STATE OF THE COMPUTER GRAPHICS ART
IN THE UNITED STATES

1. INTRODUCTION

In the United States, Cathode Ray Tube Graphic Terminals have been associated with digital computers for the past decade or so. Initially, the terminals were used in military command and control systems. For example, in the mid-fifties, the SAGE System (an air defense system) used CRT terminals which were not grossly different from present day units.

However, the use of CRT graphic terminals in a non-military environment is relatively new. The digital system historian, if there were such a discipline, would probably date this application of CRT terminals to the pioneering work done by Dr. Ivan Sutherland on Sketchpad(1) in the early 1960's. My company, for example, has been involved in computer controlled display systems since 1960 and, I must admit, that for several of the early years we felt that we had a cure for which there was as yet no known disease.

Today, however, the use of graphic terminals in both research and profit-making environments is growing rapidly. This Seminar, for example, is typical of those which have blossomed out during the past few years in the United States to reflect the growing interest in graphic terminals. Pro-

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fessional societies, such as the Society for Information Display and UAIDE, have been formed to service the interest of workers and users in the field. The older professional societies, such as ACM and AIEE, have recognized the importance of graphic terminals by creating sub-groups whose primary area of interest are these devices. All of these are surface indications of the growing importance of this tool. One authority estimated that in five years, about 13¢ out of each computer dollar would be spent for CRT terminals.

How many CRT graphic consoles are now installed, or are on order? How does this compare with the situation five years ago? Frankly, I don't know. I have not been able to find reliable statistics. Based on the information I do have, however, I would take an educated guess that there are probably 500 to 1000 graphic consoles now installed or on order. In 1964 there were probably no more than 100. If the authority cited earlier is correct, there will be a billion dollars worth of terminals bought in 1973. Assuming that the average price is $50,000......20,000 terminals will be sold that year. It is an interesting number but I cannot vouch for the accuracy. In any case, the present is bright, and the future is exciting.

In this presentation, I will: review with you some of the applications in which the CRT graphic terminal is currently being used and where it appears to hold promise for future use; describe some of the commercially available U.S. hardware; prognosticate a bit on future developments; and finally, make some comments about the software aspects of CRT graphic displays.

You have heard from previous speakers, and you will hear from speakers following me, detailed discussions of much of the material that I will briefly discuss at my presentation. All of the topics: what has computer graphics to offer, hardware techniques, software techniques, trade-offs, low cost graphics, mechanical and circuit design, are all being reported to you by leading experts in the field. My task, therefore, is more in the nature of a summary....to share with you my thoughts about how all of these activities fit into a pattern, if any, relative to activity in the United States.

2. APPLICATIONS

How is computer graphics being used commercially in the United States today? In this section, I will discuss applications in the following categories:

Computer Aided Design
Management Information
Simulation
Process Control
Computer Aided Education
Pattern Recognition
Graphic Arts
Computer Generated Movies
Others

COMPUTER AIDED DESIGN

In the areas of computer aided design, there appear to be several developing applications. Mechanical design (including numerical control) is exemplified by the work of Lockheed-Georgia and General Motors.

Aircraft Industry

There is, for example, a representative at this meeting who will be talking about Lockheed's efforts in the area of mechanical design using graphics. As an indication of the extent to which this work is being done, consider a recent trade press report[2]:

"Interactive graphic displays...is being used by Lockheed-Georgia Company, a division of Lockheed Aircraft Corporation, for numerical control part programming of continuous path machines. The procedure replaces APT (automatic program tools) programming system and makes it possible to produce a verified part program in as little as one hour. The system is being used to produce C5 parts and tooling jigs. 'We have programmed about 50 parts for the C5', says tooling supervisor, C. F. Nicks, 'and more than 300 tooling jigs.' By drawing the cutter path over the part blueprint displayed on a CRT, the designer tells the computer to set up a proper program to cause that particular action. The computer than displays the path it has programmed so that the designer can see that it is correct."

Indications are that other aircraft companies, particularly McDonnell-Douglas and Boeing, are also using displays in this way.

Automotive Industry

Outside of the aircraft industry, perhaps the best known program of computer aided design using graphic terminals has been mounted by General Motors with DAC (Design Augmented by Computer). DAC has been an active program with General Motors since 1962 and the work has strongly paralleled the original concepts of the Sketchpad.

In describing the justification for the DAC system, Edward L. Jacks of General Motors, asks,[3]:

"When you consider both man's and computer's time to do a job, is such a time sharing system any faster than the old method of processing computer jobs one at a time?

From the user's point of views, is the random time shared approach more efficient than the carefully pre-planned 'batch-processing system?' For both questions, the answer is a definite yes; it may be eight to ten times faster using time shared consoles based on actual operating experience with the GM DAC-1."

Indications are that General Motors is now using these systems in the design of their current automobiles.

Figure 1 is a typical drawing made with the DAC system.

There is some indication that other automobile companies are beginning research in these areas; apparently Ford Motor, for example, has developed programs for designing windshields.

Integrated Circuits

One other specific area of computer aided design which graphic consoles are making significant inroads, is the design of integrated circuits. Much of this work was pioneered by the Norden Division of United Aircraft working in conjunction with IBM. Motorola's efforts in this area have been reported in the trade journals(4). Other integrated circuit manufacturers who have begun to show an active interest in the use of Cathode Ray Tube terminals for integrated circuits include RCA, GE, Fairchild Semi-Conductor and Texas Instrument.

Textile Design

Not all computer aided design projects are limited to the drab world of manufacturing. Perhaps one measure of the increasing use of computer graphics is the inclusion in the IBM Pavilion in HemisFair 68 (Houston, Texas) of an IBM 2250 linked to a 360-30(5). During this demonstration, a computer system will be weaving a cloth in designs done by visitors. The visitor uses a light pen to draw a design on the display screen and indicates what types of weaves he wants used in different parts of the design. The information is then translated into instructions for an 11 foot high loom. Colored threads are automatically introduced into the weaves by the loom. The output of the system is a 3 inch square swatch of fabric for the person who designed it. In the application, the designer is able to select a weave from a library stored in the computer and have it inserted in all appropriate areas of the design simultaneously. Figure 2 shows a textile designer at work.

Conclusions

Certainly many of these computer aided design applications are still in the experimental stage. A U.S. Government report[6] commented:

> "All of the installations currently using this type of equipment are classed as experimental...graphic console... are still several years away from general operational usage."

