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NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

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FOR THE COMPUTER GOURMET—GRAPHICS

by
Jackie Potts

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FOR THE COMPUTER GOURMET—GRAPHICS

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Computer graphics is the piece de resistance of today's sophisticated computer endeavors. It can be divided into two main divisions–passive and interactive. Two of the most popular subdivisions of passive graphics are microfilm recorders and plotters. Plotters can be further divided into flatbed, drum and electronic. Under the glamorous interactive division are grouped computer animation and computer generated movies. A

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survey paper has been written which considers the history of all the types of computer graphics and a discussion of the typical hardware of each type including its main attributes as well as its advantages and disadvantages. This paper also contains in the appendix a comprehensive glossary of computer graphics terminology.

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FOREWORD

This report contains the information presented by the author on June 14, 1974, in an invited paper at the International Symposium on Structural Mechanics Software. The University Press of Virginia published many of the papers of the symposium in Structural Mechanics Computer Programs. "For the Computer Gourmet - Graphics" may be found on pages 913-959 of this book. Permission to publish the computer graphics glossary as an appendix to the paper was granted by the Board of Directors of SHARE Inc., on January 25, 1974. Permission for the author to publish the paper in this report was granted by the University Press of Virginia.

"For the Computer Gourmet - Graphics" was prepared under the auspices and funding of the Ship Protection Division, Structures Department, Naval Ship Research and Development Center. It is being distributed in this report in the hope that the initial and continued use of computer graphics will be made more efficient by the knowledge of the graphics terminology explained in this report; that this report will improve communications between the computer graphics professional and the rest of the scientific community; and that knowledge of the divisions of computer graphics and their beginnings, of the types of computer graphics hardware, and of the scientific possibilities in computer generated movies and computer animation will enable engineers, physicists, mathematicians, and other professional and technical workers to understand and use effectively the fascinating world of computer graphics.

Jackie Potts

ABSTRACT

Computer graphics is the piece de resistance of today's sophisticated computer endeavors. It can be divided into two main divisions- passive and interactive. Two of the most popular subdivisions of passive graphics are microfilm recorders and plotters. Plotters can be further divided into flatbed, drum and electronic. Under the glamorous interactive division are grouped computer animation and computer generated movies. A survey paper has been written which considers the history of all the types of computer graphics and a discussion of the typical hardware of each type including its main attributes as well as its advantages and disadvantages. This paper also contains in the appendix a comprehensive glossary of computer graphics terminology.

INTRODUCTION

Just as Camarones a'la Espanola, Escargots a'la Cablisienne, or Escargot's a'la Mode de l'Abbaye are deemed necessary to an epicurean - Just as, according to the senses of a wine connoisseur, Lobster Absintha or Supremes of Pheasant Berchoux should be accompanied by a chablis, bordeaux blanc or emerald dry wine and Tournedos a'la Bearnaise, Entrecote a'la Mirabeau, or chateaubriand should be accompanied by a cabernet sauvigon or pinot noir wine - Just as an art cognoscente will select only a Mona Lisa or a Picasso - Just as an automobile dilettante will only consider a jaguar - Just as a musical savant will accept no less than a Mackintosh pre-amp, amplifier and tuner with a Tanberg tape deck and Dolby unit playing through Bose 901 speakers - In the same way, the computer gourmet will insist that computer graphics be part of his computer endeavors.

The sophisticated computer graphics that we use today is a far cry from the graphics of our remote ancestors. In the Stone Age our ancestors drew simple lines on the walls of their caves with crude sticks. Pictures enabled Stone Age men and women to communicate with each other and with all the ages that have followed. These early forms of graphics were the first recorded attempts of one person to interface with another. In his turn, Archimedes drew pictures in the sand. In fact in all ages pictures of various degrees of sophistication have contributed to man's communication with his human world.

Ever since Archimedes countless scientists have been grateful for the ability to use drawings, diagrams, and physical analogies to solve intractable problems. Leonardo da Vinci, Galileo, Lord Kelvin, and others through the centuries have felt that knowledge had to have good mathematical symbolism to be scientific. In 1882, Babbage wishing to ensure the accuracy of the output from his calculating engine had sterotyped plates made. Today digital symbolism is added to alphanumeric and numeric symbolism to create accurate, real-time, pictorial, and interpretable communication which aids a decision making environment.

In the present era men and women using computer graphics; teach; contribute to the knowledge and improvement of our environment; solve highly technical problems; and draw complicated engineering, architectural, medical, artistic, and constructional designs and simulations on picture tubes with an elaborate joy stick. How true that computer graphics forces the computer machine both to understand man's natural language and to extend and expand the human being's capability for creative thinking! How true that computer graphics provides the Rolls Royce for computer users!

OBJECTIVES AND MAJOR DIVISIONS

Since computer graphics has become a very vital link to Homo sapiens's interaction with his machine world, it deserves a closer investigation. Just what is it? Whence did it materialize? Are all computer graphics alike? What are the kinds of computer graphics? What are the essential elements of each type? What are some applications of each type? What groups are contributing to its growth? What are its future benefits for mankind? This overview will attempt to answer these questions. All the major types of graphics will be discussed. First will come the microfilm recorders. Plotters will follow and then - the most publicized - interactive graphics. This will be followed by a discussion of four different applications of computer generated animation and movies. The last division of this overview concerns itself with some of the drawbacks of computer graphics. In the author's opinion the drawbacks must be corrected for computer graphics to live up to its future potential.

In all areas a brief description and history will be presented along with several applications. In some instances manufacturers will be mentioned. No attempt has been made to include all manufacturers or even the most powerful and well known. Nor does mention of a manufacturer or product imply the author's endorsement. Due to limitations of space and time this overview must limit itself to being as general and as representative as possible rather than covering in minute detail any special aspects of the entire field. Thus only the highlights in the history and current state-of-the-art can be mentioned and only the major type can be discussed in detail.

The material in this paper was gathered from manuals, specification sheets, books, journals, proceedings, magazines, newspapers, courses, attendance and participation in conferences and symposia, and individual conservations. The industrial and technical details presented are true to the best of the author's knowledge but they are subject to rapid change.

GLOSSARY OF TERMS

Of first consideration should be the definition of computer graphics. Computer graphics is "the art of image generation and manipulation." It "usually applies to computer-generated displays which contain lines and points. However the term has been used to indicate displays containing only alphanumeric data." This explanation is provided by the SHARE Inc.[1] Glossary.

In an attempt to communicate effectively and to agree on terminology the author has included at the end of this overview the glossary of computer graphic terms which was used as reference. This glossary was prepared under the author's supervision in association with SHARF Inc., and is reprinted here with the approval of the SHARE executive board. It has been published in the Proceedings of SHARE XXXVI and in Computer Graphics, the quarterly magazine of SIGGRAPH, the special interest group on Graphics of the Association of Computer Machinery (ACM). The glossary has been considered by the American National Standards Institute (ANSI) Technical Committee X3K5 for use in the American Standard Vocabulary for Information and Processing and as a basis of graphic terms and graphic

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1 SHARE Inc., is composed of users of large scale scientific computer machines. Its by-laws which were revised in August 1973 state that its principal purposes "shall be to foster research and development, and the exchange and public dissemination of data pertaining to computer science in the best scientific tradition."

definitions in the International Business Machine (IBM) Data Processing Glossary GC 20-1699-4, published in December 1972.

PASSIVE COMPUTER GRAPHICS

Computer graphics has two main divisions. They are interactive and passive. Interactive computer graphics is associated with the glamorous graphics as illustrated by commercials on television. This graphics uses a display console while the console is in the "interactive mode." Passive graphics includes plotters, microfilm recorders, and other devices which do not allow immediate active participation.

MICROFILM RECORDERS

The charactron which is part of some microfilm computer graphics appeared early in the life of computers. The charactron is a special-purpose cathode-ray tube which was developed by Joseph T. McNaney (1) and engineers of Consolidated Vultee Aircraft Corporation. It was described in the January 1952 issue of the Digital Computer Newsletter as a matrix which contains character-shaped openings that are located between the electron gun and the flourescent screen. The stream of electrons that is directed through the matrix openings forms a shaped beam which produces a display of characters on the screen of the tube. These characters can be either read or photographed. The character selection in the matrix is designated by an electrostatic deflection system while the character images on the screen are positioned by either electrostatic or electromagnetic deflection. In this way the proper sequence of applied deflection voltages selects and thus positions the matrix characters and translates input signals into visual intelligence (2). Within the year 1952-1953 dry printing techniques and other refinements had been made to the charactron. It was suggested that one of its uses might be in computer display but there was no sign at that time that anyone anticipated its use as a microfilm input or output peripheral and thus a major contributor to the advancement of computer graphics.

It remained until the Western Joint Computer Conference of 1956 for the charactron to be considered as an aid in debugging, in the editing of input data, in the plotting of graphs, and in real time simulation. In 1956 multiple graphs could be plotted on the same frame.

Early in the fifties Convair, a division of General Dynamics, San Diego, California, installed a charactron on its ERA 1103 Computer. It had a type C7A cathode-ray tube (CRT) which could display alphanumeric characters at a rate of 10,000 characters per second. The equipment included a CRT with a 7-inch diameter screen, a test generator for noncomputer alignment adjustments, a Beattie 35 millimeter magazine camera and a Kenyon camera which was camera and photo laboratory combined. A 6-bit code selected the proper alphanumerical character from a 6 x 6 matrix, a 20-bit code positioned the characters on the face of the tube.

Stromberg Carlson (SC)[2] entered the field in the late fifties. David Taylor Model Basin (DTMB)[3] obtained one of the initial SC 4020's and published their first programmer's manual in June 1961. For a short while DTMB used a high-speed automatic processing camera which permitted visual observation of a selected frame of film eight seconds after exposure. The frame to be viewed was selected by an instruction in the program. This camera was called the Kelvin-Hughes (3). North American[4] installed their first SC 4020 in November 1961 and produced a plot package which was modified by SC and republished in 1965 under the name SCORES.

The SC 4020 is a peripheral system which processes a specially coded magnetic tape obtained as output from a computer program to produce graphical, pictorial, or alphanumeric output. As the tape is read, the desired lines and characters are displayed on a specialized CRT. Sensitized paper and/or film is exposed to the display and the results are developed and returned to the programmer. The raster orientation of most of the SC 4020 routines are comparable to the origin of the Cartesian coordinate system. The (0.0) point is on the lower left-hand corner and the (1023,1023) point is on the upper right-hand corner (4).

Fig. 1 shows an SC 4020 as viewed by the user. Its hardware consists of a 7-inch, shaped beam CHARACTRON[5] tube as a generator for characters

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2 In the late sixties Stromberg Carlson became Stromberg Datagraphics (SD). Thus the use of the letters SD in the discussion of the 4060 microfilm recorder and SC for the 4020.

3 Now Naval Ship Research and Development Center. (NSRDC)

4 Now Rockwell International

5 CHARACTRON is a trade mark of the Stromberg Carlson Corporation, (1964).

and lines. Two of its best features are a F-30 vector generator, and a F-20 variable length generator. The vector generator means that two addressable points can be connected with a straight line, thus obtaining a continous graph. The variable length axis generator gives the capability of drawing a continuous horizontal or vertical line the full frame width, starting at any plotting position. The position of a character to be plotted is specified by selecting one of 1024 horizontal positions with any one of 1024 vertical positions. For normal printing, up to 64 lines with up to 128 characters per line may be recorded on a frame of film, which, when developed, yields a page of outupt. For negative output the information appears as

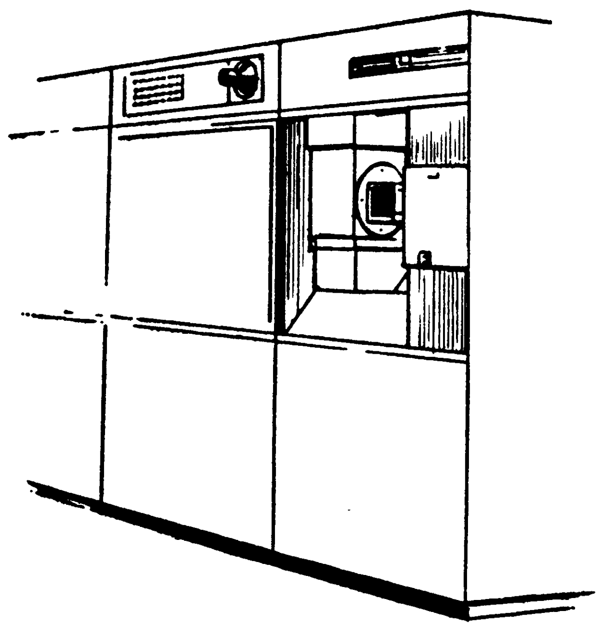

Fig. 1 - SC 4020

clear (transparent) areas on a totally dark (black) background. A Fulton Reversal Processor provides a film output at 20-feet per minute. From this 18 x 24 inch paper copy is produced on a Zerox 1824 printer. This is a 114.5 magnification. Besides the tube, F-30 vector generator, and F-20 axis generator already mentioned, the recorder system consists of the necessary electronic controls and logical circuitry; an automatic, electrically operated 35 mm (Richardson) camera for high quality permanent photographic recordings; a F-10 Typewriter Simulator which positions each character automatically along a printing line, returning to a margin upon completion of a line or receipt of a carriage return signal; a F-50 tape adaptor which accepts input directly from a tape unit and processes it into a form acceptable to the recorder; and a F-55 DC power supply. Fig. 2 is a sample of the SC 4020 output from a naval architecture computer program showing the longitudinal design of a shell of a ship.

