# Mathem: tical Biology Newsletter

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## 1991 ANNUAL MEETING REPORT

The Annual Meeting of the Society was held from August 18-21, 1991, in Santa Fe, New Mexico. It was the time of the failed coup in the former USSR. Gorbachav was out shortly after the meeting started and was back in with plenty of time left over for the orderly progress of the SMB scientific and business sessions in Santa Fe.

This was the second stand-alone meeting of the Society. The only previous stand-alone meeting was held over fifteen years ago (in Bowling Green in 1975). It is certainly fair to say that the general sentiment of those present at Santa Fe was that the level of invited and contributed sessions was of substantial interest and that holding stand-alone meetings, either on a regular or alternate year basis, would be conducive to the effectiveness of the Society. Thanks go to Stuart Kauffman, now Past President, for his efforts in organizing the meeting. Torcom Chorbajian organized the contributed paper sessions, which comprised thirty-two talks. Elizabeth Kauffman is also to be thanked for help with the organization.

The venue of the 1992 annual meeting was one topic of discussion at the board and business sessions. Alan Perelson, President of the Society, proposed Berkeley, California, as a possible site. The Board authorized Alan to pursue this suggestion, and in fact the meeting will be held in Berkeley from July 23-26. For details see the announcement below.

Torcom Chorbajian, the Society Treasurer, reported that total assets were now $63,480, with somewhat more than half ($35,000) in the Landahl Scholarship fund for supporting student attendance at SMB sponsored mathematical biology meetings. The Board voted to raise dues to $40, or $10 above what Pergamon charges. At present the Society has approximately 500 members, although not all these are paid up.

Stuart Kauffman reported on his contact with the European Society for Theoretical Biology. His impression was that the European Society wanted its own sense of identity, though some sort of confederation seemed possible. It was noted that the SMB initiated meeting in Grenoble served as the organizing point for the European Society. The following motion was passed: The SMB views with favor the emergence of the theoretical biology society in Europe and empowers its President to negotiate cooperation.

Other topics discussed included electronic networking for the Society and the *Bulletin*. It was noted that Pergamon wanted to raise prices because of the volume of *Bulletin* papers. The question arose as to whether there should be a lid on the number of papers. Lee Segal reported that at the present time the acceptance rate is about sixty percent. Some concern was expressed over the number of special issues. An advisory straw vote to deemphasize special issues passed. The issue of $1000 of prize money made available by Pergamon also arose. The attendees at the Business meeting voted to have a prize. Nominations should be open from the community. The President will appoint a committee for this purpose, to consist of the Chairman of the Publications Committee and one to three other people.

M. Conrad, Secretary

## President's Message

As the new president of SMB I have tried to make electronic communication among members of the Society and others in the field of mathematical biology a high priority. With the help of Raymond Mejia at the Mathematical Research Branch, NIH, and Jeff Garlaugh of the Advanced Scientific Computing Laboratory (ASCL) of the National Cancer Institute, NIH, we have set up SMBnet. With this electronic network, messages can be distributed to all members of SMB as well as to others who subscribe to the distribution list. The network can be used to announce new results, the availability of preprints, the availability of positions for graduate students or postdocs, the publication of books of potential interest to the community, and announcements of meetings. As the subscription list grows, we may want to break it up into sublists corresponding to different specialties, e.g., physiology, ecology, immunology, etc. Volunteers interested in organizing subnetworks should contact me. Currently we are publishing SMBDigest in which information of the type indicated above is distributed to the membership, as well as a list of papers to appear in the *Bulletin of Mathematical Biology*, the official journal of the Society. If you have not already subscribed to SMBnet, I urge you to do so.

To obtain information about SMBnet, send mail to:

listserv@fconvx.ncifcrf.gov

with "help" in the body of mail. For example:

echo help | mail listserv@fconvx.ncifcrf.gov

Anyone wishing to subscribe to the SMB email digest should send mail as follows:

echo "subscribe smbnet <given_name family_name>" | mail list serv@fconvx.ncifcrf.gov

The listserver will get your email address from your mail.

To unsubscribe from an address that is to change, for example, send mail as follows:

echo "unsubscribe smbnet | mail listserv@fconvx.ncifcrf.gov

The above script is suitable from a UNIX system; there are many variations depending upon your electronic mail facility.

To send a submission to SMB Digest: Mail to smbnet@fconvx.ncifcrf.gov

Anonymous FTP is available for the exchange of files, including pre-prints in various formats. To obtain instructions for the use of this service, download the INFO file as follows:

ftp fconvx.ncifcrf.gov or ftp 129.43.52.4
Name: anonymous
Password: <your_email_address>
cd smb
get INFO
bye

Last year SMB had a very successful three-day annual meeting in Santa Fe. At that meeting it was decided to try the format of a stand-alone meeting again this year. This year's meeting will be held on the campus of the University of California, at the Foothills Complex. The meeting will begin with an informal gathering the evening of Thursday, July 23. Formal sessions will begin the morning of Friday, July 24 and continue through Sunday, July 26. Rooms have been reserved at the Foothills residential complex. Details about housing and registration are given in a separate article in this newsletter.

The theme of the meeting will be a Festschrift for Lee Segal in honor of his 60th birthday. Lee, as I am sure you all know, has been a leader in the field of theoretical biology for the last two decades, has written many excellent texts on the subject, and since 1986 has served the Society by being editor of the *Bulletin of Mathematical Biology*. The meeting will focus on the many areas of research interest that he has had over the years and will include neurobiology, chemotaxis, intracellular signaling, pattern formation, theoretical immunology, and molecular biology. The program will include:

Volker Brendel, Stanford
Rob De Boer, Utrecht
Charles DeLisi, Boston University
Albert Goldbeter, Brussels
Evelyn Fox Keller, Northeastern
Nancy Kopell, Boston University
Byron Goldstein, Los Alamos
Garrett Odell, University of Washington
George Oster, Berkeley
Hans Othmer, University of Utah
John Rinzel, NIH
John Tyson, Virginia Polytechnic Institute
David Wollkind, Washington State University

Participation by Simon Levin (Cornell), Jack Cowan (Chicago), Bart Ermentrout (Pittsburgh), Leah Edstein-Keshet (Vancouver) and Alan Perelson (Los Alamos) is also expected.

I would like to encourage all of Lee's friends, students and collaborators to participate.

A major part of the meeting will be devoted to talks contributed by members and posters. To be considered for the program, please send an abstract on the enclosed abstract form. Please indicate whether you wish to speak or present a poster.

Limited funds are available to student members from the Society's Landahl Travel Fund to help defray the costs of attending the meeting. Please contact John Rinzel, Chief, Mathematical Research Branch, NIADDKD, Bldg. 31, Room 4B-54, NIH, Bethesda, MD 20892, if you wish to apply. Preference will be given to students that have submitted abstracts.

The Society will hold its annual business meeting during the Berkeley meeting. Please contact me if you wish to have any items placed on the agenda.

I look forward to seeing all of you at the meeting.

Alan S. Perelson, President

*1992 NATIONAL MATHEMATICS AWARENESS WEEK*

*April 26 - May 2, 1992*

The theme of Mathematics Awareness Week is
*MATHEMATICS AND THE ENVIRONMENT*

# SMB MEETINGS

## 1992 SMB ANNUAL MEETING

The 1992 Annual Meeting of the Society for Mathematical Biology will be held at the University of California at Berkeley, July 23-26, 1992.

