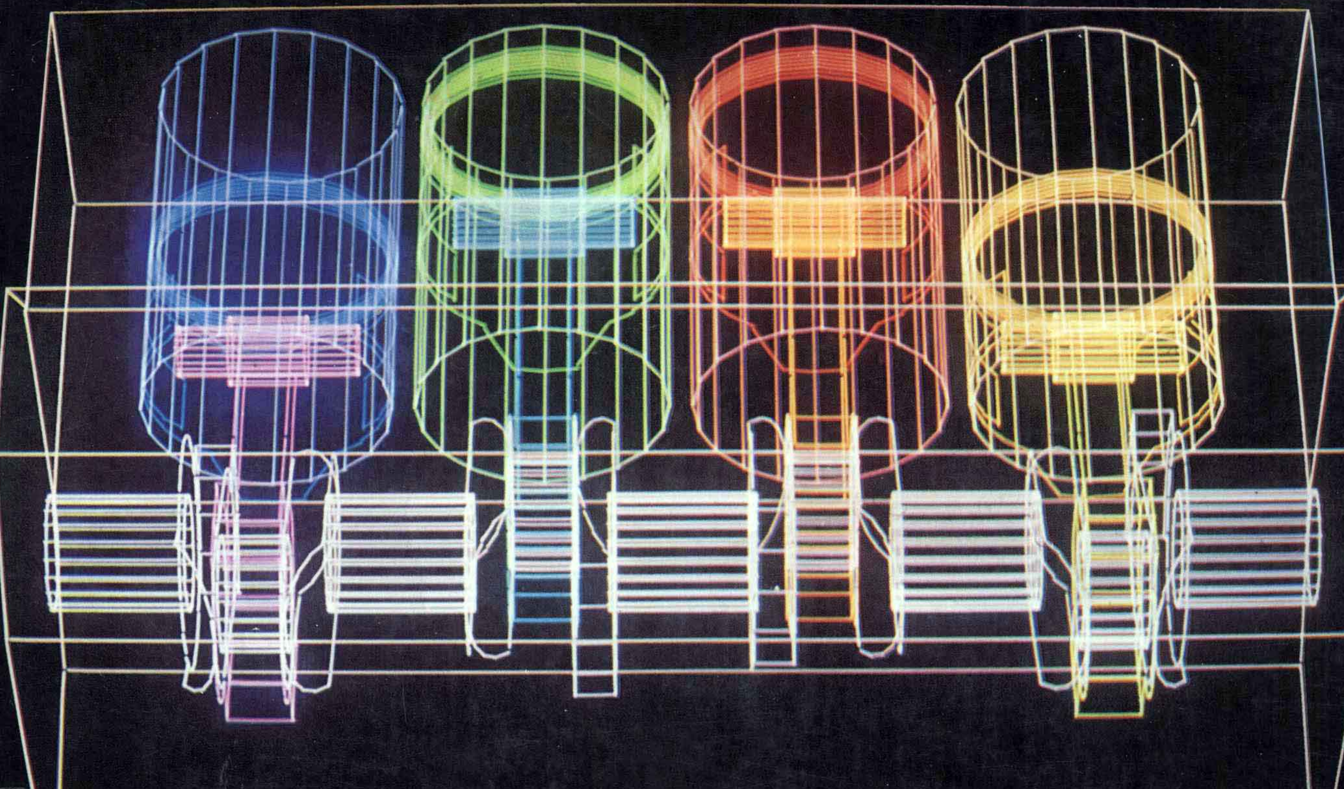
Introduction to Computer Graphics



John T. Demel and Michael J. Miller

Introduction to Computer Graphics

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We dedicate this book to our wives,
Margaret Demel and Joan Miller,
who were supportive, and to
our children, Craig and Teresa Demel
and Barbara, Michael, and Julie Miller,
from whom we stole many hours.

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Preface

Introduction to Computer Graphics grew out of our experiences teaching computer graphics programming to freshman engineering students. Our course objectives included creating graphics entities such as lines, polygons, circles, arcs, and special shapes. The data for these entities had to be retrievable so that the figures could be redrawn on the screen or on a hardcopy device and so that portions of the drawings could be selectively erased. Further, the routines for doing the various tasks had to be built into a menu-driven program that was easy to use.

