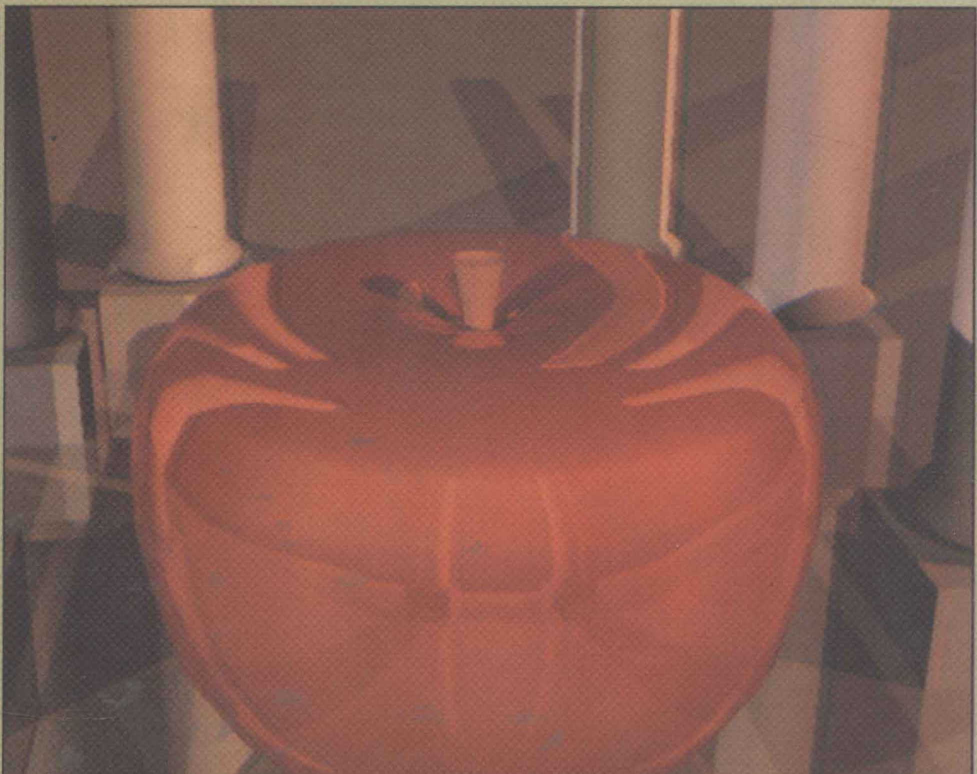
David F. Rogers • Rae A. Earnshaw

EDITORS

Techniques for Computer Graphics



Springer-Verlag

David F. Rogers   Rae A. Earnshaw
Editors

Techniques for Computer Graphics

With 274 Illustrations, 82 in Color

Springer-Verlag
New York Berlin Heidelberg London Paris Tokyo

David F. Rogers
Aerospace Engineering Department
U.S. Naval Academy
Annapolis, Maryland 21402, USA

Rae A. Earnshaw
University of Leeds
Leeds LS2 9JT
United Kingdom

Cover illustration: *Copper Apple with Columns* (Michael Kaplan, Eliot Feibush, and Paul Hughett)

Library of Congress Cataloging-in-Publication Data
Techniques for computer graphics.
Papers for an International Summer Institute on the State of the Art Computer Graphics, held at the University of Stirling, Scotland, summer 1986, sponsored by the British Computer Society Computer Graphics and Displays Group and the Computer Graphics Society.
Includes bibliographies and index.
1. Computer graphics—Congresses. I. Rogers, David F., 1937– . II. Earnshaw, R. A. (Rae A.), 1944– III. International Summer Institute on the State of the Art in Computer Graphics (1986 : University of Stirling) IV. British Computer Society. Computer Graphics and Displays Group. V. Computer Graphics Society.
T385.T45 1987 006.6 87-9766

Printed and bound by H. Stürtz AG, Würzburg, Federal Republic of Germany.
Printed in the Federal Republic of Germany.

9 8 7 6 5 4 3 2 1

ISBN 0-387-96492-4 Springer-Verlag New York Berlin Heidelberg
ISBN 3-540-96492-4 Springer-Verlag Berlin Heidelberg New York

Techniques for Computer Graphics

Acknowledgments

The papers in this volume formed the basis of an International Summer Institute on The State of the Art in Computer Graphics held at the University of Stirling, Stirling, Scotland, United Kingdom.