An accommodations package at the Foothills Housing Complex is being provided for those who wish to stay on campus. The package includes room on Thursday, Friday and Saturday nights, breakfast and lunch on Friday and Saturday, and breakfast on Sunday. The package rates are $97.00 per person, double occupancy, and $139.00 per person, single occupancy.

An information and registration packet will be mailed shortly. In the meanwhile, please note, and make use of, the enclosed abstract form.

## 1992 AMS-SIAM-SMB SYMPOSIUM

*Mathematical Modelling in Cell Biology* is the theme of the ***1992 Symposium on Some Mathematical Questions in Biology***, the twenty-fifth in the annual AMS-SIAM-SMB sponsored series. The Symposium will be held at the 1992 annual meeting of the American Society for Cell Biology, November 15-19, in Denver, Colorado. The Symposium consists of two sessions with three speakers in each session. The sessions will be held on consecutive days during the meeting, the exact dates to be announced. The speakers for the 1992 Symposium and the topics they will discuss are as follows: **George Oster** (University of California, Berkeley), the dynamics of single-motor molecules; **Micah Dembo** (Los Alamos National Laboratory), modeling cell adhesion; **Elliot Elson** (Washington University School of Medicine, St. Louis), interpretation of measurements of cellular deformability; **Michael Reed** (Duke University), the transport of organelles in axons; **Jennifer Linderman** (University of Michigan, Ann Arbor), cell-cell interactions and the activation of T cells in an immune response; and **Byron Goldstein** (Los Alamos National Laboratory), cell activation through the aggregation of cell surface receptors.

For additional information, contact either of the co-organizers of the meeting: Professor Carla Wofsy, University of New Mexico, Department of Mathematics and Statistics, Albuquerque, NM 87131 (e-mail: wofsy@pandora.unm.edu), and Dr. Byron Goldstein, Los Alamos National Laboratory, Theoretical Biology and Biophysics Group, T-10, MSK710, Los Alamos, NM 87545 (e-mail: bxg@lanl.gov).

### THE LANDAHL TRAVEL AWARDS

The Society for Mathematical Biology has funds for partial support of the travel of graduate students to meetings co-sponsored by the SMB. Graduate students who wish support may apply to: John Rinzel, Chief, Mathematical Research Branch, NIADDKD, Bldg. 31, Room 4B-54, NIH, Bethesda, MD 20892. The application, which should be received by June 15, 1992, should include a one-page research summary and one letter from a faculty sponsor.

# Other Future Meetings

***3rd International Conference on Mathematical Population Dynamics***. June 1-5, 1992, University of Pau, France. The 3rd International Conference on Mathematical Population Dynamics will take place in Pau, France, from June 1-5, 1992. It is intended to be an interdisciplinary meeting of biologists and mathematicians concerned with populations of biomolecules, genes and cells, as well as other topics of mathematical population biology and epidemiology. The meeting will be of interest to applied mathematicians, probabilists and statisticians, ecologists, epidemiologists and biomedical scientists. Mathematical theories and analysis of models will be included, together with quantitative data from cell and molecular biology, epidemiology and cancer research. The Scientific Committee consists of: **S. Busenberg, O. Diekmann, K. Hadeler, M. Iannelli, P. Tautu,** and **G. Webb**. A small selection of topics covered by the conference is: *Structured populations* (Differential and integral equations, semi-groups of operators, dynamical systems, mathematical epidemiology...), *Stochastic models* (Branching processes, random walks, spatial processes, cellular automata, biostatistical methods...), *Molecular Biology* (Genome instability, gene amplification, RNA splicing, oncogenes/antioncogenes, mutation, replication...), *Cell Biology* (Cell cycle control, cell kinetics, cell differentiation, malignant transformation, senescence, metabolic control adaptive systems...), *Biomedicine* (AIDS, long latency syndromes, cancer, stem cell dynamics, normal blood cell production and leukemia, pharmacokinetics...).

The conference fee is 400FF (approx. $80US). Proceedings of reviewed and selected papers will be published. Previous conferences in this series were held in 1986 (University of Mississippi, USA; the proceedings were published as a special issue of "Computers & Mathematics", Vol. 18, no. 10/11, 1989), and 1989 (Rutgers University, New Jersey, USA; proceedings published in the Marcel Dekker series, "Lecture Notes in Pure and Applied Mathematics").

Persons interested can contact: O. Arino, I.P.R.A. Mathématiques, Université de Pau, 64000 Pau France, e-mail (bitnet): Arino@FRUPPA51, tel.: (33)59923058, fax: (33)58941696.

***11th Pacific Coast Resource Modeling Conference (PCRMC)***. June 3-5, 1992, University of California at Berkeley. Particular emphasis will be given to the modeling of biological processes, population dynamics, and bioeconomics, especially as they relate to problems in fisheries, forestry, pest and wildlife management, water resources, and environmental and conservation issues.

Featured speakers will be **Richard Carson** (University of California at San Diego) on natural resource damage assessment; **Michael Gilpin** (UCSD) on the viability of populations in conservation planning; **Stephen Hubbell** (Princeton University) on sustainable management of tropical timber; **John Pickering** (University of Georgia) on GIS (geographic information systems) in pest management; and **Nicholas Stone** (Virginia Polytechnic Institute and State University) on knowledge systems in agriculture.

For further information, please contact either: Wayne Getz, Department of Entomological Sciences, 201 Wellman Hall, University of California, Berkeley, CA 94720, USA; Phone: (510)642-8745; Fax: (510)642-7428; Email: getz@cavebear.berkeley.edu or Peter Berck, Department of Agricultural & Resource Economics, 207 Giannini Hall, University of California, Berkeley, CA 94720, USA; Phone: (510)642-7238; Fax: (510)643-8911; Email: peter@are.berkeley.edu.

***1992 Gordon Research Conference on Theoretical Biology and Biomathematics***. June 8-12, 1992, Tilton School, Tilton, NH, Leah Edelstein-Keshet and Steven Strogatz, chairs.

Program:

Monday morning, June 8, *Pattern Formation and Developmental Biology*, **George Oster**, UC Berkeley, Chair.

- **Scott Camazine**, Cornell, and **James Sneyd**, UCLA, *Pattern Formation on Honeycombs of Bees.*
- **Michael Welliky**, UC Berkeley, *Exploring the Cellular Basis of Morphogenesis.*
- **Thurston Lacalli**, University of Saskatchewan, *Pattern Formation by Reaction-Diffusion: Strategies for Making Theory More Biologically Relevant.*

Monday evening, June 8, *Pattern Formation and Developmental Biology* (Continued), **V. Manoranjan**, WSU, Pullman, Chair.

- **Paul B. Green**, Stanford, *Recursive Pattern Generation in Plant Shoots: A Mechanism Based on Minimal Energy Buckling Modes of the Surface Tissue.*

Monday evening, June 8, *Evolution and the Genetic Code*, **Rosemarie Swanson**, Texas A&M, Chair.

- **John Jungck**, Beliot College, WI, *Genetic Codes as Code.*

Tuesday morning, June 9, *Evolution and Artificial Life*, **Art Winfree**, University of Arizona, Chair.

- **Tom Ray**, University of Delaware, *Optimization and Creativity in Synthetic Life: Evolution and Ecology of Digital Organisms.*
- **William Hamilton**, Oxford, *Parasite Aid to Macroevolution.*
- **Joel Cohen**, Rockefeller, *Evolution and Complexity.*

Tuesday evening, June 9, *Control of the Cell Cycle*, **Joe Mahaffy**, San Diego State University, Chair.