We have found that, while there are a number of texts that might be suitable for graduate students, most presume a level of mathematical and computer-programming sophistication that freshmen have not yet achieved. Our goal in writing this book is to present these topics on a level that can be readily understood by people who do not have extensive math backgrounds while still providing enough depth of coverage to make the material truly instructive and useful. Topics covered include writing a screen dump to a dot matrix printer, outputting to a pen plotter, and using digitizing tablets and joysticks as alternates to the keyboard for data input. We show step by step how to write computer code to accomplish these and many more tasks, such as creating and using data files for storage and retrieval of drawings (both data and image representations) and combining the routines for individual graphics entities into a program that facilitates creating usable drawings as well as charts and graphs. We wrote a drawing package to develop and test the techniques presented in this book, and we used it to create the sample drawings and flow charts.

Introduction to Computer Graphics is intended for use in a classroom setting, but we have tried to present the material in a complete and straightforward manner that should make it easily understood by any reader who wishes to use the book for self-study. All of the example code is presented in both FORTRAN/PLOT10, for large shared-use computers such as DEC VAX 11/750s, and in BASIC, for IBM PCs. In addition, most of the routines are duplicated in Appendix A in Applesoft BASIC for use with the Apple II computers. Appendix B contains Tektronix series 4050 BASIC/PLOT50 versions of the routines of Chapters 4, 5, and 6 for drawing points, lines, polygons, circles, and arcs. With these three versions of BASIC code as examples, the reader should be able to create coded routines for most microcomputers. Sample coded routines and complete, usable programs in BASIC for IBM PC and Apple II computers are available on disk for readers and instructors who desire to obtain them.

Completion of a book of this type requires the combined efforts of many people. We are indebted to the many individuals and organiza-

tions who have provided their support and assistance: the students who helped to check the routines and the computer laboratory support staff who helped to bail us out when things went wrong; the hardware and software firms who provided illustrations and loaned equipment and material to be used for testing routines; the editors and layout staff who refined both the material and the way in which it is presented; and the many others who added their support in a number of ways. We also extend our thanks to the reviewers who provided valuable feedback as to what was good and what needed to be added, changed, or deleted: Jon K. Jensen, Marquette University; Robert S. Lang, Northeastern University; Richard Latimer, California State University, Sacramento; Gerald McClain, Oklahoma State University; Peter W. Miller, Purdue University; Donald Riley, University of Minnesota; and Harsh V. Zadoo, Wichita State University. These people all have our undying gratitude. Special thanks is due our families for their understanding and patience when work on the book took precedence over family activities, as well as for their reading of the manuscript and their helpful suggestions.

John T. Demel
Michael J. Miller

Introduction to Computer Graphics

Contents

1 Computer Graphics Purposes and Procedures

This chapter will provide the reader with information about the impact of computer graphics, its application in various fields, and the benefits it brings to these fields. In addition, this chapter will provide details about how the book can be used, what background and materials are needed to best utilize the book, and what will be found in the coming chapters.

The Impact of Computer Graphics

A picture is said to be worth a thousand words. Although this statement is trite, it is true, and computer graphics expresses it in a modern way. Computer graphics seems to be tuned to the way people think; that is, to the way that the brain is designed to work. Engineers and scientists have always capitalized on the value of pictures by expressing the results of their design work and calculations in the form of engineering drawings and charts and graphs. However, it is now possible to create and modify pictures using modern computer graphics systems. These new systems have led to great changes in the methods that are used to produce drawings and, in some cases, the nature of the drawings themselves.