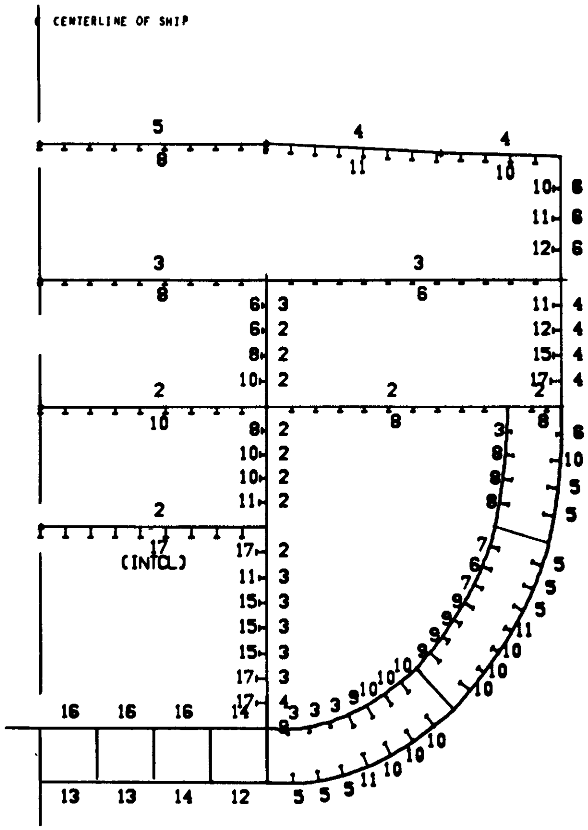

Fig. 2 - Sample of SC 4020 Output from
Ship Design Program of Natale Nappi

In the late sixties the Stromberg Datagraphics (SD) 4060 was produced. It contains an individual computer, called the Product Control Unit, as well as a CRT, camera, film developer, and a hard copy unit. The resolution has a matrix of (4096, 3072) and the beam in the CRT is shaped by a 119-character stencil. Lines may be drawn in four different widths. A special hardware feature is the drawing of characters with the stroke generator (5).

There are other microfilm recorders but Stromberg Datagraphics is the most well-known company in this field. About 12 years ago the users of the SC 4020 formed an organization named UAIDE.[6] In the Fall of 1973 UAIDE formally joined the National Microfilm Association.

6 UAIDE - Users Association Of Information Display Equipment

PLOTTERS

The next form of passive graphics to be considered in this article is the plotter. As early as 1953 when computers were first beginning to show their importance to science and industry, two companies were displaying computer plotting devices. They were the Benson Lehner Corporation and the Logistic Research, Inc.

The Benson-Lehner Corporation announced in 1953 the production of an incremental plotter for use by the Computer Research Corporation Model 105 (CRC-105) Digital Computer. This plotter permitted preparation of punched tapes, and the plotting and reading of curves. From a single tape input it could plot a curve on an area 11 x 17 inches. The plotter would advance one increment in the abscissa and the tape reader would advance one step each reading of the plotter. Then the increment in ordinate was prepared by feeding the tape reader to the plotter. The slope of the curve could not be more than one.

The Logistic Research, Inc. (LOGRINC) developed two automatic graph followers for use on the Magnetic Drum Digital Differential Analyzer (MADDIDA) - 44A, developed by the Northrop Aircraft Corporation, and the CRC-105. As an input or output device either model could be used without additional equipment. As an output medium the two-dimensional followers plotted any two variables against one another. The three-dimensional device could handle functions of two variables. Families of curves on a single sheet could be placed on a drum and a separately externally control input would cause the follower to switch automatically from one curve to another. The separate input or "z" axis control was also incremental and bi-directional. Both the two dimensional and three dimensional models were built on the principle that an electric impulse when received caused an increment movement of the pen. They were a "combination of the Digital Plotter and the necessary photo-electric and electronic components for automatically following curves and converting the data into electrical impulses"(2).

At the present time we have much more advanced peripheral devices which employ the use of flatbed, drum, or electronic digital plotters and which can operate either off-line or on-line. Fig. 3 shows a schematic of both off-line and on-line plotting systems.

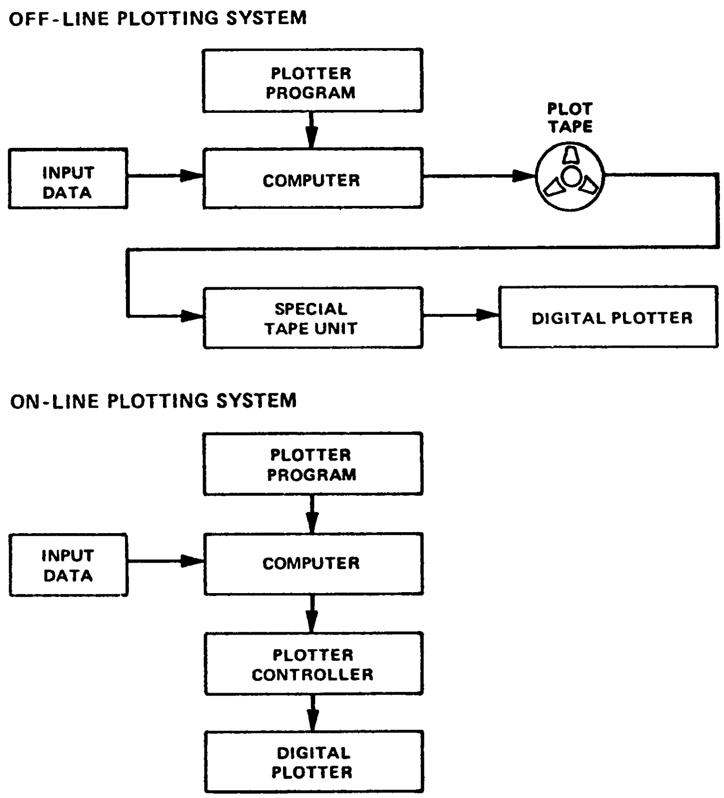

Fig. 3 Schematic Off-Line and On-Line Plotting Systems

Plotters are manufactured by many companies - among them, Gerber Scientific Instruments, Hewlett-Packard, and Electronic Products, Inc. One company which produces all three types mentioned in the previous paragraph is the California Computer Products, Inc. (CALCOMP). Their drum plotters, such as shown in Fig. 4, present computer output data in an uninterrupted manner. Continuous plots up to 120 feet in length are produced on a 21-inch or 30-inch drum by the rotary motion of the drum and lateral motion of the pen carriage. CALCOMP claims that these plotters are drift-free and the operation is fully incremental. Digital commands activate step motors to produce a recording of the pen movement relative to the surface of the paper. The pictorial representation may include any desired combination of letters, symbols, lines and axes with unlimited choice of scale factors, letter and symbol sizes and printing angles. When the digital plotter is used off-line, the plot data and required control

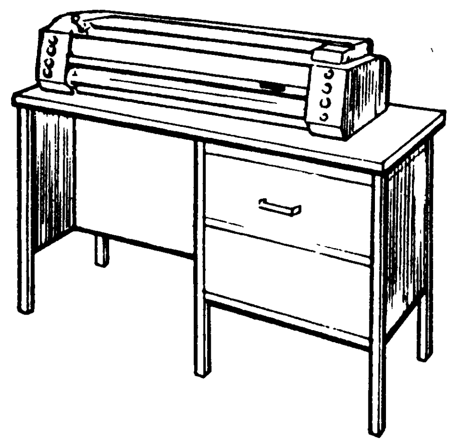

Fig. 4 - CALCOMP Drum Plotter

commands are recorded on magnetic tape. For plotting purposes the tape is then played on a CALCOMP magnetic tape unit. This unit, which includes the control logic circuits that locate the plot data on the tape, decodes the circuits that supply the X and Y axis drive signals to the plotter and the commands to the pen. When the digital plotter is used on-line, the plot data and control commands are supplied either directly to it by a plotter adapter or through interface electrons supplied by the manufacturer.

Flatbed plotters are used for application where total visibility is a prime concern. They can also handle a variety of preprinted forms and special materials not practically handled by a drum type plotter. The plot is produced by a motion of a beam and pen carriage. Z-axis commands are used to raise or lower the pen. Either ball point or liquid ink pens may be used.

The third type of plotter is the electronic digital. These plotters are employed for ultra high-speed plotting and microfilm recording of computer output data. They operate on the same basic incremental principal as the ink-on-paper plotter. The plot is generated elecronically on the screen of an 8 x 10 inch CRT and automatically recorded on microfilm or paper. It is advertised that one model can accept imput commands at rates up to

100,000 characters per second. When this model is used off-line with a special CALCOMP tape unit all data on a complete 2400-foot roll of magnetic tape can be plotted in eight minutes (6).

Three-dimensiomal work on a plotter was sponsored in part by the United States Atomic Energy Commission and reported on by David L. Nelson as early as March 1966 (7). The program plotted a three-dimensional perspective of the data on an off-line plotter. It plotted any two-dimensional array interpreting the value of the array as the z component and the address of the array as the x and y components. Invisible data points were deleted.

Applications of digital plotters are growing constantly. In science, plotters have been used in atomic structure analysis, nuclear explosion, seismograms, weather data mapping, radio telescope studies, satellite flight tracking, and submarine hull designs. In medical and psychiatric diagnosis, plotters have been used in such studies as the biomedical research on the graph of sound vibration in the inner ear. In industry, applications include automatic drafting, Critical Path Method (CPM) and Planning Evaluation Review Techniques (PERT). In engineering, plotters have aided in air

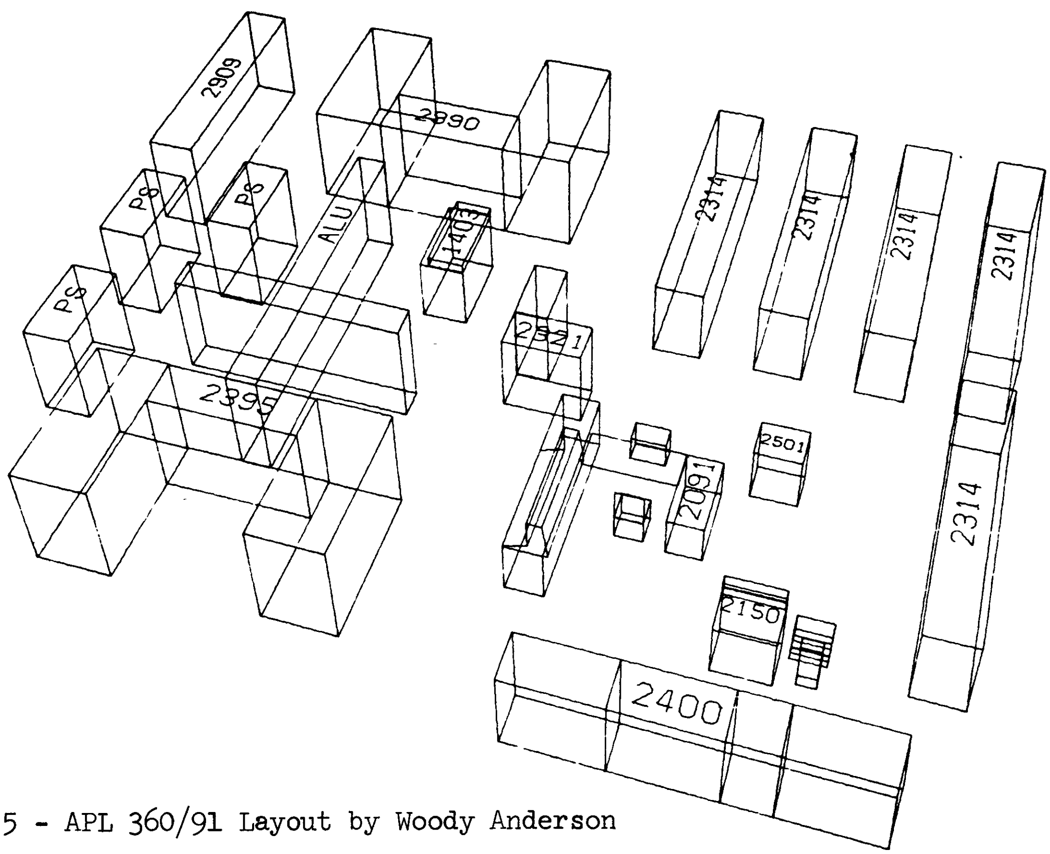

Fig. 5 - APL 360/91 Layout by Woody Anderson

traffic recordings, traffic pattern analysis, oil survey measurements, test data graphics, and contour mapping. In business, the studies of inventory and budget control, advertising and market research, and profit and loss trends as well as financial analysis have been aided. Several examples of various outputs of plotters are presented in Figs. 5-9. Fig. 5 shows how a plotter contributed to decision making. An interactive computer program was employed to arrive at the proper layout of the computer equipment. Then a plotter was activated to permanently record the decision. Fig. 6 shows the results of a test problem at the John Hopkins University, Applied Physics Laboratory (APL) using a complicated mathematical equation.

