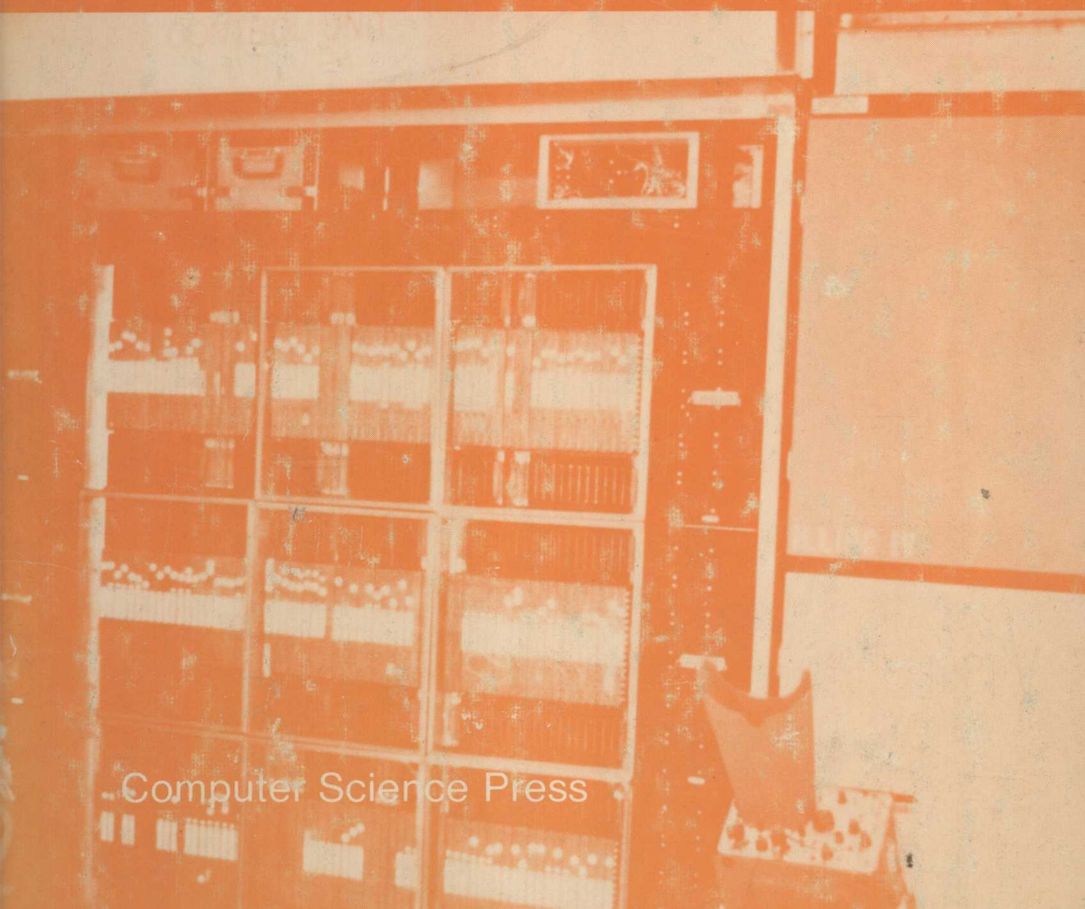
THE ILLIAC IV

The First Supercomputer

R. Michael Hord



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I. Introduction

The Illiac IV was the first large scale array computer. As the forerunner of today's advanced computers, it brought whole classes of scientific computations into the realm of practicality. Conceived initially as a grand experiment in computer science, the revolutionary architecture incorporated both a high level of parallelism and pipelining.

After a difficult gestation, the Illiac IV became operational in November 1975. It has for a decade been a substantial driving force behind the development of computer technology. Today the Illiac IV continues to service large-scale scientific application areas including computational fluid dynamics, seismic stress wave propagation modeling, climate simulation, digital image processing, astrophysics, numerical analysis, spectroscopy and other diverse areas.

This volume brings together previously published material, adapted in an effort to provide the reader with a perspective on the strengths and weaknesses of the Illiac IV and the impact this unique computational resource has had on the development of technology. The history and current status of the Illiac system, the design and architecture of the hardware, the programming languages, and a considerable sampling of applications are all covered at some length. A final section is devoted to commentary.

The story of the Illiac IV is also in part the story of the Institute for Advanced Computation. This is the government organization formed in 1971 by the Defense Advanced Research Projects Agency and the National Aeronautics and Space Administration Ames Research Center to develop and operate this computer. The Institute provides access to the Illiac through a connection to the ARPANET, a national communication network. The Institute also performs software development, maintenance, and research in various advanced computation topics.