If we were to modify that statement as it might apply now, three years later, we could say that most of the installations currently using this type of equipment are classed as experimental. However, in selected applications, the past experimenting was completed successfully and the equipment is now being used in a profit making environment. Further, we can fairly say that graphic consoles are beginning to come into general operational usage.

Current users claim reductions of from 2 to 1, to 6 to 1 in the time required to perform certain design functions. There is more than sufficient justification for management interest in this type of increased productivity[7].

MANAGEMENT INFORMATION SYSTEM

The complexity of the job to be done by the modern manager has led to great interest applying computer graphics. Westinghouse now uses an on-line system (consisting of a UNIVAC 494 and a IDI display) for sales forecasting and production planning of their washing machine line. It is reported that Boeing has installed a graphic management information system which allows such things as on-line PERTing. Boeing also installed a similar system for the Air Force. Systems Development Corporation has implemented an on-line system in a time sharing environment.

It will be instructive, I think, to examine in some detail the manner in which the Westinghouse and SDC systems have been implemented. These demonstrate some of the characteristic features of interactive displays in this type of environment.

Primarily, the display is used as a "what if" device. It allows the manager to ask the question "what if?" in the context of changing inventory levels, changing production levels, and a variety of other things which are so much a part of the management environment. In this environment, the problem is to create a tool with which the non-computer specialist can work comfortably. The tool requires presentation of the problem in the non-specialist's language and the translation of non-specialist's decisions and questions (made in a form most convenient for him), back into computer language.

In the Westinghouse application, for example, all parameters of the problem are initially presented to the manager in a form of a light pen menu, Figure 3. By pointing the light pen at the information on the CRT, the manager can choose a period over which he wants the information displayed, can choose the item for which he wants the data shown, and can specify the form in which the information is to be presented. The displayed data, Figure 4, can be manipulated by light pen and keyboard. In this way, the manager conveniently moves back and forth within data base, asking "what if", and making decisions. Although the data is computer generated, it is presented in the form with which the manager is intimately familiar. He need not learn a new language in order to communicate with the computer. And his response from the computer is fast enough so that he doesn't forget his original "what if" question.

The Systems Development Corporation in Santa Monica, California, has been developing a display system over the last several years for use in a time sharing environment. Their system, using a prototype program called DISPLAY, is designed to provide automatically determined standard graphic presentation in response to the user's light pen inputs. An underlying principle in the design of the display was to make the scope face serve as a helpful guide to the user in creating a display.

For example, to achieve a simple scatter plot, like that shown in Figure 5, the user provides the DISPLAY with five light pen actions. It takes two inputs to specify the X variable, two to specify the Y variable, and one to cause the program to exit. Axis scaling, axis labelling, data scaling, data plotting, are all performed by the program. The user may browse through his data base under light pen control. Figure 5 illustrates some of the flexibility of the display. The picture was achieved by moving through a series of light pen control in a prior display. Titling, axis labelling and graduation, as well as the scaling of the data, were automatically performed by the program after the title and labels were selected. The control button at the bottom of the scope allows the user to read out the value at a specific point. Notice at the bottom of the picture are the exact values of assessed valuation and taxes at the point located with the cross hatch. The user may also delete data labels or titles. The light button AXIS SCALE permits the user to re-scale his data to examine some area of particular interest to him. Other light buttons include: SAVE (permits the user to put a picture and data away on peripheral storage for subsequent examination);and START-OVER (the escape hatch necessary to recover from unfortunate use of the various touch-up options).

SIMULATION

Simulators are using CRT terminals as the output device and have become fairly widespread. Included in the pioneer work is the SKETCHPAD program which allowed simulation of a bridge design. The structure was drawn on the face of the CRT and calculated. Compression or tension in each member were displayed. With a light pen, the experimentor could modify the design by adding or removing structural members. The structure would be recalculated and the new values displayed at the appropriate locations.

Boeing has used computer graphics effectively to simulate the view through the windshield of a airplane to study the visibility problems during refueling operations. On-line problem solving is a kind of simulation. The Bolt, Beranek, Newman Teleputer System which has been in operation for the last few years, allows conversation between the scientist (or student) and the data base, allowing them to solve problems by computer aided techniques.

Dr. Edgar Meyer, formerly of MIT and now with Texas A&M, and Prof. Cyrus Lerinthal, formerly of MIT and now with Columbia, have developed programs which display crystallographically determined structures on a CRT. Inputs to the system include normally published, experimentally determined parametric data (name and coordinates for each atom in the assymetric unit, as well as cell constants and space group number from this International Table, together with connectivity tables). A molecule is represented by connecting bonded atoms with a visible line. Also, the assymetric unit or the contents of the unit cell may be displayed together with the edges of the cell. The perception of the third dimension is greatly enhanced by slowly rotating the display. It is expected that this technique which is now experimental, will find significant application among the pharmaceutical companies. Great insight into chemical structures can be achieved with this kind of simulation.

Closely akin to the simulator applications are those in which the display is used to monitor simulated or on-line tests. For example, the graphic displays allows comparison between standard test data and the actual test data being received. One such system is installed in the NASA Space Flight Center and this computer controlled dynamic test system provided vital data on the Saturn IV Moon Rocket structural response to the stresses of flight. Systems Engineering Laboratories designed and built this system to simulate the vehicle flight dynamics in a laboratory environment. Data from shake testing was used to prepare mathematical models for simulation of actual flight conditions for both the vehicle and guidance systems.

IDI has installed similar graphic systems at ARO for on-line monitoring in wind tunnel tests.

PROCESS CONTROL

Two power companies in the United States, one in San Antonio and one in Houston, are in the process of installing CRT displays to be used instead of the traditional status board common in the industry.

David E. Weisberg recently described typical applications of display consoles in process control[8]. Graphic equipment can be used in closed-loop processes (as typified by refining units in the oil industry, nuclear reactors, chemical plants, paper making machines, cement kilns and blast furnaces) to monitor past and projected future action of several variables. Figure 6 shows a representative display of this type. Open-loop processes, requiring operator intervention (such as a chemical or oil movement system) can be controlled by a graphic console using presentations like those shown in Figure 7. In such systems, the operator can control pumps and valves by pointing a light pen at the symbolic representation on the CRT.

