RESUME

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Education:	B.Tech, Electrical Engineering, I.I.T. Delhi, India, 1981. Ph.D, Computer Science, University of Illinois at Urbana-Champaign, U.S.A., 1986.
Research Interests:	Computational Geometry, Combinatorial Optimization, Graph Algorithms, Data Structures, Graphics, Quantum Computing.

Experience:

1. Professor, Dept. of Comp. Science , IIT Delhi, Jan 2000-present.
2. Associate Prof. , Dept. of Comp. Sc., IIT Delhi, Jan. 1994- present.
3. Asst. Prof., Dept. of Comp. Sc., IIT Delhi, Feb. 1988- Jan. 1994.
4. Visiting Asst. Prof., Dept. of Comp. Sc., IIT Delhi, July 1987 - Jan. 1988.
5. Bell Labs, Murray Hill, New Jersey, U.S.A., Post Doctoral Member of Staff, Sept. 1986 - June 1987.
6. Visiting researcher at Max-Planck Institute fur Informatik, Germany,
   June- July 1993,
   June- July 1994,

Sept- Dec 1995,
May- July 1996,
June 1997.

7. Visiting Researcher, Bell-Labs, June-July 1999.

Research Experience and Future Plans.

My research in the past has been concentrated on optimal algorithm design. Lately, I am also concentrating on applying the design techniques to problem solving with implementions as deliverables. In this direction, I have worked in the following areas:

1. *Graphics*: In this area I am interested in computational geometry algorithms which solve the *Dynamic Hidden Surface Removal Problem.* The static version of this problem has been well researched. However, the dynamic version of the problem is becoming increasingly important in animation, virtual reality etc. Hardware solutions proposed for the static case do not appear very efficient for the dynamic case. I am the principal investigaor in an approved project for this problem.

2. *Optimization*: In this area one important problem we are attempting to solve is the problem of *Bus-Routing*, a hard combinatorial problem, using optimization tools. The underlying theoretical problem is that of integer multi-commodity flows. We are also investigating the vehicle routing problem. These projects form part of a larger project on Transport Research funded by the Department of Industry, Govt. of India.

3. *Embedded Systems*: My intitial involvement was in the area of *Hardware-Software Co-Design.* The problem that was addressed in an M. Tech thesis co-guided by me dealt with optimum partitioning, at the functional level, of program flow graphs so that an assignment of functions for software or hardware execution could be made. Currently I am involved in such partitioning problems for embedded system design in a sponsored project.

I am interested in continuing to apply design principles to important real-word problems. I summarize my research in various areas below:

Research Experience and Contributions.

Computational Geometry

(1) Finding shortest paths on the plane amongst obstacles. This problem is of interest for trajectory planning in the area of Robotics. The following results have been obtained:

(i) Shortest paths in the rectilinear metric in almost optimal time.

(ii) Simple algorithms for shortest paths in Euclidean metric. Optimal for restricted cases.

(iii) Simple and efficient schemes for constructing Visibility Graphs.

(iv) Nearly optimal and optimal schemes using wavefront method for the Euclidean metric.

- Rectilinear shortest paths amongst Polygonal Obstacles, (with K. Clarkson and P. Vaidya), 3rd Annual *A.C.M. Symposium on Computational Geometry*, 1987.
- Efficient Algorithms for Euclidean Shortest Path among Polygonal Obstacles, (with S.N. Maheswari and J.S.B.M Mitchell), *Discrete and Computational Geometry*, Dec. 1997.
- Efficient Algorithms for Euclidean Shortest Path and Visibility Problems with Polygonal Obstacles, (with S.N. Maheswari), 4th Annual *A.C.M. Symposium on Computational Geometry*, 1988,pp.172-182.
- Efficient Algorithms for Flows and Shortest Paths in Polygonal Domains, Technical Report, 1993 (with S.N. Maheshwari), submitted.
- An Efficient Wavefront method, 1993 (revised 1995),submitted.

(2) Almost optimal schemes for the geodesic shortest path problem on a polyhedron in 3-d.

- Efficiently Computing Geodesic Shortest Paths, in *ACM Symposium on Theory of Computing*,1999.

(3) Data Structures in Computational Geometry. The following dynamic data-structures have been obtained:

(i) Optimal maintenance of the set of Maximas in 2-d.

(ii) Improved maintenance of the Convex Hull of a set of 2-d points.

(iii) New techniques for the design of data structures for the closest-pair problems, a problem of fundamental importance amongst proximity problems.

(iv) Data Structures and Algorithms for maintenance of shortest path trees in simple polygons under changes to simple polygon.

