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Nürnberg, June 1981
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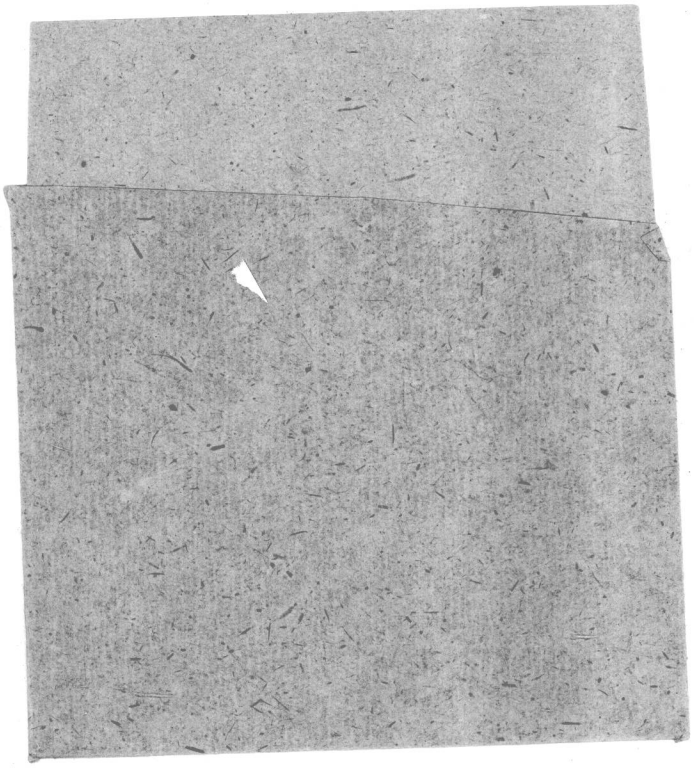

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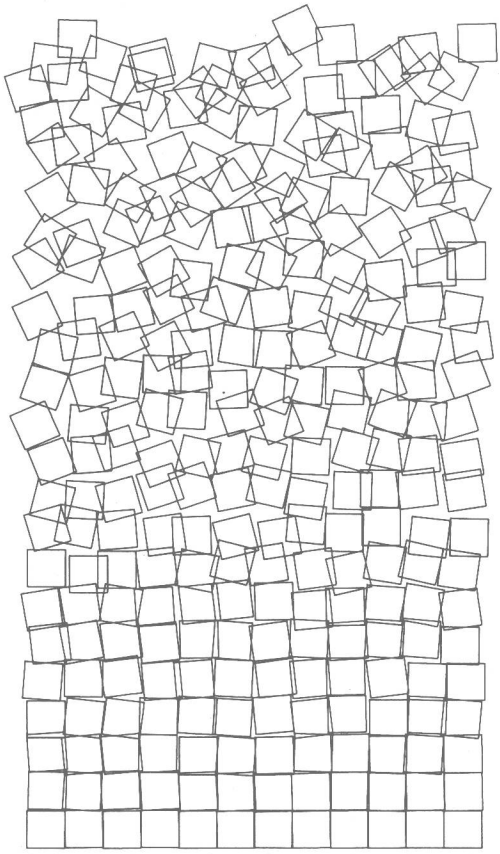

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P R E F A C E

Wolfgang Händler
General Chairman

In its title this conference differs from some similar events dealing with parallelism in computer systems and with distributed computing. Such conferences discuss structures which are proposed for the solution of problems by the computation of particular algorithms, but are only useful for these problems. Some more sophisticated structures are useful in broader classes. Finally there are good reasons to expect in the future <Adaptable Architectures> [1, 2].

Nevertheless there is a lack in knowledge about the very nature of algorithms, their partitionability in principle into parallel constituents and about the way in which such algorithms can be dealt with, e. g. by <divide and conquer> methods. An interesting hint was given by C. R. Vick [3]:

> I've always felt that the challenge to map an inherently parallel problem space into a parallel solution space with as few artifical transformations as possible represents one of the most interesting challenges ... (1978).

The German pioneer in computing, Konrad Zuse [4], developed similar ideas (1969). He argues that the contemporary procedure is very often a roundabout way. For example one endeavours to transform an ultimately discrete problem into an analytic, i. e. continuous, approach and to discretize it again for solving it by a (digital) computer. He recommends a direct procedure using what he calls a <Computing Space>.

It seems to be a worthwile goal for CONPAR 81, to investigate general methods, examples, or case studies, which center on the problem, how parallel algorithms (as a general term) can be implemented and utilized for higher throughput, speed, and fault-tolerant computing. In such a way the Program Committee and the staff of IMMD interpreted the commission from the "Gesellschaft für Informatik" to organise CONPAR 81.

The responsibility of the Program Committee turned out to be not an easy one. In accordance with the decision of the committee not to admit 'parallel sessions' during the conference, we had to select 29 papers from a total of 80 submitted papers. Despite the good quality of some papers we had to reject them because they did not fit the declared aim of CONPAR 81.

