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Video & Communications Arts

COMPUTER ARTS ISSUE

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CHALK

NEW DRAWING TOOLS

Computer Animation

A PRIMER

by Larry Cuba

Computer animation has been in development and use for years, but only recently has become a common feature of our visual world. We see it in movies, TV commercials and video games.

There are hundreds of computer animation techniques just as there are hundreds of ways to make music. To help understand these techniques, we can group the computer animation systems into categories, just as musical instruments are grouped into woodwinds, strings, percussion and brass.

In this article we will discuss seven generic systems as illustrated in Figure 1.

All the computer animation systems that we look at are composed of at least two component parts: the computer and a drawing device. The drawing device makes the images which are photographed onto film or videotaped. The computer controls the drawing process by sending the device electronic signals, and the artist controls the computer.

There are two kinds of computers: Analog and Digital. Usually when we use the word *computer*, we're talking about digital computers. These are the ones that send out utility bills and run video games.

Few people have even heard of analog computers, because when we encounter one, it's called something other than a computer. An electronic musical synthesizer, for example, is actually an analog computer.

Since the machine is not usually called a computer, calling the work produced with it *computer animation* has led to a confusion between analog and digital work. Rather than argue the semantics of the term 'computer animation,' we'll consider techniques based on both kinds of computers.

PART 1—ANALOG SYSTEMS
1. OSCILLOGRAPHICS

Analog computers were being used by artists to make films as early as the 1950s. Figure 2 is from a film by Hy Hirsch. The system used to create this film consists of an analog computer and an oscilloscope, and the technique is called oscillographics.

An oscilloscope is a screen and a beam of electrons which hits the screen and draws a point of light. The point of light can be controlled in three ways. The beam's position is
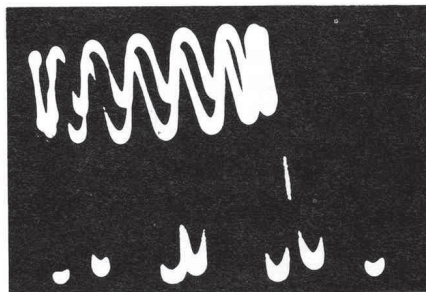

Figure 2

controlled by turning 2 knobs, one for Horizontal movement and one for Vertical movement. A third knob controls the intensity of the beam, and consequently the brightness of the point on the screen.

Instead of using knobs, we can attach wires to these functions and control them by changing the voltage in the wire. The amount of voltage flowing in the wire substitutes for the 'position' of the knob, and determines the position of the beam.

The position of the beam is *analogous* to the amount of voltage in the wire. That's why this is called an analog system. In digital systems, numbers are used to specify the position of the beam rather than voltage levels. The pattern of voltage channels in the wire is called an electronic signal.

So the problem of making drawings on an oscilloscope is a matter of generating electronic signals. This can be accomplished with an electronic music synthesizer. The classic music synthesizer (Moog, Buchla, Arp) is an analog computer.

The film or video artist creates animating images on the scope by generating signals with the music synthesizer and using them to control the movement of the beam. This process of composing an electronic signal by patching modules together with cables is used on all analog systems. The differences are in how that signal is used to make an image.

2. IMAGE PROCESSOR

By generating two independent signals and using them to control the vertical and horizontal movements, a pattern can be formed which com-
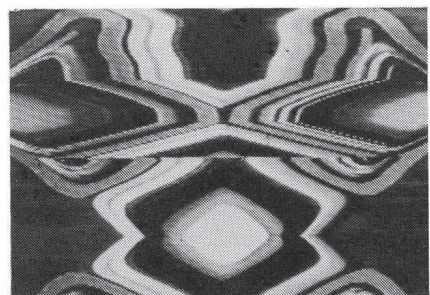

