IMA Workshop

Minorities and Applied Mathematics: Connections to Industry

October 4–6, 1996

Organizers: Raymond Johnson, Fletcher Jones, James Turner

Sponsored by Honeywell

Institute for Mathematics and its Applications
University of Minnesota
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I. Workshop Summary

Preparing for opportunities was the theme of a workshop on **Minorities and Applied Mathematics-Connections to Industry,** held October 4–6, 1996 at the Institute for Mathematics and its Applications (IMA), University of Minnesota. Approximately sixty invited minorities in mathematical sciences attended the workshop. Of these, forty were Ph. D. students from mathematical sciences departments in North America; the other twenty participants represented a range of professional experience from postdoc to senior scientist. Also attending were Avner Friedman, Director of the IMA; Robert Gulliver, Associate Director of the IMA; and Barry Cipra, a science writer.

The workshop was arranged by the IMA Director and the organizers to provide an atmosphere in which minority graduate students could hear about the research and careers associated with applying mathematics to real-world problems. The real-world problems presented to students involved mathematics at all levels from elementary to technical, and showed students the need to communicate across disciplines with scientists and engineers having sophisticated mathematical training. Students began that communication process (listening and speaking) at this workshop. Their careers will be enhanced by this type of exposure; they were encouraged to seek similar opportunties at their home insitutions and in their home regions. Each graduate student attending the workshop agreed to return to their home institution and make a presentation about the workshop, so that its benefits would not be limited to those who attended.

The composition of the workshop— a relatively small group, mostly graduate students— was based on the model used at the workshop for women at the IMA in February, 1996 and was intended to create a comfortable and relaxed environment. The workshop contained four components:

1. Overview talks by senior participants about their technical work and career experiences;
2. Technical talks about the applications of mathematics associated with various real-world problems;
3. Focused small-group discussions charged to produce action items for colleges and universities, government laboratories, funding agencies and professional organizations;
4. An after-dinner talk by Earl Barnes of Georgia Tech describing how the discovery of Karmarkar's algorithm affected IBM's business strategy and the relationship between further developments in the mathematics and changes in strategy by IBM and its competitors.

The minority mathematics community is small, and the workshop was the first opportunity for many of the students to network with minority professionals sharing their interest in mathematics.

The technical talks were uniformly of high quality, and covered a range of applications, including manufacturing of semi-conductors, microstructure of materials, design of a chemical

vapor deposition reactor, mathematical problems arising in biology including freezing of tissues for biomedical engineering, dynamics of proteins in aqueous solutions, transport of solutes across cell membranes and reconstruction of images in tomography. The mathematics involved included wavelets, Markov processes, optimization, partial differential equations and computer models. (Abstracts of all the talks are in Section IV below.)

The small-group discussion sessions were also modelled on the program held for women in February. Each group included about twelve people, typically eight graduate students and four senior mathematicians. One or two people served as coordinators to assure that everyone had a chance to speak and to assure that the group covered all relevant topics. One person was designated as recorder to prepare notes of each group's discussions. Another member of each group was asked to present the group's recommendations at the final assembly of all workshop participants. Student volunteers introduced speakers after the morning session, providing another chance for them to practice their communications skills.

The organizing committee was extremely pleased with the workshop. Participants were so enthusiastic that one of their primary suggestions was a request to meet again to see how people had carried out the suggestions made to them. They wanted to use another meeting to practice skills suggested at this workshop, where graduate students would give more of the talks, and would receive advance help in order to make maximum use of the conference.

The primary value of workshops like this is the students' exposure to people like themselves with interests like theirs, who have accomplished what they are striving to accomplish. All mathematicians are members of many communities— minorities, women, men, analysts, geometers, topologists, applied mathematicians. Workshops like this do not substitute for the specialized meetings of those communities; they serve to demonstrate the existence of a minority mathematics community which is not visible to students isolated in their graduate programs.