- **John Tyson**, Virginia Polytechnic, *Modeling the Cell Division Cycle: cdc2 and Cyclin Interactions.*
- **Garrett Odell**, University of Washington, *The Mitotic Oscillator in Drosophila Embryos: A Very Fast Variation on a Usually Slow Theme.*

Wednesday morning, June 10, *Geometry and Topology of DNA*, **W. Olson**, Rutgers, Chair.

- **DeWitt Sumners**, Florida State, *Knot Theory and DNA.*
- **Sylvia Spengler**, UC Berkeley, *Analysis of the Topological Linkages of Trypanosome DNA.*
- **Craig Benham**, Mt. Sinai School of Medicine, *Stressed DNA—Transitions and Regulation.*

Wednesday evening, June 10, *Resetting of Biological Oscillators*, **John Rinzel**, NIH, Chair.

- **Charles Czeisler**, Harvard Medical School, *Bright Light can Induce Strong Resetting of the Human Circadian Pacemaker.*
- **Leon Glass**, McGill University, *Effects of Stimulation on the Properties of Biological Oscillators.*

Thursday morning, June 11, *Population Dynamics*, **Joan Aron**, Johns Hopkins, Chair.

- **Carlos Castillo-Chavez**, Cornell, *Towards a Unified Approach for Population Dynamics: Demography and Epidemiology Revisited.*
- **Tamara Awerbuch**, Harvard School Public Health, *Bacterial Dynamics in a Diffusion Bioassay.*
- **Andrew Dobson**, Princeton, *Population Dynamics of Red Grouse and Their Natural Enemies.*

Thursday evening, June 11, *Motor Control of Movement*, **André Longtin**, University of Ottawa, Chair.

- **Anne Beuter**, Université du Québec, *Feedback, Delays and Noise in Neuromotor Control Dynamics.*
- **Tamar Flash**, Weizmann Institute, *Computational Approaches to Motor Control.*

Friday morning, June 12, *Ecology and Spatial Population Dynamics*, **Don Ludwig**, UBC, Vancouver, Chair.

- **Marc Mangel**, UC Davis, *Interactions between Plants and Insects.*
- **Vincenzo Capasso**, Bari, Italy, *Transmission of Infectious Diseases.*
- **Akira Okubo**, SUNY, Stony Brook, *Modeling Animal Aggregations.*

For further information, contact: Leah Edelstein-Keshet, Department of Mathematics, University of British Columbia, Vancouver, BC V6T 1Z2, Canada, 604/822-5889 (office), 604/224-4796 (home), 604/822-6074 (fax), USERKESH@UBCMTSG (E-mail).

***Conference on Theoretical Renal Physiology***. June 13-14, 1992, Colby Sawyer College, New London, NH. A conference has been organized by Donald J. Marsh, USC, and John L. Stephenson, Cornell, to permit presentation and discussion of simulations of kidney mechanisms. Three half-day sessions are planned:

- Session 1. June 13, 1992. 9 am - 12 noon
  *Epithelial Transport.* **J.L. Stephenson**, Moderator.
- Session 2. June 13, 1992, 1:30 pm - 5 pm
  *Hypertonic Urine Formation.* **D.J. Marsh**, Moderator.
- Session 3. June 14, 1992, 9 am - 12 noon
  *Nonlinear Dynamics of Glomerular Filtration and Blood Flow Control.* **H.S. Layton**, Moderator.

There will be formal presentations and discussion in each session. The final program has not been set, and interested individuals are encouraged to propose presentations. Others who do not wish to present, but who wish to attend, are also welcome.

The conference has been scheduled to follow one day after the Gordon Research Conference on Theoretical Biology. A small NIH Conference Grant has been awarded to support this conference. The organizers intend to use these funds to support the attendance of students and fellows. Housing will be at the Colby Sawyer College at rates established by the Gordon Research Conference Foundation.

For further information, applications for travel support, reservations, and proposals for inclusion on the program, contact (preferably by e-mail): Donald J. Marsh, Department of Physiology and Biophysics, USC School of Medicine, 1333 San Pablo Street, Los Angeles, CA 90033, (213) 342-1040, E-Mail: marsh@phad.hsc.usc.edu.

***The Canadian Society for Theoretical Biology (CSTB).*** June 18-20, 1992, Victoria, British Columbia, held under the auspices of the Canadian Federation of Biological Sciences (CFBS).

A symposium on Energy, Entropy, Ecology and Evolution has been organized by **Lionel Johnson**.

The theme of the program is: Can the patterns observed in nature be interpreted in physical terms or are we condemned to an "autonomy of biology" posture? This Symposium is designed to bring together those with a mathematical/physical background and

# Careers in Theoretical Biology

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## What is Theoretical Biology?

Theoretical biology may be defined as the application of reason to biology. In this sense, every biologist is, at least part of the time, a theoretical biologist. However, the daily goal of a theoretician is to explain the biological world. The theoretical biologist's product is a theory, an idea, not an observation or an experimental result, though it is based on them. This is what sets the theoretical biologist apart from other biologists.

The theoretical biologist delves deeply into all the data available, comes up with unexpected relationships, tries to quantify them using *all* the tools of reason (math, logic, computers, etc.), and makes specific predictions about the outcome of future experiments and observations. Sometimes a critical experiment would never have been done without the inspiration of your theory in the first place. There is nothing more satisfying than seeing your theory proven correct.

## Examples of Theoretical Biology in Action

Let's consider some practical problems. How many fish can we take from the ocean? If we catch most of the fish of reproductive age, then after the current fingerlings grow up, there won't be another batch to replace them. We may find the fishery crashing a few years later, and then recuperating. Can we avoid these ups and downs? How do we account for the effects of pollution, habitat destruction, poaching, or stocking from hatcheries? A theoretical biologist formulates models, math, and computer programs to make predictions about how the fish population will change. The equations may have chaotic solutions, which means that what happens is sensitive to small changes. The theoretical biologist may be driven to politically unpopular conclusions. Fisheries represent but one small part of our environment. We need theoretical biologists working on the problems of our impact on the biosphere, and what we could do about it. With the environmental changes and plant and animal extinctions we are causing, time is short, and we need answers soon. Theory is essential, because we have only one earth to experiment with.

Consider a medical problem. We know that x-rays can cause cancer, yet they also provide marvelous images of the inside of the body. These images are often calculated by computer programs running inside computed tomography scanners. How can we get the best pictures for the smallest dose of x-rays that will lead to accurate diagnoses? Does the math tell us how to design a better scanner?

At a more philosophical level, consider the problem of evolution. Is natural selection a sufficient explanation for why we have so many different species of plants and animals on earth? Why do they seem to have become more complicated over geological time, or is "progressive evolution" just another way of putting humans on a pedestal? Some theoretical biologists are suggesting that entropy-like processes drive evolution to produce ever more complex organisms. Can these notions be stated precisely and tested? Can we predict the long term evolutionary effects of the present round of human caused extinctions? Can we formulate theories relating the DNA molecule to evolution and recreate extinct organisms?

- How does the brain work? There are trillions of nerve and other cells in our brains. What is their relationship to our thought processes? Are we in any sense computers? What is consciousness, and can we explain it and simulate it with "artificial intelligence" from our present scientific concepts, or is something new needed? As Wendy Brandts asks, "Are life forms essentially different from physical and chemical systems, even though they are comprised of them?"

