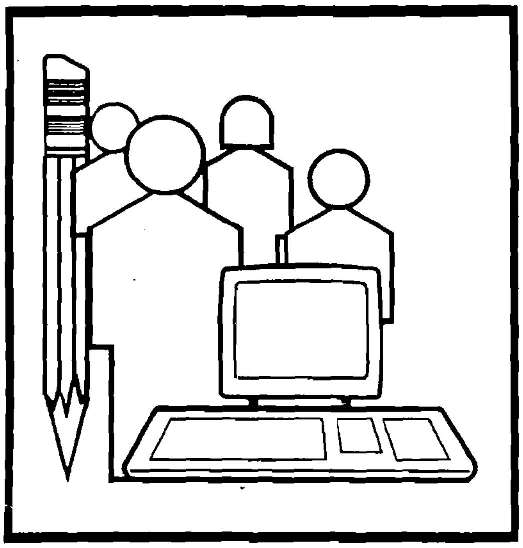

TECHNICAL REPORT

ROLE OF GRAPHICS IN COMPUTER ASSISTED LEARNING

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ROLE OF GRAPHICS IN COMPUTER ASSISTED LEARNING

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ABSTRACT

For many years, graphics has been considered as the most natural form of student interaction in computer assisted learning applications. Until recently, however, the cost of graphics relative to standard low-cost, alpha-numeric terminals has restricted their widespread exploitation. Recent technology advances in both raster scan graphics and personal microcomputers have significantly changed this cost ratio. Today, therefore, it becomes relatively more cost effective to exploit graphics terminals more fully.

This paper traces the evolution of graphics in a wide range of computer assisted learning applications. Different types of graphics terminals are reviewed against the desirable requirements of a student learning terminal. One conclusion is that there will be a technology convergence between intelligent graphics terminals and personal microcomputers with graphics. A further conclusion is that cost will not be the limiting factor against their widespread usage -- the more important factors will be software and organizational and "social" obstacles. Once these obstacles are removed, the exploitation of graphics will occur extremely rapidly in the computer based learning environment.

This report is based largely on a paper presented at the CAL '81 Conference in Leeds, England, in April 1981.

THE USERS' VIEW OF CAL

The Scope of Computer Assisted Learning

Computer assisted learning (CAL) encompasses not only computer assisted instruction (CAI), but also problem solving, modelling, simulation, games, and other modes which are appropriate to a learning environment [1,2]. The diversity of CAL could imply an equally diverse set of student computer relationships. Even for one specific mode of learning, a wide range of student computer interaction patterns could result. However variable the overall pattern of interactions, it is possible to derive a very basic set of system-user transactions, as shown in Figure 1.

The Student Interface

Our model is based on an interactive terminal environment, whether this be a terminal on a timesharing system or a stand-alone personal microcomputer. In both cases, the interactions