The meeting was valuable because minority mathematicians have an unparalleled opportunity. Mathematics research and education are rapidly changing. The minority mathematics community did not prosper under the old model; there is a willingness in our community to consider other models of preparation for a career in research. This workshop showed that minority students are eager to prepare themselves for twenty-first century opportunities.

II. Workshop participant list

AGONAFER, DEREJE	IBM Corporation	OCT 4 - 6
AQUINO, LESLIE	Rensselaer Polytechnic Institute	OCT 4 - 6
ARREDONDO, MIGUEL	Purdue University	OCT 4 - 6

BARNES, EARL	Georgia Institute of Technology	OCT 4 - 6
BLAYNEH, KBENESH	Florida A & M Univ.	OCT 4 - 6
BRANA-MULERO, FRANCIS	Shell Development	OCT 4 - 6
CANTU, SERGIO	Purdue University	OCT 4 - 6
CLARK, ANTWAN	Rensselaer Polytechnic Institute	OCT 4 - 6
DONALDSON, JAMES	Howard University	OCT 4 - 6
ECHOLS, CARRAE	University of Kentucky	OCT 4 - 6
FOSSER, CECILIA	University of Arizona	OCT 4 - 6
GARCIA, ANGEL	Los Alamos National Laboratories	OCT 4 - 6
GILYOT, DUANE	University of California-Berkeley	OCT 4 - 6
GOMEZ, ELVIA	Texas Tech Univ.	OCT 4 - 6
GOWARD, RUSSELL	University of Missouri-Columbia	OCT 4 - 6
GRAHAM, MERIDITH	Rensselaer Polytech Institute	OCT 4 - 6
GREENE, DAVID	Florida A & M Univ.	OCT 4 - 6
HANSEN, BEN	Univ. of California, Berkeley	OCT 4 - 6
HAYES, LINDA	University of Texas-Austin	OCT 4 - 6
HOUSTON, JOHNNY	Elizabeth City State University	OCT 4 - 6
HUNT, FERN	Nat. Inst. of Standards and Technology	OCT 4 - 6
INNISS, TASHA	University of Maryland-College Park	OCT 4 - 6
JACKSON, MONICA	University of Maryland	OCT 4 - 6
JOHNSON, RAYMOND L.	University of Maryland	OCT 4 - 6
JONES, FLETCHER	IBM	OCT 4 - 6
KEEVE, MICHAEL	Georgia Institute of Technology	OCT 4 - 6
LIAMBA, LUKEMBA	University of Wisconsin-Milwaukee	OCT 4 - 6
LIVINGSTON, ALICE	Florida State University	OCT 4 - 6
LONDONO, JAIME	University of California-Riverside	OCT 4 - 6
LOPEZ, GILBERTO	Northwestern University	SEPT 1 - AUG 31
MACK, IRIS	Associated Technologies	OCT 4 - 6
MAIR, BERNARD	University of Florida	OCT 4 - 6
MARTINEZ, MONICA	Rice University/ Univ. of Texas	OCT 4 - 6
MASON, TOM	Florida A & M Univ.	OCT 4 - 6
MCINTYRE, CLAUZELL	Clark Atlanta University	OCT 4 - 6
MEJIA, RAYMOND	National Institutes of Health	OCT 4 - 6
MEZA, JUAN C.	Sandia National Laboratories	OCT 4 - 6
MOLEFE, DANIEL F.	Northern Illinois Universitiy	OCT 4 - 6
MOORE, JOY	University of Cincinnati	OCT 4 - 6
NIGUSSIE, YARED	Ohio State University	OCT 4 - 6
PERRY, STEPHANIE	North Carolina A & T Univ.	OCT 4 - 6
PHILLIPS, ALFRED	Cornell University	OCT 4 - 6
RAMIREZ-GOMEZ, EDGARD	Virginia Tech	OCT 4 - 6
SARKAR, SHYAM	Centura (Gupta) Software Corp.	SEP 1 - OCT 30
SIMON, TAMMY	North Carolina State Univ.	OCT 4 - 6
ST. MARY, DONALD	Univ. of Massachusetts-Amherst	OCT 4 - 6
TATE, CALANDRA R.	Xavier University of Louisiana	OCT 4 - 6
TAYLOR, KEVIN	University of Iowa	OCT 4 - 6
TURNER, JAMES	Florida A&M University	OCT 4 - 6
TWUM-DANSO, NANAYAA	Harvard Unversity	OCT 4 - 6
WALLACE, ALTON	Institute for Defense Analysis	OCT 4 - 6