The computer accepts this command, sends out appropriate signals to accomplish the operation and displays the results by modifying the movement pattern. Without the line drawing console, the status display would usually be wall mounted. In a very large system, it would probably be limited in detail with the status of valves, pumps and switches indicated by colored lights. The flexibility of the CRT display system permits the operator to use a large or smaller section of the total process, as he desires. The amount of detail increases as he works in smaller sections.

COMPUTER AIDED EDUCATION

In the last two years, there have been several programs in computer aided education under development, where the individual student interacts with the computer via a CRT. Now, there are at least three such public school experimental installations in the United States. At the Brentwood School in Palo Alto, California is an installation using the IBM 1500. The New York School system is engaged in a program with RCA and Philco-Ford has installed a system for the Philadelphia schools.

Two major problems which seem to stand in the way of broader acceptance of CRT terminals in the computer aided education environment are (1) the writing of programs, (2) the terminal cost. Some estimates indicate that the terminal costs give rise to an expenditure of about two or three times that normally encountered in the usual elementary school environment. However, the costs become much more competitive when compared to the university environment and become very attractive when compared with the costs occurred in specialized training situations, such as the military.

Each programs seems to be directed at somewhat different levels. For example, the program at Brentwood involves experiments with a group of slightly more than 100 first graders, while the Philco program is at the high school level and is currently used in teaching 10th grade biology and 9th grade remedial reading[9].

Several universities, including UCLA, Harvard, University of Wisconsin and University of Minnesota, have continuing programs of computer aided education.

PATTERN RECOGNITION

Computer graphics is helping to solve the general problem of pattern recognition. Various kinds of film (reconnaissance, X-ray, or bubble chamber, for example) are digitized and the data processed by computer. Using various correlation techniques, programs are developed which allow the computer to abstract significant information from the pictures. One may wish, for example, to detect man-made objects or special particle tracks, or the presence of a tumor. The display is useful because it permits rapid comparison between the raw data and the computer decisions. In more sophisticated systems, the programs can be refined on line by experimentor using his light pen. Scientists at Albert Einstein College of Medicine and Columbia University are working with these techniques. A bit more than 1984ish, perhaps, is the use of a display to monitor the performance of experimental robots[10]. At Stanford Research Institute in Menlo Park, California, for example, a "baby" robot is learning to navigate in a cluttered room. Although, at the moment, the experimental machine can only move from one point to another through a room full of obstacles, it is hoped that in the future the device can be developed to carry on much more complex instructions, such as moving all of the waste baskets from Room 217 to Room 321. It will be necessary for the robot to recognize objects and a display is being used now to monitor the performance of the robot in this respect.

GRAPHIC ARTS

From many indications, a revolution is quietly taken place in the graphic arts industry. The third generation of equipment involving cathode ray tube displays and film processing systems is predicted by some to mean the death of hot lead within the next five years. Characteristic of these systems is the ability to produce extremely graphic quality characters at high rates of speed. The RCA Videocomp, for example, can put 1000 characters per second on film or photosensitive paper. These rates mean that a complete newspaper page can be composed in about 10 minutes. Systems are also produced by Alphanumeric, Inc., Harris Intertype in a joint effort with CBS Laboratories, and Merganthaler. Business Week estimates these electronic devices have made photocomposition a $250,000,000 a year market.(11) In the future, some experts expect that graphic consoles will begin to play a part in the edit and compose functions.(12),(13)

Art directors and illustrator will probably work on the face of the CRT displays rather than on paper. Although final art work may still be prepared by these conventional materials and inserted into the system by electronic scanner, CRT display unit would be excellent for sketches and preliminary studies. The art work could be displayed simultaneously in several newspaper editorial offices, discussed by telephone and revised on the spot by any of the participating editors. Further, the art director could insert graphic specifications into the system from his console for accurate page make-up and can receive proof for verification within seconds. He could either review these proofs on his display screen or obtain a hard copy print from a character generating proving unit.

COMPUTER GENERATED MOVIES

Bell Laboratories is playing a leading role in the production of computer generated movies,[14] some of which can be characterized in the simulation field. Among the films that have been produced include films on harmonic phasors, produced by Professor William H. Huggin of Johns Hopkins University, and Professor Donald D. Weiner of Syracuse University. This film concerns the composition of complicated periodic wave forms by adding projections on an axis of rotating vectors or "phasors". The result is the presentation of a basic lesson in electrical engineering done in a way that is much more graphic than can be done on a blackboard. One of the classic computer films was first produced by Bell Laboratories in 1963 by E. E. Zajac and showed the result of the simulation of the motion and communication satelite. Another film produced by D. E. McCumber was especially useful to the investigator in studying Gunn-effect instability, which had been implicit in, but not immediately apparent from, the mathematical description of the phenomenon.

The Boeing Company, Los Alamos Scientific Laboratory and Lawrence Radiation Laboratory have also been very active in the areas of computer graph movies. A group has been formed in the United States which actively supervises the production of films in several universities. This group, The National Committee for Electrical Engineering Films (NCEEF) is chaired by Professor John Brainerd of the University of Pennsylvania.

One of the attractive features of computer generated films is the relative economy. The technique makes feasible the production of some kinds of films which previously would have been far too expensive and/or difficult. Typical films so far produced have fallen in the range of $200 to $2000 per minute.

The cost of corresponding hand-animated films would have been at least twice as much in the simpler cases, and in other cases would not have been possible at all without a computer.

OTHER

In addition to the specific applications described earlier, it will be of interest, I think, to review some of the uses for graphic consoles being investigated by many universities in the United States. This list is representative rather than inclusive, and is meant only to give an indication of the thrust of academic research:

Albert Einstein College of Medicine....medical research.

Brown University....3D presentation.

University of California (Berkeley)....graphic consoles are being used in the development of a natural language, as well as in a research environment.

UCLA....computer aided problem solving and instruction.

Columbia University....pattern recognition in conjunction with nuclear research.

Harvard University....computer aided problem solving and instruction.

University of Illinois....during this Seminar, Professor W. Gear will describe a project using a graphics terminal for program writing.

Illinois Institute of Technology....on-line problem solving

Massachusetts Institute of Technology....general problems of man-machine interaction.

University of Michigan....development of programming languages.

New York University....computer aided design.

University of Ohio....nuclear research.

Pennsylvania State University....underwater technology studies.

Reed College....medical research.

Stanford University....computer aided learning.

University of Utah....displays are being used in computer aided design, architectural design, and medical research.

