FOREWORD

"Good mathematicians see analogies between theorems or theories, the very best ones see analogies between analogies." Stefan Banach

Stanislaw Ulam's affiliation with Los Alamos National Laboratory spanned over two-thirds of his professional life. There was no aspect of its mathematical activity during this period in which he was not involved, either centrally or tangentially.

His catholic view of the role of mathematics vis-à-vis other sciences extended far beyond into the mathematical and scientific community at large, as did his genius for problem formulation and for applying the most abstract ideas from the foundations of mathematics to computing, physics, and biology. In addition he possessed the ability to excite others—many of them not trained as mathematicians—and involve them in his researches. The impact of his work is still felt both at the Laboratory and in those larger communities, for he liked to disseminate his ideas orally in an ever widening round of lectures and seminars from where they took on a life of their own. The Monte Carlo method which he originated with von Neumann in order to study neutron scattering and other nuclear problems at Los Alamos is one such example. Its offshoots are now so universal that they are even applied to regulate traffic lights!

His influence, along with that of John von Neumann, the brilliant Hungarian mathematician, contributed to the establishment at the Laboratory of an atmosphere and a tradition that fostered and supported an exceptional—if not unique—interaction between mathematics and science. Extensive testimony and documentation concerning the integral role that Stan Ulam played in this interaction can be found in "From Cardinals to Chaos, Reflexions on the Life and Legacy of Stanislaw Ulam" published by Cambridge University Press in 1989.

From 1944 until his death in 1984, while connected with Los Alamos in a variety of ways, from staff member, to group leader, to research advisor, to 'no-fee consultant'—one of his favorite expressions—he wrote Laboratory reports (many with the help of trusted and talented collaborators) that show a breadth of scientific interests unusual for a mathematician. They cover pioneering work, in the horse-and-buggy days

of computing, on mathematical modeling of physical processes, nuclear rocketry, space travel, and biomathematics. (Another eleven, weapons-related reports, with Evans, Everett, Fermi, Metropolis, von Neumann, Richtmyer, Teller, Tuck, and others are still classified and unavailable for publication.)

Mathematically speaking, three motifs run through Ulam's theoretical and applied work: the iteration or composition of functions, or relations; the use of evolving computer capability in the exploration of analytically intractable problems; and the introduction of probabilistic approaches—while knowing that most practical applications are made in the presence of uncertainty. The fusion of these themes is characteristic of the central contributions of this collection.

As to the quotation from which the title of this book is derived, one must remember that Ulam held Banach, along with von Neumann and Fermi, "as one of the three great men whose intellects impressed me the most." Stefan Banach was an outstandingly original Polish mathematician and one of the founders of the now famous Lwów school of mathematics (see Chapter 20, Preface to "The Scottish Book.") Banach was Ulam's friend and mentor in Poland before World War II. His influence on Ulam was profound and Ulam liked to quote his comment on the ability of some mathematicians to see "analogies between analogies." There is no question that in the practice of his craft and his art, Ulam was guided by this principle, and that he, in turn, epitomized its application. In addition, to Ulam the idea of analogy was itself amenable to mathematical discussion.

In 1983, when D. Sharp and M. Simmons, editors of this Los Alamos Science series, asked Ulam to gather his unclassified—and declassified—reports for publication in one volume, they intended to omit a few that had appeared elsewhere. After his death in 1984, it was decided to publish them all as many represent preliminary studies of subjects that were subsequently expanded elsewhere, leading, in several instances, to the development of new and extensive theories.

Ulam had dictated brief introductory notes and a sketch for a preface which he intended to develop. Rather than put words in his mouth, it was thought more appropriate to reproduce his notes in their short and unpolished form. It was also decided to leave the style and substance of the reports untouched, as evidence that scientific advances do not usually arise in their final, definite form. More often than not they are the product of sequences of tentative, sometimes repetitive, and even at times inaccurate steps. Two appendices complete the volume: a list of Ulam's publications and a brief biographical chronology. (More detailed biographical material can be found in his autobiography, "Adventures of a Mathematician," as well as in "From Cardinals to Chaos.")

This collection represents an important complement to the selection of papers and problems, mostly in pure mathematics, published by MIT Press in 1974 as "Sets, Numbers, Universes," and to a volume of essays, "Science, Computers, and People," published by Birkhäuser in 1985. And, whereas these two books are composed of papers readily available albeit scattered in the scientific literature, the Los Alamos Reports have been for the most part difficult of access and little known. Their historic value is therefore very real.

As mentioned earlier, many of these reports and much of Ulam's work was done in collaboration. He liked to stress the importance of working with collaborators, with whom, he said, the nature of their "shared ideas and techniques" depended "on the personality and experience of the individuals." We add a few words about these colleagues as well as about the work they and Ulam engaged in.

As early as 1944, when he joined the Manhattan Project, Ulam and David Hawkins (Chapter 1) were "playing" with the notion of branching processes, or multiplicative systems, as they called them, motivated by their application to atomic physics.

David Hawkins, a philosopher of science by profession and mathematician by inclination, was, in Ulam's words "the best amateur mathematician I know," and they became fast friends. Hawkins is presently professor emeritus at the University of Colorado.

