A National Effort for Motivating Indian Students and Teachers towards Algorithmic Research

Subir Kumar Ghosh
School of Technology and Computer Science
Tata Institute of Fundamental Research
Mumbai 400005, India
ghosh@tifr.res.in

Sudebkumar Prasant Pal
Department of Computer Science and Engineering
Indian Institute of Technology
Kharagpur 721302, India
spp@cse.iitkgp.ernet.in

Abstract

During 2008-2015, twenty-two introductory workshops on graph and geometric algorithms were organized for teachers and students (undergraduate, post-graduate and doctoral) of engineering colleges and universities at different states and union territories of India. The lectures were meant to provide exposure to the field of graph and geometric algorithms and to motivate the participants towards research. Fifty-eight professors from TIFR, IITs, IISc, IMSc, CMI, ISI Kolkata, and other institutes and universities delivered invited lectures on different topics in the design and analysis of algorithms, discrete applied mathematics, computer graphics, computer vision, and robotics. The first four workshops were funded by TIFR, BRNS and IIT Kharagpur, and the remaining workshops were funded by the NBHM. In this paper, we present the salient features of these workshops, and state our observations on the national impact of these workshops.

1 Introduction

1.1 Background

Abū Jafar Muhammad al-Khwārizmī, a Persian astronomer and mathematician, wrote a treatise in 825 AD, Kitāb hisāb al-adad al-ḥindi (Book on Calculation with Hindu Numerals), which was translated into Latin in the early 12th century as Liber Algorismi de numero Indorum (The Book of Algorismi on Indian Numerals). The word “Algorism”—the Latin form of al-Khwārizmī’s name—came to be applied to any systematic work on ancient Indian-style computational mathematics. The present term “algorithm” is a distorted form of “algorism” [10].

The field of algorithms, which is at the very heart of computer science, has witnessed a number of significant advances during the last five decades. These advances include the development of faster algorithms and the discovery of certain natural problems for which all known algorithms are inefficient [12]. These startling results have kindled a keen interest in the area of algorithm design and analysis. Teaching and research in this foundational aspect of computing is therefore a natural and desirable thrust area.
As algorithms are also at the heart of every nontrivial computer application, computer scientists and professional programmers are expected to know about the basic algorithmic toolbox: structures that allow efficient organization and retrieval of data, frequently used algorithms and generic techniques for modeling, understanding and solving algorithmic problems. Hence, algorithmic studies form a major component of computer science programs in colleges and universities.

In the last four decades, graph and geometric problems have been studied by computer science researchers using the framework of design and analysis of algorithms [1, 33]. While graph algorithms have been studied for almost 300 years, graphs provide essential models for many application areas of computer science, and at the same time, they are fascinating objects of study in pure and applied mathematics. There have been a number of exciting developments in graph theory that are important for designers of algorithms. Correspondingly, the algorithmic viewpoint of computer science has stimulated much research in graph theory. Graph theory and graph algorithms are inseparably intertwined subjects.

On the other hand, the main impetus for the development of geometric algorithms came from the progress in computer graphics, computer-aided design and manufacturing [2]. In addition, algorithms are also designed for geometric problems that are classical in nature. The success of the field can be explained from the beauty of the geometry problems studied, the solutions obtained, and by the many application domains – computer graphics, geographic information systems, robotics and others, in which geometric algorithms play a crucial role.

1.2 Motivation

We know that basic algorithmic research has helped building today’s computer technology and will keep on playing a crucial role in the achievement of tomorrow’s technological breakthroughs. Therefore, we believe that algorithmic research is certainly important even for India.

At present, research is being carried out in India in several sub-areas of algorithms and results are being published in reputed conferences and journals in computer science and discrete applied mathematics. Algorithmic research started in India in premier academic institutes like TIFR, IITs and IISc, way back in the 70’s. In recent years, algorithmic research is also carried out in computer industries in India including Microsoft Research, IBM Research, TCS Innovation Labs, etc. Today, computer industries in India provide financial support to projects on algorithmic research in Indian academic institutes and also provide fellowships to Ph.D. students working in algorithmic research.

The need for algorithmic research in India was felt in the late 70’s. Perceiving future needs, the course “Design and Analysis of Algorithms” was introduced in the 80’s in the undergraduate and postgraduate levels as a core course in premier institutes like IIT’s, TIFR and IISc. This course used to cover asymptotic analysis of running time and space requirements for quantitatively measuring the efficiency of algorithms, searching and sorting algorithms, data structures, sequential algorithms for graph and geometric problems, NP-completeness, etc.

Designing efficient algorithms for graph and geometric problems within the framework of the design and analysis of algorithms started also around the same time. There were a few researchers in India (including S. N. Maheshwari (IIT Delhi), C. E. Veni Madhavan (IISc Bangalore), Subir Ghosh (TIFR Mumbai)), who were involved in algorithmic research during that time. In the 90’s, Ph.D. and Master theses on algorithms for graph and geometric problems started coming up in increasing numbers, demonstrating the acceptability of algorithmic research in India. Many of these theses for designing efficient algorithms used mathematical
techniques from combinatorics, probability theory, graph theory, etc., and algorithmic tech-
niques like greedy methods, divide and conquer, approximations, randomization, etc.