And there are more applications of graphic consoles. For example, music is being composed...animated cartoons are being drawn...aircraft proposals are being developed...proposed building designs are being shown to prospective clients. Implicit in these, and many other applications, is the use of graphic consoles in the time-sharing environment.

3. HARDWARE

CRT Terminals

There are some 17 United States manufacturers producing direct view CRT consoles suitable for computer graphics. See Table 1.

TABLE 1

U.S. MANUFACTURERS OF COMMERCIALLY AVAILABLE CRT GRAPHIC TERMINALS

Adage
Bolt, Beranek & Newman, Inc.
Bunker-Ramo Corporation
Computer Displays, Inc.
Control Data Corporation
Digital Equipment Corporation
Information Displays, Inc.
Information International, Inc.
International Business Machines Corporation
International Telephone & Telegraph Corporation
Philco-Ford Corporation
Sanders Associates
Scientific Data Systems, Inc.
Stromberg-Carlson Corporation
Systems Engineering Laboratories, Inc.
Tasker Instruments Corporation
UNIVAC

To this could be added a number of manufacturers producing alphanumeric systems...but this discussion will be limited to graphic consoles.

The performance range of these systems is indicated by Table 2.

TABLE 2[15]

RANGE OF PERFORMANCE

COMMERCIALLY AVAILABLE GRAPHIC CRT TERMINALS

Function	Quantity Per Frame (Based on 40 Frames/Sec)
Random Dots	250-8300
Incremental Dots	2500-25,000 (assuming random, not raster, scan)
Random Characters	125-5000
Incremented Characters	220-8300
Connected Line Segments (Fixed Time Vector Generator)	160-830 (depending on Vector Generator, this can represent up to 16,000 inches per frame)
Connected Line Segments (Proportional Vector Generator)	160 inches - 50,000 inches
Circles	80-250
Price	$20,000 to $300,000

NOTE: Quantities shown exclude Display Generator, Computer and Memory Logic and/or cycle times, which can reduce data per frame by up to about 20%.

Ronald A. Siders presented an excellent summary of the requirements for an active graphic system.[7] He states, in part:

> "The first requirement for an active graphic system is to accept graphical input on the scope face. A variety of capabilities of this type have been developed. Existing systems currently accept points, lines, circles, general conics and free-form lines directly on the scope. Geometrically perfect forms can be defined by inputting parameters. Scale can be changed by almost any useful factor. Elements of drawing can be deleted. The drawings can be rotated about any axis giving the illusion of three-dimensions. Dimensions can be automatically calculated and displayed. Components can be duplicated as often as desired and placed in mathematically correct positions (such as teeth on a gear). Orthographic projections can be interchanged with perspectives and isometrics. One of the most powerful capabilities is that of calling up from core a wide range of standard components to add to the design on the scope. A circuit of a standard electronic component can be rapidly laid out. At any point, the design being worked on can be filed away in memory for later recall. In this fashion, parts of the overall design can be worked on independently and called up for examination singly or as a whole."

During the past two years, several distinct trends seem to be developing in commercial hardware available for computer graphics.

Integrated Systems

Several manufacturers produce integrated systems. These are fully buffered consoles which use a small digital computer, both as the display buffer and to do display "housekeeping", so that the load from the central computer can be reduced. Included in this category are the IDI IDIIOM, the IBM Model 2250 MOD 4, the SEL 816A, the Adage Graphic Terminal, Digital Equipment Company's 338 and 339 Programmed Buffered Display, the CDC Digigraphic series, and the Bunker-Ramo BR90. With the exception of the Adage Graphic Terminal, all of these units use digital computers as the programmable memory. The Adage Terminal uses a hybrid computer. Some systems, such as the IDI IDIIOM, include a number of digitally controlled analog function generators, such as, character, line, and circle generators. Others, such as the CDC Digigraphic System, use point plotting displays that depend on software to generate graphic images. Because these units range in price from about $60,000 to about $200,000, they can be classed as low cost systems.

Figure 8 shows one of these typical integrated systems, and Figure 9 is a typical block diagram.

Lower Cost Terminals

Many workers, and potential users in the display field, have felt that broader usage of graphic consoles has been limited by their relatively high cost. In an effort to reduce terminal costs, several approaches have been explored.

Storage CRT

When Tektronixs introduced their $2000 Type 564 Oscilloscope with a 5" storage CRT, several groups began to use it as the heart of a low cost graphic terminal. One of the pioneers was the Bolt, Beranek & Newman Teleputer System (Figure 10). AMTRAM (automatic mathematical translation), a NASA development, was another interactive display system using the small storage CRT.[16] MIT's Electronic Systems Laboratory invested in the development of the low cost graphics terminal which would hopefully sell on the $5000 to $15,000 range.

However, although the terminals were low cost, the small CRT tended to limit its use in graphic applications.

Within the past year, Tektronix has introduced a new larger screen (11" diagonal) storage scope, the Type 611. This scope sells for approximately $2500. And a new company has been formed, Computer Graphics, whose intention it is to produce commercially the MIT design, using the larger Tektronix scope. In fact, also, the Digital Equipment Corporation has just announced the availability of the VD8/I Storage Tube Display Controller. This relatively low cost controller provides the necessary conversion between the digital signals from a small computer, such as the PDP-8, and the analog signals required to drive the storage oscilloscope, such as the Tektronix 611.

In spite of some limitations in the storage tube approach (difficulty of interaction and the presentation of rapidly changing data) the low cost should make it attractive for several applications.

TV Systems

The low cost of a standard TV Monitor has generated interest in producing a graphic display using the TV set as the output. Interactive graphic TV Systems have been produced by Hazeltine, Computer Control Company, Monitor Systems, and Philco-Ford. However, to-date, when the necessary programming is considered, costs have been high.

Low Cost Random Position Monitors

Low cost, wide bandwidth, large screen (17" diagonal) X-Y CRT plotters have been offered by Hewlett Packard (HP 1300A), and Fairchild (736A, no longer in production). Experimental systems, using incremental stroke techniques and wide bandwidth high capacity discs (as the refresh memory) to drive these X-Y plotters, have been developed by Bell Telephone Laboratories, Friden and several research groups. None have yet been offered for sale, however.