  - Theoretical biologists cover all of biology, and are invading areas of philosophy, sociology and public policy. It is an exciting time to be a theoretical biologist, because so many tough problems are starting to yield tantalizing hints of solutions. Colleges are beginning to offer courses in theoretical biology. Biology is maturing, changing from a science of cataloging plant species and describing animal behaviors to a quantitative one explaining the how and why of living organisms. Theoreticians and experimentalists are beginning to respect one another and work closely together.

## Where do Theoretical Biologists Work?

- Most theoretical biologists work as professors in universities (Table). They are found in all major faculties. There is no single best way to prepare to become a theoretical biologist. For the professions, a degree that matches that of one's colleagues is likely to ensure not only a comparable salary and advancement prospects but a better chance you'll be listened to.

- While their job prospects are similar to that of their non-theoretical colleagues, because theoretical biologists work in so many fields, they can also take advantage of many more job opportunities than their peers. There is a shortage of professors predicted for the near future and an "explosion" of activity at the research level in theoretical biology, so if you prepare now, in high school and college, you will be ready to take advantage of it.

## How Does One Get an Education in Theoretical Biology?

- The many ways of entering theoretical biology and the newness of the field make a career in it a highly individual matter, requiring improvisation, i.e., designing your own education. Today's theoretical biologists vary widely in their career paths, and they often cross from one discipline to another. This will likely be the case for many years.

- The best way to become a theoretical biologist is to become an apprentice to one. The typical way of doing this is to become a graduate student, but why wait? It may be better to seek out a mentor early in your career, during your first year in university or even while still in high school. You can request names of nearby theoretical biologists from the societies listed here.

- Ask if summer or part time jobs are available. If jobs are not immediately available, there is no better way to get someone to try to create a paying job for you than to start off as a volunteer helping them with their research. My most productive paid students have been high school students and undergraduates who started as volunteers. By volunteering you will learn many valuable skills and gain experience you just can't find in the lecture hall, and sometimes you can get credit hours for it, so be sure to check out that possibility. Don't be afraid to try again with someone else if it doesn't work out the first time.

- There is one other tremendous value in finding a mentor early. Much science and math teaching in the first years of college is carried out in huge, impersonal classes. The dropout rate is enormous, and it may be hard to retain your motivation to stay in science, let alone in theoretical biology. One of the best ways to retain your spark is to have a job, paid or not, in someone's lab. That is where the real science occurs. It also gives you a home base in an otherwise large institution, not just a locker and a student number.

## How Much Math Do I Need?

- There is a statistical correlation between the amount of math one learns and how much one earns later in life, regardless of your final career choice: "More math means more money" (*Science* **243**, 314, 1989). It is as simple as that. Think money next time you're wondering about why you should care about that stupid $x$ and $y$. If money is not motivation enough, then think about this. Mathematics is the sharpest tool of rational thought. While there is not always a mathematical

solution to every problem in biology, the discipline of mathematics provides practice in clear thinking: expressing one's assumptions, testing them out, and predicting their consequences. Biological problems seem sooner or later to yield to mathematical formulations.

◇ Most theoretical biologists, though not all, have a substantial background and ability in mathematics. In fact, there is a subtle difference between mathematical biologists and theoretical biologists. Mathematical biologists tend to be employed in mathematical departments and to be a bit more interested in math inspired by biology than in the biological problems themselves, and *vice versa.* Mathematical maturity ranges widely, from those who found a need for mathematics late in their careers and were forced by the problems they tackled to train themselves in mathematics, to those who loved math, or physics, or computing before anything else and found ways to apply this love to biological problems. Excellent places to learn math, in addition to the obvious departments, are in physics, chemistry, engineering, computer science, statistics and business courses.

◇ Math goes well beyond introductory algebra and calculus. If you take, say, a traditional biology or pre-med curriculum, take the extra time to attend additional math courses, whether or not they help you fulfill your degree requirements. Audit them without the pressure of grades and exams (sometimes at no charge) simply to gain knowledge. I have one student who audited all her required math courses before taking them for credit because she had trouble with math but needed these courses for her chosen field. I promised myself I would take one math course every semester while trying to decide whether to go into chemistry or physics, and ended up getting my undergraduate degree in math, after which I turned into a theoretical biologist while doing my doctorate in chemical physics. This mixture is actually recommended, though seldom practiced: "Associated with this glamorisation of the biologist is a misconception, especially prevalent among high-school students, that the biological sciences are 'soft' sciences. However, today more than ever, analytical and experimental approaches are essential and require that zoologists be well-trained in the basic sciences of chemistry, physics and mathematics" (Canadian Society of Zoologists, 1991. *Careers in Zoology.* )

◇ Most theoretical biologists are breaking new ground and work in many fields at once. Therefore they cannot afford to be constrained by curricula designed by non-theoretical biologists. After you finish calculus and linear algebra, look for courses in differential equations, finite elements, advanced calculus and linear algebra, numerical and nonlinear methods, mathematical physics, chemical physics, stochastic processes, fractals, chaos, image and signal processing, pattern recognition, perturbation analysis, population dynamics, etc. Universities also provide opportunities to attend seminars, lectures by invited speakers, and journal clubs. While these are generally oriented towards graduate students and professors, and may often be over your head, you will usually find you are welcome and will learn much from frequent exposure to the language of mathematics and other disciplines. At least go for the free donuts.

## ◆ Computers in Theoretical Biology

◇ Despite its elegance, today's mathematics is not up to solving many biological problems. For this reason, computers are rapidly becoming a central tool of thought in biology. Spreadsheet and graphics programs permit us to pull together and visualize vast quantities of data. Microscopes are sold with computer vision systems and robotic, motorized stages and focussing knobs. Computers make possible new forms of biological imaging: confocal scanning laser microscopy, 3D x-ray microscopy, the visualization and design of biological molecules, and digital satellite pictures of the earth, showing us what biological resources we have to work and live with. Mathematics itself has been computerized, since computers can manipulate symbols as well as numbers and pictures. The human genome project is a vast compilation of the string of chemical symbols representing our DNA molecules.

◇ Any experience you can get in using computers is likely to help you become a theoretical biologist. But remember it's a tool: precise formulation of a computer program for a biological problem requires a keen understanding of the biology and mathematics involved; otherwise: garbage in, garbage out.

- Finally, don't forget that computers are used for communicating with people. Try to get on electronic mail or bulletin boards, and locate your peers who are also interested in theoretical biology. They'll be your colleagues and collaborators later.

## Do I Also Have to be an Experimentalist?

- The short answer is yes, because as a theoretical biologist you will often find that the measurements or observations you need simply haven't been done. At this point, you have three choices:

  - 1) do what you can with the available data;
  - 2) seek an experimental biologist to help you;
  - 3) do the experiments yourself.

- Many theoretical biologists end up also being good experimentalists (and vice versa, as the data an experimentalist obtains draws them towards desiring a theoretical explanation). Collaborations sometimes work, and often last for years. However, like marriages, they cannot be depended on and can even end in messy divorces. Furthermore, you can only understand the reliability of data by getting some yourself. Thus training as an experimentalist is very important for theoretical biologists. The best training is in someone's lab, going beyond what you get out of laboratory courses. Again, volunteering often provides a foot in the door. You can also experiment at home, and most biological supply companies will respond to orders from individuals.

- Theoretical biologists, because they are better trained in math than their departmental colleagues, are somewhat like square pegs in round holes. Being at least a part-time experimentalist reduces this necessary tension, which will last so long as vast areas of biology remain near virgin territories in terms of our theoretical understanding. You need a lot of self-motivation. As one senior theoretical biologist, Robert Rosen put it: "Theoretical biology is intended to stand in the same relation to experimental biology as theoretical physics does to experimental physics. You should pursue a 'career' in Theoretical Biology if, and only if, you love it. That is, if and only if a day would be unbearable without it."