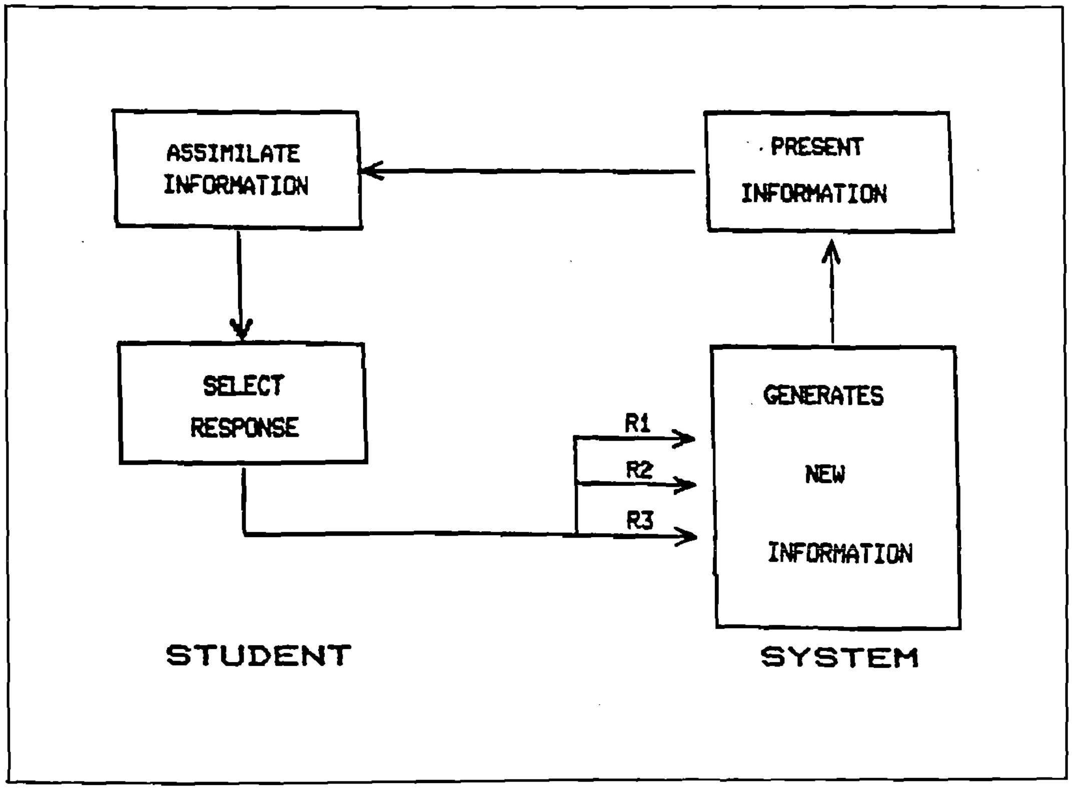

Figure 1

STUDENT-SYSTEM INTERFACE

follow a basic standard pattern:

- first, information is presented to the student;
- on valuation of this information, the student typically selects one of several responses;
- based on the response the computer takes appropriate branching action and generates new information.

This basic loop is repeated many times in an interactive learning session and is the basic element of almost every different learning strategy. We shall return to this basic model later, after first reviewing the different types of student terminals available and their evolution over the last decade.

STUDENT TERMINAL

The Lowest Common Denominator

Historically, the lowest cost computer terminals have been ASR-33 Teletypes*, which in 1970 cost over $1500. Faced also with the issues of software transportability, it is not surprising that a large amount of educational CAL material developed in the early 1970's was based around Teletype input/output [3]. At this time typically available graphics stations such as the IBM-2250 cost nearly $100,000.

To provide some graphics facilities for CAL at a realistic cost, various techniques were used to create "pseudo-graphics." The most popular methods employed capital letter I's and dashes to create boxes and graphic axes, and letter x's to plot points on a graph. The resolution of such points on graphs is limited to the basic character spacing, typically a tenth of an inch. The example shown in Figure 2 is typical of the output generated by a Huntington simulation program. Apart from their lack of graphics, the traditional printing terminals also suffered from being noisy, mechanical and slow.

Their lack of speed can be a severe detriment to the efficiency of CAL. James Johnson, the Director of CONDUIT, quotes an example of a CAL dialogue to different environments [4]. The dialogue output was 100 frames of ten words each, initiated by student input to the computer.

- Environment 1: a 10 character per second terminal on a system with a 5 second response time required 1,100

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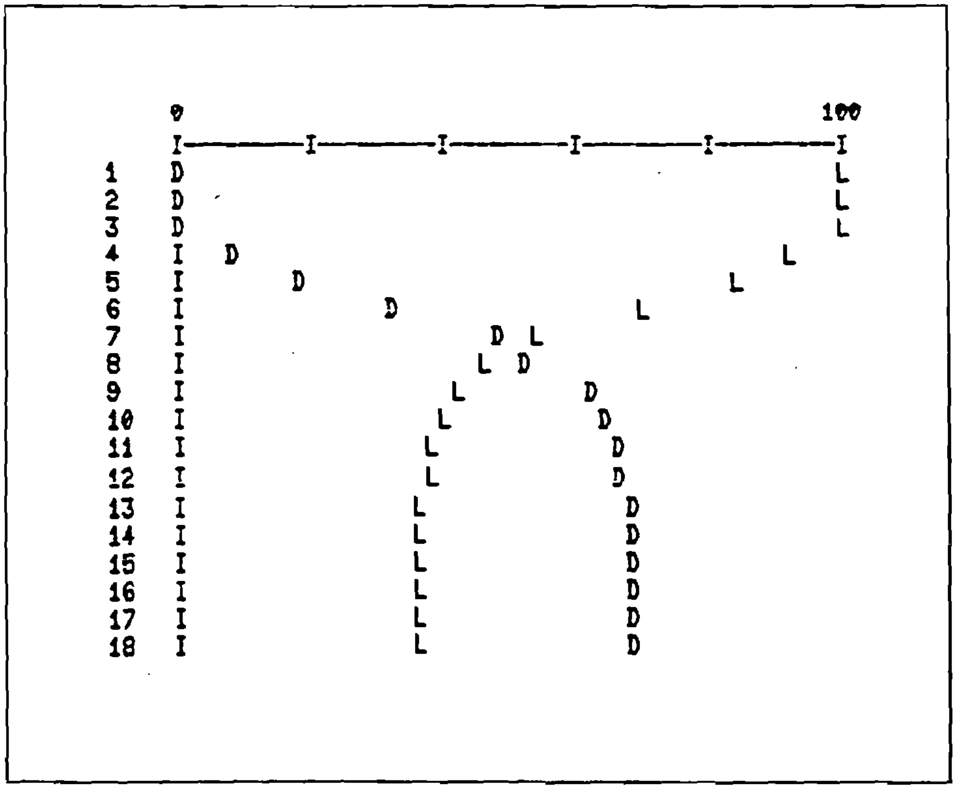
* Teletype is a registered trademark of Teletype Corporation.

seconds to print out the dialogue.

