COMPUTER GRAPHICS

Techniques and Applications

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Foreword

About four or five years ago one began to hear about the enormous interest being taken in on-line consoles and displays. Nothing much was done with them, but computer men felt that this was the way computing ought to go: one might dispense with cards, and overcome many of the problems of man–machine communication. It quickly appeared that, as with computers, there had been a great underestimation of the amount of work involved, of the difficulties of programming, and of the cost. So it began to emerge that graphics was not the ultimate answer, in spite of superb demonstrations where one might watch a square being converted into a cube and then rotated.

But my mind goes back to 1951 and the first computers. There, there were demonstrations of arithmetic speed and storage facility; but not much idea of actual use. However, we now understand how to use computers, and in the last year or two, significant developments in the field of graphics have led to genuine applications, and economic benefits. The equipment is still expensive, but it is becoming cheaper, more uses are being found, and I believe that we are just at the stage when the subject is gaining momentum, to become, like computers, a field of immense importance.

This book, and the symposium at which the papers were first read, will generate ideas for new applications in the minds of those who could use graphics, and further steps will be taken in using the computer as a tool. For it is not only to the specialist, but to all who need the power inherent, but so often locked up, in the computer itself, that graphics is bringing its benefits.

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GORDON BLACK

Preface

"One picture is worth a thousand words", and in computing it is certainly true that one picture can be considerably more valuable than several yards of lineprinter output. This is all the more true if a scientist or a business executive has to interpret the output and take further action on it with the computer.

The graphics terminal opens up a completely new range of fields of application for computers. For the first time an executive or engineer can have direct access to the power of a computer, communicating in visual terms which are natural to man.

The potential recently revealed for interaction between computer and user is vitally important for the greater application of these machines in all spheres of industry, commerce and scientific development. The interactive graphic terminal transfers the computer from a cumbersome specialist "tool" into a "colleague" helping to work out a solution to problems during a dialogue through the common visual link.

To gain the most immediate benefit from computer graphics it is essential for all who are involved to be informed about existing applications and about the trend of further development. These are the computer technologists designing for the future; the computer manufacturers producing for today; the researchers and designers in every field whose problems might be all the more easily solved by the new means available; and the industrial and technical managers who can now begin to think of computers as an accessible means of making their organisations more efficient. Only a combination of the thought and efforts of all these parties can ensure the speediest and most effective development of the new techniques and equipment.

For this reason the Computer Science Department, Brunel University, decided to organise an International Computer Graphics Symposium, where carefully selected themes were covered by foremost authorities from the USA and UK.

A glance at the Table of Contents will show how contributors were invited from the world's leading academic institutions, manufacturing firms, research establishments and industrial and commercial users.

The material for the Symposium (held at Brunel University, Uxbridge, England, in July 1968) was kindly made available and specially edited with relevant additions and amendments for this book. The aim has been to allow those people employed in the field to learn of each other's activities and for those who can benefit from their efforts to discover what facilities are being made available.

The book is in four parts.

PART 1 covers the systems, equipment and software, which can now be employed; the general stage of development in the USA and

UK; and the trends for the future. It serves as an introduction to the field for non-experts and also as a valuable résumé for the initiate.

PART 2 consists of specific applications in science and industry, with several case histories of successful installations. These cover many fields, from architectural design and costing to nuclear physics, aircraft engineering and stock control.

PART 3 is for the computer technologist and is a review of material which was presented and discussed at a Specialist Session which followed the Symposium.

PART 4 is devoted to computer graphics hardware, which is presently available. It includes manufacturer's descriptions of a wide variety of equipment.

A glossary has been provided to explain graphics terms used in the book, so that all interested readers can obtain maximum value from the ideas expounded, unhindered by unfamiliar terminology.

This book has been designed to cover the field of Computer Graphics in a logical and comprehensive manner. It can be read as a whole to review all the important aspects of the subject or studied piecemeal as a report on particular topics.

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ROBERT D. PARSLOW
ROGER W. PROWSE
RICHARD ELLIOT GREEN

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PART 1

Systems, Equipment, Techniques, and Trends

What Has Computer Graphics to Offer?

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The computing capability of second and third generation computers has far outdistanced the growth rate of accompanying input/output equipment. This statement is not intended to minimise the increased efficiency and flexibility of card readers, tapes, discs, key punches and printers. However, it is meant to point out the need for convenient new means of communicating with computers.