Figure 1-1 shows a typical computer-aided drafting (CAD) system. Such systems are already powerful tools for aiding people in their work, but we are only at the threshold of the changes that will be brought about by computers and computer graphics. While engineers and scientists have used graphics for hundreds of years to record and transmit ideas, and while they have used computers for at least thirty years, it

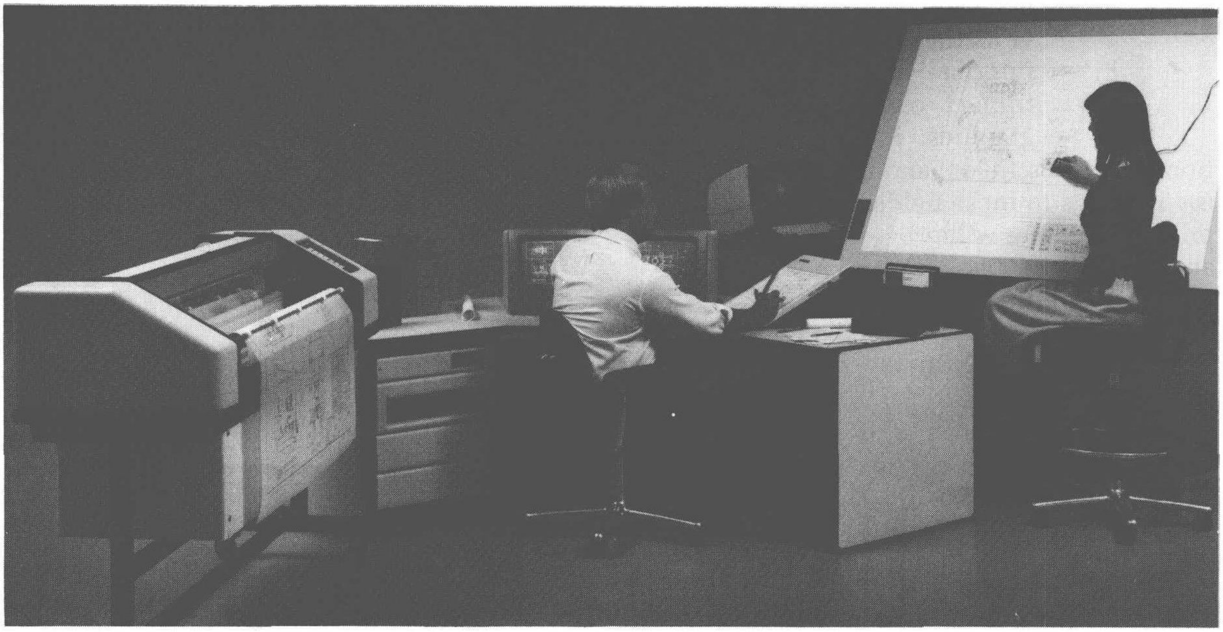


Figure 1-1. People working at a Bausch & Lomb computer-aided drafting system. (Courtesy Bausch & Lomb)

is only the past five to fifteen years that computer graphics systems have become less expensive and easier to use.

As computer graphics systems become more commonplace, a typical design-to-manufacturing process may occur in the following manner. First, the manufacturing companies will provide the engineer and the designer with computer graphics systems. As their ideas reach the formative stage, the engineers and designers will be able to put the descriptive information (data base) into their own systems. These systems will communicate with larger computers, which will store and distribute the information to the process planning and manufacturing personnel, who, in turn, will take the information, modify it, and make the changes to the data base. These changes will be immediately available to the machines that handle material and that shape or form the product. Thus, it will be possible to go from the design stage to the finished product without having to put the drawing on paper. The machines used in manufacturing will be "intelligent" machines (that is, they will have computers for local control) such as robots, stacker cranes, flexible manufacturing centers, and numerically controlled milling machines and lathes. Two such machines are shown in Figures 1-2 and 1-3. When systems such as these are common, the net savings in total design-to-manufacturing cost will be large, but the greatest savings will be in the reduction in changes to product design necessary to meet regulations or to correct flaws. The net result should be better products and systems and ones that are easier to update.

