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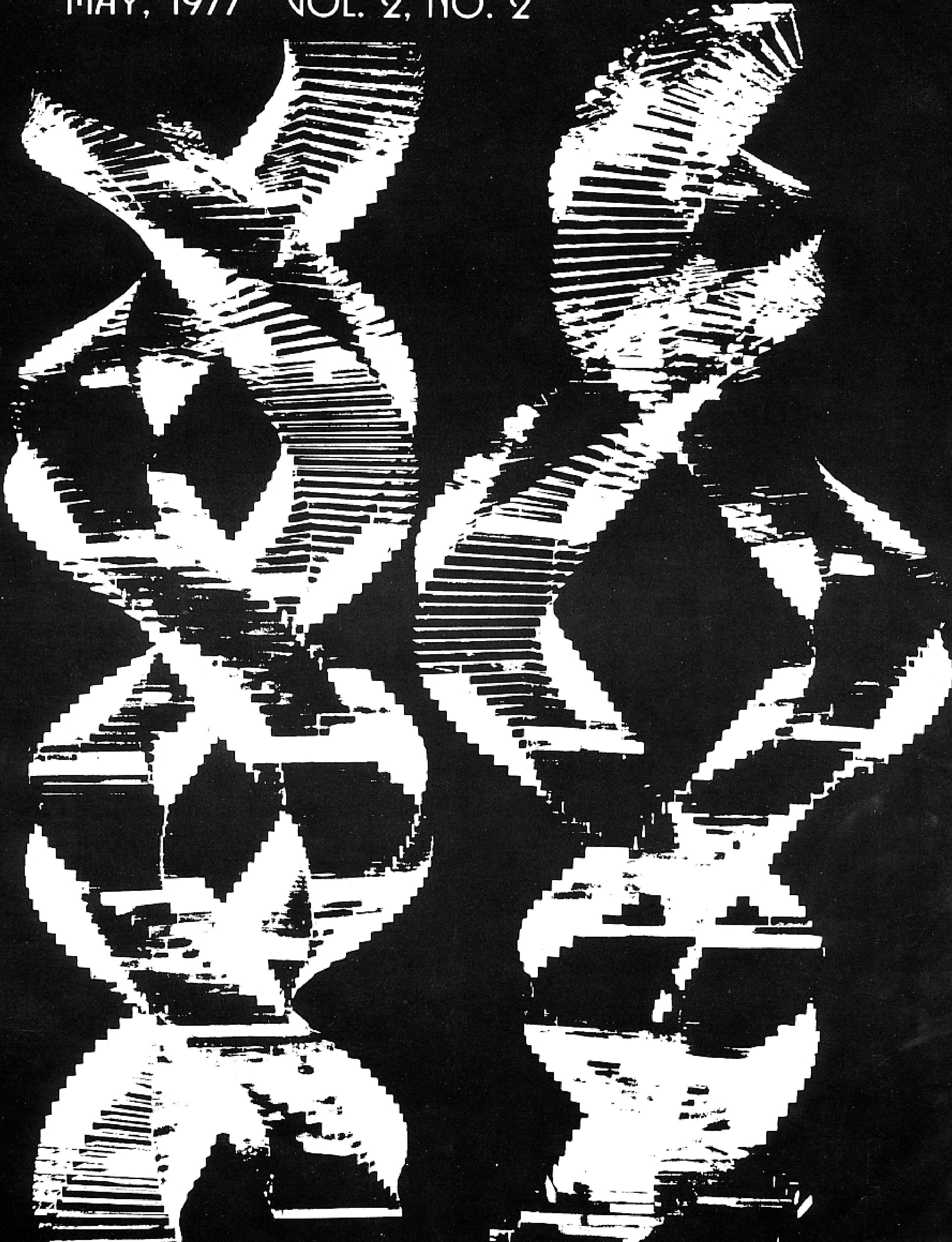

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THE MAGAZINE OF INTERDISCIPLINARY COMPUTER GRAPHICS FOR PROFESSIONAL GRAPHICS PEOPLE AND COMPUTER ARTISTS.

ANNOUNCEMENT - REGARDING THE EXHIBITION, "THE VARIED COMPUTER ARTS"

Last June, the Editor was given the "green light" to assemble a new, extensive exhibition to be called "The Varied Computer Arts", to be shown at the museums of the Association of Science and Technology Centers. A proposal was submitted with an exceptionally low budget -- and a roster of important artists assembled. Some personnel changes occurred at the Association, and finally the below-cost funding was not forthcoming. Reluctantly, for the present, this exhibition will be postponed. We are in need of a patron. GCH

EDITORIAL

COMPUTER GRAPHICS, A VARIED TOOL: ANALYSIS OF LEVELS OF GRAPHIC USE

Many professionals (and would-be computer professionals) seem to evidence an obvious form of elitist behavior regarding levels of computer expertise in graphics (and general computer expertise). The white coat of the doctor and researcher has been brought into the computer field, and computer people are in danger of becoming the "high priests of the machine", rather than thinking of the computer as a varied tool, to be used for myriad purposes. Too many computer people feel that unless one is using the computer at a very advanced level, then the problem-solving (and resultant accomplishments) are low level, or "Mickey-Mouse". What is important is the thinking and problem-solving of the originator, not the type of system used, or the level of system. For one may program exquisitely, at a very high level, to solve useless and very trivial problems!

Here are some notes paraphrased from recent writing on computer applications by the author.[1]

BACKGROUND

To the uninitiated, using the computer may mean a "take-over" of the job, where a human being is replaced. However, in many graphic applications, the computer is a useful ally and colleague, eliminating hours of boring, tedious, and imprecise work. Computer graphics in many applications can afford insights and techniques not obtainable before computer use. Medical graphic applications are one such example. As time makes graphics (and computer) applications more common, visualization of problem-solving will be as common as present processing of data.

Here are a few brief examples of levels of graphics use, ranging from user-oriented systems to complex engineering software visualization.

A. USER-ORIENTED GRAPHING SYSTEMS

A banking clerk is introduced to a special user-oriented graphic system in a workshop scheduled by the bank during the assistant's regular working hours. In one week, five such sessions are held. The clerk easily learns to execute a great number of charts and graphs, and to display the data in several forms, attaining new understanding of the problem-solving. The long hours of manual drawing of charts and graphs are replaced by stimulating computer graphing. The clerk merely uses the system, and <u>does not write</u> new routines, much as we drive a car, and take it to a specialist for repairs and alterations. But life is more pleasant for this person, because new and more complex tasks are easily achieved with the aid of computer graphics.

B. USER-ORIENTED SYSTEMS PLUS MODIFICATIONS

A student geographer enrolls for an upper division class, in order to learn SYMAP from the Harvard Spatial Analysis Group. He learns SYMVIEW, and after completing his studies, he is able to modify and alter some routines, to achieve new modules and routines that others may use. These are stored on the library. Later, the geographer goes on to study a special STATPAK visualization system available on the library. He is capable of learning a system, and writing a limited number of new routines. Here is another level.

C. INTERDISCIPLINARY STUDIES

A computer science major is studying computer art and is fascinated by medical patterns. After doing a research paper on computer graphics in medicine, she decides to take more graphics courses and also to enroll as a pre-med minor. After obtaining a bachelor's degree, she obtains a position in a large hospital and goes on to take additional courses in medical graphics, becoming a specialist in graphics/medical applications systems. Here is yet another level of computer graphics use.

D. DOUBLE MAJOR - DUAL EXPERTISE

An engineering student takes a computer course and enrolls as a computer science minor. However, after taking an engineering graphics course, he decides to become a double major in both areas, and to specialize in engineering graphics software writing. After graduation, he obtains a position in a large engineering consulting firm that designs software packages for specific engineering graphics applications. He writes packages for student engineers, so that they can become more facile in their own professional work. Here is another level of graphics/computer use, in which the skills are of a higher level.

SUMMARY

I once heard a remark from a scientist in a think tank, "Too many people are computing -- but they have absolutely no idea of <u>why</u> they are computing." This is equally true of graphics people. One may use the computer to graph or chart innumerable types of problems--and we use computer graphics for diverse reasons: speed, efficiency, even presion, beauty, understanding, etc.

One day in the near future, we will have transcended our great pride in being able to communicate with and use computers -- and we will progress to the level where we will think more clearly and logically about many kinds of problems -- and perhaps do something about them. The computer and graphics could be literally "wings of the mind" to lift us beyond the present pleasures of processing to genuine problem-solving of important issues, where results are important, and not the level of computer expertise. The computer is a useful tool for <u>all kinds</u> of nice people.

Grace C. Hertlein
Editor, CG&A

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[1] Berkeley, E. C. and Hertlein, G. C., "Computers" in <u>Social Consequences of Engineering</u>, H. Kardestuncer, Editor. New York: Dun-Donnelley, 1978.

COMPUTER DISPLAYS OPTICALLY SUPERIMPOSED ON INPUT DEVICES

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"A console of this design can serve alternately as a typewriter, computer terminal, text editor, telephone operator's console, or computer assisted instruction terminal."

ABSTRACT

A set of pushbuttons on a console may appear to have computer-generated labels temporarily inscribed on them if the button set and computed display are optically combined, for example, by means of a semitransparent mirror. This combines the flexibility of light buttons with the tactile and kinesthetic feel of physical pushbuttons; it permits a user to interact more directly with a computer program, or a computer-mediated operation, in what subjectively becomes an intimately shared space.

A console of this design can serve alternately as a typewriter, computer terminal, text editor, telephone operator's console, or computer-assisted instruction terminal. Each usage may have several modes of operation: training, verbose, abbreviated, and/or special-privilege. Switching from one mode or use to another is done by changing the software rather than hardware; each program controls in its own way the momentary details of visibility, position, label, significance, and function of all buttons.

Several demonstrations are described, including a prototype of a proposed Traffic Service Position System (TSPS) console, and an interactive computer terminal resembling a Picturephone ® set with a Touch-Tone® pad. Also suggested are combinations of computed displays with x-y tablets and other input devices.

INTRODUCTION

In interactive use of computers, a large number of advantages result from virtually superimposing the computed display on an input device such as a two-dimensional array of pushbuttons. /1,2/ A display so arranged can be used effectively to label buttons or relabel them with new meanings; indeed the buttons themselves may seem to appear and disappear according to their momentary significance or nonsignificance to the program. The same composite console--display plus input device--may have vastly different uses depending on the program that labels buttons and reacts to them. Thus combined are complete flexibility, normally associated with light buttons, and the tactile and kinesthetic feel of physical buttons that move, as on a typewriter. A button set may thus "be" a typewriter, calculator, telephone operator's console, computer-assisted instruction terminal, or music keyboard. An x-y tablet or other two-dimensional input device may likewise have a computed display superimposed on it. In all cases, the user enjoys a sense of close interaction with the computer in an intimately shared input-output space.

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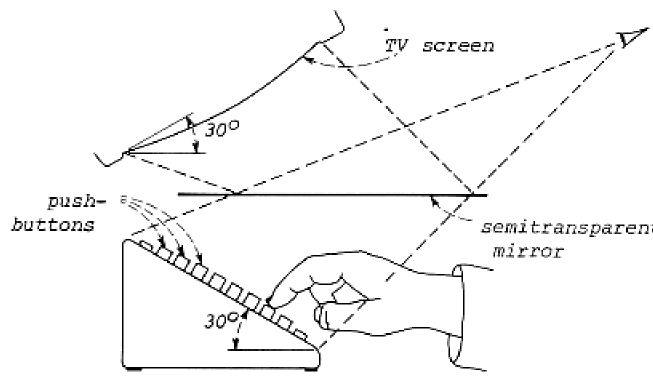


Figure 1 - Basic arrangement for superimposing a computed display on a two-dimensional array of buttons.

I. BASIC PRINCIPLES

A straightforward way of superimposing a display on a button set involves a semitransparent mirror, as illustrated schematically in Figure 1. The user looks through the mirror and views his/her hand directly as it pushes buttons. The display--a television monitor in the illustration--and mirror are so arranged that the virtual image of displayed light buttons conforms in three-dimensional space exactly with the position of the physical keytops. Perceived spatial congruence is so precise that if the display is a bulging TV screen, then it is best for the button tops to conform to a convex envelope, as in Figure 1, so that the central buttons do not seem too soft (i.e., so that the finger meets the physical button top at exactly the same depth as the image position). When displayed image, button set, and mirror are properly aligned, there is no parallax effect and bystanders perceive interactions exactly as the user does. In fact, the actual buttons need not be seen--it is best if they are painted a dull black so that they seem to disappear when the corresponding light button is extinguished. For proper hand-eye coordination, the user does want to see his/her hand; therefore, lighting from the side is useful. If it is strong enough, then the mirror used need be only slightly transmitting (say 10 percent) and may thus be highly reflecting (say 75 percent) to maintain high visibility of the virtual display. Ambient light is no problem except that strong room illumination, direct or reflected, should be kept off the display screen.

The display, of course, needs to be generated upside down so that it appears right side up when viewed in the mirror. This is no fundamental problem except that one commonly imports or implements software in which the assumption of right-

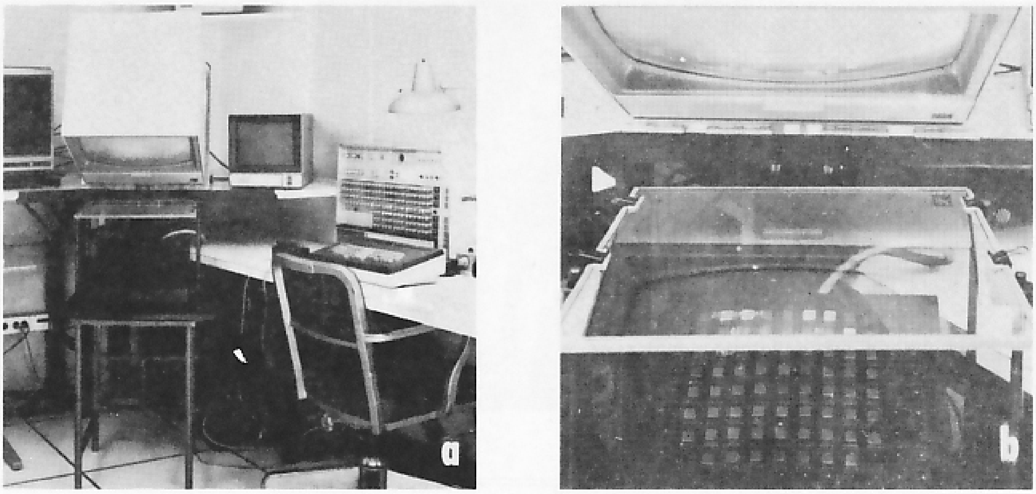


Figure 2. (a) A laboratory setup for experimenting with displays superimposed on button tops. (b) Close-up of TV screen, mirror and 12 x 10 set of buttons.

side-up generation (of alphabetic characters, for instance) may be embedded deep in the code.

One curiosity of these systems is that the hand seems transparent to light buttons, since it does not intervene in the path of reflected light. We can read through our fingertip the current label of the button pushed, as well as see other buttons beneath the hand. This is not in the least confusing to a user who has been at the machine for a few seconds; on the contrary, it is definitely helpful not to have to remove your hand to see what's beneath it.

Figure 2a (above) is a photo of one generally useful laboratory prototype for experimenting with usages of virtual pushbutton consoles; Figure 2b (above right) is a closeup of display, mirror, and button set as seen from farther away and lower than the user's normal head position. The computer used has 32K 24-bit words of core storage; programming is done in FORTRAN and an assembly language. The display is a normal 525-line TV monitor, with separate red, green, and blue (RGB) inputs, refreshed 30 times per second by specially built hardware from a separate core memory that holds 3 bits per picture cell. /3,4/ (The displayed picture is only 496 lines of 528 pixels per line.) Each of the eight logical colors is program-definable to 128 levels per primary. The button set is a 12-wide by 10-high array of pushbuttons, $\frac{1}{2}$-in. square on 1-in. centers, each with 3/16-in. travel. The computer reads only rows and columns in which buttons are momentarily depressed--all single hits are clearly decodable, as are multiple hits in the same row or column and some patterns produced by progressively adding buttons. The mirror is 16 in. square by $\frac{1}{4}$ in. thick; it is first-surface 75 percent reflecting and 10 percent transmitting.

II. PROTOTYPE FOR A TELEPHONE OPERATOR'S CONSOLE

The setup of Figure 2 has been used to implement an experimental demonstration of a flexible telephone operator's console--in particular, a possible replacement of the present Traffic Service Position System (TSPS) station and/or future versions of it. /5/ Figures 3 and 4 illustrate many of the features that such a console might have. In the demonstration, button tops are $\frac{1}{2}$-in. green squares, containing green labels; lines connecting logical groups of them are blue--sometimes these alone appear where an entire set of button tops has has vanished in order to preserve a sense of orientation and geography. Lights at the very top of the board, indicating what type of call is presently being processed, are red, as are occasional wide frames around buttons, pointing out mandatory operator actions. (Please turn to pages 6 and 7 for Figures 3 and 4.)

The sequence of Figures 3a through 3e illustrate the handling of a particular call, which is being charged to a third phone. Figure 3a shows the board before the call arrives, with only a few buttons present, indicating the limited number of things an operator can take initiative on with no call to process, such as to inquire as to the time of day (lower left). In Figure 3b, a "zero+" call has arrived from a non-coin phone (the calling party has dialed the called number, but asked for operator assistance by the leading zero). The operator asks,"May I help you?" and the calling party requests that the call be charged to a third phone, whereupon the operator prepares to push the special calling (SPL-CLG) button. With the class of charge thus declared (Figure 3c), this button lights brightly and other class-of-charge buttons disappear; also, the key pulse special (KP-SPL) button lights with a red frame, in effect insisting that the operator enter a third phone or credit card number. (Notice that the KP-SPL with red frame can be read through the hand.) When the operator pushes this button, the keyset appears and is used for entering the third phone number (Figure 3d). The number entered appears in the center of the panel and the SPL-NO display button appears, indicating that henceforth there is a special number, which may be redisplayed at a later time. The ST-TMG button with red frame means that no more information is needed; if it is pushed, the telephone machinery may start timing the call as soon as the called party answers the phone. When this button is pressed, it disappears (Figure 3e) and the POS-REL button appears permitting the operator to release the call from this position, whereupon the board reverts to the quiescent state of Figure 3a.

