in the ^{8}B abundance is introduced by the extrapolation. Furthermore, the reaction rates are very sensitive to the conditions in the sun—conditions which have not been measured directly. For example, Bahcall suspects that the flux of ^{8}B neutrinos depends roughly on the 13th power of the sun's internal temperature.

Now nuclear physicists are remeasuring the rates of many of the nuclear reactions in the ^{8}B series. With more accurate reaction rates, measured under closer-to-solar conditions, theorists hope to be able to reduce the uncertainty in the ^{8}B abundance within the sun, and thereby improve the predicted ^{8}B neutrino flux.

Whether or not the discrepancy between the observed and predicted flux of ^{8}B neutrinos is resolved, physicists think it is vital to establish the main line of energy generation in the sun. To this end, the favored solar neutrino detectors are the gallium experiment—because it will measure directly the flux of p-p neutrinos, and the technology is straightforward—and the indium experiment—because it will record the entire solar neutrino spectrum. However, each of the proposed new detectors could provide information vital to understanding the power source of the sun and settling the solar neutrino problem.

—BEVERLY KARPLUS HARTLINE

Additional Reading

1. J. N. Bahcall, "Solar neutrino experiments," *Rev. Mod. Phys.* **50**, 881 (1978).
2. ———, "Solar neutrinos: Theory versus observation," *Space Sci. Rev.*, in press.

Gian-Carlos Rota and Combinatorial Math

One strength of combinatorics is its interaction with other areas of mathematics and science.

Gian-Carlos Rota of the Massachusetts Institute of Technology is, at age 47, one of the oldest mathematicians in the field of combinatorics. "You can count the members of my generation on your fingers," he says. Most mathematicians in this active and growing field are in their 20's and 30's and are students of a few "grand old men" like Rota. Thus Rota, although not old as a scientist, can speak of his field from the perspective of one who has been in it nearly from the beginning.

This is the first of a series of occasional articles about mathematics as seen through the eyes of its most prominent scholars.

Rota himself did not set out to be a combinatorial mathematician. Fifteen years ago, he was doing research in the field of probability, specifically ergodic theory. He kept coming across problems involving ways to count things or ways to arrange objects—problems mathematicians would call combinatorial. "I noticed that most people in the field shunned these combinatorial problems," Rota says. "But I decided to take 6 months off, learn combinatorics, and solve my problems in ergodic theory. The 6 months became 15 years and I never did return to ergodic theory."

An urbane Italian who enjoys good food and drink, Rota hardly fits the stereotype of the shy, retiring mathematician. His colleagues tell stories of his sending back $75 bottles of wine in restaurants ("If it tastes like ink, why shouldn't I send it back?" he asks).

Rota loves to talk and enjoys speculating about the origins and future of his field of mathematics. In an interview with *Science*, he discussed how combinatorics began as a field unto itself, where its most interesting and challenging problems come from, and what it is like to do research in this field.

Combinatorics, Rota explains, began as a separate discipline about 30 years ago (most other fields of mathematics are hundreds of years old), and it began partly because so many combinatorial problems had arisen in other disciplines. These problems had been ignored or converted to other forms in the past, but it was becoming increasingly obvious that techniques were needed to solve them. The time was right for the birth of combinatorics as a separate field, especially because the advent of the computer made possible experimental work, thereby opening new avenues in solving problems.

The field gained momentum in the past decade because of a movement in mathematics toward greater concreteness. Combinatorics, which deals with finite sets of objects and how to count or arrange them, is the epitome of concreteness. In contrast, in the 1950's mathematicians emphasized abstractions and great general theories. Rota calls that time "the age of nothing but," noting that mathematicians were fond of beginning sentences by saying, "Mathematics is nothing but . . . ." When he studied linear algebra as an undergraduate at Princeton in the 1950's, Rota was taught that all work was to be done in infinite dimensional spaces—the most general ones for the purpose of proving theorems. Now, according to Rota, mathematicians are reviving the spirit of the 19th century when concreteness was emphasized. They are reprinting old books and papers from that time, looking for interesting mathematical examples. It is in this context that combinatorics has come into its own.

As combinatorics gained followers it also gained methodology. Now the field is at a point where there are some standard techniques for solving problems and there are a great many important problems to be solved. When the field was born, these techniques were not available and the only combinatorial mathematicians were a few very talented people such as the Hungarian Paul Erdös (*Science*, 8 April 1977, p. 144) and William Tutte of the University of Waterloo. "Early combinatorial mathematicians used very crude methods," Rota says, "and so they had to be very bright people. Now even people who are not too bright can do research."

One of the great strengths of his field, Rota says, is its interaction with other areas of mathematics and science. He firmly believes that mathematics must interact with other sciences, that mathematics, if left to itself, will eventually dry up.

Rota foresees biology, linguistics, statistical mechanics, and elementary particle theory as contributing vast numbers of important problems to combinatorics.