- Environment 2: a 30 character per second terminal on a system with a 1 second response time required 300 seconds to print out the dialogue.

The difference between the two environments is over 13 minutes. This time is virtually lost, since the average student can read at 6-8 words a second. Yet even until recently, many students throughout the world were participating in CAL in Environment 1.

In recent years, the widespread availability of low-cost visual display units (VDUs) has significantly enhanced the quality of pseudo-graphics. In addition, they can operate at significantly higher speeds, typically 960 characters per second or more. With advanced video features such as reverse video, spaces can become solid squares, thus providing an ideal basis for histograms. Modern VDUs also have optional "graphic" character sets which provide additional symbols. The exploitation of these techniques is discussed more fully in reference [5]. The only significant disadvantage of a VDU compared with a teleprinter is its lack of



```
     0                                                100
     I---------I---------I---------I---------I---------I
 1   D                                                 L
 2   D                                                 L
 3   D                                                 L
 4   I   D                                         L
 5   I        D                                L
 6   I               D                  L
 7   I                       D  L
 8   I                      L  D
 9   I                    L         D
10   I                   L           D
11   I                  L             D
12   I                  L             D
13   I                 L               D
14   I                 L               D
15   I                 L               D
16   I                 L               D
17   I                 L               D
18   I                 L               D
```

Figure 2

PSEUDO-GRAPHICS

hardcopy output. However, the costs of VDUs are typically comparable or even lower than those of hardcopy terminals.

The Plasma Panel Display

By 1970, developments of the PLATO system, which had started at the University of Illinois in 1964, had come to fruition. The basic student interaction in this system was a plasma display panel. A plasma panel consists of two coated glass plates separated by a space containing gas. Horizontal embedded electrodes on one plate and vertical electrodes on another form a matrix of intersections. A voltage pulse applied to one horizontal and one vertical electrode will create an orange glow (a plasma discharge) at their point of intersection. This glow remains until a different voltage pulse cancels the discharge (Figure 3).

These terminals went into production in 1971 at a cost of about $10,000. They offer several significant advantages for the CAL user.

- They have a moderately high resolution (512 x 512) and do not require the continual refresh cycles of other graphic displays. They therefore provide a steady, good quality image without significant computer overhead.

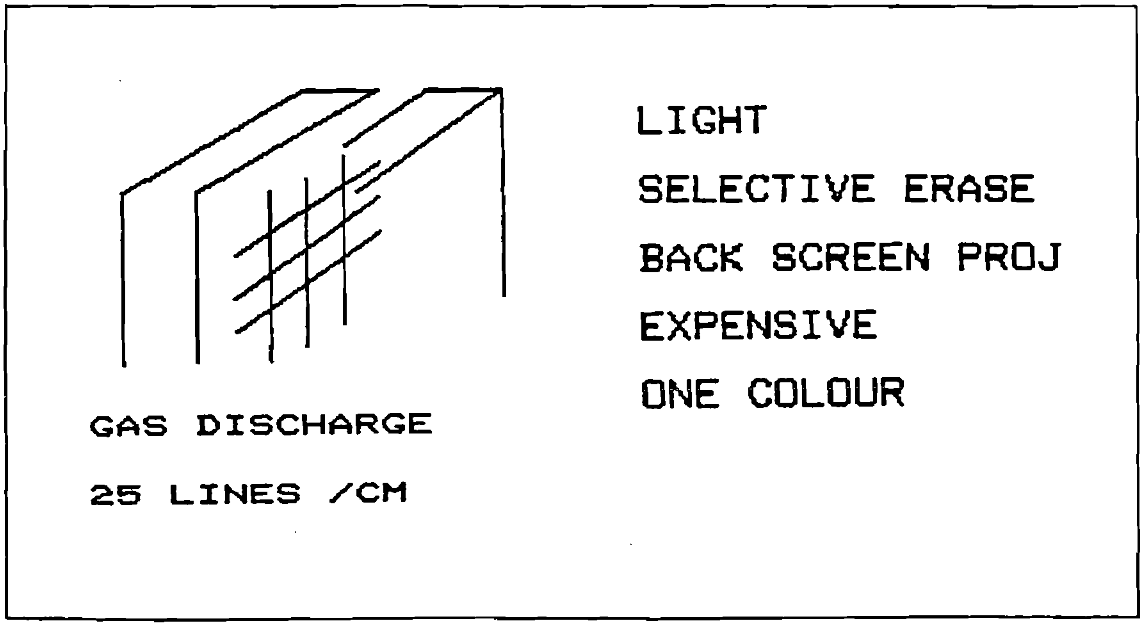


Figure 3

PLASMA PANEL

- Optional enhancements to this display terminal include a backscreen microfiche projector (for displaying non-computer generated images), a touch panel (to enable users to point at images or menu items directly with their fingers), and connectors for attaching external devices, such as random access slide projectors.