## What to Read

### Books

- You will find literally hundreds of books on specialized topics of theoretical biology in any university library. The following include classics of theoretical biology and some recent offerings:


  - Bonner, J. T. 1988. *The Evolution of Complexity by Means of Natural Selection*. Princeton: Princeton University Press.
  - Darwin, C. 1861. *Origin of Species*. 3rd ed. London: John Murray.
  - Edelstein-Keshet, L. 1988. *Mathematical Models in Biology*. New York: Random House.
  - Eisen, M.M. 1988. *Mathematical Methods and Models in the Biological Sciences, Linear and One-Dimensional Theory*. Englewood Cliffs, NJ: Prentice Hall.
  - Elsasser, W.M. 1975. *The Chief Abstractions of Biology*. Amsterdam: North-Holland Publishing Co.
  - Glass, L. & Mackey, M.C. 1988. *From Clocks to Chaos: the Rhythms of Life*. Princeton: Princeton University Press.
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- ◇ Wolpert, L. 1991. *The Triumph of the Embryo*. Oxford: Oxford University Press.
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- ◆ Young women interested in theoretical biology could also find it valuable to read books such as:
  - ◇ Ainley, M.G. (ed.) 1990. *Despite the Odds: Essays on Canadian Women and Science*. Montreal: Véhicule Press.
  - ◇ Gornick, V. 1990. *Women in Science : 100 Journeys into the Territory* (rev.). New York: Simon & Schuster.
  - ◇ Kreinberg, N. 1977. *I'm Madly in Love with Electricity and Other Comments About Their Work by Women in Science and Engineering*. Berkeley: Lawrence Hall of Science, University of California. (37pp.)
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- ◇ In my personal mailing list, 13% of theoretical biologists are women. All potential scientists should read as many biographies and autobiographies of scientists and mathematicians as they can find. Such books show how diverse and human scientists are, emphasize their individuality, and show that many kinds of contributions are possible.

## ◆ Journals

- ◆ You might be surprised how soon you can start reading the scientific literature. The key is to find things that interest you, pick up what you can, and fill in your own background via textbooks, specialty dictionaries, and courses. The following scientific and medical journals cover theoretical biology or are more general* and should be available at most university libraries, which always allow high school students in, and sometimes give them borrowing privileges. You can xerox or write to the authors of individual articles and ask for reprints, even if the articles are a few years old. Plain postcards are quite acceptable. If they haven't run out, you'll usually get a copy. Be sure to also ask for "related articles" and the author's personal bibliography. That way you can get an in depth look at their work and careers.

- ◇ Acta Biotheoretica
- ◇ Advances in Biophysics
- ◇ Annual Review of Biophysics and Biophysical Chemistry
- ◇ Biology & Philosophy
- ◇ Biophysical Journal
- ◇ BioScience*
- ◇ Bulletin of Mathematical Biology
- ◇ Cell Biophysics
- ◇ Cognition and Brain Theory
- ◇ Computer Applications in the Biosciences
- ◇ Computer Programs in Biomedicine
- ◇ CRC Critical Reviews in Bioengineering
- ◇ Developmental Dynamics

- Evolutionary Theory
- Journal of Mathematical Biology
- Mathematical Biosciences
- Natural Resource Modeling
- Progress in Theoretical Biology
- Science*
- Theoretical and Experimental Biophysics
- Journal of Computer-Assisted Microscopy
- Journal of Theoretical Biology
- Medical Hypotheses
- Nature*
- Radiation and Environmental Biophysics
- Studia Biophysica
- Theoretical Population Biology

- Many other biology journals print some theoretical articles. Be sure to learn how to use computer search techniques, such as the *Index Medicus* and *Science Citation Index,* which are now available on compact disk. Look for review articles.

- Some magazines are excellent for keeping up with science in general, and it's a good idea to subscribe to one or more of these: Discover, New Scientist, Omni, Science Digest, Science News (weekly), Scientific American.

## Societies

- **Canadian Society for Theoretical Biology**, c/o Canadian Federation of Biological Societies, 360 Booth Street, Ottawa, Ontario K1R 7K4, Canada, phone: (613) 234-9555, fax: (613) 234-6667, E-mail: CFBS@UOttawa.CA.

- **European Society for Mathematical Biology**, c/o Dr. James D. Murray, President, Department of Applied Mathematics, FS-20, University of Washington, Seattle, Washington 98195 USA, phone: (206) 685-2841, fax: (206) 685-1440, E-mail: MurrayJD@Seattle.amath.Washington.edu.

- **Society for Mathematical Biology**, c/o Dr. Torcom Chorbajian, Treasurer, P.O. Box 11283, Boulder, Colorado 80301 USA, phone: (303) 530-9406. You can reach all members at once via E-mail: SMBnet@fconvx.ncifcrf.gov.

- Most biological societies have reduced rates for students, and you should join one or two in an area of your choice. See a reference librarian or the following for more addresses:

  - Saigo, R.H.; Saigo, B.W. 1988. Careers in biology - III. *Carolina Tips* **51**(10): 1-4.

## Acknowledgements:

- This brochure has benefitted substantially from the comments of Catherine Berg, Natalie K. Björklund, Wendy Brandts, Robert Clasper, Isla Crawford, Debbie Bazan, Donald R. Forsdyke, Efraim Halfon, Lionel G. Harrison, Neil J. Holliday, Sareli Joseph, Jennifer Lisakowski, Michael J. Lyons, Michael C. Mackey, Jay E. Mittenthal, James D. Murray, Alan S. Perelson, Brent Poole, Robert Rosen, Natalie Schito, Robin Shealy, Ian Silver, John M. Stewart, Ruwani Subramaniam, David Topper, Gail Wolkowicz and Michael Zuker.

## Table 1: Employers of Theoretical Biologists

This table is based on the North American members of the Society for Mathematical Biology.

| Employer | Percent |
|---|---|
| Faculties of universities and colleges | |
| Agriculture | 3 |
| Arts | 1 |
| Engineering | 8 |
| Medicine | 22 |
| Physical Education | 1 |
| Science | 51 |
| Hospitals | 4 |
| Business and government research laboratories | 6 |
| Museums | 1 |
| Private businesses | 3 |

those struggling to find coherent explanations for phenomena encountered in the field. The Symposium has been divided into two sections, the first on the morning of Thursday, June 18, and the second on the morning of Friday, June 19. A workshop is to be held in the afternoon of the 19th to try and formulate some general conclusions and establish firm thermodynamic principles for biologists generally.

Speakers scheduled for Thursday, June 18, morning session: **Bruce Weber**, Keynote speaker, State University of California, Fullerton, "The Thermodynamics of Non-Equilibrium Systems: Conceptual Considerations"; **Robert E. Ulanowicz**, Chesapeake Biological Laboratory, Solomons, Maryland, "The Concept of Ascendancy in Ecosystems"; **Peter Vanriel**, Terrestrial and Aquatic Environmental Managers Ltd., Saskatoon, SA, "Thermodynamic Relationship between Trophic Levels in a Small Arctic Lake Ecosystem"; **Ross Tallman**, Freshwater Institute, Department of Fisheries and Oceans, Winnipeg, "Evolution of Top Predators in Arctic and Tropical Mammals: The Thermodynamics of Top Consumers", and **Hironori Hirata**, University of Chiba, Japan, "Network Thermodynamics".