We are very grateful to our co-sponsors: the British Computer Society (BCS), Computer Graphics and Displays Group, and the Computer Graphics Society (CGS). We also thank the Association for Computing Machinery (ACM) for their co-operation and support.

Our thanks and appreciation go to Mrs. Frances Johnson, Conference Officer at the University of Leeds, and to Brian Booker, for all their help and support with the practical arrangements for the Institute.

Our thanks and appreciation also to all those delegates who attended from many countries and contributed by their discussion, interaction and inspiration. The following countries were represented: Belgium, Canada, Denmark, Federal Republic of Germany, Finland, Iceland, Japan, Netherlands, Norway, Poland, the United Kingdom, and the United States.

A volume such as this is the result of many months of planning and preparation, and we thank all those who have assisted us. Colleagues, students, contributors, and publisher—we thank you all for your forbearance and patience, and for enduring our persistence in seeking to bring this project to a successful conclusion.

David F. Rogers
Annapolis, Maryland, USA

Rae A. Ernshaw
Leeds, UK

Contents

Introduction to Techniques for Computer Graphics

Capturing the state-of-the-art in computer graphics is akin to attempting to photograph a fast moving target. The result, at best, is a synoptic snapshot. The current volume represents a snapshot of a number of topics in computer graphics. These topics include: workstations, graphics standards, image generation, computer-aided design (CAD), curves and surfaces, human-computer interface issues, electronic documents, integrated graphics and text, solid modeling, VLSI, and innovative applications.

Many of the papers first present a background introduction to the topic followed by a discussion of current work in the topic. The volume is thus equally suitable for non-specialists in a particular area, and for the more experienced researcher in the field. It also enables general readers to obtain an acquaintance with a particular topic area sufficient to apply that knowledge in the context of solving current problems.

The volume is organized into eight chapters as follows: Design, Modeling, Image Generation, Workstations, Hardware, Human-Computer Interface, Graphics Standards, and Documentation.

In the first chapter John Lansdown provides an overview of the design process in the context of computer graphics. In the first of two papers Lansdown points out that computer graphics has been used as a design tool for some thirty years. In most cases it has enabled the iterative design process to be performed more efficiently and quickly. However, one of the real problems is in the central area of design, viz, intuition and creativity. Modeling of these activities seems to be far more difficult than modeling objects. Lansdown presents an analysis of these issues and outlines a method of parametric variation for using computers to fine-tune a designer's proposals.

His second paper examines the relationship of visual literacy to the design process. Indeed, such a relationship is vital if effective images are to be produced. More attention needs to be paid to the classical form and content of images and pictures in order to better understand the use of color, texture and form. Increased understanding of these aspects of computer graphics will result in more effective composition and exploitation of inherent information.

The second chapter discusses the requirements and techniques for creating models. In particular, it provides a survey of current work in geometric modeling including curves and surfaces.

The first paper by Robin Forrest raises several key issues in the development and implementation of geometric models. He points out that the quality of rendering is now so good that deficiencies in the underlying models are clearly evident. Thus, more attention needs to be paid to the rigor and quality of the model definition and to the numerics associated with the model.

The second paper by John Woodwark and Peter Quarendon provides an introduction to solid modeling. Solid modeling enables real objects (e.g. buildings, engineering components, organs of the human body, etc.) to be represented in a complete form such that ultimately quantitative information can be extracted during the design process. Picture generation techniques are outlined and anticipated developments for future advanced architectures capable of dealing with more complex models are summarized.

The abstract of Brian Barsky's elegant lectures summarizing the concepts and application of the beta-spline, a mathematical technique for curve and surface representation, appears next. Dr. Barsky pointed out that the underlying geometric nature of the technique combined with local control through shape parameters forms a powerful tool for computer graphics and computer-aided geometric design and modeling. These aspects of the technique are amply illustrated in a highly recommended forthcoming book by Professor Barsky entitled 'Computer Graphics and Geometric Modeling Using Beta-splines'. The book is to be published by Springer-Verlag.