Two new and in some ways related developments have given computers a new dimension: time-sharing and graphic data processing. Time-sharing makes it economically feasible to give a single user access to a large computer on an immediate, local basis with quick response time and fast turn-around. Graphics allows the user to communicate with the computer conveniently and in his own terms. This makes it possible to provide to the computer information in its most natural form. Furthermore, it allows the computer to communicate information to the user in a form which is compact, descriptive and most appropriate for a given application. The application areas of computer graphics span the entire spectrum from engineering analysis and design to mathematical analysis and data reduction, and last but not least, to the use of computer graphics as an aid to computer programming and debugging. The other chapters in this book deal with the various aspects of computer graphics in some detail. The purpose of this chapter is to provide a basic frame of reference and some common background for the whole book. It will review some of the history, outline the advantages, describe the major concepts involved and indicate the areas most suitable for the application of computer graphics.

One can trace the beginning of computer graphics to the Jacquard loom where for the first time a digitised representation of a graphical form in punched cards was used to control a loom. Modern computer graphics had its beginning at the M.I.T. Lincoln Laboratory where Dr. Ivan Sutherland developed the SKETCHPAD program which allowed the user to sketch on a cathode ray tube. SKETCHPAD opened the horizons for industrial developments by illustrating the feasibility of having a designer construct rather complex diagrams with the aid of a computer. This work was first published in the Spring of 1963 at the Joint Computer Conference of the American Federation of Information Processing Societies.

What has happened in the five years since then?

A number of different hardware systems have been developed ranging from simple scopes with only text printing capability to elaborate graphic displays equipped with function keys, light pens, and keyboards where one can draw arbitrary shapes in two and three dimensions.

In the software programming area Sutherland's SKETCHPAD has been followed by the development of various programming systems of different levels of flexibility utilising graphics to enhance their effectiveness and/or efficiency. The programming systems provide basic assembly level graphic languages as well as higher level language graphics such as FORTRAN and PL/1. In addition, sometimes application programs include problem-oriented languages and console procedures. Programs have been developed for particular application areas such as drafting, engineering design, statistics, data reduction, optics, etc.

The key to the importance of graphic data processing lies in the additional capability graphics adds to the computer's ability to perform applications. Graphic data processing is a new dimension which has been added to computers. With the capabilities of graphic data processing, a large number of new application areas can be addressed by computers. In addition, a large number of traditional computer applications are enhanced by adding graphics capability.

The advantages and importance of computer graphics for enhancing traditional computer applications is sometimes overlooked. Because historically graphics were looked upon as a technique for allowing the implementation of computer applications which would not otherwise be feasible, they tend to be associated with large systems only. This in turn has discouraged many potential users from applying computer graphics to areas where they could get immediate benefits. Published case studies have shown that when used appropriately computer graphics not only reduces the turn-around time for solving a problem but also cuts down the total cost for a particular problem solution. A specific example was in one of the satellite runs in the U.S. military program. The problem was that of data reduction, analysing data coming back from a satellite run. Without graphics, it took one month to get all the calculations done and to get a result. With the use of graphics, it took only 48 hours, and computer time was cut from about 17 hours to about 8 hours. This was where seeing immediate results allowed one to do a much more efficient programming job.

Graphic data processing provides a common language of graphics and alphanumerics between the man and the computer. A man normally thinks in terms of sketches, drawings, graphs, letters, characters, and numbers. A computer operates in terms of bits, bytes and registers. This makes it difficult for the man to communicate with the computer. In the past, the burden has been on the man; namely, he has had to convert all of his ideas and thoughts to letters, numbers, and a few special characters. The computer, in turn, conversed back with the man in the same medium. With the advent of graphic data processing, the man can work in the medium he understands best; the computer can continue to work in the medium it understands best, with the graphic display console acting as an interpreter between the two. This new dimension in man/machine communication has proved to be of value in applications where:

Graphic representation is of assistance in the performance of the application, or
Rapid turn-around time is required, or
Human imagination, judgement, or experience is required in the solution of the problem.

It is important to realise that computer graphics can be applied to many areas outside what is normally accepted as scientific application areas. There are many potential uses of computer graphics in business data processing as well. For example, a financial analyst can use a graphic display to see the market trends for a particular stock, provide his judgement on the expected value for a period of time, and observe on a real time bases the deviation of the actual fluctuations of the market from the expected range of highs and lows. Then, in turn, he can modify the expected range of values appropriately and thus provide a more accurate and realistic projection.