In conjunction with the PLATO system, plasma panels have been used in a wide range of CAL applications, most of them in the CAI drill and practice and tutorial modes. Many good examples are in evidence at the University of Delaware, where 200 terminals are in regular use by over 230 faculties [6].

Despite their advantages, including a certain ability to handle moving images, manufacture of plasma panels is a difficult process and there have been few significant improvements or price reductions over the past 10 years. Indeed, apart from certain military and high altitude applications, plasma panel usage is in decline even on the PLATO system where it has been replaced by the newer refresh raster scan technology.

Storage Tube Displays

An important advance in graphics occurred around 1970 with the development of terminals based on the Tektronix storage tube [7]. In these tubes a process of secondary electron emission takes places at a grid behind the screen and causes a drawn image to be retained for a considerable time. To erase or alter the image however, the screen must be "flooded" with electrons changing the potential on the grid, thus causing the familiar "green flash." Thus no selective erase of portions of the image is possible. However, as with the plasma display, no continual image refresh is required.

But perhaps its biggest breakthrough was the cost of the storage tube, which at the time of introduction was less than $8,000 and by 1972 the introduction of the Tektronix 4010 had reduced this yet further to under $5,000. The storage tube could also display a fairly complex image without the penalty of flicker, a problem which occurs with some of the directed beam refresh displays. For the first time, the educational community had access to a graphics terminal which could be readily supported by a terminal based computer system at a realistic cost. This should be contrasted with the plasma display which was exclusively associated with PLATO, a dedicated CDC mainframe-based system.

A typical example of the type of application supported by the storage tube is the work of Dr. Smith of the Computer Assisted Teaching Unit at Queen Mary College [8]. Here, a PDP-11/40 operates with six workstations, each consisting of a teletype and storage tube terminal. This system is used for the teaching of various aspects of engineering design to undergraduates in both nuclear engineering and electrical engineering. Many engineering problems are multivariate with multiple inputs and outputs. By use of modelling techniques, the student can explore the effects of changing input parameters on the different outputs. A typical session involves

(1) entering initial values;

(2) selecting an input parameter together with increments;

(3) computing each output parameter for each increment of input parameter;

(4) displaying the output parameter over a range of increments.

When first developed using teleprinters, significant time was consumed to output tabular data which then needed careful interpretation to convey any real meaning to the student. However, with the advent of graphics, the student could easily discern the effects changing parameters and select representative plots for hard copy output.

In recent years, continual development efforts on the part of Tektronix have added "write thru" mode features to the storage tube which allows a part of the image to be refreshed conventionally prior to storing. This overcomes the former disadvantage of non-selective erase. Such a facility is particularly useful for entering data and checking it for errors before confirming it. However, in recent years, the price of the lowest cost storage tube terminal has stabilised at between $3000-$4000 and no significant new breakthroughs in technology have occurred. It is appropriate here to categorise the different types of displays. Figure 4 shows one such categorisation. Variants of the cathode ray tube serve as the basic building block in the majority of display categories.

In refresh displays, the description of the screen image is typically stored in a local memory, and this description is converted by display generators (vector, character and circle generators) into voltages which deflect the CRT electron beam on the screen (see Figure 5). To retain a steady image, this process must be repeated within the decay time of the CRT phosphor which is typically 1/30th to 1/60th of a second. Such refresh of the image requires some processing power in either the computer central processor or the display processor. While this may appear to be a disadvantage, it can be turned into an advantage. For example, dynamic images can easily be created by changing image descriptions between refresh cycles.

In the learning environment, such dynamic images can be particularly useful for introducing difficult concepts such as wave motion studies. The technique has also been applied in mechanical engineering, where concepts of linkages have been conveyed to the student. One example in the field of structures used Digital's VT11 direct beam display, which is the basis of the GT40, GT42 and GT44 display systems [9].

Despite certain advantages, however, such displays cost between $10,000-$15,000 and can generally only be justified in engineering disciplines or in others where dynamics are essential to the learning process. Another advantage of this type of display has been the use of the light pen which proved a useful input device and a useful "pointer" for selecting points of interest, selecting plant components and also for sketching in mechanical shapes.