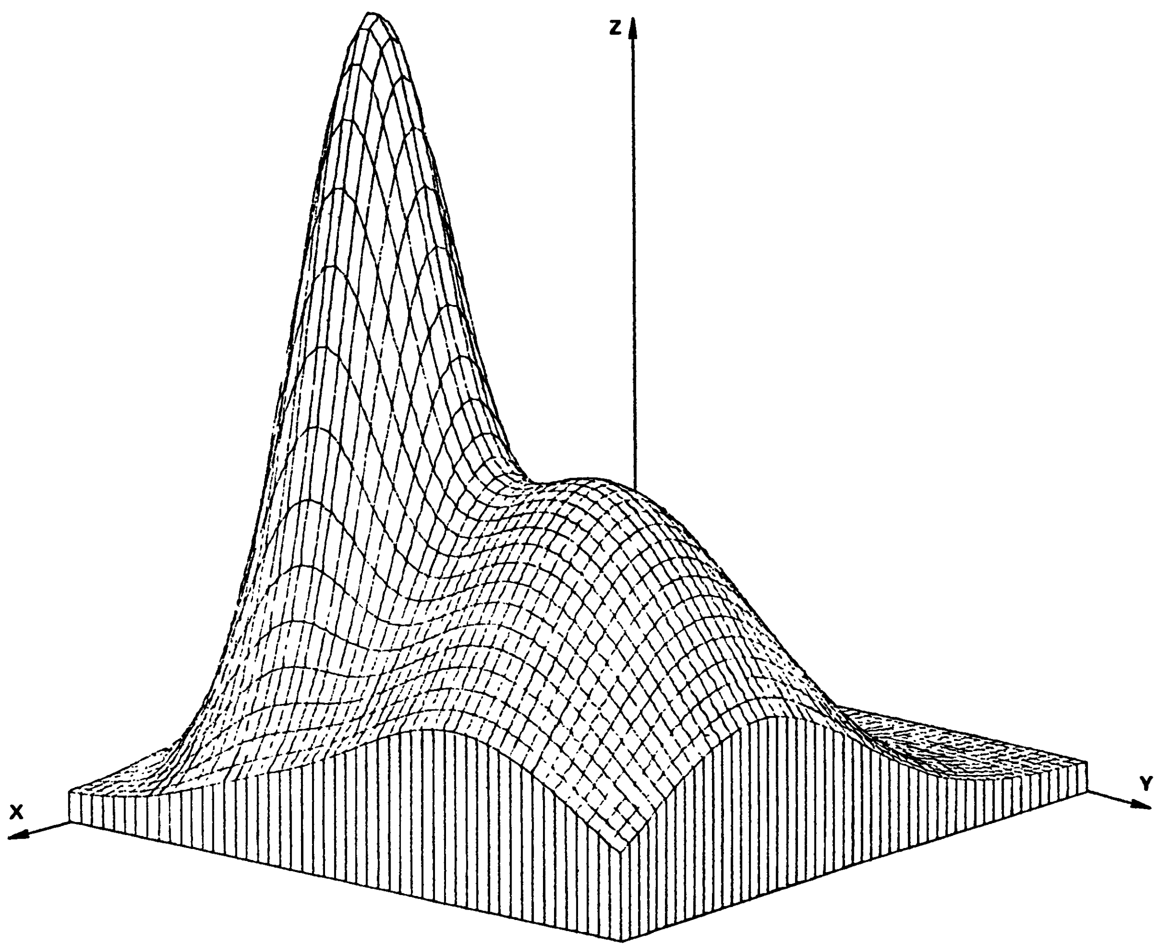

Fig. 6 - Results of Test Problem at John Hopkins University

Fig. 7 presents another drawing of a solution of a mathematical equation, this time from NSRDC. Fig. 8 shows a reduced drawing of the compartments of an aircraft which was produced by Robert H. Thompson of NSRDC. Fig. 9 was produced on a flatbed plotter at the National Aeronautics and Space Administration (NASA), Langley, Virginia, from information sent by satellite. It is a view of the Chesapeake Bay Bridge Tunnel are of Hampton, Norfolk, and Portsmouth, Virginia.

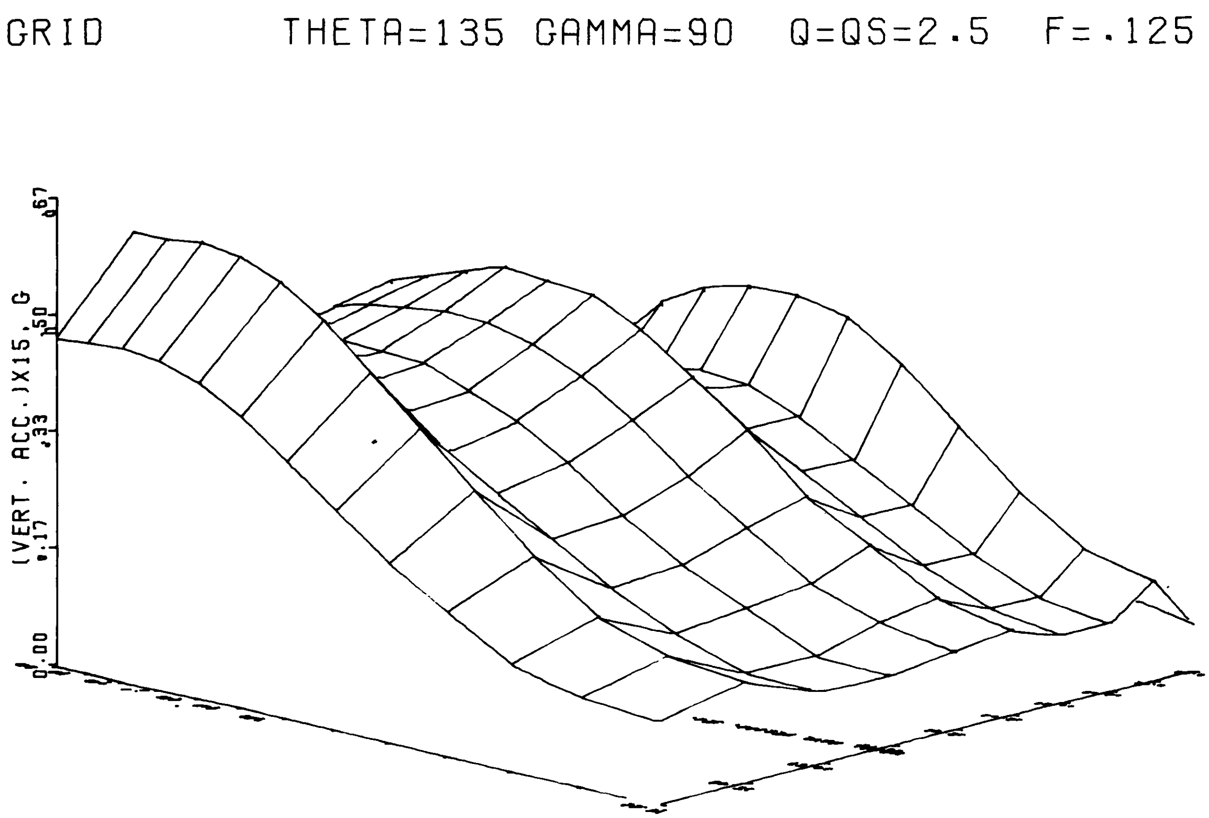

Fig. 7 - Computer Drawing of a Mathematical Solution

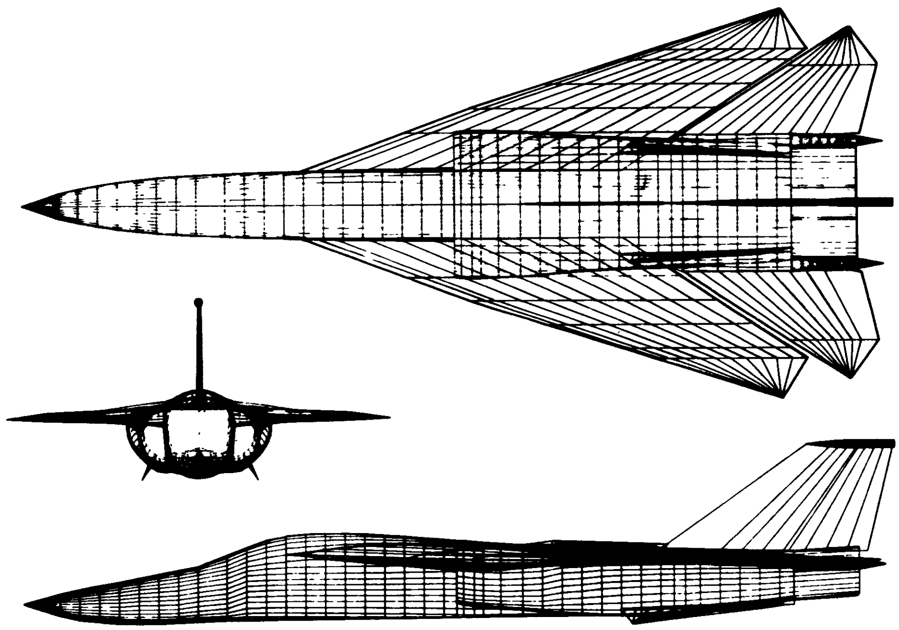

Fig. 8 - Reduced Drawing of Compartments of an Aircraft
Produced by Bob Thompson

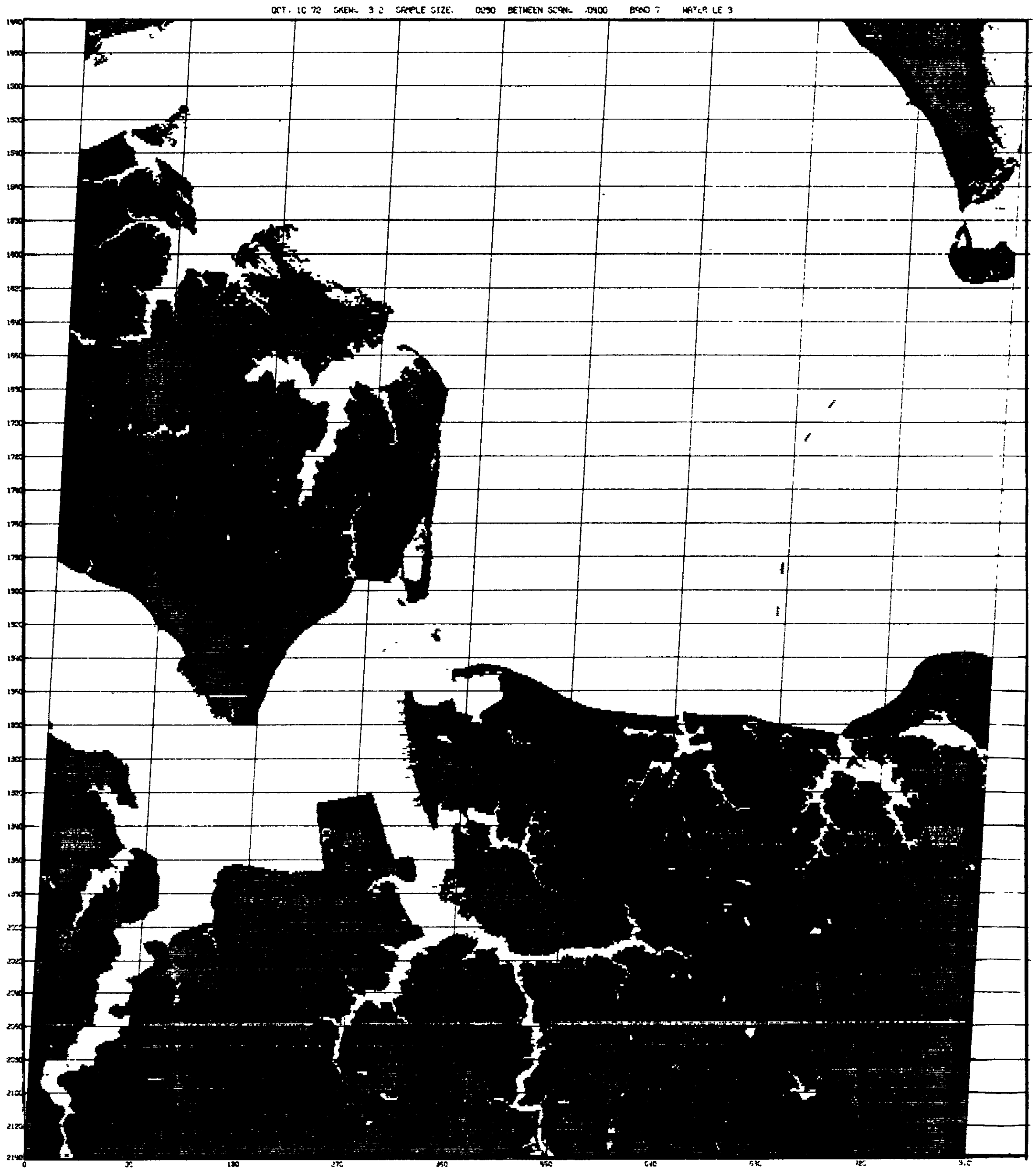

Fig. 9 - View of Chesapeake Bay Tunnel Area of Hampton, Norfolk and Portsmouth Va. Produced on a Flatbed Plotter from Information Sent by Satellite.

MISCELLANEOUS

One of the first passive forms of computer graphics output was on a computer printer along with other output of the program. Even though the printer was slow and expensive, it was effective. Today - with the advent of high speed printers and with the costs of the installation of off-line graphics - interest in printer graphics has been revived. Fig. 10 shows a picture of a printer which was used as a plotter. Fig. 11 shows a more artistic endeavor of the printer.

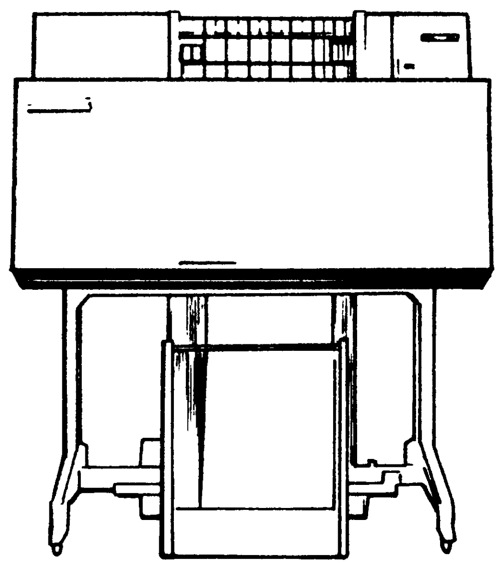

Fig. 10 - Picture of Printer Which was Used as a Plotter

Fig. 11 - Artistic Endeavor of the Printer

The last type of passive graphics to be mentioned in this overview is the ink pen recorder which gives simultaneous graphs of one or several variables depending upon the number of channels. A typical example of this type of recorder is the Brush Recorder System. In Fig. 12, eight different displacement histories for finite element analysis are shown. Fig 13 shows a typical Brush Recorder system. This system uses as imput the output tape of a computer program and converts the information on the tape to