As another example, people working in urban planning are starting to experiment with the use of terminals where they can get a map of a particular area displayed, and then they can ask for a display of various demographic information such as the spread of a population (e.g. by income level). This can help them to make decisions by allowing a quick evaluation of the current situation.

While computer graphics adds a new dimension to programming it is not in any real way different from conventional computer programming. The various problems and their solutions are similar and analogous to those for many other areas. The availability of graphic higher level languages has made it possible for engineers and scientists to define their problems with computer graphics as easily and inexpensively as they can using a language such as FORTRAN, PL/1 or COBOL. A factor which complicates the problems associated with computer graphics is that practical application of this new tool implies the use of an on-line often real time environment. To practically implement a graphics application, it is necessary to face and solve all of the problems which are inherent in such an environment (time-sharing, multi programming, multi processing, job control, remote job entry, etc.)

A very important area which is currently receiving increasingly growing attention is the problem of modelling and structuring the data to be displayed. This is most important in order to allow the user to efficiently retrieve the information as required. Traditional list processing is only a partial answer to this problem. Graphical data requires much more elaborate structured lists. A number of approaches have been developed, such as plex structures, ring structures, parallel structures. One of the papers presented at the 1968 Congress of the International Federation of Information Processing in Edinburgh, Scotland, described a data structure language and an associated data structure programming system which allows the user to utilise this capability. This work is being carried out at Brown University, Providence, Rhode Island, under the direction of Professor Andries van Dam.

The amount of computer storage required for a graphic representation of a display is quite large even for rather simple displays. Research in this area is currently under way to develop means for storing the representation of graphical displays in large scale secondary storage media such as disks, so that the user can retrieve this information within the time limits necessary to provide for a realistically rapid response for practical use. One of the relatively new techniques which is being explored is known as hash coding which provides for the retrieval of graphical data on the basis of appropriate keys or masks. This work coupled with the concepts of time-sharing may indeed provide at least part of the answer to this major problem area. The structuring of data and its organisation in store are the programming problems that have not necessarily been fully appreciated when people are talking about the potential of computer graphics and why it has not yet been fully realised.

Basically, there are three facets to graphic data processing: the input process, the output process, and the manipulation process. Graphic data processing provides for the input, manipulation, and the output of graphic data, where we define "graphic data" as lines, curves, letters, and characters; basically, anything that can be put on a piece of paper using a pen, a pencil, or a typewriter.

There are a number of devices available to assist in the input, manipulation, and output of graphic data. These include: display consoles, tablets and scanners for input; consoles for graphic manipulation; printers, plotters, drafting machines, recorders and display consoles for output.

Another way of classifying computer graphic displays is across the three facets of graphic data processing in terms of their functional capability. Thus, one can distinguish:

1. Passive output displays *v.* interactive input/output consoles. In the output category one would include printers (which have been used for the generation of schematic diagrams) plotters, as well as, sophisticated drafting machines. The interactive consoles are generally implemented by cathode ray tube displays.
2. Alphanumeric *v.* full graphic displays. Both types include a range of capabilities. Alphanumeric devices often provide for upper and lower case characters. Experimental devices provide for characters of different fonts and multiple size and intensities. Graphic devices allow for the drawing of points and vectors in any direction. Some units are equipped with hardware capability for rotating the display in three dimensional space.

3. Small screen individual *v.* large screen group displays. Most of the units associated with computer graphics are of the small screen variety. Large screens have been used primarily for military applications.

Computer manufacturers have developed experimental systems of graphic equipment families which include a scanner for input, a film recorder for output, and a C.R.T. console for man/machine interaction. None of these systems has so far survived the test of time and/or grown to full-blown commercial use. The primary reason for the lack of success of graphic equipment families has been the enormous programming task of providing software support for such equipment. The outstanding case in this context is the programming required to scan and recognise pictorial information. For example, the lack of techniques for "reading" an engineering drawing by computer, constructing a data structure with sufficient detail to reproduce this drawing and making the necessary associations of graphic and dimensional information. Quite a bit of work is being done in this area and undoubtedly the future will bring additional achievements.

It is expected that other future developments will include the production of colour displays as well as improved means for producing three-dimensional displays. Current research with computer generated holograms as well as work with stereoscopic projections seems to show considerable promise.

