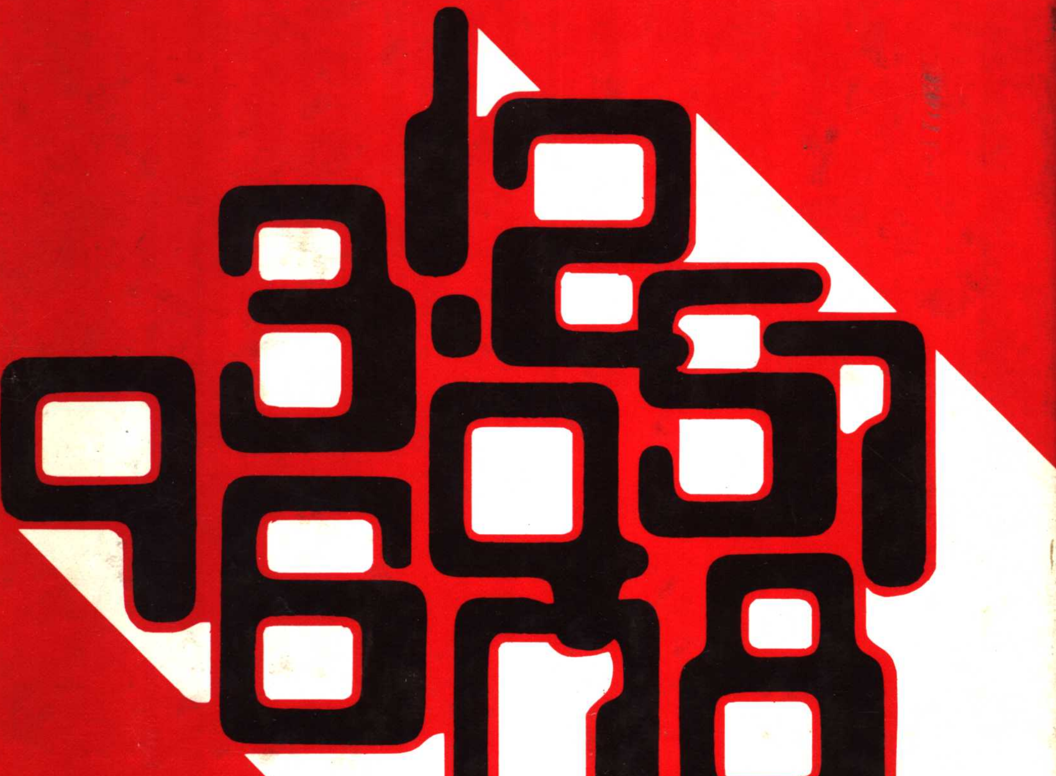
A PRACTICAL GUIDE TO COMPUTER METHODS FOR ENGINEERS



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A PRACTICAL GUIDE TO COMPUTER METHODS FOR ENGINEERS

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To my parents Betty and Dale Shoup

PREFACE

The present revolution in size, cost and capability of modern computational equipment has led to the application of computer methodology to a diversity of technological areas. With the increased emphasis on computer applications in engineering problem solving, more and more engineers are relying on the computer as a tool to assist them in their work. In most practical situations, the engineering programmer will build his or her program from the building blocks of available algorithms. This programming approach is based on sound judgment because it saves time and allows the engineer to exploit the computational talents of his or her computer science and mathematics colleagues. Although most practicing engineers and engineering students have a good working knowledge of computer programming, most are not well acquainted with the characteristics and limitations of the computer methods available to solve their problems. This book is aimed specifically at meeting this need--namely, to provide practical insight into selection of the best available algorithm to perform a given computational task. Unlike most texts in numerical methods, this book is written by an engineer specifically for use by engineers. The philosophy of presentation in this text begins with a clear, basic presentation of the fundamental algorithms. This is done with narrative, figures, logic flow diagrams, and example applications. Once the various algorithms are understood, they are compared and discussed with a view toward their unique advantages or limitations in a particular engineering situation. Whenever possible, available software is listed along with guidelines for practical application. A brief appendix of available computer software for engineering applications is presented at the end of the text.