The next paper by computer graphics pioneer Tosiyasu Kunii briefly discusses several examples of modeling systems. These include an apparel pattern making system, a constructive solid modeling system, an animation system for engineering models, a system for generating, manipulating and managing the many tables required in engineering and manufacturing, a scheme for region detection for rasterized data, a device independent model driven system for accessing local area network facilities, and finally a system for generating and managing user friendly interactive menus.

The final paper in the chapter is by Mike Muuss. Muuss presents an excellent review of the origins and basic principles of solid modeling. In contrast to many papers on solid modeling, he discusses, in detail, the mathematics of typical solid primitives, including their mathematical definitions, the mathematics of Boolean operations as applied to these primitives and the mathematics of ray (line) - primitive intersections. As an example of a modern geometric solid modeler he describes MGED—a fully implemented production engineering design solid modeler currently in daily use at the U.S. Army Ballistic Research Laboratory. MGED is capable of representing models composed of in excess of 5000 objects. The modeler is fully integrated with critical engineering analysis programs. The paper also provides an excellent introduction to ray tracing including a discussion of the general data structures, code organization and space partitioning algorithms. In MGED, ray tracing provides critical analysis as well as rendering capability.

The third chapter contains two papers on image synthesis. First, Mike Kaplan provides a very complete description of a modern space partitioning ray tracing algorithm. The algorithm, which for a given resolution, operates in nearly constant time independent of the number of objects in the scene, is more than two orders of magnitude more efficient than the naive algorithms of less than ten years ago.

Next, Roy Hall discusses illumination models and color in the context of illumination models. Hall first provides a physical model for a nearly complete general illumination model. He then shows, in detail, how the traditional illumination models used in computer graphics, including Bouknight, Gouraud, Phong, Blinn, Whitted, Cook, Hall and the radiosity method, approximate the general model. Each model is illustrated by a specially generated comparative color image. Finally, he discusses a number of image display considerations, particularly with respect to video, required for optimal presentation.

These first three chapters basically address the questions of how do we model a design and effectively and realistically render it. In the fourth chapter Zsuzsanna Molnar discusses the characteristics and capabilities of a modern engineering/scientific professional graphics workstation. The workstation described by Molnar uses VLSI hardware technology to achieve increased graphics performance. Using a current 32 bit super-microprocessor makes the workstation suitable for a wide range of applications requiring both high compute power and fast image generation.

In the fifth chapter three authors discuss current state-of-the-art research using VLSI based hardware to further enhance graphics performance. In the first of these papers Henry Fuchs discusses the origins of todays graphics systems from a hardware viewpoint. He outlines the generic organization of several types of systems. Historically, three kinds of graphics systems have been optimized for different requirements: the high-performance 3-D system, the color frame buffer, and the general workstation display. With increasing power and flexibility, it is now becoming common for a workstation to satisfy two or more of these requirements.

Next, Adrian Thomas presents a series of interrelated concepts for a display and modeling system based on the use of Boolean expression models to represent shape. This display system, which transforms models into pictorial form, is implementable in VLSI hardware. A prototype system is outlined. A further area of interest is the reverse process of capturing shape information by generating the corresponding Boolean model from TV camera input. This simple form of machine vision is capable of extension and improvement. Thus, Boolean models provide the common baseline linking together real-time object display and real-time image processing techniques.

Finally, in this section Alistair Kilgour discusses a practical requirement in the generation of VLSI circuits: the merging of different polygons in the description. He describes the formulation, implementation, and performance of an efficient and secure algorithm for processing such polygons.

Chapter 6 turns to the popular area of human-computer interaction with two papers by current researchers in the field. Brian Shackel addresses the issues of hardware; Tom Stewart outlines current research and development in the field.

The human interface is concerned with all those features that characterize the interaction of the user with the machine. It consists not only of hardware but also any relevant software and documentation. Interaction may consist of a sequence of communications based on response to messages produced by the system. These messages may be alphanumeric, graphical, or both. Brian Shackel's paper is concerned with the hardware aspects of the human interface, including input and output devices such as terminals, VDUs, displays, printers, workstations, and the characteristics of the environment in which they are used. The relative merits of input devices such as the keyboard, lightpen, trackball, mouse, touchscreen, touchpad, and voice are discussed. Characteristics of output devices are analyzed and the issue of visual versus auditory response/cues is examined. Finally, the ergonomic issues of screen size, use of color, and terminal design are presented.