RASTER SCAN GRAPHICS

For many years, graphics users were looking for a terminal which combined the attributes of a dynamic refresh display with the price advantages of the storage tube. Since the late 1960's raster scan displays were seen as a potential way of fulfilling this promise. The fundamental component, the cathode ray tube,

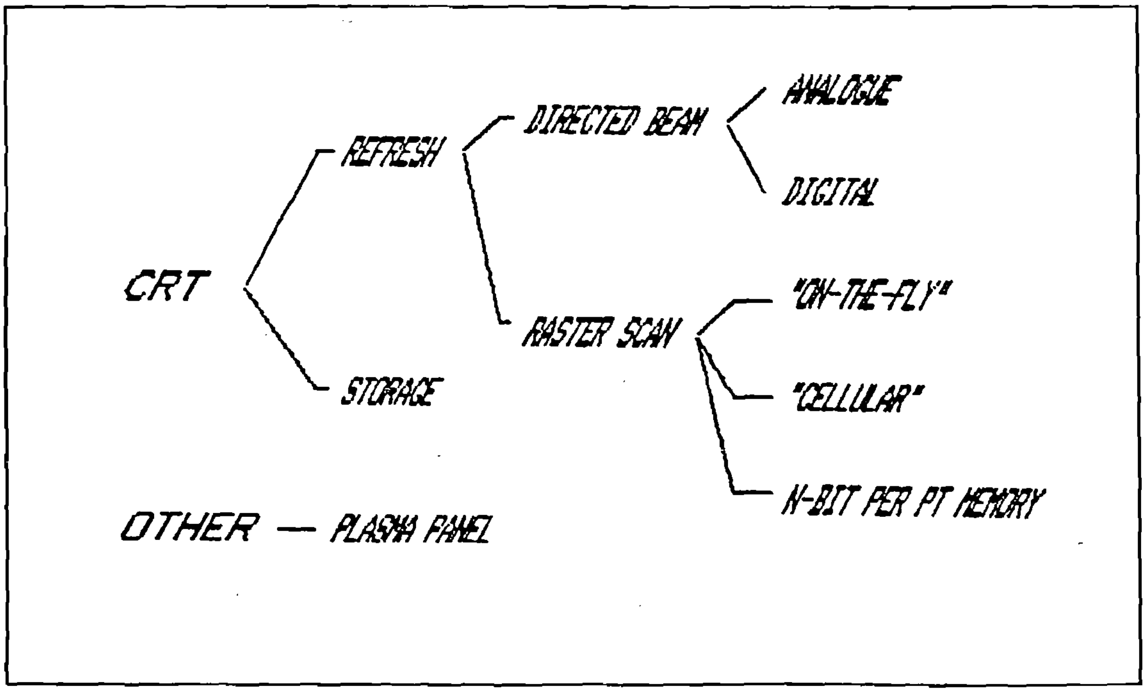


Figure 4

TYPES OF DISPLAYS

with its left to right, top to bottom beam scanning sequence, was already proven technology in low cost domestic television sets. With television, however, the expensive image generating facilities are at the television studio.

An individual learning environment requires individually generated images which can only be created by modulating the beam at precisely the right time during its predefined scanning sequence. Thus, a line is in fact a series of intensified dots drawn on adjacent scan lines. The obvious way to achieve this is to consider every position of the screen as a picture element (or pixel) as being light or dark depending on the contents of a binary digit, 0 or 1 in a local memory. The contents of this memory are then read out synchronously as the CRT beam scans the screen. Unfortunately, this approach requires large amounts of memory with a high read out rate. For example, to convey a 512 x 512 image in black and white requires 32 kilobytes of memory which in the early 1970's was very expensive. Thus, various innovative techniques such as "run length encoding" or "on the fly scan conversion" were used in many research projects. Compared with these, the only commercial raster scan display terminal of the time, the "Data Disk," actually used a rotating magnetic disk to store the picture image. But the main upsurge in the use of raster graphics displays awaited price performance