We succeeded in getting contributions from distinguished experts in the field, accordingly announced as 'invited speakers'. In this context I welcome in particular our outstanding keynote speaker, Prof. Arthur W. Burks, who directed our attention at an early point of time to the activities of the late John von Neumann [5] concerning cellular automata and also 'growing' automata. Being one of the best known pioneers of the computer scene, A. Burks is at the same time a distinguished philosopher, which made it particularly valuable to receive his contribution.

Originally we planned to hold the conference at the Campus Erlangen-South of the University Erlangen-Nürnberg, where activities in parallelism are located. Unfortunately another conference with the same date in the city of Erlangen prevented this.

Nevertheless Nuremberg (Nürnberg) is an excellent alternative which offers a great spectrum of other opportunities, and we hope that the participants enjoy the medieval and stimulating atmosphere around the conference site.

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SESSION 6, PARALLELISM OF NUMERICAL ALGORITHMS

PART I

PART II

PROGRAMMING AND STRUCTURE CHANGES IN PARALLEL COMPUTERS

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1. Introduction

It is perhaps appropriate in a keynote paper to look at programming for parallel computers from a general point of view. What, we may ask, is computer architecture all about? Well, there are domains of problems to be solved and there are available hardware building blocks. The architecture of a computer is the way in which these building blocks are organized, and is to be judged on how well that organization is adapted to the given class of problems.

This conference is directed to the issue of parallel problems. These are problems which can be solved efficiently and rapidly on a computer capable of carrying out many interacting streams of computation simultaneously. But any parallel problem can also be computed serially. Hence, to understand the domain of parallel problems we need to study its relation to other problem domains. One of the architectural choices to be made is that of specialization vs. generalization: Should special machines be made for parallel computations?

Consider the Illiac IV, the most powerful parallel computer of its time. Looking back one can ask: As a working computer, was it an economic success? Has it solved important problems that could not otherwise be solved? Can it solve parallel problems more cheaply than other computers? If the answers are negative, one should then ask: At the time, was building a machine the best way to answer these questions? Would the answers be different if the machine had been built at another time?

It is characteristic of the computer industry, and a reflection of the rapidity of the computer revolution, that these questions are highly time-dependent. The Illiac IV would have been impossible five years earlier, but much easier a chip generation later. Today the time is ripe for the development of many useful kinds of parallel computers. By its nature, parallelism requires many small computing subsystems, with many fast cross-connections between them. Both are feasible with very large-scale integrated circuits.

The situation was quite different when electronic computers were born, at which time the most efficient computers were highly serial. As Dr. Händler has stressed in his call to this meeting, there is a vast architectural distance between "the conventional Princeton-type computer" and current concepts of multiprocessing, array and cellular computers, and other parallel organizations. Let me make some historical remarks on this topic.

I will first compare the old method of rearranging the parts of a machine for each new problem, as by the use of a plugboard, with the modern method of programming a machine for each problem. Then I will discuss the architecture of the first stored program computers.

2. Machine Assembly versus Machine Programming

Imagine that you have only one problem to solve, that it is to be solved many times with only a variation of input conditions, and that your technological means consists of an indefinite number of primitive building blocks at a fairly low logical level: switches, registers, adders, connecting cables, etc. To solve your problem you assemble a machine from these primitives. In a sense, you design a new machine for each problem.

Let us call this "the machine assembly method" of solving problems. No doubt this approach seems far out, a Tinkertoy or Meccano method of computing as compared to the use of programs. But at one time and for certain purposes it was the best approach. The most powerful computers in the period 1925 to 1945 all used it: the electrical network analyzer, differential analyzer, and the ENIAC.

The competitors of these machines were the electromechanical computers of Konrad Zuse, Aiken and IBM, and Stibitz of Bell Laboratories. These were programmed with punched paper tape, and were thus limited by the slow speed of their tape readers. Machines with paper tape programs were an important step on the way to the stored program computer, but they were not in general superior to machines that used the machine assembly method of solving problems. It should also be noted that the two methods sometimes overlapped. For example, the new MIT differential analyzer, though it calculated mechanically, was set up in a few minutes from punched paper tapes. Incidentally, the differential analyzer was a parallel computer to the core, for all its parts had to work simultaneously.

Despite its being archaic, I think there is something to be learned from the concept of assembling a machine to solve a problem. For any given algorithm there are many possible machines that will execute it,

so that the basic architectural question is: Which of these machines is best? This question can be partially formalized by assigning a cost to each building block and asking: Which machine has the minimal cost? But like any formalization, this one has its limitations.

The first limitation concerns what is left out. The most important omitted characteristics are uniformity and simplicity of assembling the machine to do a particular problem, and of debugging and maintaining it. Humans are involved in these tasks, and uniformity and simplicity are aids to human understanding; moreover, the ratio of labor cost to hardware cost is rising rapidly, as we are all well aware.

The second limit on this formalization concerns complexity. Though our optimality problem can be defined precisely for any particular system of primitive building blocks, because of the complexity of computers it cannot be solved either mathematically or computationally for interesting cases. Hence machine assembly formalisms are valuable mainly as points of view. The same is true, in my opinion, of many formalizations in computer science. In the field of computer architecture it is certainly the case that formalisms are limited to a conceptual role, for actual architectures can be evaluated only by experience and simulation.

