LA-UR -85-1202

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RECEIVED BY OSTI MAY 06 1985

TITLE: MONTE CARLO: IN THE BEGINNING AND SOME GREAT EXPECTATIONS

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LA-UR--85-1202

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SUBMITTED TO: LANL/CEA Monte Carlo Conference, April 22-26, 1985, Cadarache, France

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FORM NO. 836 R4

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MONTE CARLO: IN THE BEGINNING AND SOME GREAT EXPECTATIONS

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ABSTRACT

The central theme will be on the historical setting and origins of the Monte Carlo Method. The scene was post-war Los Alamos Scientific Laboratory. There was an inevitability about the Monte Carlo Event: the ENIAC had recently enjoyed its meteoric rise (on a classified Los Alamos problem); Stan Ulam had returned to Los Alamos; John von Neumann was a frequent visitor. Techniques, algorithms, and applications developed rapidly at Los Alamos. Soon, the fascination of the Method reached wider horizons. The first paper was submitted for publication in the spring of 1949. In the summer of 1949, the first open conference was held at the University of California at Los Angeles.

Of some interest perhaps is an account of Fermi's earlier, independent application in neutron moderation studies while at the University of Rome.

The quantum leap expected with the advent of massively parallel processors will provide stimuli for very ambitious applications of the Monte Carlo Method in disciplines ranging from field theories to cosmology, including more realistic models in the neurosciences. A structure of multi-instruction sets for parallel processing is ideally suited for the Monte Carlo approach. One may even hope for a modest hardening of the soft sciences.

MONTE CARLO: IN THE BEGINNING AND SOME GREAT EXPECTATION

INTRODUCTION

I should like to thank the Organizing Committee for the invitation to participate in this conference.

My remarks shall begin with the early history of the Monte Carlo Method. They will be somewhat discursive and episodic but perhaps not too nostalgic.

It is of interest to be reminded of the historical setting, beginning in 1946:

1. Scientists at Los Alamos had tried to cope with some compelling nonlinear problems during the war. Their only recourse was a numerical approach using some electromechanical devices plodding along noisily in a very tortuous manner.

2. Toward the end of World War II, the first general purpose electronic computer, the ENIAC, became operational. (It is a sad reflection on our civilization when it takes a global catastrophe to enable such research.)

THE CENTRAL ROLE OF THE ENIAC

Since the ENIAC undoubtedly provided the spark, not only for Monte Carlo but also for other developments, it is perhaps worthwhile to dwell briefly on it.

It was the creature of John Mauchly and Presper Eckert, physicist and electronics engineer respectively. John was familiar with Geiger counters and their associated electronic circuits. The key thougnt was that if electronic circuits could count, then arithmetic can be realized and differential equations can be integrated. So when he saw at Ballistics Research Laboratory in Aberdeen, Maryland a large hall with seemingly endless rows of desks each occupied with a woman computing firing tables by cranking away on an electromechanical desk calculator (now museum pieces) Mauchly became inspired. Why not propose (to the Government, i.e., the U.S. Army) that the process be automated—electronically. The project was consummated at the Moore School, University of Pennsylvania, for the Ballistics Laboratory.

John von Neumann was a consultant to both Los Alamos and the Ballistics Laboratory. Strangely enough, he persuaded the authorities at Aberdeen to permit Stan Frankel and me from Los Alamos to provide the shakedown exercises for the ENIAC by attempting to do a much more challenging set of problems than mere firing tables. Thus is was that Los Alamos had tne inside track on this spectacular development. As if the nuclear physics activities of the Laboratory were not exciting enough, it was compounded to breath-taking proportions by the exposure to electronic circuits of 18,000 double-triode vacuum tubes, (also a museum curiosity.)

A DIGRESSION

We'll digress (within a digression) for a moment.

Enrico Fermi was intererested in computers. After my first preliminary visit to the ENIAC (at the University of Pennsylvania), before it became operational, he asked a lot of questions, like "how many vacuum tubes did you say there are in the system?" When I responded, he made a simple calculation, comparing the number of similar vacuum tubes in his scaling circuits, say twenty, and the associated experience and then extrapolating to 18,000, he shook his head and expressed doubts whether the system could operate error-free for even a second! The actual experience was considerably more favorable. Where had the Master slipped? (For the first time ever! in my experience.) A scaling circuit may malfunction occasionally without attracting any attention, not so a computer; hence the latter circuits are much more conservatively designed, painstakingly so—a one-bit error could be catastrophic!

After the shakedown exercises, our experiences with the ENIAC were reported at a thermonuclear conference back at Los Alamos. Many in the audience had become quite familiar with computing using electromechanical machines but not quite prepared to contemplate computing at speeds several thousand times faster.

Among those present at the conference was Stan Ulam with his fertile imagination. In his contemplations, he soon realized that with such increased computing power that it was appropriate to revive model- or statistical sampling techniques. The approach has been known to statisticians for some time before the advent of electronic computers. But it must have been dull and tedious to crank out statistical samples or genealogies by hand calculations or even when aided by mechanical calculators. Only when there was no other recourse and the interest in the results sufficiently high would one appeal to it. I shall refer later to one such outstanding instance. For the most part, the technique fell into desuetude.

