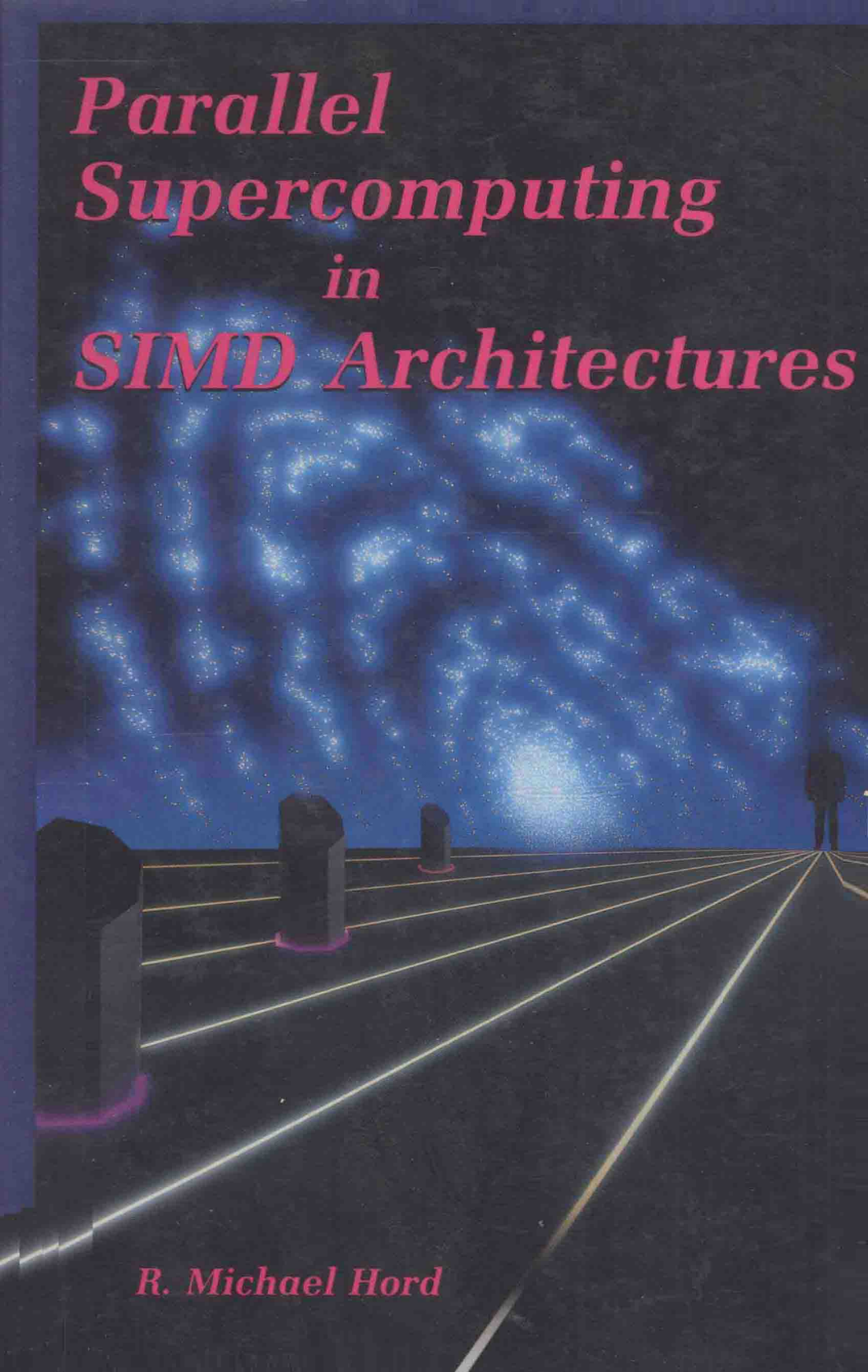
Parallel Supercomputing in SIMD Architectures



R. Michael Hord

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R. Michael Hord
Advanced Technology Laboratory
General Electric Company
Moorestown, New Jersey

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FOREWORD

We live in a golden age of computer architecture innovation. The advent of parallel processing has produced a flood of architecture paradigms, some more successful than others.

The most well known taxonomy for parallel computers was proposed by M. J. Flynn in 1966. It is based on the multiplicity of the instruction and data streams, which identifies four classes of computers: (1) Single instruction stream single data stream (SISD) computers correspond to regular Von Neumann non-parallel computers that can execute one instruction at a time on one data item at a time. (2) Single instruction multiple data (SIMD) computers are based on a central program controller that drives the program flow and a set of processing elements that all execute the instructions from the central controller on their individual data items. (3) Multiple instruction single data (MISD) computers are based on a pipeline principle. A given data item passes from processor to processor and is acted on differently at each stage of this assembly line. (4) Multiple instruction multiple data (MIMD) computers consist of a number of SISD computers configured to communicate among themselves in the course of a program.

Examples of recent successful MISD computers include the Cytocomputer and the PIPE. Instances of the MIMD category are too numerous to list but include NCUBE, iPSC, PASM, WARP, ZMOB, transputer based machines, Encore, Sequent, Alliant and Datacube.