With these limitations on the value of a formal approach to architecture in mind, let us continue our comparison of the machine assembly method of solving problems with the programming method. The former created a new architecture for each problem, which might be optimized for that problem. In contrast, the architecture of a programmable computer has to be optimized over its whole class of problems. Of course, there was a greater set-up cost in the machine assembly method.

The relative merits of the two methods changed with the state of technology. While both were important from 1925 to 1945, after capacious electronic stores were developed in the mid and late 1940's, making the stored program computer possible, the programming method quickly came to dominate. Electronic analog computers with plugboards for problem set-up persisted for some time, but they are rare now.

The plugboard method of problem set-up is forever dead, because manual and electromechanical technologies are outdated. Of course, we still use these technologies at a high architectural level, as when we add a second processor, a new terminal, etc., or augment a minicomputer by plugging in another disk drive. But these changes, being high-level, are infrequent, whereas the changes made by the plugboard method were low-level, and hence frequent.

However, the idea of radically restructuring a machine for a new problem, or a new group of problems, still has merit. I intended the

expression "machine assembly method of solving problems" to cover any such radical restructuring. The plugboard method of earlier computers, and the interconnection method of the differential analyzer, were electrical and mechanical ways of machine assembly, suitable for their era but now outdated.

Compiling a machine at the machine assembly level is much more difficult than compiling a program. However, technology changes rapidly. Modern chip manufacture is much more like book printing than was the construction of vacuum tube machines. Printed books will eventually be replaced by hard computer copy. Maybe these kinds of development will someday make it economical to produce specific computers for particular problems. We can imagine an automated manufacturing system that receives an algorithm as input and produces as output a computer which executes that algorithm efficiently. But even if that never comes to pass, there may be other ways of radically restructuring computers. I will return to this topic near the end of my paper.

3. The Architecture of the First Stored Program Computers

The stored program computers grew directly out of the ENIAC. The architectures of the two machines were radically different in a way that is relevant to this conference, so it may be instructive to say a few words about them.

The ENIAC was highly parallel and highly decentralized. It had twenty-seven different computing and input-output units, each with its own local program controls. There was a central program control unit for supervisory management. For its version of the machine assembly method of solving problems, it had a vast plugboard-like switch running past all the units; to structure the system to solve a problem, the operator set switches on the program controls and manually interconnected the units to one another via the switches in a manner appropriate for that problem.

In theory it was possible to set up the ENIAC so that all the units operated simultaneously. In practice, this potentiality for parallelism was not as useful as had been anticipated. The ENIAC's complete parallelism was rarely employed, and arranging it for partial parallelism added to the burden of the operator. Thus users of the first general-purpose electronic computer met two problems basic to parallel processing: Which algorithms can be efficiently executed in parallel, and which not? What is the best way to plan a parallel computation and to structure or program a machine to execute it?

The ENIAC's parallelism was relatively short-lived. The machine

was completed in 1946, at which time the first stored program computers were already being designed. It was later realized that the ENIAC could be reorganized in the centralized fashion of these new computers, and that when this was done it would be much easier to put problems on the machine. This change was accomplished in 1948. Since the original ENIAC employed the machine assembly method of solving problems, very little additional equipment was required to convert it to a centrally programmed machine. Thereafter the plugboard of the ENIAC was never modified, and the machine was programmed by setting switches at a central location. Thus the first general-purpose electronic computer, built with a parallel decentralized architecture, operated for most of its life as a serial centralized computer! Ironically, the fact that the ENIAC incorporated the machine assembly method of problem solving made it very easy to transform the machine into a computer that did not use this method.

The jump from the ENIAC to the stored program computer was an important historical event, for modern computers are revolutionizing human life. The question of who invented the stored program computer is therefore of interest, and as you may know, has been hotly debated for a long time. This is not the place for a careful analysis of the contributions of the participants, but since the architecture of the Princeton machine is still taken as a paradigm, albeit an out-of-date paradigm, a few remarks are appropriate.

First of all, the "time is ripe" theory of discovery and invention applies to the stored program computer. This is the theory that whenever an appropriate combination of materials, methods, problems, and needs coalesces, invention is likely to result. Frequently, when the time is ripe, there are independent discoveries of the same item, though not always. Many examples come to mind of independent and nearly simultaneous discovery. I'll mention a few cases that involved contributors from our host country: the invention of the adding machine (Schickard and Pascal), the creation of the calculus (Newton and Leibnitz), invention of the telegraph (Gauss, Morse with Henry), the discovery of Neptune through calculations from the perturbations of Uranus' orbit (Leverrier with Galle, Adams), the invention of the general-purpose electromagnetic computer (Zuse, Aiken with IBM, Stibitz with Bell Laboratories), and the conception of the general-purpose electronic computer (Schreyer with Zuse, Atanasoff with Mauchly and Eckert).

The stored program computer was not a case of independent discovery on the part of several people or institutions. But it did arise out of a background of pre-electronic and electronic digital computing in the United States which involved much original discovery, some of it