Engineers have estimated the magnitude of time savings to be on the order of one-half to one-third of the total time to bring a new

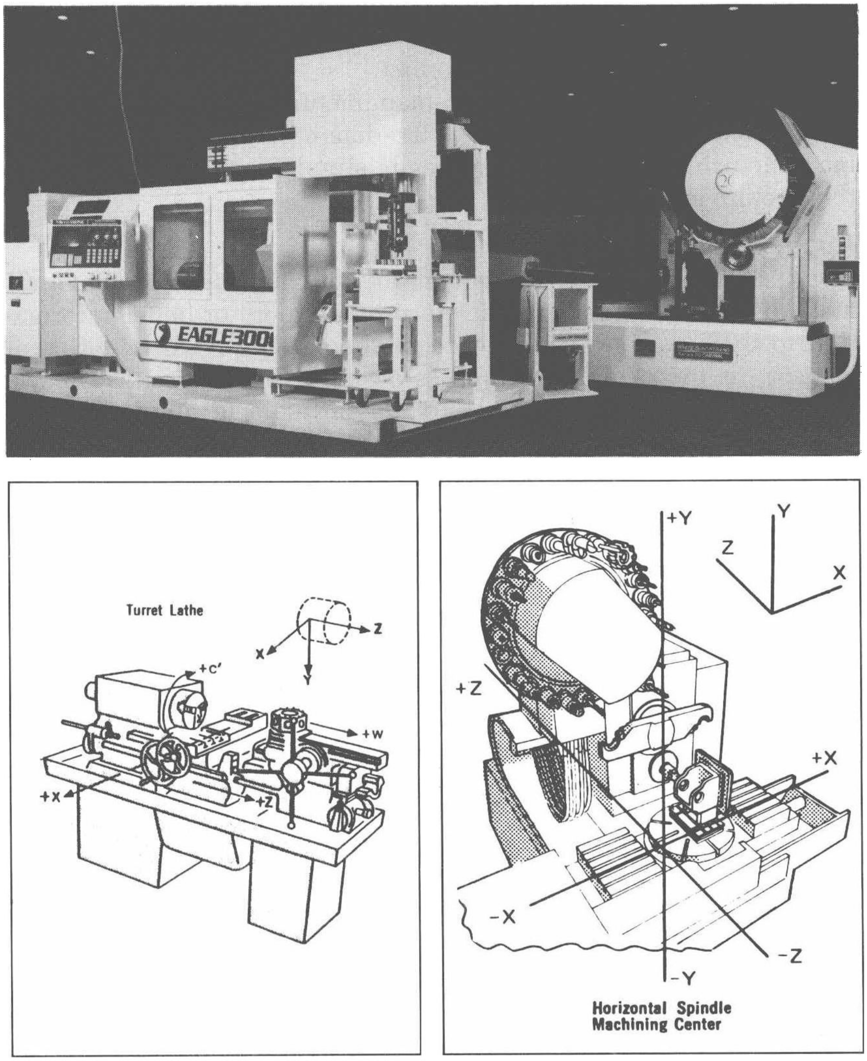


Figure 1-2. An American Tool Eagle 3000 unmanned turning center and a White-Sundstrand Series 20 numerically controlled machining center. (Courtesy White Consolidated Industries)

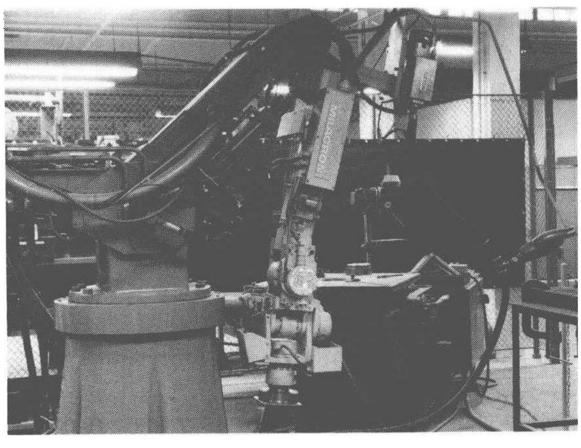


Figure 1-3. A Cincinnati Millicron robot used for welding.