Friday morning, June 19, scheduled speakers are **Charles B. Schom**, St. Andrews Fisheries Laboratory, New Brunswick, "The Canadian Long-term Ecological Research Program"; **Eric Schneider**, Chesapeake Biological Laboratory, Solomons, Maryland and **James Kay**, Department of Systems Engineering, Waterloo, ON, "Evolution and Non-equilibrium Thermodynamics"; **Gabor Forgacs**, Clarkson University, Potsdam, New York, "The Interplay between Generic (Physical) and Genetic Mechanisms of Evolution"; **Bertrand Clarke**, Purdue University and **J.E. Mittenthal**, University of Illinois, Urbana, "A Model for the Evolution of Genes"; **Wendy Brandts**, Oxford University, "Energy Minimization as the Organizing Principle in Regulating Tetrahymena Cells"; **Richard Gordon** and **C. Cristofre Martin**, University of Manitoba, Winnipeg, "Differentiation Trees, Junk DNA and the Evolution of Neoteny in Salamanders"; and **Joseph Vogel**, University of Southern Mississippi, Hattiesburg, "Privatization as a Conservation Policy".

For a registration package contact: Ms. Crystal Hache, Canadian Federation of Biological Societies, 360 Booth Street, Ottawa, ON K1R 7K4, Canada, (613)234-9555, fax: (613)234-6667.

***IMA Summer Program. Environmental Studies: Mathematical, Computational, and Statistical Analysis.*** July 6-31, 1992, University of Minnesota, Minneapolis. Organized by **Mary Wheeler** (Chair), **Julius Chang**, **Michael Ghil**, **David McTigue**, **John Seinfeld**, **Paul Switzer**. Environmental protection has become a universal issue with world-wide support. Environmental studies have now bridged the realms of academic research and societal applications. Mathematical modeling and large-scale data collection and analysis lie at the core of all environmental studies. The IMA Summer Program on Environmental Studies is designed to provide a much needed interdisciplinary forum for joint exploration of recent advances in this field.

The program consists of four segments: Weeks 1 and 2 (July 6-17): Environmental models; Weeks 2 and 3 (July 13-24): Environmental data and assimilation; Weeks 3 and 4 (July 20-31): Stochastic modeling and optimization; Week 4 (July 27-31): Global climate modeling. The overlap in each segment of the program is intended to increase interaction among scientists and mathematicians working in specified areas. During the program there will be (as well as the theoretical and applied research talks and informal discussions) ten expository talks setting the physical and mathematical reference point for each type of environmental model or analysis.

For additional information, contact: Avner Friedman, Director, IMA, University of Minnesota, 514 Vincent Hall, 206 Church Street SE, Minneapolis, MN 55455, (612) 624-6066, Fax: (612) 626-7370, e-mail: ima_staff@ima.umn.edu.

***International Symposium on Symbolic and Algebraic Computation***. July 27-29, 1992. Berkeley, California. The annual International Symposium on Symbolic and Algebraic Computation (ISSAC), sponsored by the ACM Special Interest Groups on Symbolic and Algebraic Manipulation and on Numerical Mathematics, will be held on the campus of the University of California at Berkeley, July 27-29, 1992.

For further information, please send your name, address, and electronic mail address to: Professor Katherine Yelick, ATTN: ISSAC U92, 571 Evans Hall, Computer Science Division, University of California, Berkeley, California 94720, e-mail: issac@cs.berkeley.edu. Please indicate if you would prefer to receive information via electronic mail or postal mail.

***5th Interdisciplinary Conference on Natural Resource Modeling and Analysis.*** August 12-15, 1992. St. John's, Newfoundland, Canada. Sponsored by the Resource Modeling Association, Department of Fisheries and Oceans, and Memorial University of Newfoundland. The purpose of the conference is to provide a forum for presentation of recent progress in the mathematical modeling of biological processes, population dynamics and bioeconomics, especially as they relate to problems in fisheries, forestry, wildlife management and water resources.

Principal speakers are **Andrew Rosenberg** (Woods Hole), **Philip Neher** (University of British Columbia), **Anthony Starfield** (University of Minnesota) and **James Wilson** (University of Maine).

The abstracts deadline for papers is July 1, 1992. Registration fees for RMA members are $55 before July 1, 1992 and $65 after July 1; for non-members the fees are $75 before July 1, 1992 and $85 after July 1. Students can register for $20.

For further information, submission of abstracts, or additional registration materials, please contact: Ransom Myers or Peter Shelton, Science Branch, Department of Fisheries and Oceans, P. O. Box 5667, St. John's, Newfoundland, A1C 5X1, Canada; (709) 772-5431 or (709) 772-2341, Fax (709) 772-2156, e-mail: rmillar@kean.ucs.mun.ca.

***The World Congress of Nonlinear Analysts***. August 19-26, 1992, Tampa, FL. Expository addresses will be given by **A. Bensoussan** (France), **H. Brezis** (France), **W. Brock** (US), **F. Browder** (US), **L. Chua** (US), **P. Clarlet** (France), **S. Emelyanov** (Russia), **A. Friedman** (US), **J. Hale** (US), **F. John** (US), **G. Kallianpur** (US), **H. Keller** (US), **I. Kevrekidis** (US), **L. Knopoff** (US), **P. Kokotovic** (US), **M. Krasnosel'skii** (Russia), **J.-L. Lions** (France), **A. Majda** (US), **L. Markus** (US), **B. Mandelbrot** (US), **Yu. Mitropolsky** (Ukraine), **J. Nccas** (Czechoslovakia), **L. Nirenberg** (US), **C. Olech** (Poland), **I. Prigogine** (Belgium), **P. Rabinowitz** (US), **W. Rheinboldt** (US), **R. Rockafellar** (US), **R. Sagdeev** (Russia), **A. Samarsky** (Russia), **A. N. Shiryacv** (Russia), **V. Skorohod** (Ukraine), and **S. Smale** (US).

Approximately 70 organized sessions will be given in areas including nonlinear operators, dynamical systems, control theory and systems analysis, mathematical modelling, stochastic analysis, engineering and technological sciences, physical sciences, chemical sciences, biological sciences and medicine, economics and social sciences, and atmospheric, ecological, and space sciences.

Biomathematical sessions, each with several speakers, will include: **S. I. Andersson** (Sweden): *Mathematical Modelling of Cellular Interaction Dynamics with Special Emphasis on Immune System Mechanisms*; **C. Castillo-Chavez** (US): *Mathematical*

*Epidemiology*; **N. DeClaris** (US): *Recent Advances in Neural Networks*; **J. Demongeot** (France): *Asymptotic Behavior of Nonlinear Systems: Attractors and Confinors: Application to Biology*; **T. G. Hallam** and **J.M. Cushing** (US): *Structured Models in Ecology: Theory and Application* and *Models in Ecology: Spatial Heterogeneity*; **U. an der Heiden** (Germany): *Differential Delay Equations and Applications to Biology and Medicine*; **R. Heinrich** (Germany): *Mathematical Modelling of Enzyme Systems*; **M. Kimmel and G. Webb** (US): *Dynamics of Populations of Cells and Genes*; **H.G. Othmer** (US): *The Dynamics of Oscillatory and Excitable Biological Systems*; **M.A. Savageau** (US): *Canonical nonlinear modeling: Biological applications*; **C.D. Thron** (US): *Bursting Rhythms and Complex Oscillations in Biological Systems*.