On the other hand, after personal computers became more and more available in India in
the late 80’s, a large number of scientists, engineers and administrators in India across all dis-
ciplines started using personal computers for solving problems arising in research, applications
and in commerce. This gave rise to the need of computer programmers, as the IT industries
proliferated. Naturally, several softwares were designed in 80’s and 90’s and many of them
used basic algorithmic techniques and data structures that were routinely taught in the courses
of “Design and Analysis of Algorithms” not only in IITs, IISc and TIFR but also in NITs, BITS
Pilani, and several universities in India. Algorithmic studies gained further impetus in the 90’s
in India like anywhere in the world after personal computers became connected through net-
works, forming the world wide web. New types of algorithms like streaming algorithms, web-
based algorithms, network algorithms, distributed algorithms, big data algorithms, etc. came
into play in the last two decades.

Though the number of researchers working in India on graph and geometric algorithms has
increased substantially in the last two decades, the number of active researchers in algorithms
is still far lesser in India compared to the large number of bright students and teachers involved
in studying and teaching computer science and discrete applied mathematics. In order to moti-
vate them towards computer science research in general and algorithmic research in particular,
twenty-two workshops of introductory lectures on graph and geometric algorithms were orga-
nized during 2008-2015 for teachers and students (undergraduate, post-graduate, and doctoral)
of engineering colleges and universities at different locations in India.

Our workshop series may be viewed as a human resource development program for raising
the level of algorithmic knowledge amongst Indian college and university students and teachers
in computer science and discrete applied mathematics.

2 Workshop data

2.1 Organizational details
During 2008-2015, twenty-two workshops of introductory lectures on graph and geometric
algorithms were organized at different states and union territories of India as shown in Tables
I(a) and II(b), and in Figure 1.
Table I(a): Dates, Workshop Venues and Coordinators

| No | Date          | Workshop Venue                                      | Coordinators                                           |
|----|---------------|-----------------------------------------------------|--------------------------------------------------------|
| 1  | July 22-23    | Fr. Conceicao Rodrigues College of Engineering       | Subir Ghosh, Sunil Surve, Deepak Bhoir, Vijay Bilolikar|
|    | 2008          | Mumbai, Maharashtra                                 |                                                        |
| 2  | October 31-   | Indian Institute of Technology                       | Subir Ghosh, Partha Bhowmick, Sudebkumar Pal           |
|    | November 2    | Kharagpur, West Bengal                               |                                                        |
|    | 2008          | Engineering, Mumbai, Maharashtra                     |                                                        |
| 3  | January 22-24 | Birla Institute of Technology & Science               | Subir Ghosh, Poonam Goel, Navneet Goel                 |
|    | 2009          | Pilani, Rajasthan                                    |                                                        |
| 4  | July 15-18    | Indian Institute of Science                         | Subir Ghosh, Sathish Govindarajan, Sunil Chandran, Vijay Natarajan |
|    | 2009          | Bangalore, Karnataka                                 |                                                        |
| 5  | January 7-9   | National Institute of Technology                     | Subir Ghosh, Venkatesh Raman, Hemalatha, Ramakalyan,    |
|    | 2010          | Tiruchirapalli, Tamilnadu                             | Sunil Chandran                                         |
| 6  | January 27-29 | Banaras Hindu University                             | Subir Ghosh, Arun Agrawal, Pramod, Mishra, Sudebkumar  |
|    | 2010          | Varanasi, Uttar Pradesh                              | Pal, Sunil Chandran                                    |
| 7  | March 25-27   | National Institute of Technology                     | Subir Ghosh, Banshidhar Majhi, Pankaj Sa, Partha        |
|    | 2010          | Rourkela, Odisha                                     | Goswami, Sudebkumar Pal                                |
| 8  | 28-30 October | Thapar University                                    | Subir Ghosh, Deepak Garg, Sandeep Sen, Subhas Nandy    |
|    | 2010          | Patiala, Punjab                                      |                                                        |
| 9  | January 6-8   | PSG College of Technology                             | Subir Ghosh, R. S. Lekshmi, R. Nadarajan, Venkatesh   |
|    | 2011          | Coimbatore, Tamilnadu                                 | Raman                                                |
| 10 | March 26-28   | National Institute of Technology                     | Subir Ghosh, Sawal Singh, Subhas Nandy, Sathish        |
|    | 2011          | Patna, Bihar                                         | Govindarajan, Md. Haider                              |
| 11 | October 21-23 | Indian Institute of Technology                        | Subir Ghosh, R. Inkulu, Pinaki Mitra, Sudebkumar Pal   |
|    | 2011          | Guwahati, Assam                                      |                                                        |
| 12 | January 10-12 | National Institute of Technology                     | Subir Ghosh, Suresh Hegde, Shyam, Kamath, P. Jidesh,   |
|    | 2012          | Surathkal, Karnataka                                  | Sathish Govindarajan                                  |
| 13 | March 14-16   | Dhirubhai Ambani Institute of Information and         | Subir Ghosh, Srikrishnan Divakaran, Rahul Muthu,        |
|    | 2012          | Communication Technology, Gandhinagar, Gujarat        | Sathish Govindarajan, V. Sunitha                       |
| 14 | November 1-3  | Indian Institute of Information Technology, Design    | Subir Ghosh, Sudebkumar Pal, Pritee Khanna, Srbaban    |
|    | 2012          | and Manufacturing Jabalpur, Madhya Pradesh            | Mohanty                                               |
| 15 | January 17-19 | Birla Institute of Technology & Science               | Subir Ghosh, Tarkeshwar Singh, Anil Pundir, B.M.        |
|    | 2013          | Pilani, Goa                                          | Deshpande, Venkatesh Kamat                             |
| 16 | March 14-16   | Bengal Engineering and Science University             | Subir Ghosh, Arindam Biswas, Sekhar Mandal, Partha     |
|    | 2013          | Shibpur, West Bengal                                  | Bhowmick, Chandan Giri, Sanjay Saha                    |
| 17 | October 23-25 | National Institute of Technology                     | Subir Ghosh, R.B.V. Subramanyam, Sandip Das, P V        |
|    | 2013          | Warangal, Andhra Pradesh                              | Subba Reddy                                           |
| 18 | January 23-25 | University of Kerala & Indian Institute of Information | Subir Ghosh, Manoj Changat, T.K. Manoj, Kumar, K.       |
|    | 2014          | Technology and Management, Trivandrum, Kerala         | Satheesh Kumar, T. Radhakrishnan, V. Rajeshwari        |
| 19 | March 6-8     | Indian Institute of Technology                       | Subir Ghosh, Sudebkumar Pal, Rajdeep Niyogi, Vaskar    |
|    | 2014          | Roorkee, Uttarakhand                                  | Raychowdhury                                          |
| 20 | October 16-18 | Sikkim Manipal Institute of Technology                | Subir Ghosh, Sudebkumar Pal, Biswajit Deb Tejbhanta   |
|    | 2014          | Sikkim Government College, Sikkim                    | Chinthamani, Debabrata Purohit,                       |
| 21 | January 15-17 | Visvesvaraya National Institute of Technology         | Subir Ghosh, Manish Kurhekar, Abhiram, Ravindra        |
|    | 2015          | Nagpur, Maharashtra                                  | Keskar, Umesh Deshpande                                |
| 22 | May 18-20     | University of Kashmir                                | Subir Ghosh, Shariefuddin Pirzada, Abhiram Ranade,     |
|    | 2015          | Srinagar, Kashmir                                    | S. M. K. Quadri                                        |