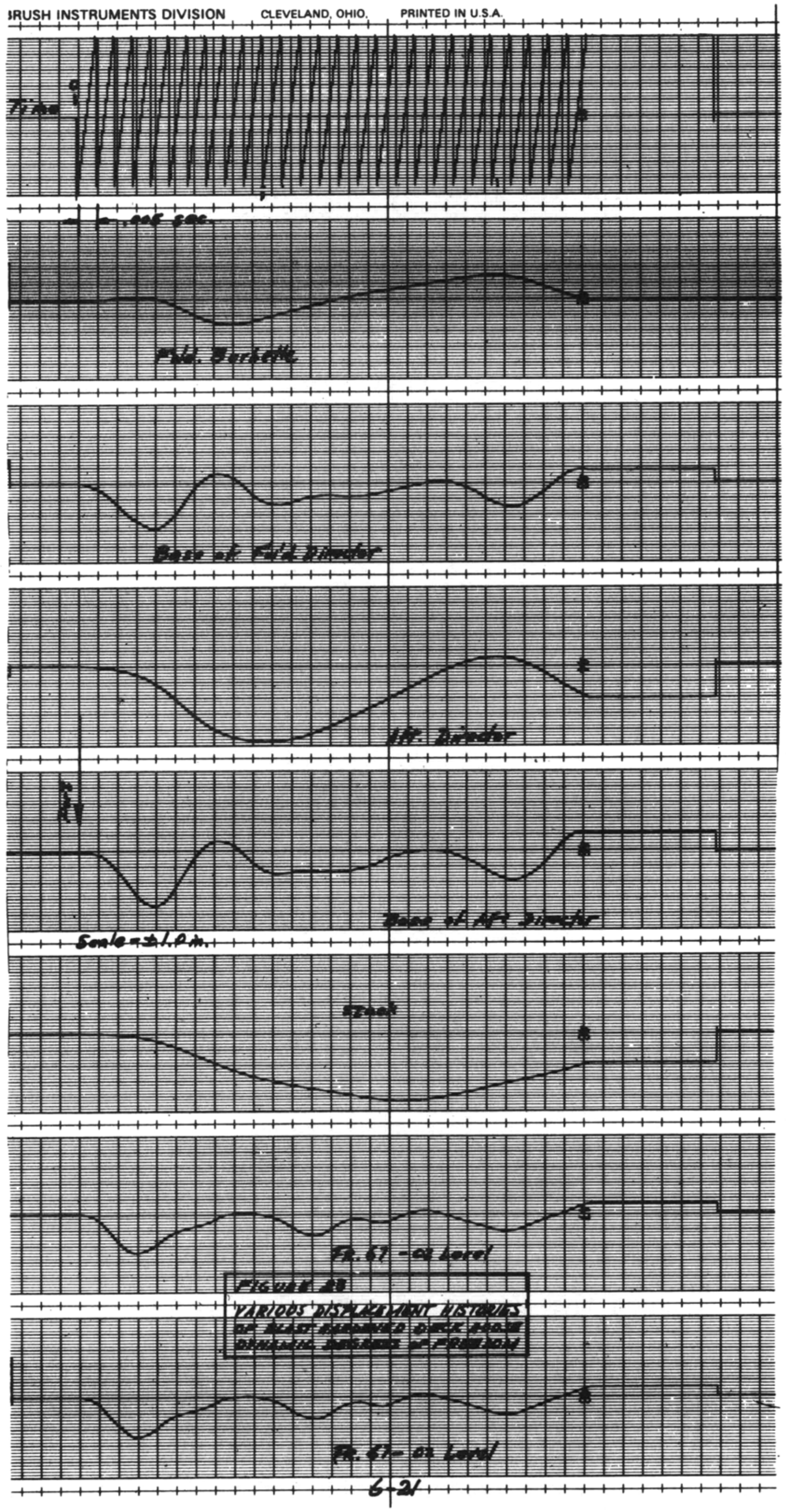

Fig. 12 - Eight Different Displacement Histories for Finite Analysis

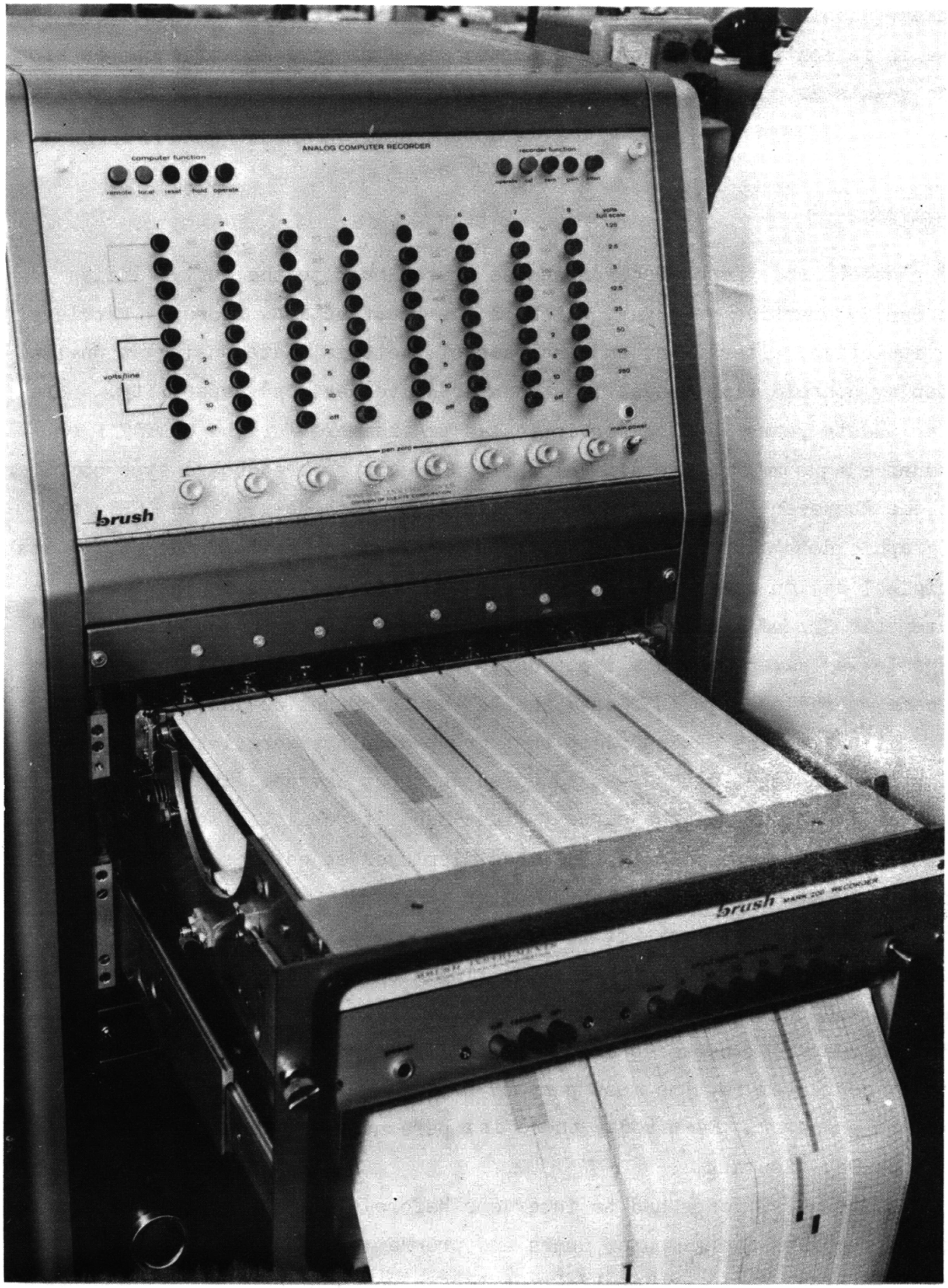

Fig. 13 - Brush Recorder System

a form usable for plotting the graphs. The position of each pen along the x-axis is controlled by a time base signal. The position of each pen along the y-axis is controlled by signals representing the values of the variable.

INTERACTIVE

HISTORY

If plotters and the charactron can be traced back to the early fifties so can interactive graphics, which is the construction, storage, retrieval, manipulation, alteration, and analysis of pictorial data, using an on-line display console with manual input (interactive devices) capability. More than twenty years ago the sophisticated programmers for the ORDVAC - an Ordnance Department eight digital shifting register breadboard type computer at the Aberdeen Proving Ground - utilized the cathode-ray tube (CRT) as a graphic debugging device in addition to making the most of the CRT in its original design role as an address counter. As early as in the Semi-Automatic Ground Environment (SAGE) Air Defense System Computer, the CRT console was given moderate input capabilities (2). The Whirlwind I which became operational in 1950 used the CRT as an output device (10).

It was in the SAGE project that group displays were introduced and a light gun or light cannon was added as an input device. The light gun was the forefather of the current light pen; it permitted the operator (now also the user) to select desired displayed objects as targets and thus to direct the operation of the computer program.

One of the drawbacks of the early cathode-ray tubes was the inability to maintain a picture on the screen. The display image appeared once for an instant and then quickly faded out of sight. The refresh rate was so low that regeneration became quite apparent. This phenomenon is called flicker. It was corrected for the most part by refreshing the CRT from data stored in the computer. Even today there is a percentage of flicker in many cathode-ray displays.

Quite a few years had to intervene before a display console became really popular with computer users and programmers and was widely used as an interactive computer input/output device for applications. The breakthrough occurred in 1963 and was accomplished by I.E. Sutherland and T.E. Johnson with the SKETCHPAD programs. These programs proved that an interactive display console could be used as an imput/output device to accept or exhibit data in both pictorial and alphanumeric characters and to provide a more efficient means for controlling the sequence of a program than any other device such as an on-line typewriter (11), (12). Licklider is quite enthusiastic over the advances made in interactive graphics because of the SKETCHPAD. He reports that Ivan Sutherland mentioned his SKETCHPAD project in 1962 during a discussion period of the session on Man-Computer Communication at the Spring Joint Computer Conference of the American Federation of Information Processing Societies (AFIPS). At the end of the session, Sutherland showed to those who lingered their first glimpse of his very dramatic on line graphical compositions (20). Since this is quite the most significant advancement in interactive computer graphics so far more details are worthwhile.

The basic elements of the SKETCHPAD - which revolutionized interactive graphics - are points, lines, and arcs. Its lines are ideally straight and its arcs are ideally circular. The lines used can be constrained to be parallel or perpendicular to each other, or to be parallel with the axes of the coordinate frames. Two points can be constrained to be parallel or perpendicular to each other, or to be parallel with the axes of the coordinate frames. Two points can be declared identical and their identity can be enforced by the computer and its programs.

By means of the SKETCHPAD, a user could employ a CRT display and a light pen to construct pictures while a computer monitored the user's motions and also constructed a set of data representing the picture which was being drawn. The data structure thus created represented the topological properties of the drawing. These properties were displayed on the CRT and served as names and labels in the data structure which were chosen as easily as pointing the light pen at them. By use of this mechanism the user could extend his data structure to include numerical and other non-pictorial attributes simply by pointing his light pen at the desired element and then typing in the additional information desired. In the same way the different elements of the system which the drawing represented and their relationship could be designed with the aid of the light pen which selected the elements and then indicated their relationship. By allowing the user to make this selection even if the relationships were as simple as the elementary one of the definition of a line in terms of its end points or as complicated as that of geometrical constraints with limitations of size, parallelism of two lines or perpendicularity, accurate displays could be drawn in spite of precision inaccuracies of the light pen.

From 1962 on use of the CRT display console mushroomed. In the fall of 1962 the first GM DAC-1/7090 was shipped. It was known as the Windshield Design and was in production in 1965. The prototype of the earliest IBM graphic console was available on the IBM 7044 and used in Alpine. The IBM 2250 appeared at the 1964 Fall Joint Computer Comference. The third and fourth version of the IBM 2250 were announced in 1966 and 1967 respectively. The IBM 2285 was presented at the 1968 Fall Joint Computer Conference. In IBM, interest was so pronounced that interactive graphics was the subject of an entire issue of the IBM Systems Journal in 1968.

In 1965 Bell Telephone installed a computer system which was built around a display console, Centralized Records Business Office (CRBO). This system consisted of a 28 Raytheon 401 display terminals divided between two Raytheon 425 control units.

In the medical field the IBM System 360 Model 50 MFT (multi-programming with a fixed number of tasks) with 256,000 bytes of core was placed in operation in 1967 for Hobbs-Baylor Medical School. The system used an IBM 2260 Display Station and in 1968 served both scientific users at Baylor University College of Medicine and the hospital data management system at the Texas Institue for Rehabilitation and Research (TIRR)(13).

The Graphics Data Processor, as described by E.J. Smura in 1968, was capable of producing a halftone picture of a 16th intensity level picture or a four-bit intensity level picture. The equipment consisted of Scientific Data Systems (SDS) 930 digital computer into which graphical data were entered and stored in digital form, a graphical recorder which used several cathode-ray tubes to present the graphical data for recording or direct view, and an interface between the computer and recorder for interpreting data from the computer and converting it to analog from so this it was suitable for presentation to an output device (14).

By 1968 CRTs were being used in interactive graphics systems for data display, geographical display associated with command and control systems, and structural data files. Computer animation sprung off in the late sixties. As early as 1969 SHARE Inc. started a film festival under the sponsoreship od the Graphics Division.[7]

At the present time interactive graphics is used in almost all fields including commercial aviation. To help take care of a large number of passengers - it flew more than six million passengers in California in 1972 - Pacific Southwest Airlines (PSA) installed an on-line terminal system. It consists of a National Cash Register (NCR) 101 computer, 140 identical Bunker Ramo 2210 CRT data terminals, and four Bunker Ramo multi-station control units. The size of the 2210 screen in only about three inches. But, in normal working position with the eyes at a distance of about 15 inches from the screen, the alphanumeric display can be read like a book. The keyboard is designed for use by nontypists. In the future if the need arises, the 2210's can be unplugged and replaced with larger CRT terminals capable of displaying up to 960 characters and fitted with typist's keyboards. While a customer is at the counter or on the telephone, the agent uses the CRT terminal to key in flight numbers, date and number of seats desired. There is an instantaneous display. The NCR 101 computer automatically deducts the seats from the inventory. If the desired flight is sold out, the computer displays up to six alternate flights. The display can also be used to cancel reservations and to check on the customer's PSA travel card status (15).

INPUT

In the late sixties several interactive devices were available. There were the alphanumeric and function keyboards, the light pen, the cursor, the joystick, the mouse, and the tablet. The Rand tablet, orginated at RAND Corporation, was one of the first tablets to be developed. It was developed further and marketed by Bolt, Beranek and Newman. All the input devices are defined in the glossary.

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[7] The Graphics Division is now the Graphics Group in the Integrated Systems Division.