For full information, please contact Dr. V. Lakshmikantham, Chairman, Global Scientific Advisory Committee, Florida Institute of Technology, Department of Applied Mathematics, 150 University Blvd., Melbourne, FL 32901, USA. Telephone: (407) 768-8000 ext 8091 or 7412. Fax: (407) 984-8461. Internet: gsac@zach.fit.edu.

***5th BioThermoKinetics Workshop***. September 23-26, 1992, Bordeaux, France. The 5th BTK workshop organized by the international study group of BioThermoKinetics will be held in Bordeaux in September 1992. There will be lectures, poster sessions and a software market where the following topics are being considered:

- Experimental applications of metabolic control theory
- NMR studies of metabolism
- Thermodynamics and kinetics of membrane proteins and pumps
- Efficiency of coupling in biological energy transduction
- Protein dynamics and catalysis
- Gene expression and regulation of the phenotype
- Modelling of cellular processes and application to biotechnology
- Theoretical oenology (with practical exercises)
- Metabolic channelling
- Software presentation
- Further developments in theory (non-equilibrium thermodynamics, kinetics, control theory, optimization)
- Mathematics and biology

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## Hans Bremermann—Man of Biomathematics

(Interviewed by Michael Conrad)

*University of California Medical School, San Francisco, 1964—Professor Hans Bremermann on this day gave a talk at a joint U.C. Berkeley-U.C. San Francisco meeting on biophysics and bioengineering. The topic was evolutionary programming. Bremermann showed how algorithms that mimic Darwinian variation and selection can serve to solve significant mathematical optimization problems, in particular problems with dimensionality too high to be efficiently treated by traditional calculus methods (Newton's method). Bremermann described experiments with biologically motivated variations on the algorithm, such as variations that incorporate sexuality and crossing over, and also outlined experiments with a number of purely mathematical variations.*

I haven't been able to locate the above newsflash in the *San Francisco Chronicle* and I doubt whether it was ever reported. But the scene, with Professor Bremermann center stage in the U.C. San Francisco auditorium, is vividly set in my memory. At the time I was just coming off my first year as a Biophysics grad student at Stanford, beginning to design computational models of evolutionary ecosystems. I had heard about Bremermann's work from my thesis adviser, Howard Pattee, and somehow had found out that he was to speak at U.C. San Francisco.

Some years later, in the early 70's, I did one of my two postdoctoral fellowships with Bremermann, at the U.C. Berkeley campus. My office was in the math department, one floor below Bremermann's, and periodically I wandered over to the Medical Physics-Biophysics group in Donner Lab, where Bremermann spent the other half of his time. Two chairs are difficult to straddle; but Bremermann could somehow balance both with the grace of a ballet dancer. Actually, as anyone who has tried this knows, the better analogy is probably to the skill of a circus performer.

Bremermann believes the affiliation with Biophysics was the key for his being able to teach his popular courses on mathematical and theoretical biology "year after year...for a reasonable size audience". He and his group of students worked on problems ranging over artificial intelligence, pattern recognition, language processing, neural nets, applications of evolutionary optimization to a wide variety of biological problems, modeling ecological systems, physical limits of computation and information transmission, and complexity theory. In recent years much of his work has focused on host-parasite dynamics, immune system modeling, and the problem of AIDS. Connections between evolution and the deeper nature of mind pervade his scientific work.

How did mathematician Bremermann, originally known for his work in complex analysis, transmogrify into a biomathematician of such wide scope? "I have seen too much chaos during my early years", he begins. "I was born in 1926 in the beautiful and ancient Hanseatic City of Bremen." It was a time of civil strife and of vast inflation (4.2 trillion marks for the dollar). Most people, including Bremermann's grandparents, lost their life savings. Things went from bad to worse, with the fall of the Weimar Republic in 1933, the rise of the Nazis, and the horrifying aftermath of war. Bremen suffered heavy damage from air raids, but Bremermann somehow survived (was "lucky") and in 1946 enrolled in the University of Münster. The town and the university were destroyed. "Laboratories were in shambles—but there was mathematics...a haven of truth, and there was Heinrich Behnke, a caring mentor who had remained a member of the world-wide community of mathematicians, with ties especially to Henri Cartan in Paris and friends in the U.S."

Bremermann received his doctorate in complex analysis (several complex variables) in 1951. Later that year he met Hermann and Joachim Weyl, who helped him arrange a postdoc with Stefan Bergman at Stanford, and also a summer job at Harvard. After a year back in Germany he went to the Institute for Advanced Study in Princeton, then "the center of the world in mathematics". Bremermann solved a problem of analytic continuation in quantum field theory and Oppenheimer invited him back for another year as a theoretical physicist.

In Münster there was a lot of "talk about Turing machines". At Princeton Bremermann programmed von Neumann's computer. Most of von Neumann's colleagues "thought he was wasting his precious talent on toys". Bremermann was also influenced by von Neumann's book "The Computer and the Brain", and by discussions with Oskar Morgenstern on the theory of games and economic behavior. "From von Neumann's works, and directly from Joachim Weyl and Morgenstern I learned that mathematical ideas and models can help capture facets of the real world—very important facets—beyond the confines of classical applied mathematics, with its emphasis on differential equations." Shannon's information theory and Frank Rosenblatt, of the

perceptron, also supplied strong influences at this point. Bremermann spent a summer with Rosenblatt later on, in 1962.

The idea of simulating evolution came to Bremermann in Princeton, back in the 1950's. If natural evolution could be so effective as an optimization process, why not use the same procedure on von Neumann's machine? And why not apply it to the perceptron, since it was already clear to Bremermann that all the interesting dynamics would be in the multilayer perceptron. Training such networks would require the adjustment of hundreds of weights. Over the years, Bremermann and his group applied his stochastic optimizer (itself evolved from his original evolutionary algorithms) to numerous problems: the identification of rate constants in the Calvin cycle and to other biochemical processes, to early methods of determining nucleic acid sequences, to the analysis of spectra. Other groups have used the optimizer for problems such as protein folding. Bremermann constructed a model of bacterial chemotaxis using a variant of the idea. And most recently, with Anderson (a doctoral student) he applied the idea to the original problem: training neural nets.

Bremermann spent a year in Seattle, at the University of Washington, and then moved to Berkeley in 1959. He took over a seminar on artificial intelligence, "which was fascinating virgin territory then. I dealt with theorem proving by machine, game playing (especially chess), pattern and speech recognition, which turned out to be much more difficult than anyone imagined, and language translation, which optimists viewed as a decoding-recoding problem governed by Chomsky's mathematical rules of grammar." It was at this time that Bremermann began his computer simulations of evolution, of what is now called "genetic algorithms", including the effects of crossing over—"which experience provided insights for the theory of evolution of sex", to which Bremermann contributed in the early- and mid-eighties.

But Bremermann's lectures, as I remember them, took a dim view of classical population genetics per se. It did not fit with the new molecular ideas, and did not fit with information theory. The genes could only specify rules for the development of the brain, not the connectivity of the brain itself. The disparity between the information content of the genes and the amount of information required to specify the nervous system was too great. Bremermann was one of the first to emphasize this point. Though it is a matter that is hardly in explicit dispute today, one can still sense it as an implicit error in many of the current attempts to apply evolutionary methods to optimization problems. It is the error of thinking of evolution merely in terms of optimizing linear strings without considering the way they are mapped into the phenotypic properties on which selection acts.

