COMPUTER SIMULATION and MODELLING

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To
my parents who made it all possible
and
my son Arun, who missed a lot of fun

Preface

This book is about modelling and simulation of systems with the aid of computers. Both modelling and simulation (continuous and discrete) aspects are covered in sufficient detail; however, the emphasis is on digital computer simulation of discrete systems.

Modelling and simulation is not a clearly defined subject; it has its roots in several fields and derive its strength from the concepts, theories, and techniques developed in all the major disciplines over the last several decades. It is more than an art, but not a fully developed science. Human judgement, experience and computer programming skill still play an important role in the formulation and solution of problems by this method. Earlier applications of modelling and simulation centred around the problems arising in science and engineering, and it has now become clear that modelling and simulation can make a significant contribution in solving problems in economics, management, social and behavioural sciences.

A number of books on modelling and simulation have appeared on the market during the past 15 years, and the classroom trial of these books highlighted several deficiencies in the structure, organization, presentation, and practical orientation of various aspects of computer modelling and simulation. This book describes all important aspects (concepts, techniques, tools, strengths, and weaknesses) of computer-aided modelling and simulation in a single volume suitable for adoption as a textbook for an undergraduate or a postgraduate course on the subject. Concepts and theories have very little meaning unless they are illustrated through diagrams and examples, which make both teaching and learning enjoyable. Diagrams, numerical examples, sample program listings (Pascal, CSMP, GPSS, SIMSCRIPT) and output from actual computer runs are the main features in the presentation of various topics. The emphasis is on practical problem-solving and not on theorem-proving. Unnecessary proofs and theoretical derivations are avoided and more theoretically motivated readers are referred to selected additional reading materials which in turn will lead to further sources.

This is the age of microprocessors and supercomputers. Interactive computer graphics, animation, artificial intelligence, and expert systems have become usable tools. The computer is no longer a luxury and micros are currently accessible to the vast majority of students, researchers, and other practitioners. The use of microprocessors for modelling and simulation, and the availability of micro-based simulation software have been stressed throughout the book so as to make simulation an attractive tool for problem-solving in a wide range of disciplines.

Reading is a necessary first step in learning the subject, but what is more important is the actual construction and implementation of simulation models and interpretation of results. The summary and exercises given at the end of each chapter are designed to encourage reading and 'learning by doing', and thus gain experience and confidence in the practice of modelling and simulation.

The reader of this book is assumed to be familiar with basic algebra, calculus, statistics, and at least one of the computer programming languages such as Pascal, Fortran, Basic, etc. No previous knowledge of simulation languages is required. Students in computer science, engineering, natural sciences, operations research, management science, and social sciences will find this book particularly useful. The bulk of the material can be covered in a standard 1-year university course. People from industry and other fields, who are engaged in modelling and simulation projects, should also find this book helpful. A brief outline of topics covered in various chapters appear in Section 1.7 of Chapter 1.

Several people have aided me directly or indirectly in writing this book. In particular, I would like to thank my colleagues at the Department of Computer Science, Trinity College, Dublin and University of Kansas (1984–85) for their constructive criticisms and suggestions; Stella Coughlan for her help in the preparation of the manuscript, and all my students who served as a test population during the last so many years. Finally, I am grateful to A. Mullarney of CACI, Dublin, for his comments on SIMSCRIPT in Chapter 9.

Francis Neelamkavil

Contents

1

Introduction and Overview

1.1 Background

A system is a collection of interacting elements or components that act together to achieve a common goal. Systems can be studied by direct experimentation, by building prototypes, or by building mathematical/logical models. The experimentation with the prototype or the real system is highly undesirable due to a variety (expensive, impractical, risky, or time-consuming) of reasons, and these methods are not dealt with in this book. The purpose of systems study through modelling is to aid the analysis, understanding, design, operation, prediction, or control of systems without actually constructing and operating the real thing. The mathematical/logical models which are not easily amenable to conventional analytic or numeric solutions form a subset of models generally known as *simulation models*. A given problem defined by a mathematical/logical model can have a *feasible solution*, *satisfactory solution*, *optimum solution*, or *no solution* at all. Computer modelling and simulation studies are primarily directed towards finding *satisfactory solutions* to practical problems. In Figure 1.1, points inside the shaded area are all feasible solutions and any point close to the optimum solution can be treated as a satisfactory solution.

Modelling and Simulation emerged (revived) as an identifiable numerical problem-solving technique during World War II when the so-called *Monte Carlo methods* (Hammersley and Handscomb, 1964) were successfully used by John Von Neumann and Stanislaw Ulam of Los Alamos scientific laboratory for solving neutron diffusion problems. Simulation need not necessarily involve computers. However the evolution of modern computers and high-level simulation languages popularized (Zeigler, 1979) the application of modelling and simulation for solving real-life problems in several disciplines, and the expected advances in computer technology indicate that this trend will continue.