Figure 3

ANALOG — DISPLAY REPRESENTS ANALOGUE OF REAL PHYSICAL QUANTITY

DIGITAL — DISPLAY REPRESENTS STORED ABSTRACT QUANTITIES

Oscillo-scope — Oscillographics

Vector-scan display — Stroke display

Video monitor — image processor

Raster-scan display — raster graphics

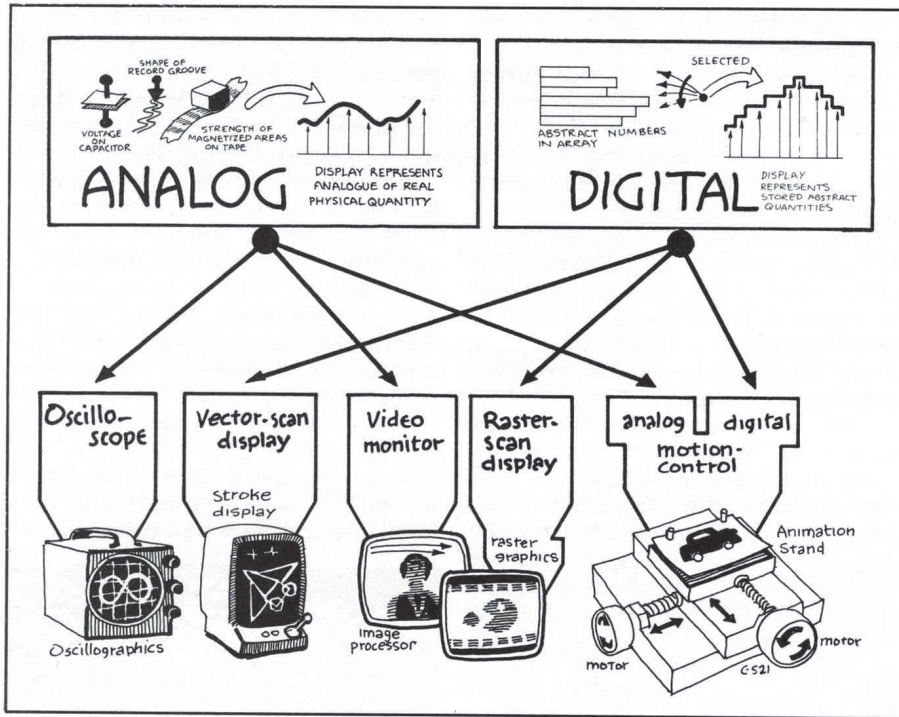analog digital motion-control — Animation Stand, motor, motor, GS21

Figure 1

pletely fills the screen from top to bottom with horizontal lines. This is the scanning pattern used in video and the pattern is called Raster scan.

A television picture tube is similar to an oscilloscope except that the horizontal and vertical motion is fixed in such a way so that the beam is constantly scanning out a raster pattern. If the horizonal and vertical movements are fixed, then that leaves only the Intensity signal to form the image.

Variations in the beam's intensity during the scan produces an image composed of various shades of grey. The levels of grey in the image range from black to white and correspond to the range of possible intensity levels.

If we use signals generated with a synthesizer to control the intensity, then variations in the voltage level of the signal will result in variations in grey level. This is how a video synthesizer forms an image. The image in Figure 3 is from *Electronic Masks* by Barbara Sykes and was produced with the Sandin Image Processor (Figure 4).
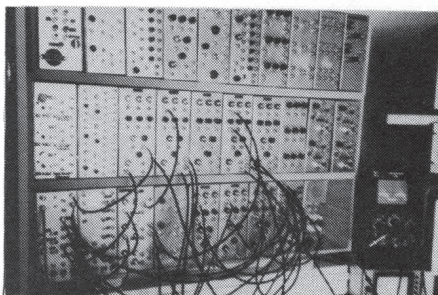

Figure 4

3. SCAN PROCESSOR

The next analog system we'll discuss is the scan processor. Video artist Woody Vasulka used a scan processor to produce the image in Figure 5. A scan processor, like the music synthesizer system, uses an oscilloscope-like display.

In a scan processor, the raster is scanned as in video, but unlike standard video, the pattern can be modified by the user. Any of the three signals forming the raster pattern (vertical movement, horizontal movement, and intensity) can be modified. These

Figure 5

modifications come from either synthesized signals or a video camera.

In both of the video synthesizers we've looked at, image processors and scan processors, signals could be generated internally or with video cameras.