Hard Copy Systems

Besides interactive, direct view graphic CRT consoles, another widely used family of computer graphic devices is cathode ray tube plotters. About 100* are currently installed in the United States. Here, the speed of the CRT allows rapid outputs from rapid translation of computer language to pictures....much faster than one can expect to get from mechanical plotters, although certainly not as accurately. A number of manufacturers now offer these on-line or off-line systems. Systems are offered by Stromberg-Carlson (the SC4020 and SC4060), the GEO Space Corporation (TP203), California Computer, Benson-Lehner, CDC (DD80), and IDI. These devices generally incorporate a 16 or 35 mm camera and some kind of immediate hard copy capability, using electrostatic or photographic paper (such as the 3M dry silver paper). Units range in price from approximately $50,000 to $300,000.

* This is another "educated" guess.

Color

Multicolor CRT displays have been of interest. From a practical point of view, only one manufacturer currently offers to the industrial market a CRT terminal with color capability. This is Philco-Ford's series of basic alphanumeric inquiry units that have some graphic capability. These displays use conventional color mask tubes. An experimental graphic system (random positioning) was delivered to the Air Force by Digital Equipment Company several years ago. Hazeltine has produced a color TV system for military inter-traffic control applications.

Last year, Sylvania announced a color tube operating on a completely different principle. Instead of having three guns, each of which is directed toward an appropriate apperture, the tube depends on beam penetration for its color. At one depth of penetration, green is produced and at another depth, red is produced. This type of CRT is also available from Thomas Electronics. Much work still needs to be done to solve the high speed switching and dynamic focusing problems associated with this kind of tube. General Electric has just announced the availability of one of their alphanumeric terminals, the Datanet 760 with this Sylvania type color tube.

Input Devices

One of the powerful features of CRT graphic consoles is the provision for operator input of basically pictorial material. This capability is in addition to Alphanumeric or Function Key inputs.

A number of input devices have been developed and some are now commercially available.(17) Figure 11, reproduced from Reference (17), is an excellent summary of these devices.

Most commonly used is the light pen. Becoming quite popular now is the graphic tablet, of which the RAND unit (produced commercially by the Data Equipment Division of Bolt, Beranek & Newman) shown in Figure 11, is one example and the Data Tablet produced by Sylvania is another.

In addition to the unit shown in Figure 11, several other interesting devices have been reported. Tasker Instrument Corporation has demonstrated a transparent pressure sensitive matrix over the face of the CRT. This allows the user to indicate a point on the face of the tube simply by pressing at the desired location. Early versions of the General Motors graphic system, DAC, used a transparent conductive coating on the face of the CRT so that the location of a stylus would be determined by the stylus voltages.

Three-Dimensional Displays

Interest in three-dimensional displays seems to have diminished somewhat. Work is still being done in the generation of two slightly displaced images that can be viewed as a stereo pair. However, with the possible exception of the use of holography to develope three-dimensional images, (principally by CONDUCTRON), there appears to be very little current U.S. work or interest in 3D.

4. SOFTWARE

Commercial availability of hardware for use with the various applications described earlier continues at an accelerated pace. Special mathematics have been developed to facilitate the solution of some computer aided design problems.[18] However, software perhaps presents a different and not necessarily encouraging picture. A number of different languages, suitable for the generation and display of pictures, have been developed. Other languages have been developed for analysis or interpretation of picture. What is needed, however, is a single language to handle these problems while containing features useful in a general purpose language.

An excellent summary of graphic language requirements is contained in a recent ACM article by H. E. Kulsrud.(19)

There is not as yet a common universally accepted graphic language and it would be foolhardy, I think, to make a prediction about either when such a language will be available, or in what form the language will be. It appears that the development of graphic languages has followed the Tower of Babel that occurred early in computer languages. Each experimentor and user has individually developed ideas and each is not quite ready yet to merge these common universally accepted languages.

5. SUMMARY AND FORECAST

In summary then, the state of the art of graphics in the United States may be characterized as in a transition state, between experiment and operational use. In such fields as aircraft design, integrated circuit design, and high speed printing, the profit making aspects are becoming more common. Systems which can be characterized as low cost graphics are just becoming available.

The thrust of future developments, it seems to me, has three directions. The use of color in graphic terminals.... the further refinement of low cost terminal devices....and the development of a common graphic language.

The presentation of this paper will be followed by a short movie to illustrate various aspects of the State of Computer Graphics in the United States.

6. ACKNOWLEDGMENTS

I acknowledge, with grateful thanks, the contributions of technical material, slides, photos, and films made by the following companies and individuals:

Sally Bowman - System Development Corporation

E. L. Campbell - RCA

Professor Steven A. Coons - MIT (Project MAC)

Frank Hagan - Digital Equipment Corporation

Professor B. Herzog - University of Michigan

John D. Joyce - General Motors Corporation

Dr. H. Kasnitz - MIT (Lincoln Laboratories)

Kenneth C. Knowlton - Bell Telephone Laboratories

Dr. Edgar Meyer - Texas A and M

George Micheals - Lawrence Radiation Laboratory,
Boeing Airplane Company

C. B. Rogers, Jr. - IBM

R. E. Wye - Philco-Ford Corporation

LIST OF FIGURES

FIGURE 1

TYPICAL DRAWING PRODUCED BY

GENERAL MOTORS DAC SYSTEM

FIGURE 2

TEXTILE DESIGN WITH GRAPHIC CONSOLE

FIGURE 3

WESTINGHOUSE LIGHT PEN "MENU"