- Dynamically Maintaining Maxima in 2-dimensions, 10th *ACM Symposium on Computational Geom*, 1994.

- New techniques for exact and approximate dynamic closest-point problems, (with M. Smid), *SIAM J. of Computing*, August 1996. Also in 10th *ACM Conf on Comp. Geom*, 1994.

- On the Dynamic Maintenance of 2-D Convex Hulls, Technical Report Max-Planck Institut fur Informatik, 1995, submitted.

- Dynamically maintaining shortest path trees in simple polygons, (with Tripurari Singh), Proc. of *FST & TCS*, 1996, Springer-Verlag.

(4) Developed a data structure called the AGN-tree which is a decomposition of S to capture approximate geographic neighbors. This data structure allows the computation of a spanner graph of bounded weight and also gives a framework for computing the MST of the set of points S in $O(T_{CFP}(n,n))$ steps which is the time required to compute the closest pair of points from two separated point sets.

(5) New methodologies developed for proving lower bounds on some problems in Computational Geometry.

(i) Simple Lower Bounds for Convex Hull and Maxima Problems. The techniques used here have found applications in proving other lower bounds.

(ii) Lower Bounds on approximating Euclidean TSP and MST.

- Lower Bounds on Maximal Layer and Convex Hull Problems, (with P. Ramanan), *Algorithmica* 4, (1989), 447-459.

- On the Complexity of approximating travelling salesman tours and minimum spanning trees, 1996 (with G. Das and M. Smid), *Algorithmica*, 1997. Also in Proc. of *FST & TCS*, India 1996, Springer-Verlag.

(6) Also developed are algorithms for Vornonoi diagrams and relative neighborhood diagrams in simple polygons with obstacles. Also, we have developed a divide and conquer schema for computing the k-th order Voronoi diagrams.

- Algorithms for Relative Neighborhood Graphs and Vornoi Diagrams in Simple Polygons, (With V. Sarin), 4th *Canadian Conference on Computational Geometry*, 1992.

Graphics

(1) Dynamic Hidden Surface Removal Problems: We address the hidden surface removal problems where the viewable scene is changing with time. Objects may be deleted or inserted. Alternately, the viewpoint may change. We have developed techniques for determining the 3-d ordering in the dynamic setting. Improvements in the hard case of deletions have been shown. The underlying structure is that of BSP Trees. These trees have applications to solid modelling also.

- Dynamic Binary Space Partitioning for hidden surface removal, (with A. Kumar, V. Kwatra, B. Singh), Proc. of ICGVIP 1998 (part B), New Delhi.

- Using Separating Planes between Objects for Dynamic Binary Space Partitioning, (with A. Kumar, V. Kwatra, B. singh), to appear in Proc of International Conference on Visual Computing, Goa, India, Feb. 1999.

- Object oriented Ellipsoid BSP Trees, (with N. Jain, S. Bansal), ICVGIP, to appear, Dec. 2000.

Mathematical Programming and Graph Optimizations

(1) Interior Point Methods: Provably good interior point algorithms were developed by Karmarkar for Linear Programming. Extensions of thas work are as follows:

(i) An interior point method for Convex Quadratic Programming.

(ii) An interior point method for efficient computation of Multi-Commodity Flows.

- Efficient Algorithms for Quadratic programming and Multi-Commodity Flows, (with P. Vaidya) Procededings of the 18th Annual *ACM Symposium on Theory of Computing*, 1986, pp.147-159.

- Speeding up Karmarkar's Algorithm for Multi-Commodity Flows, (with P. Vaidya), *Mathematical Programming*, 1996.

(2) The following results in Graph Partitioning have been obtained:

(i) Generalizing the classical non-crossing results for minimum cuts in graphs obtained by Gomory and Hu to 3-cuts.

(ii) Improved algorithm for finding 3-cuts in graphs.

(ii) Techniques to give improved approximations for k-cuts.

- On Minimum 3-cuts and Approximating Graph Partitioning using Cut Trees, Proc. of 5th *International IPCO Conference* , LNCS Springer-Verlag, 1996.

(3) Developed Constarined Shortest Path algorithms with applications in Networks.

- Improved Multicast Routing with Delay and Delay Variation Constraints, (with S. Raghavan), IEEE GlobeCom, to appear, Nov. 2000.

(4) Developed algorithms using the exchange property for Minimum Spanning Trees and Matroids.

Graph Theory

(1) Enumeration of Subgraph Structures.

(i) One set of results deal with optimally enumerating spanning trees for undirected graphs.

(ii)Further results deal with almost optimally enumerating spanning trees for directed graphs. We have also shown how to enumerate efficiently all maximal cliques in graphs.