In addition to coordinators, two groups of people were involved in organizing these workshops. One group typically consisted of students and staff of host institutes who were involved essentially during the workshop days. The other group consisted of administrative and technical staff of School of Technology and Computer Science, TIFR who were involved from the preparatory phase till the completion of every workshop spanning a period of over 3-4 months.
Figure 1: Workshop venues
Mr. Raymond J. D’Mello worked as the secretary for this workshop series for the entire period of 2008-2015; he was assisted by Mr. John Barretto, Mr. Pravin N. Bhuwad, Mr. W. K. Gawade and Mr. Nitin S. Gawandi. Workshop websites for all the workshops during 2009-2015 were designed, developed, updated and maintained by Mr. Ravikumar Naik, and he also provided a necessary platform for online registration of participants.

2.2 Financial support

The first four workshops were funded by Tata Institute of Fundamental Research (TIFR), Indian Institute of Technology, Kharagpur (IITKGP), and the Board of Research in Nuclear Science (BRNS) of the Department of Atomic Energy, Government of India (see Table II(a)), and the remaining eighteen workshops were funded by the National Board for Higher Mathematics (NBHM), Department of Atomic Energy, Government of India (see Table II(b)). There was no registration fee for the workshops after the first three workshops. Thus the workshops were almost entirely funded by the above mentioned organizations. In addition, some host institutes provided small grants to cover some local expenses. In most cases, host institutes provided many facilities including auditoriums and guest houses at subsidized rates. Some invited speakers used their own travel grants for paying their air fares. Taking all these facts into consideration, it can be seen that budgets for the workshops were indeed quite low.

Table II(a): TIFR, BRNS and IITKGP Support

| Workshop Venue | TIFR Grant | BRNS Grant | IITKGP Grant |
|----------------|------------|------------|--------------|
| CRCE Mumbai    | Rs. 80,000/- | –          | –            |
| IIT Kharagpur  | –          | –          | Rs. 2,15,000/-|
| BITS Pilani    | Rs. 3,00,000/- | –      | –            |
| IISc Bangalore | Rs. 6,00,000/- | 2,00,000/- | –            |

Table II(b): NBHM Support

| Workshop Venue | NBHM Grant | Workshop Venue | NBHM Grant |
|----------------|------------|----------------|------------|
| BHU Varanasi   | Rs. 2,60,000/- | HNITDM Jabalpur | Rs. 3,70,000/- |
| NIT Tiruchirapalli | Rs. 2,60,000/- | BITS Goa     | Rs. 3,70,000/- |
| NIT Rourkela   | Rs. 2,60,000/- | NIT Warangal  | Rs. 3,70,000/- |
| Thapar University | Rs. 3,00,000/- | IIITM Kerala | Rs. 3,90,000/- |
| PSGTECH Coimbatore | Rs. 3,00,000/- | IIIT Roorkee  | Rs. 3,90,000/- |
| NIT Patna      | Rs. 3,00,000/- | BESU Shibpur  | Rs. 3,90,000/- |
| IIT Guwahati   | Rs. 3,50,000/- | SMIT Sikkim   | Rs. 4,10,000/- |
| NIT Karnataka  | Rs. 3,50,000/- | VNIT Nagpur   | Rs. 3,60,000/- |
| DAIICT GandhiNagar | Rs. 3,50,000/- | University of Kashmir | Rs. 4,30,000/- |

2.3 Invited lectures

In the 22 workshops, 266 invited lectures were delivered by 58 professors under 114 lecture titles. A complete list is given in Appendix. These lectures can be classified broadly into four categories: (i) Algorithmic Paradigms, (ii) Graphs and Algorithms, (iii) Geometry and Algorithms, and (iv) Geometry and Applications.