Ulam also realized that there were many problems of interest to Los Alamos, especially those with nontrivial geometries and many velocity components that lent themselves to suitable transformations to these techniques.

As mentioned earlier, John von Neumann was a consultant and frequent visitor to the Laboratory. He knew mathematics, physics, statistics, computers and a lot of other disciplines. He was quick to see the implication of Stan's remarks with respect to, among other things, neutron transport. In addition, he became interested in the computer generation of uniformly distributed numbers, the basis for obtaining, by suitable algorithms, various other desired distributions, such as exponential, or logarithmic or trigonometric, etc. A principal idea is to find a function such that using a uniformly distributed random variable it has values with the desired distribution. Forgive me for mentioning such obvious facts to this audience of experts. You might be amused to know that von Neumann was quite amused to devise some simple and efficient little games that could be played on computers to provide samples of various distributions without explicitly using inverse functions.

THE ENIAC IS TO BE MOVED!

To continue the saga of the ENIAC; there was a break in the action that had some ancillary consequences at Los Alamos.

The ENIAC was to be moved to its permanent home at the Ballistics Research Laboratory in Maryland from Philadelphia. What a gargantuan task; few observers were of the opinion that ENIAC would ever do another multiplication or even an addition. It is a tribute to the skills of Josh Gray and Richard Merwin, two fearless uninitiates, that it was indeed a successful move in a very finite time.

The point about the hiatus in ENIAC operation is that it prompted Fermi to dream up a simple, but ingenious analog device to implement neutron transport. He persuaded his friend and collaborator, Percy King, while on a hike one Sunday morning in the surrounding mountains of Los Alamos to build the instrument, later to be called affectionately, the Fermiac. It expedited the computation of neutron histories in two dimensions and distinguished fast and slow neutrons.

AN INDEPENDENT DEVELOPMENT

Perhaps more interesting is the fact that according to Emilio Segré, his student and collaborator, in his From X-Rays to Quarks (Modern Physicists and Their Discoveries) published in 1980, that "Fermi had invented, but of course not named, the present Monte Carlo method when he was studying the moderation of neutrons at the University of Rome. He did not publish anything on the subject, but he used the method to solve many problems with whatever calculating facilities he had, chiefly a small mechanical adding machine." This was in the early 30's.

In a more recent conversation with Segré, I learned that Fermi took great delight in astonishing his Roman colleagues by his remarkably accurate, "too-good-to-believe" predictions of experimental results. After enjoying sufficient amusement, he revealed that his "guesses" were really derived from the statistical sampling techniques that he calculated whenever his insomnia prevailed in the wee morning hours!

And so it was that nearly fifteen years earlier, Fermi had independently invoked what was later called the Monte Carlo Method. The Master, as always, had just the "right feel" for what was relevant and meaningful to do in setting up the analog computer while the mighty ENIAC was being moved.

THE FIRST AMBITIOUS TEST OF THE MONTE CARLO METHOD

Let us return to the ENIAC and learn that it was operational once again in late spring of 1948; it had survived the vicissitudes of its 200 mile journey, much to the amazement of many "experts"! In the meantime, one Richard Clippinger, a staff member, suggested that ENIAC had perhaps sufficient flexibility that its controls could be re-organized to permit a more convenient, static, stored-program mode of operation with a program capacity of some 1800 instructions from a vocabulary of about 60 arithmetical and logical operations. The original method of programming might be likened to a giant plugboard, that is to say, to a can of worms. Implementing the new approach is an interesting story by itself, but it must await another occasion. Suffice it to say that Klari von Neumann and I designed the background controls in about two months and completed the implementation in a fortnight. We then had the opportunity of using the ENIAC in its new modus operandi for making the first ambitious test of the Monte Carlo method on a variety of problems in neutron transport with the collaboration of the brilliant and delightful John von Neumann.

The series of tests consisted of some nine problems, using various configurations of materials and various initial distributions of neutrons, running times and the like. An adequate number of sample neutron histories were taken and several kinds of statistical analyses made. Not long afterward, other staff members of the Laboratory made their pilgrimages to Aberdeen to run their Monte Carlo problems. These included J. Calkin, C Evans, F. Evans, and B. Suydam. It should also be remarked that R Richtmyer was very active in using the SSEC built by IBM.

Back in Los Alamos, the exceptional (and mysterious) mathematician, C J Everett, began his distinguished collaboration, first with Ulam and then with E. Cashwell, on matters Monte Carlo.

In many ways, as one looks back, it was among the best of times!

RAPID GROWTH

The applications in the open literature were many and varied and spread quickly. Already by midyear in 1949, a symposium on the Monte Carlo method was held in Los Angeles, California sponsored by the Rand Corporation, the National Bureau of Standards, and the Oak Ridge National Laboratory. The proceedings were edited by A. S. Householder, G. E. Forsythe and H. H. Germond.