The sequence in Figure 3 shows that this console is dynamic even during the processing of a

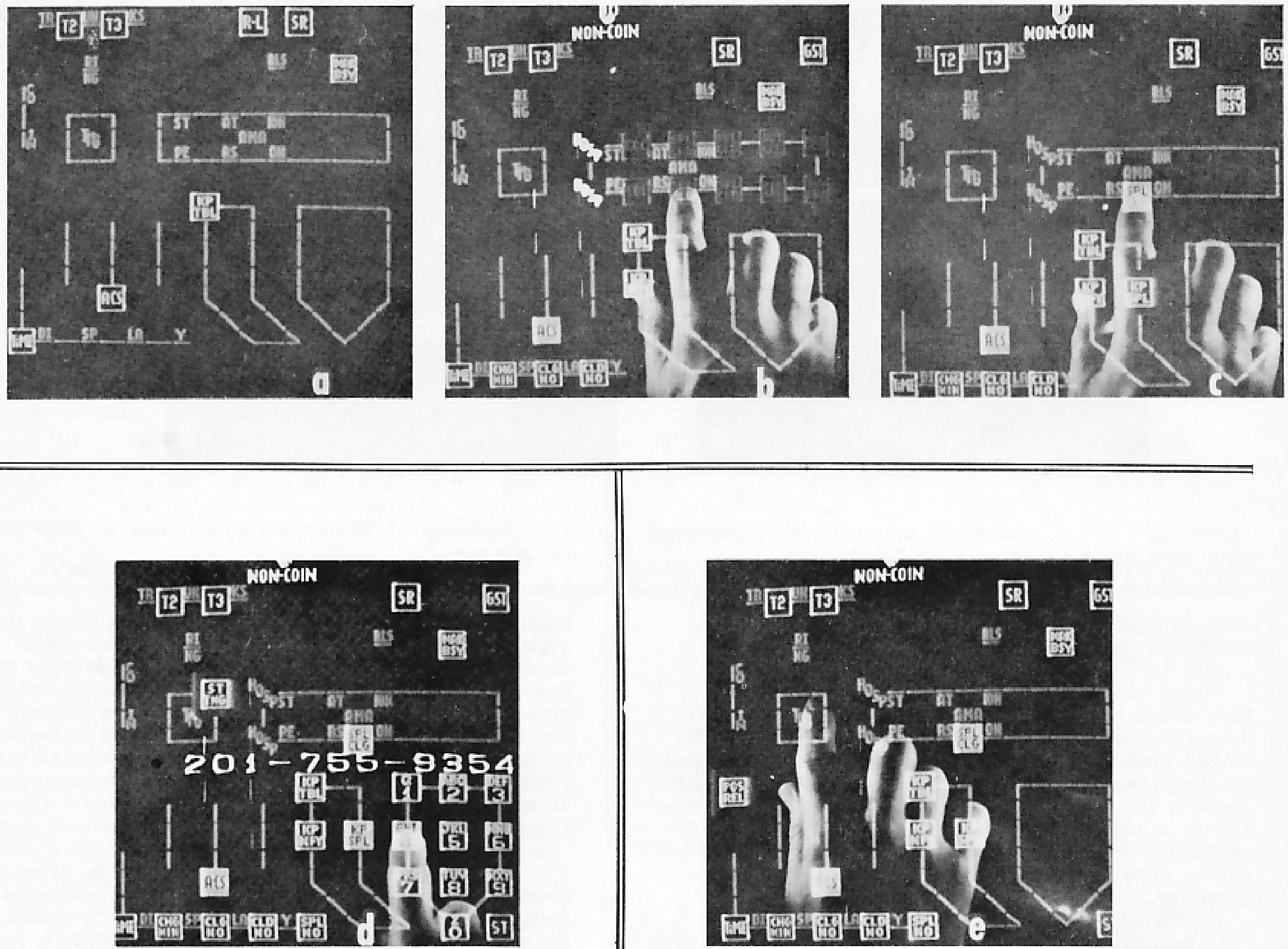


Figure 3 - Demonstration of a charge to a third phone. (a) Quiescent board; (b, c) Operator pushes the SPL-CLG button; (d) Third phone number is keyed in; (e) ST-TMG button pushed, permitting POS-REL.

phone call; all of the buttons that have meaning at any moment, and only those buttons, are visible. The sequence in which they appear, in fact, tends to lead the operator through the required series of decisions and actions; this should be a significant help in the training of new operators (there could be a verbose mode, or a HELP button to spell out in words or phrases the meaning of buttons or situations encountered.)

Figure 4 illustrates more features of the TSPS demonstration. (See page 7 for Figure 4.) For the sake of comparison, Figure 4a shows the complete set of buttons corresponding approximately with the currently used board. It is not immediately obvious here that the KP-TBL (meaning, "prepare to key in a trouble code") is one of the few meaningful actions when no call is present. (Figure 4d, on the other hand, is the recommended appearance of the quiescent board, with only valid buttons showing; here, the operator is inquiring as to the time, which is displayed while the TIME button is pushed.) Figures 4b and 4e compare the left- and right-handed boards; a left-handed operator presumably will want the keyset for entering phone numbers, etc., on the left. (Programming, as one should expect, is done in terms of logical buttons--where each button happens to be any time is a matter of mapping. Individual operators might even be allowed to make their personal rearrangements of the board.) Figure 4c shows the entire board temporarily turned into a typewriter keyboard for possible future applications requiring alphanumeric input. Figure 4f repeats something that already appeared in Figure 3: a call originates from a patient at a hospital, an institution which does not want to be the collecting agent for phone calls and therefore requests the phone company not to let the call be billed to the calling phone. Thus, in the spot where the operator might have expected a class-of-charge button PAID (by the calling phone) there is an explanatory note, HOSP, which neither appears nor functions like a button.

The key word is flexibility, including the option of introducing new buttons for new services or functions. All such alterations, including adding, modifying, rearranging, relabeling, or deleting buttons, are changes in software; they would be much easier to implement on any or all of the consoles than would be equivalent changes in hardware (once the changeover has been done).

One should finally note that, for the handling of phone calls, a great deal of electronic equipment is already needed, including circuitry and other means for detecting and decoding button pushes. The significant addition suggested by the present prototype is that the main call-handling mechanism could tell the console what buttons to light and extinguish, and where. In other words, the console would show what button presses are legal, something which is already implicit in the program. Operators would be less likely to do things out of order, simply because they would not expect anything to happen in response to pushing an unlighted button. A simple case in point is: if the start timing (ST-TMG) button is not present but the class-of-charge panel is entirely illuminated, it should be immediately obvious even to the beginner that the class of charge still needs to be declared (perhaps among other things) before it is legal or possible to start timing of the call.

III. A RELABELABLE "TOUCH-TONE" PAD AS AN INTERACTIVE CONSOLE

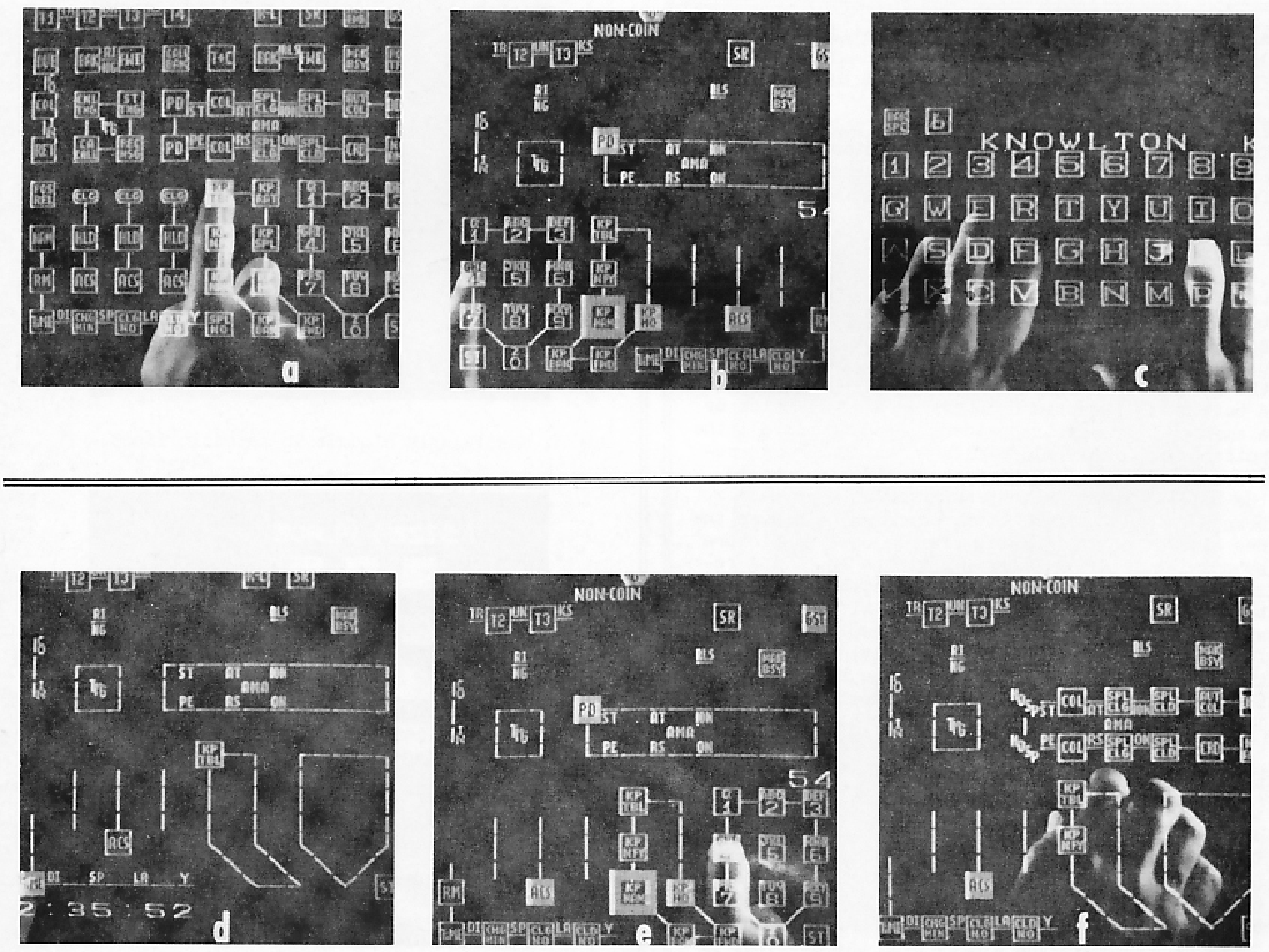
A set similar to Picturephone set could be used as an interactive remote computer console, with the Touch-Tone pad as the input keyboard. A schematic for a mockup is shown in Figure 5, where a semitransparent mirror effectively puts the computed image on

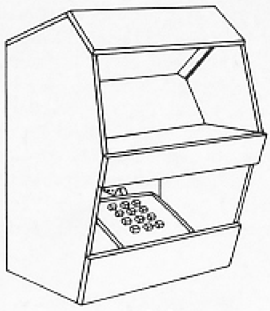
(See page 6 for discussion of Figure 4.)

the Touch-Tone buttons so that the 12 buttons can have several labelings and a corresponding extended range of functions. A proposed new feature, as illustrated in Figure 5b, is the use of the bottom quarter of the screen as a light source for illuminating the hand, but only when function buttons are displayed, not when some other graphic program result is being shown. In the latter instance, when the hand should not be seen, the screen "light" goes off. A partial cabinet hides the hand from room light.

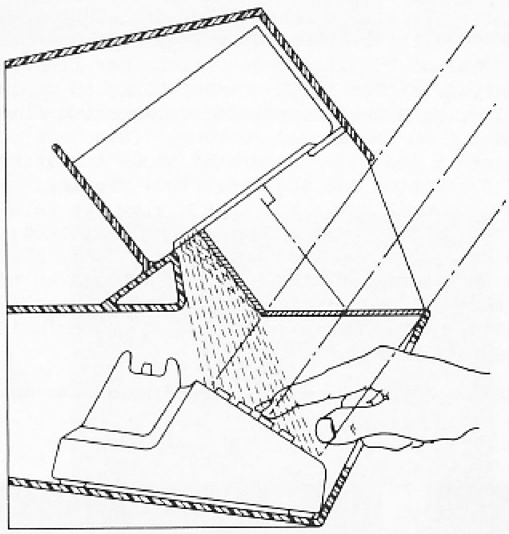
Such a console has been built using a computer, a Touch-Tone pad as the keyboard, and a color television RGB monitor so modified that each of its three color signals is essentially a Picturephone signal. /6/ The picture is again 3 bits per pixel with a total of 254 lines, 240 pixels per line. The front-surface mirror is 45 transmitting, 45 percent reflecting, with an antireflective magnesium fluoride coating on the second surface. (See page 8 for Figures 5 and 6.) Figure 6a shows a distant view of the button set and (inverted) display, whereas Figure 6b shows the user's view for this same circumstance. These buttons are not black, yet the computer-generated image effectively obliterates the intrinsic labels on the buttons to the extent that one could turn the pad into a normal calculator, high numbers on top, with no confusion as to current numbering.

Below: Figure 4 - Illustrating features of TSP demonstration.





(a)



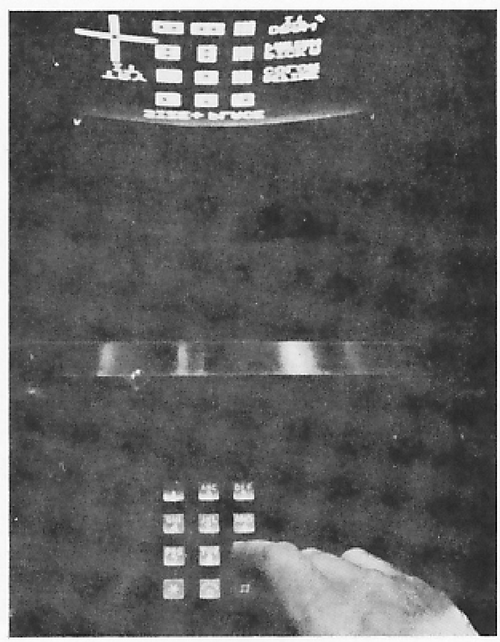
(b)

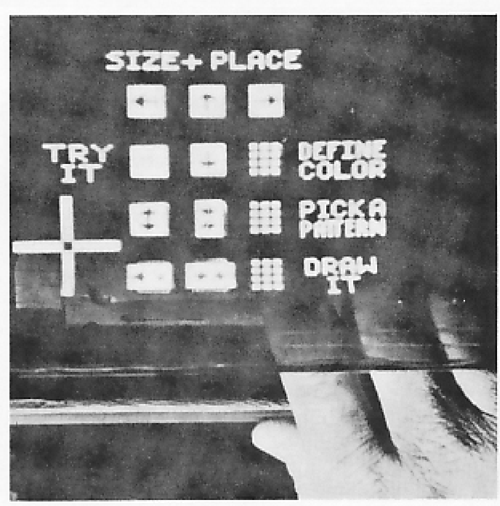
Figure 5 - (a) Console setup with a relabelable Touch-Tone pad as an iterative graphics console. (b) Side view of console showing extra mirror for reflecting bottom-of-screen light source.

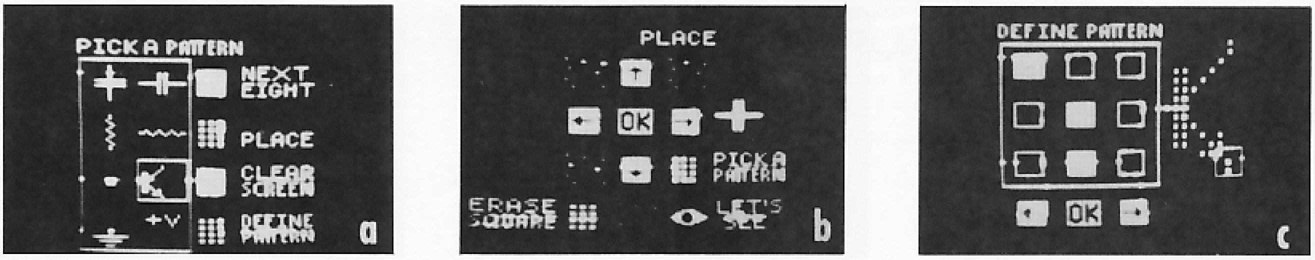
Two demonstration graphics programs have been written for this system. The first, whose three basic button labelings appear in Figure 7 (page 9), provides for drawing electronic circuit schematic diagrams, such as the one shown in Figure 7d, by the juxtaposition and combination of basic patterns. A pattern is selected by pressing a key labeled by a small picture of the pattern (see Figure 7a); the button marked NEXT EIGHT causes paging through several such sets of eight patterns. When pressed, the pattern is framed, as shown. The user may branch to that part of the program which places the new element on the faintly visible current picture by pushing PLACE. (Program branches involving relabeling buttons are indicated by symbols resembling miniature sets of 12 buttons with a label alongside.) Figure 7b shows the result: buttons for moving the new instance, for saying, "OK, add it," and for seeing the result. The LET'S SEE button causes the button set and labels to go out, likewise the light illuminating the hand, whereas the faint circuit diagram in the background comes up to full brilliance, as in Figure 7d. The speckling of unused buttons serves to obscure the intrinsic Touch-Tone labels. Another program branch provides for the redefinition of a pattern (see Figure 7c). Here, an enlarged pattern appears on the right with a 3 by 3 window drawn on it. Contents of this window are displayed on the top nine buttons, where a button press flips the cell. The arrow buttons move the window over the pattern; OK returns control to the rest of the program, with the pattern redefined.