Under algorithmic paradigms, introductory lectures were delivered on different types of algorithms [8, 20]. Specifically, approximation algorithms [35], randomized algorithms [27], on-line algorithms [4], distributed algorithms [24], fixed parameter algorithms [29], quantum algorithms [30] and streaming algorithms [28] were covered.

Under graphs and algorithms, introductory lectures were delivered on graph theory [3, 14, 16, 18], networks [34], graph algorithms [20, 23] and scheduling [22]. Specific topics covered
from graph theory were graph matching, graph representations, extremal graphs, graph partitioning, probabilistic graphs, topological minors of graphs, expander graphs, graph coloring, graph spanners, and graph spectra. Similarly, specific topics covered from graph algorithms were planarity testing, network flow, shortest paths, social networks and wireless networks.

Under geometry and algorithms, introductory lectures were delivered on computational geometry [2,13,31], combinatorial geometry [11,25] and digital geometry [19]. Specific topics of computational and combinatorial geometry covered were geometric graphs, facility location, convexity of points, art gallery problems, duality transformation, geometric data structures, geometric shortest paths, geometric spanners, Voronoi diagrams, centerpoint location, and geometric prune and search technique. Similarly, specific topics covered from digital geometry were shape transformations by local interchanges, algorithms for circles and spheres in digital space, isothetic covers for digital objects, anatomies of lines and circles in the light of number theory and on good digital distances.

Under geometry and applications, introductory lectures were delivered on computer graphics [5,9,26], computer vision [17,32], visualization [15] and robotics [6,21]. Specific topics covered from these application areas were 3D reconstruction from images and videos, projective geometry for graphics and computer vision, visibility maps for point clouds, motion structure using shape spaces, character animation, haptic rendering, symmetry and structure detection for 3D geometry, rendering using directional distance maps, cache friendly compressed representation of geometry, modeling for shape classes, manifold discovery in data, scalar field visualization, 3D surface reconstruction, graphics processor units, mesh generation, object recognition, a number theoretic introduction to geometry, and sequential and online algorithms for robot path planning.

2.4 Participants

Participants of the workshops were mainly undergraduate, post-graduate and doctoral students and teachers of computer science and discrete applied mathematics. They were required to have taken basic courses in discrete mathematics, data structures and algorithms at the undergraduate level. There were around fifty participants in the first workshop at CRCE Mumbai. Since then, the number of participants were at least 90 in every workshop. In some workshops, there were around 120 participants. The workshop at IIT Guwahati had the maximum number of 156 participants.

Normally, around three-fourths of the participants were from the host institute and its nearby institutes and university. The remaining participants, who were from the same state and from neighboring states, were provided with return train fares and free boarding and lodging. All participants were provided free lunch and snacks, and were issued certificates for attending workshops. Also, a standard textbook on algorithms (Indian edition) was gifted to every participant for further study.

3 Impact on the participants

3.1 Interaction

Usually, there were 4 or 5 invited one-hour lectures in a day. Many of these lectures were designed as interactive lectures. Around 10-20% of the participants took active part in such interactions and many of them got inspired by this opportunity to involve themselves. Interaction with speakers continued during lunch and tea breaks. The active participants were mostly
students from IITs, IISc, some NITs, BITS Pilani and ISI, Kolkata. Although around 15-30% participants were really at a loss during many of the lectures, the remaining participants followed several lectures even though they did not interact during the lecture. In fact, many of them met the speakers during breaks and clarified doubts. At the end of each workshop, we always had a feedback session. We received appreciation and valuable comments in feedback sessions. We also received emails from participants after almost every workshop on the merits and demerits of the workshop.

In every workshop, there was a session on open problems in which unsolved research problems on algorithms were stated and discussed. Many participants showed interest in the sessions on open problems.

3.2 Panel discussion

The general trend for computer science students in India is to take up a job in IT industry after completing B.Tech or M. Tech. degree. Most of them do not even consider that research in computer science could be his/her profession. In view of this, a panel discussion was conducted in every workshop on the topic “Is research a good career option?” Normally, some young invited speakers of the workshop took the role of panelists. During the discussions, participants asked panelists questions on various career options: What are the benefits in a research profession? What are the pitfalls in a research career? How much salary one can expect in research profession? What are the good institutes in India for doing research? How can one get a good research guide? Can good research be done in an industry? How do I convince my parents that research is a viable career option? Is it not better to do research in the USA rather than in India? During the panel discussions, extensive interactions took place due to diverse opinions and counter-opinions expressed by panelists and participants. We observed that panel discussion was an extremely effective way for motivating participants towards research.

4 Concluding remarks

We understand that the workshops have indeed inspired some students to seriously consider algorithmic research as a career option. In fact, professors of the various host institutes have informed us that some of their students, who are now pursuing Ph.D. program in computer science (in India or abroad), were actually motivated by our workshops. Moreover, the benefits from the exposure to the broad field of graph and geometric algorithms will certainly get reflected in the future profession of many of the participants. As organizers, we felt that it was worth making the effort, and we hope that in the interest of the nation and in the interest of algorithmic studies (in which India was a pioneer), such efforts will continue in the future.

