



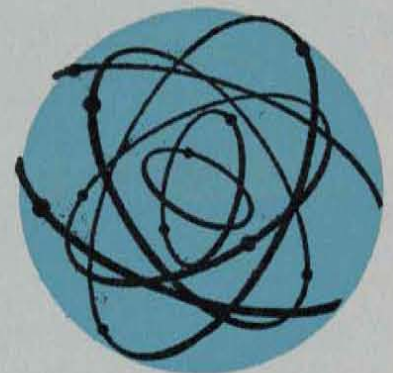
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GRAPHIC 1—A remote graphical display console system

by

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GRAPHIC 1 — A REMOTE GRAPHICAL DISPLAY CONSOLE SYSTEM

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INTRODUCTION

Graphical information exchange using direct-view display consoles is a rapidly growing means of communicating between a human and a computer. One reason for this growth is that results presented to a human in graphical form are concise and readily understandable. Another reason is that through alternate viewing of graphical output displays and entering of new inputs, either graphically or by other means, based on these output displays, a user can monitor and guide a computer during the course of a complex problem solution. Such interaction generally produces more rapid and often better problem solutions. In many cases, interaction allows a problem to be solved which would not even be attempted using other techniques.¹

Most work to date on providing man-computer graphical communication facilities has been based on consoles which require full-time occupancy of, or, in the least, immediate access to a large digital computer.^{2,3,4} Display maintenance has been provided by the large computer or by a data channel off the large computer. The high transfer rates needed for such an organization have dictated that the con-

soles be very close, if not physically adjacent, to the supporting computer or channel.

Significant research work is now concentrating on providing computing power to a large user community through a sharing of the facilities of a central computer.* The user community is distributed over a wide geographical area and communicates with the central facility using remote consoles. The pace of such work definitely seems to be accelerating, the reason being that early experience has shown that a time-shared central computer facility can serve many people very well.

The console facilities used to date to communicate with time-shared computer centers have been teletype or other typewriters. With such low-speed character oriented devices, slow access to the central computer (a few hundred milliseconds) is not readily apparent to a user. The real limiting factor in the use of such devices is the transmission delay, the time required to transmit messages between the computer and a user. For long messages with 10 character/second rates, this delay becomes both long and annoying, and strongly affects what can be done.

For a high-speed remote graphical display, the transmission rate can be increased so that the delay problem is reduced. Access time then becomes a

*Such work is going on at Bell Laboratories, M.I.T., G.E., Dartmouth, Carnegie Tech, U.C.L.A., I.B.M., S.D.C., RAND, and other places.

major problem. A few hundred milliseconds is certainly suitable access for certain aspects of a problem. To allow a user, however, to do real-time composing, editing, or other manipulation of graphical information with a light pen or other graphical input device, the sum of access time and transmission delay must be only a few milliseconds. For a truly remote console in a time-shared center, such timing will generally not be available. Therefore, to allow such light pen operations, a remote graphical console facility in a time-shared central computer environment should have local computing power.

Also if such high speed consoles are to be used remotely, local display maintenance is essential. Thus, a picture need be transmitted only once,

maybe over low-cost low-speed lines. The central facility is then relieved of any further immediate responsibility. The console itself provides the broad band capabilities to maintain a picture at a flicker-free rate. Local computing power and display maintenance not only reduce the requirements on the central computer, but also should allow many interesting things to be done without even disturbing the central facility.

The GRAPHIC 1 console has been designed for use in exploring the problems associated with local computing power and display maintenance for a remote graphical console which eventually will be operating in a time-shared central computer environment. A photograph of the console is shown in Fig. 1.



Figure 1. The GRAPHIC 1 console

GRAPHIC 1 SYSTEM ORGANIZATION

The console system can be divided into two major units. The first unit consists of a control computer, which provides the local console computing power, and the console input devices. The second unit contains a display scope and an associated core buffer memory for storing display material. These last two elements and their connecting interface make possible a locally maintained output display. The two console units are connected by an interface

which allows control signals and other information to be passed between them.

This interface also allows communication between the control computer and/or the display memory and the central computer facility, an IBM 7094 in the Murray Hill Computation Center. A block diagram of the described organization is shown in Fig. 2.