The work in the Ulam-Hawkins report was subsequently developed with Everett in the three extensive reports grouped in Chapter 3, which are reproduced here for the first time. While clearly motivated by the need to understand neutron multiplication in fission processes, the reports lay the foundations for—in their own words—a "formalism general enough to include as special cases the multiplication of bacteria, radioactive decay, cosmic ray showers, diffusion theory and the theory of trajectories in mechanical systems."

C. J. Everett, who died in 1987, was a mathematician with whom Ulam worked on a conceptual as well as technical level in Wisconsin and at Los Alamos, where he became a member of Ulam's group. An eccentric, shy, and witty man, he was quite probably the only person who ever opted for bus transportation to come to Los Alamos for a hiring interview, and he was known for having turned in a monthly progress report—in which staff members were supposed to describe their research—which said tersely "progress was made on last month's progress report."

The first written proposals for the Monte Carlo method put together in a 1946 "report" called "Statistical Methods in Neutron Diffusion" appear in Chapter 2. This method of approaching precise but intractable problems through the introduction of random processes and

probabilistic experimentation, has found wide application not only in areas close to those motivating its origin but others more removed, such as operations research, and combinatorics. In fact, the "report"—of which only eight copies were made—consists of two letters and handwritten calculations photographed and stapled together. Its cover specifies that the "work" was "done" by Ulam and von Neumann and "written" by von Neumann and Robert Richtmyer—then head of the Laboratory's Theoretical Division. Its informality attests to the casual manner in which information was disseminated through the Laboratory at the time.

The long term professional and personal rapports between von Neumann and Ulam need not be recounted here—references to them can be found in the books already mentioned. Suffice it to say that though there exist few papers and abstracts under their joint names, von Neumann's extensive correspondence with Ulam attests to their interacting interests in pure mathematics, in pioneering computer technology and techniques, and in cellular automata and the brain. (The correspondence is now stored in the archives of the Philosophical Society in Philadelphia.)

Ulam's collaboration with Enrico Fermi initiated the computer simulations of nonlinear dynamical systems that lead to the evolution of a major field of research popularly labeled "chaos theory." Fermi called this work, which was developed with the programming assistance of John Pasta, "a minor discovery," a modest understatement given the seminal character of this investigation (Chapter 5.) Chapters 10 and 11, with P. R. Stein, address the subject of nonlinear transformations in greater detail.

Fermi, with whom Ulam became acquainted in Los Alamos during the war, was a man of simple tastes and life style. The Ulams had an opportunity to sample this while motoring together across France one summer. Feeling ill at ease during a lunch in a recommended temple of gastronomy, Fermi decreed he would select the night's lodgings. Meandering through a picturesque valley he chose a modest inn by a babbling brook where, after dinner, sitting under the stars they discussed physics and new mathematical problems to experiment with after the vibrating string calculations. However the night's encounter with fleas, bedbugs, and mosquitoes made him admit the next morning that the higher-class hostelry next door that Ulam had eyed, might perhaps have provided a more restful night.

In the area of space technology, Ulam investigated schemes for nuclear rocketry with Everett and with Conrad Longmire, a physicist from the mountains of Tennessee who played a mean banjo. Chapter 7 describes a way to propel very large space vehicles by a series of small external nuclear explosions which later developed into Project Orion. Chapter 9 deals with the propulsion of space vehicles by extraction of gravitational energy from planets. Schemes based on a similar idea are now used in "flyby" missions to the outer planets and to provide part of the energy for spacecrafts going beyond the planets.

A study of patterns of growth, with Robert Schrandt (Chapter 12) investigates how simple recursively defined codes can give rise to complex objects. Such studies have become a growth industry of their own in the improved computer graphics world of today.

Several other reports are devoted to biomathematical questions. Their findings have opened new fields of biomathematical research. Abstract schemata of mathematics are applied to pattern recognition with the help of computers investigating, for example, the way visual pictures are recognized. Using metrics in molecular biology shows how a new mathematical concept of distance between finite sequences or objects can be applied to reconstruct the evolutionary history of biological organisms.

Closely involved with Ulam in this work was Paul Stein, a physicist turned mathematician—under Ulam's influence—who became an invaluable collaborator able to implement and develop the gist of Ulam's directions. William Beyer, a gifted fellow mathematician, also collaborated on a conceptual and technical level in the biological investigations.

John Pasta, Mary Tsingou-Menzel, Robert Schrandt, and Myron Stein lent their talents to creative programming, at a time when the art was in its infancy and pre-microchip-era machines with names like "Eniac," "Maniac," "Johnniac," presented storage and timing constraints. Pasta, who died in 1980, was a self-made man of Italian descent. He had furthered his education and became a physicist while working on the New York city police force.

The mathematician Al Bednarek, one of the editors of this volume and coauthor of this foreword, also collaborated with Ulam on problems of parallel computation (Chapter 18). He is a former chairman of the mathematics department at the University of Florida.

Shortly after his arrival at Los Alamos in 1944, Ulam was asked by a colleague what it was that he was doing. Since at the time he was a very pure mathematician and had not yet familiarized himself with the nature of the work, his Socratic answer was "I supply the necessary don't know how!" Stan Ulam's "necessary don't know how" as well as his modestly unenunciated "know how" are sorely missed by all who were privileged to have known him or worked with him.

Last but not least, the editors wish especially to thank Peggy Atencio, Ben Atencio, Janet Holmes, Debi Erpenbeck, Gary Benson, Chuck

Analogies between Analogies

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