References

[1] A. V. Aho, J. E. Hopcroft and J. D. Ullman, The Design and Analysis of Computer Algorithms, Addison Wesley, 1975.
[2] M. de Berg, M. van Kreveld, M. Overmars and O. Schwarzkof, Computational Geometry: Algorithms and Applications, Springer, 1997.
[3] B. Bollobas, Extremal Graph Theory, Academic Press, London, 1978.
[4] A. Borodin and R. El-Yaniv, Online Computation and Competitive Analysis, Cambridge University Press, Cambridge, 2005.
[5] S.-W. Cheng, T. K. Dey and J. R. Shewchuk, Delaunay Mesh Generation, CRC Press, Florida, 2012.
[6] Howie M. Choset, *Principles of robot motion: theory, algorithms, and implementation*, MIT Press, 2005.

[7] F. Chung, *Spectral Graph Theory*, Americal Mathematical Society, 1997.

[8] Thomas H. Cormen and Clifford Stein and Ronald L. Rivest and Charles E. Leiserson, *Introduction to Algorithms*, Prentice-Hall, India.

[9] T. K. Dey, *Curve and Surface Reconstruction : Algorithms with Mathematical Analysis*, Cambridge University Press, 2006.

[10] A. Dutta, *Decimal System in India*, In Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures (Edited by Helaine Selin), pp. 1-14, Springer, Dordrecht, 2015.

[11] H. Edelsbrunner, *Algorithms in Computational Geometry*, Springer, 1987.

[12] M. R. Garey and D.S. Johnson, *Computers and Intractability: A Guide to the Theory of NP Completeness*, W. H. Freeman, 1979.

[13] S. K. Ghosh, *Visibility Algorithms in the Plane*, Cambridge University Press, Cambridge, United Kingdom, 2007.

[14] M.C. Golumbic, *Algorithmic Graph Theory and Perfect Graphs*, North-Holland Publishing Company, 2004

[15] C. D. Hansen and C. R. Johnson (editors), *Visualization Handbook*, Academic Press, 2004.

[16] F. Harary, *Graph Theory* Addison Wesley, Reading, MA, 1969.

[17] R. Hartley and A. Zisserman, *Multiple View Geometry in Computer Vision*, Cambridge University Press, New York, 2nd edition, 2004.

[18] T. Jensen and B. Toft, *Graph coloring problems*, Wiley, New York, 1995.

[19] R. Klette and A. Rosenfeld, *Digital Geometry: Geometric Methods for Digital Picture Analysis*, Morgan Kaufmann, San Francisco, 2004

[20] J. Kleinberg and É. Tardos, *Algorithm Design*, Pearson Education, Delhi, India.

[21] J.C. Latombe, *Robot Motion Planning*, Kluwer Academic Publishers, Boston, MA, 1991.

[22] J. Leung (editor), *Handbook of Scheduling: Algorithms, Models, and Performance Analysis*, CRC Press, 2004.

[23] L. Lovasz and M. D. Plummer, *Matching Theory*, AMS Chelsea Publishing, vol 367, 2009.

[24] N. Lynch, *Distributed Algorithms*, Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1996.

[25] J. Matousek, *Lectures on Discrete Geometry*, Springer, 2002.

[26] A. Menache, *Understanding Motion Capture for Computer Animation and Video Games*, Morgan Kaufmann Publishers Inc., San Francisco, 1999.

[27] R. Motwani and P. Raghavan, *Randomized Algorithms*, Cambridge University Press, 1997.

[28] S. Muthukrishnan, *Data Streams: Algorithms and Applications*, Foundations and Trends in Theoretical Computer Science, vol. 1, no. 2, pp. 117-236, 2005.

[29] R. Niedermeier, *Invitation to Fixed-Parameter Algorithms*, Oxford University Press, 2006.

[30] M. Nielsen and I. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press, 2010.

[31] F. P. Preparata and M. Shamos, *Computational Geometry: An Introduction*, Springer-Verlag, New York, 1985.

[32] K. Salisbury, F. Conti, and F. Barbagli, *Haptic rendering: Introductory concepts*, IEEE Computer Graphics and Applications, vol. 24, no. 2, pp. 24–32, 2004.

[33] R. E. Tarjan, *Data Structures and Network Algorithms*, SIAM, 1983.

[34] R. M. Tripathy, A. Bagchi, and S. Mehta, *Towards combating rumors in social networks: Models and metrics*, Intelligent Data Analysis, 17, pp. 149-175, 2013.