WATKINS, BOYCE	University of Kentucky	OCT 4 - 6
WHITAKER, SHREE	North Carolina State	OCT 4 - 6
WRIGHT, PAUL	Bell Laboratories	OCT 4 - 6
ZAMORA, PAOLA	Univ. of North Carolina	OCT 4 - 6
ZEIGLER, DAVID	Texas A&M University	OCT 4 - 6

III. Workshop Schedule

IMA Workshop:

Minorities and Applied Mathematics: Connections to Industry

October 4–6, 1996

Organizers: Raymond Johnson, Fletcher Jones, James Turner

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Mathematical problems arising in industrial applications typically embody complicated, interdisciplinary issues of formulation, analysis and solution. Minorities in mathematical careers are often attracted to areas in which their results can have a societal impact. There are manuy opportunites provided by real-world problems for high-quality research, contributions to practical results, and rewarding scientific careers. The purpose of the weekend workshop is to show examples of people and problems from industrial settings and to develop a set of concrete action items that individuals and agencies can carry out and help minority scientists at all levels and in varied environments become involved with industrial problems.

The first goal will be achieved through technical talks by selected participants chosen based on their success with real-world problems. The collection of action items will build on suggestions received at earlier workshops.

6:00 pm	**Reception**	Radisson Hotel Metrodome

Participants will gather outside the Nolte Room, second floor of Radisson Hotel

7:00 pm	**Dinner** Radisson Hotel Metrodome	Ballroom D, second floor of Radisson Hotel
8:30 pm	**Avner Friedman** IMA Director	Welcome
8:40 pm	**James Turner** Florida A&M University	What we intend to accomplish

Saturday, October 5

7:30 am	**Registration and Continental Breakfast**	Reception Room EE/CS 3-176

Five technical talks:

8:00 am	**Dereje Agonafer** IBM	An integrated solid-model-based CFD modeling methodology for computer packaging applications
8:25 am	**Linda Hayes** University of Texas-Austin	Applications of Freezing in Biomedical Engineering
8:50 am	**Fletcher Jones** IBM Watson Labs	Three-Dimensional Modeling of Optical Lithographic Patterns Used To Manufacture Computer Chips
9:15 am	**Monica Martinez** University of Texas-Austin	Shallow Water Equations: Modeling of Bays, Estuaries and Oceans
9:40 am	**Alfred Phillips Jr.** Cornell University	Field-Effect Transistor Theory
10:00 am	**Coffee Break**	Reception Room EE/CS 3-176

Two technical talks:

10:30 am	**Angel E. Garcia** Los Alamos National Lab.	Multi-basin Dynamics of Proteins in Aqueous Solution
11:00–12:00	**R. Johnson/F. Jones/J. Turner** Maryland/IBM/Florida A&M	Overview session on "concrete action"

Two "personal experience" talks:

1:30 pm	**Iris Mack** Associated Technologies	Financial Engineering & Risk Management
2:00 pm	**Alton Smith Wallace** Institute for Defense Analyses	Life as a "Beltway Bandit"

Five technical talks:

2:30 pm	**Fern Y. Hunt** National Inst. of Standards and Tech.	Mathematical Modelling of Barkhausen Jump Size Distributions