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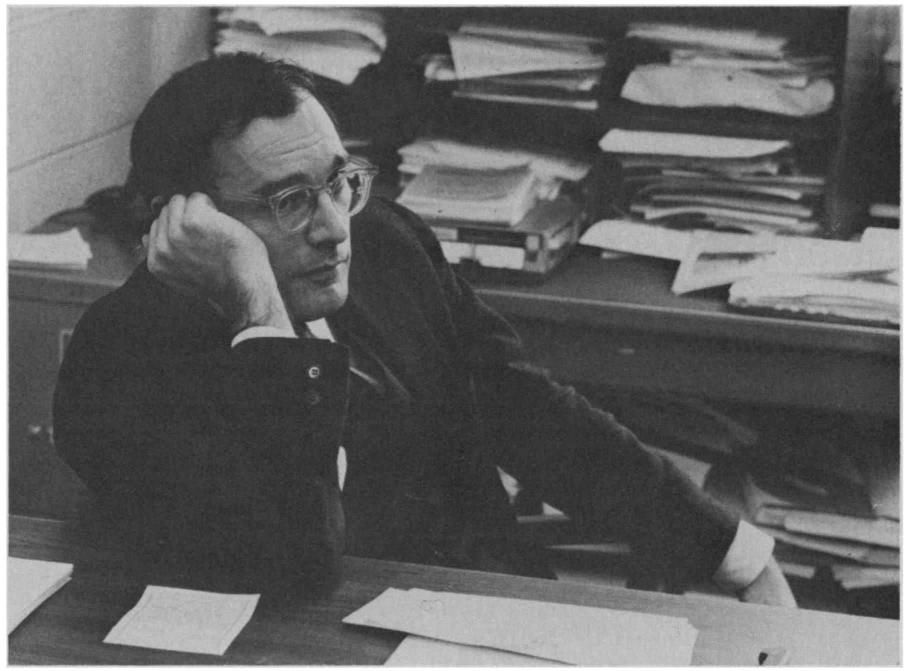
Deciding the structure of nucleic acids or other large molecules is an example of a combinatorial problem in biology, he says, and it is one on which progress has recently been made. But there are difficulties in looking to biology for problems. "I used to talk to biologists quite frequently, thinking to solve their problems," Rota says. "This was hopelessly naïve. Biologists have too primitive a mathematical background to pull out important problems from their morass of experimental classificatory work." He believes that gifted middlemen are urgently needed to carry concepts and problems from one field to another, and nowhere are they more needed than in biology.

Combinatorics was the key to major advances in linguistics in the recent past, Rota says, and he believes it will be equally important to this field in the future. Language, he explains, is now perceived as far more sophisticated and complex than it was previously believed to be. During the 1960's the combinatorial mathematician M. P. Schützenberger of the University of Paris developed the theory of context-free languages. This theory, which is viewed as a great breakthrough, is the basis of work by Noam Chomsky of M.I.T. and others. It provides a simple set of rules for creating words and studying languages. Recently, it was merged with the theory of automata. In Rota's view, the precise mathematical investigations of the 1960's and 1970's have exhausted the field of linguistics. Now investigators are gathering more data which, Rota is confident, will lead to new combinatorial problems and new theories of language.

Some of the major unsolved problems in statistical mechanics are combinatorial in nature. For example, there is the "pennies-on-a-carpet" problem, which is related to the problem of phase transition: why does a liquid change to a solid at a certain temperature and pressure? The pennies-on-a-carpet problem is concerned with determining the probability that no two pennies will overlap when a group of pennies is dropped on a carpet. Its relation to phase transition arises from the view of the transition of a liquid to a solid as a tighter packing of atoms.

Rota sees the central problem in elementary particle theory as understanding the vast amount of experimental data. This understanding, he believes, requires more knowledge of group representations, which is a difficult and abstract mathematical subject, and of combinatorics. He said that one main area of investigation is to explain the effects of interacting elementary particles.



Gian-Carlos Rota

This involves very specific questions that can be answered with a combinatorial technique known as Young symmetrizers—a technique that Rota says is the most effective algebraic system ever invented to work with symmetries and to exploit them to the hilt.

When asked what combinatorics research is like, Rota first explains how it is similar to all other mathematics research. People who are unfamiliar with mathematics research "think that you learn theorem 2, then go out in the wide world and apply it," he says. "Actually, it is your vision that you apply. Theorems never quite fit, you always have to doctor them up. Theorems only give guidance." He likes to tell his students, "You must learn mathematics in order to forget it."

But combinatorics research does have a distinctive flavor and requires a specific talent, which is often quite different from the talents required by other fields of mathematics. Those who enjoy combinatorics, Rota says, like to count, enjoy puzzles and finite structures, and like symmetries. Many are attracted to the field because of its finiteness. Combinatorial mathematicians tend to be extremely constructivist, meaning that they like to demonstrate how to find particular mathematical objects as opposed to showing only that the objects exist. Yet even in combinatorics, practitioners can be classified according to what the English mathematician Alfred North Whitehead called "muddle-headed" and "simple-minded," Rota says. He describes himself as muddle-headed—he likes to generalize at the cost of fuzzing things up. Others are simple-minded—they like to simplify, to look at specific problems.

When considering a new combinatorial problem, mathematicians generally begin by restating it. Rota explains that since most problems come from other fields of science or mathematics, "when a problem comes to us it is usually imposed. Most problems disguise their real nature. A major step in solving a problem is to reformulate it in many ways."

Other than reformulating problems, there are a few tricks of the trade used by combinatorialists. One of the most important, and the most paradoxical, is to solve the problems that deal almost exclusively with finite situations by "reducing" them to infinite situations. Rota notes, "One lesson to be learned from mathematics is that the infinite is simpler then the finite. The finite has too many possibilities. The calculus is far easier than the calculus of finite differences."

As for his personal style of doing research, Rota fits the image of the casual Italian. He stays up late at night, working at home, and finds it difficult to come to his office before 11:00 a.m. His large office at M.I.T. is cluttered with books and papers—every available surface is piled with documents. When he opens his desk drawer, he reveals total disarray. He procrastinates about writing papers, having waited 7 years, for example, to write up a symposium he headed at George Washington University. Yet in this environment of apparent chaos, Rota manages to vigorously participate in one of the most active fields of mathematics.—Gina Bari Kolata