An image processor is designed to process the image as encoded in the standard video signal (that is, the intensity signal only). A scan processor, on the other hand, can actually alter the scanning pattern itself (that

is, it can modify the horizontal and vertical movements of the beam).

If the scanning pattern is modified, then the result is no longer a standard video signal. (So, it can't be fed directly to a TV or tape recorded.) The results appear on an oscilloscope-like display and so scan processors belong with oscillographics on our chart (Figure 1). And just like oscillographics, to be recorded the screen must be filmed or rescanned with a video camera.

If rescanned with a video camera, then a video signal is created which can be processed with an image processor. So you could produce an image on a scan processor and process it and colorize it on an image processor.

These two functions are combined in a single system called the *Scanimate,* which was developed by Lee Harrison in the late 60's. Ron Hays used a Scanimate system to create his videotape *Canon* (Figure 6).
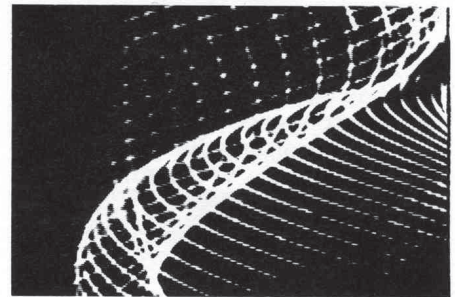

Figure 6

REAL TIME VS. CONVENTIONAL ANIMATION

In the systems covered so far, we've seen analog computers used to generate and process electronic signals. These signals were used to drive two types of displays: oscilloscopes and video monitors. With each of these two displays we could see the images moving on the screen in front of us. This display could then be filmed or videotaped like a live action scene. Should we call this animation, though?

In any film, what we see as a moving image is really a series of stills projected in sequence at great speed: 24 per second. In live action, these stills were created by the camera capturing a series of snapshots of the constantly changing real world at the same speed as projection: 24 per second.

In conventional animation, each of these stills is a photograph of a drawing. The drawings are placed on an animation stand and photographed, one at a time. When projected back at 24 frames a second, movement is synthesized. Film is the mechanism

which allows us to project at great speed drawings which were created and photographed at slow speed (or one at a time).

In contrast to conventional animation, the systems we've looked at so far create and display the sequence of images at high speed so movement is visible directly on the display.

This is called Real Time Animation. The sequence of images is being produced and displayed at a speed which produces the illusion of movement. This eliminates the need for film as the mechanism of animation. Once a sequence of images is visible on the screen, then either film or video can be used to capture it at live action speed.

VIDEO ANIMATION

In conventional frame-at-a-time animation, the recording medium must be capable of recording in a still-frame mode.

This is easy for a film camera, hard for a videotape recorder. So animation has traditionally been made on film. More recently, single frame videotape recording has been developed, making "video animation" possible.

But this "video animation" has been confused with work produced on a video synthesizer, which has also been called "video animation." In one case, you have video record single frames, so you can shoot drawings with it, and in the other, you use video technology to synthesize animating images in real time.

4. ANALOG MOTION CONTROL

The movement in conventional animation comes from two sources:
1) changes in the image from one drawing to the next, and
2) slight movements of the stand between exposures to animate pans and zooms. These stand movements can be automated and controlled with computers, and since these movements alone can create animation, the animation stand can be considered a drawing device. This technique is called Motion Control.

Analog computers, because of their speed, have an advantage over digital computers when it comes to generating real time animation.

But for motion control, which is frame-at-a-time animation, you're better off with digital computers because of their many other advantages. And today's motion control systems are all digital. Still, the first motion controlled stand used an analog computer. It was called The Whit-

ney Cam Machine. Motion Control techniques opened the door to a whole new world of special effects magic in Hollywood. When the movie *Star Wars* came out in 1977, it started a science fiction craze in Hollywood with dazzling effects like the jump into "hyperspace."

This jump into "hyperspace" effect is called a streak, and was invented by John Whitney, Sr., who invented motion control in the 50's by building the first computer-controlled animation stand in his garage with an army surplus analog computer.