A more elaborate program uses the capabilities of the color monitor to generate four-color designs like the one shown in Figure 8 by selecting and applying variously stretched and positioned instances of basic patterns. Figure 9 shows its seven basic button labelings. The user may start with any of the four colors as background (figure 9a) and selects a pattern as before (Figure 9b). In addition to placing it anywhere on the screen, the user may change its height and width independently (Figure 9c). Before finally drawing the addition

Notes on Figures 6(a) and 6(b) below: 6(a) - Distant view of a simulated PICTUREPHONE® console setup, showing inverted image on screen. mirror, and user's hand operating TOUCH-TONE® buttons. 6(b) - User's view (through mirror) of situation depicted in Figure 6(a), with TOUCH-TONE® buttons effectively relabelled by the computed display.







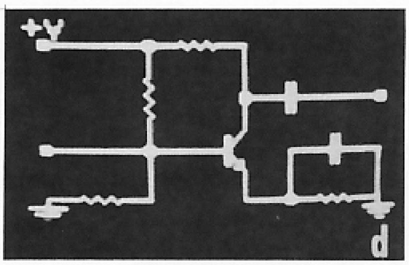


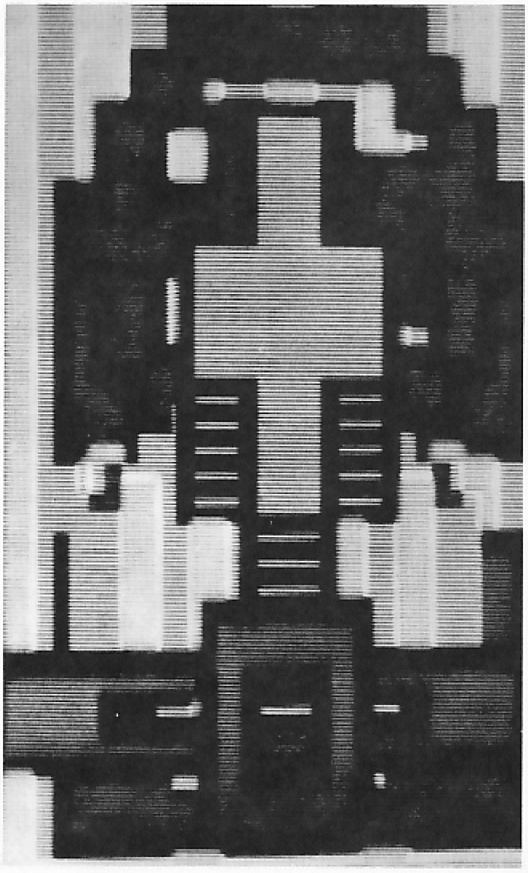
Figure 7 (a-C) - Button labellings of a program for composing electronic circuit diagrams. (d) A result.

onto the picture, an optional border, of width), 1, 2, or 3, and its color, are chosen (Figure 9g). The colors themselves may be redefined (Figure 9f) by increments or decrements of the three primary colors, the ± button serving to flip between modes ADD and SUBTRACT. Throughout the program, buttons which are temporarily meaningless disappear; if border width is zero, the color buttons vanish; if no more red can be added in defining the currently selected color, RED goes out; if position or size are extreme, the corresponding cursor arrow button disappears.

To summarize the Touch-Tone demonstrations, a complicated interactive graphics program can be run by means of a 12-button Touch-Tone pad if the buttons are easily relabeled to provide a rich variety of functions. Button forms and features found useful are:

- Solid square with a 1- to 3-word label alongside.
- Small pictures of symbols significant in the program.
- Other iconic symbols:
  - An eye meaning, "Let's see the picture."
  - Miniature 12-button set with label: a program goto involving relabeling.
  - Arrows for positioning a cursor and setting its size.
- Picture cells in a basic pattern being defined.
- Speckles to hide the intrinsic label of a nonfunctioning button.
- A frame marking the current selection.
- Alternation or cycling:
  - Paging through sets of patterns.
  - Add vs. subtract for defining colors.
  - Black vs. white cells in pattern being defined.
- Buttons that disappear when not meaningful:
  - Cursor arrows when at extreme size or position.
  - Color increments when at limit of range.
  - Border color when width = 0.
- Button set that disappears for viewing program result.
- Frame around logical groups of buttons:
  - Enlarged window of pattern cells.
  - Pattern set.

Figure 8 - Sample result of a more general program for production of 4-color designs made of variously stretched and positioned geometric patterns.



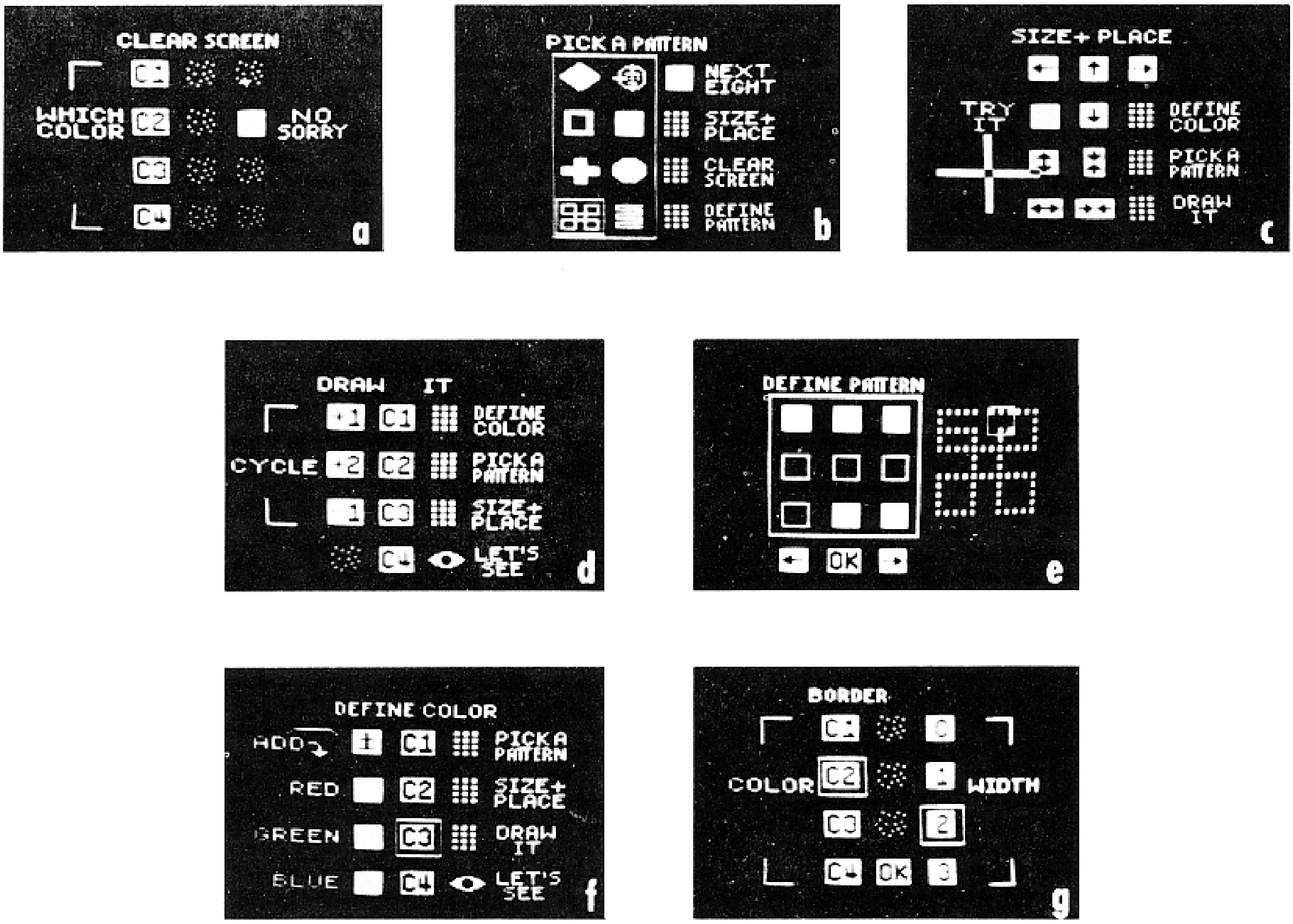


Figure 9 - The seven basic labellings for design-generating graphics system used to produce Figure 8 (see text for details).

IV. COMPARISONS WITH OTHER DEVICES

The existing system closest in form and function to this one is the touch panel /7,8/ developed as a part of the Plato computer-assisted instruction project, /9/ where the user's finger on the screen intercepts one vertical and one horizontal light beam, with position decoded to one spot out of 16 by 16. Virtual light buttons have the following advantages over the touch panel:

(i) The hand is transparent; it does not obscure buttons pressed or buttons below it.

(ii) The keyboard has tactile feedback through button motion, but it does not respond to fingers passively resting on unpressed buttons--both characteristics are very important in typing.

(iii) Keyboards can easily be made for the simultaneous detection of more than one button hit (as in defining a pattern, typing a capital letter, or inputting a musical chord).

(iv) Only one kind of electronic-detection circuitry is required, that for detecting contact closings. (Almost every commonly used system has a keyboard.)

A light pen, like a touch panel, also is a single-position indicator, and it obscures part of the region pointed to, but it does permit drawing free-hand curves and precise positioning on the picture cell level. Virtual light buttons do not lend themselves well to these tasks; for such operations we might use instead an x-y tablet with virtually superimposed display. We can, however, use a button array for pointing with much finer resolution than button spacing, by any of a variety of protocols:

(i) A first button hit can position a cursor at the same button center, and thereafter a small panel of four buttons in the left or right lower corner may serve to step the cursor in fine increments. In addition, the cursor may slew in any of these four directions if a slew button is simultaneously depressed.

(ii) Alternatively, after a single button hit positions the cursor to the center of the button, a second nearby button depressed, before the first is released, can mean, "so many subdivisions in this direction." This method is quickly learned and provides for easy positioning on a grid five or seven times finer in both directions than button spacing. Subsequent button hits, relative to either the first or second button, could mean picture cell displacements in the corresponding direction.

V. ONGOING WORK

Experimental and developmental work is continuing with hardware and with both general and specific software, as follows:

(i) The virtual light button setup is being considered as a possible form for a TSPS console. It would have the following advantages for operating companies: It would be expected to reduce training time; additions or changes in service or protocol would not require hardware changes to the consoles; one design would serve many purposes--handling phone calls, maintenance, traffic control, clerical work. Implications of the latter are that the operator's job could be restructured considerably, with periods of instruction or other jobs easily interleaved with normal call handling in off-peak hours.

(ii) A versatile and economical console is being designed, and a mockup built, using a 128-button panel, and a 512 by 512 60 pel/inch plasma panel /10/ as shown schematically in Figure 10. (The plasma panel needs no external refresh system--cells may be lit or extinguished individually, and each retains its state until changed. The panel is flat, permitting the button set to be flat, and since picture cell positions are defined by the structure of the device, the overall setup cannot become misaligned by electronic drift.) The board is arranged basically as an 11 by 11 array on 3/4-in. centers (normal typewriter spacing) with slight adjustment of the bottom rows so they conform closely to a regular typewriter. Some buttons hang partially off the $8\frac{1}{2}$ by $8\frac{1}{2}$-in. display area; their meanings will normally be understood. The labels in Figure 10 indicate how a typewriter keyboard is intended to be mapped onto the buttons set; the buttons can also be used as an 11 by 11 rectangular array but with some distortion in the lower lines, at least for the lowest 12-button row. Arrangements are being made to read all combinations of simultaneous button presses.

Commercially available plasma panels, sadly, are monochrome (neon orange). They are, however, much more economical than color TV monitors plus refresh buf= fers.

The ultimate flexible-but-economical console is expected to be close to the above design of keyboard + plasma panel, with addressing and driving electronics of the plasma panel in the lower cabinet, not in a bulky frame around the display. It would contain a character-generator capable of generating (hierarchically) parts of buttons, button tops, and sets of button tops. The remote computer would then need to designate only which light button(s) to put up and/or extinguish, and where, whereas the console

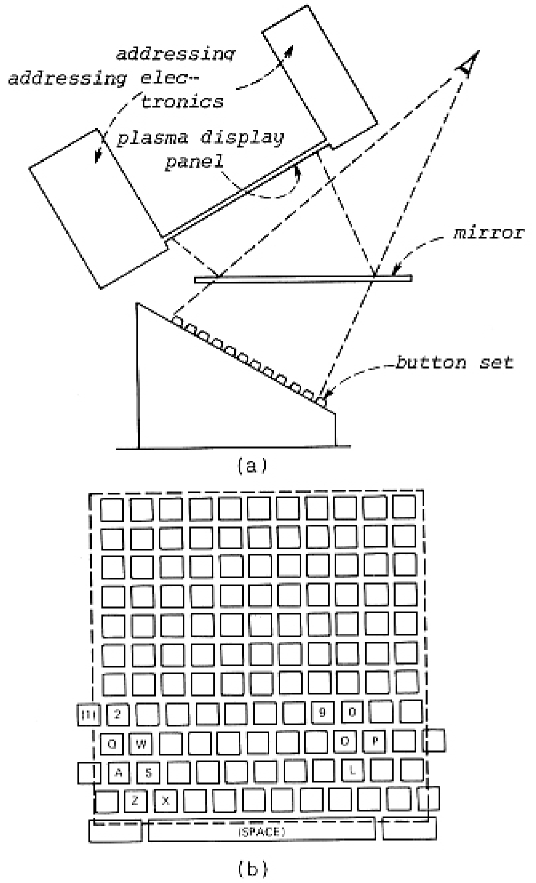


Figure 10 - Console under construction, using plasma panel display. (a) Schematic side view. (b) Button layout: 128 buttons basically positioned on 3/4" centers. Labels illustrate usage of lower board as a typewriter. Large square indicates virtual position of $8\text{-}\frac{1}{2}$" square plasma panel display area.

would report button hits, perhaps with local culling of hits on nonlighted buttons. Both are low-capacity channels; a twisted pair phone line would suffice. An 11 by 11-in. mirror would be big enough for a single user (larger mirrors are useful for demonstrations).

(iii) A general-purpose software package under development will ultimately facilitate the writing of specific usage programs. It will permit convenient design and labeling of light buttons, plus facilities for conveniently defining mappings between logical and physical buttons and describing changes in state: appearance and disappearance of buttons, changes in values of variables, and flow of control. It will also provide a testing ground for one of the author's basic attitudes about usage of such a system: that there should always be exact correspondence between buttons which appear and those responded to. This ground rule should aid the development of complex systems like TSPS where there is a huge number of combinatoric states of the board, and where it is a big and difficult job to define precisely and completely which button hits are or should be legal from instant to instant.

(iv) One application nearing completion is a text editor, where text being worked on appears in the top part of the screen, while the bottom part serves as a typewriter keyboard. The novel feature of the setup is that pointing (to lines or words or positions for deleting, changing, inserting) is done by pointing into the text. Text is displayed with three lines of five characters on each button top, and designates a character by a sequence of two button hits: first the button on which the character appears, followed by the same button if the character is centered on this button, or by a nearby button in the direction that the character is off-center (the second button is always one of the 3-high by 5-wide subarray centered on the first).

VI. ACKNOWLEDGMENTS

Dan Franklin designed and implemented the text editor. I thank Max Mathews and Peter Denes for facilitating the hardware developments and for suggesting the telephone operator console application, and Steve Bauman and Stu Silverberg for helping to formulate a meaningful TSPS demonstration. I thank Marie Hill, former Manager of Operator Services at Morristown, N. J., for several helpful consultations and for arranging for me to observe and monitor operators processing actual calls.

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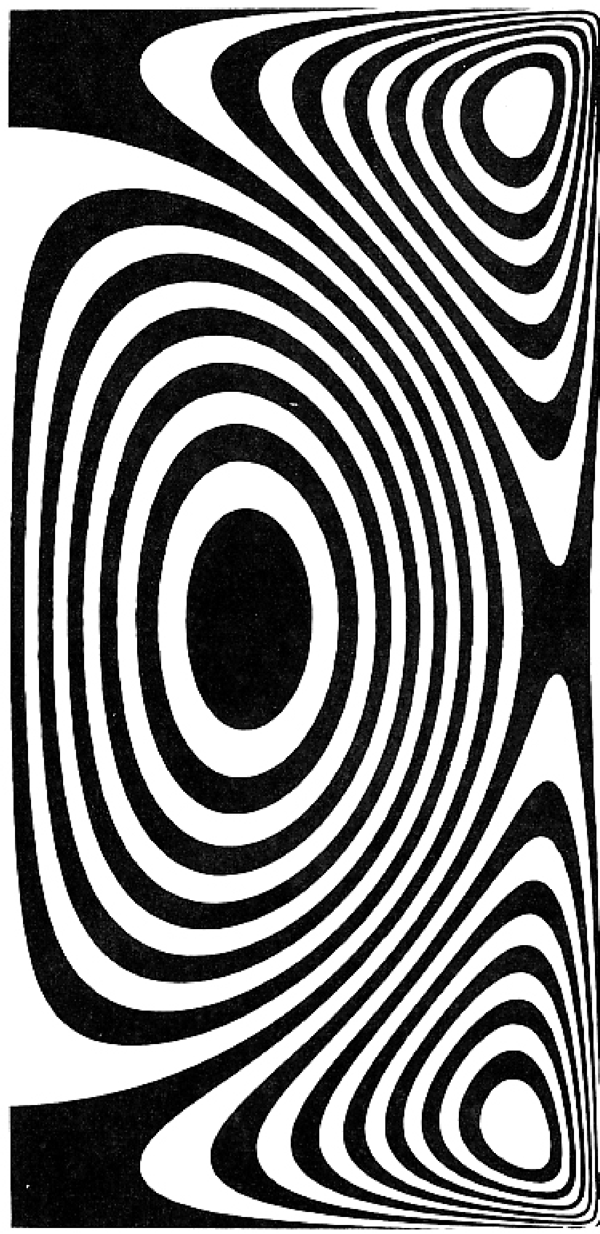
BELOW: Detail, "Untitled Graphic" by Aldo Giorgini.