Tom Stewart examines Human-Computer Interface (HCI) design and surveys research and development in User Interface Design. The features and facilities of the interface govern the quality of the HCI: Good user interface design promotes good HCI–it has to be designed in, it cannot be bought in. Usability and acceptability are user and task specific. The results of numerous studies of user/task combinations are outlined in the paper. User interfaces in graphics systems are reviewed as is the incorporation of AI techniques to create adaptive user interfaces. Some reasons for poor interfaces are outlined. In the main these are due to too little attention being paid to human factors at an early stage in the design. Finally, current developments in HCI and user performance are reviewed, and prospects for the future summarized.

In the next chapter, Jose Encarnacao reviews current progress in graphics standards, including PHIGS, GKS, and the new PHI-GKS proposal. Computer graphics metafile standards, GKSM and CGM, along with the WSI, CGI and GDS device and workstation interface standards are also reviewed. A number of application areas in which on-going research and development is taking place are summarized. These include documentation systems (an interface to SGML), presentation graphics, window management and user interface management systems. The relationship to expert systems (e.g. GKS and functional languages), robot programming and simulation is discussed. Work on embedding GKS functionality in silicon is also reviewed.

The final chapter contains two papers on documentation issues. Peter Brown's paper analyzes methods for displaying documentation and describes a new approach for attractive presentation and user-interaction. These techniques can be applied to any form of documentation, whether computer hardware and software manuals, office procedures, encyclopedias, or timetables. Utilizing workstation facilities, the user is able to tailor what is displayed to what he wishes to see. In addition, the use of graphics and multiple fonts can make the documentation more readable and attractively presented.

Methods for combining text and graphics are outlined by Heather Brown. This task is a subset of a larger problem, viz, the combination and integration in one document of several different forms of input such as images, voice, tables, spreadsheets, text and graphics. The emergence of international standards for documentation description and interchange (e.g. Office Document Architecture (ODA)) is beginning to provide a framework for formally combining these different elements. This paper outlines the exploitation of these features for combining text and graphics.

Computer graphics pioneers looked to the time when computer graphics would come of age, when anticipated developments would become the reality of today. This has now happened. The contributors to this volume have made it very clear that computer graphics is not just a potential tool, it is a real tool. Many of the powerful methods and techniques that are encapsulated in the body of knowledge called computer graphics are increasingly being embedded in silicon. Consequently they are now available on the desk top, under the workstation keyboard at affordable prices. Images can be generated, rendered and displayed in real time; interaction and modification of reasonably complex images is almost instantaneous. In the future, desk-top systems will have even greater power and performance than today's mainframe. In the meantime, current functionality will move to down-market systems that provide greater flexibility and attractiveness. Graphics standards are already producing greater uniformity of software interfaces - the key to greater transportability and to greater migration of programs and data across high-speed networks. Engineering design and manufacture has benefited substantially from the modeling systems currently in use. Quantitative design information can now be output from the computer model and sent directly to the manufacturing plant. Finally, the human-computer interface has been the subject of increased scrutiny and rigorous experiment. All this is to the benefit of the user. It enhances his problem-solving capability and capacity. We look to even greater developments in the future in the areas of image and print generation, adaptive user-interfaces, the modeling of the design process, and the rendering of images. The computer is an information processing machine, and in the context of computer graphics is processing pictorial information in one form or another. In order to fully exploit this capability, greater attention needs to be paid to visual input, image handling, the utilization of parallel processors, effective links to data bases, and the efficient display of the resulting image.

Acknowledgements. The papers in this volume formed the basis of an International Summer Institute on The State of the Art in Computer Graphics held at the University of Stirling, Stirling, Scotland, United Kingdom. We are very grateful to our co-sponsors: the British Computer Society (BCS) Computer Graphics and Displays Group, and the Computer Graphics Society (CGS). We also thank the Association for Computing Machinery (ACM) for their cooperation and support. Our thanks and appreciation go to Mrs. Frances Johnson, Conference Officer at the University of Leeds, and to Brian Booker, for all their help and support with the practical arrangements for the Institute. Our thanks and appreciation also to all those delegates who attended from many countries and contributed by their discussion, interaction and inspiration. The following countries were represented: Belgium, Canada, Denmark, Federal Republic of Germany, Finland, Iceland, Japan, Netherlands, Norway, Poland, the UK, and the USA.