[35] V. Vazirani, *Approximation Algorithms*, Springer, 2003.
## Appendix

### Table: Invited Speakers and Lecture Topics

| Invited speaker | Lecture title | Delivered at |
|-----------------|---------------|--------------|
| John Augustine  | (i) Algorithms for Big Data  
IIT Madras       | VNIT Nagpur, IIITM Kerala, BITS Goa  
(ii) Introduction to Distributed Algorithms | |
| Amitabha Bagchi | (i) Information Diffusion on Social Networks  
IIT Delhi        | BESU Shibpur, NIT Patna, SMIT Sikkim BHU Banaras  
(ii) Random Geometric Graphs and Wireless Networks | |
| Niranjan        | (i) Graph Coloring  
Balachandran     | University of Kashmir  
IIT Bombay        | BESU Shibpur, NIT Patna, SMIT Sikkim BHU Banaras  
(ii) Introduction to Distributed Algorithms | |
| Amitabha Bagchi | (i) Probability and Graphs  
IIT Delhi        | Thapar University  
(ii) Big Data: The Future of Computing | SMIT Sikkim, NIT Rourkela |
| Niranjan        | (i) Shortest Paths in Presence of Vertex Failures  
Balachandran     | NIT Patna  
IIT Bombay        | IISc Bangalore |
| Surender Baswana| (i) On Anomalies and Algorithms Related to  
IIT Kanpur       | NIT Rourkela, NIT Patna  
(ii) Algorithms for Graph Spanners: Static,  
Warangal, BITS Goa  
Dynamic and Fault Tolerant | IIT Kharagpur, IIT Guwahati, IIITDM Jabalpur |
| Partha Bhowmick | (i) Art Locally, Change Globally: Shape  
IIT Kharagpur     | Thapar University  
Transformations by Local Interchanges  
NIT Rourkela, NIT Patna, BITS Pilani, BHU Banaras, IIITDM Jabalpur, IIT Guwahati, SGC Sikkim*  
(ii) Introduction to Randomized Algorithms  
Warangal, BESU  
(iii) Introduction to Network Flows  
Shibpur, IIT Kharagpur  
(iv) Introduction to Computational Geometry  
BHU Banaras, IIITDM Jabalpur, IIT Guwahati, SGC Sikkim* | |
| Arijit Bishnu   | (i) On Large Scale 3D Reconstruction from  
ISI Kolkata       | University of Kashmir  
Images and Videos, (ii) Projective Geometry  
Thapar University  
for Graphics and Computer Vision, (iii) Singular  
NIT Rourkela, NIT Patna, BITS Pilani, BHU Banaras, IIITDM  
Value Decomposition and its Applications to  
Jabalpur, IIT Guwahati, SGC Sikkim*  
Computer Vision  
IIT Kharagpur, IIT  
Roorkee | |
| Subhashis Banerjee| (i) Visibility Maps for Point Clouds, (ii) Using  
IIT Delhi         | CRCE Mumbai, IIT Kharagpur, DAIICT  
Shape Spaces for Structure for Motion,  
Gandhinagar, IIITM Kerala  
(iii) Geometric Data Structures Random | |
| Sharat Chandran | (i) Geometric Representations of Graphs  
IIT Bombay        | NIT Tiruchirappalli  
(ii) Rainbow Coloring of Graphs  
BITS Pilani, BHU Banaras  
NIT Rourkela, BITS Goa  
BITS Goa | |

* indicates that the speaker had delivered two lectures in this workshop.
| Invited speaker               | Lecture topics                                                                 | Delivered at                                                                 |
|------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Parag Chaudhuri              | (i) Motion Graphs for Character Animation                                      | Thapar University BESU Shubpur, IIT Guwahati, IIITM Kerala                   |
| IIT Bombay                   |                                                                               |                                                                              |
| Subhasis Chaudhuri           | (i) Haptic Rendering: How do we touch an object?                              | BESU Shubpur, NIT Karnataka, IIT Roorkee, SMIT Sikkim                       |
| IIT Bombay                   |                                                                               |                                                                              |
| Sandip Das                   | (i) Introduction to Approximation Algorithms                                  | University of Kashmir BESU Shubpur, VNIT Nagpur, NIT Rourkela NIT Warangal, NIT |
| ISI Kolkata                  | (ii) Convexity of Point Sets                                                  | Tiruchirapalli, NIT Patna, IIT Kharagpur IISc Bangalore, BHU Banaras, IIT Guwahati IIITDM Jabalpur, IIITM Kerala |
|                                                                            | (iii) Geometry Facility Location Problems                                      |                                                                              |
|                                                                            | (iv) Geometric Approximation Algorithms                                        |                                                                              |
|                                                                            |                                                                               |                                                                              |
| Srikrishnan Divakaran        | (i) Introduction to Randomized Algorithms                                      | DAIICT Gandhinagar                                                          |
| Divakaran, DAIICT Gandhinagar|                                                                               |                                                                              |
| Ajit Diwan                   | (i) Extremal Graph Theory, (ii) Graph Partitioning, (iii) Topological Minors of Graphs | NIT Tiruchirapalli IISc Bangalore PSG TECH Coimbatore NIT Karnataka         |
| IIT Bombay                   |                                                                               |                                                                              |
| Sumit Ganguly                | (i) Streaming and Semi-streaming Algorithms for Processing Massive Graphs, (ii) Introduction to Streaming Algorithms | BHU Banaras IIITDM Jabalpur                                                  |
| IIT Kanpur                   |                                                                               |                                                                              |
| Deepak Garg                  | (i) Introduction to Approximation Algorithms                                   | Thapar University                                                           |
| Thapar University            |                                                                               |                                                                              |
| Daya Gaur                    | (i) Approximation Algorithms and Linear Programming, (ii) Introduction to Approximation Algorithms | Thapar University IISc Bangalore DAIICT Gandhinagar                           |
| IIT Ropar                    |                                                                               |                                                                              |
| Subir Ghosh                  | (i) Computational Geometry, (ii) Robot Path Planning, (iii) Robot Path Planning: Offline and On-line Algorithms, (iv) Robot Online Algorithms for Searching and Exploration in the Plane (v) Online Algorithms in Computational Geometry (vi) Art Gallery Problems and Approximation Algorithms, (vii) Introduction to Network Flows (viii) Introduction to Approximation Algorithms | All workshops except at IIT Guwahati. (Two lectures were delivered at PSG TECH Coimbatore.) |
| TIFR Mumbai                  |                                                                               |                                                                              |
| Partha Goswami               | (i) Introduction to Computational Geometry, (ii) Geometric Data Structures, (iii) Duality Transformation in Geometry | University of Kashmir* Thapar University BESU Shubpur, VNIT Nagpur, NIT Rourkela NIT Warangal, NIT Patna, SMIT Sikkim NIT Tiruchirapalli CRCE Mumbai, IIT Kharagpur, BITS Pilani, IISc Bangalore BHU Banaras, IIT Guwahati, NIT Karnataka, IIITDM Jabalpur*, IIT Roorkee |
| Calcutta University          |                                                                               |                                                                              |