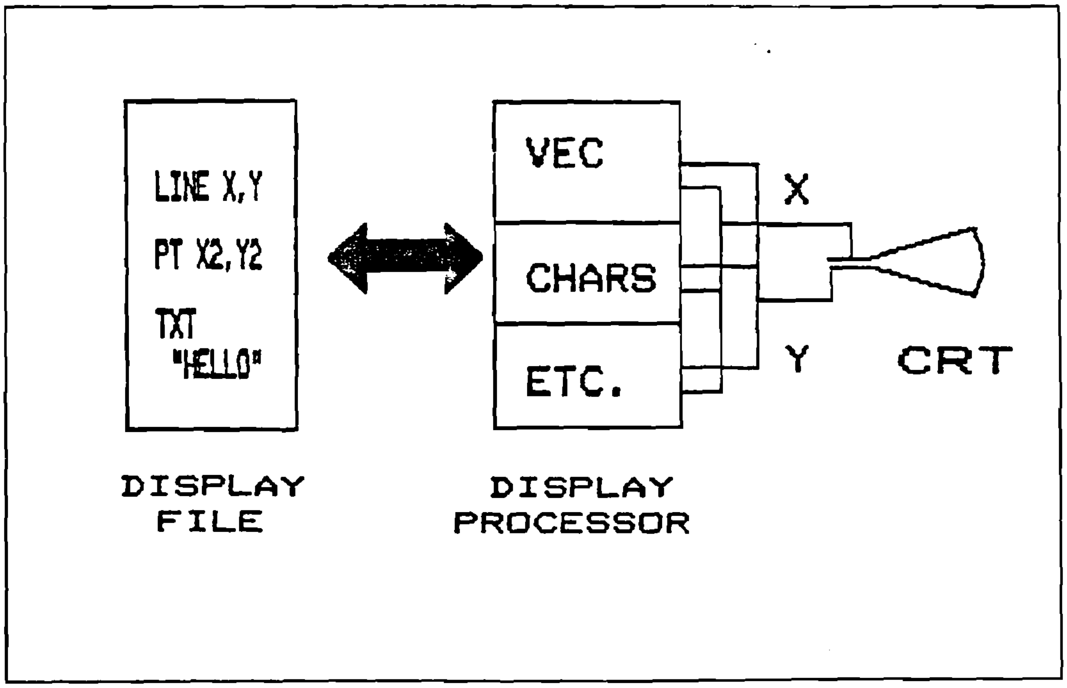


Figure 5

TYPICAL DIRECTED BEAM DISPLAY

improvements in three areas:

- First were the continual developments in cathode ray tube technology, which received a major impetus from the television industry. Advances in colour CRT's, even industrial colour monitors, particularly benefited from consumer "pull."

- Second was the continued evolution of microchip technology has resulted in price performance improvements in microprocessor logic, at typically 40% per year.

- Third has been the even more dramatic decline in semiconductor memory prices by some 80% per year. Indeed, these improvements in the price performance of semiconductor technology follow predictable and well defined curves [10] thus allowing realistic estimates to be made of the future prices and performance of graphic terminals and computer systems.

The convergence of these three developments has resulted in a take-off of the number of available raster scan and graphic display terminals during the last few years. Manufacturers such as Ramtek, Tektronix, Hewlett-Packard and Digital have all brought to market, within a very short space in time, general imaging displays with colour and additional features. Prices continue to decline steadily and several raster graphic terminals are now comparable in price to storage tube terminals.

Figure 6 illustrates the general architecture of the GIGI terminal, a raster graphic display. Graphics commands from the computer are interpreted by a microprocessor based display processor. In the example of GIGI, these graphics commands constitute ReGIS, the Remote Graphics Instruction Set. The appropriate bits in memory planes are set according to whether a line, circle, box or other entity is to be drawn. Asynchronously with this generation process, which only takes place once, the video generator is constantly accessing image memory to modulate the CRT raster.

If multiple memory planes are provided, it is possible to define colours and other attributes. For example, the image memory of GIGI is 767 x 256 pixels x 4 bits and provides 3 bits for colour (eight colours) plus one attribute bit (blank). Erasure of an entity stored in image memory is possible simply by reversing the process of image generation, although this can give rise to leaving holes at points of intersection. Care, therefore, needs to be taken when attempting dynamic displays, unless, of course, each frame is totally regenerated. For a complex image, however, this can take time. Another problem with raster displays is the display quality of diagonal lines. These sometimes exhibit a staircase effect, which is most noticeable on shallow, horizontal lines.

These are the only real disadvantages of raster displays. In comparison with other displays, they offer significant advantages for the CAL user. Colour becomes a relatively low cost addition, limited more by memory costs than CRT costs. For example, the Barco GD-33 high quality colour monitor used extensively with GIGI costs only $995. Other advantages accrue from the fact that video signals adhering to a well defined standard are generated. This permits inexpensive slave displays to be connected as well as more expensive large screen displays (2 metres diagonal) such as the Advent 1000A. Both of these facilities are useful for lecture room or classroom use. Video recording playback is another possibility, as is the mixing of external video signals with computer generated video output.

Standards

A few words of caution should be added at this stage, based on the fact that there is more than one video standard. First, the line scanning standard may be either 625 line (European) or 525 line (U.S.) with 50 or 60 Hertz refresh. More crucial are differences in colour encoding standards; high quality raster displays (such as the Barco GD-33 quoted above) adopt the RGB