2:55 pm	**Juan C. Meza** Sandia National Laboratories	Optimal Design and Control of Chemical Vapor Deposition Reactors
3:20 pm	**Raymond Mejia** National Institutes of Health	Mathematics in Biology - An Application in Kidney Physiology
3:45 pm	**Bernard A. Mair** University of Florida	Two Mathematicians, an Engineer, and a Pet
4:10 pm	**Coffee Break**	Reception Room EE/CS 3-176
4:40–6:00	**Breakout Groups**	Rooms EE/CS 3-180 & 3-176, Vincent Hall 556, 559 &570

Participants will divide into groups to draft portions of the "concrete action" document

6:30 pm	**Dinner**	Campus Club

Wine and cheese at 6:30, buffet dinner at 7:00. The Campus Club is on the fourth floor of Coffman Union (the student union)

8:30 pm	**Earl Barnes** Georgia Inst. of Technology	Some Reflections on My Days at IBM

Sunday, October 6

8:00 am	**Coffee**	Reception Room EE/CS 3-176
8:30–11:30	**Breakout Groups**	Rooms EE/CS 3-180 & 3-176, Vincent Hall 556, 559 &570

Participants will return to their groups to continue drafting portions of the "concrete action" document, returning for a general session in EE/CS 3-180

11:30–12:00	**R. Johnson/F. Jones/J. Turner** Maryland/IBM/Florida A&M	Summary

IV. Abstracts of workshop talks

Tech. talk: **Dereje Agonafer**
IBM

An integrated solid-model-based CFD modeling methodology for computer packaging applications

Abstract: Technological advances in integrated circuits have resulted in sizeable increases in density of electronic components. As a result, much greater amounts of memory are available for product developers. One major problem which is a by-product of the advances in computing power, is a very large increase in heat load. For example, the heat flux at the chip level on IBM mainframes has increased by over an order of magnitude compared to the early IBM 303X mainframes. The performance of the electronic components is very much related to temperature values in the components. If the maximum temperature exceeds some value (typically 85^0C), a severe degradation in performance will result. Consequently, heat transfer is playing an ever increasing role in packaging technology.

The presentation will begin with a brief background of cooling challenges in IBM high end systems. This is followed by a presentation on an integrated approach for modeling of thermal problems related to electronic cooling. In particular, the use of an interface program that enables the extraction of mechanical related information (geometry, material property, ..) from a 2D circuit board design resulting in an automatic creation of 3D CATIA(1) solid models is presented. The required CFD model is then constructed in CATIA using a special function key developed jointly with Vimba (1991). The rest of the presentation will focus on applications of CFD to electronic packages, and will conclude by highlighting some of the CFD challenges that are of special interest to applied mathematicians.

The first problem is the solution to a system-level benchmark problem in electronics cooling consisting of a box with covers, floppy drive, hard file, power supply, planar, fans, feature cards and Single In-line Memory Modules (SIMM's) is described. The benchmark problem, proposed in an earlier paper (joint work with Linton), is solved using an integrated solid model based pre-processor coupled with a commercially available Computational Fluid Dynamics (CFD) package.

The second problem is the computation of the internal resistance of a TCM. A numerical model of an entire TCM module (without resorting to symmetry conditions) is presented. The model includes a 10×10 array of pistons, and a hat. All the chips (10×10) are included in the model by using thermocoupling technique to introduce the interface resistance between the chip and the piston. This is joint work with Free.

The third problem is a conjugate model of a 9×9 pinned fin heat sink for both parallel and impinging flow. The conduction problem is solved using a network model, and the convection problem is solved using a Finite Control Volume (FCV) technique. This is also joint work with Free.

The last problem is a turbulent modeling challenge in electronic cooling applications. Most of the flow regimes in electronic cooling lie in the transitional regime. A number of investigators have used the k-ϵ model; unfortunately, the model is best suited for much higher Reynolds numbers. The low-Reynolds number version of the k-ϵ model, employing damping functions on the k and ϵ equations, has been widely used for resolving the low-velocity near-wall region but requires a high computational time which makes it impractical. In this last section, the use of LVEL (a scheme that requires a knowledge only of the wall distances and the local velocities) is described. The model performs as well as the older Lam-Bremhorst-Yap and 2-layer-k-ϵ models, but is considerably less computationally expensive. This is joint work with Gan-Li and Spalding.