The analog computer controls the movement of the artwork which is back lit on a light table. The film camera looks down from above and photographs the artwork as it moves. The principles of the Whitney Cam Machine were copied in machines that Doug Trumball built for the *2001* stargate corridor sequence, the ones Bob Abel built to make TV commercials, and the one John Dykstra built for *Star Wars*. Since *Star Wars*, motion control has blossomed into an industry standard, but now all systems are controlled with digital computers. We'll see them shortly in Part 2 on Digital Computers.
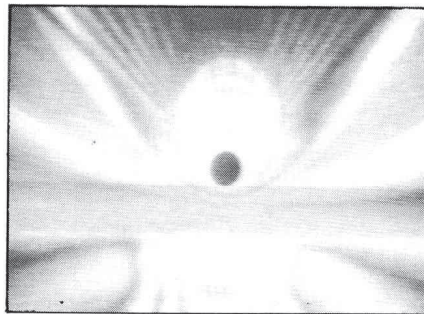
Figure 8

WHITNEY CAM MACHINE

The control mechanisms have advanced and become quite elaborate since motion control was invented, but the basic vocabulary of effects was established on the Whitney Cam Machine:
1) multiple exposures,
2) streaks, and
3) slitscan.

One benefit of motion control is the precise repeatability of animation stand movements. This ability can be used to produce multiple exposures. If, while the shutter is open, an object that emits light is moved into several positions and its light turned on, then multiple images of the object will appear on the film.

This principle is applied to animation in motion control: on an animation stand, artwork can be lit from behind. When the artwork is moved

around in a circle and the lights flashed several times during the exposure, a multiple image is created. This is the technique used by James Whitney (John's brother) to produce the film *Lapis*. (Figure 7)

Another way to use motion control is to leave the lights on while the artwork is moving. This creates a time exposure effect like a photograph of car headlights whose movements are visible as a streak of light. A film, *Terminal Self* was consisting entirely of streaks were made by John's son, John Whitney, Jr.

This streak effect has often been mistakenly called slitscan, but streak and slitscan are two totally different effects. The only thing they have in common is that they are both
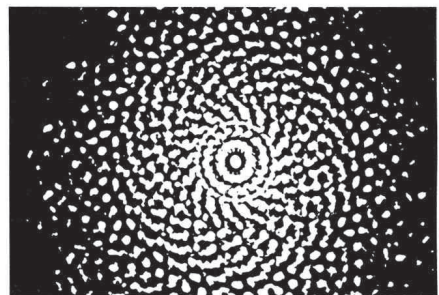
Figure 7

time exposures. Slitscan is a 3rd technique developed on the Whitney Cam Machine. In slitscan, the artwork is not seen by the camera lens all at once. The artwork is completely covered except for a sliver revealed through a narrow vertical slit in the covering. While the camera shutter is open for a time exposure the slit moves across the artwork and reveals it progressively to the camera which records an image on film.

If, during the exposure, there is no movement of the artwork or the camera but only the slit, then the art appears on the film as it would without the scanning slit, i.e. normal. However, if while the slit is scanning across the artwork the camera zooms in toward it, then a distortion is introduced: a bulge is produced in the figure. For example, a rectangle is transformed into a trapezoid.

These three elements of the basic vocabulary of the Whitney Cam Machine can be found in the later (and current) crop of motion controlled animation stands that use digital computers.

PART 2—DIGITAL SYSTEMS

For each of the 4 types of analog animation systems we have covered, there was a different KIND of analog computer. One was a Scan processor, another was an Image processor, and so on.

We'll look at several digital animation systems, but only one kind of digital computer. That's because all digital computers do the same thing fundamentally: they follow lists of instruction and can store these lists (and other data) internally.

The major variations among digital computers are:

1) the speed at which they operate,

2) the size of their internal storage. These are usually a function of the size, cost, and age of the computer.

What distinguishes the digital animation systems on our chart in Figure 1 is the type of display. We'll consider three different kinds (vector, raster, and animation stands), but they're not mutually exclusive; a single system can include more than one type of display.