* indicates that the speaker had delivered two lectures in this workshop.
| Invited speaker       | Lecture topics                                                                 | Delivered at                                      |
|-----------------------|--------------------------------------------------------------------------------|--------------------------------------------------|
| Sathish Govindarajan  | (i) Geometric Graphs, (ii) Introduction to Combinatorial Geometry               | University of Kashmir, NIT Tiruchirapalli, NIT Rourkela, BITS Pilani, IISc Bangalore, PSGTECH Coimbatore, NIT Karnataka, DAIICT Gandhinagar, IIT Roorkee |
| IISc Bangalore        |                                                                                  |                                                  |
| Suresh Hegde          | (i) Labeled Graphs and Digraphs: Theory and Applications                         | NIT Karnataka                                    |
| NIT Karnataka         |                                                                                  |                                                  |
| R. Inkulu             | (i) Finding Minimum Degree Spanning and Steiner trees, (ii) Buy-at-Bulk Network Design, (iii) Graph and Geometric Shortest Paths | VNIT Nagpur, NIT Warangal, NIT Patna, IIT Guwahati |
| IIT Guwahati          |                                                                                  |                                                  |
| Subrahmanyam          | (i) Introduction to Randomized Algorithms                                         | University of Kashmir, VNIT Nagpur, IITM Kerala, IIT Roorkee |
| Kalyanasundaram       |                                                                                  |                                                  |
| IIT Hyderabad         |                                                                                  |                                                  |
| Deepak Kapur          | (i) Algorithms for Automated Reasoning and Symbolic Computations                  | IIT Roorkee                                      |
| UNM, Albuquerque       |                                                                                  |                                                  |
| K. Murali Krishnan    | (i) Graph Representation of Codes and Decoding Algorithms                         | IISc Bangalore                                   |
| NIT Calicut           |                                                                                  |                                                  |
| Subodh Kumar          | (i) Accurate and Efficient Rendering of Detail using Directional Distance Maps, (ii) Cache Friendly Compressed Representation of Geometry, (iii) Symmetry and Structure Detection for 3D Geometry | VNIT Nagpur, NIT Rourkela, IIT Patna, BITS Pilani, BITS Goa, DAIICT Gandhinagar, IIT Roorkee |
| IIT Delhi             |                                                                                  |                                                  |
| Anil Maheshwari       | (i) Geometric Spanners                                                           | CRCE Mumbai, IISc Bangalore                      |
| Carleton University   |                                                                                  |                                                  |
| Ottawa                |                                                                                  |                                                  |
| S.N Maheshwari        | (i) Network Flows and Applications                                              | IIT Guwahati                                     |
| IIT Dehi              |                                                                                  |                                                  |
| Amitabha Mukerjee     | (i) Robot Motion Planning, (ii) Geometric Modeling for Shape Classes, (iii) Manifold Discovery in High-Dimensional Data | University of Kashmir, Thapar University, NIT Warangal, SMIT Sikkim, DAIICT Gandhinagar, IIITDM Jabalpur, BITS Goa, IIT Roorkee |
| IIT Kanpur            |                                                                                  |                                                  |
| Niloy Mitra           | (i) Scalar Field Visualization, (ii) Symmetry and Structure Detection for 3D Geometry | IIT Kharagpur, BITS Pilani                       |
| IIT Delhi             |                                                                                  |                                                  |
| Anurag Mittal         | (i) Graph-based Algorithms in Computer Vision                                    | PSGTECH Coimbatore                               |
| IIT Madras            |                                                                                  |                                                  |
| Sudhir Mudur          | (i) The 3D Surface Reconstruction Problem and Some Solutions                      | BITS Goa                                         |
| Concordia University   |                                                                                  |                                                  |
| Montreal              |                                                                                  |                                                  |
| Jayanta Mukerjee      | (i) In the Quest for Good Digital Distances                                      | IIT Kharagpur                                    |
| IIT Kharagpur         |                                                                                  |                                                  |
| Krishnendu Mukerjee   | (i) Distributed Leader Election                                                  | NIT Patna                                        |
| ISI Kolkata           |                                                                                  |                                                  |
| Subhas Nandy          | (i) Introduction to Randomized Algorithms, (ii) Voronoi Diagram                  | Thapar University, NIT Rourkela, CRCE Mumbai, BITS Pilani, IIT Kharagpur, IISc Bangalore, BHU Banaras |
| ISI Kolkata           |                                                                                  |                                                  |
| Invited speaker | Lecture topics | Delivered at |
|-----------------|----------------|--------------|
| P. Narayanan IIT Hyderabad | (i) Graphics Processor Units: For Graphics and Beyond | IISc Bangalore |
| Vijay Natarajan IISc Bangalore | (i) Scalar Field Visualization: Level Set Topology (ii) Symmetry in Scalar Fields | IIT Kharagpur, BITS Pilani, IISc Bangalore, PSGTECH Coimbatore, NIT Karnataka, BITS Goa, NIT Nagpur |
| N. S. Narayanaswamy IIT Madras | (i) Special Classes of Intersection Graphs (ii) Perfect Graphs, (iii) Graph Classes with Interesting Structural Properties, (iv) Tree Path Assignments: An extension of the Consecutive Ones Property, (v) Algorithms for Perfect Graphs | NIT Tiruchirapalli, NIT Warangal, IISc Bangalore, IIT Guwahati, NIT Karnataka, DAIICT Gandhinagar, IITDM Jabalpur, IIT Roorkee |
| Sudebkumar Pal IIT Kharagpur | (i) Link Paths and Reflection Visibility Problems, (ii) Geometric Data Structures | BITS Goa, Sikkim, NIT Patna, NIT Tiruchirapalli, CRCE Mumbai, BITS Pilani, IISc Bangalore, BHU Banaras, IIT Guwahati, NIT Karnataka, DAIICT Gandhinagar, IITDM Jabalpur, IITM Kerala, IIT Roorkee |
| Sachin Patkar IIT Bombay | (i) Network Flows and Applications | BITS Goa |
| Shariefuddin Pirzada UK Srinagar | (i) Graph Spectra and Applications | University of Kashmir |
| Venkatesh Raman IMSc Chennai | (i) Fixed Parameter Algorithms | NIT Tiruchirapalli, IISc Bangalore, PSGTECH Coimbatore |
| Abhiram Ranade IIT Bombay | (i) Graph Partitioning, (ii) Geometric Packing (iii) Algorithms for Precedence Constrained Scheduling, (iv) Mumbai Navigator, (v) Some Formulations of the Genome Assembly Problem | VNIT Nagpur, NIT Warangal, BITS Goa, BESU Shibpur, SMMIT Sikkim, BITS Pilani, PSGTECH Coimbatore, DAIICT Gandhinagar* BHU Banaras, IIITM Kerala, IIT Roorkee |
| M. Panduranga Rao IIT Hyderabad | (i) Introduction to Quantum Algorithms | BITS Goa |
| Tathagata Ray BITS Hyderabad | (i) Mesh Generation | NIT Warangal, IIITM Kerala |
| Sasanka Roy CMI Chennai | (i) Introduction to Computational Geometry (ii) Voronoi Diagram | VNIT Nagpur, NIT Guwahati, PSGTECH Coimbatore, BITS Goa |
| Yogish Sabharwal IBM Delhi | (i) Randomized Techniques in Geometry | IIT Kharagpur |
| Sudeep Sarkar USF, Tampa | (i) Graphs and Object Recognition | IISc Bangalore |