The console system is currently connected to the 7094 by a parallel transfer data connector. However, a request for service by the console system can

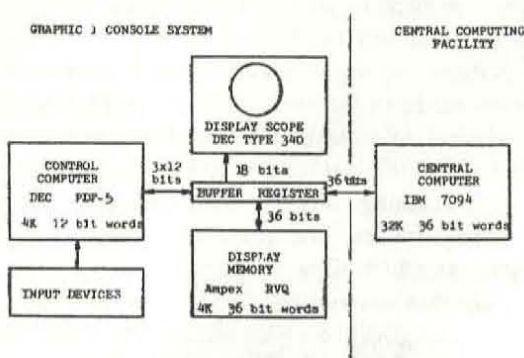


Figure 2. Organization of the GRAPHIC 1 console.

only be recognized at interjob points, i.e., between jobs on the normal input batch tape to the 7094. Response time is governed by the length of jobs on the batch tape, an average of from two to six minutes during daytime working hours.

This access is far from ideal and certainly will be improved when the Laboratories converts to a multiprogrammed central computer facility. The present waiting time does, however, simulate to some extent the access time and transmission delay that would take place if the console were connected to the central facility over a serial voice-band transmission line. It has strongly reinforced the necessity of having local computing power at the console.

The control computer in the console, a Digital Equipment Corporation PDP-5, is a small fixed-point core-memory digital machine.⁵ The 6 microsecond cycle time memory contains 4096 12-bit words. The instruction set allows addition, subtraction, indexing, direct and subroutine branching, accumulator manipulation, and accumulator testing to be done internally. A microprogrammed input-output instruction allows extensive external manipulation and control operations to be performed. This instruction set can be used to compose, edit, translate, group, or otherwise manipulate graphical information in real time. However, the limited word size and the absence of hardware multiply-divide instructions prohibit computations in the PDP-5 itself involving a wide range of numbers or computations for rotations.

The display scope, a modified DEC Type 340 Precision Incremental Display, allows the rapid conversion of digital data to graphical form through point plotting on a 1024×1024 raster.⁶ This plotting area occupies about a $9\frac{3}{8}$ inch square on the scope face. Plotting is accomplished through use of six standard modes of operation. One of these is a control mode

which allows the entering of parameter information such as scale factor, intensity, scope image reflection, and light pen enabling. The other five are display modes which allow the plotting of points, curves, vectors, axes, and characters. Internal vector and character generators produce the points needed to form lines and characters from the coded input words. A seventh non-standard mode for use in display linkage has been added. This will be described shortly. Of the display modes, only one, the point plot mode, is absolute. By absolute is meant that fixed X and Y absolute coordinates are assigned to a point. The remaining display modes (vectors, curve, axis, and character) are incremental in nature. Thus they essentially contain only differential or ΔX and ΔY movement information.

The plotting rate in one of the incremental modes is $1\frac{1}{2}$ microseconds per point. For the X-Y or point plot mode, 35 microseconds are required per point. Since the characters average 20 points, average character plotting time is 30 microseconds. Considering these timing values and the scope grid size, about 20 scope diameters or 200 inches of line can be maintained on the scope at a flicker-free rate (30 frames/sec). This is equivalent to about 1000 characters.

The display material memory is an Ampex RVQ core unit with 4096 36-bit words and a 5 microsecond cycle time. This storage capacity represents about eight large pictures, i.e., those which take about 1/30-th of a second to display.

As was previously stated, the console system is divided into two major units: the control computer and input devices, and the scope and display memory. The former is the supervisory and input unit; the latter, the output unit.

The function of the output unit is the conversion of words in the display memory to an output picture on the display scope. These words can be a mixture of those composed in the 7094 and transferred to the console and those composed at the console using the input devices and the control computer. Successive words are supplied to the scope from the memory through operation of a rather complex interface. Since the scope accepts 18-bit words the interface accomplishes the gating necessary to load first the left half and then the right half of each 36-bit word from the memory into the scope. The interface also operates in conjunction with the scope and the display memory to execute display linkage instructions. These instructions, a direct transfer or

jump and a subroutine jump, operate essentially as will be described. There are slight additional complications which result from the left-right usage by the scope of the halves of a word from the display memory.