- Algorithms for Enumerating All Spanning Trees of Undirected and Weighted Graphs, (with H. Ramesh), *SIAM J. Computing* , vol 24, No. 3. 1995.

- Algorithms for Enumerating All Spanning Trees of Undirected, Directed and Weighted Graphs, (with H. Ramesh), Proc. *Workshop on Algorithms and Data Structures*, Carleton University, Canada, Springer Verlag, August 1991.

Data Structure

In the field of basic data structures the following results have been obtained:

(i) A construction of optimal searching when costs of each test is a function of the outcome of the test.

- Optimum Lopsided Binary Trees (with E.M. Reingold), *J. of A.C.M.,* vol. 36, No. 3, July 1989, pp.573-590.

(ii) A stochastic self-organizing list data structure which reduces data movements.

- Stochastic Rearrangement Rules for Self-Organizing Data Structures, (with E.M. Reingold), *Algorithmica* (1991) 6:278-291.

Quantum Computing

My main interest is to develop algorithmic paradigms in the Quantum model of computing. This model has shown promise in achieving speedup in the solution of various problems.

The following problems have been solved:

(i) Finding the maxima of a set of points.
A quantum algorithm for finding the maxima, (with A. Ahuja)
http://xxx.lanl.gov/list/quant-ph/new

(ii) Finding an ϵ-approximate median, manuscript.

Publications:

Journals

- Recurrence Relations Based on Minimization and Maximization (with E.M. Reingold), *J. of Math. Anal. and Applications*, 109, No.2 (August 1985), 591-604.
- Minimizing Channel Density in Standard Cell Layout, (with J. Blair, E.L. Lloyd, K.J. Supowit), *Algorithmica*, Vol. 2, No. 3, (1987), pp. 267-282.
- Optimum Lopsided Binary Trees (with E.M. Reingold), *Journal of A.C.M.*, vol. 36, No. 3, July 1989, pp.573-590.
- Lower Bounds on Maximal Layer and Convex Hull Problems, (with P. Ramanan), *Algorithmica* (1989) 4: 447-459.
- Stochastic Rearrangement Rules for Self-Organizing Data Structures, (with E.M. Reingold), *Algorithmica* (1991) 6:278-291.
- Algorithms for Enumerating All Spanning Trees of Undirected and Weighted Graphs, (with H. Ramesh), *SIAM Journal of Computing*, vol 24, No. 3. 1995.
- Speeding up Karmarkar's Algorithm for Multi-Commodity Flows, (with P. Vaidya), *Mathematical Programming*,Volume 73, Issue 1, April 1996, pp 111-127.
- New techniques for exact and approximate dynamic closest-point problems, (with M. Smid), *SIAM Journal of Computing*, August 1996.
- On the Complexity of approximating travelling salesman tours and minimum spanning trees, (with G. Das and M. Smid), *Algorithmica*, 1997.
- An Efficient Algorithm for Euclidean Shortest Paths amongst Polygonal Obstacles, (with S.N. Maheshwari and J.S.B. Mitchell). *Discrete & Computational Geometry*, 1997.
- Algorithms for Enumerating All Spanning Trees of Directed Graphs, (with H. Ramesh), Algorithmica 27(2): 120-130 (2000).
- Dynamically Maintaining Maxima in 2-dimensions, SIAM J. Comput. 29(6): 1858-1877 (2000)

- Efficiently constructing the visibility graph of a Simple Polygon with Obstacles, (with S.N.Maheshwari), *SIAM Journal of Computing.* Vol. 30, No. 3, 2000, 847-871.

Conference Publications

- Efficient Algorithms for Quadratic programming and Multi-Commodity Flows, (with P. Vaidya) Procededings of the 18th Annual *ACM Symposium on Theory of Computing*, 1986, pp.147-159.

- Rectilinear shortest paths amongst Polygonal Obstacles, (with K. Clarkson and P. Vaidya), 3rd Annual *A.C.M. Symposium on Computational Geometry*, 1987.

- Efficient Algorithms for Euclidean Shortest Path and Visibility Problems with Polygonal Obstacles, (with S.N. Maheswari), 4th Annual *A.C.M. Symposium on Computational Geometry*, 1988,pp.172-182.

- On Enumerating all spanning trees of directed and undirected graphs, (with H. Ramesh), Proc. *Workshop on Algorithms and Data Structures*, Carleton University, Canada, Springer Verlag, August 1991.

- Algorithms for Relative Neighborhood Graphs and Vornoi Diagrams in Simple Polygons, (With V. Sarin), 4th *Canadian Conference on Computational Geometry*, 1992.

