COMPUTER GRAPHICS
Systems & Concepts

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PREFACE

"I have told you, you have to have an unbending intent in order to become a man of knowledge."

Carlos Casteneda, *A Separate Reality*, Penguin, 1973, p. 132.

Computer graphics is a major force in a revolution that is changing the way people perceive and use computers. Moreover, its impact is far beyond the confines of computer science, reaching out to touch many aspects of everyday life, as illustrated by a glance through the colour plates in this book. Computer graphics not only plays an important role in applications such as advertising and entertainment but also in engineering design, medicine, architecture and aerospace. The power of modern computing equipment to generate realistic 3D pictures has also been exploited in the generation of images of often unreal entities. The synthetic production of hitherto only imagined scenarios has found a major application in science fiction films, as well as in medicine and real-time simulation and control.

Aims and Objectives

This book offers a practical guide to the construction and implementation of computer graphics systems. It does this by:

- demonstrating the power and range of applications of computer graphics,
- presenting the basic principles involved in constructing a computer graphics system capable of these applications, and
- introducing the reader to existing computer graphics systems, in particular the international standard Graphical Kernel System (GKS).

A detailed description, evaluation and critique of GKS as an example of a graphics system and its comparison with other graphics systems, including PostScript, is a major theme throughout the book.

The book aims to provide the reader with a detailed knowledge of the *fundamental programming tools* of computer graphics, making it suitable as a basic tutorial text on computer graphics for computing, mathematics and science undergraduates. It also provides a complete tutorial text on GKS, and the reader should become something of an expert in the understanding of the *design* and *use* of the GKS standard. This will suit students in a range of disciplines, as well as commercial and industrial professionals. Attention is also paid to 'state-of-the-art' approaches such as PostScript, and the

application of graphics in the *design* and *implementation* of *modern user interfaces*. As well as becoming proficient in graphics programming systems, the reader should gain insight into the *design* and *organization* of *graphics hardware*. Here, 'hardware' not only means the computer equipment used to display and interact with images, but also the human visual system that perceives and interprets them.

An Overview

The *graphics algorithms* discussed in this book are initially developed in an abstract programming notation based on a *functional language*, which can be understood independently of any actual programming language. The proposed *Pascal language binding* for GKS is also used. It is assumed throughout that the reader has some familiarity with basic geometry and computing terminology.

Chapter 1 introduces computer graphics by reviewing some important applications, thus setting the scene for the rest of the book. Part One really begins with Chapter 2, which attempts to extract the basic features of a graphics library system by considering a paradigm based on the printed page. Chapter 3 discusses the architecture of device-independent software systems. Chapter 4 then discusses the fundamental algorithms needed to generate computer graphics. Chapter 5 considers the heart of any graphics system – its functions for graphical output and interaction. In this chapter, graphical output of geometric pure entities (for example, infinitesimally thin lines) is discussed, whereas Chapter 6 introduces methods for specifying style – such as line thickness and colour. Chapter 7 introduces the basic modelling tool of picture segments. Chapter 8 considers some special features of GKS which an applications programmer or systems implementor needs to understand to be aware of GKS in actual operation. Chapter 9 presents an abstract view of the GKS event input model.

Chapter 10 goes beyond GKS by discussing the essential ideas of graphics modelling. This is done by first considering functional graphics, and then widening this to a more traditional approach. In this chapter, the basics of perhaps the most far reaching, recent development in computer graphics is considered, the PostScript system. Many PostScript examples and programs are given in this chapter. There is also a brief discussion of some of the ideas of modelling as embodied in the proposed PHIGS standard.

The revolution in computing mentioned at the beginning of this Preface has at its base the introduction of bitmapped display technology and the concomitant development of powerful personal workstations with bitmapped graphics. The basic concepts of bitmapped graphics are discussed in Chapter 11, based on the Smalltalk-80 model.

Having considered alternative systems in Chapters 10 and 11, Chapter 12 compares these with GKS, as part of a critical assessment of the

standard. The chapter concludes with a strategy for the use of GKS in large-scale projects.

Part One concludes with an introduction to the basic features of 3D graphics. Sufficient information is given in this chapter to enable the reader to construct quite a powerful 3D system.

Another major aspect of the computer revolution has been the growing desire of systems designers to provide interfaces to their products which people can easily learn to use, and which people like to use. Some of the main concerns of human–computer interaction research, and user interface design, are discussed in the opening chapter of Part Two. Chapter 14 concludes with a detailed discussion of the human response to colour.

