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elementary computer graphics

ELEMENTARY COMPUTER GRAPHICS

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PREFACE

This book is addressed to those who are exploring computer graphics for the first time. As an introductory book on the subject, ELEMENTARY COMPUTER GRAPHICS is useful to both engineers and computer scientists. The overview of computer graphics and the fundamental ideas of mathematics, data structures and color useful in computer graphics are explained in Chapters 1 through 5. Two-dimensional and three-dimensional graphics are covered in Chapters 6 and 7 respectively. Chapter 8 gives an application of computer graphics systems to engineering science problems. Chapter 9 briefly describes computer graphics methods using a microcomputer. FORTRAN is used as a computer language for programming the text with the exception of Chapter 9 throughout.

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CONTENTS

1 OVERVIEW OF COMPUTER GRAPHICS

1.1 INTRODUCTION

In several branches of engineering and architecture, the designer/analyst is faced with the problem of imagining geometric objects in two-dimensional and three-dimensional spaces. Once the imagination is translated into a design, illustrations have to be drawn to achieve the material construction of these objects. Therefore, we have to develop the knowledge that will translate a thousand words into one picture. In computing, it is certainly true that one picture can be considerably more valuable than several yards of line printer output. This is all the more true if an engineer has to interpret the output and take further action on it with the computer.

The recent development of computer graphics devices opens up a completely new range of fields of application for computers. For the first time, an engineer can have direct access to the power of a computer, communicating in visual terms which are natural to man. As the complexity of the engineering system under a computer study increases, the time spent by an engineer and the likelihood of committing errors increases at a very high rate; thus, it becomes very important for him to use a computer with a graphic system. This will open new vistas and present the engineer with opportunities to make full use of design skills in order to build a world in which mankind is freed from the drudgery that has haunted its past.

There are several engineering and scientific applications of computer graphics. The well-known ones are:

1. Computer-aided design
2. Computer-aided manufacturing
3. Computer-aided drafting
4. Real-time process control
5. Manipulation of cartographic data
6. Real-time simulation and training
7. Automobile, aircraft, and ship design
8. Integrated circuit layout
9. Architecture and structural design
10. Air-control systems

1.2 BASIC DEFINITIONS

It is essential to discuss the terminology associated with the subject of computer graphics in order to introduce a reader to the subject. Since the inception of computer graphics in the 1960s, the field has captured the imagination and technical interest of a rapidly increasing number of individuals from many disciplines. The field of computer graphics is expanding rapidly and it combines the age-old art of graphical communication and the new technology of computers.

A number of terms and definitions are used rather loosely in this field:

1. Computer-Aided Design (CAD)
2. Computer-Aided Design and Drafting (CADD)
3. Computer-Aided Manufacturing (CAM)
4. Computer Graphics (CG)
5. Interactive Graphics (IG)

These are used interchangably or in such a manner that considerable confusion exists as to their precise meaning. Therefore, these terms should be defined and differentiated as much as possible.

Of these terms, CAD is the most general. CAD may be defined as any use of the computer to aid in the design of the individual part, a subsystem, or a total system. The use does not have to involve graphics. The design process may be at the system concept level or at the detailed part-design level. It may also involve an interface with CAM. However, when drafting is included as a part of computer-aided design, computer graphics is an essential component of CADD.

Computer-aided manufacturing is the use of a computer to aid in the manufacture or production of a part, exclusive of the design process. A direct interface between the results of a CAD application and the necessary part programming using such language as APT (Automatic Programmed Tools) and UNIAPT (United's APT), the direction of a machine tool using a hardwired or softwired (minicomputer) controller to read data from a punched paper tape and generate the necessary commands to control a machine tool, or the direct control of a machine tool using a minicomputer may be involved.

Computer graphics is the use of a computer to define, store, manipulate, interrogate, and present pictorial output. This is essentially a passive operation. The computer prepares and presents stored information to an observer in the form of pictures. The observer has no direct control over the picture that is being presented. The application may be as simple as the presentation of the graph of a single function using a high-speed line printer or a time-sharing teletype terminal, or as complex as the simulation of the automatic reentry and landing of a space capsule.

Interactive graphics also uses the computer to prepare and present pictorial material. However, in interactive graphics the observer can influence the picture as it is being presented—i.e., the observer interacts with the picture in real time. To see the importance of the real-time restriction, consider the problem of rotating a complex three-dimensional picture composed of 1000 lines at a reasonable rotation rate—say, 15°/s. As we shall see subsequently, the 1000 lines of the picture are most conveniently represented by a 1000×4 matrix of homogeneous coordinates of the end points of the lines, and the rotation is most conveniently accomplished by multiplying this 1000×4 matrix by a 4×4 transformation matrix. Accomplishing the required matrix multiplication requires 16,000 multiplications, 12,000 additions, and 1000 divisions. If this matrix multiplication is accomplished in software, the time is significant. To see this, consider that a typical minicomputer using a hardware floating-point processor requires 6 microseconds to multiply two numbers, 4 microseconds to add two numbers, and 8 microseconds to divide two numbers. Thus, the matrix multiplication requires 0.15 seconds.