ANALOG VS. DIGITAL

The usual method of distinguishing between analog and digital computers is by comparing the way they process signals internally: analog computers use a gradual scale, whereas digital computers use discrete on-off elements. But these characteristics are at a microscopic level
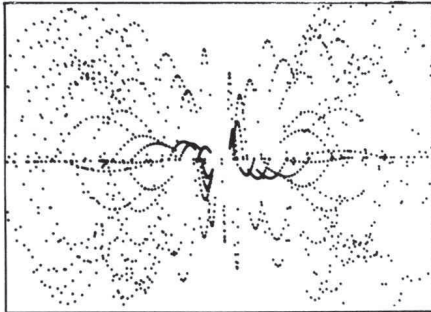
Figure 9

and do not directly affect the user. A more useful distinction is at the level of user control. The way in which an instrument's control is structured will determine what will be easy to do and what will be hard.

For example, imagine trying to drive a car by typing commands on a keyboard, or trying to write by guiding a pencil with a steering wheel. Clearly, then, the control structure of a tool can determine its usefulness to a large degree.

If we compare the control structures of analog and digital computers we find . . .

Analog computers are controlled by routing signals through modules with cables, and by turning dials. Digital computers can be controlled in a number of ways, which may include turning dials of drawing with a pen, but primarily they're controlled by typing in commands at a terminal. A list of these commands is a

computer program. A program is just a description of the steps required to complete a task. In the past when someone might have built a mchine to perform a particular task, now one need only describe the process in a program. A digital computer is a robot which will exhibit the behavior specified by the program and so become the machine desired by the user.

This is the most important feature of digital computers, and apparently the least understood by the computer illiterate. For example, when a TV journalist reports a story with the sentence, "Some students at MIT have developed a computer that can play chess," they invariably mean, not that they've built a computer but
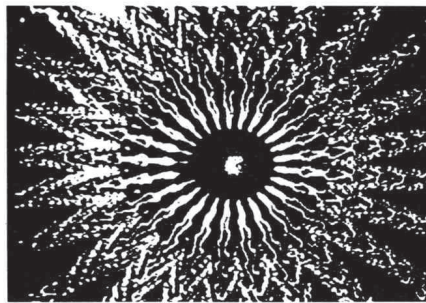
Figure 10

that they've developed a program. We use the word 'computer' to mean a general purpose programmable machine. As soon as it's designed for a specific purpose, then it's no longer a computer. Also, once a program is stored in a digital computer, you can use it at any time in the future.

With analog systems, the way in which the modules are connected is the 'program,' and there's no way to store it. If you take it down so someone else can use the machine, you'll have to put it back together again next time you want to use it.

And there is another difference between analog and digital computers: in the analog systems, we saw that values, such as how far the beam is to be moved on the screen or how bright it is, were encoded in the amount of voltage in the wires. On digital computers, when using a vocabulary of commands to control the display, these values are conveyed with numbers. Inside the computer, electronic signals encode these commands and numbers, but unlike the situation in analog systems, the user does not have to deal with them as much.

5. DIGITAL MOTION CONTROL

The Analog Cam Machine movements are controlled by an electronic signal. There is a correspondence between amount of voltage in signal and position of artwork being moved.

In the digital system, the animation stand is structured the same, but the user doesn't control its movements with signals per se. Instead, commands are sent via the computer with numbers to specify the desired positions of the artwork and the camera. For example, for a simple streak the program might look like this:

> Open shutter
> Zoom IN 50 units
> Close shutter

This program puts one streak on one frame of film. For a stationary image to appear on film, this streak must go on every frame. So what we want to happen is for the computer to repeat this sequence of commands once for each frame. A 5 second effect lasts 120 frames, so we add a Repeat command, causing this group of commands to be repeated 120 times:

> Repeat 120: [Open shutter
> Zoom IN 50 units
> Close shutter
> Zoom OUT 50 units]

After the frame is exposed, the command, Zoom OUT 50 units is used to reposition the camera to begin the
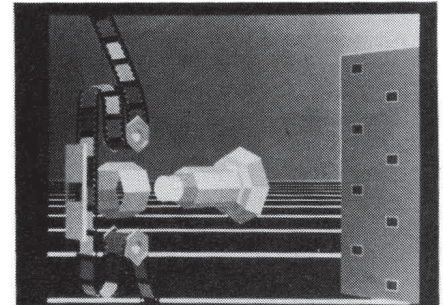
Figure 11

next frame. (There is also an assumption here that opening and closing the shutter advances the film one frame). This puts the same streak on each frame, producing a static image. For a moving streak, we introduce a slight change between frames, such as a small vertical movement of the artwork. This we do with the command, "Move UP 2 units":

