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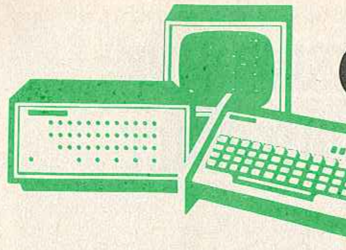


Computer Bits

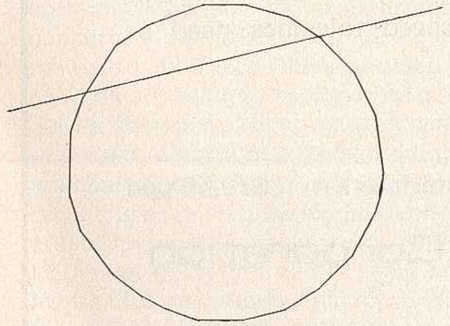
By Hal Chamberlain

COMPUTER GRAPHICS

MORE and more of the sophisticated computer applications that were once reserved for big computer systems are being successfully pursued by hobbyists. Sooner or later, after the novelty of having "your very own computer" has worn off, the typical hobbyist will settle down and concentrate on one or two particular applications for his computer. In many cases, hardware specific to the chosen application will be built or purchased and increasingly complex software will be written to get the best performance possible out of the hardware.

The conceivable applications of hobby computers are almost too numerous and diverse to list. However, one application that might interest all computer hobbyists is computer "graphics".

What Is Computer Graphics? In a nutshell, computer graphics is a general term referring to the equipment and programs used for *pictorial* input and output rather than the usual alphanumeric input/output. Computer graphics is very useful for game-playing boards, artistic pursuits, architectural and engineering drawings, plotting mathematical curves, amateur slow-scan TV, and of course impressing your friends. Graphics can also be an integral part of other hobby computer applications. Interactive computer games is one obvious example and electronic music is another where graphics might be used to enter and plot waveforms or envelope shapes.



Circle and line drawn on vector display 30 × 30.

If the user can control the pictorial display in real-time (the picture changes immediately when so commanded), the system is said to have *interactive* graphics capability. This is obviously very useful in action computer games such as Space War where objects are constantly moving around on a screen under both computer and player control. Interactive capability is also useful in artistic and drawing situations when editing of the picture is done.

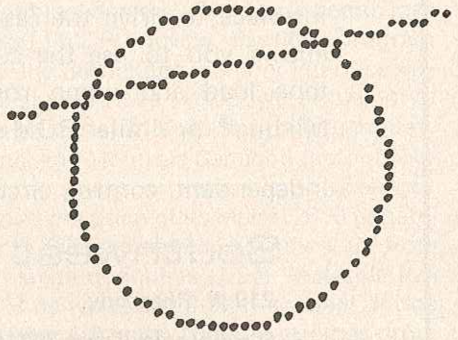
Computer Graphics Hardware. Perhaps everybody with any exposure to commercial computers has at one time experimented with "printer pictures." These are created with standard characters printed at selected places on a printout page. Input of the image data is usually done by an imaginative and patient operator. The results are quite coarse and have to be looked at from across a room to be appreciated. For more practical results, specialized graphics hardware is needed.

The most common graphics output devices are CRT (cathode ray tube) displays and mechanical plotters. CRT's have the advantage of much lower cost and interactive capability. Plotters, of course, produce an image on paper that can be saved for later use away from the computer.

Graphic input devices are much more diverse. The most common are special "function keyboards" and potentiometer dials. A function key may, for example, erase a previously designated line from the image when depressed. Two potentiometers can be programmed to move an object around the screen in horizontal and vertical directions. A "joystick" can replace two controls and provide greater ease of movement control. Light pens are used to "point out" or select an object that is being displayed. With proper programming, the operator can seemingly draw images directly on the CRT screen. A "graphic tablet" allows one to trace a paper drawing into the computer's memory. A digital TV camera such as the Cyclops (POPULAR ELECTRONICS, February 1975) can also be used for graphical input.

There are two fundamental methods of displaying or drawing a picture with a computer. Any image can be broken up into a number of dots as is done in newspapers or television. If the brightness or size of the individual dots can be controlled, then grey-scale pictures can be displayed. Images can also be broken up into straight lines of various lengths and angles. Although grey-scale display using lines is uncommon, it is possible. Computer graphics output equipment uses both methods on CRT displays and plotters. Let us compare these two output methods.