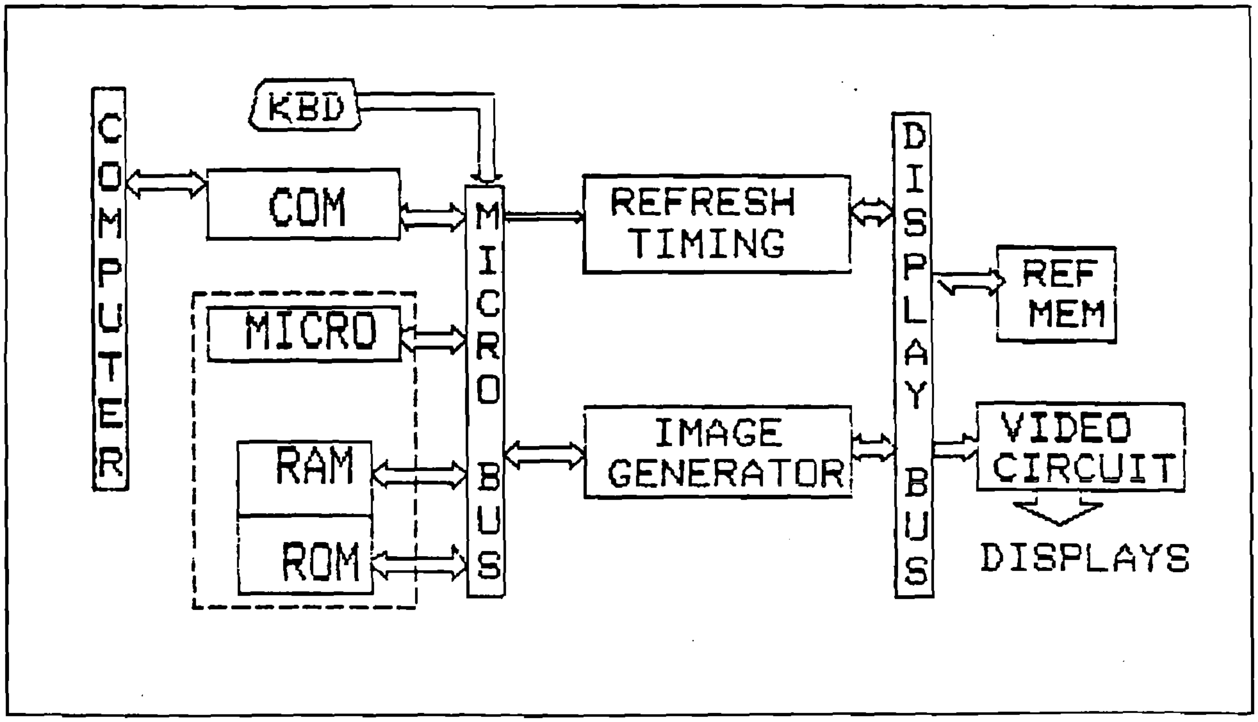


Figure 6

GIGI ARCHITECTURE

(Red, Green, Blue) format and use a high bandwidth (much greater than 4 MHz) monitor where each colour is transmitted on a separate cable. Colour television, on the other hand, modulates the signal using several different standards, NTSC in the USA, SECAM in France, and PAL in the rest of Europe. The resultant image is lower in quality and limited to about 300 resolvable points across the screen or approximately 40 characters. However, the universality of TV and TV-related equipment (such as video recorders) has meant that the raster displays which come with personal microcomputers mostly conform to the local television encoding standard. Indeed, many personal microcomputers rely on the availability of a television to reduce their cost.

THE MICROPROCESSOR REVOLUTION

We have already referred to the continued decline in logic and memory costs and that this was a significant factor in making raster scan displays economically viable. These developments had an even greater impact in the field of small computers. The period 1975-1977 was one of rapid development, culminating first with the breakthrough of the $2000 barrier, and then the $1000 barrier with products such as the Commodore PET 2001 and later the Tandy TRS-80. These completely self-contained microcomputers actually cost less than many computer terminals. For this reason alone, personal microcomputers have rapidly established themselves not just in education, but in many fields in industry and commerce.

It is not without reason that they have been avidly exploited in CAL applications. A typical microcomputer includes a microprocessor with a fairly powerful instruction set, a built in BASIC ROM cassette (or floppy disk) storage, keyboard and a visual display unit which typically offers some rudimentary graphics. Add to such a system a simple authoring language such as PILOT, and its use in CAL takes off with a vengeance! Significantly, the fastest growing area of the CONDUIT library is in that of CAL packages for microcomputers. Currently, their major problem is that programs, particularly those which exploit graphics, have to have significant changes specific to the particular system for which it is developed, be an Apple, a PET or a Tandy.

The graphics on these micros takes several forms, but all are of raster scan type. A typical basic resolution graphics system subdivides the basic character cell into six elements, which can be individually selected. Such a system provides a resolution of 80 x 72. Medium resolution graphics would typically increase this to 150-200 horizontal points. "High resolution" graphics on these microcomputers are typically add-on memory boards. The best example is the Apple-III, which can provide a resolution of 280 x 192 for 16 colours and even finer 560 x 192 for monochrome, still, however, short of the "high resolution" as defined by graphic users.

Nevertheless, such resolutions may be sufficiently adequate for CAL applications. The ubiquitous nature of personal microcomputers has given CAL a tremendous boost, not just in universities, but schools and colleges and even industrial training establishments. They have, however, also reinforced the problems which were always there with CAL, and which must now be tackled with more determination.

