in the right. The tag-cloud for the sub-period 1989-1993 shows that "Algorithm", "Mathematical Models", "Computer Simulation" were the leading topics in I100, whereas W100 had frequent occurrence of "Algorithm", "Computer Simulation", "Optimization" and "Image Processing". In the 1994-1998 block, "Algorithms", "Communication", "Optimization", "Information Technology" & "Artificial Intelligence" were the top topics in I100, whereas "Mathematical Models" & "Computer Simulation" dominated in W100. In 1999-2003, "Mathematical Models" again took the leading position followed by "Algorithms for I100 and "Mathematical Models" & "Optimization" dominated in W100. In 2004-2008, "Mathematical Models" became more significant as compared to "Algorithm" for I100 and in W100, "Problem Solving" & "Optimization" were prominent. In 2009-2013, we can see a slight change from previous block's trends, as "Computer Simulation" & "Algorithms" appeared as major research themes for I100, whereas W100 shows a variation including "Optimization", "Artificial Intelligence" & "Signal Processing". In general, "Algorithm", "Computer Simulation" & "Mathematical

[15] https://sci2.cns.iu.edu/user/index.php
[16] http://www.vosviewer.com/

Models" are prominent research themes in both I100 & W100 data. The W100 data also shows "optimization" as a frequent research theme.

9. Summary and Conclusion

The paper reports our results on scientometric, network-theoretic and text-based analysis of CS research in major institutions in India (I100 as representative sample) and in the world (W100 as representative sample) during the last 25 year period (1989-2013). The analytical results present measurements the characteristic similarities and differences between I100 and W100 showing primary and secondary indicators of CS research, such as absolute and comparative growth, collaboration patterns, year-wise citation-based impact assessment etc. We have also attempted to show the contribution of Indian institutions to world CS output and the impact of Indian CS output. The Quality-Quantity Exergy performance measures were shown and discussed for top institutions from I100 and W100. Finally, we report outcome of research theme trend mapping through a text-based analysis of the data. A year-block wise temporal trend identification of research theme is done along with burst detection of CS research output data and visualized graphically.

The results found indicate that India has a lot to enhance it research activities with quality. Although India maintained the same trends in CS research but the quality research is still lacking. The results report analysis of a substantial period of 25 years and can be used in many ways: to take a look at CS research in India vis-à-vis top ranking world institutions; to formulate policies for promoting research and enhancing quality output; to help a student selecting an institution for his/her research; and other academic/ scientific purposes.

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