Computer modelling and simulation was introduced into university curricula in the 1960s, and books (Tocher, 1963; Forrester, 1961) and periodicals (Ören, 1974, 1976) on the subject began to appear around the same time. The multidisciplinary character of modelling and simulation is evident from

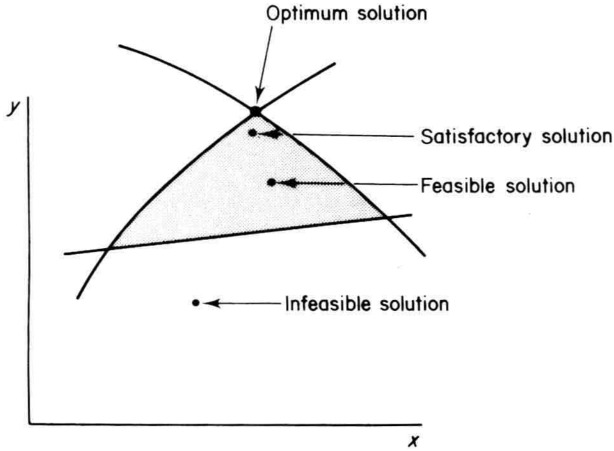

Figure 1.1 Types of solutions to a problem.

the fact that the subject is taught by different departments in different universities around the world.

1.2 Principle of computer modelling and simulation

The method of problem-solving by computer modelling and simulation can be best explained by a simple example. In Figure 1.2 the shaded area A bounded by the non-negative function $y=f(x)$, the x axis and the vertical lines at $x=b$ and $x=c$ is given by the definite integral

$$A = \int_b^c f(x)\mathrm{d}x \tag{1.1}$$

where $0 \leqslant f(x) \leqslant h$ and $b \leqslant x \leqslant c$.

The area A is a portion of the total area enclosed by the rectangle R with base (b,c) and height h. If a point P is dropped at random on R (this can be visualized as the throwing of a dart P from a distance on to the plane R so that the probability of hitting any point on R is the same), then the probability p of the point P falling in the area A is given by

$$p = \frac{A}{h(c-b)}$$

If the point P is dropped N times and K times it fell within the area A, then

$$p = \frac{K}{N} = \frac{A}{h(c-b)} \quad \text{when N} \rightarrow \infty$$

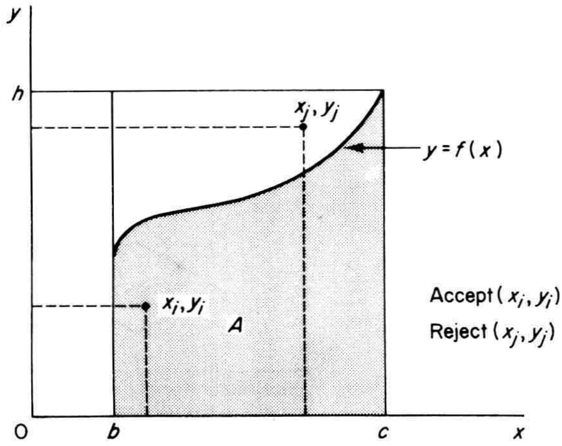

Figure 1.2 Area under the curve $y = f(x)$.

or

$$A = \frac{Kh(c-b)}{N} \tag{1.2}$$

Figure 1.3 shows a simple flowchart to determine the area A by computer simulation, using the model defined by equation (1.2). A Pascal program and the actual computer (VAX 11/780) output are given in Figure 1–4 where N=3000, b=0, c=h=1, y=$f(x)$ = $\sqrt{1-x^2}$ and a standard library routine MTH$RANDOM is generating random numbers in the range (0,1).

The computer modelling and simulation method of problem-solving (here, the evaluation of a definite integral) becomes attractive only when it is difficult, time-consuming, expensive, hazardous, or impossible to solve the problem by conventional analytic, numeric, or physical experimentation methods. It must be clear by now that simulation results are likely to be less accurate than analytic solutions.

1.3 Simulation versus Monte Carlo simulation

The city of Monte Carlo is well known for its gambling (roulette wheel) activities, and hence this name has come to be associated with simulation (Von Neumann gave the code name Monte Carlo for his military project at Los Alamos) which involves the generation and use of random or chance variables. Some authors use the terms *Monte Carlo simulation* and *simulation* (discrete system simulation) synonymously. However, there is a distinction between the two. Both simulation and Monte Carlo simulation (Shreider, 1966) imply that the simulation model is influenced by random events;