Considerable effort has been invested by the Institute in documenting the evolution of the Illiac system and providing those publications to the user community. Frankly, this material has experienced quite limited circulation and to most of the computer world the Illiac remains mysterious. This attitude is fostered by the lack of a thoroughgoing summary of the Illiac's environment, design and capabilities. It is in response to that information gap that this book is addressed.

The Illiac IV consists of a single control unit that broadcasts instructions to sixty-four processing elements operating in lock step.

Each of these processing elements has a working memory of 2K sixty-four bit words. The main memory of the Illiac is implemented in disk with a capacity of eight million words and with a transfer rate of five hundred megabaud. Arithmetic can be performed in 64, 32 or 8 bit mode. In 32 bit mode, on algorithms well suited to the parallel architecture, the Illiac performs at a rate of 300 million instructions per second. Although it uses electronics from the late 1960's, for certain classes of important problems, the Illiac remains the fastest computer to date.

This book is written primarily for computer professionals. Certainly a much wider audience of engineers, scientists, students, program managers and laymen interested in this dynamic technology will find much to engage them. Some sections, however, include considerable detail and assume a fairly sophisticated background in computer science.

II. Background

A. History

The Illiac IV story begins in the mid-1960's. Then, as now, the computational community had requirements for machines much faster and with more capacity than were available. Large classes of important calculational problems were outside the realm of practicality because the most powerful machines of the day were too slow by orders of magnitude to execute the programs in plausible time. These applications included ballistic missile defense analyses, reactor design calculations, climate modelling, large linear programming, hydrodynamic simulations, seismic data processing, and a host of others.

This demand for higher speed computation began in this time frame to encounter the ultimate limitation on the computing speed theoretically achievable with sequential machines. This limitation is the speed at which a signal can be propagated through an electrical conductor. This upper limit is somewhat less than the speed of light, 186,000 miles per second. At this speed the signal travels less than a foot in a nanosecond. Through miniaturization the length of the interconnecting conductors had already been reduced substantially. Integrated circuits containing transistors packed to a density of several thousand per square inch helped greatly. But the law of diminishing returns had set in.

Designers realized that new kinds of logical organization were needed to break through the speed of light barrier to sequential computers. The response to this need was the parallel architecture. It was not the only response. Another architectural approach that met with some success is overlapping or pipelining wherein an assembly line process is set up for performing sequential operations at different stations within the computer in much the way an automobile is fabricated. The Illiac IV incorporates both of these architectural features.

The first section of this chapter introduces the design concept in somewhat more detail. This detail will be elaborated in the course of the book. The design concepts were enormously innovative when the Illiac project was undertaken. It was the first of what today have come to be called supercomputers.

The second section of this chapter is based on an article by Howard Falk that appeared in the IEEE Spectrum,* October, 1976. It provides chapter and verse in describing the horrendous problems that were overcome in making the Illiac IV a reality.

1. The Design Concept

The Illiac IV computer is the fourth of a series of advanced computers designed and developed at the University of Illinois, and this accounts for the origin of its name. Its predecessors include a vacuum tube machine completed in 1952 (11,000 operations per second), a transistor machine completed in 1963 (500,000 operations per second) and a 1966 machine designed for automatic scanning of large quantities of visual data. The Illiac IV is a parallel processor in which 64 separate computers work in tandem on the same problem. This parallel approach to computation allows the Illiac IV to achieve up to 300 million operations per second.

Conventional computers solve problems by a series of sequential steps in much the way an individual mathematician would solve the same problem. In a parallel processor, however, many computations can be performed simultaneously; on the Illiac IV for example, 64 calculations are done at once.

If the problem at hand is to calculate the price earnings ratio for the stock of a corporation, parallelism is of no advantage since the problem cannot be broken into pieces that the separate processors can address independently. Hence 64 mathematicians can solve the problem no faster than one mathematician. If, on the other hand, the problem is to calculate the average price earnings ratio for all of the stocks listed on the New York Stock Exchange, then by assigning the calculation of the different ratios to different mathematicians, a productive division of labor is achieved and the result is obtained more quickly than one mathematician could obtain it sequentially.

Fortunately, a very large fraction of the world's scientific computational problems satisfy this parallelism requirement. For these problems that are suitable for implementation on the Illiac, very handsome run-time reduction factors have been achieved.

The father of the Illiac IV was Professor Daniel Slotnick who conceived the machine in the mid-1960's. The development was sponsored by the Defense Advanced Research Projects Agency. Subsystems for the Illiac were manufactured in a number of facilities throughout the U.S. These subsystems were then shipped to the Burroughs Corporation in Paoli, Pennsylvania for final assembly. The Illiac was delivered to the NASA Ames Research Center south of San Francisco in 1971.

The logical design of the Illiac IV is patterned after the Solomon computers. Prototypes of these were built in the early 1960's by the Westinghouse Electric Company. This type of computer architecture is