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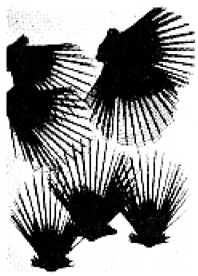

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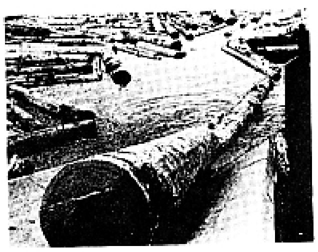

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Computer Programming Using Natural Language

Computer Applications

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Computing Facilities at Stanford Univ.: Their Development and Direction

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The Social Responsibility of Computer Specialists

Ralph Nader, Attorney and Consumer Advocate
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SIGGRAPH '77 PRELIMINARY PROGRAM

1. ANIMATION - C. CSURI, Ohio State University, Computer Graphics Research Group, 1314 Kinnear Road, Columbus, Ohio 43212.

   LEVOY, M., "A Color Animation System Based on the Multiplane Technique," Cornell University, Program for Computer Graphics, Ithaca, NY 14853.

   POTEL, M. J., "Real-Time Playback in Animation Systems," University of Chicago, Institute for Computer Research, 5640 Ellis Avenue, Chicago, IL 60637.

2. GRAPHIC LANGUAGES - TONY LUCIDO, Ohio State University, Dept. of Computer and Information Science, 2036 Neil Avenue Mall, Columbus, Ohio 43210.

   KAUFMAN, A.; BERGMAN, S., "Association of Graphic Images and Dynamic Attributes," Ben-Gurion University, P. O. Box 2053, Beersheva 84120, ISRAEL.

   EASTMAN, C. N., "Language for a Design Information System," Carnegie-Mellon University, Institute of Physical Planning, School of Urban and Public Affairs, Schenley Park, Pittsburgh, PA 15213.

3. APPLICATIONS - D. KASIK, Battelle,Columbus Labs, 505 King Avenue, Columbus, Ohio 43201.

   MALLARY, R., "ECOSITE: An Application of Computer-Aided Design to the Composition of Landforms and Reclamation," University of Massachusetts, Surface Mine Research Group, Institute for Man and Environment, Amherst, MA 01002.

   MAZZLOTTA, J.; HAMILTON, B.; HUANG, H. K., "Three-Dimensional Computer Reconstruction and Display of Neuronal Structure," National Biomedical Research Foundation, Georgetown University Medical Center, 3900 Reservoir Road, NW., Washington, DC 20007.

   TRACY, F. T., "Graphical Pre- and Post-Processors for 2-Dimensional Finite Element Method Programs," Department of the Army, Waterways Experiment Station, Corps of Engineers, P. O. Box 631, Vicksburg, MS 39180.

   HAWRYLYSHYN, P. A.; TASKER, R. R.; ORGAN, L. W., "CASS - Computer Assisted Stereotaxic Surgery," University of Toronto, Clinical Science Division, Medical Sciences Building, Rm. 7316, Toronto, CANADA, N5S 1A8.

4. BUSINESS - JACKIE S. POTTS, Social Security Administration, 3P7 Annex Bldg., 6401 Security Blvd., Baltimore, MD 21241.

   WILLARD, C. G., "Interactive Graphics: An Aid to Health Planning and Decision Making," University of Minnesota, Department of Laboratory Medicine and Pathology, Division of Health Computer Sciences, Medical School, Box 511, Mayo Memorial Bldg., Minneapolis, MN 55455.

   RENFROW, N. V., "Computer Graphics for Facilities Management," Cost, Planning and Management International, Inc., 4045 Merle Hay Road, Des Moines, Iowa 50310.

   BENSON, W. H., "Interactive Analysis & Display of Tabular Data," Lawrence Berkeley Laboratory, University of California, Computer Science and Applied Math Department, Berkeley, CA 94720.

5. CARTOGRAPHY - HAL MOELLERING, Ohio State University, Department of Geography, 1775 College Road, Columbus, Ohio 43210.

   EDSON, D. T.; LEE, G.Y.G., "Structuring Cartographic Data within a Digital Cartographic Data Base," U. S. Dept. of Interior, Geological Survey, Topographic Division, 345 Middlefield Road, Menlo Park, CA 94025.

   DUTTON, G. H., "The MIRAGE Program: Vector Graphics Approaches for Mapping Matrix Data," Laboratory of Computer Graphics an and Spatial Analysis, Graduate School of Design, Harvard University, 520 Gund Hall, 48 Quincy Street, Cambridge, MA 02138.

   GOLD, C. M.; CHARTERS, T. D.; RAMSDEN, J., "Automated Contour Mapping Using Triangular Element Data Structures and an Interpolant Over Each Irregular Triangular Domain," University of Alberta, Department of Geology, Edmonton, Alberta, CANADA T6G 2E1.

6. DATA BASE GRAPHICS - RICHARD PHILLIPS, Department of Aerospace Engineering, University of Michigan, Ann Arbor, Michigan 48104.

   PHILLIPS, R. L., "A Query Language for a Network Data Base with Graphical Entities," University of Michigan, Aerospace Engr.

6. DATA BASE GRAPHICS SECTION - CONCLUDED

Building, Ann Arbor, MI 48109.

STONEBRAKER, M., ; BERMAN, R., "CED-QUEL: A System for Manipulation and Display of Geographic Data," University of California, Berkeley, College of Engineering, Department of Electrical Engineering and Computer Sciences, Berkeley, CA 94720.

7. 3D INPUT TECHNIQUES - DONALD GREENBERG, Cornell University, Program of Computer Graphics, 120 Rand Hall, Ithaca, NY 14853.

FUCHS, H.; DURAN, J.; JOHNSON, B., "A System for Automatic Acquisition of Three-Dimensional Data," University of Texas at Dallas, Programs in Mathematical Science, Richardson, TX 75080.

WU, S.; ABEL, J. F.; Greenberg, D. P., "An Interactive Computer Graphics Approach to Surface Representation," Cornell University, Program for Computer Graphics, Ithaca, NY 14853.

ANDERSON, D. C.; BREWER, J. A., "Visual Interaction with Overhauser Curves and Surfaces," Purdue University, School of Mechanical Engineering, West Lafayette, IN 47907.

PARENT, R. E., "A System for Sculpting 3-D Data," Ohio State University, Computer Graphics Research Group, O.S.U. Research Center, 1314 Kinnear Road, Columbus, OH 43212.

8. ALGORITHMS - R. CLARK, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439.

BLINN, J. F., "Models of Light Reflection for Computer Synthesized Pictures," University of Utah, Department of Computer Science, Salt Lake City, UT 84112.

EARNSHAW, R. A., "Line Tracking for Incremental Devices," Centre for Computer Studies, University of Leeds, Leeds LS2 9JT, ENGLAND.

HAMLIN, G.; GEAR, C. W., "Raster-Scan Hidden Surface Algorithm Techniques," ICASE, Mail Stop 132C, NASA Langley Research Center, Hampton, VA 23665.

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9. TUTORIALS - DAN BERGERON, University of New Hampshire, Dept. of Mathematics, Durham, NH 03824.

BLINN, J. F., "A Homogeneous Formulation for Lines in 3 Space," University of Utah, Department of Computer Science, Salt Lake City, UT 84112.

CROW, F. C., "Shadow Algorithms for Computer Graphics," University of Texas at Austin, College of Natural Sciences, Department of Computer Sciences, Painter Hall 3.28, Austin, TX 78712.

10. EDUCATION - RICHARD PUK, Division 2644, Sandia Laboratories, Albuquerque, NM.

HERTLEIN, G. C., "Computer Art for Computer People - A Syllabus," California State University, Chico, Department of Computer Science, Chico, CA 95929.

MAGUIRE, R. B., "Automated Display Techniques for Linear Graphs," University of Regina, Department of Computer Science, Regina, CANADA S4S)A2.

11. POSTER - THOMAS WRIGHT, NCAR, P. O. Box 3000, Boulder, Colorado 80307; DAN WELLER, IBM-K54/282, 5600 Cottle Road, San Jose, CA 95198.

BRASSEL, K.; HANSON III, P.O.; UTANO, J.J., "The Buffalo Crime Mapping System: A Design Strategy for the Display and Analysis of Spatially Referenced Crime Data," State University of New York at Buffalo, Department of Geography, 4224 Ridge Lea Road, Buffalo, NY 14226.

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GREENBERG, D. P., "An Interdisciplinary Laboratory for Graphics Research and Applications," Cornell University, Program of Computer Graphics, Ithaca, NY 14853.

MC CLEARY, L. E., "Techniques for the Display of Ocean Data on a Raster Driven Color CRT," Department of the Navy, Naval Undersea Center, San Diego, CA 92132.

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(For conclusion of SIGGRAPH '77 speakers and their topics, please turn to page 32.)

CRT GRAPHIC TERMINALS

by Carl Machover, President
Machover Associates Corporation
199 Main Street
White Plains, New York 10601

"...Where the budget is limited, it is important to carefully consider what performance your application actually requires -- and then choose a terminal which provides enough (with some safety factor and provision for growth), but not significantly more than you need."

INTRODUCTION

Cathode Ray Tube Terminals have now been associated with digital computers for almost two decades. Initially, the terminals were used in military command and control systems. Back in the mid-Fifties, for example, the SAGE system used CRT terminals (not grossly different from present day refresh units) as one of the primary control devices for our air defense system. However, the use of CRT Graphic Terminals for design purposes in a non-military environment is relatively new. Many digital system historians (if there is such a specialty) will date this application of CRT terminals to the pioneering work done by Dr. Ivan Sutherland on Sketch-Pad in the early 1960's. I have been involved in computer graphics 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. There have been a great many changes in computer graphics since that time, and CRT terminals are becomingly increasingly common in a great many applications areas.

Today, the use of CRT graphic terminals in research, art, and profit-making situations is expanding rapidly. In 1976 one authority estimates that more than 1 billion dollars worth of computer graphics equipment and services were sold.

In this article, I plan to briefly discuss CRT Graphic Terminals within the framework of four topics:

1. How a CRT produces a graphic image.

2. A typical CRT graphic terminal block diagram.

3. Performance characteristics of commercially available equipment.

4. Trade-offs.

My objective is to give the reader a grasp of what performance can be expected from commercially available equipment, what are some of the alternatives you have in configuring a system, and finally, having made your choice, how to be reasonably sure that you can specify the desired performance so that the supplier will provide equipment to meet your needs.

1. *HOW A CRT PRODUCES A GRAPHIC IMAGE*

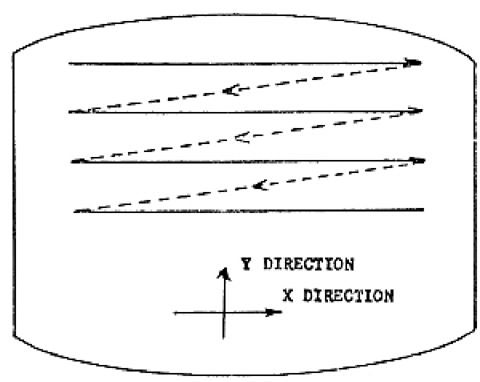
Within the CRT, a stream of electrons is produces which impinges on the phosphor screen. When the electrons hit the screen, light is emitted. Due to the nature of the electron beam and the screen, there are five parameters which can be controlled to produce a dynamic or static image.

A. Beam Deflection

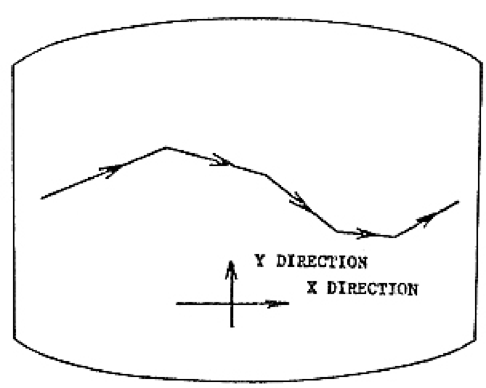
The electron beam is deflected by both magnetic and electrostatic fields. A primary advantage of the CRT is that the beam has negligible inertia, and therefore, can be moved at very high speeds (compared to a plotting pen, for example).

Two basic deflection schemes are used in typical graphic terminals. One is a system with which you are already familiar -- the same as used in your home television set. In a television set, the beam is moved in the X direction. The beam is rapidly reset to the starting horizontal point and moved again horizontally. At the same time, the beam is moved slowly in the vertical direction. (See Figure 1A below.) A typical television picture, for example, consists of 525 of these horizontal scanning lines repeated approximately 30 times a second. This regular scanning pattern is called a raster scan.

FIGURE 1 - Basic Deflection Schemes



A. *Raster Scan*



B. *Random Position*

Alternately, the beam could be moved simultaneously in an X and Y direction; along a straight or curved path, to produce the desired line. (See Figure 1B, p. 16.) This is essentially the same way that you use a pencil to produce a picture. This method is commonly referred to as random positioning, or beam steering. Although raster scan describes a TV picture, the term "raster unit" is frequently used in conjunction with a random position system. "Raster unit" usually refers to the smallest digitally addressable increment on the screen.

B. Beam Modulation

By properly modulating either the cathode or the control grid of the CRT, the beam can be turned off while it is being moved to locations on the screen and then turned on at the desired spot. Also, the intensification can be varied so that a number of light output levels are achieved.

Beam modulation can be used either with raster scanning or random positioning. With the raster scan method, as in the home television set, the beam is turned on and off in response to control signals. Areas of dark and light combine to form the desired picture.

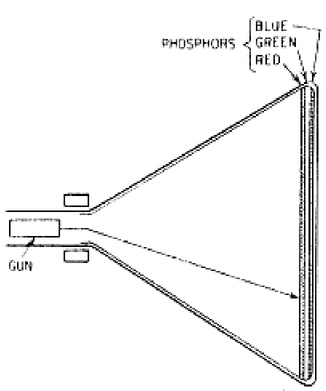
With random scanning, the beam is generally turned off until the desired position is reached, and then the beam is turned on while a beam is deflected along the programmed path.

C. Beam Cross-Section

Typically, the CRT beam is focused with an electrical lens system. Usually, one wants to create as round and as small a beam cross-section as possible. However, it is possible to intentionally distort the beam and change its cross-section. In one type of CRT, the charactron, the beam is extruded through a stencil so that its cross-section is formed into a symbol. When the beam then strikes the phosphor, light is emitted across the entire cross-section, and the symbol appears on the screen.

D. Image Persistence

A system can depend on the eye's memory or on the phosphor persistence to present an image which does not flicker. The light from some phosphors dies out within microseconds after the beam moves to another location. (See Table I above.) With other phosphors, light will continue to be emitted for milliseconds. Storage tubes are available on which the image stays until intentionally erased.



"Control of the depth of penetration into a series of phosphor layers to produce different colors has been used in several color tubes. Figure 2 (at left) illustrates the construction of such a tube." /1/

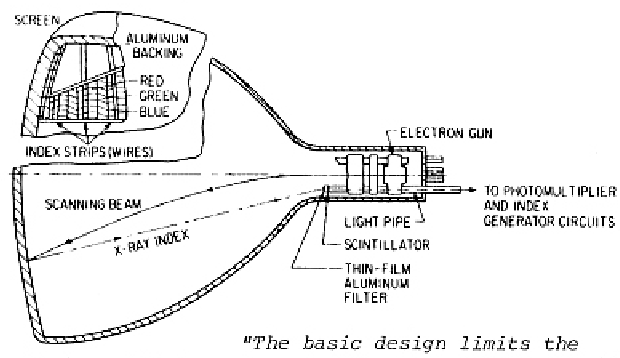
FIGURE 2 - Penetration-Control Tube

TABLE I

Time Required to Decay to 10% of Initial Brightness	Phosphor Classification
Less than 1 USEC	Very Short (VS)
1 USEC to 10 USEC	Short (S)
10 USEC to 1 MS	Medium Short (MS)
1 MS to 0.1 SEC	Medium (M)
0.1 SEC to 1 SEC	Long (L)
Longer than 1 SEC	Very Long (VL)

Except in the storage tubes, image persistence is not usually controllable, but rather is a function of the phosphor originally chosen.

NOTE: Phosphors are categorized by the length of time required for the image to decay 10% of its initial value. Phosphor classifications are summarized above.



"The basic design limits the Goodman tube to a 'scan' mode of operation..." /2/

FIGURE 3 - Goodman Radiation-Indexing Color Tube

E. Color

There is a broad spectrum of colors available to the user. Phosphors are available which emit a white, green, blue, yellow, red, or orange light. Several phosphors can be combined in one tube to achieve multicolor presentations.

In single phosphor CRTs, color is a function of the phosphor chosen. In multiple phosphor CRTs, the graphic element color can be under program control.

Color may be achieved by using multiple gun, color mask, color triad screens (as in home TV systems), or by using single gun, dual layer phosphors as in the penetration CRT.

In summary, any graphic element can be produced on the CRT properly controlling the deflection, intensity, beam, cross-action, image persistence and color. Commercially available systems will program some or all of these parameters to develop a picture.