This book has been developed and refined as a result of teaching and research experience gained at Rutgers University and at the University of Houston. During its evolution this material has successfully been presented to engineers and engineering students from a diversity of educational and experience backgrounds. The order of presentation for the topics in this text is one in which material in the early part of the book provides the necessary background for later chapters. The level of treatment presented is satisfactory for upper level undergraduates, graduate students, and practicing engineers. The spectrum of topics discussed in this text treats those problems most frequently encountered in engineering problem solving. References are provided at the end of each chapter for the reader who would like to pursue the topics in more depth.

The author would like to thank all of those who contributed encouragement and creative suggestions for the construction of this text and the approach it provides. Special thanks for encouragement and support are due to Dr. R. H. Page and Dr. L. C. Witte. Special appreciation must be expressed to my faculty colleagues Dr. R. Bannerot and Dr. M. Milleur, who contributed helpful suggestions and information. The author is grateful to S. Bass, L. Bilowich, J. Herrera, L. Sanchez, R. Strong, T. Wu and P. Young for reviewing the manuscript. Special thanks are due to R. Sodhi, K. Somkearti, and T. Zimmerman for their contributions to the "end of chapter" problems. Finally, I want to express my gratitude to my family for their patience and encouragement during the long hours spent on this project.

Terry E. Shoup

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1 INTRODUCTION

Because of its convenience and versatility, the digital computer is an extremely important tool in engineering problem solving. [Photo courtesy of Tektronix, Inc.]

1.1 Introduction to Computer-Aided Problem Solving

Within the spectrum of technological functions, perhaps no activity holds more excitement than that of engineering problem solving. Indeed, a large portion of the iterative nature of engineering problem solving is embodied in the creative nature of design. Over the years, engineers have sought ways to speed up the mundane aspects of their function in order to free their time for the more creative aspects of their calling. Because of its ability to perform routine mathematical computations with extreme speed and accuracy, the digital computer is a logical tool for the engineer to exploit. As is true for the application of any new technological tool or process, the new freedom implies new responsibility. Whenever potential for high speed exists, so also does the potential for inefficiency and misapplication. Many of the difficulties associated with the use of the computer in engineering come not from the computer itself, but rather from the need for selection and application of the proper algorithm to solve a particular problem. By taking a few minutes before solving a problem to select the proper method, a designer can often save hours of wasted effort. It is the purpose of this book to provide insight into the proper application of the computer to perform a given design task. In this way the engineer can minimize frustration and maximize achievement. Unlike traditional courses in numerical methods, this course focuses attention on providing a variety of methods to solve a particular task. Particular emphasis is placed on an explanation of the intrinsic pitfalls and advantages that characterize a particular algorithm.

1.2 The Computer as a Tool in the Design Environment

In order to understand when the computer can and cannot be applied in the engineering process, it is well for us to look briefly at the structure of design.

Engineering is a profession that employs both science and art to make a process or product for the benefit of mankind. It is different from any other field because it attempts to go from theory into practice rather than merely observing the phenomena of that science or art. The engineering process usually begins with the recognition that a need exists. It is the job of the engineer to create a usable solution to satisfy that need and to communicate that solution in sufficient detail so that the product or process can be produced. The sequence of events in the design process is shown in Figure 1-1. Here we see that the designer begins by under-