The talk will conclude by summarizing some of the challenges in CFD applications in electronic systems which could be of interest to applied mathematicians.

After dinner: **Earl Barnes** — Some Reflections on My Days at IBM
Georgia Inst. of Technology

Abstract: The speaker will give a personal view of some of the mathematics projects at IBM during the 70's and 80's. IBM researchers made many exciting contributions to mathematics during this period.

Tech. talk: **Angel E. Garcia** — Multi-basin Dynamics of Proteins in Aqueous Solution
Los Alamos National Lab.

Abstract: Simulations of biomolecular dynamics are commonly interpreted in terms of harmonic or quasi-harmonic models for the dynamics of the system. Harmonic models assume that the molecule exhibit oscillations around one energy minimum. However, experimental data suggest that the protein samples multiple minima and that transitions among minima shows a broad distribution of energy barriers.

To elucidate the nature of the dynamics of a protein we have studied the molecular dynamics trajectories of various proteins in aqueous solution. These trajectories show that proteins sample multiple local energy minima. Transitions among minima involve collective motions of amino acids over long distances. We show that nonlinear motions are responsible for most of the atomic fluctuations of the protein. These atomic fluctuations are not well described by large motions of individual atoms or a small group of atoms, but rather by concerted motions of many atoms. These motions are nonlinear in the sense that they describe transitions among different basins of attraction. The signature of these nonlinear motions can be seen in local and global structural variables.

A method for extracting molecule optimal d ynamic coordinates (MODC) is presented. A generalization of this method to identify small (1-3) dimensional subspaces of the configurational space is used to describe the dynamics of proteins within the context of, nonlinear, multi-basin dynamics.

Tech. talk: **Linda Hayes** — Applications of Freezing in Biomedical Engineering
University of Texas-Austin

Abstract: Cryosurgery and cryopreservation of human tissues are research areas with important ramifications for the field of modern medicine. Successful destruction of target tissue and successful preservation of tissue at low temperatures requires sophisticated freezing and thawing protocols. The first step in the development of these protocols in a proper understanding of the process of tissue freezing. In freezing tissue, there are three regimes of interest, an unfrozen zone, a frozen zone and a mushy zone consisting of both frozen and unfrozen phases. It is in this mushy zone that the critical interactions occur between the freeze front and the living cells and in which the ultimate survival or distruction of the cell is determined.

This talk will highlight a numerical model which has been developed for analyzing the development and progression of freezing front and illustrate its application to algae and to human tissue.

Tech. talk: **Fern Y. Hunt** — Mathematical Modelling of Barkhausen Jump Size Distributions
National Inst. of Standards and Tech.

Abstract: Ferromagnetic materials exhibit jumps in magnetization in the presence of an applied magnetic field of increasing strength, a phenomenon that is commonly known as the Barkhausen effect. It results from the motion of domain wall boundaries of the material in response to a fluctuating magnetic field. The pattern of jumps gives important information about the material microstructure and the Barkhausen signal is used to characterize photo-optical devices, computer storage and recording media.

The pinning field associated with the movement of magnetic domain walls is modelled as a reversible Markov Chain. This enables us to obtain analytical expressions for the Barhausen jump size distribution, and to describe the behavior of the distribution in terms of a parameter associated with the roughness of the material.