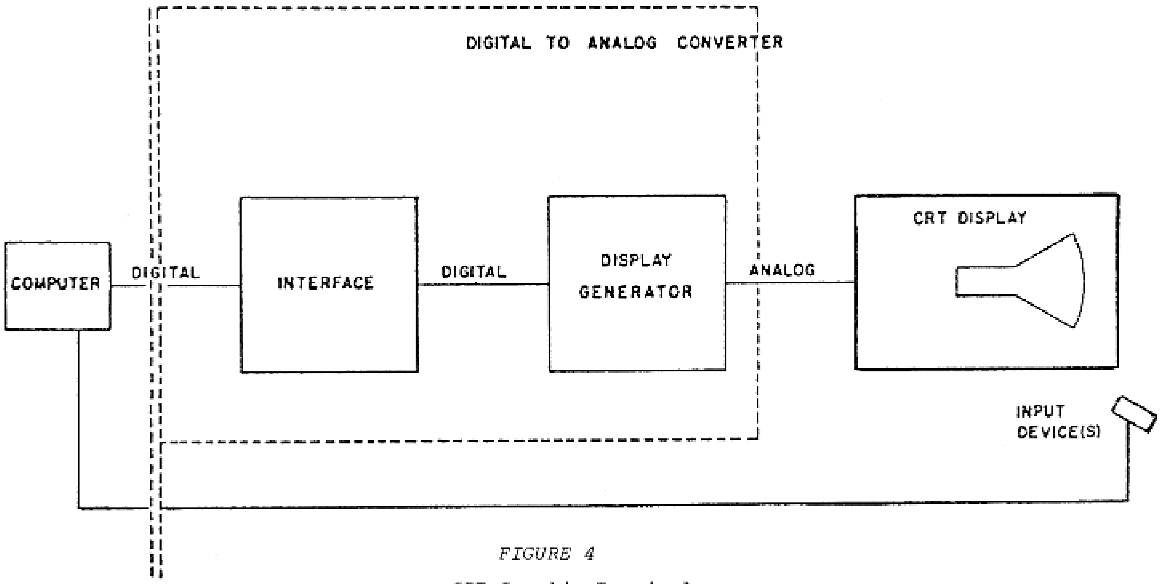


FIGURE 4

CRT Graphic Terminal Basic Block Diagram

A TYPICAL CRT GRAPHIC TERMINAL BLOCK DIAGRAM

Consider next, the basic block diagram of a CRT graphic terminal, shown in Figure *4*. The factors <u>usually</u> controlled in the CRT are reflection and intensity. Because of the nature of a CRT, these are normally controlled with analog voltages. However, the output of a digital computer is a multibit digital word--a series of 1's and 0's. Therefore, between the output of the computer and the input to the CRT a digital-to-analog (D/A) converter is required.

This complex D/A between the computer output and the CRT input has two main sections - the interface and the display generator.

A digital word is presented to the input or the interface, and a digital word is developed as the output. However, through the display generator, the digital input is converted to analog outputs.

There is one additional element in the typical graphic terminal. The block diagram developed so far takes the output of a digital computer and converts it into a graphic symbol on the face of the CRT. One of the powerful features of a graphic terminal is the facility for allowing the operator (or user) to communicate back to the computer. There are a variety of these communication devices available -- such as a light pen, keyboard, function keys, joystick, track ball, Rand tablet, etc. But first, let us examine some of the typical elements which comprise each of the major blocks.

A. CRT Display

Within this portion of the system is contained the cathode ray tube, the deflection circuits which position the beam, and the video circuits which modulate the beam. The tube may be deflected electrostatically or electromagnetically, or by a combination of both. The nature of the deflection circuits will depend on whether the system is basically a raster scanning or a random positioning system.

For now, we will assume that the tube uses a conventional phosphor and hence, no control is provided for persistence. Also, we will assume that the tube uses a single phosphor, and no control is available to change the color. Finally, we will assume that the cross-section of the beam is not varied.

Some CRTs are constructed so that an optical image can be combined with the electronically generated image. These tubes have a port, or window, through which a picture can be projected onto the screen.

B. Display Generator

Before going into a detailed discussion of the elements normally found in a display generator, it would be well to examine in detail how a digital signal might be used to produce a graphic symbol. In the simplest case, the computer data word designates an X and Y location on the screen to which the beam should be moved and then illuminated. Any graphic symbol can then be made up as a series of these illuminated dots. For example, the letter A can be made up with 16 dots. (Figure 5 shows a typical dot-pattern character. /3/ A line or a circle can also be made up of a series of closely spaced dots.

FIGURE 5 BELOW: Typical Dot-Pattern Character

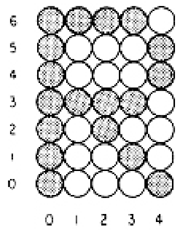
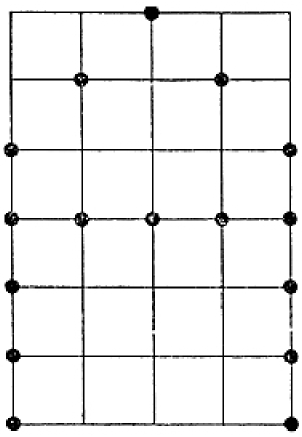


FIGURE 6 RIGHT: The letter A formed by 16 dots.



Therefore the basic elements required in a display generator are a set of conventional digital-to-analog converters which change the digital X and Y designations into corresponding analog signals to position the beam on the screen, plus a dot generator to turn on the beam after it reaches the programmed position. In this elementary system, each dot requires a separate instruction. If, as in most systems, the screen has 1024 addressable locations in the Y direction, 10 digital bits are needed to specify X and 10 digital bits are needed to specify Y.

To draw the letter A then, a series of 16, 20-bit digital words would be needed and at least one computer instruction might be needed for each dot. Therefore, one of the early trade-off decisions that one makes, (and we will examine these trade-off decisions in greater detail later) is the decision between the amount of computer software to make a graphic symbol vs. the amount of display hardware to accomplish the same purpose.

A typical graphic terminal uses a number of special purpose function generators to minimize the computer software. Included among these function generators are a character generator, a vector (line) generator, and a circle generator,

Character Generator - With a character generator, for example, instead of specifying the letter A as a series of 16, 20-bit digital words, it is necessary to specify it only by a 6-bit digital word (which allows the selection of 64 characters), or a 7-bit digital word, which allows a selection of 128 characters, plus--possibly, one 20-bit word which designates the position of the letter on the screen. In the character generator is the special circuitry which translates the 6-bit word into the necessary analog voltages. Just as in the basic display which produces images with either raster scan or by random positioning, various character generators produce characters the same way. In either case, the character generator acts as a kind of digital-to-analog converter which converts the 6 or 7 bit digital code into the necessary analog voltages.

One exception to this method was referred to earlier, in the paragraph on beam cross-section. The separate character function generator is replaced by a stencil mask in the tube. Instead of deflecting the beam to form the character, the beam is positioned to a location on the mask and then extruded through the mask. In this instance then, the character function is included within the CRT.

Vector Generator - The vector generator relieves the computer programming problem of forming a line by programming a series of closely spaced dots. Instead, the vector generator receives computer instructions which define the starting point of the line, perhaps as a 10-bit X and 10-bit Y word, and the end point of the line, also a 10-bit X and 10-bit Y word. In the vector generator is the circuitry required to deflect the beam along the desired path.

Depending on the type of vector generator, the line may appear on the CRT screen as a solid, continuous line or as a series of closely spaced dots.

Curve Generator - Hardware curve generators are also available. Generally, the generator is limited to full circles. To program a circle, it is necessary only to digitally specify the center of the circle and the radius. The hardware generates the necessary analog voltages to move the beam along the desired path.

There are some generators which can draw circle arcs, or segments of up to 3rd order polynomial curves.

BELOW, FIGURES 7 AND 8. FIGURE 7 - "A scan-pattern character generator can be obtained by using a device such as a monoscope to store the intensity modulation signals for each character. A typical monoscope character generator is shown in FIGURE 7." /4/

FIGURE 8, BELOW - "In stroke pattern generators, characters are composed of a sequence of line segments or strokes, generated by the cathode-ray tube electron-beam movement, with time allowed between successive coordinates." /5/

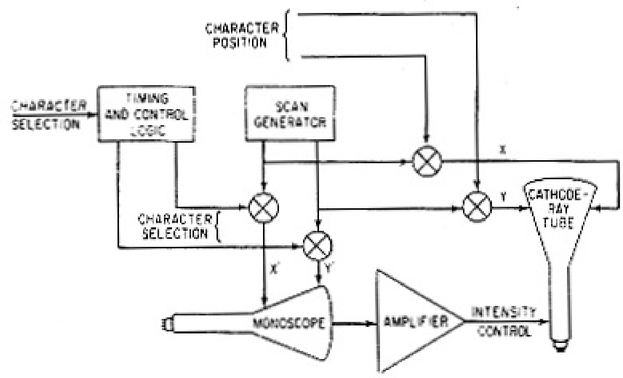


FIGURE 7 - Scan Pattern Generator (Analog Storage)

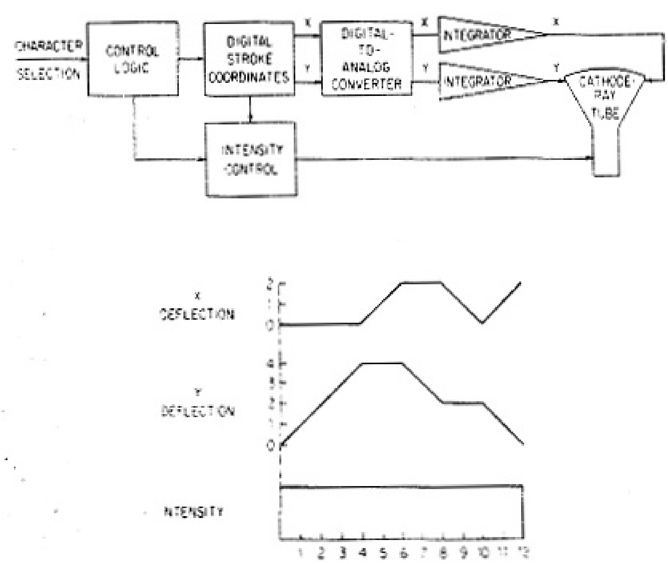


FIGURE 8 - Stroke Format Generator (Digital Storage)

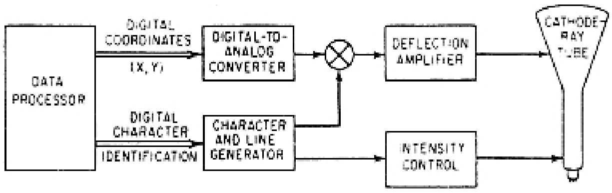


FIGURE 9 - Character and Line-Writing System /6/

Function Generator Modifiers

To further reduce computer software requirements, the typical CRT graphic terminal contains several other elements which modify the outputs of the various function generators.

For example, usually associated with the character generator is a digital size control. By using one or two digital bits, several character sizes can be programmed. The digital size control is generally a digitally controlled attenuator operating on the analog output voltages of the character generator.

At the output of the vector generator, it is possible to connect a line structure control. Instead of the line being drawn solid, it can be programmed to be dotted, dashed, or dash-dotted. This could be done with software, but the hardware alternate allows the control to be done with one or two digital bits. Also, in the typical system, modification of the line structure can be accomplished without affecting the time in which the line is drawn.

Video outputs from the dot generator, character generator, vector generator, and circle generator can be routed through a digitally controlled intensity modifier so that the intensity of any of these symbols can be varied by a one or two bit digital word. The instensity can be further modified under program control so that any of the symbols can be made to blink. This blink control is available as a hardware element.

Display Processing Unit (DPU)

With all the function generators and function generator modifiers, it is necessary to provide logic which decides the computer data word and routes the information to the appropriate function generator and modifiers. This is a block that can be called a display processing unit (DPU). In the simplest form, the DPU simply acts as a decoder. In more complex systems, several other hardware functions are assigned to the DPU.

For example, the stringing of characters across a line in a typewriter page-like format can be done by logic in the DPU. Only the initial position of the first character in the line needs to be programmed. Subsequently, characters are streamed out and the hardware takes care of advancing the character to the next location. Spacing can be made the hardware function of the character size. Provision can be made so that when the characters reach the end of the line, the line automatically resets to the left hand margin (or to a programmed margin) and advances by the appropriate space to begin the next line of characters. Circuits can be included in the DPU so that characters can be rotated by 90° and plotted vertically instead of horizontally, or the characters can be superscripted and subscripted.

The DPU might also include logic for stringing line segments so that once the first line is established, only the new endpoints of the line segments need be outputted to the display generator. Depending on the configuration of the mode control, these successive endpoints can be given either as absolute positions on the screen or can be defined as relative positions from the starting points.

Other hardware functions can also be built into the DPU. For example, a mode can be provided which allows for automatic plotting of a series of points or vertical lines where the horizontal spacing is a preprogrammable increment; or a mode can be provided that allows the incremental positioning of a series of dots. Some commercial systems also include hardware to cause the displayed image to rotate in either 2D or 3D, together with hardware for windowing, for intensity controlled depth cueing, and scaling. In some systems, the image can be defined in a world much bigger than is being shown on the CRT. Windowing refers to the problem of handling picture information which might be off-screen.

DPU complexity is part of the hardware-software trade-off. Microprocessors are now commonly used for the DPU.

Display Refreshing

Earlier it was stated that the typical phosphor used in a CRT emits a light for only the time that the beam impinges on the phosphor. There may be some persistence (or after glow), but generally this does not exceed several milliseconds. This means that something is required to create the impression of a continuous image.

If the screen has short persistence, the eye's memory must be used and the picture must be repainted many times a second to give the eye the impression that it's on continuously. The number of times per second that needs to be painted is the function of the phosphor. In practical systems this will range between 10 to 40 times per second. If there were no storage element in display generators, this refreshing of the display must come from repeated outputs of the computer. Assume for example, that 500 data words are required to form a complete image, and to give the viewer the impression that the image is constant, the image must be repainted 30 times each second. Therefore, the computer would be required to output 500 words every 30th of a second in order to refresh the display.

As an alternate to this, it is possible to include within the display generator a storage of some kind. This can be random access core memory, a delay line, or a drum. If the storage is available in the display, it is necessary only for the computer to load the memory with a frame of data (500 words, from the previous example). The display then would recycle the data out of the store as frequently as necessary to refresh the picture. The only time the computer would be required is when a picture needed to be changed. Then the computer would address the storage as needed, and the new information would appear on the screen.

It is also possible to use a CRT on which the image does not die out immediately. There are several electronic storage tubes available in which the image will remain until intentionally erased. By using this type of CRT, the computer need only program the frame once and the data will remain on the screen until intentionally erased and new information is programmed.

Today there are almost 10 times as many storage tube graphic terminals in use as compared to all other kinds (commercial, non-military applications).

The choice of whether to use the computer to refresh the display or whether to use a memory within the display, or whether to use a storage type tube is one of the trade-off decisions that faces the user. Also entering the storage trade-off decision is the possibility that the storage and part of the mode control can be replaced by a small, general purpose digital computer. The phrase, "intelligent terminal" is often used to describe a system which includes such a minicomputer or microcomputer.

Display Generator Output

The analog signals from the various function generators and function generator modifiers are combined into appropriate deflection and video line drivers which feed the CRT display analog inputs. Frequently, the character deflection voltages (which often require wide bandwidth but small deflection channels) are separated from the other deflection voltages. Therefore, the output of the display generator would consist of major deflection analog signals, minor deflection analog signals, and a video signal.

Several line drivers may be included in the display generator and may feed more than one CRT display. These auxiliary line drivers may, for example, feed a wall size display, a microfilm display, a hard copy device, or another direct view display.

The presentations on all displays may be identical, or they have, as a result of suitable programming of the video channels, different presentations.

C. Interface

The input to the display generator is a multibit digital word. The number of bits required will depend on the specific design of the display generator and may not be the same as a number of bits available from the output of the driving computer (particularly where the CRT graphic terminal is supplied by one manufacturer, and the computer is supplied by another). Also, logic levels of the display generator may not be identical to the logic levels of the computer. Therefore, an interface block is needed between the computer and the display generator. The interface has three functions:

1. To reorganize the computer data word (which may vary from 8 bits to 48 bits) into the word structure required for the display generator.

2. To convert the computer logic levels into the display generator logic levels.

3. To provide the necessary sequence signals so that the computer can properly communicate with the display generator.

D. Input Devices

The discussion thus far has been about a one-way device; information is received from the computer, converted in the display generator and presented as a graphic image on the CRT. However, one of the basic reasons for the increasing acceptance of CRT graphic terminals is the availability of an operator channel from the display back to the computer. The operator can converse with the computer on-line and in real-time, using input devices such as a light pen, joy stick, track ball, graphic tablet, mouse, and function keys.

Light Pen - A commonly used communication device is the light pen. This is simply a photosensitive device which detects the presence of light on the screen. The pen may use a photodiode or phototransistor as the light sensitive element, or it may use a fibre optics bundle to pipe the light to a photo multiplier.

If the display does not use a storage tube, the events which occur on the screen occur in time sequence (even though to the eye they appear to be occurring simultaneously).

A light pen pointed at the screen will detect light at a discrete time and generate a computer interrupt at that time. It is generally a function of the computer software to decide what to do about the interrupt. Since the interrupt is a time dependent function, normal light pen operation is not possible with a storage tube because the time reference is lost.

The light pen can be used either in a pointing mode or a drawing mode. That is, it can be used to point at information which already appears on the screen or to designate a location at which information is to appear; or it could be used to enter information directly.

Because the light pen only responds to displayed information, some kind of symbol must appear wherever a light pen signal is desired. For example, if one wishes to use the light pen to draw a line, a tracking symbol must first be generated, generally by software. With software, the tracking symbol is made to follow the pen as it moves across the screen. The operator, by activating the appropriate function keys, can designate what action the system is to take as a result of the light pen motion; i.e., draw a series of dots along the light pen path, or connect a straight line between the starting position and the present light pen position.

Joy Stick, Track Ball, Mouse - There are other devices which can indicate locations on the screen independent of time and therefore can be used with storage screens. These are units which allow the operator to mechanically control two orthogonal analog-to-digital converters.

The output of the converters are sensed, and a spot appears on the screen at the location determined by these positions. It is generally a software function to compare the dot position generated by the device with computer generated data.