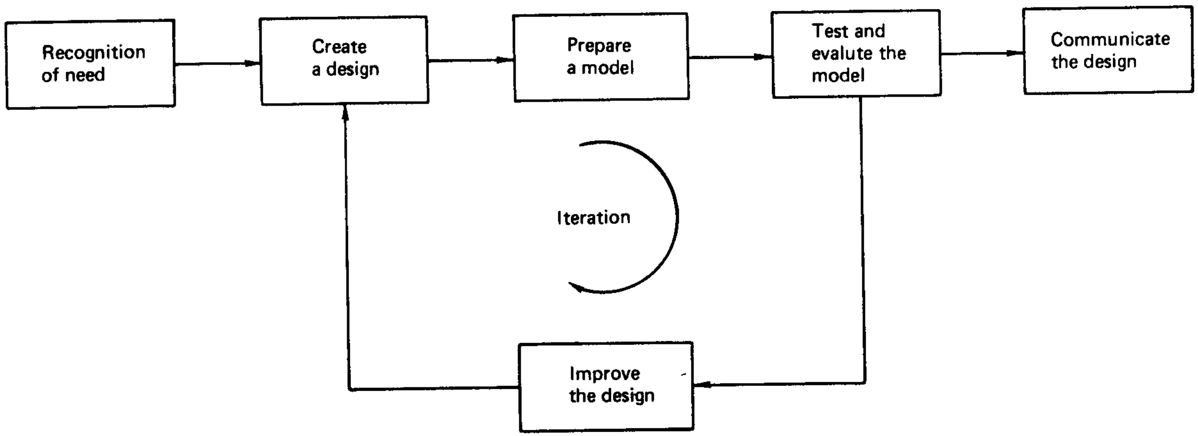

Figure 1-1 The design process.

taking a deliberate, planned exploration for possible solutions. Next, he or she assembles sufficient information to create a model suitable for the evaluation and testing of the utility of the solution. This phase of the activity is an economic convenience because to test the solution itself is nearly always too expensive, too time consuming, and too wasteful of materials and energy. Very often the idealized model used will be an analytical one or the combination of a simple prototype coupled with an analytical representation. Once the model has been prepared, the designer proceeds to test and evaluate its performance to obtain some measure of its ability to satisfy the need. Although the first attempts to create a solution to a design problem will usually produce a poor design, these first efforts will usually provide insight into where improvement can be made. Using these initial discoveries, the designer repeats the model building and evaluation cycle until he or she is satisfied that the best possible solution has been achieved. At this point the designer will communicate the design to the construction phase of the engineering process.

The various steps in the design process often consume different amounts of time. The boundaries between these steps are often difficult to observe, and frequently two or more steps will be combined. The total process is very iterative and parts can involve large amounts of computational effort. For this reason the computer can be an extremely effective aid if it is applied in an efficient way. The key to its application is to utilize it for mundane, repetitive tasks involving routine manipulations of data rather than for tasks that require the creative manipulation of abstract concepts. Thus, those tasks early in the design process are poorly suited to computer assistance whereas those at the end are best suited. An illustration of this situation is presented in Figure 1-2.

↑ Most creative

ASPECT	COMPUTER POTENTIAL
Recognition of Need	Desirable – but few applications exist
Create a Solution	Limited – computer-augmented creativity
Prepare a Model	Some – special languages and applications packages
Test and Evaluate the Model	Yes – through numerical methods
Improve the Design	Yes – optimization
Communicate the Design	Yes – computer graphics, numerically controlled manufacturing

↓ Most potential for computer assistance

Figure 1-2 The potential for computer assistance in design.

Because of the wide scope of application shown in this figure, the computer should no longer be regarded as a supplementary tool in design. Rather, it has rapidly become a vital part of the design methodology utilized in the modern industrial environment.

1.3 Considerations in the Preparation of Engineering Programs

The types of calculations necessary for the design process are diverse in scope. Both the nature and the quantity of these calculations are continuously changing. Some computational procedures are sufficiently simple so as not to justify the use of the computer, while others involve such detail that they would be impossible without computer assistance. Those design tasks that are suitable for computer assistance may be classified as follows:

1. computations similar to hand calculations that must be done many times;
2. computations that are extensions of hand calculations but are too involved to be practical by hand for reasons of accuracy and time; and
3. manipulation of data for purposes of visualization, manufacture, or documentation.