Bremermann recalls that one of the influences that led him in this direction was the attempt by Friedberg to evolve small computer programs by variation and selection. The results were about a thousand times worse than random search. "I became sensitized to complexity theory—to physical limits of computation". The quantum of action and the speed of light, Bremermann reasoned, imposed fundamental limits on what digital computers could do—limits that are overwhelmed by the combinatorial explosiveness of problems that arise in artificial intelligence and that face biological systems. It was a thesis that first appeared in a subsection of a paper on evolutionary search*. Finding solutions to problems entails computational work, and computational work entails energetic work. It implied limits on the ability of organisms to reproduce, on the ability of species to escape local minima in the course of evolution, on the structural complexity of brains, on the evolution of language (viewing communication as tied to computation), and on the ability of mathematicians to solve problems.

As Bremermann would put it, it is necessary to do physical work to navigate through the mathematical heavens. It is an irony of sorts. One could still see in Bremermann the temperament of the young Platonist of Münster finding comfort in the apperception of mathematical truth, but over-layered so by the experience of von Neumann's computer and its conceptual sequelae that he could be one of the first to come to grips with the anti-Platonic implications of algorithms, "the stepchild of mathematics", and perhaps the first to pursue of the implications of these implications for evolution, development, and intelligence. "Man kann es einsehen" ("one can see it"), Bremermann recalls Gödel as saying in reply to his question about the absolute truth of formalized logic when one has to rely at some stage on the non-formalized intuitive logic of the human mind. Bremermann's conclusion was that "if truth requires insight, or intuition, it should also require observers, who may or may not agree, and neurocomputation, subject to the laws of physics".

In 1965 Bremermann took up his half-time appointment in Biophysics. From then until his retirement in 1991 he has had the opportunity to perfect his circus performer balancing act between the Platonism of the mathematicians and the counter-Platonism of the biologists. "Biomathematics falls between the desire of mathematicians for absolutes—to get the universe out of Einstein's equations and the primordial singularity, universal Turing machines, proofs over models—and the messiness of biology. The molecular biologist wants sequence comparisons, homologies, molecular structures, protein conformations...not the holy grail, or very general principles, or grandiose ideas."

Bremermann did not wish, he would say, to discourage those of his students who aspired to be the Newtons of biology. But he did not believe that the mathematical magic would work for biology, with its complexity, in the manner that it did in physics. It is models that he advocates. The biological world is a jungle, the theorems are the paths through the jungle; models and computational work are the ways to get into the jungle. Of course it is obvious that to Bremermann complexity itself plays a unifying role. But what does it mean for the reductionist approach to biology? "Reductionism...it is an attitude...In the early sixties people thought they could solve the Schrödinger equation, but still one can't compute a protein conformation, and an organism might have $10^{14}$ cells." The modeling attitude is itself an implication of complexity.

Where is mathematical biology going? "The success of molecular biology has led to a reorganization of biology at Berkeley...Biophysics, which for forty years had brought graduates with a physics/mathematics background into biology, has virtually disappeared." Bremermann does not hide his regret. "The Renaissance-like period of tolerance and creativity may be over", he worries. Perhaps, he believes, a future home might be found in statistics departments, with their traditional involvement with biomedical problems and access to data. "Computers have taken statistics beyond the confines of its traditional methods." It could, with powerful software, assimilate dynamical models. And as to new ideas "computers should have a big influence...his generation does not know how to use computers as well as younger students". Bremermann, "blessed by wonderful students", has no doubts about the creative potential of the new generation of mathematical biologists.

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*Bremermann, H.J., Limitations on data processing arising from quantum theory, Part I of Optimization through evolution and recombination. In: Self-Organizing Systems, ed. by M.C. Yovits, G.T. Jacobi, and C.D. Goldstein, pp. 93-106, Spartan Books, Washington, D.C., 1962. For a recent comprehensive review see J.D. Bekenstein and M. Schiffer, Quantum limitations on the storage and transmission of information, Int. J. of Modern Physics C, 1, 355-422 (1990).

## News from the Latin American Association on Biomathematics

José María Cordero reports that the Fifth International Congress on Biomathematics was held at Santiago, Chile, October 14-19, 1991. Scientists from Argentina, Brasil, Canada, Costa Rica, Chile, Peru, Romania and the USA participated. The Proceedings are in press. The Sixth International Congress on Biomathematics will be held at San José, Costa Rica in 1993. For further information contact: Carlos Leguizamón, Gerencia de Investigaciones, Comisión Nacional de Energía Atómica, Av. del Libertador 8250, Buenos Aires, Argentina. Fax: 54-1-544-9252.

## 60th Birthday Fête for Colin Clark

(Communicated by Don Ludwig)

A Conference on Resource Management and Behavoural Ecology was held at the University of British Columbia, July 24-26, 1992, to celebrate the 60th birthday of Colin Clark. Invited speakers were: John Beddington of the Renewable Resources Assessment Group (Imperial College, London), Simon Levin of the Department of Ecology & Systematics (Cornell University), Marc Mangel of the Department of Zoology (University of California, Davis), Gordon Munro of the Department of Economics (University of British Columbia), and Ron Ydenberg of the Department of Biological Sciences (Simon Fraser University).

In addition to the invited talks, there were contributed talks and poster sessions. Highlights of the meeting were a hike led by Colin Clark which climbed up Mount Seymour in the fog, presentations of a special award to Colin Clark from the Resource Modeling Association by Rollie Lamberson, presentation of a special issue of the Bulletin of Mathematical Biology edited by Marc Mangel, a birthday cake and a dinner cruise in Vancouver harbour. The dinner cruise featured a near-rescue of a boat in near-distress, while the intrepid crew of the cruise ship maintained a steady supply of food and drink. Truly a remarkable achievement! A memorable time was had by all.

## Literary Events

Starting in March, 1992 the new quarterly, the **International Journal of Biological Systems**, is expected to begin publication. The goal of the journal is to promote interdisciplinary approaches in biology and medicine. The journal will emphasize concepts of general systems theory. The executive editors are P.M. Auger and R.V. Jean.

The new journal, **Nanobiology**, has commenced publication (Carfax Publishing Company). The Editor-in-Chief is Dr. Per Anders Hansson and the North American Editor is Dr. Stuart Hameroff. Many of the articles in the first volume are based on papers presented at the NATO Advanced Research Workshop on Coherent and Emergent Phenomena in Biomolecular Systems, held in Tucson in January 1991.

**The International Society for Molecular Electronics and Biocomputing** was founded in May, 1991 to foster the interdisciplinary study of molecular electronics, ionics and photonics, and information processing in natural and artificial molecular and biomolecular systems. Many of the biocomputing issues intersect with themes of interest to the mathematical and theoretical biology community. The molecular electronics work poses significant questions for theoretical biophysics. The Society Newsletter (**Newsletter of the MEBC**) is subsidized for the first year. To receive copies write to: **Ann E. Tate** (N35), Naval Surface Warfare Center, Dahlgren, VA 22448-5000 USA (Tel: 703-663-0702; FAX: 703-663-8673; Email: atate@relay.nswc.navy.mil).

### LEVIN ACCEPTS NEW APPOINTMENT

Simon Levin, past president of SMB, and the Charles A. Alexander Professor of Biological Sciences at Cornell University, has been appointed the George M. Moffett Professor of Biology at Princeton University. Levin will move to Princeton in July 1992, where he will become a member of the Department of Ecology and Evolutionary Biology. Levin will retain an Adjunct Professorship at Cornell.

A subset of the 64 participants at the Santa Fe Meeting (Photograph courtesy of Sharon Lubkin)