Our special thanks and appreciation go to Gerhard Rossbach of Springer-Verlag, Computer Science Editor, USA West Coast Office, Santa Barbara, California who organized the typesetting and production.

A volume such as this is the result of many months of planning and preparation, and we thank all those who have assisted us. Colleagues, students, contributors, and publisher–we thank you all for your forbearance and patience, and for enduring our persistence in seeking to bring this project to a successful conclusion.

David F. Rogers
Annapolis, Maryland, USA

Rae A. Earnshaw
Leeds, United Kingdom

Computer Graphics in Design:

Parametric Variation as a Design Method

JOHN LANSDOWN

Abstract

A way of using computers in visual design by means of an exploratory process which the author calls procedural or parametric variation is outlined and discussed. In this methodology, a model of some aspects of visual appearance (colour, dimension, shape and so on) is set up and the parameters to the model are modified in a systematic way under computer control. In particular, the discussion centres on the way in which the attributes of colour may be manipulated to home-in on factors which the designer might consider to be significant. Parametric variation is seen as an appropriate way of using computers to fine-tune a designers proposals.

Introduction

Computers have been used in design almost since they first came into commercial existence about thirty years ago. However, their current use generally tends to copy the techniques of pre-computer times and they are usually employed to do things more efficiently or quickly that were previously done in a similar way by hand.

This phenomenon of a new technology initially copying the one it finally replaces is not restricted to computing. It seems to be a general characteristic of innovation. Early cars, to give just one example, were horseless carriages: they looked like it, and were expected to behave like it. The phenomenon, too, is not restricted to new technology. Oppenheimer [OPPE56] reminds us that even new scientific theories also exhibit the characteristic:

> We cannot, coming into something new, deal with it except on the basis of the familiar and the old-fashioned . . . At each point the first scientists have tried to make a theory like the earlier theories, light, like sound, as a material wave; matter waves like light waves, like a real, physical wave; and in each case it has been found that one had to widen the framework a little, and find the disanalogy which enables one to preserve what was right about the analogy.

As yet, there has been little use of computers to tackle design in a new way but we can just begin to see how this might be done in a manner which broadens the designers scope and more fully exploits the computers potential.

This paper introduces a method of designing which might be called *procedural* or *parametric variation*. It is, I think, one of the possible new ways of designing. It owes little or nothing to previous methods and could not have been proposed as a possibility before computers were available to exploit it. It is a computer-aided design technique for making systematic and exploratory alterations to the parameters of the artifact being designed. By the word, parameters, I mean such attributes as dimension, material composition, shape, colour and so on - all items under the control of designers and which, if varied, produce changes in the performance or appearance of the artifact.

The basis of the technique is to create a computer-based mathematical, logical or graphical model of the object being designed and then to modify appropriate elements of the model in a regulated way. For our purposes here, the model can be thought of as a black box whose inputs are the design parameters and whose outputs are aspects of performance. Thus, for example, given a model of the thermal characteristics of a building, its design parameters would be such things as the building geometry, its insulation, plant operation, air flow, shading and so on. Note that these are the parameters under the designers direct or indirect control: there are other necessary inputs to this model that are not within the designers ambit. Climate and occupancy are examples of these. Such parameters should be accommodated in the model: they would then resemble, and have the same restrictions as, the exogenous variables familiar to simulation model builders [EMSH70].

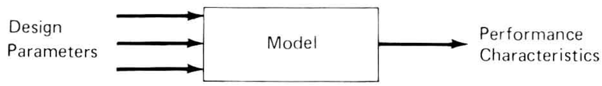


Figure 1. Parametric Model

The purpose of this form of working is to try to isolate the currently important features of a design in progress and to study the effects of changes to these independently, as far as possible, of others. Because of the essentially *interdependent* nature of many design variables, creating models for parametric variation is not always easy. It is, though , a worthwhile task for three reasons:

1. Once a suitable model has been devised, it can be applied generally to other tasks of the same type.
2. Designers are provided with a powerful tool for investigating and homing-in on the characteristics of a design which they believe to have the most significance.
3. A new way arises of teaching and learning about design.

The ABACUS Unit at Strathclyde has devised a number of models able to be used for procedural variation of *functional* factors such as thermal performance and space allocation [LANS84]. It is not my intention here to cover models dealing with such functional characteristics. What I want to do is to suggest how parametric variation of graphical models might be applied to *visual* aspects of design and, in particular, to colour.