For the direct jump instruction, the next word is taken from the location specified by the jump instruction address. The first word of a subroutine is used to store return information. Therefore, for a subroutine jump, the next word is taken from the location one beyond that specified by the jump address. Before control actually passes on to that location, however, the location where control is to return upon completion of the subroutine is planted in the location specified by the subroutine jump. Exit from the subroutine is then accomplished using the planted return information. This method of display subroutine linkage allows multilevel display part subroutines. However, it does not allow re-entrant subroutines.

Since the interface can provide successive words to the scope and the linkage words themselves can cause control to flow throughout the display memory, display maintenance is independent of control computer intervention. Thus, once started by the control computer, the display continually refreshes itself with a direct jump word at the end of the display picture providing the link back to the start. The only exception to this independence is that the control computer must restart the scope after display stoppages produced by edge overflows.

While the output unit is displaying a picture, the control computer can do other operations. Generally these are only looking for flags or interrupts indicating that an input device requires attention or that the central computer requests information. Once a flag or interrupt is found, the control computer can stop the output unit. The status of the scope can be saved. During the stoppage, the desired display composing, editing, or manipulation can then be done or information in the display memory can be read or written by the central computer. If desired, the display status can then be restored and the display cycling resumed or a new display can be started.

Cooperative communication programs in the control and central computers supervise any interchanges between the console and the central facility. The central computer can interrupt the console at any time. However, as was mentioned, the console

can only be recognized between jobs on the central computer batch input tape.

In addition to the display linkage features, other additions made to the standard 340 Display involve the inclusion of reflection properties which can be enabled using the parameter setting mode, and addition of flagging bits to the parameter setting mode, jump modes, and point plot mode. The reflection properties allow display material to be reflected about a horizontal axis, or a vertical axis, or both. By changing the reflection setting before calling for a graphical subroutine, one block of data can be used to produce a figure in different orientations. There are no hardware rotation matrix features.

The flagging bits have been added to allow programmable display stoppage and computer signaling when certain conditions are found. This has been done since the material in the display memory is a mixture of actual display words plus list and buffer areas and aid is needed in tracing such material to make changes or additions. Use of programmable trapping means that interpretive programs do not have to operate upon the display memory to find desired locations or conditions. The scope itself does the tracing. These features are particularly valuable for use in conjunction with the light pen.

Additions have also been made to the single interrupt line of the PDP-5. This permits six different signals to be passed on to the interrupt line with the allowable interrupt signals at any time being controlled by a programmable masking register.

INPUT DEVICES

The GRAPHIC 1 console is experimental as are the problems attempted using the system. Therefore, a wide variety of input devices has been included both to allow a user to pick which seems best for a particular function and to provide programming and human factors experience in the use of different devices.

The main input device for the console system is a DEC Type 370 Light Pen. The pen, which is a light sensing device, consists of a hand piece with mechanical shutter at one end of a fiber optics bundle. The other end of the bundle provides input to a photomultiplier system. The combined optic photomultiplier system is tuned to pick up the blue flash from the P7 phosphor of the scope face that is



Figure 3. Package placement using GRAPHIC 1

produced when a point is initially intensified. The pen is not sensitive to the yellow persistence. The field of view of the light pen is such that the tip can be held right on the scope face or up to three inches away without affecting proper operation. The photomultiplier sets a flag and stops the scope. Programmed operations in the control computer can then read the coordinate or address information needed for tracking or pointing before restarting the scope again.

A Teletype Model 33 ASR provides standard keyboard input-output functions. A Teletype Model 33 Self-Contained Keyboard has been added mainly for use in entering text where the display scope is used for feedback. The keyboard can be placed immediately in front of the scope for such occasions. For other occasions where the physical presence of the keyboard on the front counter interferes with light pen manipulations, it can be moved off to the side to the position shown in Fig. 1. Programs which use the self-contained keyboard echo any typed characters on the regular Teletype machine so that, in addition to the character image on the scope, a hard copy record is also available.

A track ball has been included for use in two-dimensional positioning problems. It consists of a 4 inch diameter nylon ball which drives two pickoff wheels, one for vertical travel and one for horizontal. No pickoff has been provided for rotation. The

pickoff wheels turn potentiometers. Outputs from the potentiometers go through a multiplexor into an analog-to-digital converter in the PDP-5.