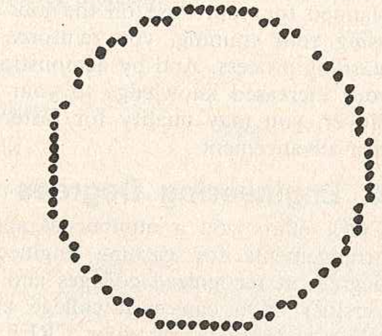
The earliest computer graphic displays were called "point plot" displays. These consisted of a modified oscilloscope and two digital-to-analog converters. A digital-to-analog converter (DAC) accepts binary numbers from a computer and translates them into corresponding dc voltages. One DAC would be connected to the x-axis deflection input and the other to the y-axis input on the oscilloscope. The computer program could display a dot at any point on the screen by giving its x and y coordinates. An image could be drawn by displaying the proper dots one at a time in rapid sequence. A later improvement in display circuit technology allowed straight lines to be drawn between points. This greatly increased the possible image complexity since one command from the computer could replace literally hundreds of individual dots. Displays capable of drawing lines from one point to another are called *vector* displays and the lines themselves are called vectors. Usually, when a computer professional talks about graphic displays, he means vector displays.



Circle and line drawn on raster display 30 × 30.

A major advantage of both point-plot and vector displays is that the amount of computer memory necessary to hold the image depends mainly on the image complexity (the number of points or lines actually displayed). Display resolution can be very high, with only a small increase in memory usage. For example, take a simple image containing 100 disjointed lines. A low resolution hobby display using only 8 bits for x and y coordinates would require four bytes for each line or 400 bytes in all. A high-resolution commercial display may use 12 bits for x and y resulting in a 600-byte display list. The first display has about 65,000 (256 x 256) addressable points. The second has nearly 17,000,000 possible points with only a 50% increase in storage requirements. It should be noted that the apparent resolution (sharpness) of a vector display may be high, even if the end point resolution is rather low. This is because the lines drawn are absolutely straight and their width is limited only by the electron beam focus.

An important consideration in point-plot and vector displays is speed. Since the points or lines are plotted one at a time, a complex image may require a significant amount of time to draw. If redrawing of the image is not done fast enough, then it may fade away from the CRT screen between "refreshes" and appear to flicker. Usually the display itself limits drawing speed; but, in a hobby system the computer may be the limiting factor. Use of special phosphors with a long persistance characteristic in the CRT slows image fading and allows a greater number of lines to be drawn without flicker. If the flicker can be tolerated, very complex images can be drawn even on a simple display.



Circle on raster display with line erased.

A new type of dot display that has only recently become practical for computer graphics is the *raster-scan* display. In this type of display the electron beam is constantly scanning through a large matrix of dots in much the same way as a television receiver. In fact, raster-scan displays of interest to hobbyists actually use a television receiver modified for direct video input. To form an image, the computer must turn the beam on when it is scanning the desired dots and turn it off otherwise. The scanning speed in a TV receiver is so fast however that direct program control of the beam is almost never possible. Instead, a portion of the computer memory is read out by the display controller in step with the scanning beam and memory bits control whether or not the beam is turned on. Thus one bit in memory is required for each *possible* point on the display regardless of whether it is turned on or not. Additional bits for each display point may be used for grey scale or even full color.

A major advantage of raster-scan displays is that the display screen may be an ordinary television receiver. The rest of the display controller can be as simple as one or two circuit boards that plug directly into the computer. A vector display requires a fair amount of analog circuitry using op amps and an oscilloscope for the actual display. Although a suitable oscilloscope is already owned by many hobbyists, a large-screen display suitable for group viewing requires a special deflection yoke and high-power deflection amplifiers.

A primary disadvantage of the raster-scan technique is that the amount of memory necessary to hold the image depends on display resolution rather than image complexity. A 128-by-128 point matrix, which is an absolute minimum for graphics, has 16,384 points. At 8 bits per byte, 2K bytes of computer memory will be required to hold an image no matter how simple it is. Merely doubling the resolution to a 256-by-256 matrix quadruples the memory requirements to 8K bytes. Adding grey scale or rough color capability may quadruple the memory requirements again. It is this need for large amounts of memory that made raster-scan graphics prohibitively expensive in the past, when memory costs were 10 to 100 times more than they are now.

For some graphics applications such as engineering drawings, even a 256-by-256 resolution will not be enough. Grids of 512-by-512 or even 1024-by-1024 are used for serious graphics work. Although home televisions can theoretically handle 500-by-500 resolutions when modified for direct video input, the 30-Hz flicker of individual dots when viewed at close range may be objectionable. Higher resolutions require the special yokes and deflection amplifiers again.