* indicates that the speaker had delivered two lectures in this workshop.
| Invited speaker       | Lecture topics                                                                 | Delivered at                                                                 |
|-----------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Swami Sarvattonanda   | (i) Planarity Testing of Graphs, (ii) Voronoi Diagrams, (iii) Geometric Data Structures, (iv) Helly’s Theorem and Centre Point, (v) Computing Center Point Using the Prune and Search Technique, (vi) Prune and search Technique in Geometry | Thapar University BESU Shibpur, NIT Rourkela, NIT Patna SGC Sikkim, CRCE Mumbai, BITS Pilani IIT Kharagpur, IISc Bangalore, BHU Banaras, PSGTECH Coimbatore, IIITM Kerala |
| RKMVU, Belur          |                                                                                  |                                                                               |
| Saket Saurabh         | (i) Fixed Parameter Algorithms, (ii) Preprocessing with Guarantee              | NIT Rourkela, NIT Patna, NIT Karnataka                                        |
| IMSc Chennai          |                                                                                  |                                                                               |
| Sandeep Sen           | (i) A Short Guided Tour of Randomized Algorithms                               | BITS Pilani IISc Bangalore                                                    |
| IIT Delhi             |                                                                                  |                                                                               |
| Naveen Sivadasan      | (i) Introduction to On-line Algorithms                                         | Thapar University VNIT Nagpur, NIT Warangal, NIT Karnataka                    |
| IIT Hyderabad         |                                                                                  |                                                                               |
| K. V. Subrahmanyam    | (i) Expander Graphs and their Applications, (ii) Network Flows and Applications | NIT Tiruchirapalli NIT Patna                                                  |
| CMI Chennai           |                                                                                  |                                                                               |
| C. R. Subramanian     | (i) Introduction to Randomized Algorithms, (ii) Randomized Algorithms for Counting Problems | NIT Tiruchirapalli BHU Banaras, IISc Bangalore, PSGTECH Coimbatore, NIT Karnataka, BITS Goa |
| IMSc Chennai          |                                                                                  |                                                                               |
| Ambat Vijayakumar     | (i) Graph Dynamics                                                              | IIITM Kerala                                                                  |
| CUSAT, Cochin         |                                                                                  |                                                                               |
| Nisheeth Vishnoi      | (i) Hardness of Approximation                                                   | NIT Karnataka                                                                  |
| Microsoft Bangalore   |                                                                                  |                                                                               |