The wider utilisation of computer graphics in areas where immediate economic savings can be realised will give impetus to an expanded growth which will bring about the development of inexpensive graphic terminals as well as special purpose terminals designed for particular application areas such as text editing and composition.

There is general consensus that graphic data processing has brought new capabilities and new dimensions to computers. In particular, it greatly enhances the facility for man/machine communication and interaction. The ability to provide instantaneous man/machine communication makes the solving of problems with graphic data processing a much more rapid process with significantly reduced turn-around times. The capability of using graphics as the interface between the man and the computer allows the two to converse in a language most natural to each.

Finally, it lets the man and the computer both operate in an optimum manner. The computer gives us the capability of high speed, raw power, and low cost per calculation. The man contributes problem solving experience, engineering judgement, and imagination. In any application, there is a certain amount of man required and a certain amount of computer. Through graphic data processing the best of these two can be combined in the solution of a wide range of computer applications.

APPLICATION AREAS FOR GRAPHIC DATA PROCESSING

- Schematic and Dimensioned Drawings.
- Verification Drawings of Numerical Control Tapes.
- Electrical, Mechanical, Structural, and Civil Engineering Drawings.
- Weather Maps.
- Contour Maps.
- Layout Drawings for Printed Circuits.
- Layout Drawings for Petroleum and Chemical Processes.
- Unit Operations Drawings for Petroleum and Chemical Processes.
- Pole Line and Distribution Drawings for Electric Utilities.
- Exploration Maps for Petroleum and Mining.
- Subdivision and Construction Layouts.
- Computer Aided Design Systems.
- Ship, Aircraft, Missile and Satellite Course Plotting.
- Cartography and Hydrographic Plotting.
- Pert Network Drawings.
- Flight Test and Engine Performance Graphs.
- Business Graphs.
- Telemetry Data Plotting.
- Highway Cut and Fill.
- Research and Engineering Data Reduction.
- Temperature and Pressure Distribution Drawings.
- Fourier Analysis.
- Antenna Scatter Displays.
- Optical Ray Tracing.
- Calibration Curves.
- Strip and Disk Chart Analysis.
- Mathematical Studies-Function Analysis.
- Multi-Dimension Analysis.
- Kinematic Analysis.
- Route Layout Simulation.
- Reservoir Sizing.
- Power Spectral Displays.
- Quality Control Displays.
- Oceanographic Charts.
- Oil Production Maps.
- Cockpit Visibility Studies.
- Aircraft Landing.
- Visibility Studies.
- Wave Research Drawings.

Biographical Note

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Computer Graphics Hardware Techniques*

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Introduction

The purpose of this chapter is to outline as simply as possible, and from a logical rather than a detailed circuit point of view, some of the hardware aspects of computer graphic terminals. This will include some of the more commonly used techniques for the generation and display of alphanumeric information on Cathode Ray Tube (C.R.T.) displays, the principles of operation of some input devices and an appraisal of some display mechanisms in relation to their suitability for use as acceptable computer graphic terminals.

Design Principles

Information to be displayed is stored in digital form and data relating to the format and information content must be passed to the viewing unit back up equipment. In the back up equipment the digital data is converted into analogue waveforms which are used to drive the C.R.T.

The C.R.T. directs a beam of electrons from a "gun" at one end to the screen at the front. A special coating inside called the phosphor, glows under this bombardment, and a spot of light is seen, whose colour depends on the phosphor. The input signals are then used to deflect this spot horizontally and vertically, and a "bright-up" signal is also fed in to switch the beam on only where a visible display is required.

As the beam moves, the spot of light moves over the screen, and in the usual C.R.T. it is necessary to repeat the pattern over and over again at high speed if a steady and coherent picture, and not just a moving spot, is to be seen. This refresh rate is usually 30 to 50 times per second depending on the phosphor. Any reduction in specified refresh rate leads to undesirable flicker.

The operator will usually require facilities for entering data into the computer and this entry process should contain provisions for correction or editing the input message.

This simple concept is shown in Figure 1.

In large systems there will be multiple operator positions and the system shown in Figure 1 can be extended by either distributing the analogue waveforms to the display positions or the distribution can be in digital form with each position having its own back up equipment. In this simple concept the information to be displayed on all displays is usually fed to highways connected to each display and each display