- New techniques for exact and approximate dynamic closest-point problems, (with M. Smid), 10th *ACM Symposium on Computational Geometry*, 1994.

- Dynamically Maintaining Maxima in 2-dimensions, 10th *ACM Symposium on Computational Geometry*, 1994.

- On Minmum 3-cuts and Approximating Graph Partitioning using Cut Trees, Proc. of 5th *International IPCO Conference* , LNCS Springer-Verlag, 1996.

- On the Complexity of approximating travelling salesman tours and minimum spanning trees, 1996 (with G. Das and M. Smid), Proc. of *FST & TCS*, India, LNCS Springer-Verlag, 1996.

- Dynamically maintaining shortest path trees in simple polygons, (with Tripurari Singh), Proc. of *FST & TCS*, India, LNCS, Springer-Verlag, 1996.

- Dynamic Binary Space Partitioning for hidden surface removal, (with A. Kumar, V. Kwatra, B. Singh), Proc. of *ICGVIP* 1998 (part B), New Delhi.

- Using Separating Planes between Objects for Dynamic Binary Space Partitioning, (with A. Kumar, V. Kwatra, B. singh), in Proc of *International Conference on Visual Computing*, Goa, India, Feb. 1999.

- Hardware/Software Partitioning Between Microprocessor and Reconfigurable Hardware (with M. Anand and M. Balakrishnan), FPGA 1999, Monterey, USA.

- Efficiently computing Geodesic Shortest Paths, in *ACM Symposium on Theory of Computing*, May 1999.

- Bus Routing and Allocation, (with M. Kathuria), presented at *INFORMS*, May 1999, Cinicinatti, USA.

- Optimal Hardware/Software Partitioning for Concurrent Specification using Dynamic Programming (with A. Srivastava, M. Kumar, S. Kumar, M. Balakrishnan) in VLSI Design Conference, IEEE press, Calcutta, 2000.

- Object oriented Ellipsoid BSP Trees, (with N. Jain, S. Bansal), ICVGIP, Bangalore, Dec. 2000.

- Improved Multicast Routing with Delay and Delay Variation Constraints, (with S. Raghavan), IEEE GlobeCom, San Fransisco, Nov. 2000.

Other manuscripts

- An extension of Karmarkar's interior point method to convex qudratic programming,(with P. Vaidya)Technical Report, University of Illinois at Urbana-Champaign, 1988.

- Efficient Algorithms for Flows and Shortest Paths in Polygonal Domains, Technical Report, 1993 (with S.N. Maheshwari), submitted.

- An Efficient Wavefront Method, 1993 (revised 1995),submitted (under revision).

- On the Dynamic Maintainence of 2-D Convex Hulls, Technical Report Max-Planck Institut fur Informatik, 1995, submitted.

- Covering Relations and Language Classes with Applications, extended abstract, to be submitted.

- The Approximate Geographic Neighborhood Tree with Applications, extended abstract, submitted.
- An Exchange Method for Minimum Spanning Trees and Matroids, manuscript.
- A quantum algorithm for finding the maxima, (with A. Ahuja) posted at quant-ph: http://xxx.lanl.gov/list/quant-ph/new
- Optimal Quantum Algorithm for approximating the median, manuscript.

Software Modules Developed

- Software Modules for Dynamic Hidden Surface Removal
- Software for Bus Routing and Vehicle Routing Problems

Research and Consultancy Projects

(1) *Dynamic Schemes in Computational Geometry*, Young Scientist Project, from Dept. of Science and Technology, India, 1994-1996. (Value: Rs 1,28,000)

The project dealt with the design of *data structures* for dynamically maintaining geometric configurations.

From an applications viewpoint implementation of a scheme for dynamic maintenance of a scene of polyhedral objects viewed from a fixed viewpoint was also carried out. The scene is allowed to change due to insertions of polyhedron. Extensions are under way to allow for deletions.

(2) Member of Executive Committee of *TRIPP*. Project on bus route optimization in *Transport Research* with *TRIPP*. TRIPP is a recently established program at IIT Delhi with funding of $Rs.70,00,000$ currently.

(3) *Dynamic Hidden Surface Removal Problems*, (Principal Investigator), funded by Dept. of Science and Tech., (Value: Approx Rs. 14,00,000)

(4) *Methodology for Embedded System Design*, project funded by NRB, India.

(5) Consultant with IBM-India research lab on algorithms in optimization.

(6) Consultant with EscoSoft, New Delhi, for graphics engine design.

(7) DTC Bus Routing and Scehduling Project.