TYPES OF INTERACTIVE GRAPHICS CRT'S

Interactive graphics CRTs may be classified into two main groups. They are the storage tube and the refreshed scope. The storage tube is a CRT with special long-persistance phosphor which retains any displayed image without refreshing until the image is erased. It usually has a small screen. It can be located quite far from a computer and is relatively inexpensive, as low as $3800. It cannot display dynamic phenomena and there can be no changes of a picture part without the picture being erased. Even so the picture may still have new information added. The generation of display is slow. A cursor is used to make additions. Because of its characteristics it does not occupy the core space of a large computer. Usually it has a mini-computer attached to it. Two manufacturers of storage tubes are Computek and Tektronix. The main host or connected mini-computer for both companies is the PDP, manufactured by Digital Equipment Company. Storage tubes can also be connected with other computers such as those produced by IBM, NOVA, and VARIAN.

The refreshed scope has a large screen and can demand a computer fairly close. These scopes are expensive and the computer is extra but this cost is overshadowed by the ability to display dynamic phenomena. Another advantage is that almost any part of the picture can be changed without erasing the entire pitcure. As in the storage tube, new information may be added to the display. The amount of display is limited by the sign of the display buffer. Even at the present time the flicker develops if the information is excessive. Thus sophisticated users should look instantly for overcrowding of their input when flicker occurs. The generation of the display is fast, but it does need adjusting from time to time. Different intensities may be displayed. The light pen as well as the cursor may be used. Windowing and hardware rotation are available. In this case of the refreshed scope, the display occupies core space. Just a few of the manufacturers of refreshed scopes are IBM, ADAGE, and IDIIOM.

DESCRIPTION OF SEVERAL SYSTEMS

In the following paragraphs are detailed descriptions of the systems of several manufacturers. An attempt was made to select typical examples rather than every system.

Adage

The Adage Graphics Terminals, Fig. 14, are refresh type or stroke drawing CRT display stations. The terminals contain a DPR2 digital processor, a Graphics Coordinate Transformation Array, and both a character and vector generator. The DPR2 is a general purpose digital computer. It performs all processing and control functions including that of the conventional input/output devices. In fact, it is the only programmable element of the entire system. There are from 4096 to 32,768 30 bit-words of core. The number of priority interrupt channels can vary from five to twenty-five. The Graphics Coordinate Transformation Array is a hybrid unit, which transforms "all vector endpoints by the current scale, rotation, and displacement factors before they are displayed" (17). The character generator serves as a high-speed stroke writer. Its vocabulary has sixty-four characters but another thirty-two can be added. The characters can be displayed in several ways, upright or italicized, in one of three sizes, and at one of three intensities. With the analog output of the Transformation Array the vector generator drives the CRT beam. This is controlled by a processor register which specifies the desired display mode. A light pen, sixteen keyboard function switches, and two pedal function switches are the interactive devices that are provided with the system. Other peripheral items such as the Adage Data Tablet, joystick, bowling ball, six variable control dials, and auxiliary keyboards may be obtained. Each piece of hardware contains its own register. These registers are addressable from the central processor. A three-dimensional hardware windowing is also available as an option. With this the programmer can designate the desired upper and lower bounds for the x, y, and z coordinates. Whenever

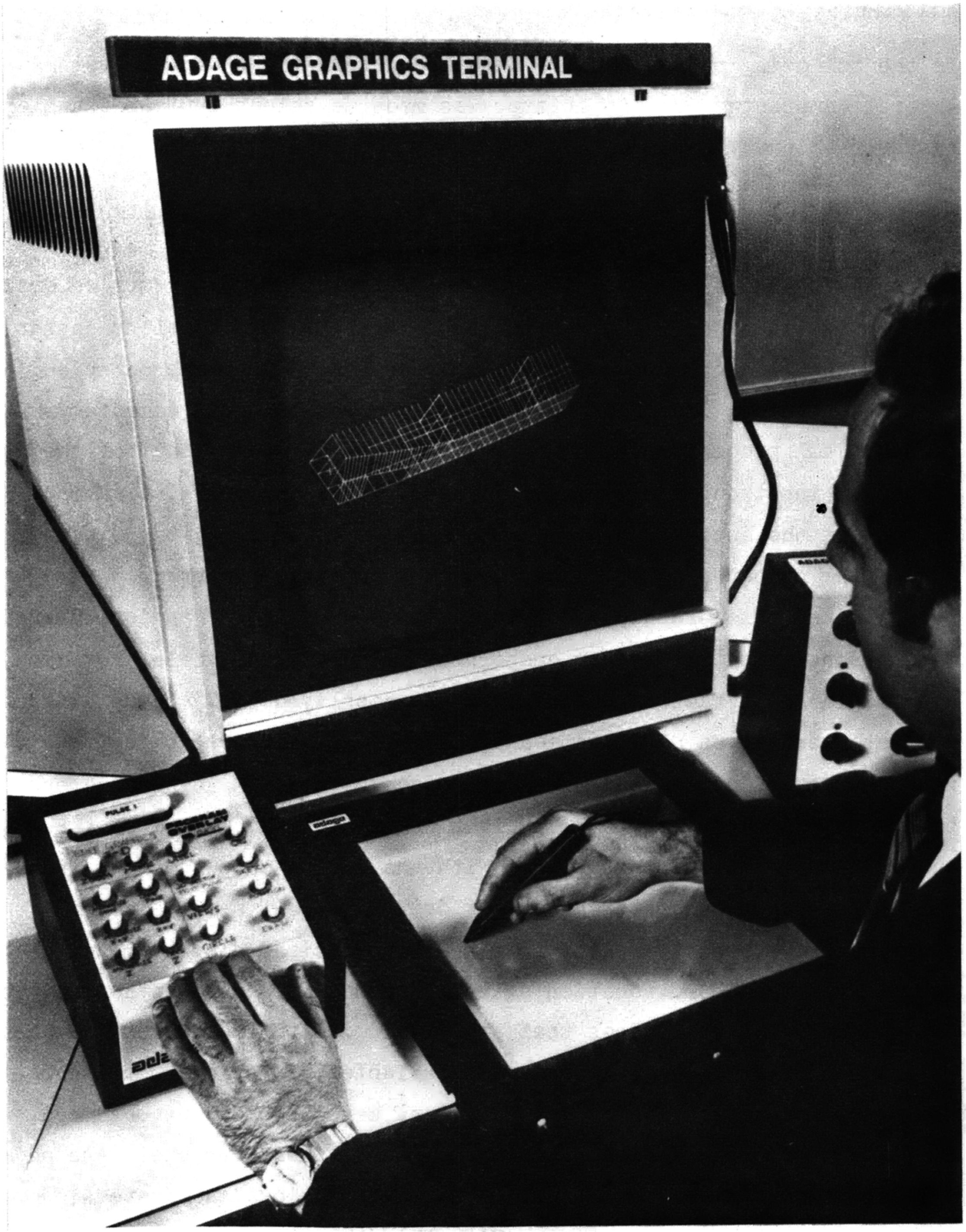

Fig. 14 - Adage Graphics Terminals

the CRT beam goes beyond any of the designated values the vector generally will blank the beams. Perhaps the outstanding characteristic of the Adage hardware is its ability to represent the z-coordinate by a varying intensity of the electron beam. Because of this feature the graphic displays can be described so that they appear to be three-dimensional. Still depth cueing by apparent change in the size of the image must be programmed (17).

Computek

The Computek terminal, Fig. 15, consists of a display controller and Type

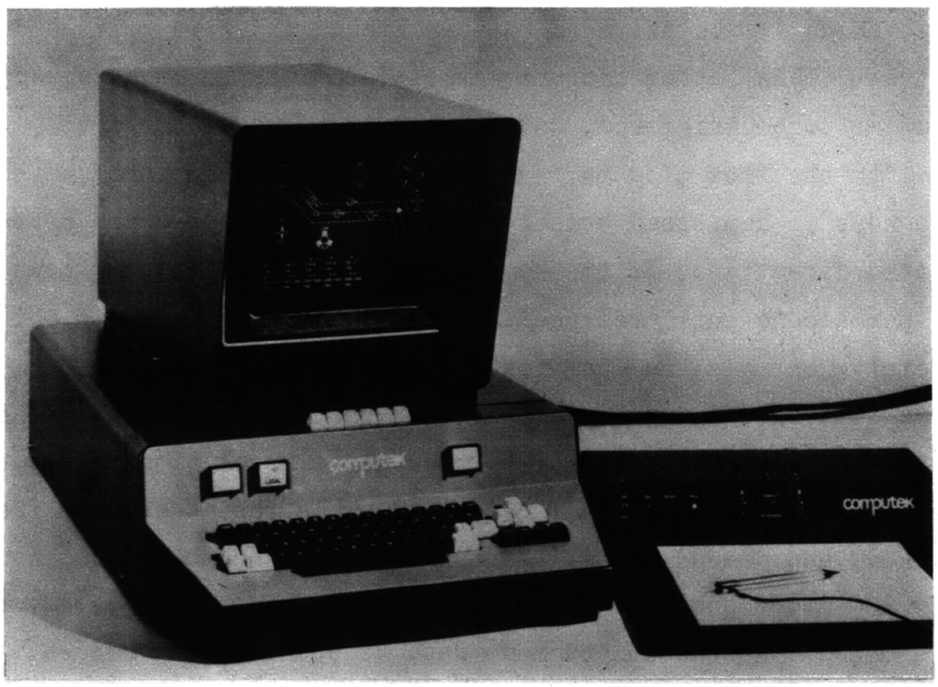

Fig. 15 - Computek Computer Terminal

611 direct view storage tube. The display controller can utilize either a single byte, a two byte, or four byte mode. The single byte mode is the one used for commands and character transmissions. The two byte and four byte modes are used for graphics. In the two byte mode, vectors of coarse definition are drawn. In the four byte mode, vectors can be drawn between any two of the 1024 x 1024 addressable points. The type 611 storage display unit is built by Tektronix. It has a 6-1/2 x 8-1/4 inch screen with a revolution of approximately 300 x 400 line pairs and an erase time of half a second. Also there is a stroke generator available. This generator allows a continuous curve to be drawn when four bytes of data are transmitted. Other features of the terminal are that it can accept data at the rate of 2000 characters per second and that it is provided with several "back panel" outputs which can be switched between ground and five volts under computer control. This latter feature permits a camera to be actuated, a capping shutter to be triggered, and other external devices to be synchronized with the flow of data. There are four cursor control keys. If one of the keys is depressed briefly the cursor is stepped one character in the indicated direction. If the key is held down, the cursor slews at three inches per second until released. The joystick when used in this system completely controls the beam position and the circular cursor; in other words, it takes control over the four cursor action keys. There are two versions of the Computek tablet. One has a resolution of eight bits. The other has a resolution of ten bits. This tablet has the free-running, stroked, and demand modes. In the free-running mode data is up updated every 300 microseconds. In the stroked mode data is updated when the stylus is moved. In the demand mode data is updated upon request. There is an interface provided for attaching the tablet to its own modem for general use. Another interface is provided for use with Computek terminal (18).

Control Data Corporation

NSRDC has onboard Control Data Corporation (CDC) equipment for its interactive graphics. The system is composed of a CDC 6700, a CDC 1700 and the

Digigraphics 274 Display Console. The host computer, the CDC 6700, has dual central processors (6600 and 6400) with a memory of 131,000 (131K) 60-bit words. The small computer, the CDC 1700 serves two special functions. First it is a broad band communication interface between the terminal and the host computer so that there is no limit to the distance between the two computers. Second, it relieves the main frame of many of its terminal control and maintenance functions. The Digigraphics 274 Display Console is connected to the CDC 1700. It allows the user to enter data directly, create, display, store, retrieve, and modify any graphics forms desired.

IDIIOM

The Information Displays, Inc. Input/Output machine (IDIIOM), Fig. 16, is characteristic of the sophistication of a refreshed scope display

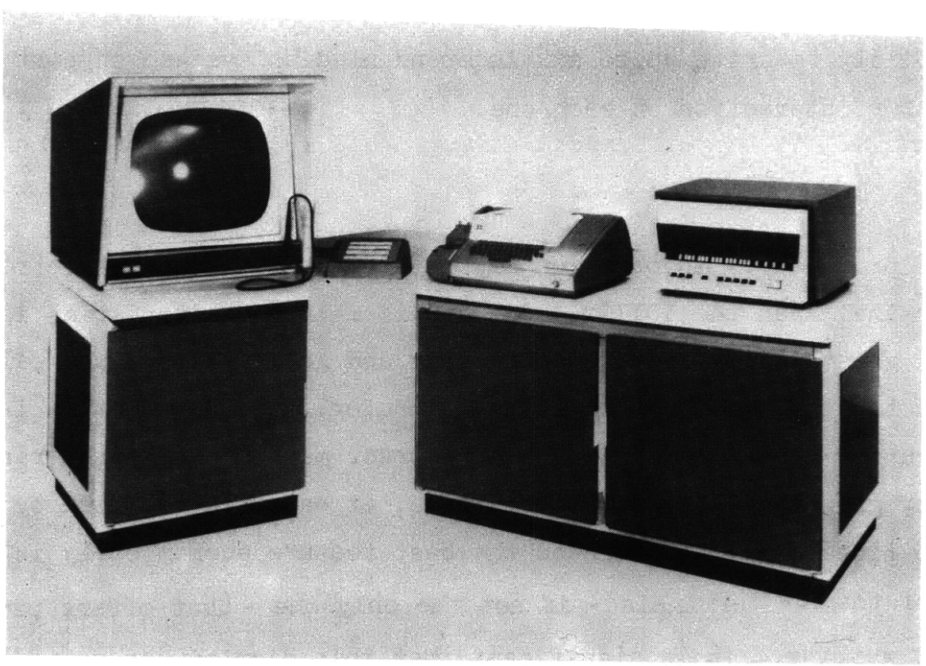

Fig. 16 - The IDIIOM Graphic Terminal

processing unit. It has seventeen registers including triple-rank input registers which significantly reduce the load on the driving mini-computer. It has several different kinds of jump subroutines, a variety of register to register transfer instructions and a number of other computer-like instructions. In fact, the number of integrated circuits used in the IDIIOM II display processing unit is complimentary to those used in a conventional mini-computer. Color displays can be obtained. A new operating system has recently been added to the capability of the system. The new system - called HIGHER - in one of the first FORTRAN type operating systems which in itself is written in FORTRAN. Because of its ability to transfer unused programs out of the mini-computer core without the need for the programmer to keep track of subroutine utilization HIGHER is unusually well suited for a mini-based system. It is estimated that the HIGHER operating system can work with having about 25 percent less core than current operating systems of comparable capacity. The IDIIOM's unique capabilities from a hardware standpoint are:

1. Combination of high resolution TV with computer generated data.

2. Programmable character set which operates at speeds equal to a hard-wired set.

3. Ability to drive up to six independent displays and support complete operator interaction on each one.

IDIgraf

The IDIgraf produced by Information Displays, Inc. is a cheaper refreshed display terminal than the IDIIOM. One of its main characteristics is that it can do a great deal of both alphanumeric and graphics hardware editing that does not require connection to any computer. Another feature is a frew slew cursor mode such that when the cursor matches any eight raster units of any graphical element, like a line, it captures the line by causing the line to blink. Perhaps the best feature economically is that it is one of the few terminals - if not the only one - that offers pention color stroke writing. It is significant that this display has up to twice the resolution of any low cost TV display. The IDIgraf contains a 17 inch rectangular CRT with bonded safety face plate. The display areas is nominally 10 inches square, as shown in Fig. 17.