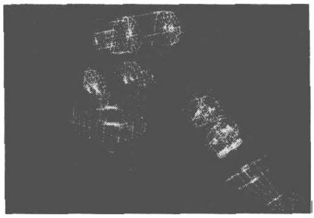


Figure 1-4. Assembly drawing created by Romulus software on the Evans and Sutherland PS300 display system. (Courtesy of Evans & Sutherland)

product from the design stage to manufacture. This time savings will enable the engineers to look at more designs, which should result in an even better, less expensive product.

The "picture" in the design-to-manufacturing example just given has become the representation of the data base used for design and manufacturing. Computer graphics is simply a faster way to draw this picture and to change it.

Applications

Engineers, scientists, businessmen, artists, and educators have all made use of computer graphics to provide more or better information to their coworkers, but each of their fields requires different features in the computer graphics systems that is used. Here we will describe the applications and the particular needs for each of these fields.

Engineering

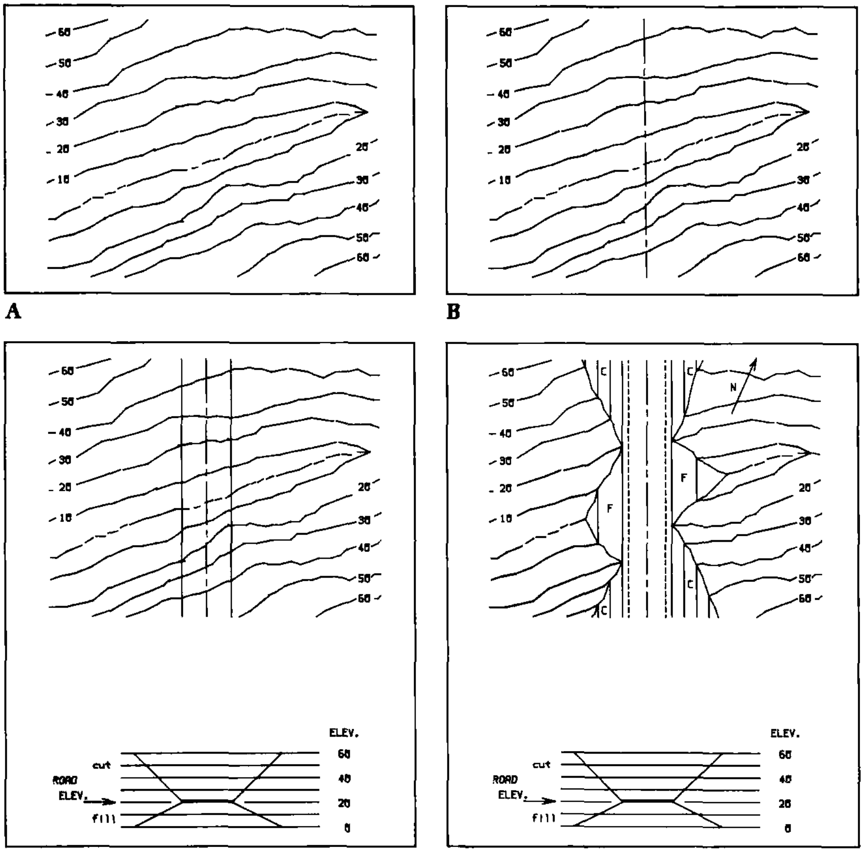
Engineering activities can be organized into five areas: design, analysis, drawing, manufacturing/construction/processing, and quality control.

In the design phase of an engineering project, engineers are looking at alternatives that may provide the solution for their problem. In general, engineers must examine each alternative in some detail. This examination can involve quick drawings to show relative locations of various parts or sizing of various parts. (Figure 1-4 shows a typical parts assembly.) These drawings can then be put into the computer data base so that the analysis phase can take place.