To reduce the directional polarization usually associated with track balls, the ball itself is not supported by the pickoff wheels. Instead, the ball rests on three ball end casters, the pickoff wheels being held against the track ball by spring tension. Mechanical lockouts are provided so that a pickoff wheel can be moved away from the ball if it is desired to leave one coordinate unchanged while the other is moved or to protect a setting from changes due to accidental bumping.

In addition to the two from the track ball, outputs from six potentiometers have been connected through multiplexor gating to the analog-to-digital converter in the PDP-5. Included are two ten-turn, two three-turn and two one-turn potentiometers. Through appropriate programming, an operator can use the knobs attached to the potentiometers to enter or change parameters in his problem.

Four switches have also been provided. Two are alternate-action and two are momentary. The alternate-action switches and one momentary are mounted on the corner panel for hand manipulation. The remaining momentary switch is located in a foot pedal. Testing instructions in the PDP-5 can determine the status of these switches.

A function keyboard consisting of 32 buttons connected by a mechanical lock and interlock is also located on the corner panel. The keyboard is wired so that the binary number of the currently depressed button can be read by the PDP-5. There is an additional EXECUTE bar located below the other keys.

The function keyboard can be used for vectoring into various special routines in the PDP-5. This is done as a two step process. First, the button corresponding to a desired function is depressed. When a user desires the function represented by the depressed button to be executed, the EXECUTE bar is pressed. This two step method of operation was chosen for accuracy in operation and for ease in repeating functions. To allow the vectoring operation to be accomplished, the output flag from the EXECUTE bar is connected to the interrupt facility of the PDP-5. The trap handler program can read in the depressed button number and enter a transfer vector table which causes a jump to the proper routine.

Since different users might desire different routines to be performed using the function keyboard, the changing of the functioning of a particular button can easily be accomplished by changing the transfer vector linkage and adding the routine to be linked. Changing of a label on a button can be accomplished by changing a labeling mask which fits over the keys. Despite this flexibility, the function keyboard has had little use. The reasons will be described in the next section.

A DEC Type 451A card reader allows the entering of information from cards into the console system. Reading speed is 200 cards/minute. A connector position for use in attaching any special or experimental devices has also been provided.

EXPERIENCE WITH THE LIGHT PEN

There seems to be considerable debate over what is the best graphical input device — RAND tablet,⁷ graphic pencil⁴ or light pen. There are advantages and disadvantages associated with each device.

A RAND tablet is a stylus-tablet device which generates 10-bit x and 10-bit y coordinate information representing the stylus position on the tablet. Thus two-dimensional information can be obtained on a surface not coincident with the display device. A graphic pencil is a voltage-pickup position pencil. It operates in conjunction with an im-

pressed voltage on a transparent conductive coating over the display screen to give position information. The advantage of these devices is that coordinate information can be entered at any time or place including on a blank area of a display or when a display is not even present. The disadvantage is that a positive reference between the stylus or pencil position and an object on the display scope does not exist. Thus a fairly complicated coordinate trace must be performed for demonstrative or pointing uses of these devices.

As was pointed out previously in the description of the console input devices, the light pen is only a sensing device. It must sense or see light from a display on the scope before it can function, i.e., set a flag and stop the display. Thus a disadvantage is that a display must be present before it can be used. Once the display is stopped and before it is restarted, however, considerable information can be extracted by the control computer. In addition to coordinate information, a positive reference to what is being plotted when the scope was stopped is available. Thus a coordinate trace does not have to be performed for demonstrative uses.

The light pen allows good feedback in pointing since programming can brighten what unit is being seen or display only the total unit being seen. The importance of such feedback cannot be appreciated until one works with a graphical system. Because of its particular value in pointing operations, a light pen has been chosen as the graphical input device for GRAPHIC 1.

To make the light pen as effective in drawing applications as the other devices, a good tracking program must support it. For the GRAPHIC 1, the tracking program uses a conventional four arm cross.⁸ Tracking is on a 60 cps interrupt basis. Thus tracking performance is constant despite variations in the amount of display material. First order prediction is incorporated. Special testing allows the center of the cross to be moved right up to the edge of the display area on the scope with the corresponding arm shortening. Backed by this programming support, the light pen is equally suitable for both pointing and drawing.

In fact, the ease of use of the light pen for pointing operations has almost eliminated the originally envisioned extensive use of the function keyboard for entering various control routines. Instead, controls have almost exclusively been placed on "light

buttons" which are displayed on the scope face. A light button is a word or figure on the scope face which has a transfer vector associated with it. When the light button is touched by the light pen, the transfer vector is used to pass control to the appropriate routine.