1.4 Computational Equipment for Engineering Problem Solving

The array of computer equipment available for problem solving in the engineering environment is presented in Figure 1-3. The spectrum of computational hardware is presently undergoing a dramatic revolution in terms of size, cost, capability, and utility.

Due to recent advances in storage capacity and speed of access, the modern digital computer system is capable of handling extremely complex and large scale engineering problems. The software for large scale computer systems tends to be universal; thus programs written for one machine can generally be adapted for use on other systems of similar size. Through the medium of time-sharing terminals connected via telephone lines, the versatility and utility of the large-scale digital computer can be available at the desk of every engineering problem solver.

If large size is not required, and if the engineer wishes to avoid the need to share the computer with other users, he or she may prefer to utilize a minicomputer dedicated to specific problem-solving needs. These devices operate in much the same way as their larger counterparts except that they have smaller internal storage capacity and they allow consider-

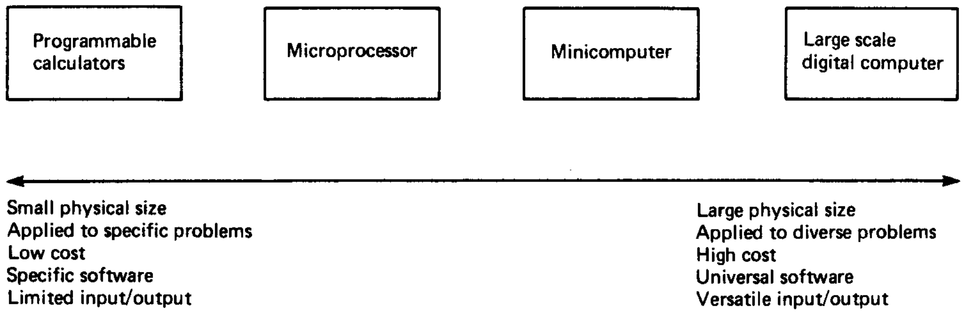

Figure 1-3 The spectrum of computational equipment for engineering problem solving.

able "hands-on" operation. This means that the engineering programmer can exercise greater personal control over the data management of problems.

If the computer in an engineering situation is to function as an integral part of an engineering system and is to be permanently dedicated to this task, a microprocessor may provide an efficient hardware solution. With such a device, the inputs frequently take the form of digitized measurements of the physical process being controlled, and the outputs typically take the form of signals or impulses that control the operation of other parts of the total system. Because of their low cost and the large domain of their practical applications, microprocessors have found their way into many aspects of our daily existence.

Recent advances in the field of programmable pocket calculators have made these miniature miracles capable of computational tasks surpassing those of larger computer systems of only a few years ago. Unlike most large scale computers, these personalized computers tend to use programming languages that are unique for the particular device to which they are applied. Programmable pocket calculators are well suited for problems requiring a small number of input values and a small number of output values. In most cases the numerical output must be displayed one number at a time. Even with their minor limitations, the price and convenience of these devices makes them readily available to every engineer. They continue to gain widespread popularity.

The actual selection of a particular type of computational device depends on the specific needs of the engineer and on the computational complexity of a particular engineering task. Since the array of available devices is a spectrum, it is not uncommon to find that several different types of devices are capable of performing a given computational task. In these situations the selection process would, of course, be based on cost, equipment availability, and personal preference.

1.5 Categories of Problems in Computer-Aided Engineering

Because of the nature of engineering phenomena, certain types of mathematical analysis problems occur again and again. Among these are:

1. the solution of algebraic equations;
2. the solution of eigenvalue problems;
3. the solution of ordinary differential equations;
4. the solution of partial differential equations;
5. the solution of optimization problems; and
6. the manipulation of numerical data.

Each of these areas is discussed in this book, and the fundamental concepts and terminology associated with the basic solution techniques for each of these areas are presented. In many cases the computer algorithms for solving engineering problems can be implemented on a variety of different computational devices. Wherever possible, familiar software is dicussed with a view toward making the best practical selection for a particular engineering problem situation.

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