SELECTING A GRAPHICS TERMINAL

In our simplified model of the student-computer dialogue (see Figure 1), we dissected the flow of interaction into a few basic components. If we examine each component in turn we can define the desirable attributes of the system from the student's point of view.

- Presentation of information -- this must be easy to see, to assimilate and to comprehend

- Input to System -- this must be simple and unambiguous; it should also be possible to correct mistakes as they are made

- System response -- it should give immediate positive feedback of acceptance of the student input; overall, the completion of the transaction and the generation of the new information frame must occur within a reasonable time

To these basic requirements should be added psychological, safety and ergonomic features, such as a noise-free and restful environment and one which provides motivation and variety. These basic requirements epitomise an individualised instructional "delivery system." This, in turn, may be part of a multi-media environment coexisting with other educational tools for individual learning, such as self-study workbooks and audio-visual material.

Let us examine the first two attributes listed above in a little more detail.

Presentation of Information

To some extent we have already assumed that a graphics terminal is the ideal kind to meet this first requirement. The adage "one picture is worth a thousand words" is now well established in graphics folklore. Fortunately there is now good evidence to support this presumption. Through a process called pre-attentive perception, it has been shown that the human brain can more quickly assimilate and understand the graphic image than it can decipher text [11]. Certain visual effects also improve the student's comprehension of a concept. These include the use of blink, colour, shading or intensity variations to highlight key information; and the use of frame by frame playback or motion to create dynamic images. The extent to which these different attributes are used in CAL material can have a marked influence on the effectiveness of student learning [12].

Input to System

After a frame of information has been presented, various kinds of input are requested from the student. Text input in response to a question may be requested; or the student may be asked to sketch in an object, or to select one from a number of alternatives. The various kind of graphic inputs have been defined by a Foley and Wallace [13] as virtual devices known as "picks," "locators," "buttons," "valuators."

- A "pick" points at an object, such as a square or circle.
- A "locator" creates a new object by sketching.
- A "button" is used to select typically a menu item.
- A "valuator" is for input of non-positional values such as numeric input.

In practice, several options exist for implementing these virtual devices in physical terms. For example, the "valuator" function is very effectively provided by a keyboard. However, "picking" most clearly lends itself to a light-pen selection of an object of interest; whereas "buttons" could be most conveniently be implemented by a touch panel where the user simply points his finger at the menu item on the screen.

Thus each type of input probably has one ergonomically preferred type of device. For certain applications, it is quite appropriate that a digitizing tablet with a cross-hairs cursor should be the main form of input. In practice, in a general CAL environment, different virtual devices are more appropriate at different times. Therefore, for ergonomic reasons a compromise is usually sought by restricting input one or two physical devices. A keyboard with a joystick, where the keyboard can also be used for "picking" or "button" selection by use of the arrow keys is an acceptable compromise.

The table on the next page compares the different types of terminals discussed so far and shows how they match up against the requirements of an ideal student terminal. It should be

DESIRABLE FEATURES FOR A CAL TERMINAL

REQUIREMENT	TERMINALS		GRAPHICS DISPLAYS				
			Non-Refresh		Refresh		
	Teleprinter	VDU	Storage	Plasma	Direct Beam	Raster	Personal Computer
1. PRESENTATION							
A. Types							
Alphanumeric	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Graph	Poor	Poor	Yes	Yes	Yes	Yes	Fair
Histogram/ Bar Chart							
Diagrams			Yes	Yes	Yes	Yes	Fair
Images			Yes	Yes		Yes	Fair
B. Highlighting							
Intensity Levels		1-4			1-16	1-4	1-16
Colour		-			v.expensive	Yes	Yes
Blinking		Yes		Yes	Yes	Yes	Yes
Shading	Poor	Poor	Fair	Fair		Yes	Varies
C. Dynamics		Limited	No	Yes	Yes	Yes	Varies
D. Ergonomics							
Image Quality	Varibale	Good	Good	Good	Good	Ave	Ave
Brightness/ Contrast	Good	Good	Poor	Good	Good	Good	Good
Limitations	Noise						Screen Size TV resolution
Speed of Presentation	Slow	Fast	Medium	Medium	Fast	Med - Fast	Medium
2. INTERACTION							
Pick		{Cursor &	{Cross-hairs	Touch	Light pen	{Cursor &	{Cursor &
Locate		keyboard}	& joystick}	(K/B)	Joystick	Keyboard	Keyboard}
Buttons				Touch	Light pen	Joystick}	
Valuators	Yes	Yes	K/B	K/B	K/B	Keyboard	Yes
3. GENERAL							
Hard copy	Yes	-	Addition	Addition		Addition	Addition
Associated Features	-	-		Slide Projection		Video Output	Local storage + computation
4. TYPICAL COST/UNIT	£750	£750	£2500	£5000	£10K-£30K	£2500	£500-£2500