> Repeat 120: [Open shutter
> Zoom IN 50 units
> Close shutter
> Zoom OUT 50 units
> Move UP 2 units]

So as we zoom in and out to streak each frame, the artwork slowly moves up on the stand and the streak moves up in the frame. Multiple exposures and slitscan are also produced on digital motion control stands. Figure 8 is a slitscan image from Ron Hays' videotape *Tristan and Isolde*.

6. VECTOR GRAPHICS

If we look at our chart in Figure 1 again, we see two types of electronic displays: Raster scan and Vector scan. The difference between the two is the way in which the beam scans the screen to create an image (like the difference between an oscilloscope and a video monitor). Raster scan, as we learned before with analog systems, is the scanning pattern that video monitors use. The whole screen is scanned, one line at a time, from top to bottom. The image is formed by varying the intensity of the beam during the scan.

A vector scan display, on the other hand, is like an oscilloscope, in that the image consists of lines (called vectors) which are drawn by the beam as it moves around the screen.

But again, in digital displays the user doesn't create the signals that control the beam. These signals are created internally by the display in response to commands. The commands instruct the display where to draw points and lines by means of numerical coordinates.

There are various kinds of vector scan displays and they can be grouped into three classes based on three ways of recording an animation sequence: film recorders, storage tubes, and real time displays.

In a typical film camera, like a Bolex, we can identify three ways to shoot animation: single frame with a time exposure, short exposures (still single framing) and live action speed. In single frame mode, we can shoot time exposures by holding the release down. This holds the shutter open. The second way is also single framing, but pushing the release

Figure 12

gives us a short exposure (1/30th sec.) no matter how long we hold down the release. And the third way, live action speed, is 24 frames/sec.

1) time exposure—A film recorder is a vector-scan display with a camera mounted facing it so a lengthy drawing process can be captured on each frame of film as a time exposure (not unlike the streaking process of motion control).

Since the drawing accumulates on the film over time, it can't be seen in its entirety by the user until the film is developed. This isn't very convenient, so these displays are usually used in conjunction with another type of display which can be used for previewing the image. This type of display is called a storage tube.

2) short exposure (but still frame-at-a-time)—the storage tube display has a screen which retains the image of the points and lines as they're being drawn instead of allowing them to fade, so that the user can see the whole drawing all at once and a camera can record the drawing on one frame of film with a short exposure (rather than a time exposure).

The process is still one-frame-at-a-time-animation, though. You can see individual drawings, but you can't see movement until the film is developed and projected. There are displays on which you can see movement directly without filming, and they're called real time displays.

3) live action speed—Real time displays draw and redraw images fast enough to see the animation without filming or taping (just like the process we saw in the analog systems). Figure 9 is from my film *3/78* which was animated on a real time system.

Since the vector images are animating in real time, we can point a video camera at the display and process the signal with an Image Processor. Figure 10 is from *Spiral 5* by Tom DeFanti and Dan Sandin and was produced on a system which combines real time vector graphics and image processing.

SOFTWARE VS. HARDWARE

Regardless of how the image is captured on film, the programming is a function of the main computer and the sofware available for it. The word 'Software' has two connotations. One contrasts Software with the word 'Hardware.' Hardware consists of all the pieces of the system which are material objects, such as the main computer, the display, the terminal, the printer, the disc drive and so on. Software, in this context, is the information that is stored in the vari-
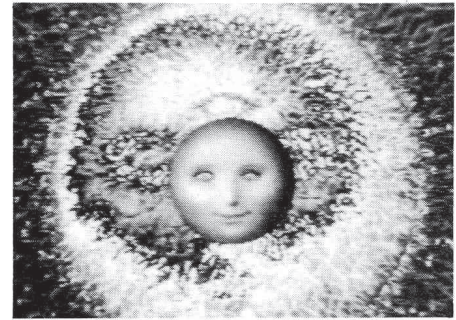
SUNSTONE

ous memory devices. Software includes programs which help you edit other programs, programs that draw pictures, or data such as the numbers in a phone book.