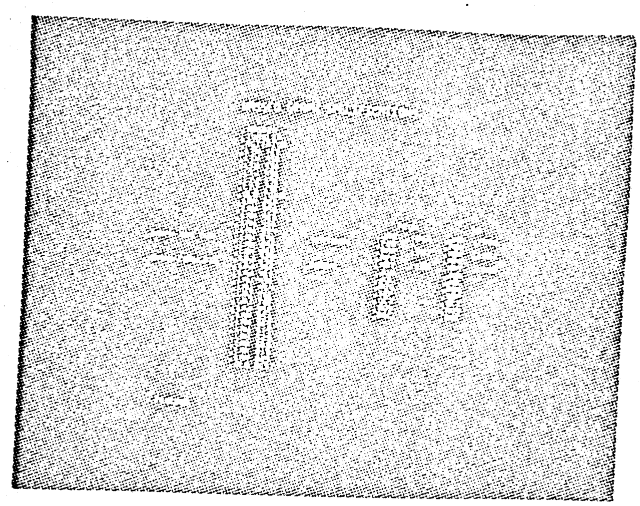


FIGURE 4

TYPICAL WESTINGHOUSE PLANNING GRAPH

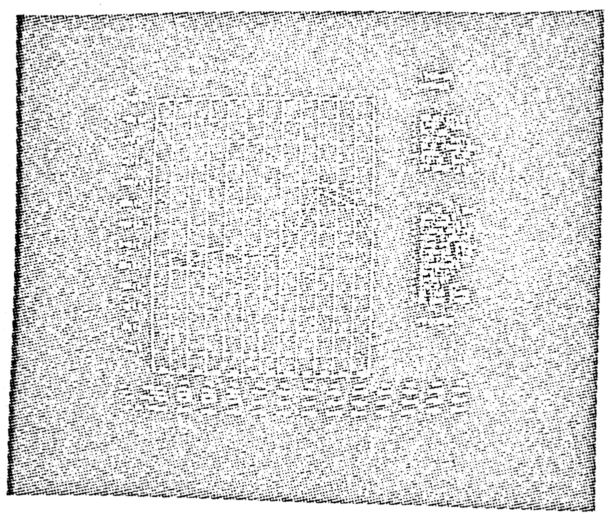


FIGURE 5

TYPICAL SYSTEMS DEVELOPMENT CORPORATION

DATA BASE DISPLAY

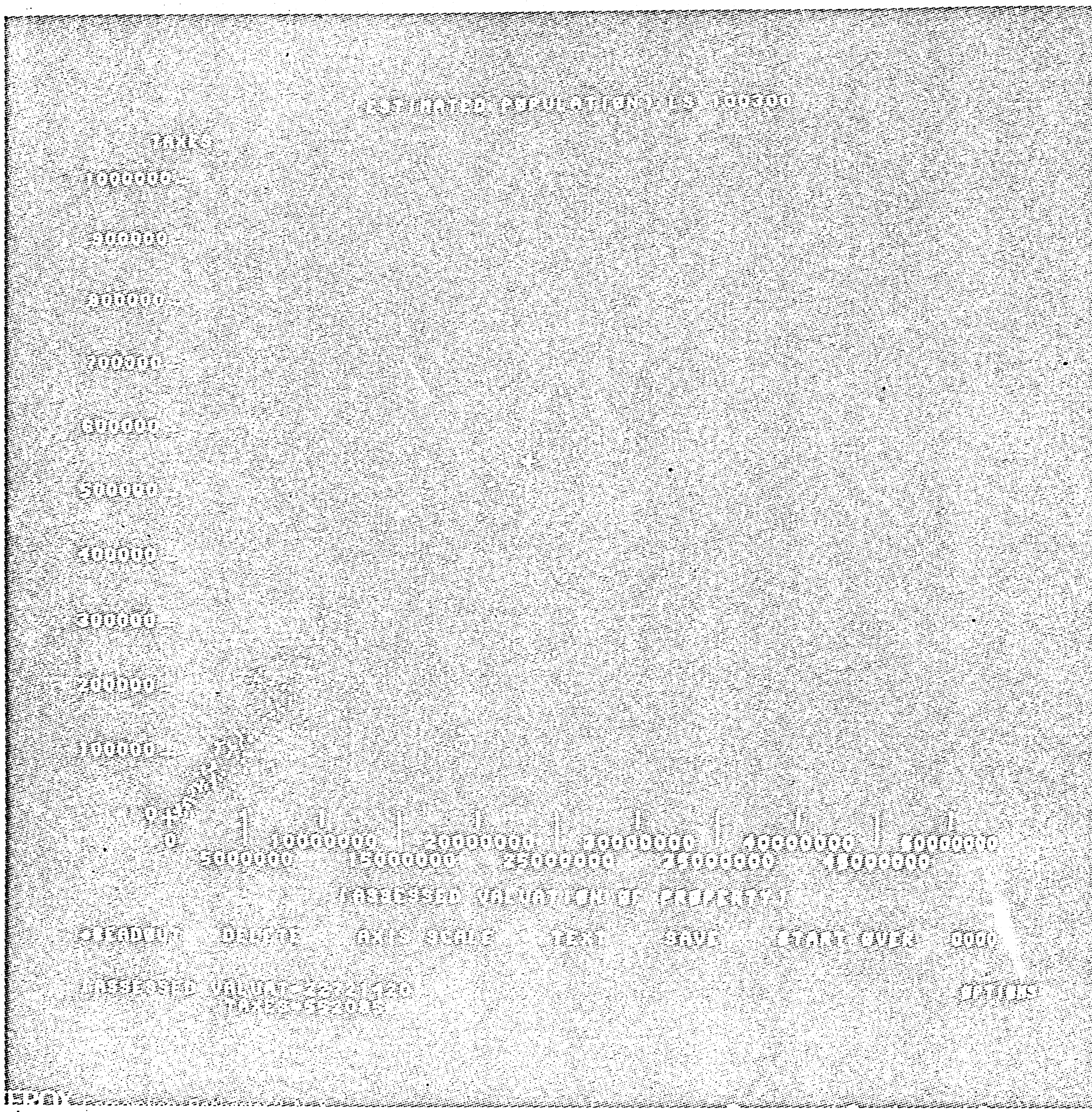


FIGURE 6

TYPICAL CLOSED-LOOP SYSTEM DISPLAY

(From Reference 8)

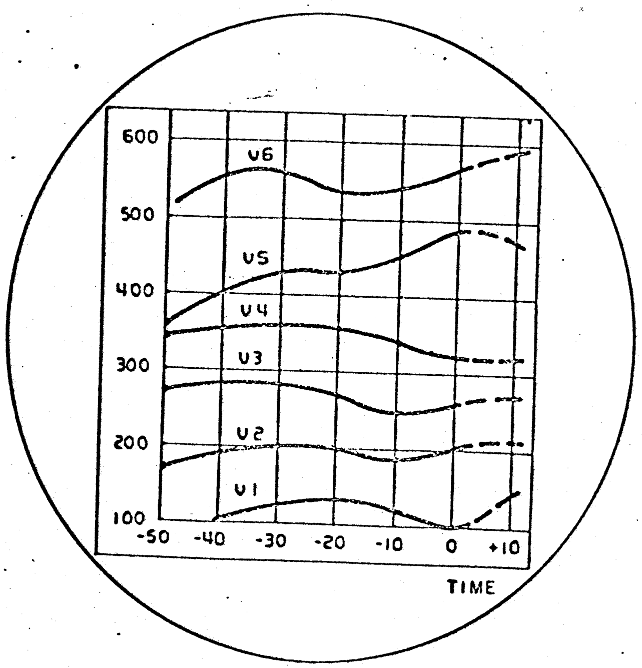


FIGURE 7

USE OF GRAPHIC DISPLAY CONSOLE IN OPEN-LOOP SYSTEM

(From Reference 8)