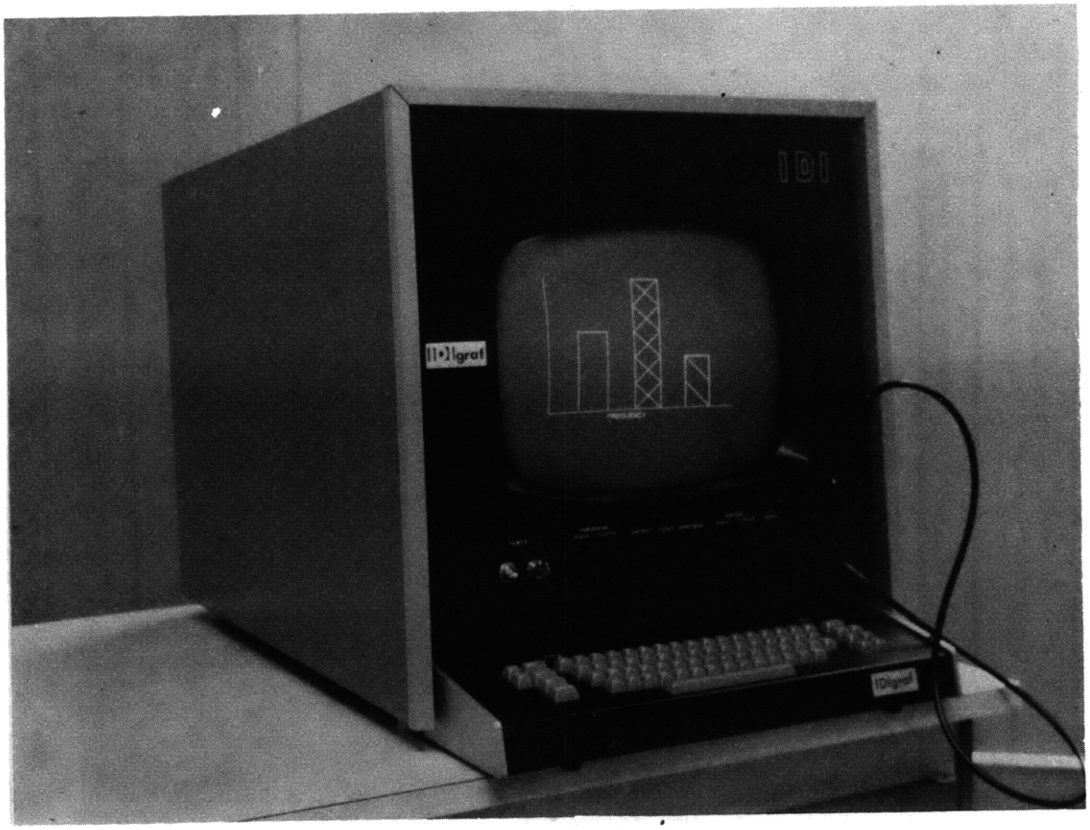

Fig. 17 - The IDIgraf Graphic Terminal

Tektronix

Tektronix, Inc. was founded in 1946 and has only lately started competing in interactive graphic terminal systems. True it produced glass - lately ceramic - CRT tubes for many other computer companies for years, but it was known more for its oscilloscopes and other electronic equipment until about 1970 when it acquired control of a great percentage of Corning's graphics capability. Now Tektronix offers a line of interactive graphic computer terminals featuring CRT displays from a direct view storage tube. A special feature of Tektronix terminals, Fig. 18, is the stand-alone design with control and interface circuitry in the mounting pedestal. Space is provided in the pedestal minibus for computer interface cards, plus one or two perpheral instrument interfaces. The 11-inch diagonal storage CRT in the present Tektronix terminals handles graphic displays

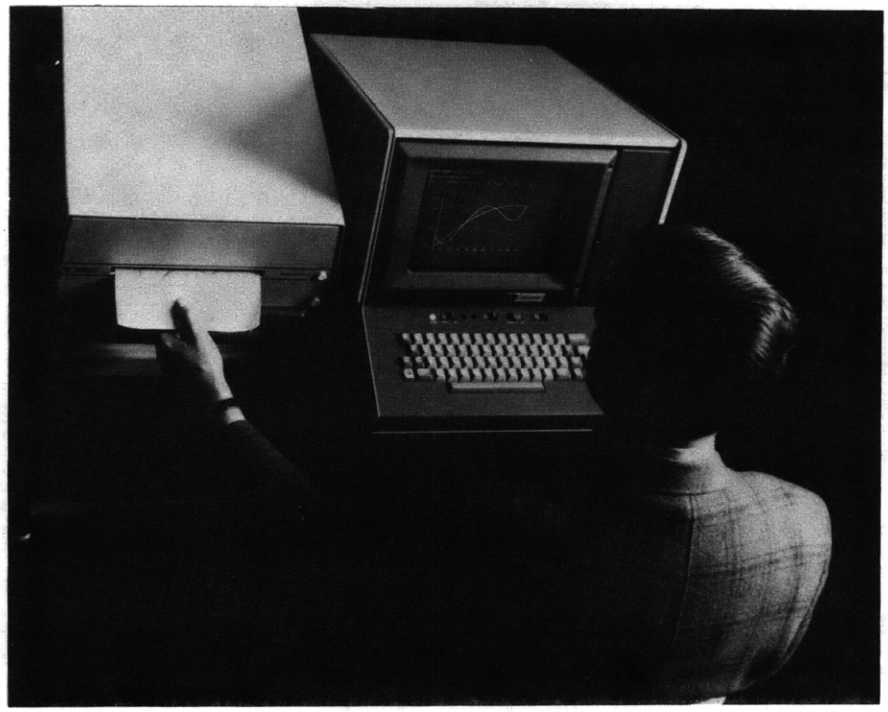

Fig. 18 - Tektronix Terminals

up to 5.6 inches high by 7.5 inches wide, or alphanumeric displays of 35 lines of 72 characters each. A new terminal is scheduled for release sometime in 1974. It features a storage tube with 19-inch diagonal measure which makes it the largest storage tube on the market. Normally storage scopes have been smaller in diagonal size than refresh scopes.

Vector General

The basic Vector General system, which is about the same in price as the IDIIOM, is one of the oldest systems. For its min-computer it employs a Digital Equipment Company (DEC) PDP 11-05 with screen refresh and control information. A unique quality about the Vector General terminal is that its three-dimensional capabilities and perspective are both incorporated into the hardware. The terminal has a 21-inch interactive screen with light pen, table, joystick, and ten control knobs. The control knobs are similar to those in the Adage terminal.

Color

As early as 1966 color cathode-ray tubes were available, but because of their comparatively limited resolution were not used extensively. The early color systems were usually projection display systems which used either single or multiple channel additives. The light valve, scribing, and film-based projection display systems used the multiple-channel additive for their multi-color accomplishments. This process formed one clear and opaque monochromatic image for each of the primary colors. Intermediate colors were then obtained by mixing the images of the primary colors on the screen.

Two different methods of the single-channel additive were experimented with. One was known as the Dufay color mosaic and involved the dot-interface. The attempts to apply this method to the pioneer display systems were apparently unsuccessful. The other method was known as the lenticular process and involved the line-interface. General Precision Laboratories (GPL) was successful in the production of the lenticular process and produced "Lenticolor." In both of these approaches to the solution of the color problem the film structure itself was more important than the optical-mechanical elements.

The transparent film base of the lenticular film was "embossed" with cylindrical ribs during manufacture. The curvature of these cylindrical lenses and the index of refraction of the film base were such that a bundle of parallel rays arriving at the film base were focused into a set of parallel linear elements at the opposite side of the base, where the emulsion was coated. By varying the direction of arrival of the parallel bundle, different linear elements were exposed (20). The lenticolor process used three directions which coincided with three bands across the face of the lens. Any standard projector could be used simply by placing the three parallel red, blue, and green filter bands across the projection lens. The CRT display was photographed with three different sets of symbols or graphics - each time one-third of the lens was photographed while the other two-thirds was covered. Thus the CRT display was photographed three times. It took approximately ten seconds for the reversal - processing of the film.

Animation

In the years since 1964 when Knowlton first discussed his BEFLIX language for producing computer animated movies, film-making under computer direction has been employed in a variety of disciplines. Computer generated movies and animation have become a new comminication interface between computers and human beings, scientists and other scientists, scientist and laymen, and educators and students. Computer picture animation seems to be especially suited for the physical sciences, mathematics, art and advertising. Perhaps its most powerful and valuable use can be its role of convincing laymen that the computer is not a powerful and undisciplined robot control-led giant but a helpful ally.

Because of its potential power several examples of computer movies and animation will be discussed in this paper. One report is taken from work done at a university. The second method discussed was developed both at a university and research laboratory. The other two methods are from commercial companies employing two different processes.

The first method of computer animation to be discussed was reported on in 1970. At that time Philips - at the University of Michigan - used as a display medium a bi-stable storage tube terminal made by Computek. He claimed that this tube, Model 400/20, retained complex, flicker-free frames for approximately fifteen minutes with undiminished brightness. The host computer was an International Business Machine (IBM) 360/67 with a Digital Equipment Corporation PDP/8 computer interfaced to act as a data concentrator. The computer animated films were made by photographing static displays a frame at a time. When a complete frame had been drawn the last character that was transmittted caused one of the "back panel" outputs to go high. This, in turn, actuated an Airiflex 16-mm pin-registered camera. The animation motor of the camera permitted the selection of two shutter speeds or the equivalent of bulb operation. A screen erase signal was sent to the display and another frame was started. Then the information was sent to a post-processor. In this case the post-processor used a SC 4020, which employed a subroutine package developed by Polytechnic Institute of Brooklyn, POLYGRAPHICS. The post-processor consisted of about 200 lines of FORTRAN IV Code. It read its input from a tape or file that contained SC 4020 hardware code (19). The SC 4020 is described elsewhere in this paper.

In the on-line system developed by S. E. Anderson at the Johns Hopkins University Applied Physics Laboratory an IBM 360/91 is used to drive a 2250/3 cathode-ray tube in a time-shared environment. Picture language commands can be typed in from the alphanumeric key-board. A light pen can be employed to scan and edit the code. Then the dynamic sequence can be displayed. In a "movie editor" mode the user can depress the programmed function keyboard switches and thus advance a selected number of frames. The acceptable picture sequence can be made into a permanent record in one of three ways, one of which is on-line. A Polaroid camera can be used to obtain a snapshot directly from the CRT screen. The off-line methods obtain a plot by means of a CALCOMP x-y plotter or a 16 or 35 mm movie by means of the SC 4020 microfilm recorder. Two major programs, adapted from Anderson's work while at Syracuse University, were written to accept this picture language. They are Hopkins Implementation of Aided Motion Pictures (HICAMP) and Hopkins Implementation of Computer Aided Movie Perspectives (HICAMPER). HICAMP produces movies of planar, two dimensional objects. HICAMPER produces movies of three-dimensional objects in perspective. Stereoscopic animations can be prepared by simply creating two slightly divergent views of a three-dimensional object and choosing two viewing points at approximately the interpupillary distance apart. If the viewer uses an image splitter when the perspective views corresponding to both right and left eye images are displayed on the CRT screen, and illusion of three dimensional sight is obtained (21).

Even "Walt Disney's World" has been transformed by computer graphics. About 1967 commercial computer generated animation was developed when special purpose computers were designed specifically for animation. These systems are hybrids of both digital and analog computers. The analog techniques are employed for structures, basic shapes, and animation while the digital techniques supply control, storage, and the timing of the total animation. Video techinques are used for detailed imagery and the surface characterization of images (22). Two of the leading animation firms are Computer Image Corporation and Mathematical Applications Group, Inc. (MAGI). Computer Image has developed two animation systems. They are SCANIMATE and CAESAR. SCANTIMATE scans and animates artwork by television pickup and input of real artwork created by an artist. The first step on the SCANTIMATE system is the preparation of "Kodaliths." Kodaliths is the preparation of black and white artwork on transparent sheets. A Kodalith is equivalent to a dozen or more of the conventional cels[8] produced in conventional animation. After its preparation the Kodalith is then placed in frcnt of a special TV camera with a high-quality scanning format pickup device which allows up to seven separate photos to be set up. At this point the art-work conversion unit converts the images that have been received into electrical signals which serve as input to the computer and which are restructured as an image on a cathode-ray tube. There are two modes of manipulating the image, (1) direct - as a joystick is moved so moves the image, (2) parametric - the user determines the motion parameters and the image moves accordingly. Color animation is added at the completion of the animation. Fig. 19 gives a schematic outline of the SCANTIMATE Computer System Developed by Computer Imafe Corporation. The cameras used are the Airi for the 16-mm work and the Mitchell or ACIME for 35-mm work. The camera and computer are linked with a synchronous motor. The speed of the camera is 24 frames per second, but the computer calculates, updates, and draws the image at a rate of 48 frames per second. CAESAR (Computer Animated Episodes by Single Axis Rotation) is a more advanced system than SCANIMATE. It is claimed that CAESAR provides flexibility and to-the-frame control of animation and color.