Sometime later, a second symposium was conducted by members of the Statistical Laboratory at the University of Florida at Gainesville sponsored by the Wright Air Development Center. The proceedings were edited by Herbert A. Meyer. Since then there have, of course, been many others, the latest being one this very week.

EXPERIMENTAL MATHEMATICS

It is perhaps interesting to look back over two score years and note the emergence, rather early on, of experimental mathematics, a natural development of the electronic computer. The Monte Carlo Method reinforced that notion in a way that should be obvious to this audience. When display units were introduced the temptations to experiment became irresistible, at least for the fortunate few who enjoyed the luxury of a "hands on" policy. It was only when shared-time became realistic that experimental mathematics became of age. At long last, mathematics achieved a certain parity—a two-fold aspect—that all the sciences enjoy.

This coupling of the subleties of the human brain with rapid and reliable implemention by the modern computer is what will enable us to achieve Olympian heights.

THE FUTURE

Having summarized the distant past and reminisced a little, I would like to close with a few remarks about the future, perhaps not even too distant a one. As all of you know better than I, there has been a spectacular technical development that may be called the miracle of the chip, almost unbelievable, as most miracles are. Because macroscopically there are no moving parts, it is a very reliable bit of hardware.

Owing to relativistic reasons, among others, a certain convergence is being reached with respect to the computing power of a single processor. But such performance has not quieted all the users, you among them. So with the aforementioned reliability in components, it is not entirely foolhardy to contemplate parallel processing. I do not refer to the simple extension of a two parallel processing system, or even four or eight. These are adiabatic transitions and, to be sure, should be part of the immediate, short term game-plan. Rather, I am thinking of massively parallel operations with a thousand interacting processors, or even, ten thousand! I do not underestimate the magnitude of such an endeavor. We can no longer ignore the demands of a high-level language; the potential capability of the new hardware should be able to deal with a more sopohisticated language (to the relief of the user). We shall probably need powerful operating systems and compilers to effect efficient parallelism; new algorithms must be prepared. Careful thought must be given to develop an elegant, comprehensive architecture using possibly whatever subleties modern combinatorial theory has to offer, perhaps even new principles of logic. A new look at numerical analysis seems self-evident; for too long we have been mesmerized by the serial approach to computation and purblind to the sophistication and artistry of parallelism. Finally, we would insist that the whole endeavor be monitored by the ambitious users so that the proposed designs would pass muster.

One natural application would be to Monte Carlo type problems where the proposed parallel structure would encourage more realistic problems by virtue of a greater number of samplings or genealogies. We might also be encouraged to study the problem of the <u>propagation</u> of the variances associated with input numbers in the course of computation in the natural sciences so that a realistic estimate can be made of the variances of the output numbers. This is a neglected, refractory but important question.

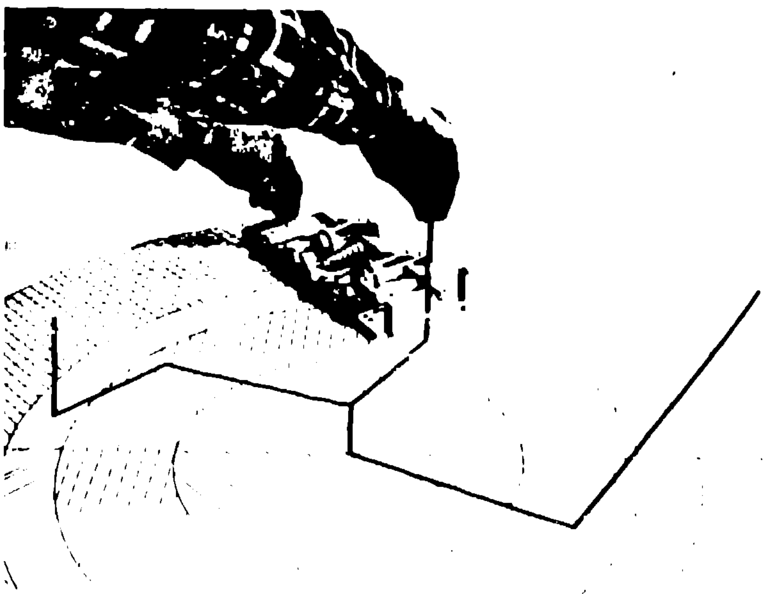
If one were to wax enthusiastic, perhaps, just perhaps, a simplified model of the brain may be contemplated and studied using the much greater capabilities anticipated in these new parallel structures. In fact, such studies might provide a certain feedback to the computer architects.

In brief, if such an integrated endeavor is to be properly orchestrated, and if the time-scale is not to be ignored, then the critical size might well be a national laboratory, or even an international one.

STANISLAW ULAM

JOHN VON NEUMANN

FERMIAC



ENRICO FERMI

TWO VIEWS OF THE ENIAC