But in another context, like the phrase 'Software Development,' the word software does not refer to data, but to a class of programs which are designed specifically as tools. A program which helps you edit text, for instance, is a software tool. Software, in this sense of the word, can determine how useful a piece of hardware will be for a particular task. Software has a hierarchical nature which allows users to extend the tools provided, with their own. This is one of the more powerful aspects of digital computers and it doesn't exist in analog. This extendable nature of software makes it unique among man's tools in that the tool user can also be the tool builder.

7. RASTER GRAPHICS

Each of the three methods of recording animation (on film or tape) that we identified for vector graphics apply to raster graphics as well, namely:

1) time exposures—the same film recorder that's used for vector graphics is capable of operating in a raster mode, too. As in the vector mode, each frame in a sequence is stored on film via a time exposure. Figure 11 is from a commercial produced by Digital Effects using a film recorder.

2) short exposure (frame-at-a-time)—in vector graphics, a storage tube was used to preview images and to avoid the need for time exposures during filming. But there is no such comparable screen that can store a raster image. So the problem of disappearing images is solved by creating a special section of the computer's memory (called a frame buffer) for the storage of the data required to draw one frame. The display screen is constantly refreshed from the data in this frame buffer memory. So, as the main computer builds the image by changing the numbers stored in the frame buffer, the results are continuously visible on the screen.
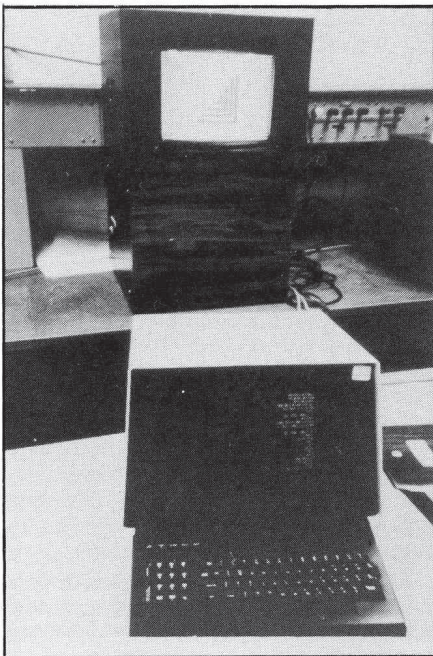
The resolution of a frame buffer is measured in number of pixels. The word pixel is a contraction of Picture Element. The pixels fill the screen the way squares fill a page of graph paper. The finer the grid of your graph paper, the smaller is each pixel and the more you have. The more pixels, the higher the resolution.

For each pixel on the screen, there is a number stored in the frame buffer which determines the shade of grey (or color) for that pixel. Changing the number assigned to a pixel changes its shade (or color). The range of numbers is limited and determines how many colors are possible for any pixel. Since this number is stored in binary form, its size is measured in number of bits per pixel. But you don't need to know binary arithmetic to compute the resolution of a frame buffer—just this relationship: 1 bit means 2 colors, 2 bits means 4 colors, 3 bits, 8 colors and so on. The amount of memory devoted to each pixel (in number of bits) is a measure of the color resolution of the buffer. The complete resolution of the buffer, then, would combine spatial and color, and would be specified as number of pixels Wide by number of pixels High by number of bits per pixel, or Depth. For example, the resolution of the frame buffer in the Datamax Zgrass computer is 320 Wide x 2 bits/pixel. (Figure 12) High resolution frame buffers were used by Ed Emshwiller to produce his videotape, *Sunstone*, (Figure 13).

3) live action speed—if these buffers can be updated fast enough, the animation can be seen in real time. From video games to flight simulators, real time animation is required when the images must respond to human interaction. Stan Vanderbeek used the flight simulator at NASA's Houston center to create the images of his film, *Euclidean Illusions*, in real time.

The difference in resolution, realism and visual quality between video games and flight simulators is obviously enormous. This reflects the large difference in size and cost of the computers. But as these factors continue to drop, who can say how long it will be before playing a *Star Wars* computer game will look like being IN *Star Wars*, the movie?