Chapter 15 moves into the area of graphics hardware, discussing the different types of display technology. Chapter 16 supplements Chapter 15 with a discussion of graphics hardware architecture and organization. Chapter 17 surveys various types of input devices – the physical basis of interactive graphics. Chapter 18 discusses hardcopy devices, including the latest laser printer technology.

Chapter 19 concludes Part Two with an integrating discussion on general ideas of building a graphics system from the first approach of a client to the delivery of the finished product.

Finally, there are two appendices. The first reviews the main ideas of the abstract programming language used in Part One, and the second presents a complete PostScript program for 3D graphics.

Using the Book in Teaching or Training

Teaching and learning computer graphics is hard work, requiring organization and planning. To do either effectively, those new to computer graphics need to gain considerable practical experience. This requires a laboratory with modern bitmapped (ideally colour) display workstations, which can be used for several hours per week.

An excellent way of re-inforcing the major concepts of computer graphics is to design and implement a complete (although simple) graphics library for interactive graphics, based on a few primitive machine-dependent functions. The student will find the exercise of providing full documentation for the system particularly useful. Further insights can be achieved by tackling the problem of re-implementing the library on a different machine – this re-inforces at an early stage the important issues of device independence. Finally, the student should attempt to write a non-trivial applications program using only the functions of the library. Here, a choice in the type of project can be given: some students are attracted by interactive graphics, with the desire to invent good user interfaces, while others are interested in non-interactive 3D graphics.

This book provides support for a course based on practical work such as that just outlined. It is not a book with lots of programs to generate 'pretty' pictures, but it is one that gives sufficient information to enable a hard-working student to construct a respectable graphics system. It is an introductory book in the sense that many fundamental algorithms and methods are discussed; however, more advanced issues can be followed up by tracing the references.

The book also encourages self-study. A synopsis at the beginning of each chapter outlines the major topics, and links the material with previous and subsequent chapters, putting it into a meaningful context. In addition, each chapter concludes with a summary, pointing to later chapters that build on this material, and exercises to test the reader's understanding and provide relevant project work.

This book represents an integration of the authors' combined experience, and originated from a joint venture to implement and install a large graphics system (GKS). Rod Salmon has had considerable experience in the industrial sector, which has been invaluable in preparing the sections on graphics systems and hardware of Part Two. Mel Slater's experience in computer graphics teaching and research is represented mainly in the chapters forming Part One, on graphics concepts and programming systems.

Writing this book has proved to be a long, sometimes painful, but often enjoyable experience for the authors. The task of producing written material in a form that readers will find enjoyable and understandable is a humbling experience. Computer graphics is not an easy or trivial subject and readers will sometimes have to work hard to understand and apply the ideas presented. The experience of the authors suggests that the effort will be worthwhile.

Rod Salmon
Mel Slater
June 1987

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Production of the Figures

About half of the figures in Part One, especially those illustrating the output of programs, were produced by an unusual method. Those relating to GKS were produced using a GKS implementation written at Queen Mary College (QMC), Department of Computer Science and Statistics. Initially, the images were 'screen dumped' and the output sent to an Apple LaserWriter. However, pictures that look acceptable on a screen often do not transfer well to paper by screen dumping, because all of the inadequacies of low resolution (for example, jagged lines, poor quality text) are caste in permanent form and easily noticeable (our expectations are higher for the printed page than for computer screens). Thus, an alternative strategy was adopted: a new GKS abstract workstation that delivered PostScript programs in a file was developed. Hence, the GKS program was executed and the result, as well as appearing on the screen, was also represented by a file of PostScript commands. This file was then interpreted on the LaserWriter, with much better results than before.

Other figures were produced by writing PostScript programs directly, or PostScript programs produced by ML. Still others were produced by traditional means, by an illustrator.

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CONTENTS

PART TWO GRAPHICS SYSTEMS AND INTERFACE

PART ONE

GRAPHICS PROGRAMMING

CHAPTER 1

INTRODUCING COMPUTER GRAPHICS AND ITS APPLICATIONS

The aim of this chapter is to introduce the reader to the world of computer graphics. Following a brief outline of the history of computer graphics and some examples of its applications and uses, the chapter goes on to describe the basic features of computer graphics needed to follow the rest of this book. The chapter concludes with an outline of the programming notation used to describe the basic concepts and algorithms.