Designing Conventionally and With Computers

When we design in the conventional way with pencil and paper we tend to work intuitively, gradually moving towards a satisfactory outcome by a process of trial and error. Since time is limited, in any practical case we have sometimes to terminate the trial and error process prematurely before we are completely satisfied with the results of our endeavours. Of course, even if we had all the time in the world, we could not be certain that a particular line of approach would ultimately prove successful. Often a given line turns out to be unfruitful but we find this out too late to make fundamental changes. Thus any tool that, if nothing else, makes it easier and more speedy to run through a range of possible design options is likely to be of value.

I have pointed out elsewhere [LANS85] that the progression towards the final outcome of a design is not a totally continuous one. Discontinuities arise as we develop our ideas. It has to be said immediately that parametric variation will not work across these discontinuities. It cannot replace genuinely new and intuitive ideas. In an excellent critique of Knuths [KNUT82] parametrisation of letter forms, Hofstadter [HOFS82] shows that the approach is not sufficient to deal with all possible design variations for typefaces:

> Clearly there is much more going on in typefaces than meets the eye - literally. The shape of a letterform is a surface manifestation of deep mental abstractions. It is determined by conceptual considerations and balances that no finite set of merely geometric...[parameters]...could capture. Underneath each instance of A there lurks a concept, a Platonic entity, a *spirit*.

This is accepted but, within the continuous stages and for a large range of outcomes, the method is valid. For we can think of the continuous stages as ones where we are fine tuning the ideas rather than conceiving new ones. Parametric variation works well for fine tuning - indeed, I believe it to be one of the most powerful ways we have of fully exploiting the inevitably limited numbers of ideas we can have.

Computer Graphics

There are, essentially, two forms of computer graphics system for visual design: *paint systems* and *modelled systems*. With a paint system we sketch our ideas into the computer using it as a more-or-less sophisticated drawing board. The paint system gives us aids in drawing straight lines in a variety of styles, circles, ellipses, pattern-filled areas and so on. Mistakes are easily rectified; for example, by asking the computer to undo our last action, and we can modify parts of drawings and save them for later re-use. Paint software can be purchased for almost every form of graphics system and many of the best allow full-colour working.

The alternative to painted computer graphics is *modelled* graphics. In this case, we do not sketch the images we want to realise; what we do here is to give the machine a mathematical model of the objects we wish to create and have the computer make its images from this. As might be anticipated, this is quite a different way of working. A painted image is nothing more than a picture. A paint system knows nothing about the objects it depicts. Thus, for example, if we are dissatisfied with the perspective viewpoint we have chosen for a painted drawing, we cannot ask the computer to give us another view from a slightly different angle. If we want a different view, we must sketch it ourselves. With a modelled system on the other hand, the computer has sufficient information about the scene (and, if needed, the laws of perspective) to be able to give us different views of it. Visual procedural variation requires the use of modelled graphics - either in 2-D or 3-D. Paint systems can only be used in a limited way for parametric variation. The technique essentially requires the use of a modelled system.

Visual Procedural Variation: an Example

In the Museum of Modern Art, New York is a model of a table lamp designed in 1924 by the Dutch architect, Gerrit Rietveld. It stands roughly 380mm high and is made from metal and glass. Despite its age, it has a quality that makes one feel that it was designed only yesterday. As an experiment, we can examine some variations of its parameters: say, its overall height, the height to the centre of the globe, the diameters of the globe and the housing tube, as well as the dimensions of the supporting and balancing tubes. Obviously, the dimensions of such objects cannot be varied absolutely independently — although it is always worth trying to do so to see whether new ideas result. In addition, there are upper and lower limits on the permissible dimensions. All these constraints can be built into a simple computer program. Figure 2 shows some examples of output from a Macintosh Pascal program to designed to allow easy manipulation of the relationships. Incidentally, those familiar with Rietvelds design should note that one of its most important and characteristic features is not taken into account in the program. This is the way in which the whole lamp is physically balanced. Rietveld achieved this by use of the bottom tube and setting the lamp housing assymetrically on a vertical support. This feature and its parameters could easily be accommodated and the necessary calculations needed to ensure physical balance performed. The demonstration program, however, does not do this.