Placing control functions on the scope face has two advantages. First, only those controls which should be present at a particular stage of a problem are displayed. If a light button labeled "MOVE" is one of those present, a user knows that he *can* move picture parts around. Similarly, if only light buttons in the form of PNP and NPN transistor symbols are displayed, a user knows he *must* select a particular type of transistor at that time. Thus, in effect, a user is steered through a problem. Second, during most operations there is only one center of attention, the scope face, on which a user need concentrate. This allows faster and smoother work on a problem.

Any shape, no matter how complicated, can be a light button since the shape has no effect on detection by a light pen. This is extremely important since the shapes can be problem oriented. The complicated zone bounding necessary when performing a similar function using a RAND tablet or graphic pencil need not be done. Light buttons can easily be moved around on the scope face. Also, the transfer vector for one light button can easily be transferred to another shape. This mobility and flexibility combine with the previously mentioned advantages to make light pen detected light buttons very powerful control elements.

BASIC PROGRAMMING SUPPORT

Software support for the GRAPHIC 1 console system consists of three basic units. First there is an assembler and assembly postprocessor which generates, merges, and links relocatable programs for the PDP-5. This assembler has been written using MACRO-FAP and runs on the 7094. Therefore, all the features of MACRO-FAP are available for use when assembling programs. This is particularly useful when generating higher level languages. The combined assembler-postprocessor aids considerably in dealing with the page boundary problems of the PDP-5. The second basic unit is a display material assembler and postprocessor. This also is written in MACRO-FAP and runs on the

7094. Symbolic linkage between PDP-5 code and display code can be accomplished. The third major software unit consists of communications routines to allow the easy passing of information between the 7094 and the GRAPHIC 1 console.

Using these three basic units, several higher level graphical languages are being developed. Furthest along of these is the GRIN (GRaphical INput) language. GRIN is particularly suitable for use in problems requiring the extensive real-time manipulation of graphical information at the console. It takes full advantage of the incremental display structure of the scope. (Recall that there is only one absolute plotting mode. The remainder are incremental.) Thus, if a display part is composed only of a sequence of incremental words, its position on the display scope can easily be changed by changing only the initial absolute entry point. Also if a part is represented only incrementally, it can be called up using the display part subroutine linkage at many places on the scope face. The part has to exist in storage only once, however.

No hard copy facility is available directly in the console system. A SC 4020 microfilm recorder is attached to the 7094. So, hard copy of the current display picture is achieved by transferring an image of the display buffer contents to the 7094 where translation programs map the scope code into comparable SC 4020 code to produce a microfilm print. Turnaround time to receive a print is from two to four hours.

USAGE

The major use of the console system so far has been for problems requiring at some stage "dynamic scratchpad" capabilities. Included in such problems have been printed circuit component and wiring placement, schematic circuit design, block or flow diagram design, text composing and editing, and placement of cards on a chassis to achieve minimum connecting wire length. Initial input or configurations to be manipulated can be provided by programs in the IBM 7094. For example, a card placement programs to minimize connecting wiring length gives a good initial placement. However, such placements are subject to local minima and frequently neglect maintenance considerations. An operator at the console, when provided with appropriate displays, can break out of local minima for reruns in the 7094 and can make placements for

easy maintenance. The photograph in Fig. 3 shows a user working on such a placement problem.

The result of any console manipulations can serve as input to a 7094 program also. As an example, text in the form of a computer program which has been composed at the console can be entered, assembled, and run. A system block diagram composed at the console can be used as input to a special compiler, the compiled program can be run, and the results viewed at the console. As a further example, a schematic circuit composed at the console can be used as input to a circuit analysis program and the results of the program returned to the console. The number of interesting uses of the console continues to grow as the existence of the console becomes known to people in varied fields of work.

SUMMARY

GRAPHIC 1 provides very flexible man-computer graphical communication facilities in a time-shared central computer environment. Local computing power and display maintenance capabilities make possible extensive real-time graphical manipulations at the console. Interaction between the console and the central computer permits attacks on large complex problems.

ACKNOWLEDGMENTS

During the period that this system was designed and constructed many people have contributed useful ideas. Chief among these contributors were H. S.

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