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8 A cel is one of the transparent sheets of celluloid on which objects or sections of objects are drawn or painted in the making of animated cartoons for motion pictures and television.

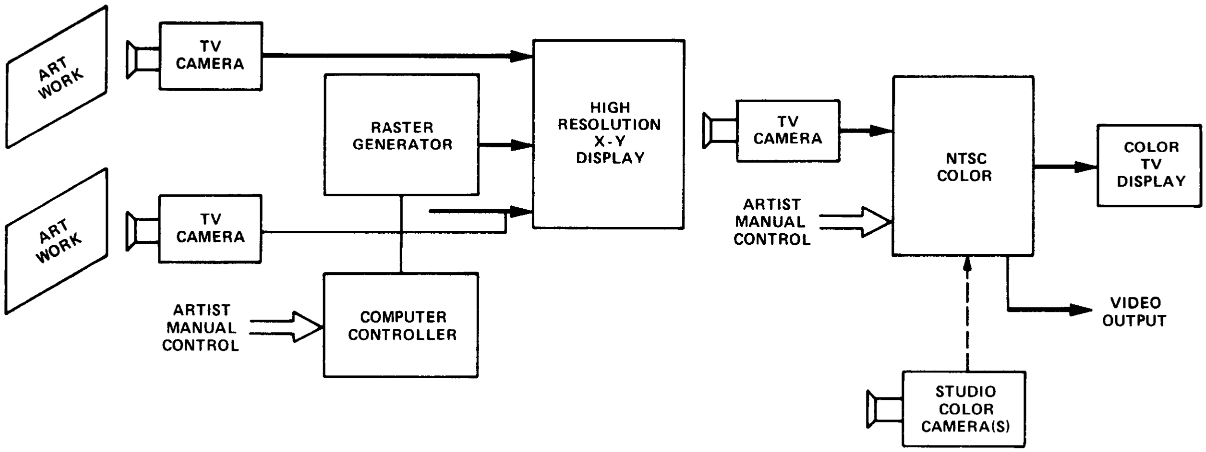

Fig. 19 - Schematic of SCANTIMATE Animation System

The MAGI system is a visual simulation technique which produces fully computer-generated perspective views of three-dimensional objects. Whereas computer graphics systems usually display an object as a collection of line segments which seem to distinguish the boundaries between surface, the simulation approach treats an object as a set of three-dimensional surfaces that reflect light. It is this reflected light impinging on photographic film that forms an image of the object. Once the three basic components of a camera, a light source, and object or objects have been defined, geometric ray tracing computes a "picture" of the object as it is shown in the simulated camera. Geometric ray tracing tracks individual rays of light from the light source to the object to the camera. Each relected ray provides the intensity at a single point on the picture. After a sufficient number of points have been computed, the entire area of intensity data may be displayed on a cathode-ray tube. The heart of the MAGI system is the three-dimensional modeling technique, known as the combinatorial geometry method (23).

CONCLUSIONS

The life ahead seems quite rosy for computer graphics. Surely there must be some pitfalls. Does it have any problems? If so, what are the major ones?

First, it might be called disjointed. It certainly seems to go in all directions at once without any guidance. There appears to be great interest by many people. But where do "youngsters" in the graphics field go for help? Sometimes they go to manufacturer's classes. Here it is obvious that they learn about only one manufacturer's type of computer graphics. Sometimes they go to workshops, conferences, symposia, and universities. At these they all too often receive the same type of instructions as they would in a manufacturer's course. How can this drawback be corrected? All who teach computer graphics can and must become truly familiar with all areas of computer graphics before attempting to teach it. If some expert is called upon to discuss his specialty he should continuously emphasize that he is talking about only a part of the field of computer graphics. Is this too much to ask? As a former teacher, the author feels that such frankness will put the teaching in proper perspective and lead to enhancement of both the teacher's knowledge and ethical reputation.

A second pitfall might be that many personnel working on computer graphics put too much emphasis on interactive graphics. True this is the glamorous area but there are other areas. No one area should be neglected. After all there are plotters and microfilm recorders in many interactive systems. The author looks forward to a future system which include a highly developed scanner or digitizer that can prepare input from all types of written drawings and designs without even requiring the user's presence most of the time. Then the system will, for debugging purposes, record the input on a display scope and if requested produce a permanent record. The input will also be sent to a computer program. The output will be produced on the scope and recorded permanently, if desired. Graphics in the desired format will be obtained. A permanent and separate record will be made of the graphics work so that single or multiple copies may be produced later. The system will include a scope, scanner, and plotter or microfilm. Does this sound far-fetched? Such systems are almost in production today.

The graf/pen sonic digitizer, Fig. 20, which is produced by

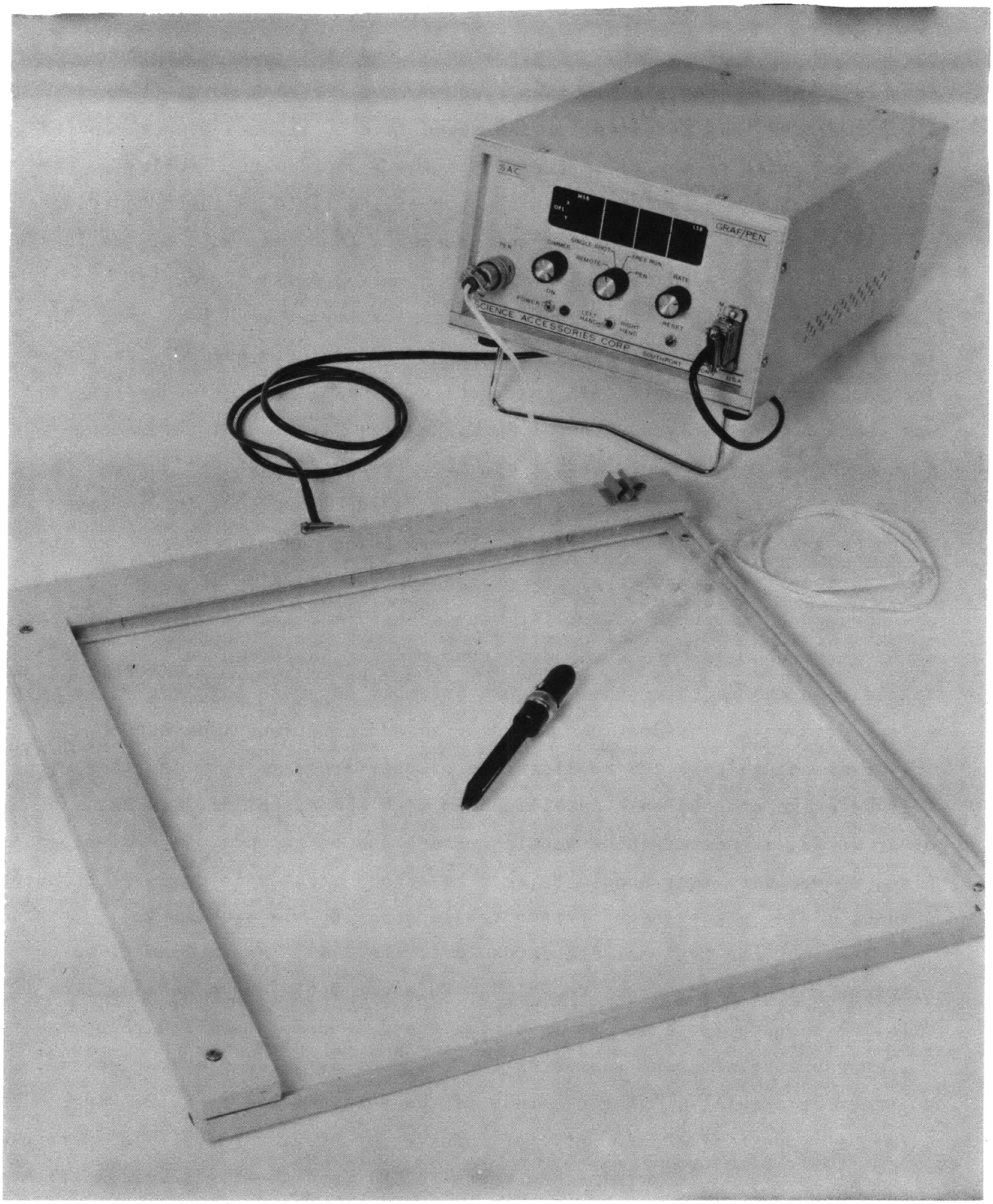

Fig. 20 - Graf/Pen Sonic Digitizer

the Science Accessories Corporation, is a big step in this direction. Its basic components are a pen, a control unit, and two-linear microphone sensors. The pen emits a hypersonic sound wave for each point to be digitized; the time required for the sound wave to reach a sensor mounted on the left side of the field represents the X coordinate; similarly, the time to reach a sensor mounted at the top of the field is the Y coordinate. Among its functions, the control unit converts the times into digits in the binary or binary-coded-decimal codes for computer consumption.

A third pitfall is that computer graphics speaks with many tongues. In fact by 1967 more than thirty languages and dialects had been developed for programming conversational instruction. This lack of standardization was mentioned recently be General C. W. Meyers, Director of the Defense Systems Management School, and it has been bemoaned by others through the years. It is true that there are several types of users of interactive graphics systems requiring different capabilities and convenience factors. For instance, the computer system programmer specializing in computer graphics may need to be thoroughly familiar with a basic machine language. But each manufacturer should not have a different machine language for each model, nor should each manufacturer have his own assembly language intelligent to only a few personnel. In addition, the program and interface language should be universal enough that the applications or user programmer is familiar with this language and can talk intelligently with the system programmer. In other words, standardization should present common grounds of terminology. Also, an ordinary user should be able to obtain results in computer graphics without adding a knowledge of computer language to his specialty.

The American National Standards Institute (ANSI) has a Committee for Drawings and Drafting Practice (Y14). This committee has a subcommittee (Y14.26) whose purpose is "to investigate and develop justified recommendations for appropriate national standards for computer assisted preparation of engineering drawings." The chairman of the subcommittee is R. W. Rau. Also with the support of the Society for Information Display (SID), The Institute of Electrical and Electronics Engineers (IEEE), and the Electronic Institute of America (EIA), an Ad Hoc subcommittee on Display Parameters has been formed. This subcommittee is under the ANSI/X3 Computer Standards Committee. Sol Sherr is chairman of this committee. In addition, the Department of Defense has assigned Wallace Dietrich of the Naval Ship Engineering Center to be the principal contact for its Computer Aided Design/Numerical Control (CDNC) Standardization Area. In a fourth attempt at standardizing, a tri-service ad hoc committee on Interactive Graphics (TRICOG) has been organized. The TRICOG Technical Working Group is chaired by Robert M. Dunn. Will any or all of these efforts really develop a standardization? Can those several groups get together for common benefit? Some prominent areas are not covered by any of these groups. Will they be covered by one of these groups or another group in the future? Whether computer graphics lives up to its potential or falls by the wayside when a new glamorous development is introduced depends in great part upon these committees and future ones formed by concerned parties. Computer graphics must encourage and adhere to standardization!

A fourth pitfall of computer graphics might be its expense. An estimate of the cost of computer graphics should include not only the dollars required for lease or purchase of all physical inventories which include all remote interconnecting and local hardware but also the cost of all software, and the education of programmers and users. In addition, wait or turn-around time, capability, and productivity should be considered. Counting all the overhead, the total costs of a console with interaction devices and host computer interface is still in the $100,000 bracket. CRT terminals have taken great strides in the past few years with the aid of mini-computers. "Minis" such as the CDC 1700, and the PDP 8 and 10 have become valuable work horses. In the future they will contribute even more to the advancement of computer graphics, for they can take care of the critical interface and core problems. More and more graphics CRTs, microfilm recorders, and plotters employ "minis" to do their mundane tasks. While mini-computers have reduced the cost of computer graphics, mini-computers, as expected, have several drawbacks. A digital buffer is needed. The software is still inadequate and tends to be exclusively for the stand alone system. Most minis have too few general purpose registers and too little core, inadequate bit and byte manipulation instructions, and poor operating systems. One possible solution to this might be a powerful intermediate priced microprogrammed graphics. Another solution might be an improvement of the mini itself. The manufacturers need to listen to the views of their customers and satisfy their customers requirements. In their turn, users need to be reasonable, definite, realistic, and cooperative.

A fifth pitfall might be the failure to satisfy the impatience of its users. No matter who the user - system or application programmer, scientist or manager, student or teacher, under 30 or over, occasional user or computer professional, employed or homemaker, educated or under privileged - he or she expects quick turn around time. This speed of response has always been requested in batch work. Even quicker response is expected of terminals and scopes. We need to turn to advances in technology for this.

Many past advancements for humanity could be cited. Many future achievements could be predicted for the computer graphics user who is a true gourmet. Hopefully his taste will always demand the finest and best contributions from computers and computer professionals.

ACKNOWLEDGMENTS

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APPENDIX - GLOSSARY

This Computer Graphics Glossary records the application of terms and concepts used within the computer graphics discipline. It is under continual review and revision to maintain it as a current reference in the field. Within a set of synonyms the definition in the text of this Glossary follows the preferred term.

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ABSOLUTE VECTOR: A directed Line segment whose end points are measured in absolute units from a point designated as the origin.

ADDRESSABLE POINT: Any place on the display surface to which the display writer may be directed. These positions are specified by coordinates. Such addressable positions are finite in number, and form a discrete grid over the display surface.

AIMING CIRCLE: A circle or other pattern of light projected by a light pen onto the surface of the display to guide the accurate positioning of the pen and/or to describe the light pen's field of view.

AUDIBLE ALARM: A short tone sounded to get the attention of the display console operator.

BLANKED ELEMENT: Display data that produces no visible output but changes the position of the display writer.

BLINKING CONTROL: A programming technique or hardware option on a display device in which a display element is repeatedly displayed and erased. Usually used to attract the attention of the user.

BUFFER: (See DISPLAY BUFFER).

CAD: Computer Aided Design.

CADM: Computer Aided Design and Manufacturing.

CAI: Computer Aided Instruction.

CAM: Computed Aided Manufacturing.

CATHODE RAY TUBE (CRT or crt): An electron tube whose face is covered with a phosphor that emits light when energized by its electron beam.