Tech. talk: **Fletcher Jones**
IBM Watson Labs

Three-Dimensional Modeling of Optical Lithographic Patterns Used To Manufacture Computer Chips

Abstract: Optical lithography is the technology used to create high-density VLSI computer circuit patterns. It is fair to say that small improvements and tighter control of a lithographic process usually lead to improved device yield and device performance. Significant advances in lithography often lead to big competitive advantages for manufacturers. Advancing lithographic technology is not easy. Evaluating engineering proposals is often very expensive. Mathematical modeling of lithography process steps often allows faster evaluation of new lithographic ideas and consequently cuts cost substantially. In this talk I will discuss models and the results of models used to simulate the three basic steps used to create photoresist patterns for VLSI circuits, *i.e.* (1) the 3D optical imaging and exposure step, (2) the 3D exposure product redistribution by diffusion during the very important bake step, and (3) the 3D dissolution of the exposed material during the development step. A video of the 3D dissolution process computed using the RD3D (Resist Development In 3 Dimensions) algorithm invented by the author will be shown.

Overview Talk: **Iris Mack**
Associated Technologies

Financial Engineering & Risk Management

Abstract: Financial engineering is the application of mathematical models in the research, development and pricing of new financial instruments and services. Although the origins of financial engineering can be traced to the work of Bachelier in the early part of this century, a major breakthrough in the field was made in 1973 with the discovery of the *option pricing formula*.

It is often said that the option pricing formula is to financial economics what the double helix was to molecular biology. In biology, the discovery of the structure of DNA gave birth to a new field of immense practical importance – genetic engineering. Similarly, the discovery of the option pricing formula gave birth to the equally important field of financial engineering.

Dr. Mack will discuss some applications of options analysis to risk management and investments analysis. Mathematical models in options analysis consist of a system of stochastic parabolic partial differential equations with fixed and/or moving boundary conditions. Dr. Mack will describe various known analytical solutions, as well as numerical approximations to the solution to these stochastic partial differential equations. Some industrial applications will also be described.

Tech. talk: **Bernard A. Mair**
University of Florida

Two Mathematicians, an Engineer, and a Pet

Abstract: In this talk we discuss new algorithms for the reconstruction of positron emission tomography images, based on the Shepp-Vardi statistical model. We also include interesting applications of abstract measure theory to understanding the numerical divergence of the classical EM iteration procedures, and to obtain partial answers to an open question of convergence of a generalized EM algorithm. This talk also deals with the vital relationships between mathematics and engineering which resulted in this work, and continues to fuel current work.

Tech. talk: **Monica Martinez**
University of Texas-Austin

Shallow Water Equations: Modeling of Bays, Estuaries and Oceans

Abstract: The applications of the shallow water equations are numerous. For instance, modeling tidal fluctuations for those interested in capturing tidal energy for commercial purposes; predicting tidal ranges and surges which can then be used in the development planning of coastal areas; and, upon coupling to a transport model, considering flow and transport phenomenon. The latter application makes it possible to study remediation options for polluted bays and estuaries, to predict the impact of commercial projects on fisheries,

to model salinity intrusion effects, and to study the effects of wetting-induced mineral seepage into streams.

We will concentrate on issues in modeling as well as on parallelization strategies for a state-of-the-art hydrodynamic model currently used by various federal and state agencies.

Tech. talk:	**Raymond Mejia**	Mathematics in Biology - An Application in Kidney
	National Institutes of Health	Physiology

Abstract: Mechanisms by which water and solutes are transported across cell membranes have been studied both experimentally and with mathematical models for decades. Tools of molecular and structural biology now make it possible to study specific transporters and channels, and thus identify more precisely mechanisms and possible sites of activity. This in turn permits the test of hypotheses based on in-vitro experiments, molecular structure and function with models of the whole organ.

In this talk we describe two mathematical tools, and how they serve to increase our understanding in renal physiology. We first describe neural net models used to characterize integral membrane proteins. Secondly, we show how a model of the rat kidney is used to incorporate information obtained in vitro and at the molecular level to test a hypothesis about regulation of urine formation by the mammalian kidney.