In this book we explore the SIMD category. After a chapter of background that includes a brief discussion of the PEPE, STARAN and SOLOMON early machines, seven important SIMD machines are examined in depth: Illiac IV, MPP, DAP, GAPP, Connection Machine, GAM and CLIP4. Other significant SIMD machines not covered here include the Adaptive Array Processor, GRID, Non Von, Hughes Wafer Stack, GF11, PAPIA and CLIP7.

All of the machines in these categories have distinct characteristics, differing in connectivity, word size, memory management, and other major parameters. But even then the field of parallel processing is not fully mapped because there are whole classes of architectures that do not neatly fit the Flynn taxonomy. What is one to do with neural network computers, logic enhanced memories, data flow architectures and heterogeneous machines? And Very Long Instruction Word machines? And optical computers? In the face of this abundance, the premise of this book is simple. SIMD computers are a successful category of parallel processors because they provide an effective balance between complexity and simplicity. They are rich in algorithmic opportunity yet conceptually clean and easy to understand. The material presented attempts to offer a rebuttal to both camps of SIMD critics: those that claim the range of applicability is narrow because many problems are not sufficiently parallel to use so many processors efficiently and those that claim that having all of the parallel processors execute the same instruction is too restricted to embody the complexities of real world problems. I say

instead that the range of applicability is enormous and hence broad enough to make good general computing and economic sense. And I say that the conceptual clarity of the architecture provides an ease of programming that keeps software costs within reason. The contents of the book are intended to allow the reader to judge these issues for himself.

Much of the material included here is based on and adapted from work previously published in government reports, journal articles, books and vendor literature. A listing of the major sources is provided following the text.

PREFACE

Parallel Supercomputing in SIMD Architectures is a survey book providing a thorough review of Single-Instruction-Multiple-Data machines, a type of parallel processing computer that has grown to importance in recent years. It was written to describe this technology in depth including the architectural concept, its history, a variety of hardware implementations, major programming languages, algorithmic methods, representative applications, and an assessment of benefits and drawbacks.

The book is intended for a wide range of readers. Computer professionals will find sufficient detail to incorporate much of this material into their own endeavors. Program managers and applications system designers may find the solution to their requirements for high computational performance at an affordable cost. Scientists and engineers will find sufficient processing speed to make interactive simulation a practical adjunct to theory and experiment. Students will find a case study of an emerging and maturing technology. The general reader is afforded the opportunity to appreciate the power of advanced computing and some of the ramifications of this growing capability.

Although there are numerous books on parallel processing, this is the first volume devoted entirely to the massively parallel machines of the SIMD class. The reader already familiar with low order parallel processing will discover a different philosophy of parallelism—the data parallel paradigm instead of the more familiar program parallel scheme.

The contents are organized into nine chapters, rich with illustrations and tables. The first two provide introduction and background covering fundamental concepts and a description of early SIMD computers. Chapters 3 through 8 each address specific machines from the first SIMD supercomputer (Illiac IV) through several contemporary designs to some example research computers. The final chapter provides commentary and lessons learned. Because the test of any technology is what it can do, diverse applications are incoporated throughout, leading step by step to increasingly ambitious examples.

For Susan

THE AUTHOR

R. Michael Hord is presently Manager of the Processing Applications Laboratory at the General Electric Advanced Technologies Laboratories, Moorestown, New Jersey. In this capacity he directs research and development activities employing the Connection Machine, the Butterfly, and the Warp advanced architecture computers. The current emphasis is on acoustic signal analysis, military data/information systems, and future architectures.

Until the end of 1989, Mr. Hord was Head of the Advanced Development Center at MRJ, Inc., Oakton, Virginia, where he directed diverse computer applications using parallel architectures including two Connection Machines. Application areas included image processing, signal processing, electromagnetic scattering, operations research and artificial intelligence. Mr. Hord joined MRJ in 1984 where he also directed the corporate research and development program.

For 5 years (1980 to 1984) Mr. Hord was the Director of Space Systems for General Research Corporation. Under contract to NASA and the Air Force, he and his staff assessed technology readiness for future space systems and performed applications analysis for innovative on-board processor architectures.

SIMD parallel processing was the focus of his efforts as the Manager of Applications Development for the Institute for Advanced Computation (IAC). IAC was the joint DARPA/NASA sponsored organization responsible for the development of the Illiac IV parallel supercomputer at Ames Reaearch Center. Projects included computational fluid dynamics, seismic simulation, digital cartography, linear programming, climate modeling and diverse image and signal processing applications.

Prior positions at Earth Satellite Corporation, Itek Corporation and Technology Incorporated were devoted to the development of computationally intensive applications such as optical system design and natural resource management.

Mr. Hord's five prior books and scores of papers address advanced parallel computing, digital image processing and space technology. He has long been active in the applied imagery pattern recognition community, has been an IEEE Distinguished Visitor, and is a frequent guest lecturer at several universities. His B.S. in physics was granted by Notre Dame University in 1962 and in 1966 he earned an M.S. in physics from the University of Maryland.

Eight men dominate the history of SIMD computer architectures. Their names are listed here to acknowledge their pioneering efforts:

S. H. Unger	First to propose spatially organized architectures (1958)
Daniel Slotnick	SOLOMON and Illiac IV
David Schaefer	TZE, MPP, GAM
Kenneth Batcher	MPP
W. Holsztynski	GAPP
Dennis Parkinson	DAP
Michael J. B. Duff	CLIP4
Danny Hillis	Connection Machine

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