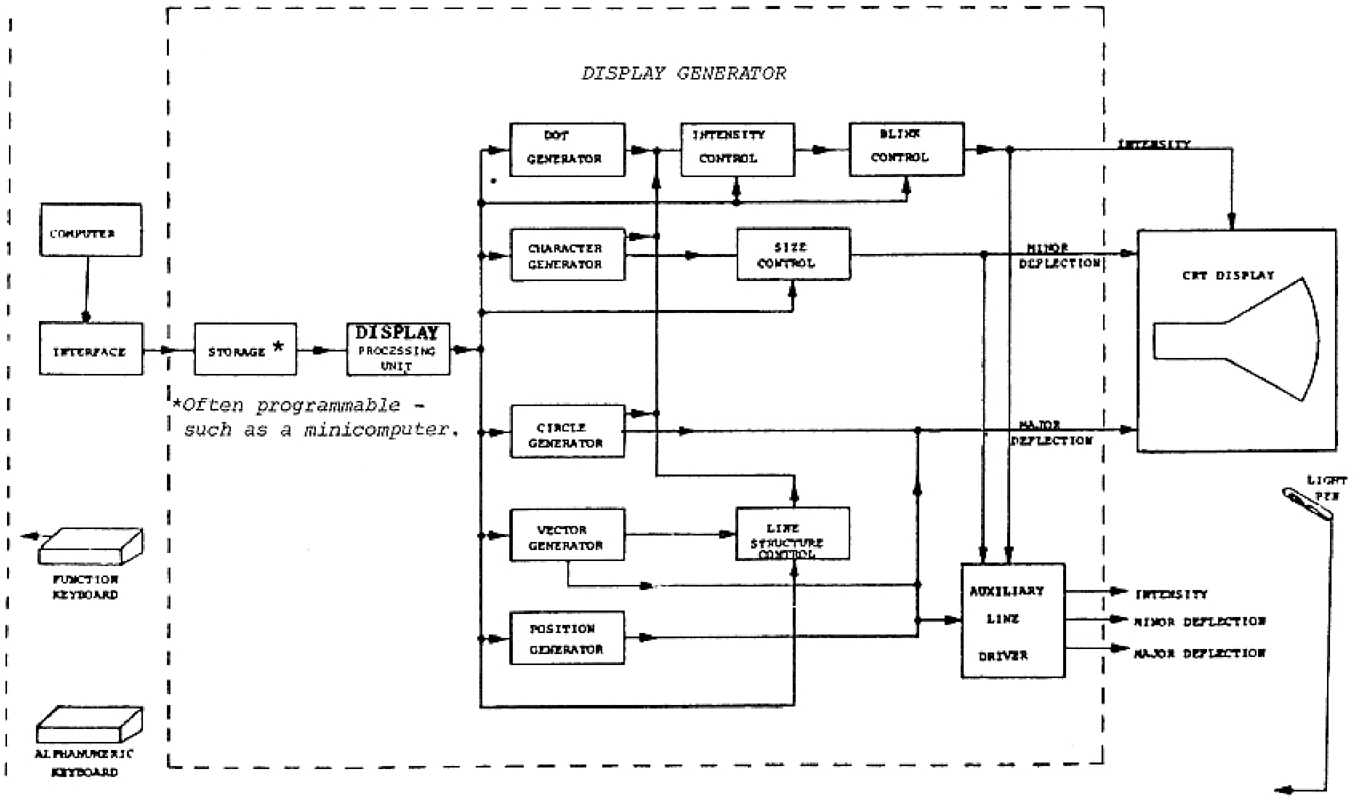


FIGURE 9 - Graphic Terminal

Graphic Tablet - Another operator input device is the graphic tablet. In one form, a graphic tablet is an electronic unit which consists of a rectangular grid of 1024 by 1024 lines. These lines are pulsed and signals are induced in a stylus removed by the operator. The location of the stylus relative to the tablet is determined by decoding the signals. A spot or line corresponding to the stylus position can be made to appear on the screen. Graphic tablets using acoustic techniques are also available.

Keyboards - Several kinds of keyboards are often used with CRT graphic terminals. An alphanumeric keyboard allows the operator to compose messages or make inquiries. Function keys permit the operator to make coded inquiries or to establish operating modes. Some function keyboards use coded, changeable overlays so that the meaning of the function keys can be changed by the operator.

Touch Sensitive - Recently, several touch sensitive panels, using LED's, capacitance, and acoustic standing waves have been introduced. (Figure 9 is a detailed block diagram of a typical CRT graphic terminal, above.)

E. Data Organization

Before leaving this general discussion of CRT graphic terminals, it will be of interest to examine in some detail how the computer data word can be used to program a picture.

There are several ways in which the computer word can be organized. These depend on how large the data word is and on how complex the display generator is.

The data word may be completely self-contained, with each word containing information about the mode of operation (character writing, line drawing, and position). Figure 10A is an example of this organization.

More often, two types of words are used. One type is a control word, which establishes the mode and sets some parameters (such as, intensity and line structure) for the succeeding data words which contain locations or characters. All succeeding words are interpreted as the same kind of data words until a new control word is encountered. A typical example of this kind of data organization is given in Figure 10B. (See page 23 for these figures.)

PERFORMANCE CHARACTERISTICS OF COMMERCIALLY AVAILABLE EQUIPMENT

Over the past few years a number of CRT terminals have become commercially available. Before reviewing the general characteristics of graphic terminals, it is helpful to see how these fit into the spectrum of computer driven CRT displays.

There are basically three types of display systems:

Point Plotting
Alphanumeric
Graphic

Each type of display system can be divided into two three broad categories:

low cost/low performance
medium cost/medium performance
high cost/high performance

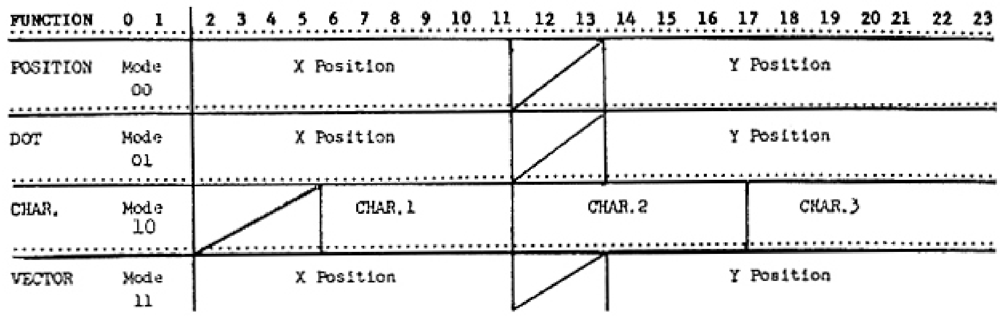
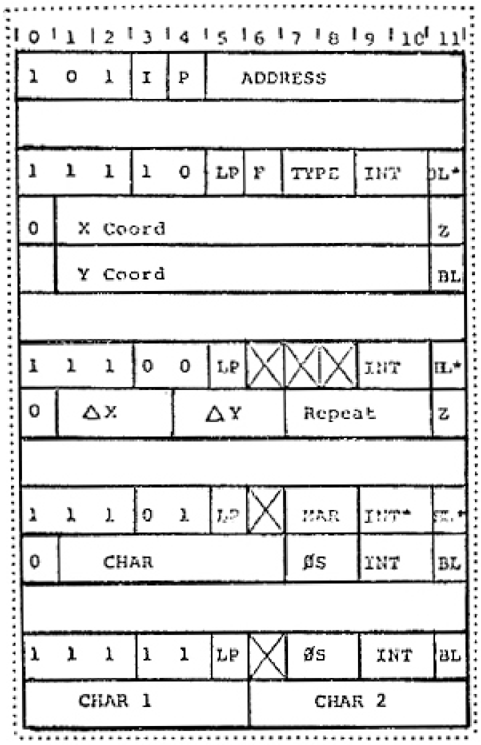


FIGURE 10A ABOVE: Self-Contained Word Organization

FIGURE 10A (Above) - Self-Contained Word Organization

FIGURE 10B (Below)

Control Word and Data Word Organization



Program Control Word

Vector Mode Control Word

Vector Data Word Pair

*These bits do not actually control the display but are included to provide programming mode compatibility.

Dot Increment Mode Control Word (See * comment above.)

Dot Increment Data Word

Symbol Mode Control Word (see * comment above.)

Symbol Data Word

Packed Symbol Mode Control Word

Packed Symbol Data Word (77_8 = escape)

LP = disable light pen
BL = enable blink
Z = blank
F = frame sync

INT = 00 - normal
01 - dim
10 - bright
11 - off

TYPE = 00 - Position
01 - Position, Write Dot
10 - dash
11 - solid

ΔX, ΔY = 001 +1
010 +2
111 -1
110 -2
Others - no increment

ØS = 00 - normal, no offset
01 - small, superscript
10 - small, subscript
11 - small, no offset

MAR = 00 - NØP
01 - set margin
10 - return to margin
11 - return to margin and line feed

	LOW ($2K – $12K)	MEDIUM ($12K – $70K)	HIGH ($70K – $300 K)
GRAPHIC	- Storage Tube - Refresh/Random - TV/Scan Converter - TV/Digital - Plasma	- Refresh/Random - TV/Digital - Refresh/Random (Intelligent Terminal)	- COM (Graphic Computer Output on Microfilm)
ALPHANUMERIC	- TV (Digital)	- COM (Line Printer Mode)	
POINT-PLOTTING	- Storage Tube - Refresh/Random	- COM	- CIM (Computer Input from Microfilm, Film Scanners)

C O S T   P E R F O R M A N C E

COMMERCIALLY AVAILABLE CRT DISPLAYS

FIGURE 11

(Note: Above, compare prices and capacities in CRTs.)

Figure 11 illustrates these divisions. Also shown in Figure 11 is indication of the basic characteristics of commercially available equipment vs. the approximate price. The price divisions are rather arbitrary and are intended only to show the range for each device.

As can be inferred from earlier discussions, a graphic CRT terminal is a conglomerate of devices, each of which has a range of characteristics which can affect the performance and useability of the terminal. For convenience, the various factors which contribute to the effectiveness of the terminal can be grouped into three categories:

1. Those which affect the data content -- that is, how much information can be displayed simultaneously without flickering objectionally and with the graphic symbols large enough to be easily read, or when small, to be easily distinguishable.

2. Those which affect the quality of the display--that is, how the display looks aesthetically to the observer.

3. Those which affect the ease of use -- both from a human standpoint and from a systems programming standpoint.

Characteristics which affect each of these categories are discussed in this section. Where appropriate, typical ranges for commercially available equipment are given.

A. Data Content

The amount of data which can be displayed simultaneously without appearing to flicker is affected by the following:

Frame Rate - The more time that can be taken to write a frame of data, the more data can be displayed per frame. In the limiting case, using a phosphor with indefinitely long storage, the amount of information which can be display simultaneously will depend only upon the resolution of the CRT.

However, in the more typical case, the CRT phosphor retains the image for times ranging from 1 USEC to 100 MS. The eye needs to have an image without any persistence repeated 35-40 times per second before successive images merge without flickering. As the persistence of the image increases, the number of times it needs to be repeated decreases. Typical phosphors used in CRT terminals produce displays that need to be refreshed from 10 frames/second (with a long persistent phosphor such as the J, or L3) to 40 frames/second for the medium-short persistent phosphors such as the P4 and P31.

Because less persistent phosphors tend to be more efficient, and more resistant to damage, most manufacturers prefer to use them in their terminals. Therefore, all frame-time dependent values -- and references to flicker-free presentations -- in the following discussions are based on a 40 cycle frame rate (or 25 MS frame interval).

Keep in mind, however, that the data content can be increased in direct proportion to frame interval. For example, if a flicker-free data content of 250 points is quoted, it is understood that the calculations are based on 25 MS frame intervals. If, in a particular system, with a particular phosphor, a frame interval of 100 MS (frame rate=10/second) were acceptable, the number of points could be increased to 1000.

Incidentally, "flicker-free" data content calculations are based on random positioning systems. Data content on TV systems is not limited by function generator times but by resolution, and memory capacity.

Deflection Amplifier Response - A primary parameter of a CRT display is the speed with which the beam can be positioned. In random positioned systems, the beam can be moved anywhere on the screen in times ranging from 3 USEC to 100 USEC. Therefore, the number of random dots which could be displayed, flicker-free, ranges from 250 to 8300.

If the data can be properly formatted, it may be possible to organize the information so that full screen random positioning is not required. Under these circumstances, the small angle positioning time of the deflection amplifier is critical. In commercially available equipment, this ranges from 1 USEC to 10 USEC. Therefore, the number of dots which can be displayed flicker-free ranges from 2500 to 25,000.

Note that these factors are based on the assumption that the system uses random positioning. There are systems, however, which use a raster scan similar to that used in a conventional television set. Such systems require complete formatting of the data. However, by doing so, as many as 1,000,000 dots can be displayed flicker-free, compared to a maximum of 25,000 dots in a random positioning system.

Deflection amplifier response also becomes less critical with storage tube displays, since the image needs to be written only once, and does not have to be rewritten. Deflection amplifier response is related more directly to the maximum speed with which a line can be drawn and stored -- which is about 5000"/second.

A second, wide bandwidth, small angle deflection channel with bandwidth ranging from DC to 10 MC, is also included in some terminals in a single channel. Alternately, there are newer deflection amplifier designs which combine fast random position with wide bandwidth small angle deflection.

Character Writing Time - Character generators available in commercially available refresh terminals, write a character in times ranging from 2 USEC to 100 USEC. To these times must be added the positioning time (ranging from 3 USEC to 100 USEC random or 1 USEC to 10 USEC, small angle). Therefore, the number of random characters that can be displayed flicker-free ranges from 125 to 5000, and the number of formatted character (text) that can be displayed flicker-free ranges from 220 to 8300. As a comparison, a typical double spaced typewritten page contains about 2500 characters.

Digital TV character generators range from about 40 USEC to 800 USEC per character, while storage tube character generators use about 400 USEC.

Line Drawing Time - Two types of vector (line) generators are offered in commercial available equipment. One type requires a fixed time to draw a line regardless of line length, while the other requires a time proportional to line length. Typical fixed time vector generators require from 30 to 150 USEC to draw lines up to full screen size, while the proportional vector generators have line drawing speeds ranging from 0.5 USEC per inch to 150 USEC per inch. This means that the fixed time vector generators can draw between 160 and 830 flicker-free line segments per frame. Depending on CRT screen size, this can represent up to 16,000 inches of line. Proportional vector generators in a refresh system can draw from 160 to 50,000 inches of flicker-free line per frame.

Digital TV line generators take about 1 MSEC/in., while storage tube line generators draw at about 200 USEC/in.

Circle Drawing Time - Hardware circle generators available with terminals can generally draw any size circle in from 100 USEC to 300 USEC. This means that from 83 circles to 250 circles can be displayed flicker-free.

Logic Time - In addition to the actual time required to deflect a beam and write the various functions, the logic in the display generator, the logic of the computer, and the memory cycle time will affect the amount of data which can be displayed. For example, the word organization of the terminal may require that the generation of each graphic element be controlled by several data words. Elapsed time from the display's request for a data word and the terminal's set-up is in the order of 1 to 4 USEC. If 1000 data words were required per frame (a typical value), and between 1 and 4 USEC were consumed in data transfer and logic set-up, 4% to 16% of the frame time is consumed and the data content would be reduced by that amount.

Resolution - Resolution determines such things as the smallest readable character that can be displayed, and the minimum spacing that can be discerned between lines. Basically, CRT beam spot size determines resolution. In commercially available terminals, the nominal spot will range from .01" diameter to .03" diameter. However, spot size might vary by a factor of 3:1 (on the same terminal) because of the beam intensity and spot position on the screen (better in the center, poorer at the edges). Some terminals use dynamic focusing techniques to keep the spot size relatively constant over the display area.

For purposes of comparison, the range from 30 lines per inch (.03" diameter spot) to 100 lines per inch (.01" diameter spot) will be used. To read a character with minimum chance of error, it is generally agreed that at least five and preferably seven lines of resolution per character are needed. Two more lines are needed in the space between characters. Therefore, assuming that a typical character and its space needs nine resolution lines, the character density with a 30 line/inch resolution display is approximately 3 characters per inch and with 100 line/inch resolution, it is approximately 11 characters per inch.

For comparison, a pica typewriter spaces characters 10 per inch, and an elite typewriter spaces characters 12 per inch.

Addressability is sometimes confused with resolution. Addressability is a statement of how many digital positions can be programmed (but not necessarily distinguished) along each axis. Typical terminals offer 9 bit (512) or 10 bit (1024) addressable locations. The term "raster unit" is often used to describe an element of addressability.

Screen Size - Screen size affects data content primarily from the standpoint of resolution. CRTs used in commercial terminals generally range from 16" round to 24" round, with available display areas of from 10" x 10" to 16" x 16". Therefore, the number of readable characters per line can range from 30 (10 inch line of a resolution of 30 lines per inch) to 176 (16 inch line with a resolution of 100 lines per inch).

Inexpensive graphic storage tube terminals with 6" x 8" display areas are also available.

Overlays - Static information can be superimposed on the beam written data by projecting pictures (slides) through an optical port in the CRT. Typical systems can select from among 25-150 slides.

B. Quality

Several factors affect the image quality. Some of these factors may also affect data content, as indicated in the following discussion.

Accuracy (Linearity) - Accuracy describes how the programmed position of the beam corresponds to some external reference. For example, if a grid were scribed in the face of the CRT and the beam were programmed with a digital instruction which should cause the beam to fall at a grid line intersection, the variance between the beam position and the intersection is the accuracy. Commercially available systems have accuracies ranging from 1% to 5% of full scale. Generally, pictures drawn with this accuracy are quite acceptable to the observer, provided there is no attempt to superimpose the electronic image with a mechanical reference. The presence of the mechanical reference will emphasize the nonlinearity or inaccuracy of the display. For comparison, the nonlinearity of a well-adjusted home television set is about 10% to 15%.