(8) Postal Van Routing in Delhi, Dept. of Posts.

Other Professional Activities

- N. Rama Rao Distinguished Speaker, IIT-Kanpur, 7-8th Nov 2000.
- Program Committee Co-Chair, FST & TCS 2000.
- Program Committee Member, FST & TCS 1992.
- Program Committee Member, FST & TCS 1991.
- Invited Speaker, Workshop on Algorithms and Data Structures, IISc, Bangalore, July 1992.
- Program Committee Member, National Seminar on Theoretical Computer Science, Kanpur, 1994.

Thesis Guided

M.Tech Students

- Chitra Prasad, *Implementing an Efficient Euclidean Shortest Path Algorithm*, 1988.
- Ann James, *On Enumerating All Stable Marriages and All Spanning Trees*, 1989.
- Ramesh Singh, *Implementing an Algorithm for Dynamic Shortest Paths Trees in Simple Polygons*, 1992.
- R. Pandian, *Algorithms for k-Relative Neighborhood Graphs*, 1994.
- Tripurari Singh, *On Dynamic Shortest Path Trees in Simple Polygons*, 1995.
- M. Anand, *Hardware-Software Partitioning for FPGA's*, 1998.
- M. Kathuria, *Bus Allocation and Routing*, Dec. 1998.
- M. Sarwat, *Multi-Commodity Flows*, Dec. 1999.
- M. Punhani, *Exact and Approximate solutions to the Vehicle-Routing Problems*, Dec. 1999.
- Srivatsan Rahgvan, *Multicast Routing Algorithms with QOS Guarantees*, Dec. 1999.

B.Tech Thesis

- 3-D Reconstruction from multiple 2-D Images, B. Tech Thesis of S. Bholla, 1989. (co-guide K.K. Biswas)
- A Study of some problems in Computational Geometry, B. Tech thesis of Manish Malhotra, 1989. (co-guide S. N. Maheshwari)
- Algorithms for Enumeration of All Maximal Cliques and all Cliques, B. Tech Thesis of R. Mehta, 1990.
- Algorithms for Spanning Tree Enumeration in Graphs, B. Tech Thesis of H. Ramesh, 1990. (Best project Award).
- Algorithms for Vornoi Diagram and Relative Neighbour Decomposition of Simple Polygons, B. Tech thesis of Vivek Sarin, 1990.
- Study and Implementation of Dynamic Planar Point location Schemes, P. Sundaresan, 1991.
- Algorithms for Finding the Link Center of a Simple Polygon, B.Tech Thesis of A.V. Rao and B. Venkata Vasu, 1992.
- Efficient Algorithms for Enumerating all Spanning Trees of a directed graph, B. Tech Thesis of V. Kumar, 1993. (Best project Award)
- Study of problems related to Hidden Surface Removal, Nitin Sharma, 1993.
- Dynamic Hidden Surface Removal, D. Verma and N. Kumar, 1997.
- Viewing Objects with Dynamic Shadowing, A. Sharma and B. Singh, 1999.
- Efiicient Hidden Surface Removal of Curved Objects, A. Kumar and V. Kwatra, 1999.

Courses Taught

- Design and Analysis of Algorithms.
- Formal Languages and Theory of Computation.
- Discrete Structures.
- Introduction to Data Structures.
- Computational Geometry.

- Algorithmic Graph Theory.
- Mathematical Programming.
- Advanced Combinatorial Algorithms.
- Introduction to Computers and Programming.
- Graphics.
- Theory of Compiler Design, QIP Short Course, 1988.
- Algorithm design, DRDO Short Course, 1996.

Referees

1. Prof. E.M. Reingold, Dept. of Computer Science, University of Illinois at Urbana-Champaign, Illinois, U.S.A. e-mail: reingold@cs.uiuc.edu
2. Prof. P.C.P Bhatt, Professor Information Systems Engineering, Kochi University of Technology, Miyanokuchi 185, Tosayamada-cho Kochi - 782 Kochi-ken (Japan) e-mail: bhatt@info.kochi-tech.ac.jp
3. Prof. C. Bajaj, Computer Science Department, University of Texas at Austin, Austin, Texas, USA. e-mail: bajaj@cs.utexas.edu
4. Prof. Dr. Kurt Mehlhorn, Director, Max-Planck Institut fur Informatik, Saarbrucken, Germany. e-mail: mehlhorn@mpi-sb.mpg.de
5. Prof. S.N. Maheshwari, Dept. of Computer Science & Engg. IIT-Delhi, Hauz Khas, New Delhi-110016, India. e-mail: snm@cse.iitd.ernet.in