CHARACTER GENERATOR: Hardware which will generate a finite set of characters onto a display surface.

CLIPPING: (See SCISSORING).

COM: Computer Output Microfilm.

CONTRAST: The relationship of the brightest to the darkest portions of a display image.

CONTROL BALL: A ball that can be moved in at least two degrees of freedom and which moves one or more display elements by providing coordinate input to the display device (Syn: ROLLING BALL; see JOY STICK).

COORDINATE: An ordered set of data values, either absolute or relative, which specifies a location.

CRT: Cathode Ray Tube.

CRT DISPLAYS: Displays utilizing cathode ray tube as the viewing element. (See RASTER SCAN, STORAGE TUBE, and DIRECTED BEAM).

CURSOR: A movable marker visible on a CRT display used to indicate the position at which the next operation (e.g., insertion, replacement, or erasure of a character) is to take place.

DETECTABLE ELEMENT: A display element which has the characteristics which permit it to be identified by a light pen detect.

DIGITIZER: A device that codes images or shapes into digital computer usable data.

DIRECT VIEW STORAGE TUBE (DVST): (See STORAGE TUBE).

DIRECTED BEAM: The CRT method of tracing the elements of a display image in any sequence given by the computer program, where the beam motion is analogous to the pen movements of a flat bed plotter. This contracts with the raster scan method which requires the display elements to be sorted in the order of their appearance (usually top to bottom, left to right).

DISPLAY: 1. A visual presentation of data. 2. Sometimes used as a synonym for a display device.

DISPLAY BACKGROUND: That portion of a display image which cannot be altered by the user. Sometimes called the static portion of the display.

DISPLAY BUFFER: A storage device or memory area that holds all orders and coordinate data required to generate a display image. This could include a portion of computer memory, direct access storage, or a special purpose storage device.

DISPLAY COMMAND: A display I/O instruction, such as those used to start or stop the display device.

DISPLAY CONSOLE: A hardware complex consisting of a display device plus one or more computer input devices. The types of input devices commonly employed are alphanumeric keyboards, function keys, tablets, joy sticks, control balls, and light pens.

DISPLAY CONSOLE OPERATOR: A person using a display device and interacting with a computer at a display console. "User" is often used in place of "display Operator".

DISPLAY DATA: 1. Any collection of data intended for display. 2. Information in a display buffer which directly produces the display image.

DISPLAY DEVICE: A device capable of presenting information on a viewing surface or image area which uses display elements such as points, line segments, and/or alphanumeric characters to construct the display. This term usually refers to a CRT but also includes such devices as plotters, microfilm records, and page printers.

DISPLAY DEVICE COORDINATE SYSTEM: The set of numerical values assigned to the addressable points on the display surface.

DISPLAY ELEMENTS: The basic hardware-generated functions, such as points, line segments, characters, etc., produced by the display writer, used to construct a display image. Display elements can be combined to form display entities; e.g., line segments combined to form a square.

DISPLAY FILE: (See DISPLAY DATA, definition 2).

DISPLAY FOREGROUND: The collection of display elements, entities, and/or groups of a display image that are subject to change by the program or by the use in interactive mode.

DISPLAY FRAMES: Analogous to the successive frames in a motion picture film.

DISPLAY GROUP: A collection of display entities which can be manipulated as a unit and which can be further combined to form larger groups.

DISPLAY IMAGE: The collection of display elements, entities, and/or groups that are visually represented together on the viewing surface of a display device. Only one display image can be presented on a device's viewing surface at any one time.

DISPLAY MENU: (See MENU).

DISPLAY PANEL: A display image for use in the interactive mode. Panels usually include a menu.

DISPLAY SURFACE: That medium (paper, film, CRT screen, etc.) upon which the display writer produces a display image.

DISPLAY SPACE: The area defined by the display device coordinate system.

DISPLAY WRITER: The part of a display device used to create a visible mark on the display (e.g., ballpoint pen, liquid ink stylus, cutting stylus, laser beam, or electron beam).

DRUM PLOTTER: A plotter which draws an image on a recording medium (paper, film, etc.) supported by a drum; the plotting head moves parallel to the line of rotation for one axis while the drum rotation provides the other axis.

FLATBED PLOTTER: A plotter which draws an image on a recording medium (paper, film, etc.) affixed to a flat table.

FLICKER: A blinking or pulsation of a display image on a CRT. Flicker occurs when the refresh rate is so low that regeneration becomes noticeable.

FLYING SPOT SCANNER: A system that encodes a picture by raster scanning and recording the brightness at each addressable point.

FUNCTION BUTTON: (See FUNCTION KEY).

FUNCTION KEY: A push button or switch which may be pressed to send an identifiable interrupt to the display control program.

FUNCTION KEY BORAD: An input device for an interactive display console consisting of a number of function keys.

FUNCTION MENU: (See MENU).

GAS PANEL: (See PLASMA PANEL).

GRAPHIC (adj.): The adjective "graphic" can be used in place of the adjective "display" in the terms in this glossary. "Graphic" usually refers to those devices which draw lines and points.

GRAPHIC DATA: (See DISPLAY DATA).

GRAPHIC LANGUAGE: The software interface between the programmer and the display device.

GRAPHICS: The art of image generation and manipulation. "Graphics" usually applies to computer-generated displays which contain lines and points. However, the term has been used to indicate displays containing only alphanumeric data.

Interactive graphics is a technique of using a display console in the interactive mode.

Passive graphics is a technique of using a display device in the passive mode, usually associated with plotters and microfilm recorders.

HARD COPY: A permanent copy of a display image.

HELP MODE: (See PROMPT MODE).

HIDDEN LINES: Line segments which are obscured from view in a projected image of a three-dimensional object.

IMAGE: (See DISPLAY IMAGE).

IMAGE SPACE: (See DISPLAY SPACE).

INCREMENT SIZE: (See PLOTTER STEP SIZE).

INCREMENTAL VECTOR: (See RELATIVE VECTOR).

INTENSITY LEVEL: One of the discrete levels of brightness of the light emitted by a CRT, usually under program control.

INTERACTIVE GRAPHICS: (See GRAPHICS).

INTERACTIVE MODE: A method of operation that allows on-line man-machine communication. Commonly used to enter data and to direct the course of a program.

JOY STICK: A level that can be moved in at least two degrees of freedom and which moves one or more display elements by providing coordinate input to the display.

LIGHT BUTTON: A display element which may be selected by an input device and is programmed to operate as a function key (also called VIRTUAL PUSHBUTTON).

LIGHT GUN: (See LIGHT PEN).

LIGHT PEN: A stylus which detects within a limited area (e.g., aiming circle) light generation on a CRT. Also see LIGHT PEN DETECT.

LIGHT PEN DETECT: The sensing by a light pen of light generated on a CRT. It can provide an interrupt which may be interpreted by a display control program to determine either positional or display element identifying information.

LINE SEGMENT: A finite section of a line, usually described by its end point.

LINEARITY: A measurement of straightness of a plotted line segment.

MAPPING FUNCTION: A transformation which converts all the points of one coordinate system into another.

MENU: A list of options on a display allowing an operator to select his next action by indicating one or more choices with an input device.

MODEL: The representation in computer storage of all relevant application data.

MODEL SPACE: The coordinate system of the model's geometric data.

MOUSE: A hand-held device, with two perpendicular wheels, which is rolled around on a flat surface to provide coordinate input to the display device. (See CONTROL BALL).

ORIGIN: A reference point whose coordinates are all zero.

PAGE: In graphics, a single display image of a set of display images. These display images are usually alphanumeric text.

PAGING: In graphics, the process of replacing one page with another page. Usually the pages are displayed in consecutive order, either forward or backward.

PARALLAX: The apparent displacement of an object as seen from two different points; e.g., the difference between where the eye perceives an object and where the light pen can perceive it.

PASSIVE GRAPHICS: (See GRAPHICS).

PASSIVE MODE: A method of operation that does not allow any on-line interaction or alteration.

PFK: Program Function Key.

PFKB: Program Function Key Board.

PHOSPHOR: The chemical coating on the inside face on a CRT which glows with visible light when energized by an electron beam.

PLASMA PANEL: A display device consisting of a flat, gass filled panel containing a grid of wires. Energizing grid intersection points ionize the gas, thus emitting light.

PLOTTER: A device for making a permanent copy of a display image.

PLOTTER STEP SIZE: Length between two adjacent addressable points in the horizontal or vertical direction. This is analogous to a raster unit on a CRT. Also called increment size.

PLOTTING HEAD: A display writer used on mechanical plotters.

PROGRAM FUNCTION KEY: (See FUNCTION KEY).

PROGRAM FUNCTION KEY BOARD: (See FUNCTION KEY BOARD).

PROMPT MODE: Prompting using separate display panels.

PROMPTING: The method of informing the user of possible actions.

RASTER SCAN: A technique for generating or recording an image with an intensity controlled, line-by-line sweep across the entire display surface. (This technique is used to generate a picture on a TV set and to digitize an image with a flying spot scanner.)

RASTER UNIT: The distance between two adjacent addressable points in the horizontal or vertical direction on a CRT display. Analogous to plotter step size.

REFRESH RATE: The rate at which a display is regenerated.

REGENERATION: The process of repeatedly displaying an image on a CRT display device. Since the image is retained by the phosphor for only a short period of time, the image must be regenerated in order to remain visible. (See REFRESH RATE and FLICKER).

RELATIVE VECTOR: A vector whose starting point is the end point of the preceding display element; and whose end point is specified as a displacement from the starting point.

REPEATABILITY: A measure of the hardware accuracy of the retrace of a display element.

RESOLUTION: 1. Plotter step size or raster unit. 2. The smallest distance between two display elements which can be visually detected as two distinct elements.

ROLLING BALL: (See CONTROL BALL).

RUBBER-BANDING: A technique for displaying a straight line which has one end fixed and the other end following a stylus or other input device.

SCALING: Transforming one or more display elements by multiplying all dimensions by a constant value, thus magnifying or reducing these elements in a display image.

SCISSORING: Removing parts of display elements which lie outside defined bounds.

SCROLLING: The continuous vertical or horizontal movement of display elements within a window. As new data is moved into the window at one edge, the old data is moved out at the opposite edge. The window may include the entire display.

SKIATRON TUBE: A CRT whose electron beam causes a phosphor surface of a tube to darken rather than brighten. The image is viewed by illumination from the rear in a dark trace against the otherwise transparent or translucent face of the tube.

STORAGE TUBE: A CRT which retains an image for an extended period of time without regeneration.

STYLUS: A hand-held object which provides coordinate input to the display device.

TABLET: An input device which digitizes coordinate data indicated by stylus position.

TRACKING: Following or determining the position of a moving input device; (e.g., the writing tip of a stylus).

TRACKING SYMBOL: A cross or other symbol in a display used for indicating the position of a stylus.

UNBLANKED ELEMENT: A visible display element. (cf. BLANKED ELEMENT)

VECTOR: A directed line segment (i.e., one in which one end point is identified as the initial point, and the other end point as the terminal point). (See RELATIVE VECTOR and ABSOLUTE VECTOR.)

VIRTUAL PUSHBUTTON: (See LIGHT BUTTON).

VOLTAGE PENCIL: (See STYLUS).

WINDOW: A bounded area within a display image that contains a scissored subset of the displayable data of the model.

ZOOMING: Continuous scaling of all elements of a window to give the appearance of moving towards or away from the object of interest.

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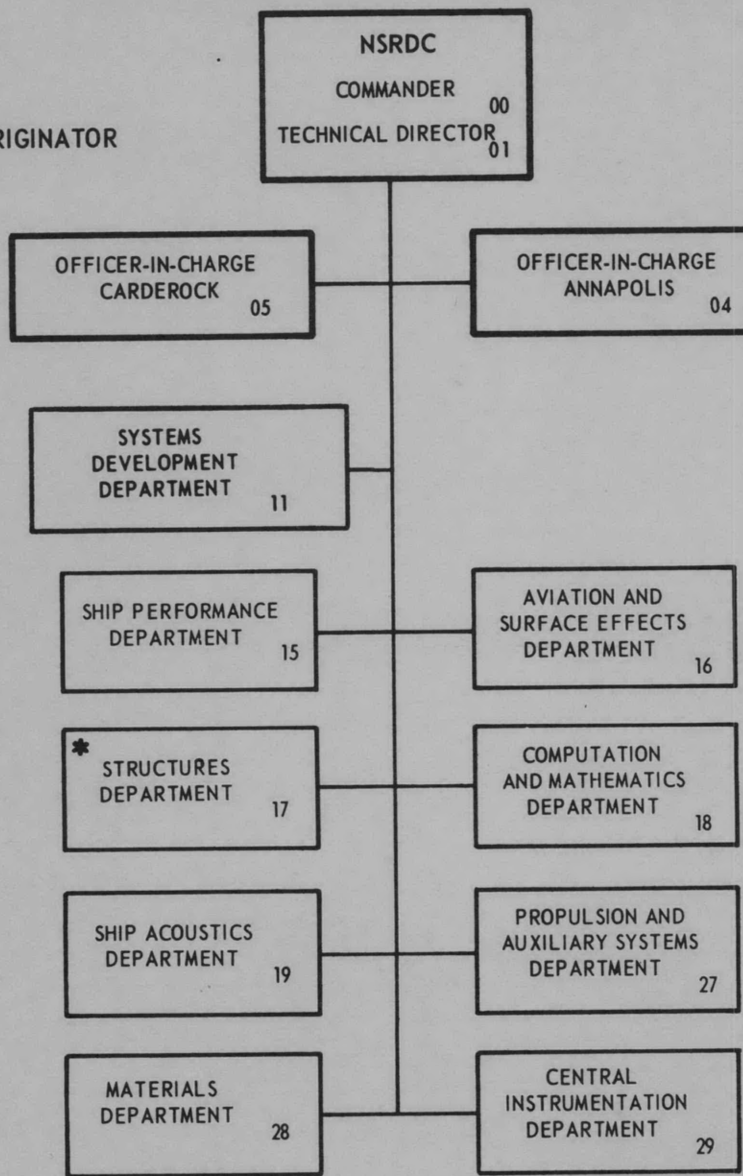

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