Short-Time Stability - Short-time stability of the image will affect the observer's reaction to it. Small movements of the graphic element, called jitter, can be quite objectionable when it occurs at low frequencies (less than 10 cps). Jitter results mainly from a beat between the frame rate and the power line frequency (or submiltiple frequency). In an adequately shielded terminal, the jitter is about 0.5 to 1 spot -- but even this value can be disturbing to the user.

Two methods are used to reduce or eliminate the apparent jitter. One is to maintain the frame rate at such a value that the beam frequency is relatively high -- typically 20 cps. Although jitter may still be present, the graphic element is moving so fast that, to the observer, the line or dot simply thickens a bit. Hence, the resolution is affected, but the image appears stationary. This technique is especially successful when used with longer persistent phosphors.

Alternately, since the jitter most frequently comes from stray magnetic fields, the display frame rate can be locked to the line frequency and the jitter essentially eliminated.

Repeatability - When the beam is programmed to the same location from various places on the screen, the successive dots will probably not be superimposed. The spread, called repeatability, may range from 1 spot size to 10 spot sizes. In commercially available equipment this effect may be particularly disturbing when various line segments are programmed to start from the same point, but, because of repeatability, they do not.

Brightness and Contrast - If the display is to be used in a normally lighted room, it is important that the presentation be bright or have a high contrast ratio. Typical terminals produce 20 foot-candle to 50 foot-candle presentations. Shorter persistent phosphors, such as the P4 and P31 do produce bright, easily read displays, but these phosphors require relatively high frame rates to reduce flicker. Longer persistent phosphors such as P19, P23, and L3 reduce the frame rate requirements at the expense of brightness. Therefore, displays using longer persistent phosphors or storage phosphors may require subdued room illumination. Contrast can be enhanced with neutral density filters. Although these filters reduce total brightness, they do increase contrast and enhance the readability of the display.

Storage tube terminals have significantly lower brightness, in the order of 5 foot-candles.

Phosphor Color - Phosphors are available which produce white, green, yellow, blue, and red outputs (and shades inbetween). The shorter persistent phosphors are generally in the white, green and blue range; while the longer persistent phosphors are in the orange, yellow range.

The eye is most sensitive in the green region, so that with equal light output, displays with a green image appear brighter. This is one reason why the P31 phosphor is used in many terminals.

Graphic Symbol Construction - Graphic elements can be constructed in a variety of ways -- some of which enhance the quality of the display, and others which tend to detract from it. For example, characters formed from a 5 x 7 dot format may be readable but not aesthetically satisfying. Other graphic elements constructed from a series of dots may be readable, but not pleasing.

Stroke characters usually produce acceptable quality formats. The beam forming and non-scope techniques permit a wide range of character formats, with few limits on character style. Higher resolution dot formats, typically 16 x 16, are also capable of producing excellent quality symbols.

C. Ease of Use

There are two categories discussed in this section -- those which are based on human factor considerations, and those which are based on programming considerations.

Human Factors - Screen angles range from approximately 10° from the vertical, to horizontal. Generally this is fixed, although at least one commercially available unit has a tiltable head.

A variety of light pen configurations are available ranging from a simple penholder type to a gun type. Some pens are relatively heavy while others are light weight. Some use a very flexible cable and others have a rather stiff cable or coil cord. Aiming circles are provided with some light pens so that the operator (or user) knows where the sensitive area of the pen is pointed. Activating switches for the light pen range from mechanical shutters on the pen, electrical switches on the pen, knee switches, and foot pedal switches.

Other operator input devices are available on various consoles. Alphanumeric keyboards and function keys are used. Some function keys use plastic overlays for additional coding. Track balls and joy sticks are preferred by some users. The graphic tablet provides an easy method for graphic input and is available as an accessory in several systems. Some displays eliminate all mechanical input devices and allow the user to get a response by simply pointing with his finger at something on the screen.

Operator controls on commercially available terminals range from having only an on-off power switch to providing manual adjustments for various display parameters.

Servicing facilities incorporated in terminals range from a logic card extender to elaborate maintenance panels, which include register lights and test pattern generators.

Terminal packaging ranges from multiple cabinet configurations, with the display console separated from the display generator, to relatively large integrated units which occupy 10-15 square feet of floor space, and are 4-5 feet high.

Systems Programming - The display command structure influences system programming. Common types of command structures are shown in Figure 10A. In one approach, each data word is completely self-contained and has a mode instruction and all other information required to define a graphic element. In contrast, the word organization currently favored-(Figure 10B)establishes a mode of operation with one word, and then uses a series of succeeding data words to program identical kinds of graphic elements.

Figure 10B also illustrates a word organization which includes computer-type instructions such as JUMP and JUMP AND SAVE. Some graphic terminals are designed so that more than one display console can be driven from a common display generator. These other consoles may be slaved (and have identical information) or they may have different information. Such displays may be photographed or used to produce wall size pictures or immediate hard copy.

More frequently now, systems are supplied with extensive software which eliminates bit level (binary) or assembly level programming.

SUMMARY

This section has discussed the characteristics of commercially available terminals from an equipment viewpoint -- not from an applications viewpoint. One can list a number of current and potential applications for CRT graphic terminals, but the data which describes terminal requirements in terms of these applications is scarce. For example, the line drawing needs of a terminal used by civil engineers for cut-and-fill analysis may be quite different from an engineer using the terminal to design integrated circuit masks.

For an applications approach to terminal selection, see "Interactive CRT Terminal Selection" by the author. /7/

GML, in their "Computer Display Review", formulated several typical presentations: schematic diagram, floor plan, and weather map, and using terminal manufacturer's supplied performance specifications, analyzed how long each terminal would take to write the display.

Generally, the terminal user considers his data (applications) content requirements proprietary, and seldom publishes his findings.

4. *TYPICAL TRADE-OFF DECISIONS*

In this section, I will discuss some of the choices you will have to make in configuring a terminal. These will be technically based decisions. Other trade-offs, such as the reputation of the manufacturer, the personality of the salesman, the availability of lease vs. purchase, and the availability of software, will enter into your final decision -- but these considerations are "beyond the scope of this paper".

Here are some of the trade-off decisions with which you will be faced in choosing a terminal for your application. The "your application" is intentionally underlined -- because it is unlikely that any one terminal will be the best for all applications. Many questions will be raised, and few answers will be found in the following discussion. My intent is to raise some caution flags!

A. Cost vs. Performance

Earlier it was emphasized that performance and capability are generally (but not always) re-- lated to cost. Higher performance units -- more data capacity, better quality characters, greater versatility -- generally cost more. Therefore, where the budget is limited, it is important to carefully consider what performance your application actually requires -- and then choose a terminal which provides enough (with some safety factor and provision for growth), but not significantly more than you need.

Notice that most of the other trade-offs discussed in this section carries some cost implications.

B. Hardware vs. Software

"Hardware vs. software" trade-off is not an easy decision to make. The kind of application, the capability of the driving computer, the number of identical systems in related facilities, display data content, are all factors which enter into the decision. Where hardware funds are limited, where display data content is low, when the capability of the driving computer is not being pushed, where there are many identical systems in related areas, the tendency is to use more software and less hardware.

C. Raster vs. Random vs. Storage

One of the high cost items in CRT graphic terminal systems is the display itself. This is especially true where several displays are driven from a common display generator. Generally, the display used in a raster system is significantly less expensive than one needed in a random system. This difference occurs because raster displays can use TV like techniques which are (1) inherently less expensive technically, and (2) acceptable to commercial TV monitors which are produced in substantial qualities, and therefore are less expensive.

However, the use of a raster system may have several other drawbacks. The user may not find the appearance of a raster display as pleasing as one made from continuous lines. Programming a raster system imposes burdens. Primary data is generally defined by specific locations on the screen. For example, a line may be defined by two end points, X_1Y_1 and X_2Y_2. In a random positioning system, the beam is simply programmed to move between these points. In a raster system, the end point definition must be converted into a different (time-dependent) coordinate system -- and the conversion must generally be done in the central computer (another aspect of the hardware vs. software trade-off). Communication from the display to the computer via light pen is also complicated in a raster system.

For the past few years, storage tube displays have been the most popular choice -- unlimited data without flicker, lowest cost, excellent resolution. However, storage tube systems suffer from low brightness (or value contrast), no gray level, no color capability, and no selective erase (except in the non-store, write through modes).

D. Refresh from Center Computer vs. Display Buffer

Including a buffer in the display increases the cost of the terminal. In some applications -- for example where the terminal is located more than 2000 feet from the central computer, it is not practical to use a high data rate communication line) -- the display must have a buffer. However, in many cases, the display could be refreshed directly from the central computer. Generally, central computers with data break, direct memory access, or overlap control facilities, are better suited to refresh displays. If the application does not require a substantial amount of processing time in the central computer, it may be practical to also refresh the display from the computer.

Availability of truly low cost general purpose computers (where the computer cost is not greatly different than a wired core memory) further complicates (or increases) the choice. Enough advantage may be obtained by allocating certain housekeeping functions (display refresh, light pen tracking, editing, coordinate transformation) to the small computer-used-as-display-buffer, to favor the use of the small computer where an ordinary buffer would not generally be used.

E. High Refresh Rate vs. Phosphor Storage

If storage phosphors are available, why use a high refresh rate at all? Here are several reasons. Generally, the storage phosphors are not as bright, or as efficient. Also, most storage phosphors are "soft" in the sense that they can be burned easily. It is virtually impossible to protect a storage phosphor against some condition which may damage it.

When rapidly moving data is presented, the storage phosphors will tend to show a smeared picture. Time-dependent communication between the display and the computer may be impaired because of the stored image. For example, it may not be possible to use a light pen with a storage phosphor.

However, the new low cost graphic terminals do generally use storage phosphors as the key element in reducing cost.

F. Mechanical Keyboards vs. Light Pen

Some kind of keyboard is needed with most graphic terminals in order to transmit the operator's command to the computer. These commands may call up new information, change data, or put the system in a different mode.

The light pen in conjunction with displayed information, can be used for this type of communication. Why, then, add any mechanical keyboards? Many users find that total light pen command is not efficient -- for example, when the system is being used for computer-aided design. Here, the user would be required to continuously move the pen between the command keyboard and the drawing area. By having a mechanical function keyboard, the user can work the buttons with one hand and the light pen with the other.

Message composition is somewhat easier using an alphanumeric keyboard rather than a light pen in conjunction with a displayed alphabet.

With the growth of storage tube displays, the graphic tablet has become very common, providing ease of menu selection, digitizing, and free-hand drawing.

G. Monochromatic vs. Color

Color television is here -- why not color CRT graphic terminals?

Why not, indeed? There are some applications where color would be most helpful. Using the display to design integrated circuit masks, or multilevel printed circuit boards, for example. There are many other applications where color probably would not offer enough to justify the cost or lower performance.

Generally, the manufacturer must use a commercially available color mask CRT -- the same one being used in home color TV sets. Tube construction limits the resolution. The smallest character size, for example, would be about ¼" high (compared to 3/32" in a readily available conventional monochromatic CRT). Technical problems with the convergence circuits (the circuits which allow the three primary colors to be combined to produce any other color, including white) drastically increases line drawing time in random position systems (from typically 1 USEC/inch to 100 USEC/inch). However, with the growth of digital TV, color mask systems are becoming very common.

Recently, a color CRT based on an entirely new principle, has been introduced. In effect, the CRT uses two phosphors which respond differently as a function of CRT anode potential. Adequate colors in the red, orange, and green range are produced and the tube has potentially higher resolution than does the conventional color mask CRT.

H. Light Pens vs. Joy Stick vs. Data Tablet

This trade-off decision follows the same kind of consideration as mechanical keyboard vs. light pen vs. graphic tablet. That is, the choice depends on application -- and in many cases, it's desirable to use all three. In practice, the light pen is almost always used, supplemented in some cases with the other devices.

I. Graphic Terminal vs. Something Else

I suppose it is a little late to raise this one -- because this is probably the first decision you will be called upon to make. After all, there are other computer input-output devices -- many much less expensive than a CRT graphic terminal!

Keyboards, printers, plotters, CRT alphanumeric inquiry stations are available. Generally, the CRT graphic terminal can be justified:

1. Where "quick-look" fast graphic output is needed, as in some types of pattern recognition problems.
2. Where rapid dynamic graphic man-machine communication is needed, as in computer aided design, on-line problem solving and simulation.
3. Where the user's understanding is enhanced and response time decreased by a graphic representation, as in management information and command and control systems.
4. Where you're not sure, but you have a budget which will let you find out!

SUMMARY

It is hoped that this in-depth discussion of CRT display systems will be of benefit to readers and to people who are contemplating the purchase of visual displays -- but who are not experts in this area. Again, a thorough study of the advantages and specific capacities of each system is necessary to discern the one that will adequately meet one's present and near-future needs.

As hardware becomes increasingly more affordable, more users will extend their present systems to include visual displays. The latter offer fast, informative visualization of computed data that printout systems cannot offer. Further, the active display afforded by CRTs attracts and holds the user's attention in ways that static plotter systems do not.

In the near future, the use of display systems will be so common that we will question how we lived without them -- for man is, after all, a very visually oriented creature.

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/2/ op. cit., p. 251.

/3/ op. cit., p. 267.

/4/ op. cit., p. 274.

/5/ op. cit., p. 270.

/6/ op. cit., p. 266.

/7/ Machover, C., "Interactive CRT Terminal Selection,: SID Journal, November-December, 1972.

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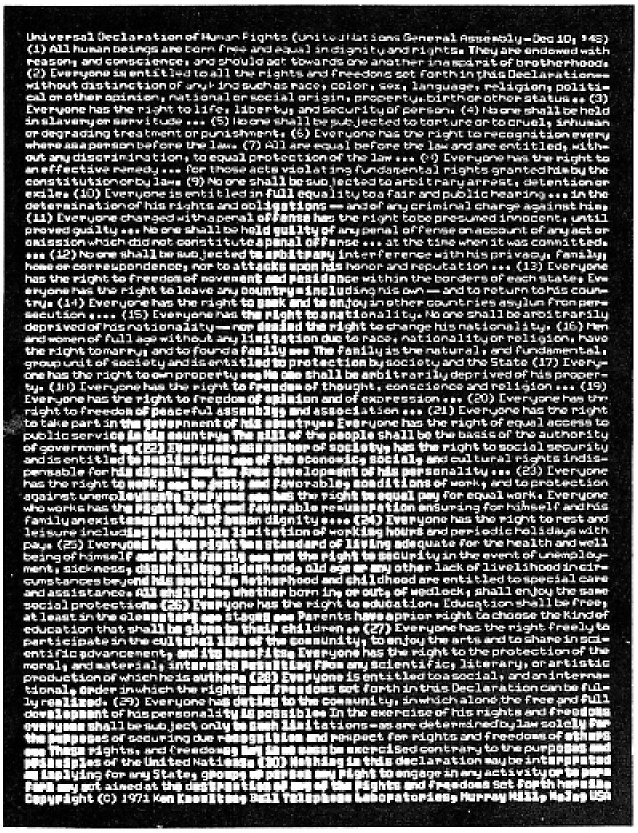

ABOVE: "Universal Declaration of Human Rights" by Kenneth Knowlton, Bell Laboratories, Murray Hill, New Jersey.

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(All materials should be in English, typed double spaced on letter-sized paper, and references are desirable. Relevant illustrations should accompany written material. Authors may write for "Suggested Guidelines for Prospective Authors".

BELOW: "People" by Waldemar Cordeiro, Sao Paulo.

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"Plotmap - Computer Representation of Geographic Data" by Lloyd Onyett, Geography Department, California State Univ., Chico, California

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"Computer-Assisted Graph-Making" by Elaine McNichols, Department of Computer Science, California State University, Chico

SOFTWARE

"Expanding the Graphics Compatibility System to Three Dimensions" by Richard F. Puk, Purdue University, Lafayette, Indiana

"How to Build Fuzzy Visual Symbols" by Alex Makarovitsch, Honeywell Bull, Paris, France

"Engineering Applications in the Design of Buildings" by Kerry Jones, American Buildings Company, Eufaula, Alabama

"Inexpensive Graphics from a Storage Tube" by Dr. Charles J. Fritchie and Dr. Robert H. Morriss, Tulane University, New Orleans, Louisiana

"Digital Computer-Based Sculpture Composed of Coloured Elements" by Professor Lawrence J. Mazlack, University of Guelph, Ontario, Canada

"A Computer System to Generate Weave Structures" by Professor W. G. Wolfgang, Philadelphia College of Textiles and Science, Philadelphia, Penna.

PHILOSOPHY - ART

"Art of the Technical World" by Dr. Herbert Franke, Munich, Germany

"Mathematics in Art and Computer Graphics" by Dr. Jean Bevis, Georgia State University, Atlanta, Georgia

"Graphics Applications: Paintings" by Roger Coqart, Bruxelles, Belgium

"An Art Chairman's Flashbacks" by Jackie Potts, Social Security Administration, Baltimore, Maryland

"The Programming Choreographer" by Analivia Cordeiro, Sao Paulo, Brazil

"RE:VIEWING" by Professor Charles Glassmire, Robert Morris College, Coraopolis, Penna.

"Diamond Theory" by Steven H. Cullinane, Jamestown, New York

"An Investigation of Criteria for Evaluating Computer Art" by Dr. Thomas E. Linehan, Ohio State University, Columbus, Ohio

"NCC '76 Art Exhibition, New York City - Preview, Comments by: Manuel Barbadillo (Spain); Hiroshi Kawano (Japan); Kenneth Knowlton (USA); Manfred Mohr (France); Georg Nees (Germany); John Roy (USA); Zdenek Sykora (Czechoslovakia); Roger Vilder (Canada); and Edward Zajec (Italy).

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CONCLUSION OF SIGGRAPH '77 SPEAKER/TOPIC LISTING: (See pages 14 and 15 for complete program.)