While a vector display is far superior for line drawings, a raster scan display is best for pictorial material. Amateur slow-scan TV applications, weather-satellite picture reception, and computer art are all best accomplished with a raster-scan display. In particular, the TV Dazzler (POPULAR ELECTRONICS, February 1976) can produce some really spectacular patterns. Either type of display can do a good job on game boards. A graphic display of either type can often replace a TV typewriter since text characters are really just graphic shapes.

Computer Graphics Software. Even the most sophisticated graphics hardware is useless without software to run it. A vector display is normally connected to several parallel output ports on the computer. Data sent to one pair of ports may cause the display to draw a line from where it was last to the new x and y positions specified by the data. The same program action using another pair of ports may just move the beam without drawing. Ordinary output instructions are used to send data to the display generator. A complete image is drawn by outputting data associated with each line until all lines are drawn. The program must continuously execute a loop to keep the image refreshed on the screen.

Image data for a vector display can be generated in three different ways. The simplest is to have the data stored in a display list in memory. A very simple program loop is used to work through the list and send data to the display. With some kinds of simple images it may be possible to compute the data in line. The x coordinate of a waveform display for example would always increase the same amount for each waveform point displayed. This technique can save a lot of space in the display list but does slow down image refresh. In a system with graphic input devices, data can be read from an input and sent directly to the display without storing it in memory. In most graphic applications, a complete image can be drawn using a combination of these techniques.

A raster-scan display can only run from a display list in memory. Also the display controller automatically runs through the list to generate the display. The computer program is only responsible for storing the proper data patterns in the display list. Thus the program is free to do other tasks without having to constantly refresh the display.

The real software job in computer graphics is generating the data to be displayed. One obvious way is to work up the list by hand. This is quite straightforward using graph paper and the computer keyboard. The desired image is first drawn on the graph paper. Then, in the case of a vector display, the coordinates of the line's endpoints are read off and entered into the computer memory. With a raster display, all of the dot positions covered by the image will have to be entered. Although simple, this method hardly makes much use of the computer.

The real value of graphics is realized when the program computes a display list from pertinent data about the image rather than a line-by-line description of it. Consider a routine that would accept an image name (cube, pyramid, etc.), its size, and its position in three-dimensional space. The routine would then generate a display list to show that object in perspective on the two-dimensional screen. Changing a parameter and calling the routine again would generate a new list with the object in the new position. Motion can be programmed by changing the position slightly each time the image is refreshed. The calculations involved are really rather simple for line images and vector lists.

With a raster display, a subroutine is needed to accept line endpoints as input data and set bits in the display list to display the line. If the lines are always horizontal, vertical, or at 45-degree angles, the routine can be quite simple. A more complicated routine is needed if lines at any angle are to be handled.

It is also frequently desirable to edit images on the display. The operator may want to add lines, delete lines, or move lines. With a vector display list, additions are handled by adding the extra lines to the end of the list. Deletions can be accomplished by replacing the deleted line coordinates with a null line such as a zero distance move. If the list gets too big during editing, a "garbage collection" routine can compress the null lines out of the list. A line change can be easily made right in the list.

Making additions to a raster display list is also easy; just set the bits covered by the added line or object. A deletion might be handled by calling the line generation subroutine with the endpoints of the line to be deleted and have it reset the bits covered by the line, thus erasing it. All lines crossed by the deleted line will have little gaps left over. The same problem occurs when a line is moved since it must first be deleted and then added elsewhere. The only real solution to this problem is to have two display lists. One is a vector list and the other is the raster list that is actually displayed. Editing is done on the vector list. Whenever any change is made to the vector list, the raster list is first cleared. Then it is completely regenerated from the vector list by repeatedly calling the line generation routine. Unfortunately, complete regeneration is slow, which restricts the kind of motion that can be programmed on a raster display.

In conclusion, graphics is one of the most creative applications for a hobby computer. It is simple enough to get gratifying results with only a little effort yet has the potential of keeping the most serious hobbyist occupied for years. Graphic output is readily appreciated by those with no computer experience and at the same time is appreciated by the experts. ◈

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North Carolina
Triad Amateur Computer Society, Greensboro and Winston-Salem (NC) area. Doug Drye, (919) 373-0040.

Triangle Area Computer Club (temporary name), Raleigh, Durham, and Chapel Hill (NC) area. Russell Lyday, (919) 787-4137.