Tech. talk:	**Juan C. Meza**	Optimal Design and Control of Chemical Vapor Deposition Reactors
	Sandia National Laboratories	

Abstract: The optimal design and control of a chemical vapor deposition (CVD) reactor is an important issue in the microelectronics industry. In the optimal control problem, the goal is to determine a set of parameters that will yield a target temperature distribution in a CVD reactor. In this talk, we examine the issues of using optimization methods for the design and control of CVD reactors for which the objective function is expensive, noisy, and derivatives are not readily available.

Tech. talk:	**Alfred Phillips Jr.**	Field-Effect Transistor Theory
	Cornell University	

Abstract: We have created a two-postulate theory for field-effect transistors (FETs) that applies to metal-oxide-semiconductor FETs, junction FETs, metal-semiconductor FETs, and hetero-structure FETs. Although FETs are the most important electronic device fabricated in industry today, the mathematical model of FETs given in current texts is based on Shockley's forty year-old low drain voltage approximation. We will discuss the mathematics of our theory and compare its predictions with measurements.

Overview	**Alton Smith Wallace**	Life as a "Beltway Bandit"
Talk:	Institute for Defense Analyses	

Abstract: This talk presents an insider's view of the career of a typical "Beltway Bandit" operating within the confines of the Washington, DC Beltway. While no *products* are produced and few *services* are rendered inside the "Beltway", still an industry of technical consultants flourishes providing the US Government with advice and counsel on a number of technical subjects.

The speaker will discuss the technical consulting business from the perspective of a neophyte just starting a new career, and from the perspective of a senior manager in one of the Washington, DC area's premier "think tanks". Emphasis will be placed on the conduct of studies and analyses to support the Department of Defense. The discussion will identify those attributes required to succeed, and identify opportunities for minorities in the Washington, DC consulting environment.

V. Breakout group recommendations

Each breakout group was asked to discuss the following topics:

1. Undergraduate and graduate education in mathematical sciences
   - Transition from undergraduate to graduate work;
   - Curricular issues;
   - Uses of technology.
2. Preparing for opportunities
   - Bridging the gap between academia and industry;
   - Breadth of training;
   - Role of interdisciplinary work;
   - Role of internships;
   - Entrepeneurs and the global ecnonomy.

Although each group took a slightly different perspective on the main issues, many common elements were cited. Means of overcoming difficulties faced by students at the transition points (undergraduate to graduate, graduate to work) were subjects of numerous suggestions. Since members of the minority community frequently work in isolation, most of the recommendations were actions for individuals to undertake to prepare themselves better. The key to increasing the number of minority mathematicians is **individual inititative** on the items discussed below.

The main recommendations from all breakout groups are listed here in four groups; recommendations for faculty and students, recommendations for students, recommendations for academic mathematical sciences departments and recommendations for the professional societies. (Some recommendations are listed under more than one heading.)

A. Actions for everyone

1. Get connected; have and use e-mail and internet access
2. Make departmental presentations about this workshop; invite students from other departments
3. Take advantage of computer center resources (C, C++, software packages, LATEX, UNIX, EXCEL)
4. Encourage the Department to invite speakers who can give talks about applications of mathematics (and to make contacts with local industry)

5. Attend seminars in other departments
6. Contribute information to Internet sites for minorities (information about internships, co-ops, programs, etc.)
7. Become aware of other minority/professional organizations
8. Look for internships and summer appointments in industrial settings
9. Keep in contact with mentors
10. Set up a Web site on the Internet containing:
    (a) Profiles of minority industrial mathematicians
    (b) Names and research areas of minority graduate students who are working toward the Ph. D. degree; thesis topics when completed
    (c) Profiles of minority businesses
    (d) Listing of available internships
    (e) Profile of tools needed for successful graduate experience (C, C++, Hypertext, GAMS, presentation skills, LATEX)
    (f) Profile of conference abstracts, speakers, e-mail addresses, as in AARMS at `http://www.wam.umd.edu/~flj/aarms.html`; contribute to such sites
    (g) Information on how to subscribe to minority e-mail lists
    (h) Current sources of minority scholarships
    (i) List of industrial and academic mentors
    (j) Support for budding entrepeneurs, such as information on how to get started, information about others interested in starting businesses and information about writing proposals and reviewing proposals
    (k) Information about getting involved with "virtual" companies
11. Use the Web to foster Applied Math team projects
    (a) Identify hot areas in applied mathematics
    (b) Recruit students
    (c) Encourage students to form teams around these areas
    (d) Support students planning and executing their chosen project
    (e) Encourage student presentations on their projects at conferences