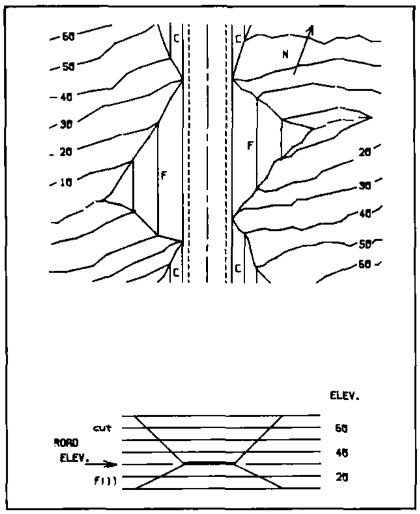
For example, design of a road construction project in a certain area will depend on the terrain where the road will be located. The terrain information will be put into the computer's data base (the collection of numbers and letters that are recorded by the surveyors). The engineers' calculated numbers that make up the designs proposed for the road will be added to the data base to form the alternatives. Then the cost and benefit analyses will take place to choose the alternative that appears to maximize function and minimize cost. Figure 1-5 shows the contour plot (A), the proposed road center line (B) and the proposed road width (C). Note that the road profile in Figure 1-5C shows how the road would appear if the viewer's line of sight were coincident with the centerline of the road.

In a road construction project the amount of earth to be removed from some areas (cut) and the earth to be added to other areas (fill) must balance, or additional fill must be purchased and moved. Figures 1-5D and 1-5E show a road constructed at two different elevations. Note that the road constructed at an elevation of 20 feet has a better balance of cut and fill than the one at an elevation of 30 feet. In general, roads are built to minimize steep grades. This constraint can be in direct conflict with minimizing the amount of earth to be moved.

The computer, with its computer graphics display, can provide



A B C D



E

Figure 1-5. (A) A contour plot of the terrain where a proposed road will be constructed. (B) The proposed route is shown by the road center line on the contour plot. (C) The edges of the road are plotted showing the alignment with the proposed profile. (D) The road constructed at an elevation of 20 feet. Note the apparent balanced cut and fill sections, which are labeled 'c' and 'f.' (E) The same road section constructed at an elevation of 30 feet. Note that more fill is required with less volume cut from which to obtain the fill dirt.

engineers with graphic information about the amounts of fill required at any particular slope for each of the various areas. The engineers can look at many alternatives and determine which provides the best combination of function and economy.

When the decision has been made about the location of the roadway, the engineers have the responsibility to produce the drawings for construction. The data base (surveyors' information) can provide the coordinates for drawing the terrain features. The terrain can be displayed on the graphics terminal but must be modified so that construction personnel can get the needed dimensions. It takes an experienced draftsperson to be able to make decisions about the symbols and lines used to portray the desired design. When the design drawing on the graphics terminal screen is ready, the plotter provides rapid inking of the lines and the symbols. The greatest time-savings occur in the transfer of the drawing process from pencil layout in the old-style drawings to electronic layout in the new method. If the drawings need to be revised because, say, the land to be used for the chosen route cannot be obtained, this revision is easily done with computer graphics.

During construction of the highway, the information about the changes to the land and the amount of fuel and manpower used can be added to the computer data base to provide a running record of the progress of the project. Drawings of the as-built (finished) highway can be created by changing the original drawings on the basis of information collected in the field, showing actual locations of the highway, culverts, power lines, gas lines, and any other elements that may have affected the construction.

Quality control in the construction project is determined by the accuracy with which the plans are followed. Slopes vary depending on the type of soil that is available for fill material and the methods used to pack the earth during the preparation phase. This information will have been stored as part of the data base, and the inspectors can turn in their findings about soil type and compaction to be checked by the designers as the construction progresses.

Science

Scientists use computer graphics in a variety of ways. The application described here will be the study of the structure of chemical substances. Scientists who do chemical crystal-structure determination are called crystallographers.

Crystallographers use x-rays to determine the location of atoms in molecular structures. Determining the locations of the atoms in chemical structures provides information about the bonds that hold the atoms in the molecule together. This information shows the scientist why certain alloys are brittle (fracture easily) and why others are ductile (easy to form). Knowledge about relative sizes of atoms and bond strengths between atoms allows creation of better materials.

Crystallographers use a beam of x-rays to strike a crystal of the unknown material. The information about the way the x-ray beam is reflected by the electron clouds surrounding the nuclei provides clues to the crystal structure. Crystallographers then study sub-