VICKERS, D. L., "Moving, Computer-Generated Images via Integral Holography, Lawrence Livermore Laboratory, P. O. Box 808, Livermore, CA 94550.

WOLCOTT, N. M., "A FORTRAN IV Program for Enchanced Graphic Characters," Admin. A-234, National Bureau of Standards, Washington, DC 20234.

WRIGHT, T., "Machine Independent Metacode Translation," National Center for Atmospheric Research, Box 3000, Boulder, CO 80307.

12. RASTER GRAPHICS - W. NEWMAN, Xerox Research, 3333 Coyote Hill Rd., Palo Alto, CA 94304.

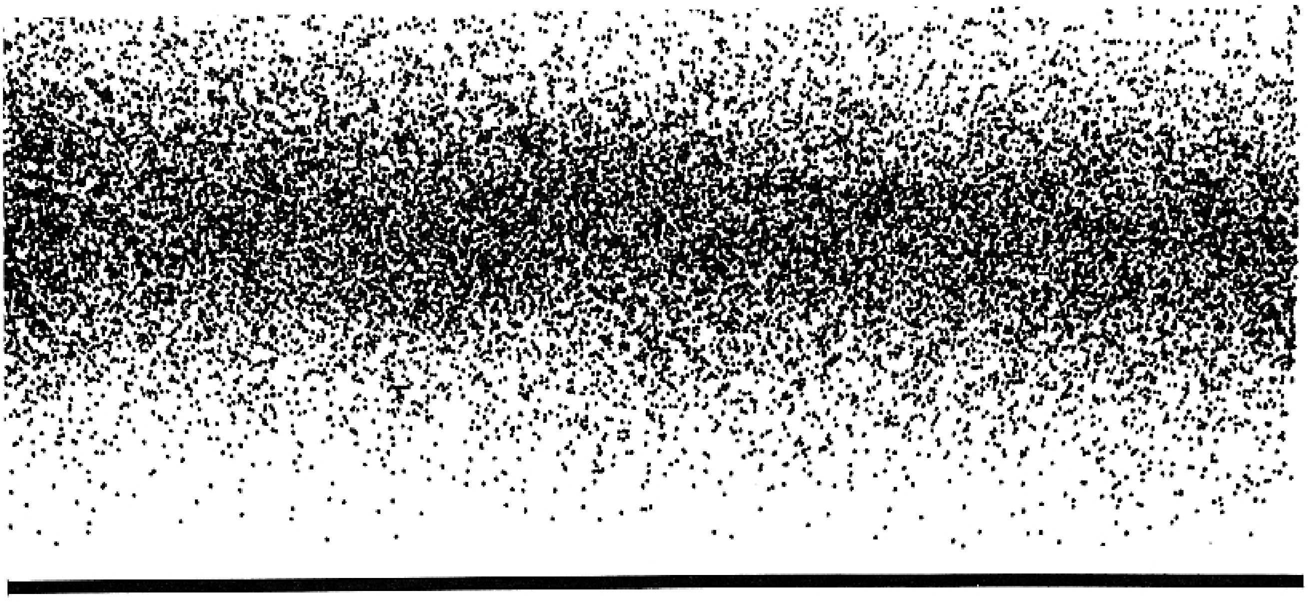
13. GRAPHICS RESEARCH - DAVE EVANS, Evans and Sutherland Computer Corp. 589 Arapeen Drive, Box 8700, Salt Lake City, Utah 84108.

14. GRAPHIC STANDARDS - BERTRAM HERZOG, Computer Center, University of Colorado, Boulder, Colorado 80309 - ROBERT DUNN, United States Army Electronics Command, Fort Monmouth, New Jersey.

15. LOW COST COMPUTER GRAPHICS - (No other information other than the title is listed in the tentative program.)

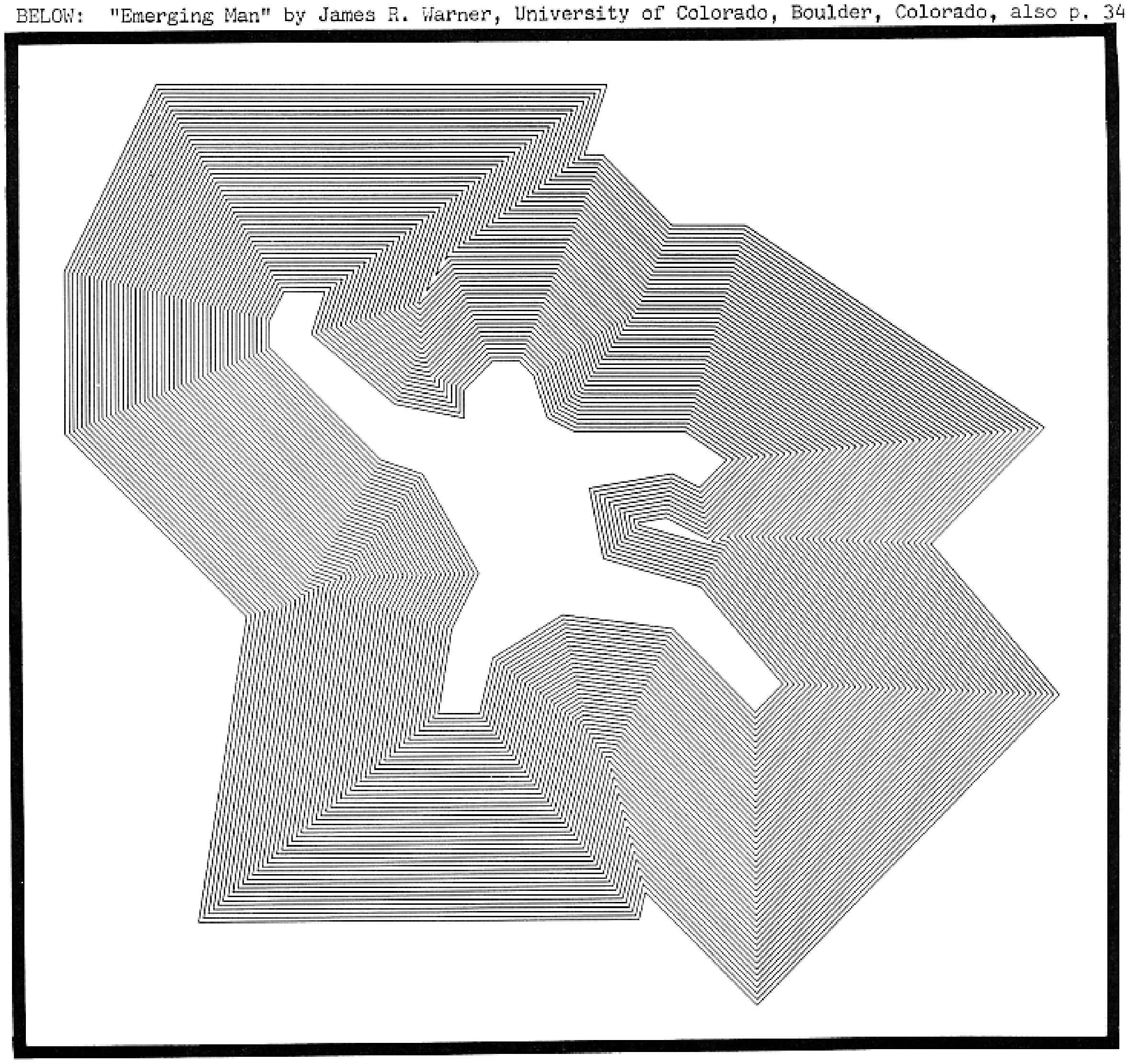
COMMENTS: The 15 sessions on varied aspects of computer graphics reveal the complexity and diversity of this field. The addresses of speakers have been included, as information for those unable to attend, who may scan the program and select specific references that are useful. The Proceedings of the conference are available - those interested are invited to write the Program Chairman.

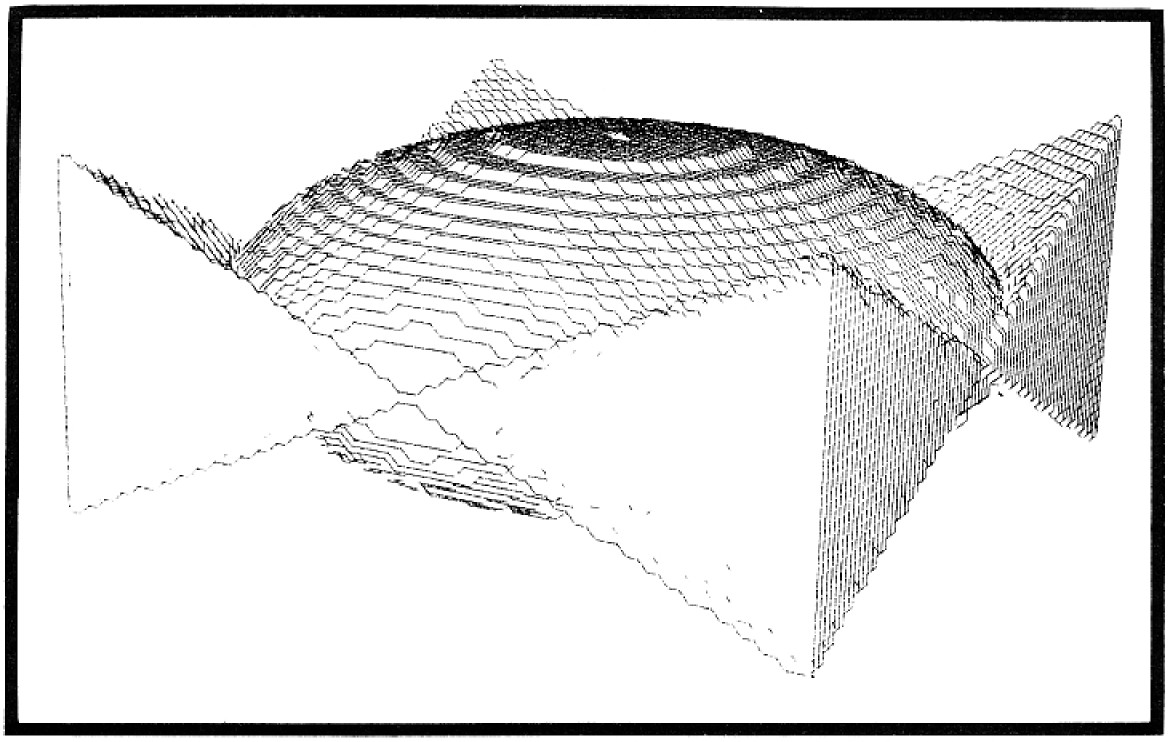
NEW COMPUTER ART



ABOVE: "Gaussian Distribution" by Kerry Jones, an engineer who enjoys computer art for fun. (See August, 1976 issue of CG&A for "Engineering Applications in the Design of Buildings", pages 5-7 by Kerry Jones.)

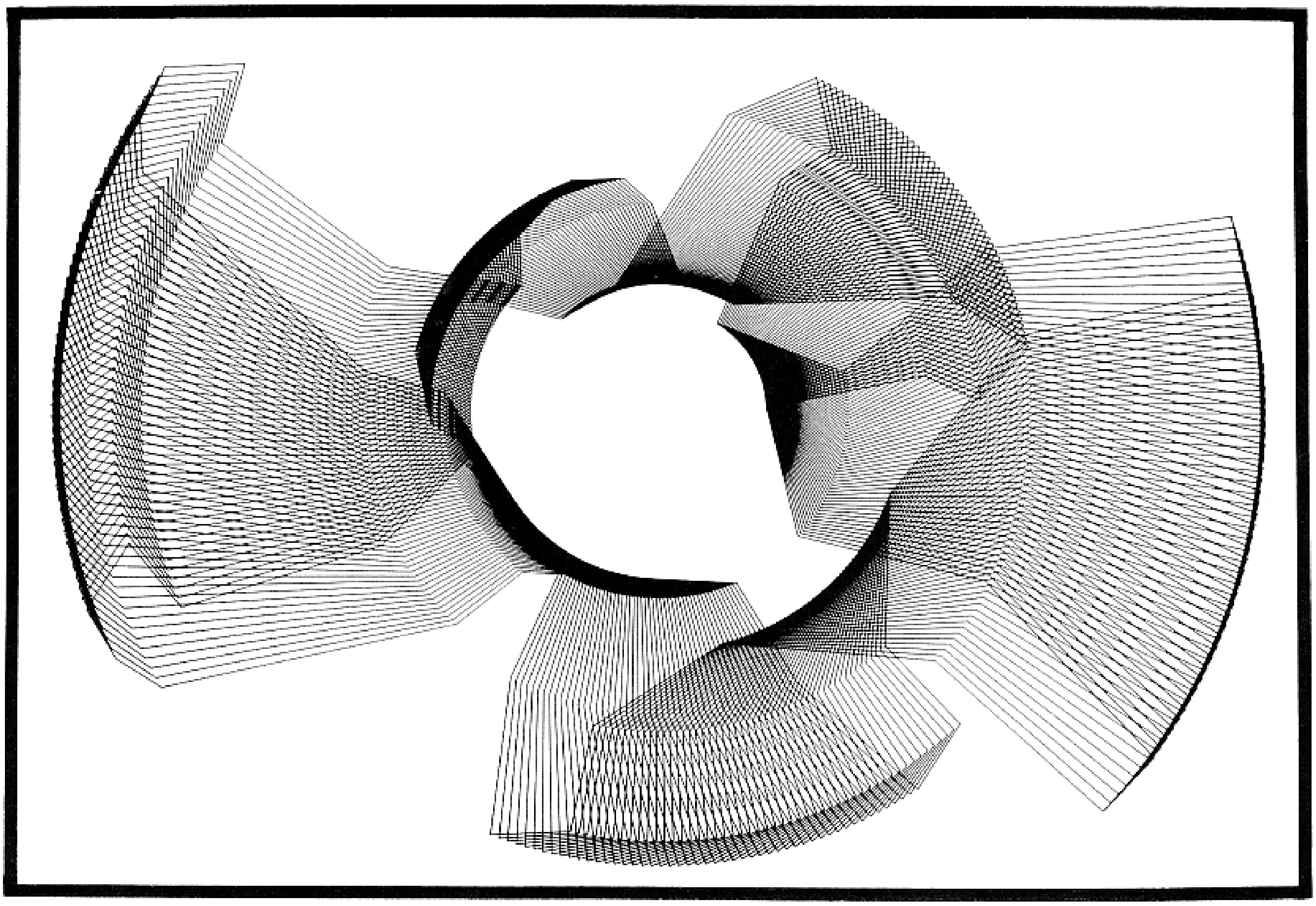
BELOW: "Emerging Man" by James R. Warner, University of Colorado, Boulder, Colorado, also p. 34.

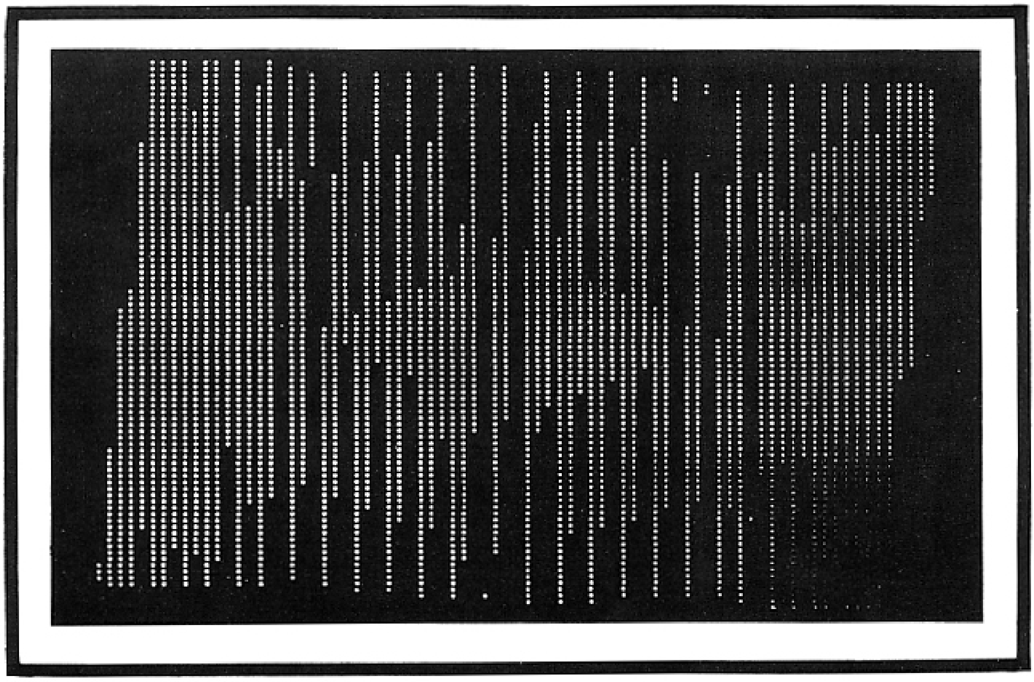




ABOVE: Ellipsoid" by Tony Martin, American Buildings Company, Eufaula, Alabama. Like many computer professionals, Tony Martin executes detailed, delicate, mathematically based computer art as an avocation. (See the August, 1976 issue of Computers and People for more of his work, and also graphics by his friend and colleague, Kerry Jones, who works for the same firm.)

BELOW: "Gyrating Form" by James R. Warner, Colorado University Computing Center, Colorado University, Boulder, Colorado.





ABOVE AND BELOW: "Untitled Serigraphs" by the Groupe de Belfort, France - a collaboration by G. F. Kammerer-Luka, Animateur, and Professor J. B. Kempf. (For an in-depth article on the work of the Groupe, see the August, 1976 issue of CG&A, and the illustrated paper describing their work in the communities near Belfort.) The group executes what we now call "supergraphics" or very large, monumental murals. These are planned in conjunction with universities and civic groups, wherein the collaboration of the group is taken back into the environment of the citizens. Humanization of the urban and industrial environment is the goal of this community of socially-oriented computer artists.