Since computer displays that allow dynamic motion require that the picture be redrawn (refreshed) at least 30 times each second in order to avoid flicker, it is obvious that the picture cannot change smoothly. Even if it is assumed that the picture is recalculated (updated) only 15 times each second—i.e., every degree—it is still not possible to accomplish a smooth rotation in software. Thus, this is now no longer interactive graphics. To regain the ability to present the picture interactively, several things can be done: (a) Clever programming can reduce the time to accomplish the required matrix multiplication; however, a point will be reached at which this is no longer possible. (b) The complexity of the picture can be reduced; in this case, the resulting picture may not be acceptable. (c) Finally, the matrix multiplication can be accomplished by using a special-purpose digital hardware matrix multiplier; this is the most promising approach—it can easily handle the problem outlined above.

1.3 HISTORY OF COMPUTER GRAPHICS

In 1950, the first computer-driven display attached to MIT's Whirlwind I computer was used to generate simple pictures. This display made use of a cathode-ray tube (CRT) similar to one used in television sets. Several years earlier, a CRT had been used as an information storage device; this technique was to emerge years later, in the form of a storage CRT incorporated in many low-cost interactive graphic terminals.

During the 1950s, interactive computer graphics made little progress because the computers of that period were not suited to interactive use. These computers were "number crunchers" that performed lengthy calculations for physicists and missile designers. Only toward the end of the decade, with the development of machines like MIT's TX-0 and TX-2, did interactive computing become feasible, and interest in computer graphics then began to increase rapidly.

The single event that did most to promote interactive computer graphics as an important new field was the publication in 1962 of a brilliant thesis by Ivan E. Sutherland, who had just received his Ph.D. from MIT. This thesis, entitled "Sketchpad: A Man-Machine Graphical Communication System," proved to many readers that interactive computer graphics was a viable, useful, and exciting field of research. By the mid 1960s, large computer graphics research projects were started at MIT, General Motors, Bell Telephone laboratories, and Lockheed Aircraft; the glorious age of computer graphics has begun.

If the 1960s represent the heady years of computer graphics research, the 1970s have been the decade in which this research began to bear fruit.

Interactive graphics displays are now in use in many countries and are widely used for educational purposes, even in elementary schools. The instant appeal of computer graphics to users of all ages has helped it to spread into many applications and will undoubtedly guarantee its continued growth in popularity.

1.4 PROPERTIES OF THE HUMAN VISUAL SYSTEM

Another important subject which should be studied in relation to computer graphics is the human visual system.

Some relevant aspects are:

1. Brightness discrimination
2. Flicker
3. Fusion
4. Visual resolution
5. Energy detection

1.4.1 Brightness Discrimination

The amount of light that must be added to a uniformly illuminated field in order to be noticeable is proportional to the total illumination of the field. For example, on a sunny day at the beach it is impossible to detect the light of a candle on the sand, but on a moonless night, it will appear quite bright.

1.4.2 Flicker

When a light is turned on and off rapidly, it appears to flicker. As the rate at which the light is turned on and off increases, it appears to flicker more and more rapidly. At some frequency, the flicker is no longer perceived and the light appears to be steady. This frequency is called the fusion point, and it is about 48 flickers/s for the human eye. (See, however, the comment in Sec. 1.4.3 below.)

1.4.3 Fusion

The fusion point is also a function of the level of illumination. The higher the level of illumination, the higher the frequency at which fusion occurs. We note that fusion can occur at a frequency as low as a few cycles/s at very low levels of illumination. This is very important in the design of display systems.

1.4.4 Visual Resolution

The eye contains two types of receptors: rods and cones. The cones are distributed with highest density in the center of the eye, with the rods off-center (see Fig. 1.1).

1.4.5 Energy Detection

The eye is an extremely efficient detector of radiant energy. In a dark-adapted eye, a few photons can lead to perception of light. The rods are more sensitive light energy detectors than the cones. The cones have high spatial resolution (acuity). The higher the brightness level (within reason), the greater the visual acuity.

1.4.6 Visual Fatigue

Prolonged exposure to high brightness leads to visual fatigue. Glare is a particularly serious cause of visual fatigue. By keeping the brightness level to a workable minimum and avoiding glare, visual fatigue will be minimized. This also lowers the fusion point and reduces visual acuity.