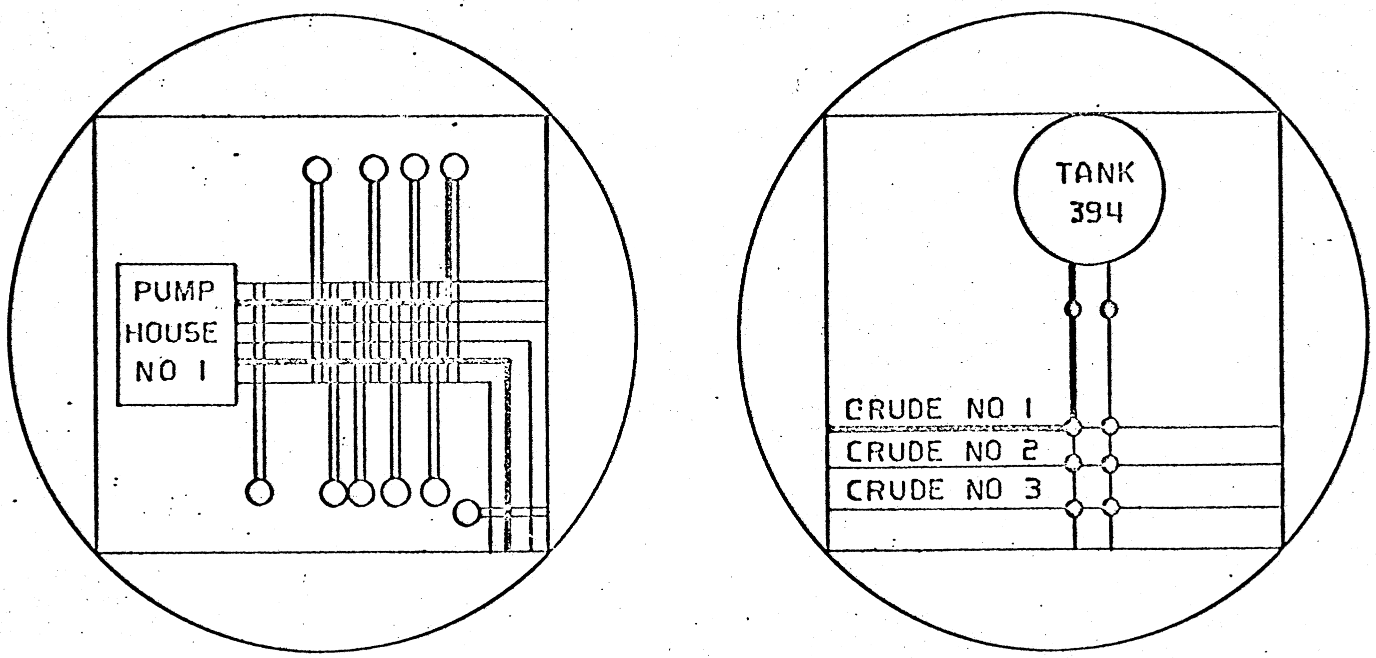


FIGURE 8

IDIIOM

A TYPICAL INTEGRATED GRAPHIC CONSOLE

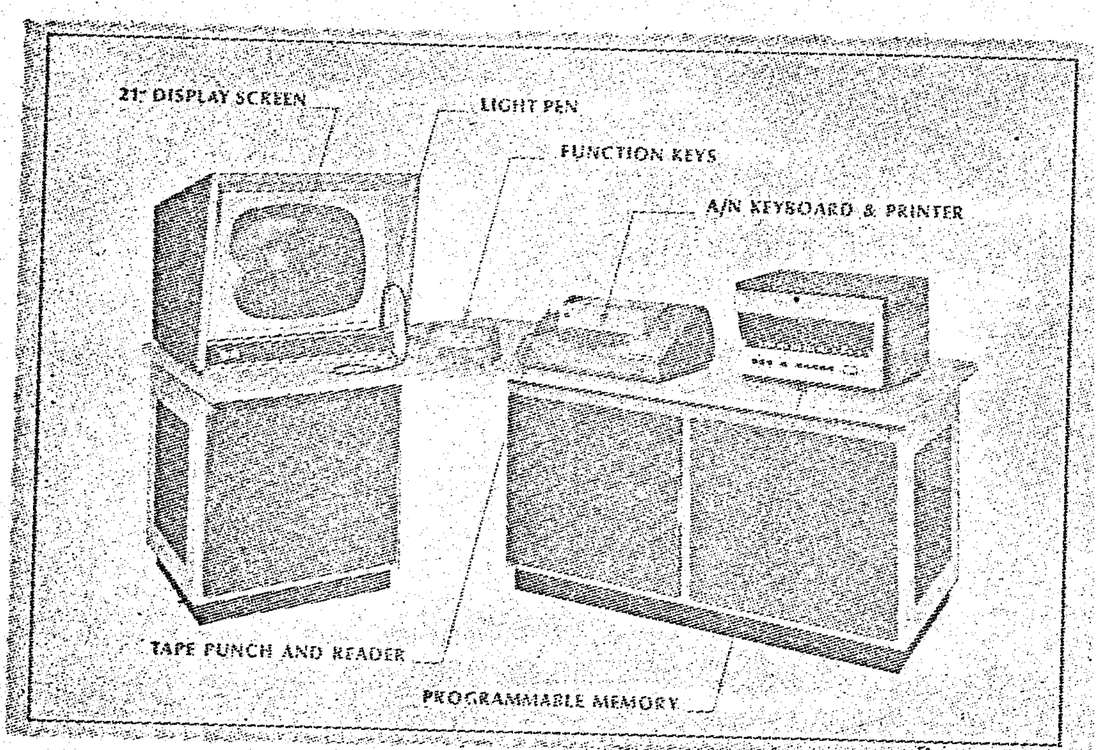


FIGURE 9

GRAPHIC CONSOLE BLOCK DIAGRAM