B. Actions for students

1. Set a goal and remain focused on it
2. Spend some time learning how to learn mathematics; take responsibility to prepare yourself
3. Explore academic offerings of other departments to broaden research opportunities: take a computer course; perhaps minor in some area of engineering, science, business, etc.

4. Develop facility with written/spoken language
5. Get computational experience; learn a computer language and how to apply it to your problem
6. Request a cross-departmental math modeling class with strong industry involvement
7. Start an interdisciplinary journal club (students getting together to read articles from journals) or a graduate student seminar
8. Get involved with a project involving applications or integrating math with other disciplines
9. Make contact with other (minority) graduate students for possible collaboration on research-seek out a "like-minded" group
10. Discuss with advisor "what lies ahead"
11. Always keep your resume in mind
    (a) Go to conferences (for example, SIAM conferences including SIAM's Diversity Day during the SIAM meeting at Stanford, July 14-18, 1997) and take a leadership role
    (b) Prepare for conferences by reading abstracts, deciding on talks you will attend and contacting authors of articles in which you are interested
    (c) Do things inside and outside of school to make yourself more marketable
    (d) When working on a project, always think about what part or extensions will be publishable
12. Make an all-out effort before graduating and looking for a job
    (a) Network at every opportunity— attend seminars, attend conferences, e-mail authors of articles
    (b) Contact all your mentors and professors as you near completion of your M. S. or Ph. D. degree, asking them to get the word out that you are close to graduating
    (c) Ask professors and mentors to send recommendations; those based on personal contact are particularly important
    (d) Send letters/resumes "out of cycle" when the majority of letters/resumes are least likely to come (this is less effective in academe than in industry)
    (e) Always follow up contacts
    (f) Continually update your resume
    (g) Stay aware of current events to facilitate conversations during job interviews
    (h) Call ahead to determine which areas of research are of interest to the company with which you are interviewing— meet industry halfway by showing them you are a good match with their needs

C. Actions for academic mathematical sciences departments

1. Organize student-to-student forums conducted by graduate students for undergraduate student math majors to talk about the transition to graduate school
2. Have a "strategies to get a job" seminar (for undergraduates and/or for graduate students). Invite employers of all types— community colleges, four-year colleges, industry and government representatives
3. Recognize and support students who plan to enter the job market with a B. S. or a M. S. degree
4. Forward all job listings to all graduate students at all levels
5. Offer a math modeling class where students can work on problems from industry— expose students to working in teams and learning how to approach problems
6. Make the modeling class interdisciplinary by cross-listing it with other departments
7. Encourage students who want to take courses outside the Mathematics Department
8. Invite speakers from industry to talk about real-world problems
   (a) Contact graduates who work in industry
   (b) Set up an Advisory Committee with invited representatives from local industry to provide another source of speakers
9. Improve advising for graduate students; some groups even suggested development and use of a placement exam
10. Offer support to students other than teaching assistantships; research internships in industry would prepare students to begin industrial careers as teaching assistantships encourage them to pursue teaching
11. Be aware of students in other disciplines, such as EE, who take lots of mathematics, as sources of double majors and graduate students
12. In industry, mathematics departments should explain their usefulness to the company; in academe, mathematical sciences departments should explain their usefulness to allied departments

D. Actions for professional societies

1. Encourage student participation at meetings
   (a) Organize events for students
   (b) Support students' attendance at society meetings (as is done by the Society for Mathematical Biology)