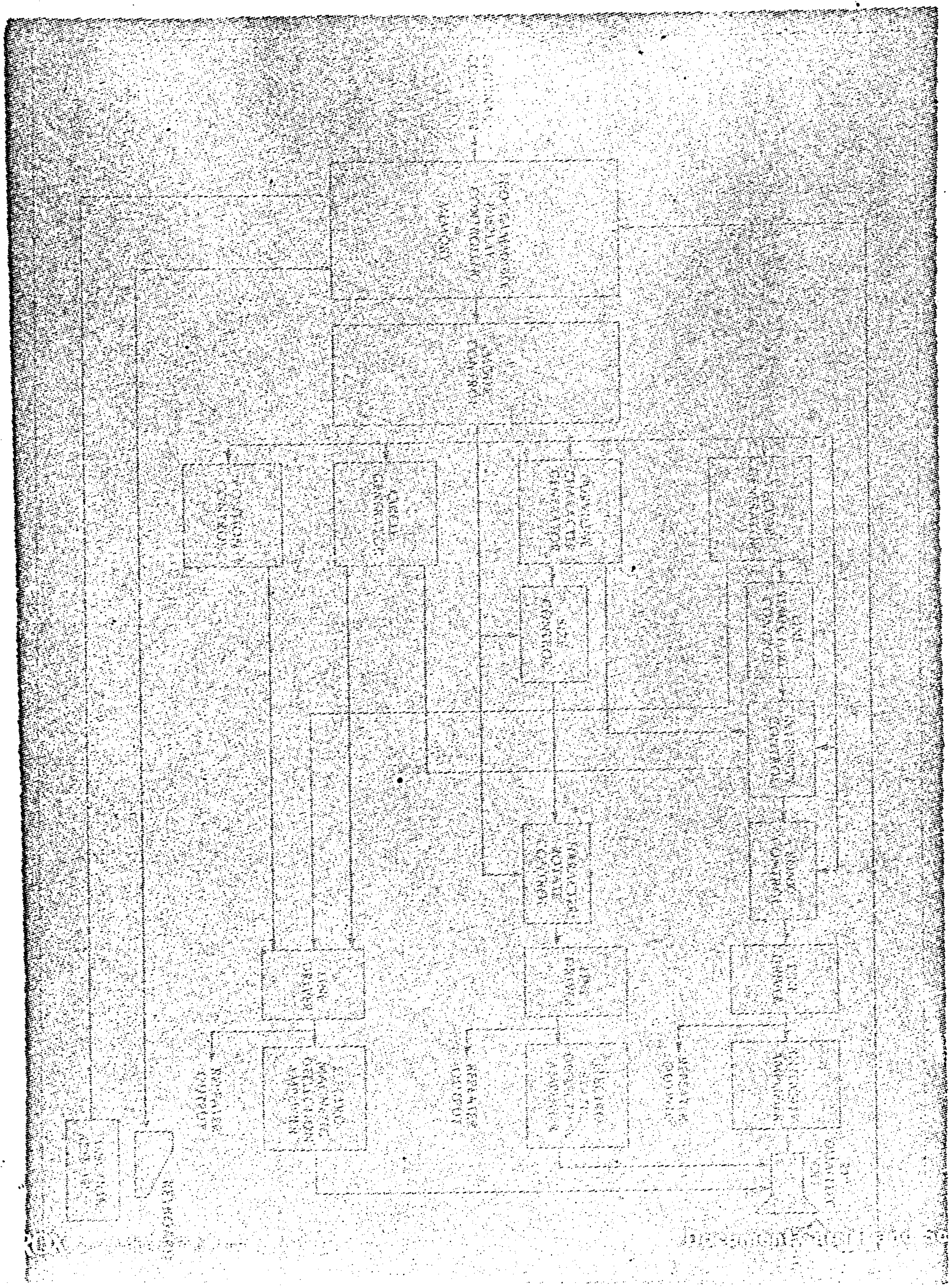
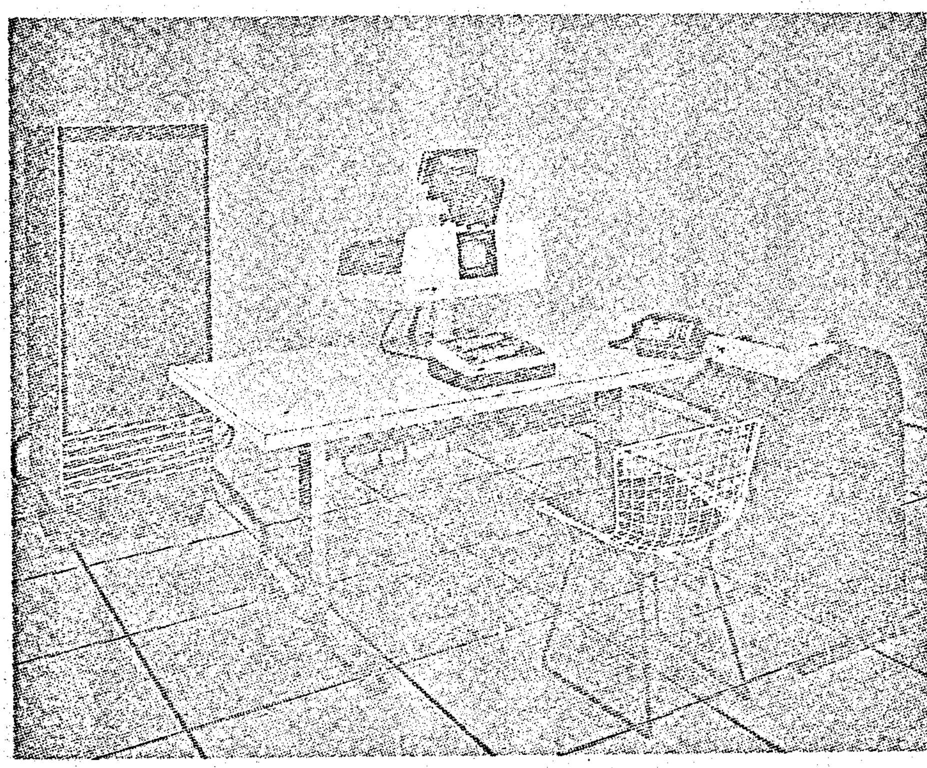


FIGURE 10

TELEPUTER SYSTEM USING STORAGE CRT



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